HIGHWAY PRACTICE

IN THE

UNITED STATES OF AMERICA

PUBLIC ROADS ADMINISTRATION

FEDERAL WORKS AGENCY — *WASHINGTON, D. C.*

1949

This bulletin has been prepared by the staff of the Public Roads Administration for the use of foreign engineers who come to the United States from all over the world to study and observe highway practice as it has developed in this country, and for other students of highway subjects.

The bulletin is divided into four major parts, which report on highway history, administration, and finance; systems and standards; location and design; and construction and maintenance.

Copies of the bulletin may be obtained from the Superintendent of Documents, United States Government Printing Office, Washington 25, D. C., at 45 cents each.

Much additional information on the same subjects will be found in another publication of the Public Roads Administration: *Principles of Highway Construction as Applied to Airports, Flight Strips, and Other Landing Areas for Aircraft*, which is available from the Superintendent of Documents at $1.50 a copy.

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History • Administration • Finance

Systems and Standards

Location and Design

Construction and Maintenance

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Part 1

HISTORY • ADMINISTRATION • FINANCE

HISTORY

The United States now has a network of improved highways reaching to every part of its area and of great importance in every phase of national life. These highways have been built largely in the past 30 years, but it may be of interest to examine briefly the history of highway transportation and the forces that brought highway improvement.[1]

Early History

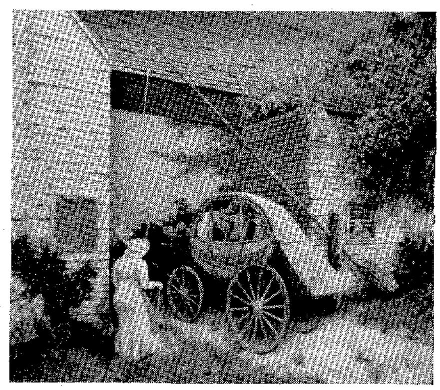
The first settlers found a complete wilderness, and located their homes along the rivers and bays close to water transportation. When lands close to navigable water were occupied new settlers went inland. Roads were built to the nearest wharf, but often they consisted only of clearings through the forests.

Prior to our War of Independence (1775–83) travel was mainly on foot or horseback. In 1717, 110 years after the first permanent settlement, post riders were carrying mail between Boston and Williamsburg, Va., at monthly intervals in summer and bimonthly intervals in winter. The route was over 600 miles long. Roads were either trails or wagon routes widened from bridle paths. Immediately following the War of Independence, chaotic social and economic conditions were not conducive to road improvement.

In 1794 the new republic was shaken by a rebellion of the farmers of western Pennsylvania against the tax levied by the Government upon whiskey. The cost of hauling grain over bad roads was so great that farmers made whiskey which could be transported more readily to distant markets. The need for an improved road was met by construction of the Philadelphia and Lancaster Turnpike, the first extensive broken-stone roadway built in this country, completed in 1795. A 24-foot surface 62 miles long was constructed with hand-broken stone and gravel. Travel became possible at all seasons of the year.

Turnpikes

In the following 40 years numerous turnpikes were constructed. These were graded, gravel, or broken-stone roads built by companies organized to make a profit through tolls. Most of the companies failed to acquire the profits hoped for. In this period stage-coach lines developed rapidly, and many freight-haul-



A toll gate on the Maysville Turnpike—1830.

[1] As an aid to the reader who may be unfamiliar with the terms used in this discussion, definitions are given on p. 45.

ing businesses were established. In later years taverns built to accommodate highway travelers remained as historic landmarks long after the travel they served had ceased.

The National Pike

In 1806, the Federal Government began the construction of a road from Cumberland, Md., to the west, known as the National Pike or Cumberland Road. Businessmen of Baltimore urged this improvement in order to carry on commerce with the rich lands being settled. By 1819 travel on this road was possible as far as Wheeling on the Ohio River, a distance of 131 miles. It took 10 years to build this section of road. The 20-foot surface had a 12-inch bottom course and a 6-inch top course consisting of stone broken with hammers. Traffic was depended upon for compaction. The cost was $13,000 per mile.

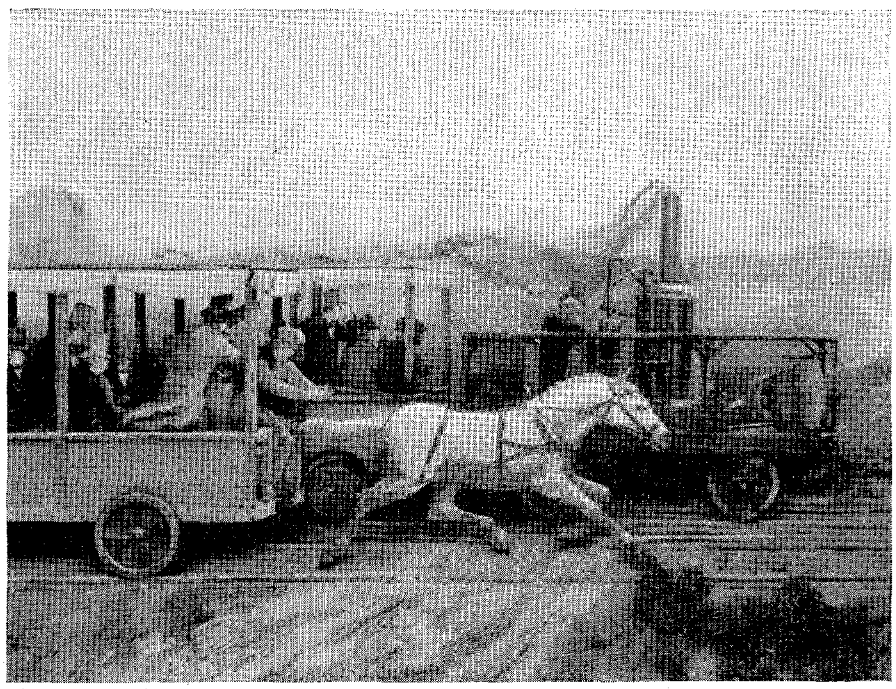
By 1819, Pennsylvania, the foremost road-building State in the Union during the period, had placed a broken-stone surface on the main highway from Philadelphia through to Pittsburgh, a distance of about 300 miles.

Lands distant from navigable waterways were occupied by new settlers. Pioneers were pushing their way westward in an expansion of settlement that eventually reached the Pacific Ocean. There was great need for land transportation.

Canals had been constructed at several places along the Atlantic seaboard. They aided greatly in developing the territory through which they passed. However, in the greater part of the country conditions were not suitable for canal construction.

The railroad era

In 1830 all indications pointed to a period of extensive highway construction but, in August of that year, the steam locomotive demonstrated its superiority over the horse-drawn vehicle on the first tracks of the Baltimore and Ohio Railroad near Baltimore. Rapid develop-



In 1830 the iron horse demonstrated its superiority over other forms of transportation.

ment of the railroad soon convinced the public that it was the ideal instrument for transportation over the long distances that must be traversed in settlement of a great area. Soon the resources of the country were devoted to construction of railroads. Highways entered a "dark age" from which they did not completely emerge until mechanization of road construction, and the motor vehicle, offered an advance in transport methods as great as that introduced by the railroads in the 1830's.

The nineteenth century

The length of surfaced roads in 1830 totaled about 27,000 miles, consisting principally of turnpikes in the vicinity of the larger settlements. At that time the country covered only 60 percent of its present area and the population was about one-tenth of the present population. The roads were built by manual labor aided by the ox-drawn plow, the horse-drawn scoop for moving earth, the road drag or scraper, the wheelbarrow, and other agricultural tools.

For the remainder of the century there was a slow growth in the mileage of road, as the population increased. Practically all work was done by local authorities with such small funds as they could find for the purpose. However, contributions were made to the science of road building and transport that were to be most useful in a later period.

A bituminous pavement was patented in 1834.

A steam shovel was patented in 1835.

The first cast-iron bridge in the United States was built in 1839.

L. DuPont offered a new blasting powder in 1856.

In 1858 Blake introduced the jaw rock crusher.

A steam road roller was imported from England in 1869.

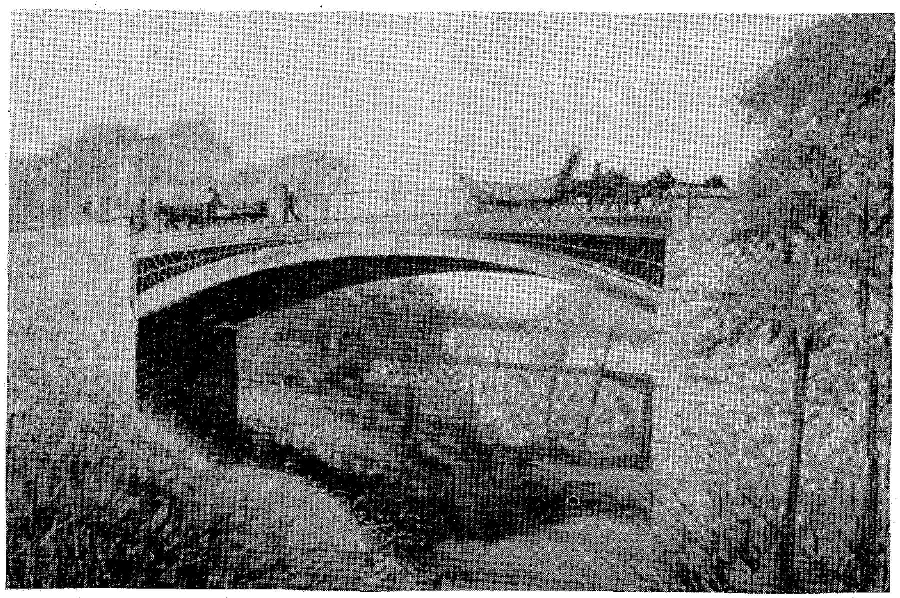
Manufacture of portland cement began in 1871.

A successful brick pavement was laid in Charleston, W. Va., in 1873.

The bicycle, which was to create a strong demand for smooth roads, appeared in 1877.

The first portland cement concrete pavement was laid in Bellefontaine, Ohio, in 1893.

In the same year, Duryea first successfully operated an automobile in the United States, and Henry Ford built his first automobile.



Our first iron bridge—1839.

At the end of the century, approximately 300 years after first settlement, the United States could claim little distinction because of the character of its roads. As in most other parts of the world, the roads were largely plain earth surfaces that were almost impassable in wet weather. Neither the Federal nor State governments had undertaken to provide funds on a scale that would permit general road improvement. Those seeking knowledge of road-building methods and administration turned to the countries of Europe for information. Past history in this country had produced some experience in road matters, but very little actual physical improvement. In many respects the position of the country was not as good as the present situation of those countries just beginning the creation of a road system, since the present accumulation of experience in highway building and transport was not available. Persuasion of the public to provide needed funds had to be based on expected rather than proven benefits.

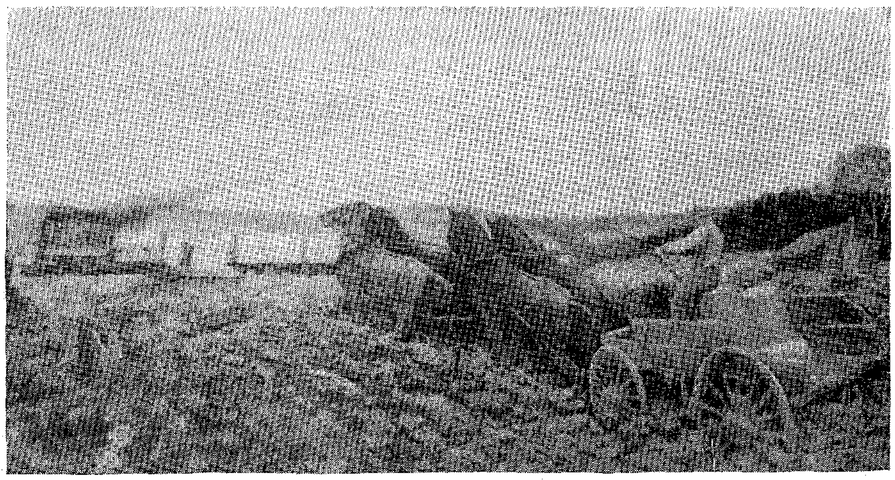
Highway Improvement Gains Momentum

By 1900 the country had again reached a stage in its development when economic forces caused a strong demand for highways. The first demand came years earlier when vacant lands could not be found close to waterways, and was ended by an era of railroad construction. Now, vacant land could not be found close to the railroad stations. A need was seen to get the farmer out of the mud—to get him to the nearest railroad. The population of cities was growing and more food had to be grown on farms, transported to the railroad, and shipped to cities. City people complained of the "high cost of living"—much of it due to inadequate transportation.

The demand was for roads extending 2 to 5 miles from the railroad station. A network of highways interconnecting the cities, and serving the business and social life of the Nation, was not seriously proposed, even by the dreamers. Progress in meeting the need as then seen was to be at a snail's pace for many more years. But the need for transportation would cause continued progress in mechanization of road building, and development of the motor vehicle. Eventually these would make possible the world's most extensive system of highway transport.

The period of preparation

The first 20 years of the twentieth century may be described as a period of preparation for road building on a large



During the period of rapid extension of rail lines, almost nothing was done to improve highways. This is a typical scene of about 1850.

scale. It was not a completely conscious preparation. Few, if any, realized the extent to which the movement would grow. However, marked advances were made in the administrative, technical, mechanical, and financial fields that were of immediate benefit and of great importance in preparing for the large program of later years.

In 1900, control of highways was still almost entirely in the hands of cities, towns, villages, and other subdivisions of government. Only very limited funds were made available for highways. Outside of cities, work was supervised by men without special training for the job. The profession of highway engineering was practically unknown.

Of the 150,000 miles of surfaced rural road in 1900, 72 percent was gravel, 24 percent was water-bound macadam, with 4 percent of miscellaneous materials. The steam roller and rock crusher, used in building macadam, were the only power tools in general use. Horse-drawn equipment and hand tools were the implements used in grading and placing surfacing. Most of the surfaced roads were less than 5 miles in length.

Between 1900 and 1920 there were marked changes in the types of roads built, in machinery for building them, and in governmental organization for the work.

Creation of State highway departments

In this period most of our State highway departments were created and grew in power until each was made fully responsible for all main highways of a State. Generally such a department was first established to administer State grants-in-aid to local units for road improvement, with little authority as to location or character of construction. Next the department was made responsible for construction with State funds, sometimes supplemented by local funds and often subject to local influence. Completed roads were turned over to local units for maintenance. Experience with local maintenance of main routes soon led to raising the State highway department to full stature by making it responsible for all operations with State funds.

These developments, and the plan adopted later by the Federal Government to aid the States in road improvement, were influenced greatly by the general form of government in this country. The United States is a union of 48 States, each with sovereign powers. The Federal Government has only those powers specifically granted in the constitution adopted as a basis for the union and in later amendments ratified by three-fourths of the States. These powers include creation and support of the Army and Navy, levying of taxes, conducting relations with foreign countries, regulation of commerce between the States, provision of a postal service, and providing for the general welfare. Each State enacts its own civil and criminal laws, provides schools, employs its own police to enforce its laws, imposes taxes, and has its own courts. It is believed that the Federal Government does have the power to build and maintain national highways throughout the country, but this question has never been made an issue in the courts. When the people wanted better roads they turned first to their State governments. Later the Federal policy was patterned to aid the State highway organizations rather than supplant them.

State highway systems

New Jersey initiated State aid to counties in 1891, and six other States had taken the step by 1900. The aid was applied to the most-used routes of travel. Every State had some form of State participation in highways by 1917. By that time most of the States were contemplating State improvement of main routes, and had small but effective highway organizations.

One of the first jobs of a new State highway department was to select or participate in the selection of a State highway system as an objective for future accomplishment. The process was a simple one. Lines were drawn on a map connecting the larger centers of population. No one knew where the money would come from to build the routes. Many people regarded the maps as products of visionary thinking, yet they were rough outlines of a plan that would be greatly expanded, and upon which a large army of men and machines are still at work.

Problems faced in planning and constructing highways were, in some respects, much simpler than are now faced by engineers in countries beginning the improvement of highway systems. The motor vehicle was not the powerful, speedy, and dependable instrument that it is today. Compared with present vehicles they were few in number, light in weight, and slow in speed. Highway standards were advanced and methods of construction improved over a period of many years as the motor vehicle continually grew in numbers. Roads now must be designed for a more severe and intensive usage than was required in the early part of the century; but we now have the advantage of an experience of trial and error gained through many years.

Advent of the automobile

The year 1904 marks the end of a period. For the preceding 100 years or more there had been no important change in methods of road construction. Either of the major types of surfacing—gravel and macadam—were known to give entire satisfaction under the horse-drawn traffic of country roads. Other types of surface had been developed but, for various reasons, had been used on only a small mileage.

About 1904 automobiles began to pour out from the cities, and the wheels of vehicles sucked the dust binder from gravel and macadam roads. Air currents thus produced blew it away and the surfaces began to disintegrate. Engineers met the challenge by substituting tar and asphalt for the weaker mineral binders, first as dust palliatives, then as protective surface coatings, and finally as internal binders.

New types of roads

The decade following 1904 was marked by the development of new types of road, a general increase in the radius of travel occasioned by the use of the automobile, and a strengthening of the demand for surfaced roads as motor-vehicle owners grew in numbers.

Although the first concrete road had been built in 1893, there were not more than 5 miles of that type on rural highways in the entire country in 1909. In that year approximately 4 miles were built; in 1910 about 20 miles were added, the following year 40 miles, and then the first big increase, in 1912, when 250 miles of rural highways were paved. By 1924 the mileage of concrete pavement had increased to 31,146 and construction was proceeding at the rate of more than 6,000 miles a year, a rate approached by no other type better than gravel.

The more extensive use of brick and of bituminous pavements of the mixed type on concrete base began also at about the same time, and was due to the same cause, the increased use of motor trucks. In 1914 there were approximately 1,500 miles of brick pavement; in 1924 there were 4,319. In 1914 the mileage of rural highways paved with bituminous concrete or sheet asphalt was still negligible; in 1924 there were more than 9,700 miles of these types. They had been developed previously for city streets, and were used on rural roads when traffic became sufficient to justify their cost.

The mileage of plain gravel road constructed surpassed by far that of all other types combined. It was not until the early 1920's that the surfaces of these roads were successfully treated with bituminous materials.

Water-bound macadam was the most frequent choice in the Eastern States, where a smooth and durable surface was desired, until after World War I. Bituminous treatment of macadam surfaces became standard practice between 1915 and 1920. Popularity of plain and surface-treated macadam declined after 1920 as cement concrete and macadam with internal bituminous binder came into use.

Low standards of design

Throughout the period 1900–1920 standards for surfaced width, grade, and alinement were very low in comparison with present practice. In 1900 the speed, weight, and size of horse-drawn vehicles controlled design. As late as 1918 legal speed limits ranged from 15 to 30 miles per hour in all but one State, which permitted 40 miles per hour. New surfaces were generally placed on the old dirt roads without change in location or only slight revision. Steep grades and sharp curves were accepted to keep costs down. They were not inconsistent with the requirements of the slow-moving traffic. The idea of an essential minimum sight distance had dawned on no one. Surfaces 9 to 16 feet in width were built. Near the close of the 20-year period advanced designers were urging 18 feet of width as necessary for safety, and were meeting opposition.

Power equipment appears

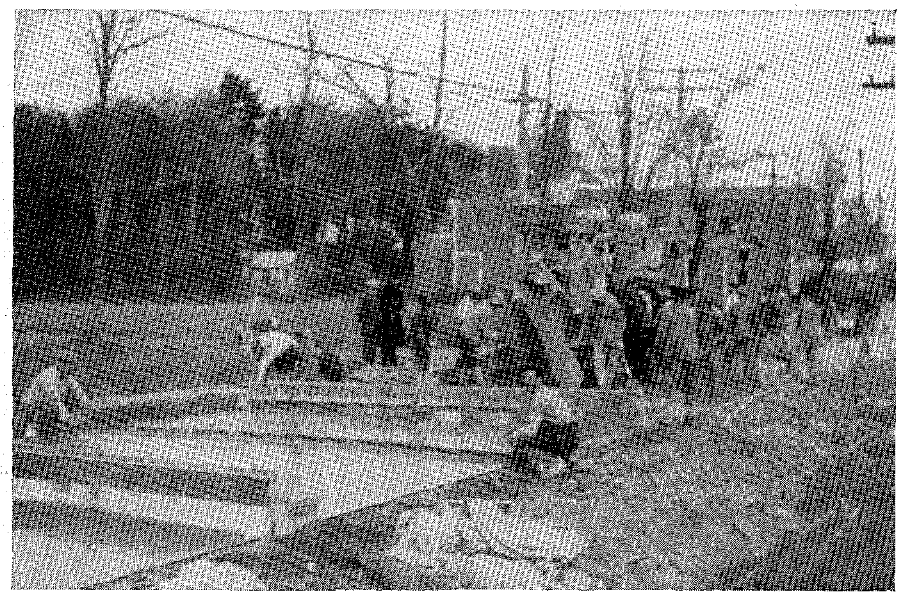
During the last half of this period, there were marked advances in machinery for road construction. Power shovels and horse-drawn dump wagons appeared on grading jobs. The dump wagon was an adaptation of the farm wagon, so constructed that the load could be dumped by pulling a lever. Mechanical mixers displaced hand-mixing labor for making cement concrete. The concrete pavement finisher was being developed as the period ended. Bituminous distributors made hand-pouring methods obsolete. Portable plants for preparing bituminous mixtures were placed on the market. These were important contributions, but utilization of the internal-combustion engine as power on road-building equipment was to produce more revolutionary changes in construction methods.

The Federal-aid Policy

Two factors of outstanding importance in causing the great increase in road building after 1920 had their origin in 1916 and 1919. They were (1) Federal aid to the States for highways; and (2) taxation of motor vehicles for highway purposes.

Origins

Federal participation in road matters on a continuing basis began with the establishment of the Office of Road Inquiry in 1893. This organization later became

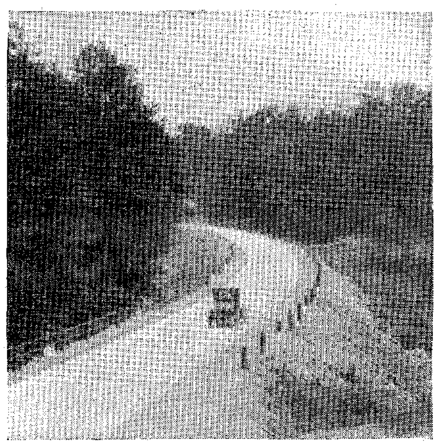


Building a concrete road in 1915. The traveling mixer was an innovation and hand methods were used in spreading and finishing.

the Bureau of Public Roads of the Department of Agriculture, and is now the Public Roads Administration of the Federal Works Agency. Initially it was directed to investigate methods of road construction and disseminate the knowledge gained. Operations were on a small scale. There were no funds for actual construction of roads. Until 1901 the total expenditure in any year did not rise above $10,000. In educational work seeds were planted that soon began to sprout in almost every State east of the Mississippi River.

Object lesson roads

After 1900, important phases of the work were laboratory studies of road materials and the construction of "object lesson roads." These were short demonstration projects built with local funds under the supervision of a Federal engineer. The small research laboratory developed tests for aggregates and other materials and made important contributions toward overcoming serious defects in early bituminous construction.



A concrete road completed in 1929. The narrow width was considered adequate for the traffic at that time.

Improvement of mail routes

In 1912 the Federal Government took the first step toward active participation in general road construction. As a tentative adoption of the Federal-aid device it authorized $500,000 to pay one-third of the cost of improving roads over which the mails were carried. At the same time a congressional committee was appointed "to make inquiry into the subject of Federal aid in the construction of post roads and report at the earliest practicable date." One of the steps taken was to make a somewhat detailed study of laws and road-building methods in the countries of Europe.

Only 17 States elected to raise the funds necessary to match the offered Federal funds—a reflection both of the absence of available funds and of officials to advance State interests. In the 17 States $1,800,000 was expended in building 425 miles of road, and the experiment taught many lessons that were later to be heeded in much larger undertakings. Experience was gained in building roads on different soils and with different materials. Defects that developed were studied and the causes determined.

Federal-aid policy established

The success of this small program demonstrated that a practicable procedure for road-building cooperation between the States and the Federal Government could be developed. In 1915 the congressional committee reported that good roads would promote the general welfare and strongly recommended Federal aid, but it did not recommend a definite plan.

One group in Congress favored a cooperative Federal-State relationship in the expenditure of the Federal funds. Another, of considerable strength, wished to parcel out the money to the 3,000 counties of the country to spend as they saw fit. Fortunately, the views of the former group prevailed in the bill which, as the Federal-aid Road Act, became a law in 1916.

The general policy of aid to the States initiated by this act has been continued up to the present time. Large sums of Federal money have been provided for highways, but the benefits of the act have extended far beyond the actual physical facilities provided. It has been the means of bringing together the highway officials of the country and coordinating their efforts toward a common objective.

The Federal-aid Road Act

The Federal-aid Road Act of 1916 provided for the improvement of any rural road over which the mails were carried, and definitely prohibited improvements in towns of more than 2,500 population. It appropriated a total of $75 million to be spent in a 5-year period, and permitted Federal participation in payment for the roads constructed up to 50 percent of the total cost but not exceeding $10,000 a mile, the remainder to be paid from funds under the control of the States. Subsequently, the limit on Federal participation per mile was increased and eventually it was removed. It was required that the funds be applied to post roads to facilitate delivery of mail by Federal employees. Since the mails were carried over nearly all roads of any importance this provision was not particularly restrictive in effect. Participation in city improvements was prohibited and the limit on Federal participation in cost was placed in order to improve as many miles of rural roads as possible.

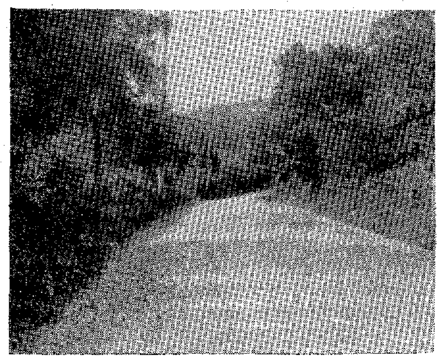
The act prescribed a formula for distributing funds among the States—a formula employing as apportioning ratios, each with identical weight, the percentage relations of the area, population, and post-road mileage of each State to the total area, population, and post-road mileage of the United States. Another important provision was that which made the aid available only to States with a State highway department adequately constituted to cooperate with the Federal agency and to assume responsibility for the construction to be undertaken. Administration of the act was placed under the Secretary of Agriculture, who acted through the organization that is now the Public Roads Administration.

Of the first apportionment of $5 million, Texas, the biggest State, with a large mileage of roads, received the greatest amount—$297,928. New York, with a large population and considerable area, received the next largest amount—$250,720. Nevada, a Western State of large area but small population, received $64,398. Delaware, limited as to all three factors, received only $8,184.

When the act was passed, only 33 States had highway departments meeting its minimum requirements and there was a general need for strengthening the powers and staffs of the departments to discharge responsibilities they would be called upon to assume. In those States without highway departments the necessity of compliance with the Federal act caused immediate creation of State agencies after the model of those which in other States had already proved their capacity for satisfactory performance.

States have initiative

This original charter of Federal-aid operation in 1916 clearly established certain conditions vital to the success of the new inter-governmental undertaking. In accordance with democratic concepts of division of authority between the Federal Government and the States, legislation preserved to the States the initiative in determining what roads were to be built, and the character of their improvement. It gave Federal officers authority to approve or reject the State's proposals. It placed the immediate supervision of construction work in the hands of the State highway departments, but made certain that the Federal funds appropriated would be spent for sound workmanship.



A penetration macadam road in North Carolina built in 1915. Standards for width, grade, and alinement were low in comparison with those now in use.

This it did by subjecting the results of the work to the final approval of the Federal authority and by directing the withholding of the Federal share of the cost until an approved result had been obtained, requiring the States in the first instance to pay for the work done under their supervision. Finally, it imposed upon the States or their subdivisions the duty of maintenance.

Sources of funds developed

State funds to match Federal aid were necessary before a State could avail itself of the benefits of the legislation. When the act was passed, highway funds were small in amount and came almost entirely from taxation of property or from bond issues supported by property taxes. Motor-vehicle registration fees, initially imposed to defray registration costs, were growing substantially. Highway usage by motor vehicles was approaching, but had not reached an intensity that justified assessing them with a large part of highway costs. It became necessary for the States to obtain an additional source of continuing highway revenue. Resistance to increases in property taxes precluded them as a satisfactory source.

Temporarily the problem remained unsolved, but in 1919 four States imposed a tax on gasoline. By 1929 every State collected such a tax. Concurrently, registration fees for motor vehicles were adjusted to produce greater revenue for highways.

Soon after enactment of the Federal-aid legislation in 1916, the United States entered World War I. Highway improvement became inactive, and remained so through the readjustment period of 1919. However, the essential machinery for a large highway-improvement program had been created. It was not smooth-running machinery — numerous faults would have to be corrected—but it was machinery sound in basic principles.

Demand for highways

In the early 1920's highway construction increased rapidly to a large volume. In 1919 an additional appropriation had substantially enlarged the scale of Federal participation. Motor vehicles increased at an amazing rate, producing more revenues for highways. As new highways were built still more people felt the need for a motor vehicle, and so the upward trend of motor vehicles, funds for highways, and construction of surfaced roads continued.

The Federal Highway Act

As enlarged highway programs were being planned by the States, two outstanding defects of omission in the Federal-aid legislation became conspicuous. The law permitted the combined Federal and State funds to be expended for the improvement of almost any rural road, and the pieces of road proposed for improvement in some of the States were so scattered as to defy any reasonable expectation of connected improvement. Too, some States, providing no funds of their own for maintenance, were dependent upon the uncertain action of county governments for preservation of the roads built.

Both of these defects were corrected by the Federal Highway Act of 1921. It was this act that established the Federal-aid highway system by requiring the State highway departments, with the approval of Federal authorities, to designate a system of the principal interstate and intercounty roads, limited in extent to 7 percent of the total mileage of rural roads then existing, and restricting to this designated system the expenditure of all Federal-aid appropriations. The legislation also strengthened Federal policy as to maintenance of highways completed with Federal aid. It placed full responsibility upon the State and provided that after appropriate notice, needed maintenance might be done under direct Federal supervision and the cost paid with Federal funds available to the State.

Influence of Federal aid

The Federal Highway Act appropriated funds only for the fiscal year 1922, an addition of $75 million to the amounts previously appropriated; but its basic provisions were destined almost without change to govern the expenditure of $1,190 million later authorized for appropriation and expenditure in the next 12 years. Federal funds authorized for the years 1921 through 1932, including special funds to provide employment through highway construction, averaged close to $100 million per year. Increasing motor-vehicle revenues and miscellaneous income, when added to the Federal funds, permitted the State highway departments to increase construction expenditures from $299 million in 1921 to $731 million in 1931. The average annual expenditure by State highway departments for the 12-year period was $457 million.

The years from 1921 to 1933 were the most productive in highway construction of all the years of our history. In these years a substantial initial improvement was effected on nearly the whole of the designated Federal-aid system. To the achievement of this result the money appropriated by the Federal Government had contributed in relatively small part; but the sound principles of highway administration established by, and in pursuance of the Federal Highway Act of 1921 had been outstandingly conducive.

Motor-vehicle license revenues and gasoline taxes collected by the States, each year in greater sums, were expended almost exclusively on the Federal-aid and State systems. They were expended on the Federal-aid system as often without as with matching Federal funds. The modest Federal appropriations made a small part of the total of funds expended on the system; but the principles and standards developed on the Federal-aid projects were applied in the whole expenditure.

In 1932 provision was made for increasing the extent of the Federal-aid system when a State had made provision for completion and maintenance of 90 percent of the original system.

During the depression years of the 1930's emergency Federal funds not required to be matched by the States were appropriated to provide employment, and at the same time create useful improvements. At this time the Federal policy was broadened to permit the use of Federal funds in improvement of extensions of the Federal-aid system into and through municipalities, and for construction of secondary or farm-to-market roads. This policy was continued in subsequent Federal legislation.

Reorienting the Highway Program

During the 1930's one State after another approached the end of what is now regarded as the pioneer period of road construction. After World War I they had established the objective of constructing a system of two-lane roads connecting the centers of population. This job was nearly done. But our highway system was far from adequate. Need for highway improvement on a scale larger and broader than in any preceding period became evident.

Causes of the problem

Most of the States had applied a policy of stage construction; that is, an effort was made to construct permanent graded highways and to save money by constructing low-type surfaces which might later be converted to higher types without great loss of expenditures already made. This procedure, though sound in principle, was not completely successful, either because the road builders of that day were unable to visualize the enormous advances in traffic volumes, and in the weight and speed of vehicles, or because, visualizing these things, they were unable to provide for them without too greatly curtailing the mileage which could be constructed with available funds.

Each year after 1930 the maintenance of low-type surfaces consumed a larger part of available funds, and programs for replacement of these surfaces with higher types had to be undertaken as measures of economy.

Main route problems

Highway users, as they became acquainted with roads built to new standards for width, grade, and sight distance, complained vociferously about the older, low-standard roads. The mounting toll of accidents on the more hazardous early construction added force to the complaints. Many miles of main rural highways now carried a traffic that justified four traffic lanes. On main routes near cities, businesses and developments of various kinds fronting immediately on the highway gave them the aspect of business streets rather than through routes for unobstructed travel. Practically every city had serious congestion problems that could be solved only by major highway improvements. The improved rural highways brought a great volume of traffic to each city entrance where it must pass over streets designed for the traffic of an earlier day. Urban residents demanded that a greater share of motor-vehicle revenues be applied to solution of their problems.

Secondary road needs

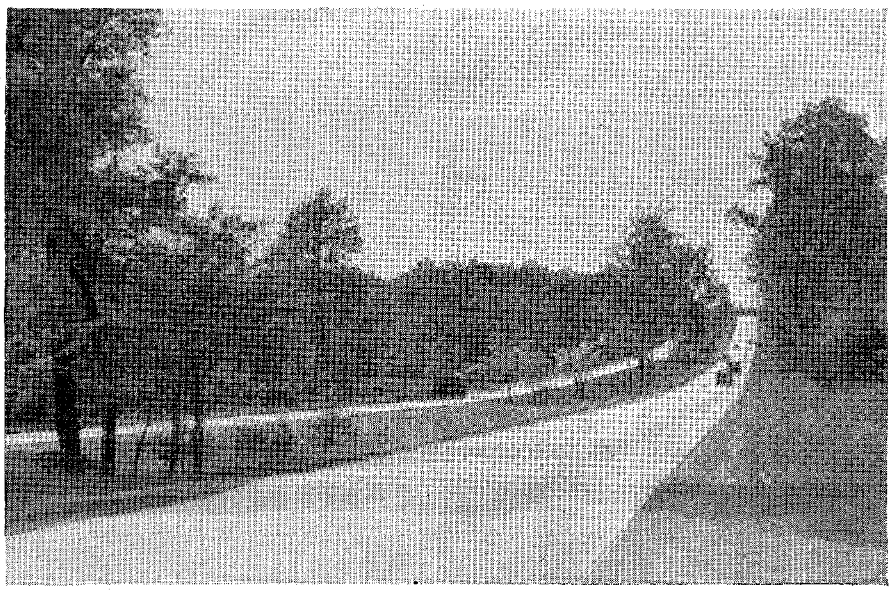
At the same time farmers throughout the country made strong claims for improvement of the secondary or farm-to-market roads which they had to travel to reach the main highway or the nearest population center. A motor vehicle was now found on almost every farm. Better rural education was provided by consolidation of schools to which children were brought by bus. The automobile brought to the farmer a broader social life, but he needed good road surfaces to enjoy the full advantages.

Comprehensive studies undertaken

In spite of the great length of highways already completed, highway problems were not nearing a solution—on the contrary, they became more complicated.

In this situation the Bureau of Public Roads saw a need for comprehensive studies to determine the condition of all rural highways, the character and extent of their use, the source of funds for different classes of highways, and how the burden was distributed among classes of highway users and other groups. This information was needed as a basis for the establishment of a definite, economically and socially defensible, integrated highway improvement program in all States.

Use of 1½ percent of the annual Federal-aid funds by the States in making



This four-lane divided highway is typical of the kind of improvement needed on a large mileage of main highway carrying heavy traffic.

highway planning surveys and other engineering and economic investigations was authorized by Congress in 1934, and the Bureau of Public Roads undertook to assist the States in organizing the surveys and coordinating the work so that the data could be used for analysis on a national basis.

The first of the planning surveys was initiated in 1935, and by the beginning of the war every State was engaged in such work. The data collected have been of the greatest importance to the States in informing the public as to road needs, and in supporting needed highway legislation. Nationally the surveys have furnished basic material for two important reports.

Facts and recommendations

The first of these—*Toll Roads and Free Roads*—was prepared by the Public Roads Administration in 1939. The second report — *Interregional Highways* — was submitted to the President and to Congress in 1944 by a committee appointed by the President to make a special study of highway needs.

These reports discussed the serious deficiencies that existed in highways of various classes, and indicated the relative urgency and character of improvements needed. Conclusions reached were supported by factual data from the planning surveys and special studies by State highway departments.

Relief from traffic congestion on main routes approaching and through cities was found to be the problem of greatest urgency. Next in importance was the improvement to high standards of the most important routes interconnecting the various regions and principal centers of population. As another step toward providing general highway service, modernization of the Federal-aid system was recommended. Needs of the agricultural population required the selection and improvement of a system of secondary or farm-to-market roads, carefully selected to give the greatest service to the rural population, and coordinated with the network of main highways.

The recommendations met with general public acceptance, and early legislative action was in prospect when this country was drawn into the Second World War.

Normal highway improvement ceased immediately. Many highway builders enlisted in engineering branches of the armed forces while others began the construction of a large mileage of access roads to training areas and war establishments of various kinds.

World War II

It is not appropriate to pass over the war period without some mention of the great use made of highways in channeling our resources to war production. The country was soon dotted with war plants, training areas, and munition centers. Heavy traffic flowed to embarkation ports on both coasts. Main highways were crowded with war traffic. Trucks carried raw materials, parts for war machines, and interchanged partly finished machines between plants. Highways and trucks became an integral part of the war production line. They were also essential in housing and feeding a great army of civilian workers in war plants and in their daily trips to and from their jobs. A superior system of highway transport gave the United States a great advantage over enemy nations.

But the war left its imprint on our highways. Many miles of the oldest highways, already worn and obsolete and scheduled for replacement, were kept in service. A situation already bad was accentuated by the wear and tear of continuous streams of war traffic. The mileage of road no longer adequate for the traffic carried and difficult to maintain in service grew in size throughout the war.

The Postwar Highway Program

In 1944, as the prospect of victory grew stronger and stronger, the Federal Government enacted legislation authorizing a postwar highway improvement program on a broad scale, and designed to meet the needs developed in the prewar studies. The recommendations made in the earlier reports—*Toll Roads and Free Roads* and *Interregional Highways*—were put into effect in the new program.

The Federal-aid Highway Act of 1944 authorized $500 million for each of the first three postwar years, to be expended according to the long-established Federal-aid plan. Since funds were to be matched by the States, a 3-year program of $3 billion was made possible. The annual authorization was assigned as follows: $225 million for the Federal-aid highway system, $150 million for secondary or feeder roads, and $125 million for the Federal-aid system in urban areas.

The legislation required the designation of two new highway systems. One—the National System of Interstate Highways—was limited by law to 40,000 miles, which, in large part, have now been designated. This system connects the principal metropolitan areas, cities, and industrial areas and has an important relation to the national defense. It reaches 42 State capital cities and will serve 182 of the 199 cities in the country having a population of 50,000 or more persons.

The other new system consists of the *principal secondary and feeder roads*, including farm-to-market roads, rural free-delivery mail routes, and public school bus routes.

Beginning of the postwar highway program was authorized late in 1945, but high prices and shortages of equipment and materials retarded progress throughout 1946. Considerable momentum was gained in 1947 and a volume of work that taxed the facilities and resources of our contracting organizations was carried on in 1948 and is being continued in 1949.

Legislation continuing the Federal-aid program was enacted in 1948, and there is every prospect of large highway construction programs for a number of years to come.

The broad general plan of highway improvement by State highway departments and of assistance by the Federal Government, developed in the period 1916–21, is being continued. Both State and Federal programs have been considerably broadened as use of highway transport has increased, but the basic concepts of the original plan are still in effect. In 1939, as a result of a reorganization of certain branches of the Federal Government, the Bureau of Public Roads of the Department of Agriculture became the Public Roads Administration of the Federal Works Agency. Its functions in administering Federal aid and in doing other work were not changed in any way.

Emphasis has been placed on the importance of mechanization of construction methods in launching large-scale road building in the early 1920's. Since that time there has been continuous progress in improving the size, efficiency, and durability of road-building machines. Competition in a large market for machines has led manufacturers to spend large amounts for experimentation and development.

Adaptation of the Diesel engine has greatly improved grading machinery, rollers, and power shovels. The truck has become an essential implement on practically every type of construction. Carry-alls now move several times the earth load that could be handled by the largest grading equipment of 1920. Crawler tractors, particularly those of the bulldozer type, are used for a wide variety of purposes. Mixing and finishing machines for both concrete and bituminous mixtures have been greatly improved, and their range of use extended. Numerous special-purpose machines are available.

Highway Systems and Their Present Condition

For each square mile of area in the United States there are, on the average, 48 persons; and there is 1 mile of road, one-half of which has a surface of some kind. But conditions vary between wide extremes. Elimination of the arid, semiarid, and mountainous regions would increase the mileage and population figures greatly. New York, a large industrial State, has 295 persons per square mile, and 1.7 miles of road of which 1.4 have been surfaced. Alabama, a southern agricultural State, has 55 persons per square mile, and 1.2 miles of road of which 0.8 mile has been surfaced. Nevada, in a semiarid and mountainous region, has only 1.3 persons per square mile, and slightly over 0.2 mile of road of which 0.04 mile is surfaced.

Nearly the entire population of the country lives within a few miles of a surfaced road.

The general pattern

The classification of the highways of the United States into systems presents a somewhat confusing picture. There is variation in State practice as to administrative control over highways. Systems of the most used highways have been superimposed on other more extensive systems, and form an integral part of them: Some highways are a part of four systems. Classification of the total mileage according to administrative control over improvement produces a result quite different from a classification according to character of highway and the traffic using it.

Of the 3,009,000 miles of rural highway, 342,000 are primary State highways under the control of the State highway departments. These are the important roads of the country, the main channels of highway traffic. Each of the other systems of particularly important main highways to be mentioned later is included in the State systems of primary highways.

The remaining 2,667,000 miles of rural roads are secondary or feeder roads that range in importance from roads carrying a considerable volume of traffic to towns, villages, and main highways, to very minor roads serving only one or two families. Improvement of these roads is mainly supervised by county, township, and other local officials but certain States have placed all or a portion of the secondary roads under the State highway department. Secondary roads in this category total 119,000 miles or 4½ percent of all secondary roads.

The highways and streets of cities total about 317,000 miles and are largely under control of city officials. However, about 30,000 miles of city arteries that are extensions of primary State highways are under State highway department control.

Federal-aid systems

The primary Federal-aid highway system, designated as a result of the Federal Highway Act of 1921, now consists of 232,000 miles of the more important primary State highways and includes both rural and urban sections. These highways have been and continue to be improved by the States and Federal Government cooperatively, but a large amount of work is done by the States without Federal assistance. This system is now initially improved throughout almost its entire extent, but there is a general need of modernization and further improvement.

The most important Federal-aid highways—those carrying the heaviest traffic and serving the long-distance traffic movement—have been selected for inclusion in the National System of Interstate Highways. This system, as thus far designated, includes 37,800 miles and is to be increased to 40,000 miles by addition of sections in urban areas. It will be improved to the highest modern standards with regular Federal-aid and State funds. Cities participate in improving urban sections. Inclusion of a route as part of the interstate system centers attention upon it as a main artery and assures high standards in improvement, but it does not make available any funds other than those provided for the primary Federal-aid system.

U S marked routes

Important main routes of the country are marked with shield-shaped route markers bearing the initials U S and a route number, such as U S 1 or U S 40. Roads so marked are parts of the United States Highway System. The most important of them make up the interstate system. Almost invariably such highways are part of the Federal-aid and State systems, but the designation as a U S route is without legal or administrative significance. These routes have been designated and numbered by joint action of the State highway departments, acting through the American Association of State Highway Officials, for the convenience of map makers, information services, and highway travelers.

Secondary systems

The great mileage of secondary or farm-to-market roads is not separated into as many overlapping systems as are the primary roads, but there is one special system within this group. Under the provisions of the Federal-aid Highway Act of 1944, the more important secondary roads—those most used for moving farm products to market, children to school, and for social activity—were selected to comprise a system eligible for improvement with Federal funds provided specifically for the purpose. Federal-aid secondary systems have been selected by State and appropriate local officials and approved by the Public Roads Administration. The system now includes 378,000 miles. A small mileage of State highways not included in the primary Federal-aid system is included in this system.

The condition of improvement of the two largest classes of rural roads is shown in table 1. The higher types of improvement are concentrated to a great extent upon the systems of most used roads that have been described.

The Federal-aid primary and Federal-aid secondary systems, which now include 610,000 miles, may be expected to expand to as much as 750,000 miles in the next 10 years. They will then embrace one-quarter of the total rural-road mileage, but that one-quarter will serve almost 90 percent of the total rural highway travel.

Use of Highways

Use of highways is closely interwoven with the economic and social life in the United States. There are 40,700,000 motor vehicles or 1 for every 3.6 persons (in 1948). The average car owner traveled 9,727 miles in 1947. He used his car to travel to and from work, to the store, on business trips, for a Sunday afternoon drive, and many owners took a summer vacation trip of some hundreds of miles.

The average commercial bus traveled 40,000 miles in that year, and the average truck traveled 9,939 miles. However, many trucks in commercial operation travel 20,000 to 30,000 miles per year.

Table 1.—Existing rural-road mileage in the United States at the end of 1946

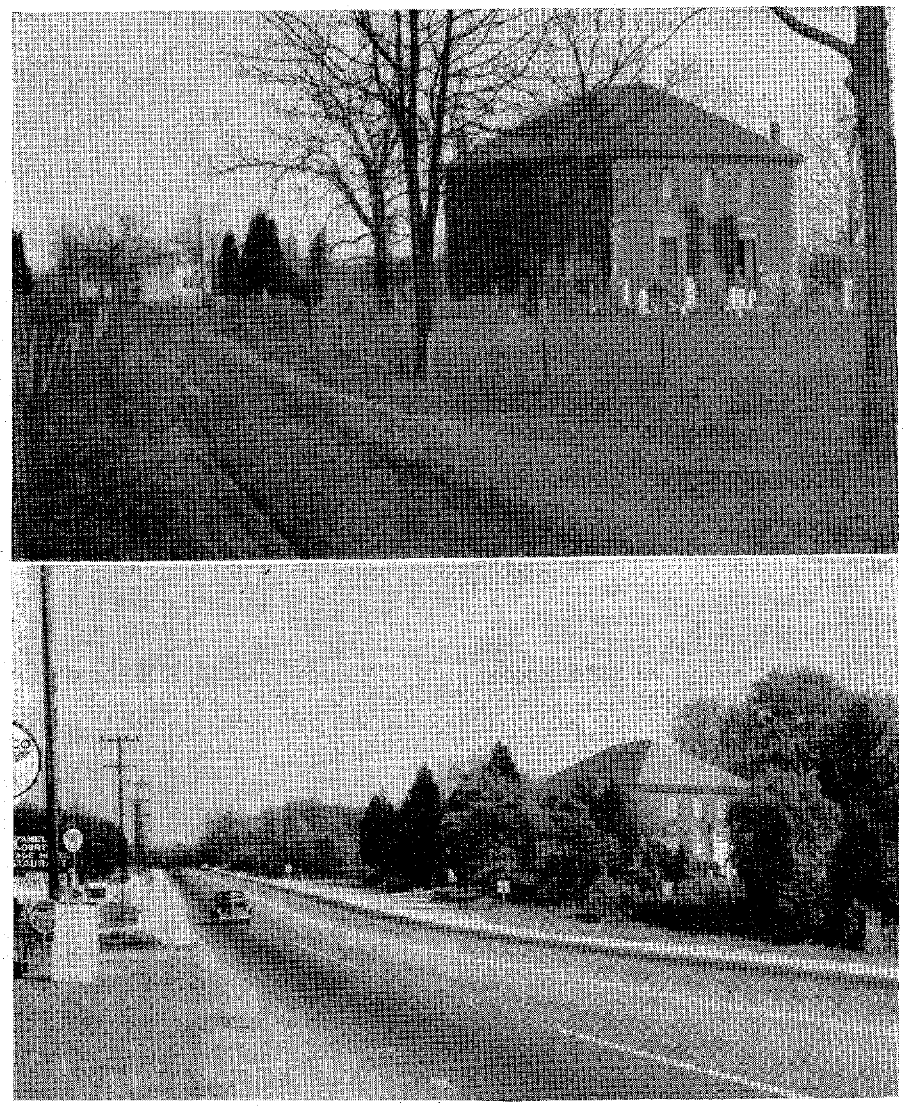
Surface type	Primary State highways (rural)	All other rural roads	Total rural roads
	Miles	*Miles*	*Miles*
Nonsurfaced	24,116	1,481,096	1,505,212
Low-type surfaces:			
Soil surfaced	2,545	82,419	84,964
Gravel or stone	48,568	870,482	919,050
Low-type bituminous [1]	132,760	172,723	305,483
Subtotal	183,873	1,125,624	1,309,497
High-type surfaces:			
High-type bituminous [2]	51,477	43,795	95,272
Portland cement concrete	79,265	14,642	93,907
Brick and other block pavements	1,218	1,263	2,481
Dual type [3]	2,122	567	2,689
Subtotal	134,082	60,267	194,349
Unclassified	--------	87	87
Grand total	342,071	2,667,074	3,009,145

[1] Includes bituminous surface-treated and mixed bituminous surfaces.
[2] Includes bituminous penetration, bituminous concrete, and sheet-asphalt surfaces.
[3] A dual-type road is defined as a road the wearing surface of which consists of 2 individual types, each of which has an aggregate width of at least 8 feet.

Truck transport

With the growth of highway transportation there has been a trend toward the abandonment of branch railroad lines, and there are many communities that are now entirely dependent upon highways for exchange of products with the outside world.

There are approximately 6,000,000 farmers producing food and clothing for the Nation, and for export to other nations. All of their products start the journey to the consumer by highway, and many of them move from the producer to the processor and then to the consumer entirely by highway.



The highway from Washington to Richmond as it appeared in 1913 and 1948. The building is Pohick Church, where George Washington attended religious services.

Forty-two percent of the fresh fruits and vegetables of 13 large cities, or the equivalent of 254,500 carloads a year, is delivered by truck.

In 1940, 17 large stockyards received by truck 77 million head or 59 percent of the total receipts.

Seventy percent of lumber moves to its destination partly or wholly by highway.

Between 1936 and 1940 an average of 29 million tons of bituminous coal was shipped annually by highway.

Seventy-nine metropolitan areas with a combined population of 25 million people receive their entire milk supply by highway.

During the war one industrial organization had four plants located in three cities. Forgings were made in plant A, heat treated in plant B, machined in plant C, and assembled in plant D. Trucks hauled the material 100, 100, and 15 miles successively for these processes.

One Florida producing area ships 50 different fruits and vegetables by truck to 26 different States.

The transport of freight over rural highways in 1947 is estimated at 86 billion ton-miles.

Recreational travel

Tourist and recreational travel on highways is of considerable importance in many sections of the country. As an example, 1,725,000 tourists visited the State of Washington in 1947 and spent there $96,500,000. Approximately 85 percent entered the State in 462,000 automobiles and drove 460,500,000 miles within the State. The gasoline-tax revenue from this source alone amounted to $1,535,000.

People of the United States visit Canada and Mexico in large numbers. They will undoubtedly extend their trips to other countries as new highways make travel possible.

HIGHWAY ADMINISTRATION

The Public Roads Administration of the Federal Works Agency represents the Federal Government in matters relating to highways. Its principal function is the administration of Federal aid to the States. A general outline of Federal-aid policies has already been given in the chronological discussion of highway development. Actual working procedures will now be described.

Federal Administration

Headed by the Commissioner of Public Roads, the headquarters of the Public Roads Administration is at Washington, D. C. The headquarters staff includes five departments: Design, Construction, Finance and Business Management, Research, and Legal. Each of the first four is headed by a Deputy Commissioner, and the latter is headed by the Solicitor.

Headquarters functions

The Department of Design determines policies in design applied in reviewing and approving plans for Federal-aid highways and bridges. It supervises activities of the field organization in dealing with the States as to the constitution of Federal-aid systems, preparation of programs for construction, preparation of plans and specifications, and other steps necessary prior to the award of a contract and beginning construction. Detailed review of plans for projects is made in the field offices but the headquarters office is frequently consulted in planning expressways, large bridges, and other work of particular difficulty.

The Department of Construction and Maintenance takes over supervision of a project when it reaches the construction stage. It is responsible for proper performance and progress on all projects undertaken; for the advancement and application of improved methods of construction and maintenance; and for correlation of field practice with research developments.

The Department of Finance and Business Management is responsible for all financial and business activity necessary in connection with the obligation and payment of funds for all work undertaken by the organization. It handles matters pertaining to budgets, personnel records, equipment purchases, property control, and miscellaneous services.

The Department of Research plans and conducts research relating to all phases of highways and their use, including design, construction, transport, administration, and finance. Results are made available in the form of technical data, research reports, and statistical tabulations.

The Legal Department is responsible for all legal activities necessary in carrying on the work of the organization. It is in charge of legal aspects of organizational matters pertaining to acquisition of right-of-way, patents, lease agreements, and investigations.

Field offices

Direct contact with State highway departments is maintained through division and district engineers who are in charge of the field organizations. There are ten divisions, each of which includes several States. In each State there is a district engineer who represents the Commissioner directly in all cooperative work with the State. Organization charts for the headquarters organization and for a typical field division are included as figures 1 and 2.

FIGURE I. — ORGANIZATION OF THE PUBLIC ROADS ADMINISTRATION

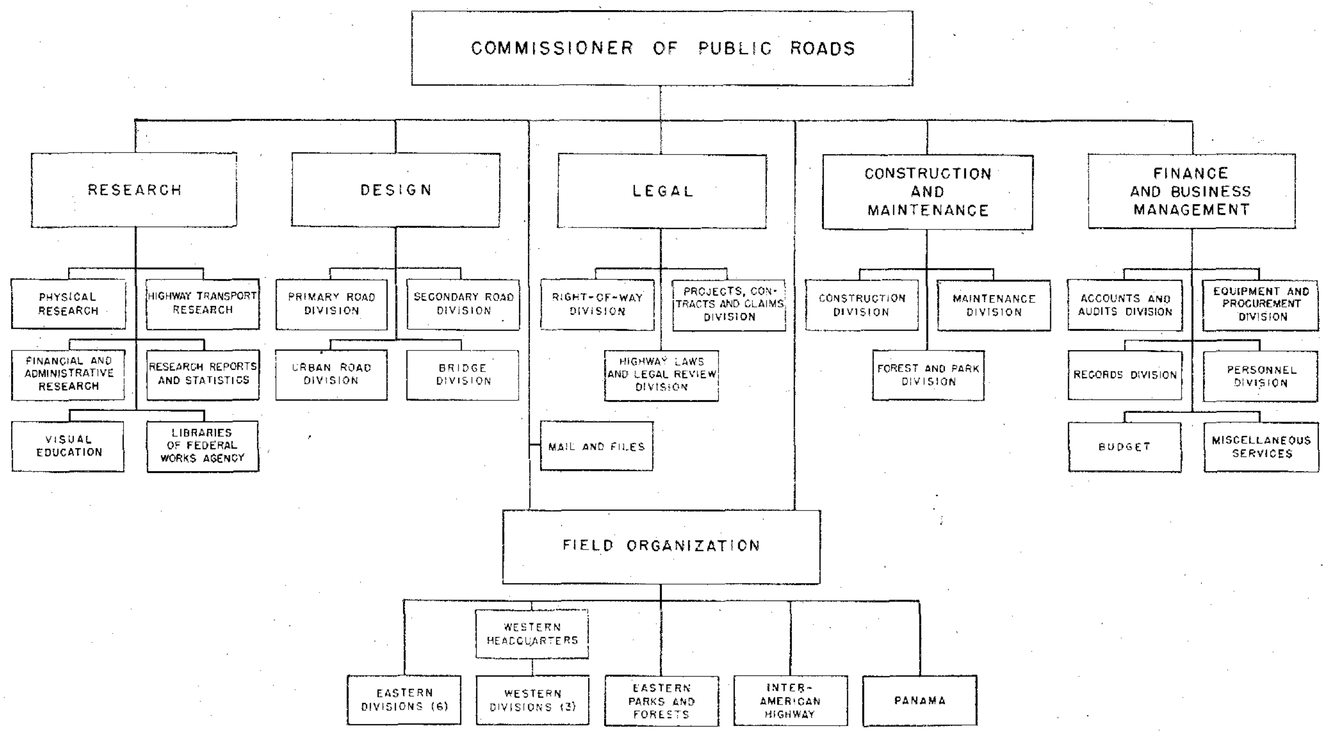


FIGURE 2. – DIVISION ORGANIZATION CHART

PUBLIC ROADS ADMINISTRATION

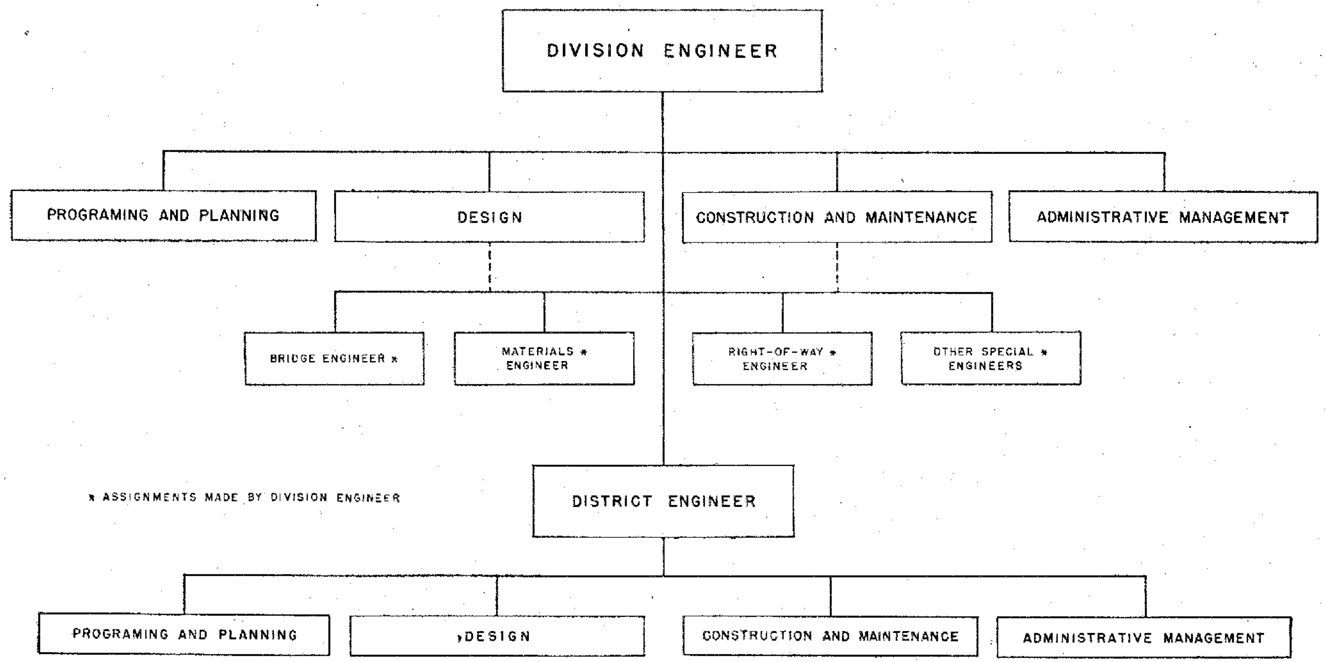


Figure 2 shows that the organizations of division and district offices parallel each other closely and the grouping of activities is not greatly different from that in the headquarters office in Washington.

The Programing and Planning Sections handle the planning and modification of highway systems and preparation of construction programs, and make studies in the general field of highway planning. A large part of the work is in connection with State highway planning surveys described later on in this bulletin. This group collects and assembles general highway and traffic statistics. The work relates to that of the Department of Research and the Department of Design of the headquarters office.

The Design Sections deal with the States in the various steps (outlined below) from the time a programmed project is advanced for immediate improvement until it is ready for construction.

The work of the Construction and Maintenance Sections and of the Administrative Management Sections parallels that of similar groups in the headquarters office.

Federal-aid procedure

Authorizations of Federal-aid funds are made for 2- or 3-year periods well in advance of the fiscal years for which they are intended. Funds for each year are apportioned to the States by Federal authorities according to the legally prescribed mathematical formulas. This is done about 6 months in advance of the beginning of each fiscal year, which starts on July 1.

The States are then required to submit to the Public Roads Administration programs of projects to be undertaken with the funds. The purpose in requiring program submissions is to enable the Federal agency to join with the States in determination of the general character of immediate undertakings needed for an orderly improvement of the highway systems, giving priority to requirements of greater urgency. Results of planning studies are important guides in reviewing programs. Following approval of a program, the State submits a more detailed description of each section of road to be improved, and the character of improvement proposed. Upon approval of a particular project proposal, a contractual agreement for improvement is entered into by the State and Federal Government.

Subsequently the State highway department prepares plans and specifications, receives bids for work to be done, awards a construction contract, supervises construction, and pays the contractor for work done. Each step is reviewed by, and is subject to the approval of the Public Roads Administration. The Federal share of the cost is reimbursed to the State only as portions of the work are satisfactorily completed.

Programs of work are reviewed in the headquarters office of Public Roads, which keeps in constant touch with field progress, but the district engineer in each State is authorized to approve each step following approval of a program.

National park and forest roads

In addition to supervision of Federal-aid highway improvement, Public Roads cooperates with the Federal Department of Agriculture in constructing principal roads in the national forests; with the National Park Service in construction of parkways and main roads in and leading to national parks; with other agencies in constructing roads through other Federal areas; and cooperates with other agencies and governments in building highways in Central America, Panama, the Philippines, and Turkey.

Research

As a guide to its own engineers and to those of the States in conducting large highway programs, the Public Roads Administration conducts extensive research on highway materials, methods of construction, highway finance, and transport, and other branches of highway economics. The information obtained has an important use in formulating recommendations as to national highway policy.

State Administration

The public highways of the country are under the full control of the 48 State governments, in their construction, maintenance, and regulation of use. Administrative authority is delegated partly to the State highway departments and partly to subdivisions of the State. Federal aid is an important source of construction funds, but its use is at the option of the State. The Federal Government does regulate certain phases of commercial operation of vehicles in interstate commerce, but it exercises no powers over the general use of highways.

Growth of responsibilities

It has already been pointed out that the State of New Jersey began the trend toward creation of modern State highway departments by passage of a State-aid law in 1891. By 1917 all States had the State highway organizations that were necessary to receive Federal aid. The growing tendency toward State participation in highway administration and the establishment of State highway administrative organizations was greatly strengthened by the passage of the Federal-aid Road Act. At the time of its approval, in 1916, only 33 States had highway departments that met the minimum requirements prescribed therein to make the State eligible for Federal aid. By 1917 the remaining 15 States had organized departments complying with the terms of the law.

State highway organizations have changed considerably since their inception. As the task of administering highways has become more complex, with the increase of highway construction and maintenance and the increase in funds expended, the highway organizations have expanded and become, in most cases, correspondingly complex. Mileages under the control of State highway departments vary in individual States from less than 1,000 to more than 60,000 miles; annual expenditures thereon vary from approximately $3.5 million to $80 million; and the number of highway department employees varies from less than 200 to more than 16,000. Even today there is no established pattern and there is still great variation among the several States, as indicated by the organization charts for California, Michigan, and Montana included as figures 3, 4, and 5. These represent the State organizations as constituted in 1948.

Forms of organization

Considering only the administrative and executive bodies—or what may be called the upper administrative level of the departments—the extent of variation is apparent. Michigan has had a single commissioner as administrative head since the creation of the department in 1905. Connecticut, too, has had a single commissioner since shortly after the department was organized in 1895. On the other hand, California has had no less than nine changes in the form or structure of the administrative body since 1895. Similarly, Oklahoma has had seven such changes.

Highway administrative organizations have developed at a different pace and in divergent directions in the various States. As might be expected, presently existing State highway bodies show considerable differences. Single executives, with no boards or commissions of any kind, head the highway organizations in 15 States. In five other States the departments are headed by single executives with a commission acting in a purely advisory capacity. An additional four States divide authority between a single executive and a commission, each acting in a coordinate capacity to the other.

In the remaining 24 States, the highway departments are under the direction of commissions. In 10 of these they exercise full administrative control, but in the other 14 States the commissions are policy-determining bodies only, with administration of the department in the hands of an executive officer. In seven of these States the commissions are limited to policy matters by law, and in the other seven States, while given full authority by law, they are part-time bodies and consequently their administrative authority is limited.

FIGURE 3. – ORGANIZATION CHART OF THE CALIFORNIA DIVISION OF HIGHWAYS

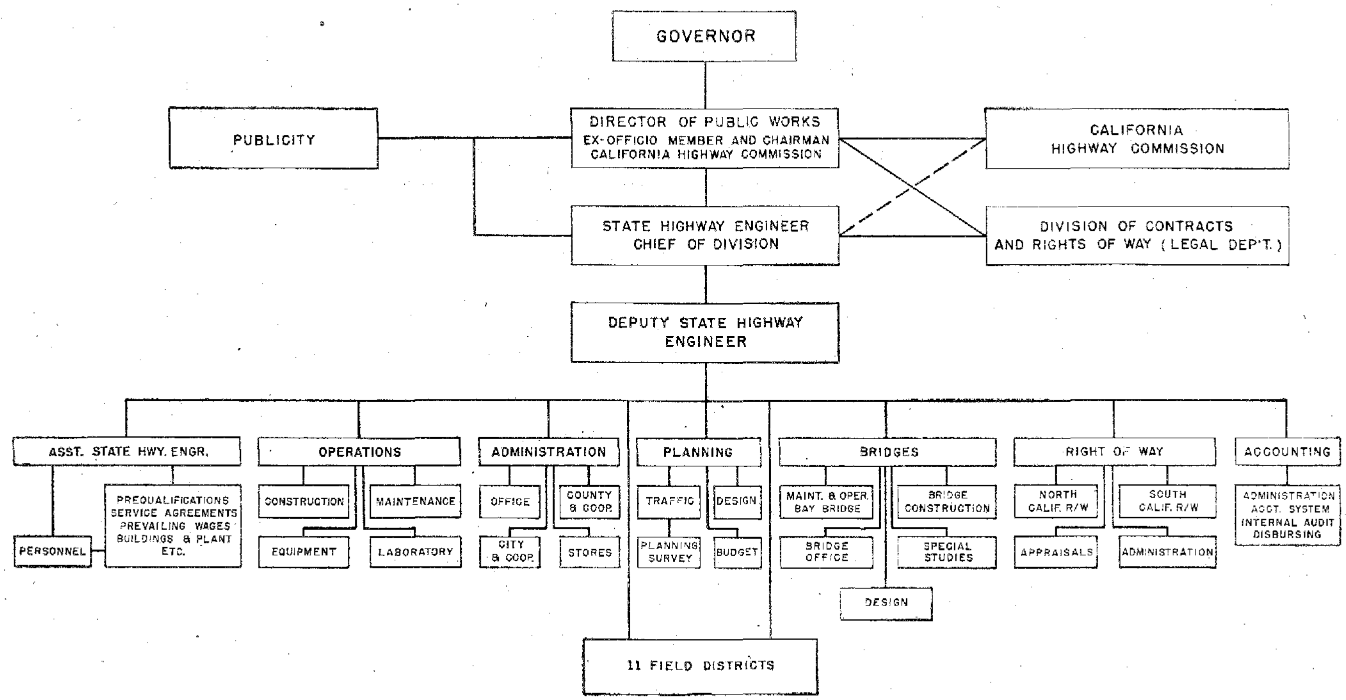


FIGURE 4. – ORGANIZATION CHART OF THE MICHIGAN STATE HIGHWAY DEPARTMENT

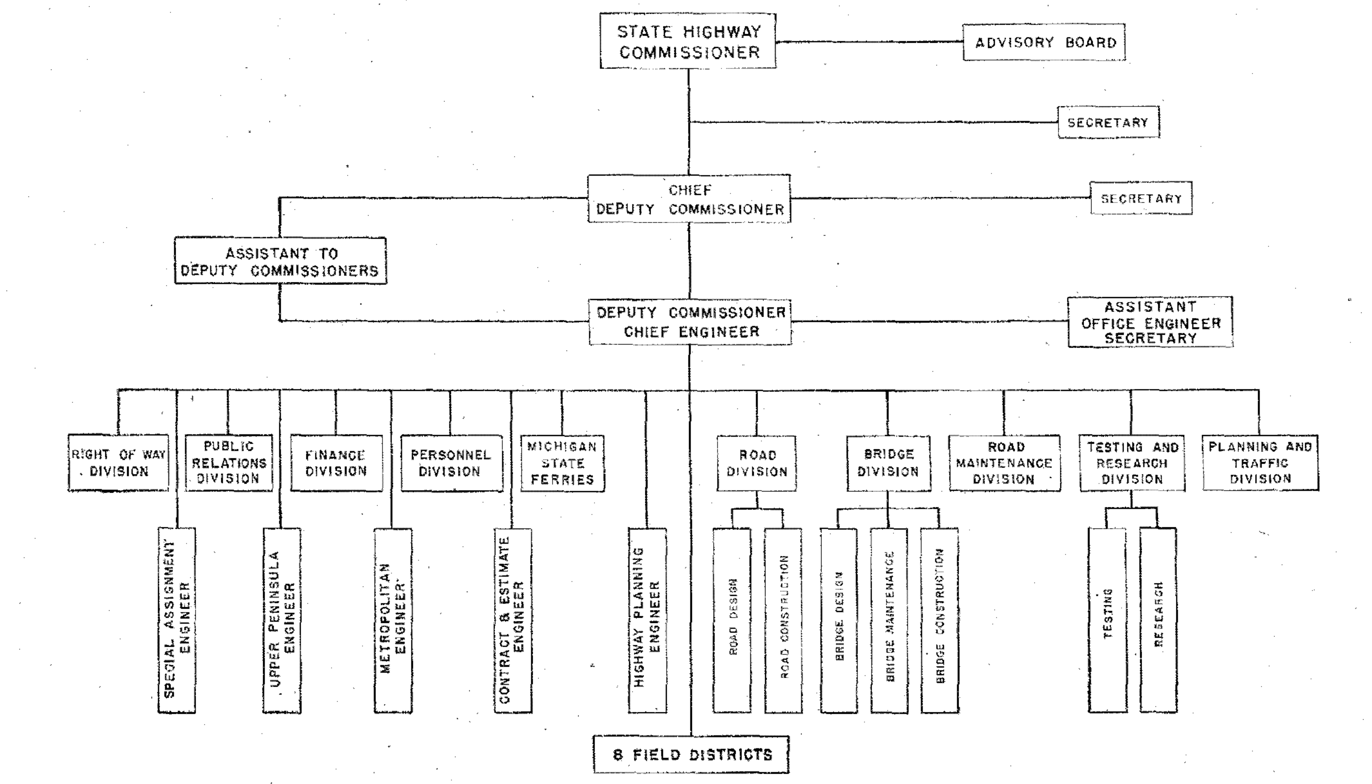


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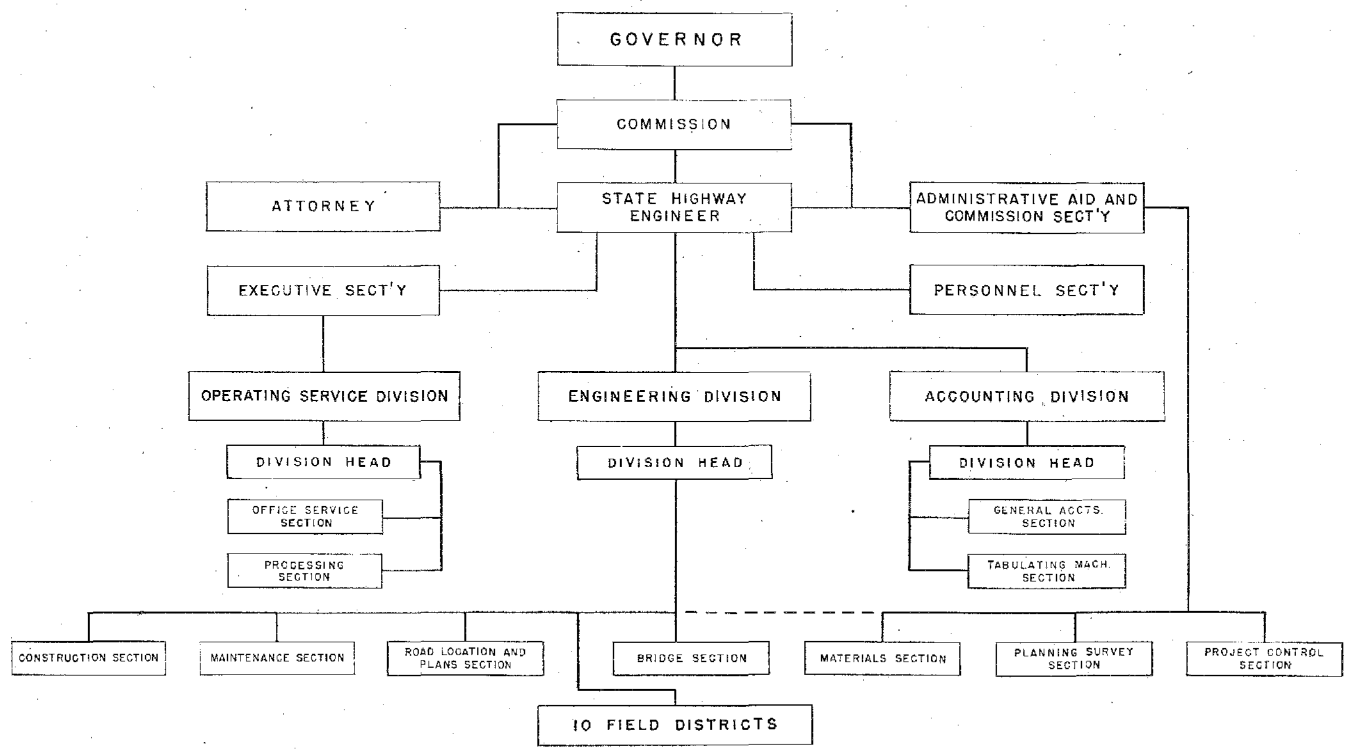
FIGURE 5. — ORGANIZATION CHART OF THE MONTANA HIGHWAY COMMISSION



Of the 48 State highway departments, then, 15 are administered by single executives, 9 are of the single-executive type with boards or commissions in advisory or coordinate capacities, and 24 are under the administrative control of commissions. In recent years, however, four States have abandoned the commission form in favor of single-executive organizations. In the same period no State has changed from the single-executive to the commission form. Time will tell whether or not this represents a significant trend in the field of State highway administration.

County and Local Road Administration

As previously indicated, nearly 2.4 million of the 3 million miles of rural roads are under the jurisdiction of local rural governments. Administration by these units is extremely varied in pattern. In the New England States and in Pennsylvania, very small subdivisions of the States administer those roads not in the State system. The counties are unimportant in highway affairs.

In the northeastern quarter of the country, excepting New England and Pennsylvania, there exists in general a dual plan of local highway administration in which counties are responsible for systems of main county roads, and subdivisions of counties, called townships, are responsible for the remaining mileage of non-State roads. The States of Iowa, Indiana, and Michigan have placed former township roads under county jurisdiction. In Kansas, approximately one-half of the counties have voluntarily adopted the county-unit plan, and here and there in "township" States counties have virtually consolidated all local road work.

Rural roads outside the State highway systems are under county jurisdiction in the south and west generally. Sometimes the county road system is supervised as a unit, and sometimes it is supervised by precincts or commissioners' districts. Thus there may be three or four or five districts operating independently within a county—each with its own funds, equipment, and organization.

The rather widespread existence of special road districts of one kind or another, superimposed on the basic county or township units and distinct from the commissioners' districts just referred to, should be noted. Approximately 1,000 of these special rural-road districts exist, principally in the north-central area and the west.

Local rural-road administration has vanished in North Carolina, Virginia (except for three counties), West Virginia, and Delaware, and in a few other States certain counties have individually passed responsibility for local roads on to the State highway department. In spite of some movement toward the consolidation and centralization of rural-road administrative agencies during recent years, however, some 2,700 counties and 14,000 townships are still concerned with highway administration.

The unit of local road administration varies in area from a few square miles to an area as large as that of San Bernardino County, Calif., which comprises over 20,000 square miles. The range of resources and expenditures is correspondingly wide. Performance of local road authorities varies in quality, and there are marked differences among the States in the extent to which county and local road work has been placed under engineering control.

It is well established that local road work requires adequate engineering control, just as does State highway work. Local road officials are slowly becoming aware of the benefits of local engineering control and its economic feasibility. The Federal-aid secondary program under the Federal-aid Highway Act of 1944 has given impetus in this direction, and with the establishment in State highway departments of special divisions to work with the counties on cooperative projects, the rapid growth of local engineering organizations is sure to follow. This development may well be one of the most important results of the new Federal-aid secondary program.

Municipal Street Administration

Local urban units engaged in municipal street administration are almost as numerous as local rural highway units. In a total of some 16,000 incorporated places there are approximately 300,000 miles of city streets. Of these 16,000 urban places, 3,000 have a population of over 2,500 and 13,000 have a population of less than 2,500.

In general, highway activities in cities over 10,000 population are under competent engineering management, but in the smaller places there is no settled pattern, and engineering control ranges from good to none at all. There is, however, an awareness and appreciation of the feasibility and economic advantages of engineering control in street planning and construction, and there is a noticeable trend in that direction in all places, both large and small.

The need for highway and street improvements in urban areas is acute, and practical recognition of the transportation problems of our cities has been given by extending Federal aid to projects in urban areas. The Federal-aid Highway Act of 1944 not only provides funds for construction but also for advance planning of needed facilities in cities on a sound basis. If progress made under previous Federal-aid programs may be used as a criterion, the next two decades may bring developments in urban highways that will overshadow the remarkable achievements made in rural highways during the past 25 years.

Nongovernmental Organizations

The administration of the Nation's highways is entirely a governmental function, working at Federal, State, county, and local levels. Beyond this sphere of actual operation, there are many nonpolitical organizations actively interested in highway development and use.

The American Association of State Highway Officials

The American Association of State Highway Officials was organized in 1914 when hardly half the States had effective highway departments. It is composed of the principal officers of the State highway departments and the Public Roads Administration.

Since its organization it has done a work of the greatest importance in bringing together highway officials for discussion of important problems, planning of concerted action, and adoption of uniform practices. Its avowed objective is "to foster the development, operation, and maintenance of a Nation-wide integrated system of highways to adequately serve the transportation needs of our country."

Annual meetings of the association are devoted to discussion of national highway problems and adoption of policies. Its technical committees, composed of outstanding specialists, prepare standards for highway design, specifications for materials, specifications for constructing bridges and various types of surfaces, and manuals on such subjects as highway signs and markings and highway maintenance. Specifications and standards approved by the Association are adopted by practically all highway agencies.

This organization has exercised a strong influence over 48 independent State highway departments in welding the State highway systems into one great network reaching to every part of the Nation.

The Highway Research Board

The Highway Research Board, an agency of the National Research Council, is sponsored by 36 national educational, technical, and commercial organizations. Its primary functions are the correlation of research by State highway departments, the Federal Government, and universities. The board holds an annual meeting for presentation of papers and reports, and discussion of committee activities. The publications include proceedings, research abstracts, discussions of current road problems, research reports, and censuses of research. The board has 6 departments, and 69 active committees with a membership of 871.

Field service is rendered by staff specialists who visit member agencies to acquire comprehensive knowledge of research, disseminate first-hand information, and correlate highway research efforts.

The American Road Builders Association

The American Road Builders Association, founded in 1902, has a membership representing the entire highway industry and profession. In its educational and scientific activities it acquires and disseminates knowledge concerning highway and airport planning, design, finance, maintenance, and operation. The association holds meetings and expositions. In its committee activities technical reports are prepared and published. The association does not conduct research but it assembles the best information available on highways and airports, and publishes it in the most practical form. By this means the scientific application of sound highway principles are given world-wide dissemination.

Other organizations

There are a number of other organizations representing and serving particular groups such as motorists, truck operators, bus operators, automotive manufacturers, and producers of highway materials and equipment. Activities of these organizations vary but they are all interested in improving methods of highway construction and in highway development. Their efforts in the interest of improved highway administration or in technical matters have aided in the national highway program.

HIGHWAY FINANCING

Beginning of the Modern Era

Highway improvement remained a small-scale operation, with weak financial support, until the advent of the motor vehicle. The motor vehicle brought a strong demand for better roads and also the financial means of building them. Previously, property taxes had been the principal source of road revenue and few roads were built.

Although the automobile made its first appearance in the United States in 1893, the real beginning of the modern era of motor-vehicle transportation did not occur much before the entry of the United States into World War I in 1917. The annual production of motor vehicles did not exceed 10,000 vehicles until 1903 when 11,235 automobiles, trucks, and busses were manufactured. By 1909 production had risen to 127,000 vehicles, and in 1915 nearly 970,000 vehicles were manufactured. From that date forward the annual production of motor vehicles did not fall below a million vehicles until 1943, when the exigencies of World II brought almost complete cessation of the manufacture of all types of vehicles for civilian use.

Registration of vehicles

The first State to require that motor vehicles be registered for purposes of regulation was New York, which imposed this requirement in 1901. Other States soon saw the need for such legislation. By 1915 all States and the District of Columbia had motor-vehicle-registration laws, all but four of which provided for annual registration, and the possibility of financing highway work from this source was recognized. Registration tax rates or license fees had been increased to the point where some 2,300,000 vehicles registered in 1915 contributed more than $18 million to the States. Registration taxes and fees produced the greater portion of the income from motor-vehicle owners until 1929.

Allied taxes, fees, and charges that have developed along with registration taxes are motor-carrier taxes, driver-license fees, titling and transfer fees, and inspection charges. These have not become important revenue producers.

Motor-fuel taxation

Oregon was the first State to impose a tax upon the sale of motor fuel. The rate established when the tax was first levied in 1919 was 1 cent per gallon, and the proceeds were dedicated for the maintenance of State highways. Other States soon adopted this attractive new method of raising revenues for highway purposes, and by 1929 all States and the District of Columbia were levying this tax. Of the 44 States that imposed motor-fuel taxes prior to 1926, the original rate was 1 cent per gallon in 26 States, 2 cents in 16, 2½ cents in 1, and 3 cents in 1. By 1929, however, the rates had been raised in most States so that the average weighted rate in that year was approximately 3 cents per gallon.

Highway expenditures

It has been estimated that the level of total annual expenditures on rural roads by all governmental agencies prior to 1904 seldom, if ever, exceeded $75 million. By far the largest portion of this money came from property taxes, although a considerable amount also came from poll taxes and "labor" taxes. Property taxes levied specifically for highway purposes were widely used, although a large part of the contribution obtained through taxes upon property was received through appropriations from the general funds of counties and local rural governments. The so-called "labor" taxes were imposts that had been adopted in many areas to replace the requirement that each male citizen make an annual contribution of his own labor to the construction and maintenance of roads in his area. However, actual labor contributions were still important to the building and upkeep of rural roads in some sections of the country.

At the beginning of the automobile era the street networks of the incorporated places in the United States were in a much higher state of development than were the rural roads. It has been estimated that in 1906, when annual expenditures on rural roads were at the $75 million level, expenditures on city and village streets were averaging about $300 million per year. Property taxes, either specifically levied for highway purposes or levied for and appropriated from general funds, provided most of the revenue used for street purposes. Borrowing to finance large construction projects, seldom resorted to in rural areas at that time, was a common practice, especially among the larger cities.

Beginning at $75 million in 1906, the total rural-road expenditure rose rapidly to about $280 million in 1915, leveled off during the war years of 1916–18, and then jumped to a level of $1 billion in 1921. During this period the chief sources of funds used to finance these expenditures were still property taxes, poll taxes, and labor contributions. Borrowing to finance construction of rural roads became increasingly popular. State imposts on highway users were still a relatively unimportant source of highway revenues; they provided less than $200,000 in revenues in 1906, and only about $120 million in 1921, nearly all of which was used on rural roads, as compared to $550 million of current revenues raised for rural roads from other sources in that year. Expenditures for city and village streets are estimated to have averaged about $300 million annually until 1921. Most of this money came from local taxes upon property or from borrowings.

Four of the factors most significant to highway finance are compared in figure 6. These are total expenditures on all roads and streets, revenues from State highway-user imposts, motor-vehicle registrations, and highway use of motor fuel. Where the curves are incomplete it is because data for early years are lacking. This graph is a brief explanation of how the great system of surfaced roads has been mainly financed. As motor vehicles became somewhat numerous, taxes were imposed on them for road purposes. More roads were built, making ownership of a motor vehicle more attractive. More vehicles were purchased which produced still more revenue and more roads—and so the cycle has continued up to the present time.

Revenue Sources and Recent Trends

The period from 1921 through 1948 was one of intensive highway construction. Figure 7 depicts the growth and fluctuation of highway revenues of all kinds during this period.

The vertical width of each shaded area represents, for any year, the magnitude of the revenues obtained from the particular source indicated, these magnitudes accumulating to the grand totals represented by the top line.

Local income

The two lowest areas represent the revenues used for highway purposes, chiefly in the form of property taxes, of incorporated and other urban places, and of county and local rural highway agencies, respectively. These local revenues reached their highest level between 1927 and 1930. The high point for incorporated places was $787 million in 1930; that for rural units was $550 million in 1928. During the depression years there was a sharp reduction in the yield from property taxes, both rural and urban. Revenues of county and local road agencies reached their prewar low point in 1934 when incorporated places got $337 million and rural units $251 million. During the war the revenues from these sources applied for highway purposes

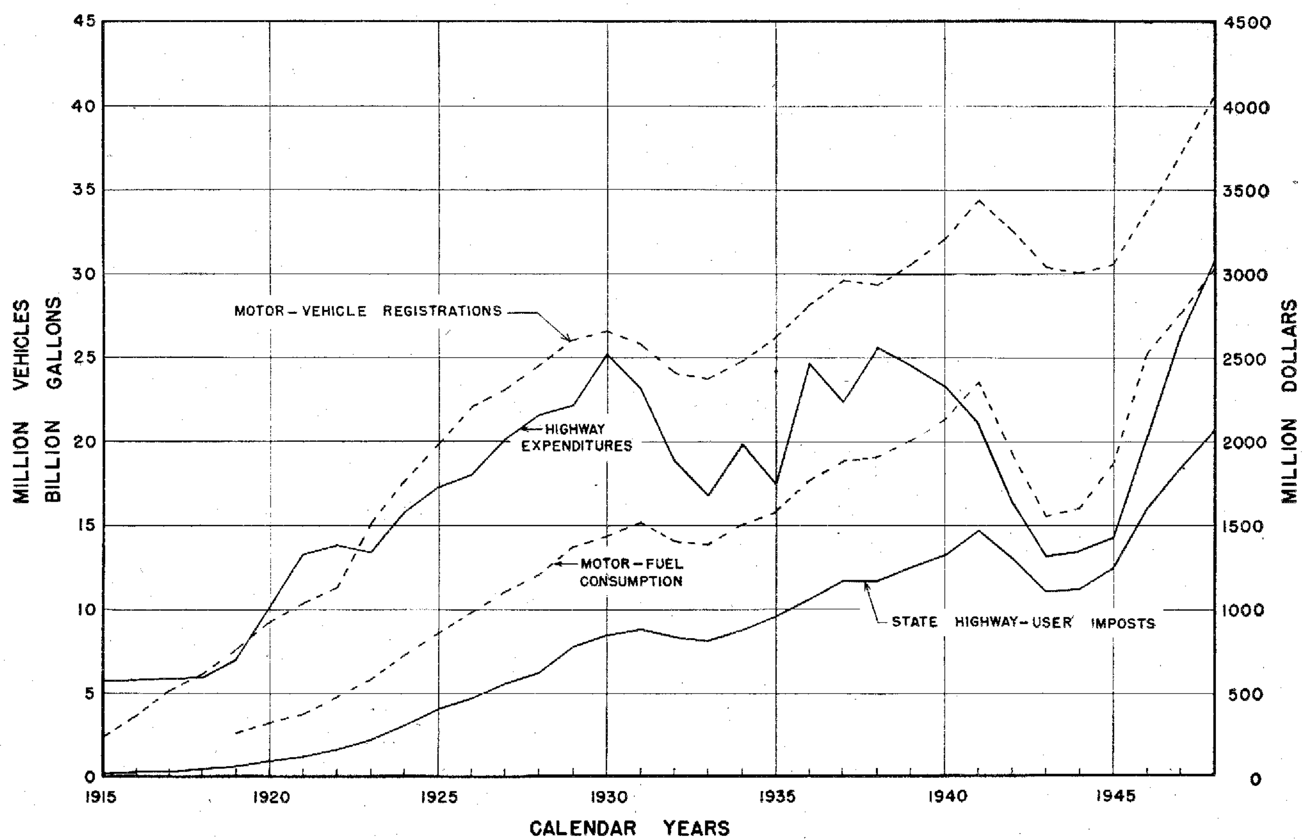


Figure 6.—Development of the automobile age: trends in highway expenditures, revenues from State highway-user imposts, motor-vehicle registrations, and highway use of motor fuel.

sank to new low levels—$205 million for incorporated places in 1943, and $258 million for rural units in 1944—but this was because of the war-imposed restrictions upon highway activity rather than the unproductiveness of such taxes.

State income

The next band represents highway income from State sources other than highway-user revenues — chiefly property taxes and appropriations from general funds. In the early 1920's these revenues were a relatively important source of highway income, but they have become insignificant in recent years in comparison with the mounting receipts from State imposts on highway users. However, the actual amount received from this source in 1946, $155 million, was greater than the amount received in any previous year.

Above this band is the one representing income from State imposts upon highway users. Of only moderate importance at the beginning of the period, $119 million in 1921, these revenues accounted for more than 60 percent ($1,800 million) of the current income applied for highways in 1948. This group of revenues includes, in the order of present importance, motor-fuel taxes, vehicle-registration taxes and related licenses and fees, and motor-carrier taxes and similar charges.

Federal funds

Next is an area representing "regular" Federal aids and funds expended directly by Federal agencies, chiefly by the Public Roads Administration. The actual funds applied began at about $90 million in 1921 and reached a prewar peak of $452 million in 1936. Annual applications of postwar funds will soon exceed this amount.

The mountainlike shaded area at the top of the graph indicates Federal funds used in work-relief construction on roads and streets by the Work Projects Administration and its predecessor agencies from 1933 through 1942. The peak contribution was $775 million in 1938. The WPA expenditures served to compensate for the great deficiency, during this period, in local revenues for secondary roads and streets. As a result the total amounts of revenue used for highway purposes from 1936 through 1941 exceeded all previous totals.

During the war the revenues devoted to highway purposes generally declined. WPA activities were terminated in 1942. The use of regular Federal highway funds was concentrated on projects necessary to the war. Wartime shortages and restrictions caused a considerable reduction in the receipts from highway-user taxes. The decline in county and local funds assigned to highways was not due to lack of revenues, as the yield from property taxes generally increased, but arose from suspension of highway construction activities.

Borrowings

Borrowings are purposely omitted from figure 7. Revenues used to repay borrowings are included. To include also the money borrowed would represent a duplication. Borrowings did and will continue to play an important part in the development of highways, and will be considered subsequently. Attention will now be directed to the development, productivity, and dependability of the more important individual sources of current income for highway purposes.

Principal Sources of Revenue

In Colonial days road administration, both rural and urban, was primarily a local affair. Rural roads were supported largely by taxes on property, poll taxes, and impressed labor, while village and city streets were financed principally from property taxes. Road taxes, especially those imposed in rural areas, generally could be "worked out", and as a result many local governments received little cash to apply toward their road work. These conditions did not change materially for more than 150 years.

Property taxes

Although the road poll tax and labor contributions have ceased to be significant factors in the support of roads, the property tax continues to possess many of the characteristics of Colonial times.

Two types of property taxes are imposed for highway purposes. "Special assessments" are levied against property abutting upon or lying near a highway that is improved, to recoup all or part of the cost of the improvement from the properties judged to be chiefly benefited by it. Special assessments are applied most frequently in cities, especially in new residential developments, although in the early days of modern highway building this method was sometimes used in the financing of rural roads. The "general property tax," levied at an *ad valorem* rate on real (or real and personal) property within a given tax jurisdiction, is a much more important source

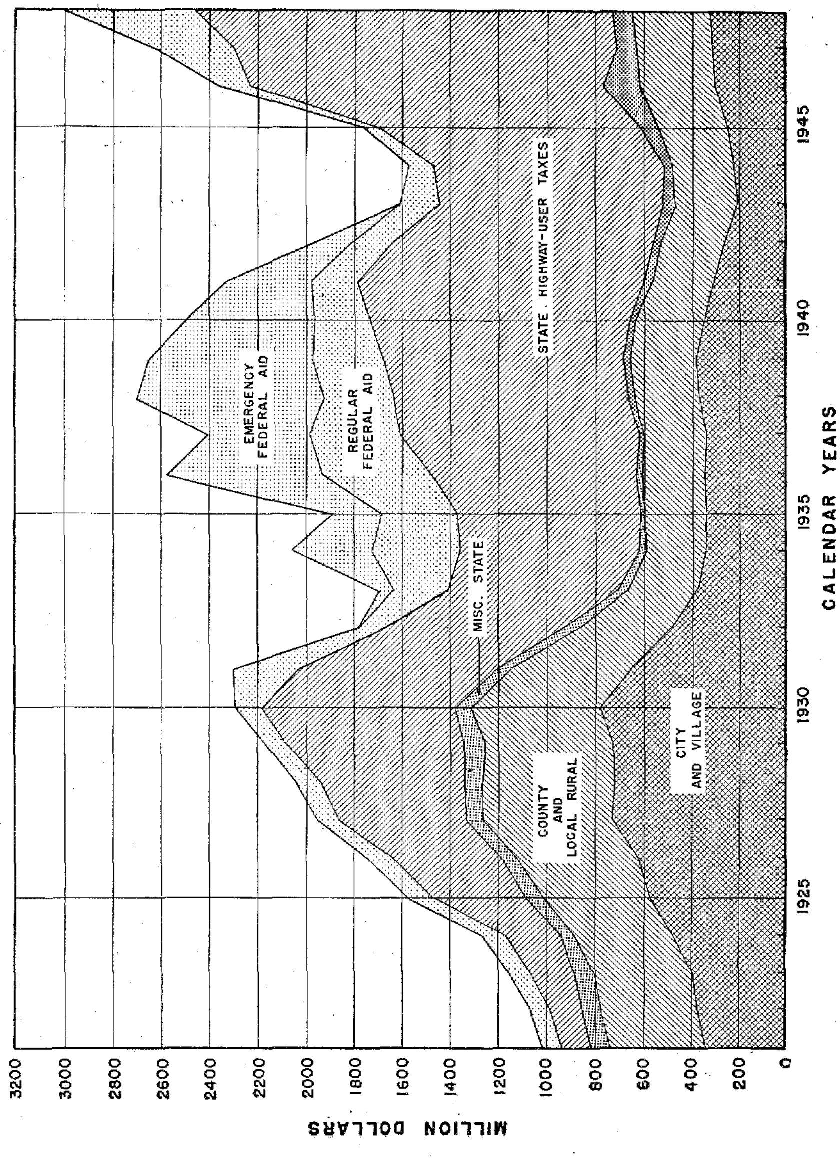


Figure 7.—Sources of revenue for highway and street purposes contributed by Federal, State, county, and local governments.

of highway revenue. The accepted opinion is that use of general property taxes is justified when the improvements to be financed are of general community benefit, or when the benefits accruing to property are expected to be more or less proportional to existing property values throughout the jurisdiction.

Property taxes have traditionally been the principal source of direct tax revenue available to counties and municipalities for the support of highways; and it is probable that this situation will continue for years to come. Although many local jurisdictions make general-revenue fund appropriations rather than specific highway levies, the revenues are derived chiefly from property taxes. Only in a few of the larger cities have other sources, such as sales and payroll taxes, become important producers of revenue.

The State governments, which have enjoyed better opportunities to exploit other sources of revenue, have relied much less heavily on property taxes than have the counties and municipalities. Prior to 1925, however, State road-tax levies and appropriations from general funds were a principal source of State highway income.

As administered in the United States, property taxes are characterized by a considerable degree of inflexibility; good productivity and dependability when times are prosperous, but poor productivity and low dependability when times are bad.

Highway-user charges

Special taxes imposed by the States on motor vehicles are of three types: (1) Registration taxes and fees and allied imposts such as operators' licenses and title fees; (2) gallonage taxes on gasoline and other motor fuels; and (3) special taxes on for-hire carriers of persons and property. Although important from a regulatory standpoint, the carrier taxes are not great revenue producers; and may be grouped, for present purposes, with the registration taxes and fees.

First adopted as a regulatory measure, the registration procedure was soon recognized as a device for raising highway revenues. As motor trucks became more numerous on the highways and their damaging effects on lightly constructed road surfaces became evident during the war period of 1917 to 1918, the practice of graduating registration fees with the weight or capacity of the vehicle became popular and gradually spread to all States.

Soon after its adoption by Oregon and three other States in 1919 the revenue-producing possibilities of the motor-fuel tax became evident to the States generally. By 1929 there were gasoline taxes in all States and the District of Columbia, with rates varying from 2 to 5 cents per gallon. At the present time the rates vary from 2 cents in Missouri to 9 cents in Louisiana, with a weighted average rate of slightly more than 4 cents. In addition there is a Federal gasoline tax of 1½ cents per gallon.

Several critical points in the history of State imposts on highway users can be discerned. By 1925 the gasoline tax had become a substantial source of highway revenue; but its yield did not exceed that of the motor-vehicle taxes and fees until the year 1929. From that time on, gasoline tax receipts increased in relative importance until, in 1941, they produced nearly twice the revenue derived from the motor-vehicle imposts.

Effects of depression and war

The depression period beginning in 1930 caused a temporary check to the upward progress of highway-user revenues. Starting in 1934 the receipts steadily recovered, except for a slight hesitation in the "recession" year of 1938, until they reached a prewar peak of $1,469 million in 1941. This amount and those that follow in this discussion are gross, including amounts assigned to meet collection costs and for nonhighway uses.

With the entrance of the United States into the war, motor-vehicle production for civilian use ceased and the major sources of raw rubber were cut off by the Japanese. Motor vehicles and tires were rationed; and gasoline rationing became the keystone of a Nation-wide effort to conserve the dwindling supply of tires and rubber. These emergency restrictions were reflected in decreased receipts of highway-user revenues which reached a wartime low in 1943. At the close of the war, in 1945, gasoline rationing was terminated, traffic volumes rose sharply during the fall months, and the receipts from highway-user taxes very definitely turned the corner. Following the resumption of full production of civilian motor vehicles the income from State highway-user imposts reached a new high of $2,095 million in 1948.

Distribution of State revenues

The distribution of the receipts of the States from highway-user revenues can be indicated by considering the disposition of the $1,852 million collected in 1947, as shown in figure 8. Collection and administrative expenses were approximately $74 million. A total of $1,110 million was allocated for State highway purposes, including $133 million for debt service and $46 million for the support of State highway traffic police. Allocations for work on county and local roads, and for debt service on county and local highway obligations, were $391 million. In contrast, only $93 million was allocated directly for work on city streets. This is not the full amount received by cities, as allocations to counties and State highway departments in some States are expended partly in cities.

The claims of urban interests for a greater share in the highway-user revenues deserve attention; and there is little doubt that they will receive more in the next few years, partly through increased State activity in the construction of expressways, arterials, and circumferential routes, and partly by direct allocation. But the cities also have a large stake in the preservation and improvement of the rural State highways, to which they contribute a lion's share of the traffic. It will probably be necessary to increase the contribution of property taxes to the support of the essentially land-service roads and streets; and to distribute the proceeds of highway-user taxes to those roads and streets which are primarily of importance as arteries of traffic rather than as means of access to adjacent property.

Allocations of highway-user revenues to nonhighway purposes in 1947 amounted to $171 million. The nonhighway purposes to which highway-user revenues have been directed are, for the most part, essential functions for which money must be obtained from some source. It is sometimes contended that the special commitment of revenues for highway purposes has no valid significance—that all governmental revenues should be general revenues and all expenses should be defrayed out of general funds. It is a fact, however, that in all States the highway-use tax schedule is predicated on the concept that the highway user, in paying these taxes, is thereby contributing his due share to the support of the highway system. If highway-use taxes are to be measured by the requirements for highway expenditures, it is argued that the product of the taxes should be used for the purpose which determines their magnitude, as a matter of common sense.

The operational administration of a highway system can be most successful only if it enjoys an assured continuity of fiscal support. The principle that highway-user revenues belong to the highways has admirably served these ends, with the result that in many States highway executives can plan their programs in anticipation of revenues that, under normal conditions, can be predicted with accuracy several years in advance.

Local levies

Imposition of levies upon highway users is not limited entirely to the Federal Government and the States, although many States specifically forbid most forms of highway-user taxation by subordinate units. However, there are some States in which such imposts are permitted and are used to a considerable extent. Registration or "wheel" taxes are in use in about 10 States and are imposed chiefly by cities, Chicago being the outstanding example. The city receives more than $5 million annually from this source. Fuel taxes are now imposed by counties or local units or

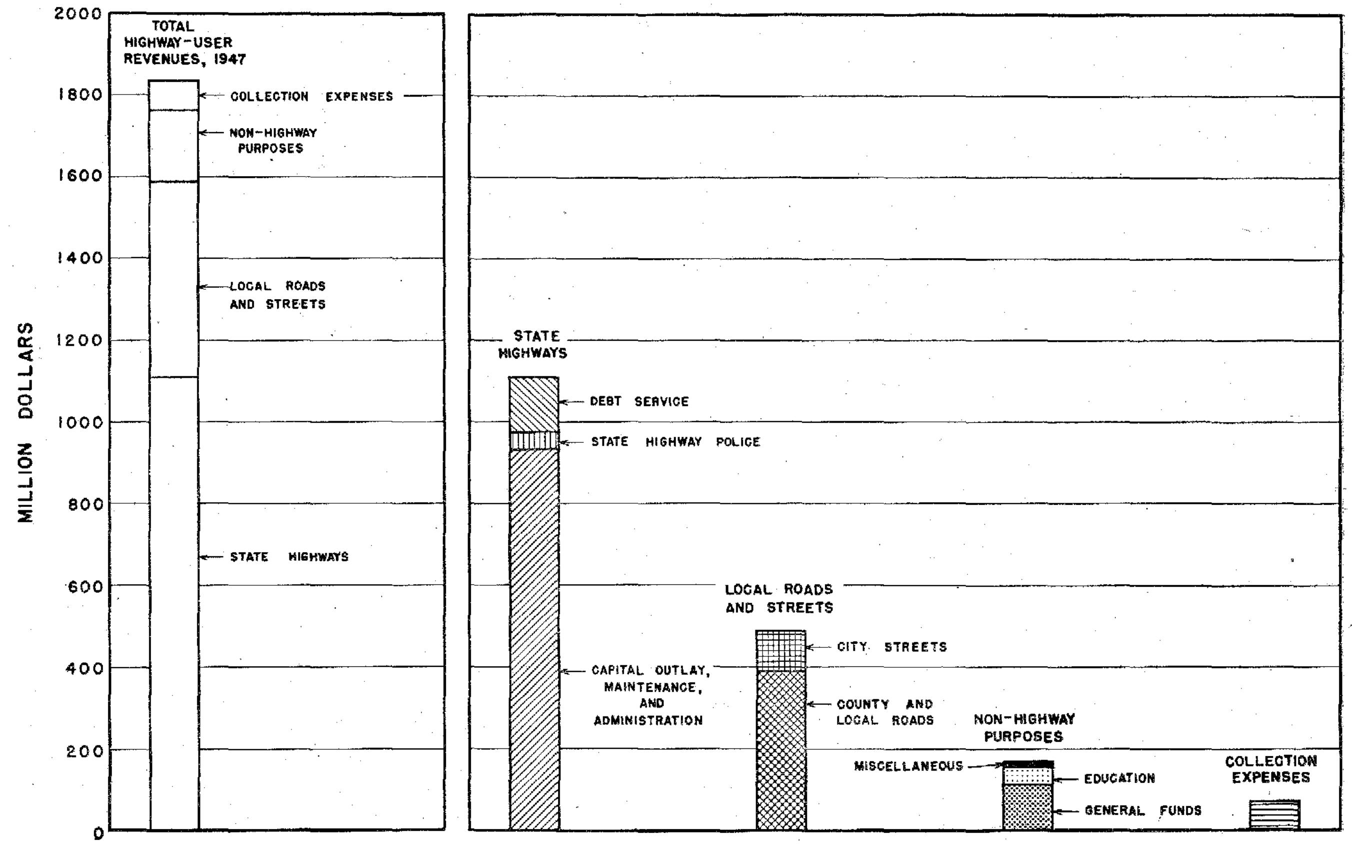


Figure 8.—Disposition of State highway-user revenues, 1947.

both in less than 10 States. The income obtained from this source is not as great as that received from the local registration taxes.

The regulation of the use of street parking by means of parking meters is becoming increasingly common in urban areas. At the beginning of 1948, meters were in use in 888 out of 2,034 cities having populations in excess of 5,000, according to the International City Managers' Association. Although the principal stated purposes of most of the individual installations were the regulation and policing of parking, the meters are proving to be attractive revenue-producers. Average annual revenues per meter for all such places were estimated to have been between $70 and $80 in 1947.

Tolls—the Principles Involved

As commonly used today, the term "toll" refers to a special type of highway-user charge levied for the use of a specific facility, such as a road, bridge, ferry, or tunnel.

The imposition of tolls for the use of certain highway facilities is an old device, and when the facility is publicly owned the impost has always been a center of hot controversy. Tolls are imposed for the use of publicly owned facilities for one or both of two reasons:

1. To finance the cost of the facility used.
2. To supplement other tax revenues.

Although both reasons are attacked as contrary to public policy, the stronger argument can be made against the second because of the extremely discriminatory nature of such financing of general governmental activities.

While the number of toll facilities owned by counties and local governmental units is relatively small, toll charges, in recent years, have provided a greater portion of the income from county and local imposts upon highway users than any other single impost. However, the rapid increase in the use of parking meters by incorporated places may soon raise the income from this source to first place among the road-user revenues of local governments.

Most of the income derived from tolls charged for the use of publicly owned facilities is expended for highway purposes, chiefly maintenance and operation of the facilities and retirement of the debt incurred when they were built. In a few instances, however, some or all of the toll revenues are applied toward the financing of nonhighway activities of the governmental units owning the facilities.

Toll roads

While there are numerous toll bridges and ferries, and some toll tunnels, there are now only three sections of main highway where a charge is made for use. In recent years it has been proposed that tolls be imposed to finance the costly improvements needed on heavily traveled routes. It seems unlikely that the plan will be widely adopted.

Toll roads are opposed for a number of reasons. Collection of tolls is a costly procedure and this cost would be passed on to the user as an added burden. Toll gates would necessarily be spaced some distance apart which would preclude use of the toll road for many short trips that make up a large part of highway traffic. Collection difficulties make it impractical to operate main routes entering cities as toll roads.

Laws, public sentiment, and operation difficulties prevent the conversion of existing free highways into toll roads. New toll roads must be in addition to existing highways. Highway users, as a group, would therefore have to pay the cost of a much greater mileage of road than is needed to serve traffic.

In a report, *Toll Roads and Free Roads*, issued in 1939, the Public Roads Administration concluded that there is only a small mileage of routes that would attract sufficient traffic to be self-sustaining when improved and operated as toll highways.

Toll bridges

There are numerous toll bridges. In greater part they are publicly owned and are to be made free when earnings have repaid the money borrowed for construction. This is accepted policy where a bridge is needed across a large stream and the project cannot be financed except by borrowing. There is an important distinction between toll bridges and toll roads. The toll bridge is a monopoly. All travelers crossing the stream within a wide range must contribute to its cost. This condition cannot exist on a toll highway. The public must pay to support both a toll road and a free road, neither of which will give the service that could be obtained by concentrating the expenditure on a single route.

Highway Debt

The financing of public improvements by borrowing is a time-honored practice, although it was the subject of much controversy during the nineteenth century. In the early days of modern road building, most of the borrowing for highway purposes was done by county and municipal road and street agencies. Massachusetts, in 1893, was the first to engage in State borrowing for highways. Other States, notably New York, California, Maryland, and Connecticut, soon followed suit. As the revenue potential of the highway-user taxes came to be realized, the practice of issuing State highway bonds gathered momentum.

Extent of borrowing

Those highway administrators who advocated the issuance of State highway bonds contended, with much justification, that the savings to highway users brought about by acceleration of the road-improvement program would more than compensate for the interest charges on the bond issues. More frugal executives in some States insisted on keeping their programs of expenditure within the bounds of current revenue. However, a number of States which either did not, or because of constitutional limitations could not, issue bonds, did not hesitate to make use of the borrowing power of the counties, townships, and road districts. These units, in numerous States, either borrowed to build roads which later became State highways, or supplied bond proceeds direct to the State highway departments. A period of partial county financing of State highways was followed by a period of partial State financing of county highway debt. Not only were State grants-in-aid made available for debt service; the legislatures in a number of States provided that the State should reimburse the counties for their contribution to the cost of State highways, either by direct assumption of the debt or by other means. This practice has materially added to the burden of State highway debt.

It is estimated that, at the end of 1940, the total highway debt of States, counties, and municipalities was $4,258 million, of which the State highway debt was $1,644 million; county and local rural highway obligations were $1,274 million; and the highway debt of cities was $1,340 million.

This total of outstanding highway debt may be compared with the total capital outlays for roads and streets between 1910 and 1940, which are estimated to have been $23,350 million. A conservative estimate of the "present value" at the end of 1940 would be two-thirds of the total investment, or $15,567 million; and the bonded indebtedness is found to be only 27 percent of this value. There has been considerable reduction in highway debt since 1940. For example, State highway obligations were reduced by $374 million between 1940 and 1944. Although there was little new investment in highways during the war, and much deterioration in their condition, the figures just cited leave little doubt that the highway agencies of the country entered the postwar period in a very favorable position with respect to the relation between outstanding debt and the value of the existing highway plant.

Types of obligation

By far the greater portion of highway debt is in the form of general-obligation bonds, to which the full faith and credit of the issuing government is pledged. In nearly all States the debt service on State highway obligations is now paid out of the proceeds of highway-user taxes. The stability of these revenues has, in many instances, buttressed the State's credit. Nevertheless, the security of the bonds rests substantially on the entire revenue structure of the State.

A number of States in recent years have issued so-called limited-obligation bonds, to the service of which all or part of the highway-user revenues are pledged. In some cases the security of these issues is strengthened by the provision of contingent sources of revenue to be resorted to if the basic source fails. For example, the 1935 law governing the issue of Maryland State Roads Commission debentures provided that the debt service should be paid, first, out of truck-license fees and franchise taxes; second, out of the proceeds of 0.14 cent of the gasoline tax; and, third, out of tolls to be levied, if necessary, at bridges on which proceeds of the issue were used. In actual fact, the truck fees alone were more than sufficient to pay the debt service on this and earlier issues.

A third type, characteristic of borrowing by special authorities created to administer toll facilities, is the revenue bond, the sole security of which (other than insurance) is the income from a single facility or group of facilities. Reliable forecasts of future traffic are essential to the financing of such enterprises. A number of States, including Alabama, Arkansas, and Tennessee, have found it necessary to refinance with general obligation bonds toll-bridge issues which could not be fully supported by the toll revenues.

Terms of issue

In the early days of highway financing there was a tendency to issue bonds to mature over periods not justified by the service lives of the improvements for which the money was used. Terms as long as 50 years were not uncommon; New York, for example, sold $100 million in 50-year highway bonds between 1907 and 1922. Such terms are not unreasonable, however, for bonds issued to build bridges and other major structures. For general highway improvements terms of 20 to 30 years are now the rule, and many issues are sold at shorter terms.

Retirement provisions

The provision made for the retirement of debt is usually of one or the other of two types, although combinations of the two are sometimes provided. In earlier years the so-called term-issue method was most common, and is still most frequently used in connection with short-term borrowings such as notes. Under the term-issue plan the entire amount borrowed falls due at a certain date fixed when the debt is assumed. A sinking or amortization fund is provided to which annual payments of a fixed amount are made. The plan is so devised that the sum of these payments, plus whatever income is obtained from investing them, will be sufficient when the debt falls due to pay the entire amount. Sometimes the provision for the sinking fund is broadened to include the payment of annual interest charges due on the outstanding principal. In recent years the "serial" method of retirement has become increasingly popular. Under this plan a predetermined amount of the principal is scheduled to be paid each year, beginning at a certain time after the bonds are sold—usually not less than one year nor more than three. This plan of retirement does not require a sinking fund. The annual principal payments are usually made directly from current income, upon which they customarily have a prior claim.

Sometimes bonds are made "callable." This feature provides that an issue which is scheduled to run for several years on a term or serial basis may be called in for payment of the principal before the regular retirement date, at the will of the borrower. This feature has certain advantages from the borrower's standpoint, but these are usually offset to some degree by the requirement of a higher rate of interest when the call provision is included.

Trends in Highway Expenditures

A review of trends in highway financing in the United States would not be complete without a brief review of the purposes for which funds have been used. Figure 7 pictures the growth and fluctuation of highway revenues for the period from 1921 through 1948. Figure 9 depicts the growth and fluctuation of highway expenditures during the same period. Both are based in part upon reasonably accurate statistical data and in part on estimates. The gross totals of revenues and expenditures for any given year will not agree, for two reasons: First, changes in balances are not shown; and, second, borrowings and principal payments are omitted, although interest payments are included.

Two other facts about these presentations must also be understood:

1. The revenues, shown in figure 7, are grouped according to the class of governmental unit that collected or received them originally;

2. The expenditures, shown in figure 9, are presented according to the administrative classification of highways upon which, or for which they were made.

Thus, revenues from highway-user imposts, received originally by the States but subsequently shared with or turned over as aids to counties are included with other State highway-user revenues in figure 7. On the other hand, direct expenditures by the States for construction, maintenance, or other purposes upon or for roads under county control are shown in figure 9 under the general heading of expenditures on county or local rural roads.

The scale of figure 9 is too small for indication of the purposes such as construction or maintenance, for which funds were expended on individual systems. However, a segregation of Federal funds spent upon each system is provided. The chart is divided vertically into four major bands which are separated by solid lines. Each of the three lower bands is subdivided into two parts; the lower representing expenditures of other than Federal funds, the upper the expenditures of Federal funds. These parts are separated by dashed lines and are further distinguished by differences in cross hatching. The vertical width of each major band represents, for any year, the magnitude of the total expenditures made on, or in behalf of the particular system indicated; these magnitudes accumulating to the grand total represented by the top line.

City and village streets

The area below the first solid line represents the expenditures on city and village streets, but does not include State expenditures upon trans-city connections of rural State highways—these latter are included in the State highway band, near the top of the graph. Excluding Federal work-relief expenditures, which comprise the entire Federal portion of this major band, the total expenditures upon city and village streets reached a high point of $799 million in 1930. This total was composed of $478 million spent for construction, $230 million for maintenance and administration, and $91 million for interest. This interest payment was the highest on record for such roads.

Federal work-relief expenditures upon city and village streets (all for improvements) began in 1933 and continued through 1942, reaching a peak of $367 million in 1938. This amount, added to the $174 million spent otherwise for the improvement of these highways, resulted in a total expenditure of $541 million for construction or improvement of city and village streets during that year, an unequaled record. The expenditure of $182 million for maintenance and administration and $55 million for interest brought the total expenditure during the year on this class of highways to $778 million, which very closely approaches the total spent during 1930.

As indicated by figure 9, total expenditures upon city and village streets reached their lowest level, since 1920, in 1943 and 1944, when only about $321 million was spent each year. The principal cause was the war-imposed curtailment of construction, which totaled only $68 million in 1943 and $74 million in 1944. On the

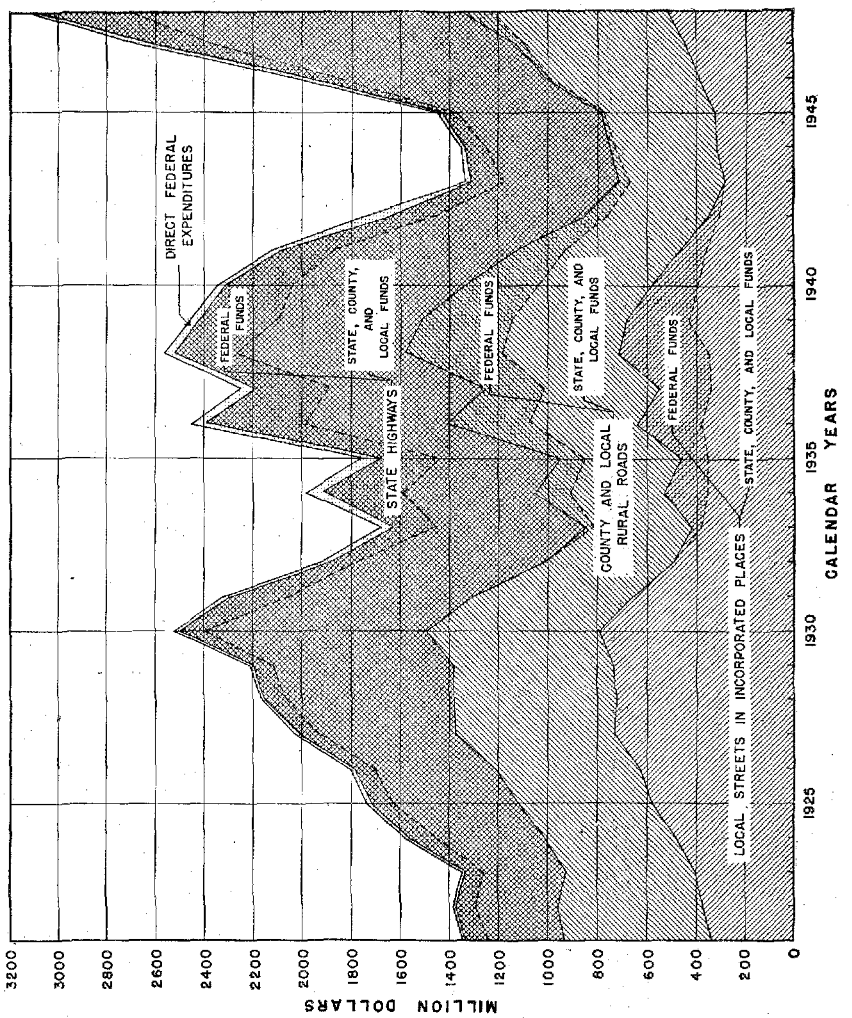


Figure 9.—Total expenditures for highway and street purposes by major road systems.

other hand, the components of the total representing expenditures for maintenance and administration, and interest, averaged $197 million and $53 million, respectively, in each of those years.

The total spent on city and village streets in 1921, $337 million, was only slightly above the low point reached in 1943 and 1944. However, the distribution of component expenditures was entirely different. For that year construction is estimated to have amounted to $191 million; maintenance and administration, $126 million; and interest, $20 million.

County and local roads

The next band, between the first and second solid lines, indicates the expenditures made for county and local rural roads. Omitting Federal work-relief expenditures (shown by the upper portion of the band), expenditures for these roads reached a total of $700 million in 1930. This total was composed of $297 million for construction; $321 million for maintenance and administration; and $82 million for interest.

Preliminary estimates indicate that total expenditures on these roads may have reached a record $753 million in 1948. However, the information upon which this estimate is based is fragmentary and more complete data may reduce this total.

Although the total was probably greatest in 1948, the expenditures for specific purposes, not shown directly on figure 9, were not at their peak in that year. Excluding work-relief expenditures, the estimated outlay of $337 million for construction of these roads in 1921 has not since been equaled; in fact, this type of expenditure has shown a general declining tendency which reached a low point of about $80 million in 1944. However, there is an indication that this trend may have been reversed; expenditures for this purpose during 1948 were about $287 million. Payments for the maintenance and administration of county and local rural roads have fluctuated widely, although within the last five or six years there have been evidences of the inception of a new upward trend. This has resulted in a record high of about $446 million being spent for these purposes in 1948. Interest payments on county and local road debt mounted steadily from $34 million in 1921 until a peak of $91 million was reached in 1931. Since then the trend has been reversed; in 1948 only $20 million was required to meet interest obligations.

Federal work-relief expenditures on these roads were higher than upon any other system, a total of more than $2 billion being so applied between 1933 and 1942. The greatest expenditure in any single year was $389 million in 1938, which, added to the $474 million spent otherwise on these roads in that year, produced a total of $863 million, the highest amount expended to date on these highways.

State highways

The next major segment of the graph depicts the expenditures made for State highways, both rural and urban portions. Total annual expenditures upon these roads increased steadily from the 1921 low point of $384 million to a high point of $988 million in 1931. From 1932 until 1945 the total fluctuated considerably; first, because of the depression and, later, because of the effects of the war. Since the close of hostilities the rate of total expenditures has increased rapidly, and reached a record high level of $1.8 billion in 1948.

The upper portion of this band, which represents Federal funds spent on State highways, differs from the Federal-funds portions of the two lower bands because it is composed almost entirely of regular and special Federal-aid contributions to the States. Direct Federal work-relief expenditures on State highways were negligible. Federal aids for State highway construction have been an important factor throughout the 25-year period.

The trends in State-highway expenditures for construction, maintenance and administration, and interest are not apparent in the graph. The trend of capital outlays has been generally the same as that of total expenditures, although in both 1943 and 1944 the level sank to $211 million, considerably below the $284 million spent for these purposes in 1921. The previous record high level was reached in 1931 when $733 million was paid out for construction. However, expenditures for these purposes totaled slightly more than $1,100 million in 1948.

Expenditures for State-highway maintenance and administration have shown almost constantly increasing trends since 1921, when only $90 million was spent for these purposes. The comparable expenditure for 1948 was $574 million, an all-time record. Interest payments on State highway debt were only $10 million in 1921, but by 1932 they had risen to $66 million. This level was maintained until 1937, after which the requirement decreased to the present (1948) level of about $36 million annually.

Federal roads

The topmost band on the chart represents direct Federal expenditures upon roads under Federal control—principally roads in National parks, forests, and other Federal reservations. These expenditures have never exceeded the $64-million level attained in 1935, and have averaged about $20 million annually. Most of these funds were spent for construction.

Changing price levels

The data presented in figure 9 represent actual dollar amounts. Adjustment for changing price levels has not been attempted. It must be remembered that present price and wage levels are far above what they were in 1941, and considerably further above what they were in the depression years of the thirties. Therefore, the high levels of expenditures made in most categories during 1948 are not matched by equally great physical accomplishments.

System changes

In considering either State-highway expenditures or those made for rural roads under county or local control, it must be remembered that although the total rural-road mileage in the United States has remained almost stationary at 3 million miles since 1921, the mileage included in State primary and secondary systems has more than doubled—from 203,000 to 428,000 miles. This increase has been matched by a corresponding decrease in the mileage of other rural-road systems. Historical information about city and village street mileage is not available. The present total is approximately 317,000 miles.

DEFINITIONS OF TERMS

The following definitions have been prepared to give foreign visitors and students a general understanding of some of the highway terms with which they may be unfamiliar. There is no standard definition of most of the terms other than the dictionary. In preparing this material simplification and definition of most frequent usage has been the objective. There has been no attempt to give complete definitions.

Arterial highway.—A general term designating a major highway, usually on a continuous or through route. The term is descriptive of character of usage and not of character of improvement.

Construction costs.—Cost of additions or betterments to the highway system, sometimes including right-of-way purchases.

Controlled-access highway.—A highway on which abutting property owners have no right, or only a limited right, of direct access and on which the type and location of all access connections are determined and controlled by the highway authorities.

County.—An area constituting the major subdivision of the State, which is usually organized as a unit of government for the performance of local functions. There are approximately 3,000 counties in the United States. The number per State ranges from 5 to 254 and averages 62.

Debt service.—The amounts required for interest and for debt retirement, whether they are paid into sinking funds or directly to bondholders.

Expressway.—A highway with full or partial control of access and with important cross roads separated in grade from the pavements for through traffic. Expressways are generally divided highways. Some streets may be left as crossings at grade to be eliminated at a later time. In some instances the term has been incorrectly applied to named highways not having expressway characteristics.

Forest highway.—The Federal Government has withheld from settlement or purchased large areas rich in timber and mineral resources, as a conservation measure. These are National forests. Roads through and approaching such areas are known as forest highways.

Freeway.—A highway with full control of access and with all cross roads separated in grade from the pavements for through traffic.

Impost.—Any charge made by a governmental unit for the support of its activities. Highway-user imposts are special taxes or fees paid by motor-vehicle users because of their use of the highways.

Incorporated place.—An area delineated and organized as a municipal corporation under State law for the purpose of carrying on governmental functions within the area.

Licenses and permits.—Payments exacted in connection with the conferring of a measurable benefit or privilege upon the individual or corporation making the payment. Licenses or permits may be issued primarily for the purpose of regulation, or they may be imposed for revenue with regulation only an incidental factor.

Local.—Used to refer to local government. Local government is commonly thought of as that government which comes in direct contact with the citizens in the performance of governmental functions of a service nature such as protection, schools, roads, recreation, and the like. The term is used loosely to include all units below the State level and, in a more restricted sense, all governmental units below the county level (cities, townships, and special districts).

Local revenue.—Revenue of the local government, exclusive of aids, or shared taxes received from other units of government; revenue originally collected by or directly for the local government.

Maintenance.—The function of preserving each type of roadway, structure, or facility, by making needed repairs.

Municipal.—Enjoying local self government as in cities and towns; of or pertaining to, or characteristic of a municipality (i. e., city, village, town, etc.). In most usage the word is closely synonymous with urban.

Parkway.—An expressway planned and designed for use by noncommercial traffic, usually located within a park or a ribbon of parklike development.

Park highway.—The Federal Government has withheld from settlement or purchased large areas of exceptional scenic beauty and recreational value. These are National parks. Roads through and approaching such areas are known as park highways.

Primary road or highway.—In general usage a highway of first importance, a main highway. In many States the term describes those highways forming a definitely designated system of main highways known as the State system. In a few States the term "trunk highway" is applied with similar meaning.

Road, highway.—Both terms are used to describe a way open to public travel. There is no definite distinction between them. The term "highway" is more often applied to the important routes of travel and the term "road" to lesser routes of travel. City streets are often referred to as highways. They are not referred to as roads except when an old name is still applied.

Rural.—Of or pertaining to the country as distinguished from urban. All highways and areas not classified as urban are classified as rural. Federal legislation provides aid for certain defined classes of rural road. Definitions of these classes should not be confused with the more general meaning of the term.

Secondary road or highway.—In general usage a road or highway not of primary importance, a road not on the State primary system. In each State there is a Federal-aid secondary system composed of selected roads secondary in importance to those of the Federal-aid primary system. In some States there is a State secondary system that does not include all secondary roads according to the general meaning of the term. Land-service roads are occasionally referred to as "tertiary" rather than secondary, but this usage is infrequent.

Special authority.—A special governmental body created by the State to carry on one or more special activities. The outstanding example is the Port of New York Authority, which operates harbor facilities, tunnels, bridges, airports, and terminals. The jurisdiction of a special authority may extend into more than one State.

Special district.—A unit of government organized to carry on special activities and vested with varying degrees of authority to levy taxes and incur debt.

Unit of government.—Any public administrative body clothed with the power to receive and expend public money.

Urban.—Characteristic of, constituting, or pertaining to a city or town. There is no precise definition of urban place or urban highway that is universally accepted. For the purposes of this publication it may be assumed that an urban place is an incorporated place having a population of more than 1,000 or an unincorporated area having a total population of 2,500 or more and a population density exceeding 1,000 persons per square mile.

Wheel tax.—A local vehicle-registration tax.

Work relief.—Assistance to the unemployed through the provision of employment on special projects designed for this purpose.

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Part 2

SYSTEMS AND STANDARDS

STATE HIGHWAY PLANNING SURVEYS

Before 1930, improvement of the primary rural highways was the relatively uncomplicated objective of road improvement effort. Primary routes had been recognized, and designated in accordance with law, as State highway systems in the several States; and the more important majority of the routes of these systems, since 1921, had been incorporated in the Federal-aid highway system.

During the decade of the 1920's a steadily increasing expenditure by the States, with Federal aid, had gone into a pioneer improvement of these main rural highways. By 1930 the end of this initial program was in sight. Some degree of improvement had been extended to nearly the whole of the selected systems, and a situation had been created which called for a reconsideration of guiding policies.

The registration of motor vehicles had increased beyond all early expectation. The volume of traffic had grown at an even faster rate. Speed of travel had increased, and was continuing to mount. Already it was seen that much of the earlier improvement of the principal rural highways would soon be inadequate for the needs of the developed traffic, necessitating reconstruction and enlargement of the facility provided.

Yet, notwithstanding their recognized inadequacy, the main rural highways were no longer the paramount concern. City streets, which earlier had been considered comfortably adequate, were beginning to signal their distress under the mounting load of traffic; and the rural secondary and feeder roads in many cases were now serving as much traffic as main highways a decade earlier. It was becoming clear that the policy of concentration upon main rural roads could not reasonably be sustained much longer.

Appraisal Needed

There was recognition of the need for a careful appraisal of the new situation, looking to a revision of policies, and it was for the purposes of developing the facts necessary for such a study that the so-called highway planning surveys were undertaken, beginning in 1935.

Opportunity to undertake these surveys was afforded by a section of the Federal act of June 18, 1934, known as the Hayden-Cartwright Act. This section authorized expenditure of not to exceed 1½ percent of the amount of Federal-aid funds apportioned for any year to any State for the making of surveys, plans, and engineering investigations of projects for future construction.

By 1940 all State highway departments, cooperating with the Public Roads Administration, were engaged in the conduct of highway planning surveys which, at the time of their undertaking, were described as follows:

"They consist of a number of related studies that seek to determine the present state of the whole rural highway system; to rate the service rendered by the numerous parts; to prepare the way for a selection of that part of the whole system which, by reason of its relative importance and absolute utility, so far as we may now see, merits inclusion in future improvement plans; to assemble the facts necessary for an estimate of the ultimate cost of owning and maintaining the economically necessary improved system; all to the end that a definite economically and socially defensible, integrated highway-improvement program may be established and the future of highway transportation may be protected from the hazards inherent in short-sighted and shifting public policy."

The Pattern

The surveys conformed to a practically uniform pattern in all States. The elements of this pattern were:

1. An inventory of all existing public rural highways.
2. An estimate of the volume and character of traffic using all rural highways.
3. A review of the financial provision and expenditure for roads and streets by the States and all of their governmental subdivisions.
4. An estimate of the number of motor vehicles owned by residents of the various subdivisions of the State as a basis for a determination of the places of incidence of State-collected road-user revenues.
5. A survey of the use of roads and streets of the various recognized systems by residents of the several subdivisions and places.
6. A so-called road-life study, utilizing records of past construction and reconstruction of roads of various types as a basis for an estimate of the service life that may be expected of each type, an element in the determination of probable future financing necessities.

To these original elements of the surveys there has been added more recently a study of the origin and destination of the principal traffic movements within the metropolitan areas of selected cities at which need for the studies has been found.

The several survey elements are more particularly described, in their character, scope, and method, in the following sections.

The Highway Inventory

The basic inventory that has now been completed was an on-the-ground check of the location and physical condition of all rural roads. Observers drove over every mile of road open to public use and recorded width, type, and condition of all roadway surfaces; the type, dimensions, and condition of all structures, such as bridges, overpasses, and underpasses; the location of all farms, rural dwellings, schools, churches, and other cultural features which are sources of traffic and have a definite bearing on road needs; and the physical characteristics of all railroad grade crossings such as sight distances, curvature, and grades of railroad and highway, and type of protection. On the important routes they measured the location and degree of curvature of all sharp curves; the location and rate of all steep grades; and the location and nature of all restrictions to road visibility which might present a traffic hazard.

Tabulations and maps

The inventory data were summarized in numerous tables. They were also used for the preparation of a series of State and county base maps, drafted in accordance with standards agreed upon by all States, which for the first time show all public roads and their surface types in relation to the adjacent dwellings and other improvements. From these base maps other series have been prepared, showing school-bus routes, postal routes, regularly scheduled truck and bus routes, and a graphical representation of the annual average 24-hour traffic volume on every mile of rural road.

It was the intention to arrange for periodic revision of both the tabulated inventory data and the several map series. During the period of the war the essential continuing work was interrupted. It has now been resumed and the data and maps will be brought up to date as rapidly as possible.

The Traffic Survey

The traffic survey consisted of several phases, the two most important of which were a determination of traffic volumes on all rural roads and the obtaining of information concerning weights, heights, lengths, and other characteristics of trucks and busses.

Key stations

Traffic was counted at a comparatively small number of "key" stations and at a much larger number of "coverage" stations, grouped in relation to the key stations. At the beginning, no mechanical traffic recorders were available. The first response of invention to need was the development of a recorder of the photoelectric type, but these were so expensive that only a few could be used at carefully selected points. Where they were used, an hourly record of the traffic was obtained that was useful in the estimation of hourly and daily variations.

Manual counts

The counting of traffic at all other points was accomplished by use of human observers, making so-called manual counts. At each of the coverage stations a single 8-hour count was made. At the key stations eighteen 8-hour counts were made during a 1-year period at different times of the day, on different days of the week, and in all seasons. These more complete key-station counts supplied the more accurate traffic estimates needed on important roads, and from them factors were derived by which the single 8-hour coverage-station counts could be expanded into somewhat less accurate estimates of the average daily flow of traffic over the entire road system.

The numbers of key and coverage stations operated varied according to the judgment of need and available funds. In the State of North Carolina, which may be cited as representative of the average practice, there were 216 key stations and approximately 14,000 coverage stations for 68,000 miles of road.

Mechanical counters

More recently, portable nonrecording mechanical counters have been developed which can be purchased for about $40 each. These machines are now used in place of the earlier manual counting, except for purposes of vehicle-type classification, and have completely changed traffic counting procedures and schedules.

There are at present about 700 of the more expensive fixed-type photoelectric machines in use throughout the United States. Many of these have operated continuously at the same location since the initial phase of the planning surveys, 10 years or more ago. They supply the hourly data by which traffic trends are measured from year to year, and also supply data for a research, the purpose of which is to perfect traffic counting schedules and determine the best and most efficient length and spacing of counts.

Weighing stations

In the initial traffic survey, trucks and busses were weighed and measured at stations located on the more important highways. More than 2½ million vehicles were thus examined at some 3,000 stations distributed throughout the country. The weighing stations were for the most part identical with the key stations previously mentioned, and they were operated on the same schedule, i. e., eighteen 8-hour operations a year at each station. The information obtained included the type and manufacturer's rated capacity of the vehicles, the gross vehicle weight, the load on each axle, the width, height, and length of the vehicle, the commodity carried, and when possible the weight of the carried load, the origin and destination of the vehicle, and other pertinent facts.

The information obtained at these weighing stations has been of value in the design of road surfaces and foundations and has been particularly useful in the consideration of essential regulatory measures, notably in the formulation of recommendations of the American Association of State Highway Officials concerning limits of the size and weight of vehicles desirable for uniform adoption by the several States.

Beginning in 1942, and yearly since that time, about 50,000 trucks have been weighed and measured at about 450 stations appropriately distributed throughout the United States. The results of these observations are used to determine trends of change in vehicle dimensions and weights, which are regularly reported by the Public Roads Administration.

Financial, Road-Use, and Road-Life Studies

The closely related financial, road-use, and road-life studies were undertaken to determine the existing condition of the highway finances of the State and all of its governmental subdivisions, and supply further the basic data required for estimation of ability to finance the future continuance of highway programs designed to achieve and maintain any ultimate condition of the entire street and highway system found to be desirable or necessary.

Finance

The purely financial phase consisted of a correct and complete determination for a single year of:

1. All forms and rates of taxation for highway purposes imposed by the State and all subordinate governments;

2. The totals of revenue accruing from each form and rate of tax imposed by each taxing jurisdiction, and the grand total raised by all taxing means and jurisdictions;

3. The relative magnitudes of highway revenues and the revenues collected for all other purposes of government;

4. The incidence of the highway tax burden upon road users and other beneficiaries resident in each taxing jurisdiction;

5. The amounts, terms, and interest rates of all existing debt created for highway purposes by the State and all subordinate governments; and

6. The amounts and purposes (such as construction, maintenance, engineering, administration, debt charges, etc.) of all highway expenditures by the State and all subordinate governments.

The financial facts were determined in part from the published financial reports of agencies of government, and in part, as necessitated by the absence of published reports, from original financial records.

Road use

The road-use study was designed to determine the relative usage of various parts of the entire highway system by owners of motor vehicles resident in various parts of the State, in rural and urban areas. Data of the study were obtained by personal interview with a representative sample of registered motor-vehicle owners throughout the State, eliciting from each owner the extent in miles of his annual travel and the portions of the total travel that utilized roads and streets of the several recognized systems, such as primary and secondary rural roads and city streets. It was possible in this way to determine with substantial accuracy the proportional amounts of travel, on each of the road systems, originating in the various governmental jurisdictions. This information, correlated with the record of revenue contributions to the several systems by residents of the same governmental jurisdictions, permitted the determination of relations between revenue contributions of the several groups of contributors to each system and the benefits derived through usage of the several systems by contributors of each group. These relations bear usefully upon the determination of equitable tax measures and revenue distributions to the several classes of highways.

Road life

The road-life study, as the name implies, had for its purpose a determination of the average service life of the several types of road surfaces and the various other elements of the highway, such as its roadbed, drainage system, shoulders, bridges, etc. With this information, obtained by an analysis of the records of surfaces and roadway elements previously constructed and depreciated, it is possible to estimate the amount and cost of replacement that will be required in each year of the future, and on the basis of these estimates to schedule the essential construction and reconstruction program and corresponding revenue needs of a future period.

Urban Studies

As previously indicated, the study of urban traffic movements was not included in the original plan of the surveys. This was due in part to a reluctance to add the cost of such studies to the already large expense of essential studies of the rural highway problem. In part, however, it is attributable to a failure to recognize, at the time, the necessity and importance of the urban studies. For these reasons the earlier traffic studies were concerned with rural highways exclusively; and it was, in fact, a most important discovery of the rural studies that inspired the present great interest in urban origin-and-destination studies.

The bypass theory

It had been widely accepted that an adequate accommodation of rural-road traffic would necessitate invariably the construction of bypass routes around the cities. In the absence of any determination of the facts it was believed that a large part of the traffic found on the rural roads approaching cities was "through traffic," i. e., traffic bound to points beyond the city, which would therefore be best accompanied by routing around, rather than through the city. Such routing, obviously of advantage to the traffic, was believed to be desirable also from the standpoint of the city, the streets of which would be relieved of a substantial volume of traffic tending to congest them.

To test these beliefs, and ascertain what volume of traffic such bypass routes would serve if provided, the rural traffic counts made in the vicinity of some cities included simultaneous counts at points on all main approach highways where these highways were intersected by cordon lines drawn about, and close to the cities. At these points, in addition to a count of the vehicles passing, arrangements were made to stop the vehicles and, by inquiry of their drivers, determine where they were coming from and where they were going. The surprising result of most of these inquiries was a finding that a large majority of the traffic was originated in the city or was bound to points within the city, rather than from and to more distant places.

Such external origin-and-destination surveys, since made at many cities, have by now demonstrated conclusively that the provision of city bypass routes must be justified by the accommodation of a small, rather than a large percentage of the rural highway traffic, and that, in any case, they may be expected to afford only small relief to city street congestion.

Traffic bound for cities

Figure 10, which summarizes the results of many such origin-and-destination surveys, made at cities of various population groups, shows that, on the average, 95 percent of the traffic approaching a city of over 500,000 population is bound into, and not beyond the city, and nearly 20 percent is bound into the central business district of the city. Even at much smaller cities, those of 25,000–50,000 population for example, an average of about 80 percent of the traffic has its destination in the city, and in this case about a third is destined to the central business district.

These facts, developed by the rural traffic studies, quickly demolished the hope that a substantial relief of the growing congestion of city streets could be effected by bypass routing of through highway traffic, and brought conviction that solution of the problem of congestion of city arteries can lie only in an enlargement of the capacity of the city arteries themselves. This conviction has since been strengthened by specific evidence that the same streets that must carry the principal part of city-entering traffic, much of it bound to the city center, are also streets that carry most of the load of traffic moving daily from homes within the city to places of work in the business section. These streets, as they approach the business center, become the most heavily traveled and most congested of all city streets.

pacity, many of them essentially of expressway character, a development that would be continued with similar aid over a somewhat extended period until the expensive task is finished.

Urban Origin-Destination Surveys

It was the necessity of estimating accurately the volume of traffic that would use the more attractive arteries to be pro-

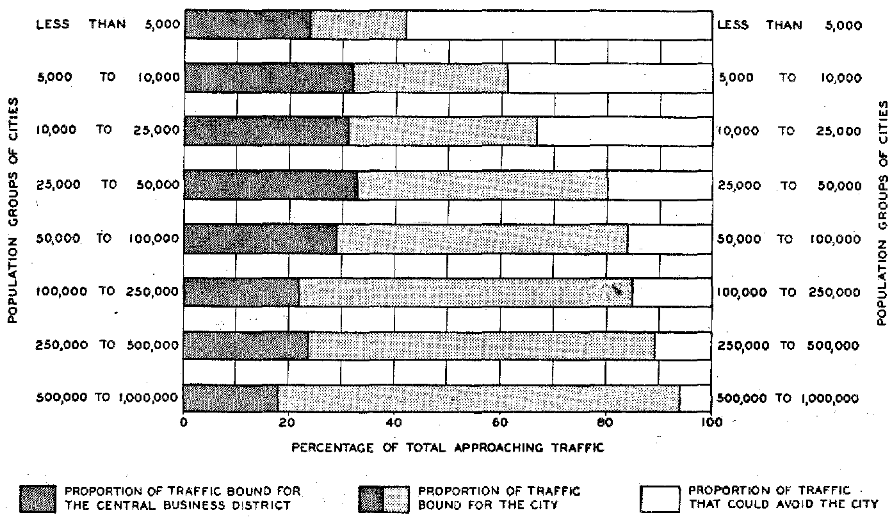

Figure 10.—Proportions of traffic approaching cities of various population groups which are bound beyond the city, to the city, and to the central business district.

Expressways needed

The obvious conclusion that a substantial and expensive enlargement of the capacity of such city arteries must be faced as inevitable, coupled with a recognition of the difficulty the cities would have in meeting unaided the large cost of the required solution, were prominent among the considerations which led to the earmarking of an annual fund of $125 million for expenditure only on routes of the Federal-aid system in urban areas, as one of the principal provisions of the Federal-aid Highway Act of 1944.

The intention was, by these means, to assist the cities in making a beginning toward the development of a system of free-flowing main arteries of ample ca-

vided, as a basis for their design, that prompted the beginning of the urban origin-and-destination surveys. Simple volume counts of traffic on the existing streets would not suffice for this purpose for two principal reasons: First, because the existing volumes are determined more by the available street capacity than by the route preference of the traffic; and, second, because such counts would afford no index of the volume of traffic that would transfer to the superior facility to be provided from less adequate, and possibly less direct routes it is now using.

The conclusion that only an origin-and-destination type of survey would serve was inescapable. But it was clear that the roadside interview method that had previously been used for such surveys at the cordon stations around the cities, involving the stopping of vehicles, would not be practicable of employment on the heavily traveled streets of a city. An entirely new method was required, and the method devised aims to ascertain the origins and destinations of the largely repetitive movements of internally originated traffic, by interviews with people in their homes. For this purpose, a representative sample of the residence units of the city is selected, a sample varying from 1 in every 10 units in the smaller cities to 1 in 20 for the large cities.

Information obtained

The sample chosen, personal interviews with the residents of the selected houses elicit information concerning all of the trips made by all members of the household on the weekday immediately preceding the day of the interview. What is sought is the origin, destination, and purpose of all trips made by any means of conveyance, whether by automobile or mass transit. The information thus obtained regarding the personal movements of city residents is supplemented by data on the movements within the city by other than city residents, obtained at external cordon stations on the main highways; and truck movements are determined by interviewing a sample of truck owners. The combined sample data, when expanded by correct statistical methods, gives a clear picture of a very large majority of all trips made in the city on a typical weekday during the period of the survey.

Controls

The accuracy of the survey results relating to automobile traffic is rigidly checked by comparing the expanded interview data indicative of trips passing chosen "control points" and "screenlines" with actual counts of the traffic passing these points and lines. Control points are usually chosen at well-known bridges or other landmarks easily identified, so that it is possible in the home interviews to determine whether they were passed in any of the trips reported. Screenlines are barriers, such as a river or railroad, with a limited number of crossings at which traffic can be counted without excessive expense.

In the carefully conducted surveys made since the war, about 90 percent of the traffic passing control points and screenlines during the 16 hours of operation of external stations has been accounted for by the expanded interview data. The other 10 percent is made up mainly of cars circulating in search of a parking place, of unimportant short trips easily forgotten in the interviews, and of trips by persons living outside the area not intercepted at the external cordon stations. The missed trips are considered of minor importance so far as the principal purposes of the survey are concerned.

Figure 11 shows the control-point check for the city of Baltimore. As will be seen, there is remarkable agreement between the ground count and expanded interview data for the 13 hours from 6 a. m. to 7 p. m. For this period 93 percent of the traffic counted on the ground is accounted for by the expanded interview data. However, the period from 7 p. m. to 10 p. m., not shown in the figure, brings this percentage down to 88.3 percent for the 16 hours of external station operation. For Seattle, Wash., and Portland, Oreg., where surveys were completed more recently, the 16-hour checks were 91.8 and 92 percent, respectively.

Desire lines of travel

The immediate, practical use of the results of these urban traffic studies is the determination of the location of expressways or other highway facilities which will best serve traffic needs, and the estimation of the traffic volumes which would use such facilities after they are constructed. For the former purpose, a "desire line" chart, such as the one for Providence, R. I., shown in the right half of figure 12, is quite helpful. It shows the major daily trip movements amounting to more than 300 trips between any pair of zones in straight lines from origin to destination. The difference between the desire lines of travel and the actual routes conforming to the existing street

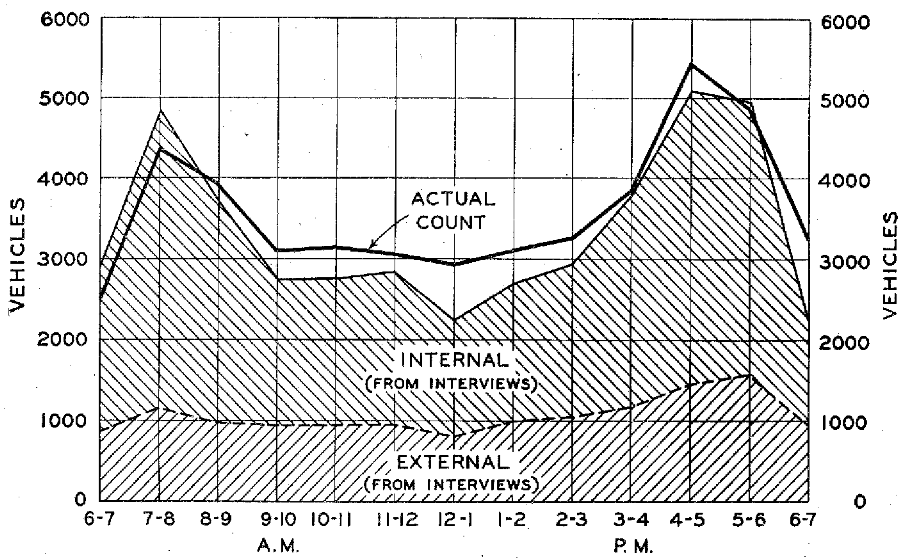

Figure 11.—Baltimore travel habit survey, 1945: Comparison between traffic passing three control points as reproduced from interviews and traffic actually counted at those points.

system can be seen by comparing the two halves of the figure.

In general, it has been found that the congestion in the central business district of a city is due in considerable measure to traffic which is only passing through the district, and has neither origin nor destination there. Thus, while a bypass around a city generally would give very little relief to urban congestion (fig. 10), an inner belt, passing around, but close to the central business district would give material relief to the congestion in that area. Figure 13 shows the origins and destinations of traffic on an interstate route through a typical city of 50,000–100,000 population. From this illustration it will be seen that slightly more than half of the traffic entering the central business district on the interstate route could be routed around this area. In contrast, note how small is the volume of external highway traffic that may be bypassed around the city as a whole.

Travel habits

In addition to the data applicable to immediate problems, much valuable information of a more general nature will come from the urban traffic studies when the results are fully analyzed. It will be possible, for example, to determine the travel habits of residents of zones of different characteristics, and thereby anticipate the kinds and volumes of traffic which will be generated by a new residential development; similarly, it will be possible to determine the effect on traffic movements of the concentration of business and industrial developments in certain areas.

Using and Publicizing the Data

As stated previously, the highway planning surveys were undertaken primarily for the purpose of determining what should be done to provide facilities adequate for present and probable future traffic needs, what are the financial requirements for carrying out such a program, and how the needed funds may best be raised. In fulfillment of the first two of these objectives, all of the State highway departments are using the data in their day-to-day operations, including design and programming of projects.

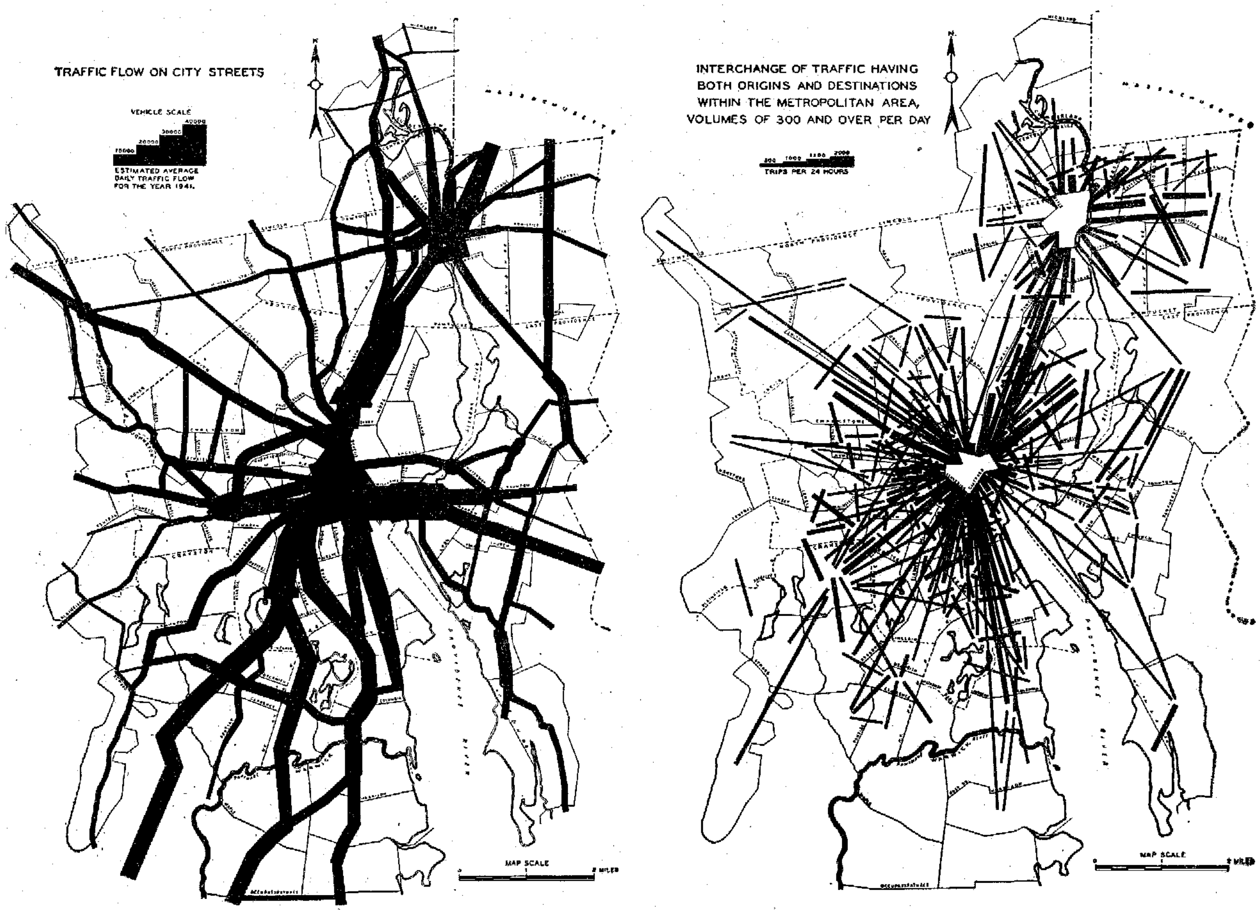

Figure 12.—Comparison of traffic on actual routes and desire lines of travel.

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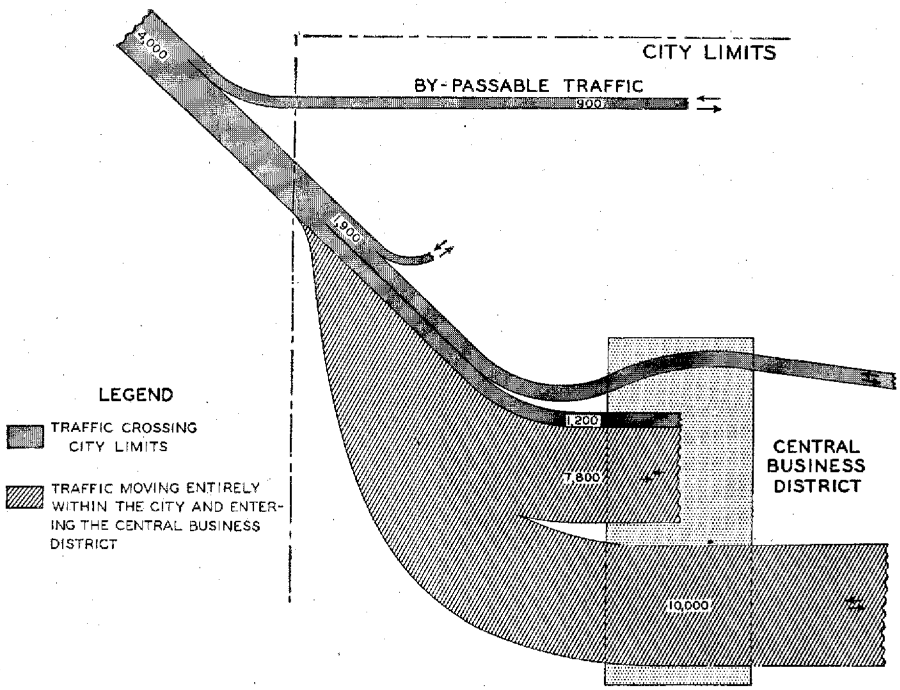


Figure 13.—Origins and destinations of traffic on an interstate route through a typical city of 50,000–100,000 population (based on data from 7 cities).

Needs studies

The last of the three objectives, that of determining how the needed funds are to be raised, is currently the concern of special committees appointed by the legislature or the governor, or otherwise created, in a number of States. Similar undertakings will certainly be launched in many additional States in the near future. The bulk of information required for consideration by these committees is already at hand in the results of the highway planning surveys.

In California, the first of such committees to be created, a joint fact-finding committee of the legislature, has completed its work. Many of the recommendations of the committee's report, including a 1½-cent increase in the gas tax, have been enacted into laws.

In Michigan, another type of committee, including in its membership representatives of road-building and road-using groups as well as public officials, has completed a report which will be presented for recommended action by the legislature. In at least 10 other States similar undertakings are immediately contemplated or in progress.

Maps

But it is not alone by legislative bodies and highway officials that the highway planning survey results are used. The information is made available to the general public in numerous ways. For example, the county maps, showing all roads and cultural features in rural areas, are printed in quantity and sold at reproduction cost by the State highway departments. They are widely used by governmental agencies, research organizations, business firms and associations, and private individuals.

Traffic data

Each month the Public Roads Administration prepares and distributes a bulletin showing traffic volume trends. Annually, there is published in *Public Roads* magazine an analysis of trends in truck weights and ton-mileages. These estimates are regularly used by manufacturers of automobiles and automobile parts and accessories, petroleum products, and the associations operating in these fields, as bases for forecasts on which to plan their operations.

Statistics

Annually, and in some cases more frequently, statistics are published on gasoline consumption, motor-vehicle registration, highway finances, and State and local road mileages broken down by surface type and width and other characteristics. Beginning with 1945 data, the practice has been followed of issuing annually the more commonly used highway statistics in pamphlet form, under the title *Highway Statistics, 1945* (the year being changed as required). A *Highway Statistics, Summary to 1945* has also been published. The demand for these pamphlets is so large that the Public Roads Administration has been unable to undertake free distribution. They can, however, be obtained cheaply from the Government Printing Office (see Bibliography).

Thus, progressively, the mass of facts which has been developed is being brought to the attention of every person and agency having an interest in, or responsibility for highway matters, and is beginning to influence thought and action with respect to the programming, design, construction, and financing of highways, and the regulation and taxation of the vehicles that use them. Since the data are now being kept current, this influence should continue and increase; and highway development in the United States will be placed on a much sounder basis than would otherwise be possible.

CONSTITUTION OF HIGHWAY SYSTEMS

One of the first and most important uses of the great body of facts amassed by the highway planning surveys is the guidance they supply to a process of re-systematization of the highways of the country now in progress.

Origins

The existing system classification had its origin in the assumption of highway responsibility by the State and Federal Governments in the early years of this century, responsive to the emergent demands of the motor vehicle. At the beginning of the century the present distinctions were virtually nonexistent. Direct responsibility for road administration fell almost completely upon the county and lesser subdivisions of government.

The demands of the rising motor-vehicle traffic for more substantial road improvement, the inability of the weaker local governments to cope with these demands, and the inception of new State-collected taxes upon the motor vehicle and its use—taxes which from the beginning have been regarded as peculiarly appropriate for highway expenditure—brought about, first, the segregation of State highway systems and, later, the designation of the Federal-aid system.

State and Federal-aid systems

The same principles guided the selection of both of these systems. Both were intended to include the roads of most general use and largest traffic concentration—arteries of the longer highway movements, as distinguished from the greater mileage of more local and less intensive usage. Both the Federal-aid and State systems, at the time of their original designation, were intended to constitute programs for a period of concentrated improvement effort. In the beginning the roads included in the two systems were little different in their physical condition from other roads; but the need for their improvement and the degree of improvement required were recognized as greater.

With a view to the concentration of effort, the mileages included in the selected systems—both State and Federal-aid—were more or less arbitrarily limited. The Federal-aid system, for instance, was limited to 7 percent of the existing total of rural-road mileage. The State systems were variously limited in other ways. In result, the roads chosen were generally those connecting the larger cities and towns of each State and of all States, such location being the most obvious criterion of the high degree of importance intended as the test of the selection. The availability of different funds for the two systems—State funds for the State systems, and State-matched Federal funds for the Federal-aid system—was, and remains, with the difference in their allowed extent, the principal difference between them. It follows that the two systems are virtually coincident to the extent of the smaller Federal-aid system.

Both of these overlapping systems of primary highways were originally composed of rural roads only. Later they were both extended into and through the connected cities, the sections within cities being still confined generally to the essential trans-city connections of the included rural highways.

Secondary systems

After the original designation of the two primary systems, the larger remainder of rural roads were left, as they had previously been, under local control. Later, in some States, some further part of this remainder came under complete or partial State control as State secondary systems, variously financed with State or combined State and local funds; and, at the request of the Public Roads Administration, partial systems of secondary and feeder roads were selected for application of the small Federal appropriations for roads of that class, made in the decade of 1930.

Rational Planning

In this latter designation the first tentative use was made of the factual information obtained by the planning surveys. All earlier system designations had been based upon information far less exact. In some part they had been undertaken by, or at the behest of State legislatures, upon considerations that were political rather than factual. In the light of the knowledge gained through the planning surveys, defects of judgment in these earlier selections were clearly apparent, and it was the purpose to avoid such defects in the selection of the system of Federal-aid secondary and feeder roads. An excellent beginning was made; but the funds available were discouragingly inadequate and, in the absence of clear legal sanction of its use, the attempted rational selective process was somewhat abortive.

Toll Roads and Free Roads

The first opportunity created by law to employ the more rational process occurred when, in 1938, the Federal Congress called upon the Chief of the Bureau of Public Roads to investigate the feasibility of a national system of transcontinental toll roads and make a report of his findings. The investigation made effective use of the planning survey information then in hand to discourage the contemplated toll-road system, and the report rendered under the title, *Toll Roads and Free Roads*, presented as a more desirable alternative the designation of a system of interregional highways to be developed with Federal aid as toll-free arteries of long-distance travel. Such a system was tentatively defined by the report, which proceeded further to recommend that "a final determination of the location of such highways should be made after further study in which the Bureau of Public Roads would cooperate with the War Department and the State highway departments."

Interregional Highways

To test the validity of the latter suggestion President Roosevelt, in 1941, appointed a committee, known as the National Interregional Highway Committee, under the chairmanship of Public Roads Commissioner Thos. H. MacDonald. The report of this committee, submitted to the President in 1944 and immediately transmitted by him to the Congress under the title, *Interregional Highways*, approved the previous proposal of an interregional system and recommended as a basis for further consideration a system of approximately 34,000 miles. In his endorsement of the report, the President requested early action by the Congress to authorize the formal designation of such a system by joint action of the Federal Government and the several State highway departments. This request was promptly answered by inclusion, in the Federal-aid Highway Act of 1944, of a provision directing the designation of a National System of Interstate Highways, not exceeding 40,000 miles in total extent, by joint action of the State highway departments of each State and the adjoining States, as provided by the Federal Highway Act of November 9, 1921, for the selection of the Federal-aid system. By the reference to precedent law, the designation to be made initially by the cooperating State highway departments was subjected to approval by the Federal Works Administrator acting through the agency of the Public Roads Administration.

The National System of Interstate Highways

Following the process thus legally defined and employing methods of rational selection exemplified in the report, *Interregional Highways*, the greater part of the National System of Interstate Highways (approximately 37,800 miles) has since been designated. A further selection of routes, principally within the connected urban areas, remains to complete the 40,000-mile system authorized. As specifically directed by the 1944 act, these designated routes, if not already included in the Federal-aid highway system, have been added to that system without regard to the previously imposed limitation of mileage of that system.

The Federal-Aid Systems

The methods of rational system selection, founded upon factual information provided by the highway planning surveys and thoroughly tested in the designation of the interstate highway system, are now being employed in the selection of roads to comprise the systems of principal secondary and feeder roads for which enlarged Federal-aid funds are made available by the act of 1944 and supplementary legislation enacted by the Congress in June 1948. Similar methods characterize a gradual process of revision of the Federal-aid and State highway systems, as these systems, in the light of the more exact information now available, are found in some respects to be inadvisedly constituted.

Primary

The Federal-aid primary system, as at present constituted, includes 232,000 miles, of which about 13,000 miles (separately termed the Federal-aid urban system) are within urban areas delimited by direction of the Federal-aid Highway Act of 1944 around and including all cities of 5,000 or more population.

Included in the Federal-aid primary system, and forming its core of the most direct routes connecting the larger cities of the country, is the National System of Interstate Highways, now of a total extent of 37,800 miles.

By further rational selection additional mileage within urban areas will be incorporated in both of these systems. The mileage that may be added to the interstate system is limited by law to about 2,200 miles. Beyond this, the urban mileage that may be included in the Federal-aid system is limited only by a rational determination of the need for city terminal and distribution facilities of the system.

The primary routes of the State highway systems at present add to a total of 372,000 miles. Thus these systems, which include the routes of the Federal-aid primary system, exceed it in total extent by about 140,000 miles.

Secondary

The Federal-aid secondary system, now in process of selection, included, in 1948, about 378,000 miles. This total embraces much of the mileage of the State primary systems not included in the Federal-aid primary system and, in its remainder, includes many roads that are parts of the previously designated State secondary systems and a large mileage presently under the administrative control of county and lesser government authorities. By further rational selection, the size of the Federal-aid secondary system will be enlarged to a probable total approximating 511,000 miles. The enlargement will incorporate mainly an additional mileage now under local government control; but will involve some transfer of roads to the secondary system that are still inadvisedly included in both the Federal-aid and State primary systems.

Upon completion of the indicated processes of addition and readjustment, the three Federal-aid systems (primary, rural and urban; and secondary) will probably embrace approximately 750,000 miles, rationally selected, and classified approximately as follows:

	Miles
Primary system (rural)	218,000
Urban system	21,000
Secondary system	511,000
Total	750,000

Correlation with State systems

With the attainment of this approximate goal of system designation in accordance with Federal law, the confusing overlapping that presently exists between the Federal-aid and State and local road systems will remain in the absence of corrective State legislation.

Expectation that such corrective and simplifying action will eventually be taken is encouraged by the increasing respect that has been won for the new rational processes employed in the Federal-aid system designation, and by the necessities of practical operation under the Federal law.

The strength of the latter inducement lies in the fact that the Federal funds authorized for improvement of the Federal-aid secondary system are matchable with State funds only if they are expended upon those portions of the Federal system that are also included in either the State primary or secondary systems. Application of the Federal funds to improvement of the large part of the designated system now under the administrative control of local governments depends upon the slender ability of such governments to contribute matching funds for expenditure under the supervision of the State highway departments. Under the Federal law, the State highway departments assume a responsibility for the maintenance of roads so constructed with locally contributed matching funds. For the discharge of this responsibility the State highway departments now depend upon agreements of doubtful binding effect with the local government authorities. Faced with this difficulty, the States may be expected to find a satisfactory solution only by assuming control over the additional mileage of roads involved; and it is equally to be expected that when the combined primary and secondary road responsibilities of the Federal and State governments are thus committed to an identical total of mileage, the subdivision of the total into primary and secondary systems will be brought into identity.

The probability of this eventuality is enhanced by the logic of the facts, as developed by the planning surveys, that by such a course the superior means available to the Federal and State governments, applied to the improvement of less than 23 percent of the entire rural-road mileage, would serve to facilitate upwards of 85 percent of all rural-road traffic.

SOME FACTORS DETERMINING GEOMETRIC DESIGN STANDARDS

Another significant advance of the last 10 years, which is a direct result of the more exact information concerning road usage that has resulted from the planning surveys, is the advance that has been made in the development of improved standards for what is here termed the geometric design of highways. The etymology of the term may be a little strained. Its scope and meaning, nevertheless, uniformly understood throughout the United States, relate to the features of alinement and profile, the plan of intersections, the clearances, and the horizontal dimensions of the highway cross section.

These are the features of road design that are most directly affected by increase of the volume and speed of traffic. It will be readily understood, therefore, that they are the features in which, as they are represented in the older highways, there has been the highest degree of obsolescence. To avoid the probability of such rapid obsolescence of highways of current design, a great deal of study has been devoted to the dynamics of highway movement; and the results of this study, combined with the evidence of traffic growth and distribution and other information resulting from the planning surveys, form the basis of the newer geometric standards which have gained wider acceptance in recent years.

Design Speeds

To determine the speeds for which highways should be designed, consideration has been given to the speed capacities of motor vehicles, the observed speeds at which vehicles are driven, and the various factors that affect these speeds.

Figure 14 shows the trend in speed records set by American stock cars. These are the vehicles that are present in everyday traffic. In 1925, only the high-priced cars were capable of exceeding 60 miles an hour. Today we find that the average low-priced car can exceed 80 miles per hour and those in the high-priced field can exceed 90 miles per hour. Top speeds, however, have been leveling off after the rapid rise of the late twenties and early thirties. Since 1934, there has been no appreciable increase in the top speeds of low-priced cars and only a slight gain in the top speeds of the higher priced groups.

Driving speeds

The trend in driving speeds has been running roughly parallel with the available top speeds of motor vehicles. Results of observations made in 1934 and 1939 on the same highways show that drivers uninfluenced by other traffic traveled at nearly the same speed during both years. Speeds during the past year have returned to the level maintained just before the war, with the greatest number of drivers traveling between 45 and 50 miles per hour when uninfluenced by other traffic. Only a scattered few travel faster than 60 miles per hour, a speed at least 20 miles per hour below the speed capacities of their vehicles. This is shown by figure 15, representing ideal highway conditions, the only limit on speed being the driver's own idiosyncrasies and inhibitions. The average speed is about 49 miles per hour. Average speed during low traffic volumes on some highways is between 50 and 55 miles per hour, but these instances are relatively few.

There is no doubt of the possibility of designing vehicles capable of higher speeds. Other factors, however, including personal traits or limitations of the

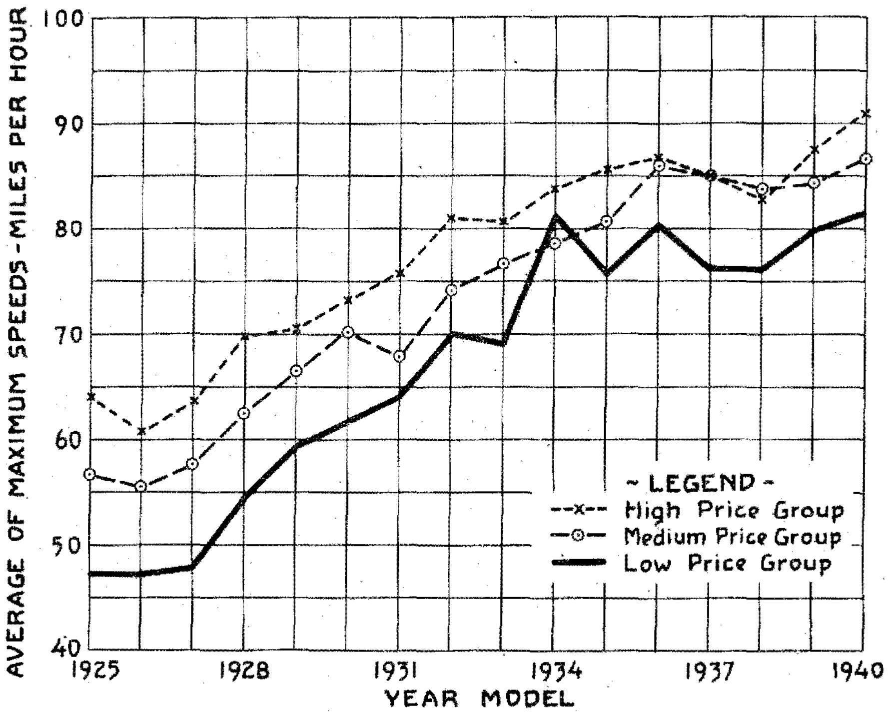


Figure 14.—Average top speeds of American stock cars in high, medium, and low price ranges by year models (source: proving ground records).

drivers, increased use of the airplane for long-distance travel, and economic considerations of highway design, indicate that the tendency in the future in relation to the main highways will be to increase average speeds by reduction of the number of vehicles that travel at the lower speeds. This will result from the provision of highways with controlled access and few intersections at grade, rather than from an increase of top speeds.

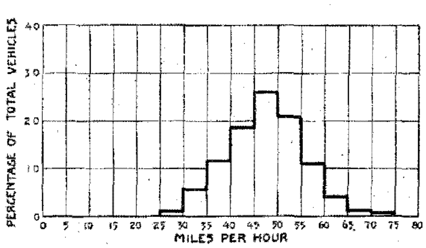


Figure 15.—Frequency distribution of speeds of free-moving vehicles on modern high-speed highways.

Driver characteristics

Investigations by the Public Roads Administration regarding characteristics of individual drivers have shown that, on an average, persons traveling long distances drive faster and generally have newer cars than local travelers; young persons drive somewhat faster than older persons; men drive somewhat faster than women; and the newer vehicles are driven faster than older vehicles. The length of trip, however, is the outstanding factor influencing the speed at which drivers travel, as shown by figure 16. Highways built to accommodate a high percentage of drivers traveling on long trips should, therefore, be designed for higher speeds than highways on which trips are predominantly short.

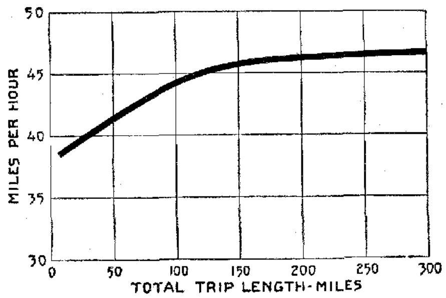


Figure 16.—Relation between speed and trip length.

The studies afford no justification for a design of highways to accommodate speeds in excess of 70 miles per hour under any condition. For local rural roads or urban facilities a design speed of 50 miles per hour is the highest that can be justified. During peak traffic volumes in rural areas, drivers do not consider the highway too congested if they can maintain a speed of 45 to 50 miles per hour on the ordinary highway and 50 to 55 miles per hour on the highest type of facility. A speed of 30 to 35 miles per hour is considered satisfactory by most drivers during peak periods on urban expressway facilities.

Width of Traffic Lanes

No features of a highway have a greater influence upon the safety and comfort of driving than the width and condition of the surface. The need of a smooth, nonskid, all-weather surface on highways carrying substantial volumes of traffic is obvious. The required surface width is not obvious, and was not apparent until extensive studies had been made of vehicle speeds, vehicle placements, and the clearances between vehicles traveling in the same and opposite directions on surfaces of different widths. Figures 17, 18, and 19 show the average results of these studies on two-lane highways for the most critical conditions, which occur when a vehicle meets another vehicle traveling in the opposite direction.

Pavement and shoulder widths

The following are a few of the results of such studies, made at hundreds of locations and including observations on thousands of vehicles under actual highway and operating conditions:

1. To permit desired clearances for commercial vehicles a 24-foot pavement is required. When a passenger car meets a commercial vehicle on a pavement 22 feet wide, the passenger car has the desired center and edge clearances, but the commercial vehicle does not.

2. Hazardous traffic conditions exist on pavements less than 22 feet wide that carry even moderate volumes of mixed traffic. On 18-foot pavements with grass or gravel shoulders, 11 percent of the drivers of trucks and 5 percent of the drivers of passenger cars fail to keep their vehicles within their proper traffic lane when meeting oncoming traffic.

3. Bituminous-treated shoulders, 4 feet or more in width, adjacent to 18- and 20-foot pavement, increase the effective surface width approximately 2 feet.

4. Well-maintained grass shoulders have the same effect on the transverse position of moving vehicles as well-maintained gravel shoulders.

5. Shoulder width in excess of 4 feet does not influence the effective pavement width for moving vehicles when there are no vertical obstructions immediately adjacent to the shoulders. This must not be interpreted, however, as implying that shoulders wider than 4 feet are not necessary for other important reasons.

6. Lip curbs on 20-foot pavements reduce the total effective pavement width during the day approximately 1 foot. At night this is true only for commercial vehicles.

Width of bridges

Closely related to road-surface widths is the width of bridges necessary to provide operating conditions consistent with those on the normal highway section. The results of the studies show that an 18-foot pavement with 3-foot shoulders requires a bridge with a roadway 26 to 28 feet in width if it is of an open-deck type (fig. 20). This required width increases to 28 or 30 feet when the total roadway width is increased to 34 feet and the pavement is either 20 or 22 feet wide.

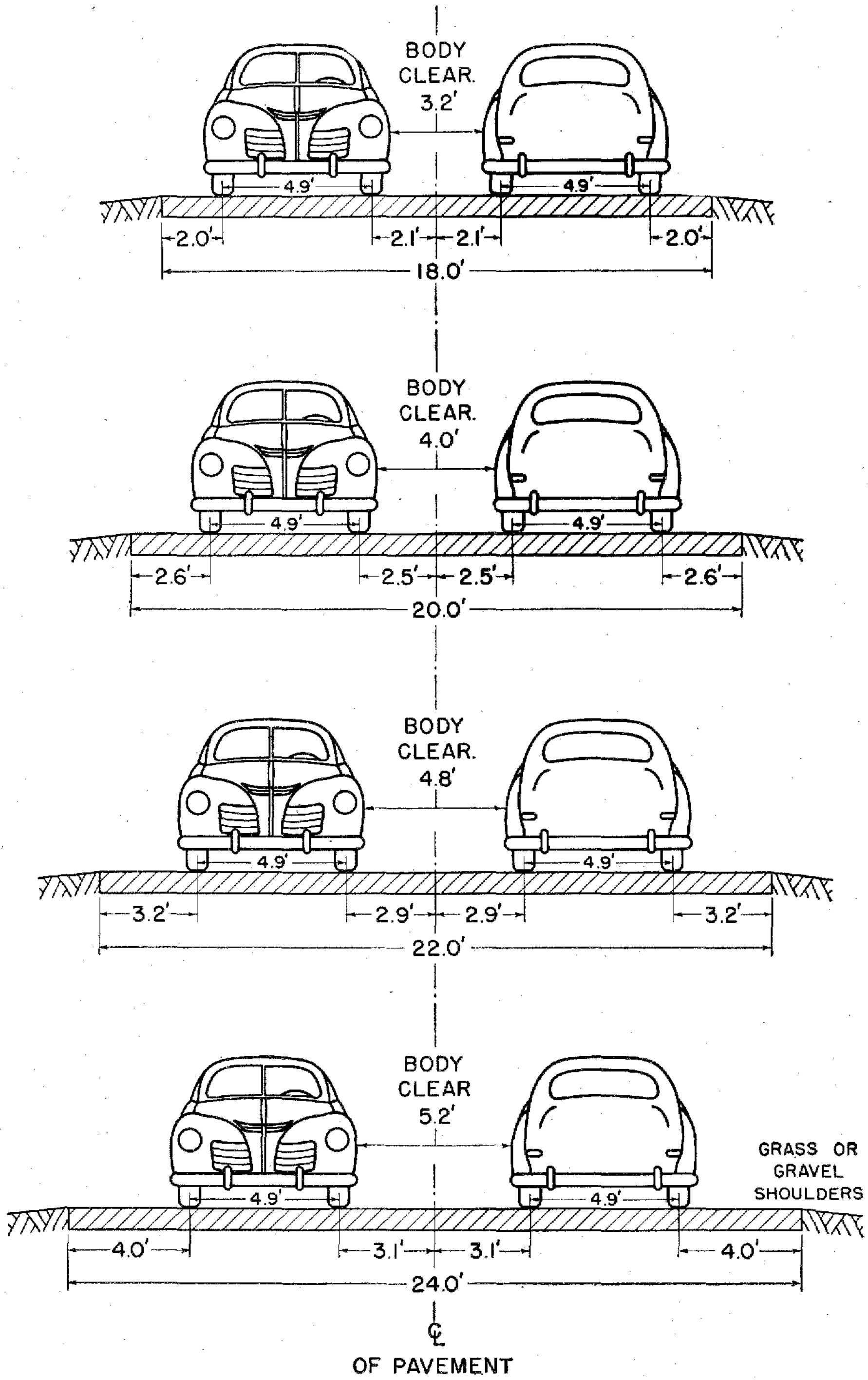


Figure 17.—Average position of passenger cars when meeting on two-lane concrete pavements during daytime.

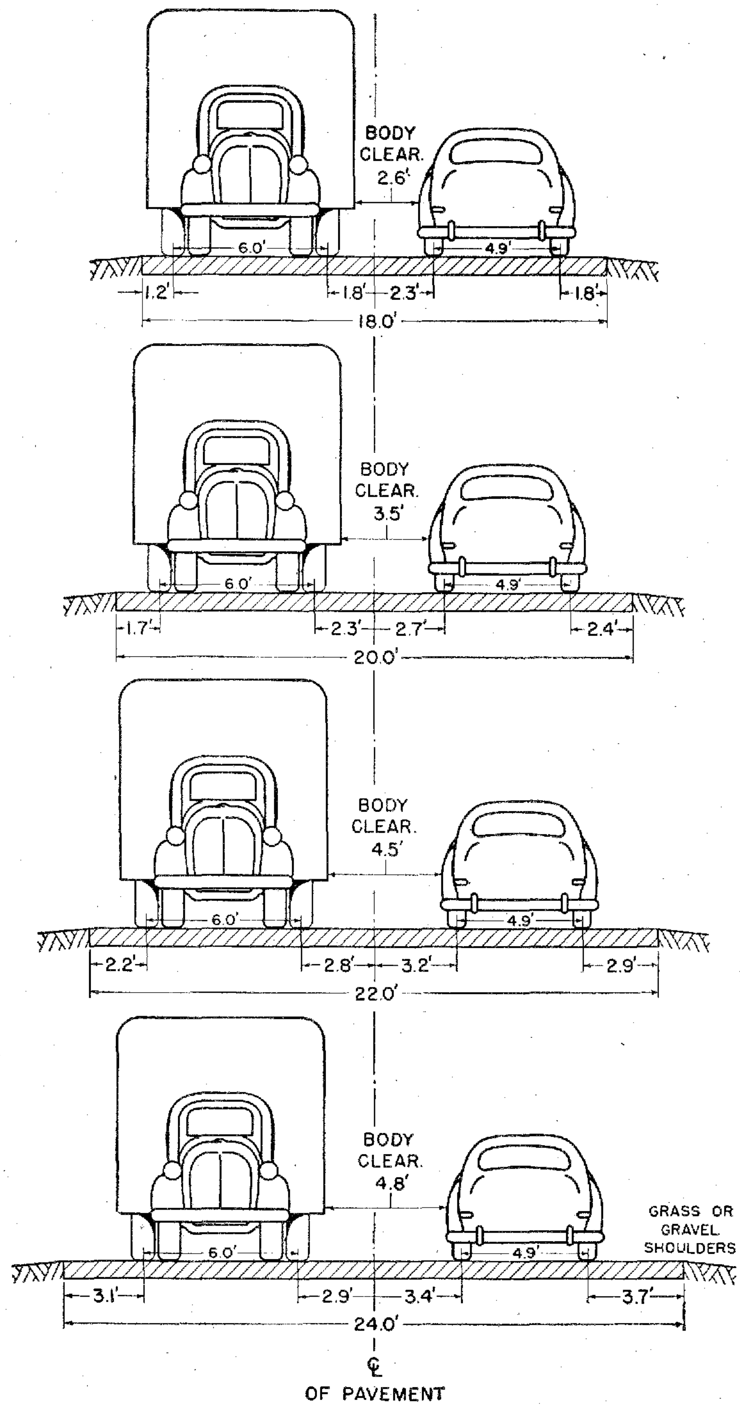


Figure 18.—Average position of passenger cars and commercial vehicles when meeting on two-lane concrete pavements during daytime.

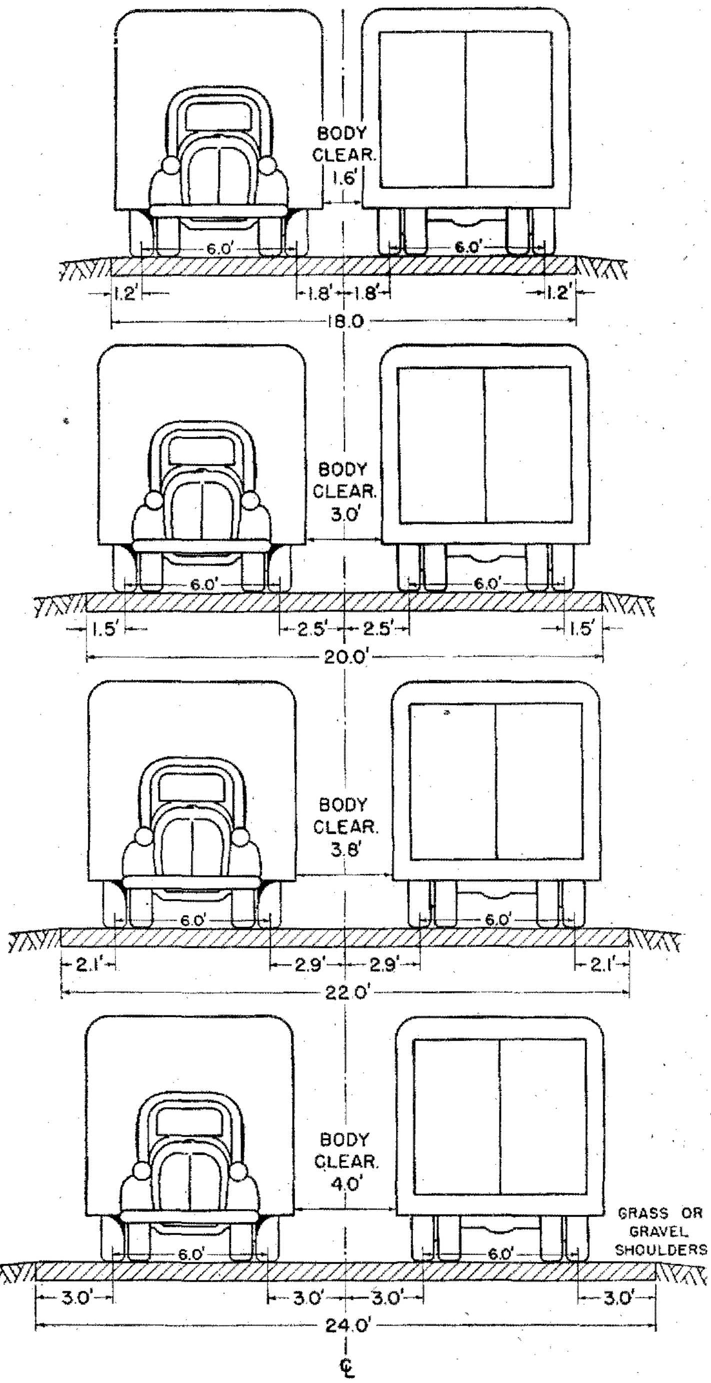


Figure 19.—Average position of commercial vehicles when meeting on two-lane concrete pavements during daytime.

A truss bridge must be 4 or 5 feet wider than an open-deck bridge to provide comparable operating conditions.

Roadside obstacles

Also closely related to decisions upon the surfaced width of a road is the clear distance that will exist between roadside obstacles of one kind or another and the edge of the pavement. The results of a study conducted by placing vehicles and barricades at different distances from the pavement edge, combined with the results of studies conducted at places where retaining walls, bridge piers, etc., were near the pavement edge, demonstrate:

1. That obstacles at the edge of an 8-foot lane cause vehicles to travel 3.3 feet farther from the edge of the pavement than when the obstacles were not present. The same obstacles at the edge of a 10-foot lane cause vehicles to travel 2.6 feet farther from the edge of the pavement; and where lanes are 12 feet wide they cause vehicles to travel 1.8 feet farther from the edge of the pavement.

2. That when an obstacle is 4 feet beyond the edge of the pavement, the distance between the vehicle and the pavement edge is increased 0.8 foot on 8-foot lanes, 0.7 foot on 10-foot lanes, and 0.5 foot on 12-foot lanes. Such roadside obstacles, therefore, have the same effect as a reduction in the pavement width.

3. That obstacles within 6 feet of the edge of a traffic lane influence the position of traffic in that lane to some extent but the effect is almost negligible for distances exceeding 4 feet.

Relation of Vehicle Performance and Geometric Standards

One of the most important problems confronting the highway designer is the selection of gradients, in conjunction with curvature and sight distance, that will result in a safe and efficient flow of traffic. For many years, there has been criticism of operators of commercial vehicles because their trucks go so slowly upgrade that long queues of passenger cars are formed behind them, and then go so fast down the other side that no one can pass. There is justification for the complaints, for the situation is found universally throughout the country on two-lane highways. However, the blame should be shared by the highway designer as well as the truck operator.

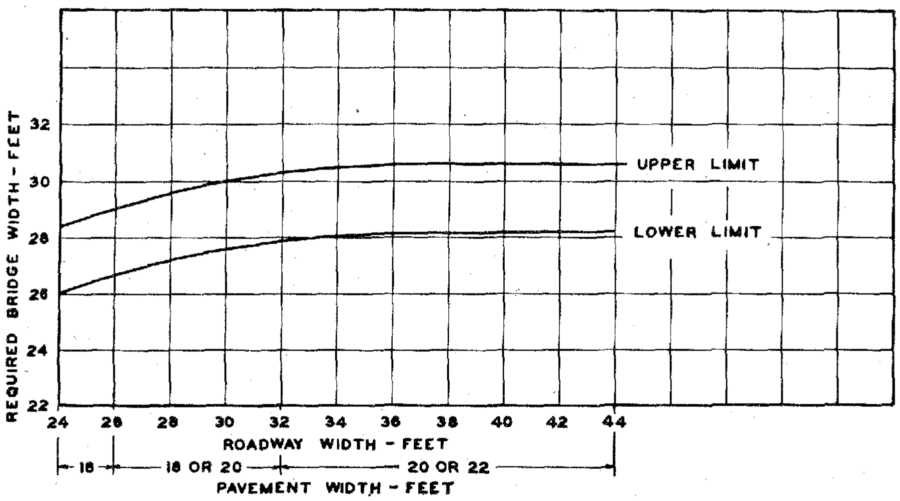


Figure 20.—*Widths of concrete bridges necessary to provide operating conditions consistent with various widths of roadway.*

Effect of grades

Efforts have been made and are being made to remedy this situation by legal measures which specify that a truck must be loaded with respect to its engine horsepower so that it can maintain some stated speed, commonly 20 miles per hour, on specified grades, usually 3, 4, or 5 percent. The highway designer has been attacking the problem by working toward grade reduction. Exhaustive studies of the hill-climbing ability of commercial vehicles, conducted by the Public Roads Administration, have developed information that has particular significance in connection with this problem.

A detailed report of the studies, published in *Public Roads* for May 1942, contains the following conclusions:

1. Grades must be reduced to 3 percent or less, or

2. Engine power must be more than doubled, or

3. Gross vehicle weights must be reduced excessively, or

4. Some combination of the three must be used that will still be costly to all interests involved and practically impossible of immediate application.

Figure 21 shows the grade ability of light-, medium-, and heavy-powered vehicles in operation in 1941. The light-powered vehicles had engines which, on an average, would develop 93 brake horsepower; the medium-powered vehicles had engines which, on an average, would develop 106 brake horsepower; and the heavy-powered vehicles had engines which would develop, on an average, 115 brake horsepower. At the present time, light-powered vehicles will develop nearly the same brake horsepower as those considered medium-powered in 1941.

The effect on the truck operator of a minimum performance requirement is seen in figure 21. The vehicles represented by the curves for heavy-powered vehicles are typical of those that when fully loaded would have a gross weight of about 40,000 pounds. This figure shows that combinations weighing 40,000 pounds gross could maintain a speed of 20 miles per hour on grades of 3 percent and 13 miles per hour on grades of 5 percent. To maintain 20 miles per hour on a 5-percent grade would require reducing the gross weight to 27,000 pounds, or, in effect, reducing the payload from about 12 to 6 tons. What would this do to highway trucking and how many passenger-car drivers would be content to trail a truck moving at 20 miles per hour?

There is no doubt that something must be done, but it is believed that the comprehensive solution lies within the realm of highway design. The highway engineer has been attempting to speed up truck movement by grade reduction; but in many cases adherence to some standardized maximum gradient has necessitated the introduction of so much curvature that passing sight distance on grades has been sacrificed. It is not sufficient to consider the various elements of design such as gradient, curvature, and sight distance independently. There is little value in the reduction of grades or flattening of curves per se.

Tests of traffic performance

The Public Roads Administration, in cooperation with one of the State highway departments, has recently conducted exhaustive tests of traffic performance, first on an old road and subsequently on a relocation of improved alinement. The new road is slightly shorter, 20.7 miles against 21.3 for the old. Each road crosses the same two ridges. In so doing the new road reaches the higher elevation, 1,242 feet, compared with the 1,070 feet reached by the old road. The total rise west-bound on the new road is 2,138 feet, compared with 2,392 on the old, an apparent slight advantage for the new. Actually, however, if the short momentum grades, of 25-foot rise or less, are deducted in each case, the comparison becomes 2,035 feet of rise for the new against 2,070 for the old location. Thus, in length and in effective rise and fall, there is little to choose between the two locations. Moreover, on each road, grades range as steep as 8 percent, and on each, heavy grades run a mile or more in length. The big

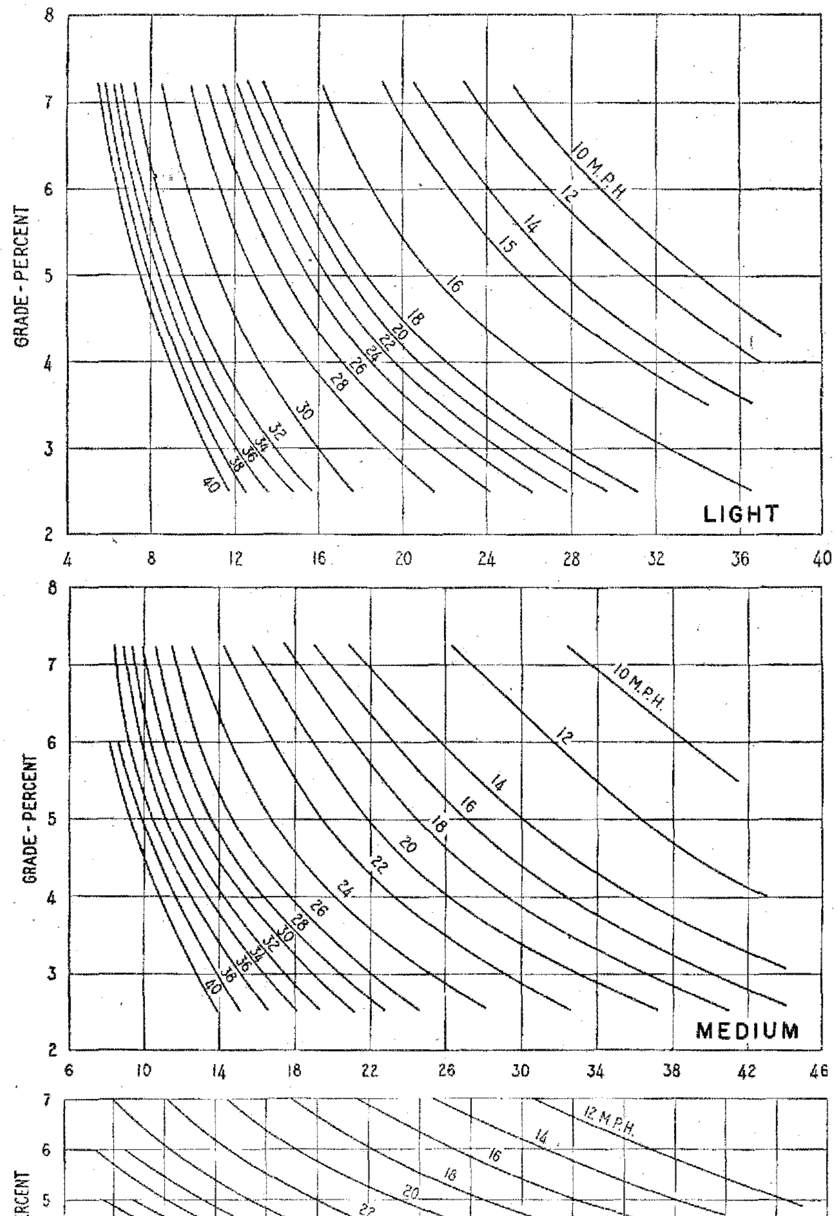


Figure 21.—Grade ability of light-, medium-, and heavy-powered trucks and combinations (without governor).

difference between the two roads lies in the percentage of the total length of each that permits passing. On the old road 49.3 percent in one direction and 45.6 in the other, or nearly half of the total length, was marked for no-passing. On the new road only 12.2 percent of the length in one direction and 11.6 percent in the other will not permit safe passing.

Results of study

Table 2 shows some very interesting results of this study. The speeds of trucks and combination units over the new and old roads, as will be observed, are not widely different, but there is a definite advantage in favor of the new road. The increased speed on the new road is probably caused by the opportunity to drive faster on the down grades. On the old road, down-grade speed is retarded by the curvature, while on the new road good sight distance and tangent alinement allow higher speeds.

Table 2.—Average speeds of vehicles over old and new roads

Vehicle type	Average speed in miles per hour	
	Old road	New road
Typical 2-axle single-unit trucks with 150-200 pounds of gross weight per maximum horsepower	28.5	33.7
Typical combination units with 300-350 pounds of gross weight per maximum horsepower	22.7	25.7
Passenger cars	33.6	42.5

Passenger-car speeds, shown in the bottom line of table 2, demonstrate the real advantage of the new alinement. Average speeds have increased from 33.6 miles per hour on the old road to 42.5 miles per hour on the new. This amounts to a time saving of over 8 minutes per passenger car in travel between the common termini. Spot speed studies made at many points along each road indicate that the reduced travel time on the new road is not the result of excessive speed but results rather from the reduction of delays caused by inability to pass slow-moving vehicles on the upgrades.

These results should not be construed as an endorsement of the particular alinement or of 8-percent grades in general. It is possible that some other location would have provided equally good operating characteristics with lower grades. However, the results do point to the fact that freedom of movement for passenger cars may be attainable with steep grades and long sight distances. The comprehensive and economical solution of the problem, in some instances at least, appears to lie in a use of steeper grades and adequate sight distance, rather than in a reduction of gradient and inadequate sight distance, or in adequate sight distance achieved at great cost.

Added lanes on hills

Another means available to the highway designer for elimination or lessening of the congestion that is created by heavy vehicles crawling up hills is the construction of "added lanes" or "truck lanes" on the uphill side of the grades. This method has been employed by several States with excellent results. It must be remembered, however, that the solution is a localized one and might be impractical of application in certain types of terrain, especially where the road is located on the side of a mountain.

In deciding upon the advisability of adding a "truck lane," important considerations are the lengths to which various gradients may be extended in the presence of different total traffic volumes before an added lane becomes necessary, and the location of the points where the added lane should start and end. It is evident that an added lane is not needed on a short grade, and need not necessarily start at the bottom of a long, steep grade, because the momentum of the heavy vehicle plus its driving power will keep its speed above a reasonable minimum of, say 30 miles per hour until the vehicle has traveled a certain distance up the grade. Since savings in construction costs will result by starting the added lane some distance up the hill, and since this is a practical solution, especially where the climb consists of several gradients with a moderate grade

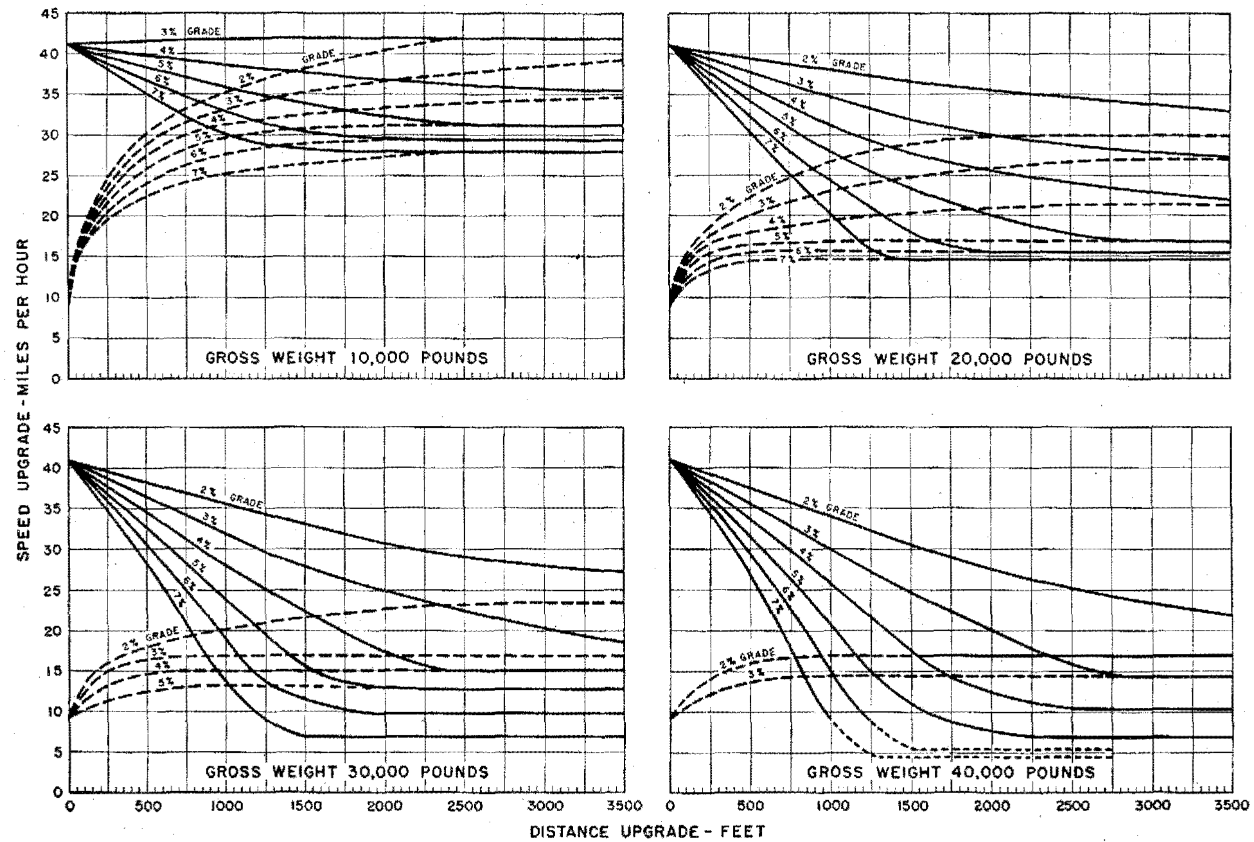


Figure 22.—Effect of length of grade on the speed of light-powered trucks and combinations.

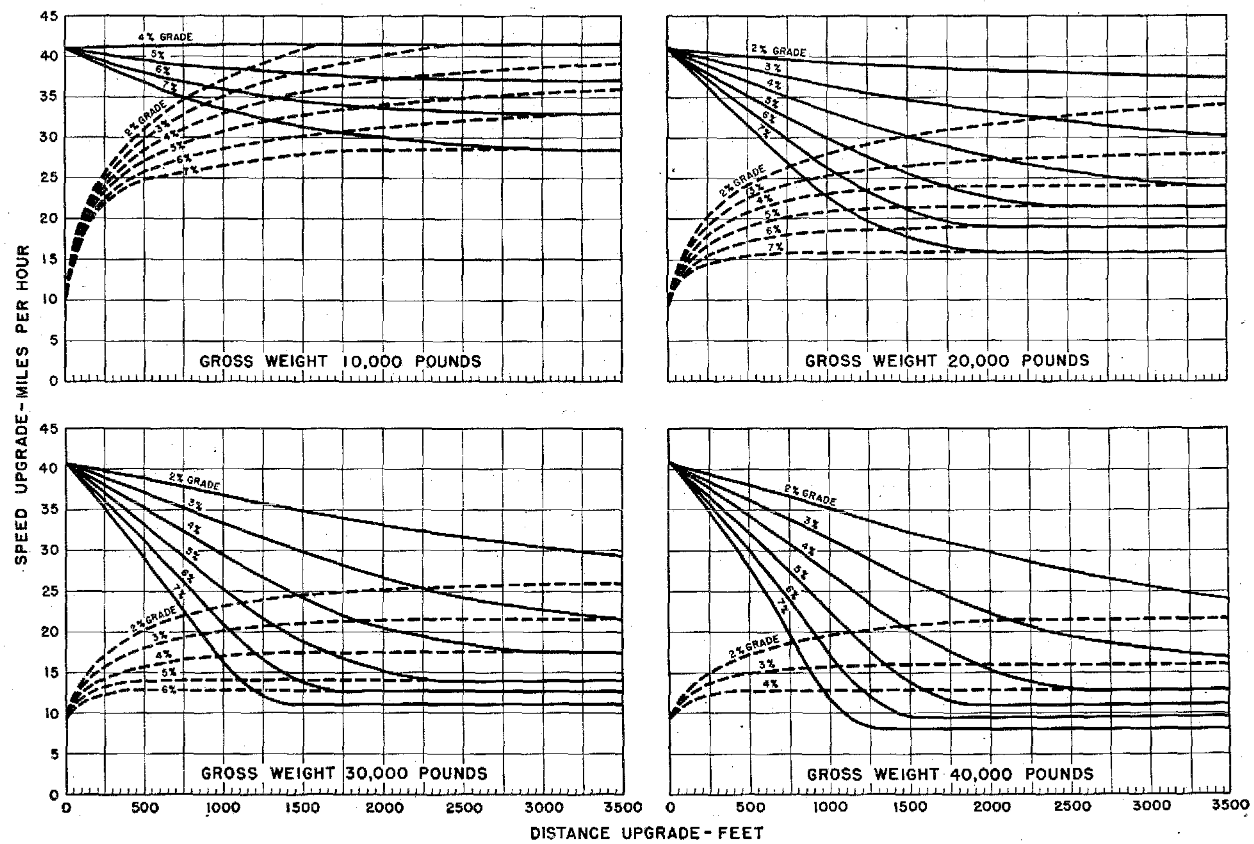


Figure 23.—Effect of length of grade on the speed of medium-powered trucks and combinations.

near the bottom, it is necessary that the momentum and driving power of the trucks be carefully considered.

The relationships between speed of trucks at the bottom of a hill, percentage of grade, and distance upgrade are shown in figure 22 for light-powered motor trucks or combination units and in figure 23 for medium-powered motor trucks or combination units. Gross vehicle weights of 10,000, 20,000, 30,000, and 40,000 pounds are considered for both the light- and medium-powered vehicles. These relationships have been derived from the results of hill-climbing studies reported in *Public Roads* for May 1942. From these data, for the power and gross weights of vehicles represented, it is possible to determine how far a vehicle, starting its climb from any speed between 9 and 41 miles per hour, can travel up various grades or combinations of grades before the speed is reduced to any desired minimum. The solid curves in the figures indicate the performance that may be expected when the beginning speed is above the possible sustained or crawl speed. The broken lines, starting at 9 miles per hour, show what performance may be expected when the hill is approached at crawl speed.

For example, it can be determined that a 40,000-pound medium-powered truck, starting at 41 miles per hour, can climb 1,000 feet of 2-percent grade and 200 feet into a following 6-percent grade before its speed is reduced below 30 miles per hour. This is determined by using the set of curves marked "gross weight, 40,000 pounds" in figure 23. Following the solid 2-percent curve to the 1,000-foot upgrade distance, it is found that a 2-percent grade will slow the vehicle to 35 miles per hour, which in turn will be the entering speed for the 6-percent grade. The solid 6-percent curve intersects the 35-mile-per-hour ordinate at an upgrade distance of about 300 feet. Subtracting this 300 from 500 feet, the point where the solid 6-percent curve intersects the 30-mile-per-hour ordinate, results in 200 feet.

If, then, the section of 6-percent grade is longer than 200 feet and it is desired by provision of a "truck lane" to avoid obstruction of faster vehicles by trucks of the power and gross weight considered, moving at less than 30 miles per hour, the added lane should be started on the hill described soon enough for the trucks to be in it when they have gone 1,200 feet up the grade.

Table 3 shows the distances light-powered trucks and combination units of 30,000-pound gross weight and medium-powered trucks and combination units of 40,000-pound gross weight can travel up various grades before their speeds are lowered from various entering speeds to 30 miles per hour. This table was derived from the data shown on figures 22 and 23. Under other conditions, as where more than a single percentage of grade is involved, it is necessary to obtain the information direct from figures 22 and 23. There is little difference between the upgrade distances indicated for the light-powered vehicles with 30,000-pound loads and the medium-powered vehicles with 40,000-pound loads.

Table 3.—Distances from bottom of grades at which trucks and combinations of 2 classes and gross weights will be reduced to 30-mile-per-hour speed from various entering speeds

Grade	Light-powered trucks and combination units of 30,000 pounds, from entering speeds of—				Medium-powered trucks and combination units of 40,000 pounds, from entering speeds of—			
	50 m. p. h.	45 m. p. h.	40 m. p. h.	35 m. p. h.	50 m. p. h.	45 m. p. h.	40 m. p. h.	35 m. p. h.
Percent	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
2	3,840	2,920	2,000	1,080	3,500	2,650	1,800	940
3	2,170	1,630	1,090	550	2,070	1,550	1,030	510
4	1,530	1,140	760	370	1,500	1,120	740	360
5	1,150	860	570	280	1,110	830	550	270
6	950	710	470	230	930	690	450	210
7	790	590	390	190	780	580	380	180

Gross loads of 40,000 pounds on medium-powered trucks will probably not occur with sufficient frequency on most of our main rural highways to justify basing the road design on these vehicles alone. Light-powered trucks with gross loads of 30,000 pounds, however, will occur with sufficient frequency on most main highways to affect seriously the operation of passenger vehicles unless suitable provision is made in the alinement and other design features of the road.

Effect of Geometric Standards on Highway Capacity

The capacity of a highway is its ability to accommodate traffic. It is expressed as the number of vehicles traveling at a given speed that can pass a point on the highway in a specified period of time. If the demand imposed by traffic upon a highway is greater than its capacity for a reasonable speed, the facility becomes congested and some type of improvement is needed. A knowledge of highway capacity is essential, therefore, to the determination of standards necessary to provide satisfactory operating conditions for various volumes of traffic. Such knowledge is also important in appraising the adequacy of existing highways, and in anticipating the length of the future period during which a particular facility may be expected to provide satisfactory service before becoming unreasonably congested.

Speed and capacity

With a low traffic volume, drivers are free to exercise their own initiative regarding the speed at which they will travel. As the number of vehicles using the highway increases, the manner in which each vehicle is operated is influenced to a greater extent by that of the slower vehicles. Finally, if the density of traffic becomes sufficiently great, all vehicles will travel at the speed of the slowest group of vehicles and the highway will be loaded to its possible capacity. Figure 24 shows the maximum number of vehicles, traveling in a single lane, that can pass a point at different speeds. Maximum possible capacities for facilities having different numbers of lanes are as follows, when roadway conditions are ideal:

Two-lane highways—2,000 passenger cars per hour (total in both directions).

Three-lane highways—4,000 passenger cars per hour (total in both directions).

Four- or more lane highways—2,000 passenger cars per hour per lane.

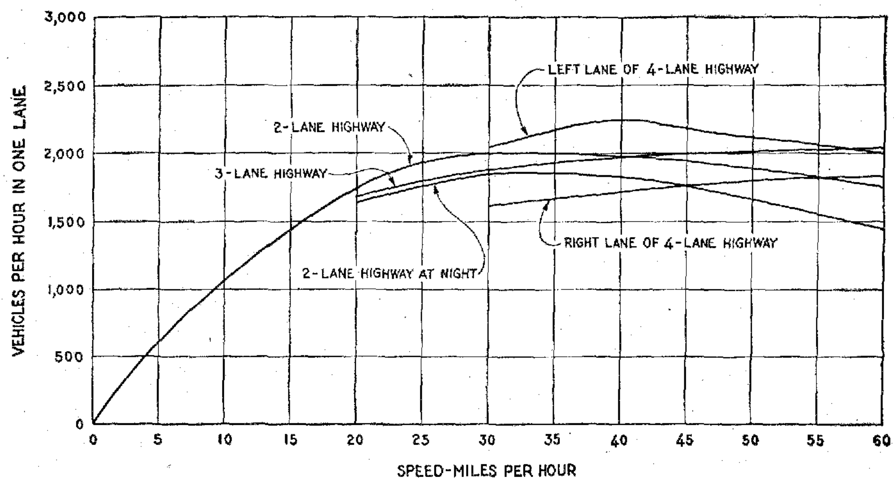


Figure 24.—Maximum capacity of a traffic lane, based on average spacings, between pairs of vehicles traveling at the same speed.

When the above volumes occur, speeds are about 30 miles per hour. These capacities cannot occur at speeds appreciably higher or lower than 30 miles per hour, as illustrated in figure 24.

Practical working capacity

The high degree of restraint placed upon every motorist when the possible capacity of a highway has been reached results in driving conditions that are wholly intolerable. Drivers demand and are entitled to receive some freedom in their selection of speed and their ability to maneuver. The maximum volume that will permit a reasonable degree of freedom from congestion may be termed the practical working capacity of the facility. Its magnitude depends in large measure upon local conditions. For rural areas, it is generally felt that operating conditions are satisfactory so long as the drivers who so desire may travel at average speeds of 45 to 50 miles per hour without undue hazard. On roads having a lane width of 12 feet and excellent alinement, such speeds can be attained with the traffic volumes shown below, for highways of different numbers of lanes:

Two-lane highways—900 passenger cars per hour (total in both directions).

Three-lane highways—1,500 passenger cars per hour (total in both directions).

Four- or more lane highways—1,000 passenger cars per hour, for each of the lanes in the heavier direction of travel.

The average speed of all traffic under these volume conditions would be about 40 miles per hour, but the drivers who so desire would be able to average 45 to 50 miles per hour. If a lower average speed is satisfactory, the practical capacities would be somewhat higher. On multilane expressway facilities in urban areas where the flow is uninterrupted, for example, a volume of 1,500 passenger cars per lane per hour is practicable for the lanes in the heavier direction of travel. The average speed at this volume would be about 30 miles per hour but drivers who so desire would be able to average 35 to 40 miles per hour with safety.

Roadway and traffic conditions are seldom ideal; hence the volumes quoted above are greater than the ordinary highway is capable of accommodating with a reasonable degree of freedom to vehicle operators. A number of conditions can cause a reduction in the practical capacities given above. The more important of these are discussed in the following paragraphs.

Narrow lanes

Narrow lanes have a lower capacity than 12-foot lanes, which are at present considered necessary for heavy volumes of mixed traffic. Factors which have been developed for computing practical capacities of lanes less than 12 feet in width are shown in table 4.

Table 4.—Effect of lane width on practical capacities

Lane width	2-lane rural roads	Multilane urban expressways
Feet	*Percentage of 12-foot lane capacity*	
12	100	100
11	86	97
10	77	91
9	70	81

Table 5.—Effect of restricted lateral clearance on practical capacities.

Clearance from pavement edge to obstruction	Effective width of 2 lanes					
	Obstruction on one side			Obstruction on both sides		
	12-foot lanes	11-foot lanes	10-foot lanes	12-foot lanes	11-foot lanes	10-foot lanes
Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
6	24.0	22.0	20.0	24.0	22.0	20.0
4	23.5	21.5	19.6	23.0	21.0	19.2
2	22.5	20.6	18.8	21.0	19.3	17.5
0	21.0	19.3	17.5	18.0	16.5	15.0

Restricted lateral clearances

Vertical obstructions, such as retaining walls, bridge trusses or headwalls, and parked cars reduce the effective width of a traffic lane. The extent of reduction in capacity may be determined from table 5, in conjunction with the factors listed in table 4. In addition to their effect on capacity, lane width and lateral clearances also affect driving comfort, accident rates, etc., which the relationships shown by these tables do not include.

Narrow shoulders

Narrow shoulders reduce the effective width of a traffic lane by causing vehicles to travel nearer the center of the pavement. The greatest detrimental effect upon capacity is created when disabled vehicles, of which there is an average of at least 1 for every 10,000 vehicle-miles, are unable to park clear of the traffic lane. The effect of either of these conditions upon capacity may be determined by use of the information given in table 5, using in the first case the width of shoulder as the clear distance to the obstruction, and a zero clearance for the pavement width not occupied by the parked vehicle in the second case.

Commercial vehicles

Commercial vehicles occupy a greater road space and influence other traffic over a larger area of the highway than do passenger cars because they generally travel at lower speeds, especially on grades. When a highway is operating at its capacity the total number of vehicles is therefore less, if there are any commercial vehicles, than if traffic is composed entirely of passenger cars.

In relation to highway capacity, one commercial vehicle has approximately the same effect as two passenger cars in level terrain and four passenger cars in rolling terrain. In mountainous terrain the effect of one commercial vehicle may be as great as eight passenger cars.

Imperfect alinement

Sight distances that restrict passing maneuvers seriously reduce the capacity of two- and three-lane roads. Where sight distances are inadequate, drivers are restricted in their freedom of movement in much the same manner as if the lane used for passing were filled with oncoming vehicles. The reduction in capacity caused by short sight distances can be obtained by using as a criterion the percentage of the total highway on which sight distances are insufficient to permit passing maneuvers to be performed safely.

The influence of speed on the standards that should be employed to provide adequate passing sight distance for two-lane rural highways is reflected in the results of passing-practice studies conducted by the Public Roads Administration in cooperation with several State highway departments. In slightly more than half of the passings observed, the passed vehicle was traveling between 30 and 40 miles per hour. In 30 percent of the passings, the passed vehicle was traveling between 20 and 30 miles per hour. Only 15 percent of the passed vehicles were traveling between 40 and 50 miles per hour and only 1 percent were traveling faster than 50 miles per hour. This is the condition found to exist on average main rural highways at places where sight distances are not restrictive.

On highways permitting the highest speeds, during periods of low traffic when passings could be made almost at will, 40 percent of the passings involved passed vehicles traveling between 40 and 50 miles per hour, another 40 percent involved passed vehicles traveling between 30 and 40 miles per hour, and only 5 percent of the passings involved passed vehicles traveling over 50 miles per hour.

Since this is the condition that exists where alinement provides unlimited opportunities for passing, the greatest need on rural two-lane highways is for sight distances that will permit vehicles traveling under 50 miles per hour to be passed safely. Any additional expenditure of highway funds to provide sight distances necessary for vehicles to pass other vehicles traveling faster than 50 miles per hour cannot be justified because such a sight distance is rarely utilized.

The results of the passing-practice studies show that for the most critical condition, when the passing vehicle slows to the speed of the passed vehicle before performing the maneuver, a sight distance of 1,500 to 2,000 feet is required to pass a vehicle traveling between 45 and 50 miles per hour with oncoming traffic traveling up to 70 miles per hour. Passing sight distances within the range of 1,500 to 2,000 feet are, therefore, those most widely needed at frequent intervals on rural highways.

Where sight distances within the range of 1,500 to 2,000 feet are not continuously available throughout the length of a two-lane highway, the percentage of the total length of highway with a 1,500-foot sight distance can be used as a criterion of the highway's practical capacity. Table 6 shows the reduction in capacity caused by sight distance restrictions when operating speeds of 45 to 50 and 50 to 55 miles per hour are desired.

Table 6.—Effect of passing sight-distance restriction on practical capacities of 2-lane highways when adequate stopping sight distances are always present

Sight distance restricted to less than 1,500 feet: Percentage of total length of highway.	Practical capacity, in passenger cars per hour	
	For operating speed [1] of 45–50 miles per hour	For operating speed [1] of 50–55 miles per hour
0	900	600
20	860	560
40	800	500
60	720	420
80	620	300
100	500	160

[1]Average speed for drivers trying to travel at maximum safe speed.

Signal control at intersections

Intersections controlled by traffic signals impair the possible capacities of all highways by depriving traffic of a portion of the time it would otherwise be free to move. The detrimental effect of a signal-controlled intersection on the practical capacity of a two-lane rural highway where conditions are otherwise ideal is not critical so long as traffic is free to move at least 50 percent of the time, provided that not more than two-thirds of the traffic is moving in one direction. On multilane facilities, practical capacities are reduced unless traffic is free to move all of the time.

This difference in the effect of a signal on practical capacities of rural two-lane roads as compared with multilane roads is caused by the difference in the traffic volumes per lane when operating at practical capacities. With two-thirds of the total traffic in one direction, the flow in one lane of a rural two-lane highway will be only 600 vehicles per hour when the total volume is 900 vehicles per hour, the highway's maximum practical capacity. The average flow in each of the lanes used by traffic in the direction of the heavier flow on a multilane rural highway could be 1,000 vehicles per hour with the highway operating at its practical capacity. In urban areas, the corresponding figure would be 1,500 vehicles per lane per hour. It is possible under certain conditions for 600 vehicles per hour in a single lane to enter an intersection where traffic is controlled by lights, whereas, it is impossible for 1,000 vehicles in a single lane to enter such an intersection.

The highest rate at which traffic can move through a signal-controlled intersection is about 1,500 passenger cars per hour per 12-foot lane during the time the signal is green. The practical capacity, or the maximum flow that will require but a few vehicles to wait for more than one green indication of the light, is about 80 percent of this rate where conditions are ideal. Conditions are seldom ideal, however, and this is especially true in cities where turning movements, pedestrians, curb parking, etc., combine to interfere with the free movement of vehicles.

Average capacities for city streets, under the conditions noted, may be determined from the curves in figures 25 and 26. There is a wide range in the capacities of city street intersections, however, as will be observed from figure 27.

Signal control under varying conditions

A number of adjustments are necessary when applying the information for average intersection conditions, as shown by figures 25 and 26, to a specific location where conditions are not "average."

Important adjustments are those involving corrections for the difference between possible and practical capacities, proportion of commercial vehicles, turning movements, bus stops, elimination of

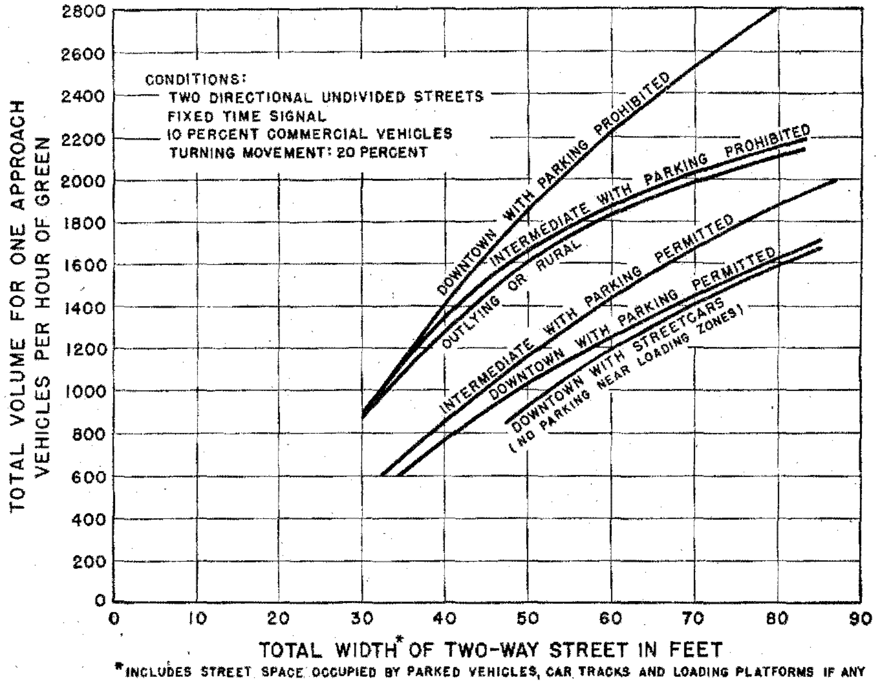


Figure 25.—Average reported intersection capacities for streets of different widths by type of area and parking regulations.

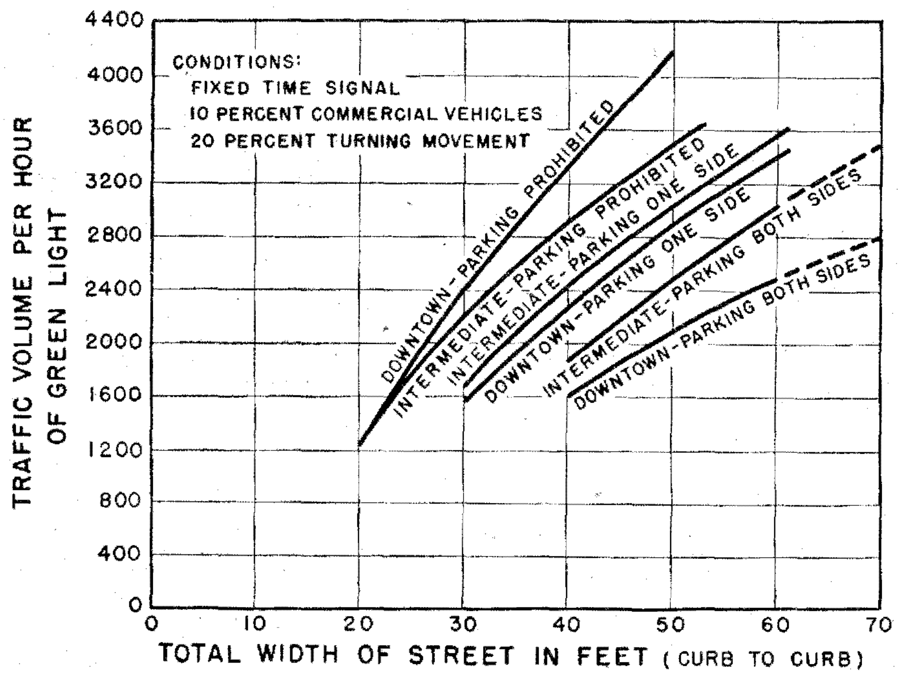


Figure 26.—Intersection capacities of one-way streets by type of area and parking regulations.

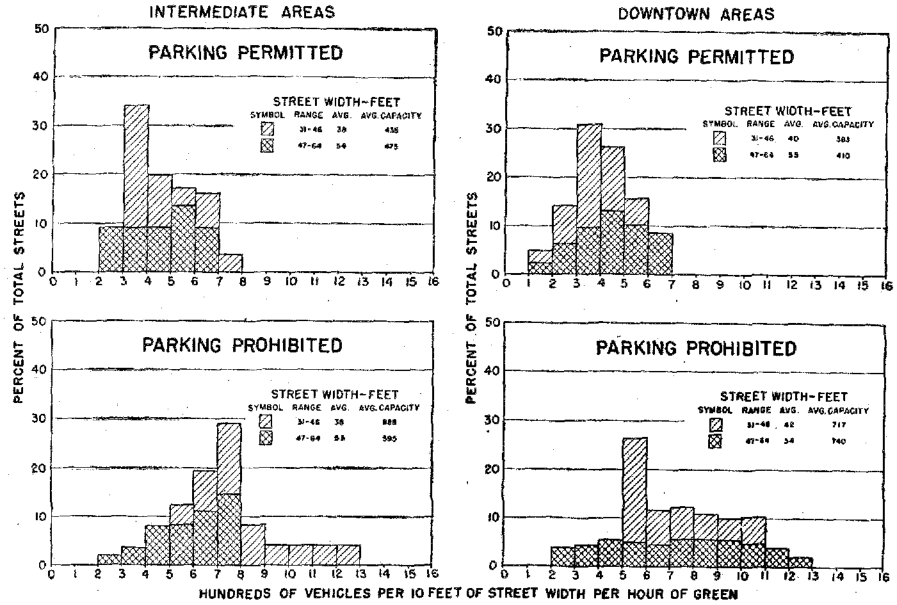


Figure 27.—Frequency distribution of intersection capacities.

parking near the intersection, added turning lanes, and separate signal indications for certain turning movements. It has been found, for example, that possible capacities are about 10 percent higher than the hourly volumes shown by the curves for figures 25 and 26, and that the practical capacities are about 10 percent lower. Also, commercial vehicles have about the same effect as two passenger cars; one left turn on a two-way street is equivalent to two vehicles going straight through; and right turns on either one-way or two-way streets, and left turns on one-way streets, have about the same effect as 1½ vehicles going straight through. On streets where parking is prohibited the volumes shown by figure 25 must be increased 5 percent when there is no bus stop, decreased 10 percent when there is a bus stop on the near side, decreased 3 percent when there is a bus stop on the far side in downtown areas, and decreased 15 percent when there is a bus stop on the far side in an intermediate area. A detailed explanation of the necessary adjustments for specific conditions is contained in the report by the Highway Research Board Committee on Highway Capacity.

Volumes shown by figure 25 are for the volume of traffic in the direction of the heaviest flow. The total flow when a street is loaded to capacity will depend on the distribution of traffic by directions. Normally, in downtown areas the distribution varies from 50 percent in each direction to 60 percent in one direction and 40 percent in the other.

Outside of the downtown area on two-way streets the flow in the heaviest direction of travel will vary between 60 and 80 percent of the total traffic. These distributions of traffic by direction are an important consideration when comparing the total volumes of traffic that can be accommodated by one-way and two-way streets. Figure 28 shows a comparison between the capacities of one-way and two-way streets under certain specific conditions in downtown and intermediate areas.

On high-type facilities of the expressway class, where intersections are given special treatment in the form of added turning lanes, and where there is little

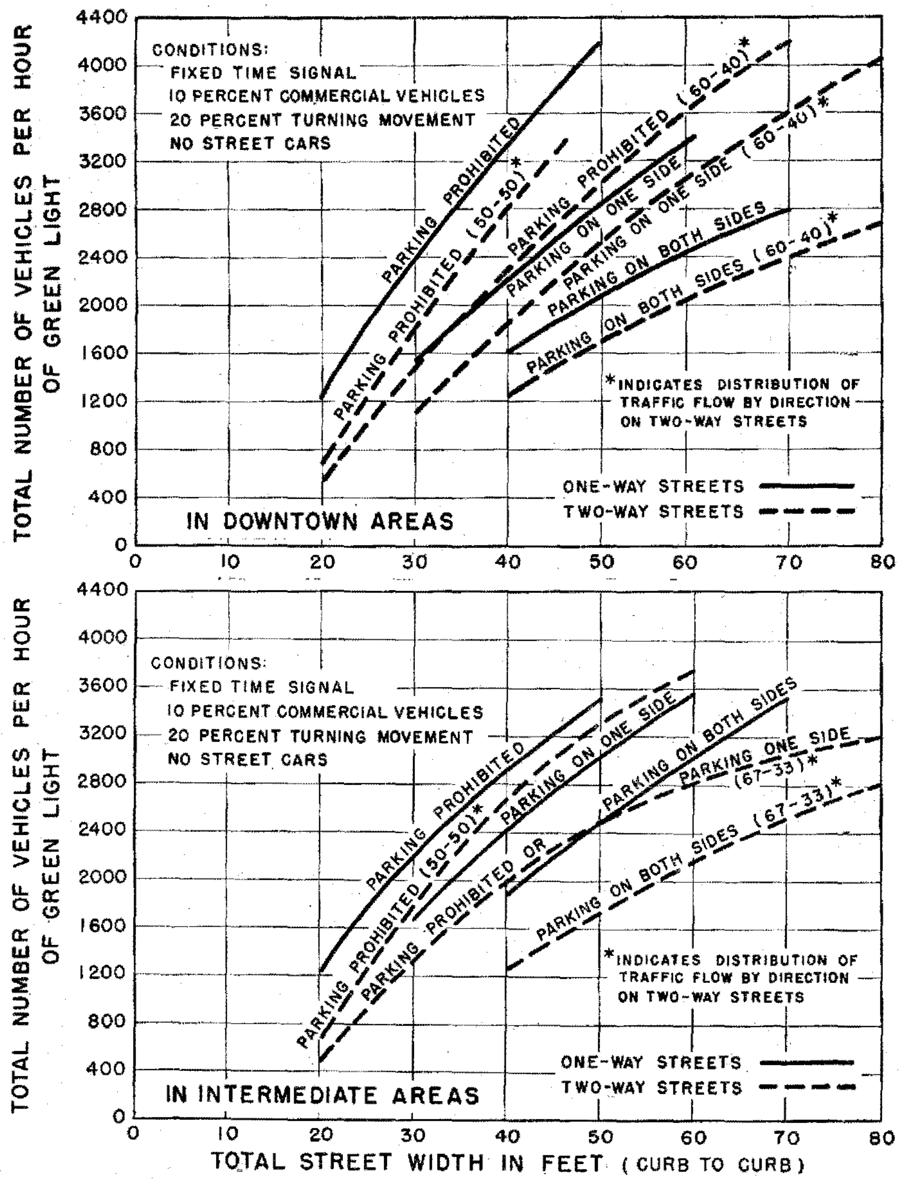


Figure 28.—Comparison of average street-intersection capacities with one-way and two-way operation, in downtown and in intermediate areas.

or no interference from pedestrians, the practical capacity of 1,000 passenger vehicles per hour of green light per 10 feet of width may be used as a basis for computation and appropriate adjustment factors applied for the commercial vehicles, turning movements, and bus stops, as given in the report by the Highway Research Board Committee on Highway Capacity.

Weaving sections—Cross movements without signal control

Weaving sections are usually selected as a compromise between the conventional intersection at grade, where delays are often excessive, and the grade separation with its costly structure and appurtenances. Weaving sections are often provided as adjuncts to grade separations. The traffic circle is, in actuality, a series of weaving sections, and there are many other applications of the principle in the layout of controlled-access highways.

The vehicles using a weaving section fall logically into two classes: (1) those entering, passing through, and leaving the section without crossing the normal path of other vehicles, and (2) those that must cross the paths of other vehicles after entering the section. The latter group are the weaving vehicles that make the facility necessary.

The results of analysis of available data on traffic volumes and speeds on weaving sections are shown by figure 29. Basically, traffic on a weaving section is affected by density in much the same manner as on a roadway with uninterrupted flow. Maximum volumes occur at speeds between 20 and 30 miles per hour. Higher speeds are possible only at volumes and densities lower than those found when the facility is operating at its possible capacity. Whenever traffic density exceeds the critical density, speeds fall below 20 miles per hour, the capacity is lowered, and complete congestion or stagnation may occur within a few seconds.

The curves in figure 29 show that there is a rapid increase in the length of section required for a given speed with an increase in the number of weaving vehicles. Doubling the traffic volume ap-

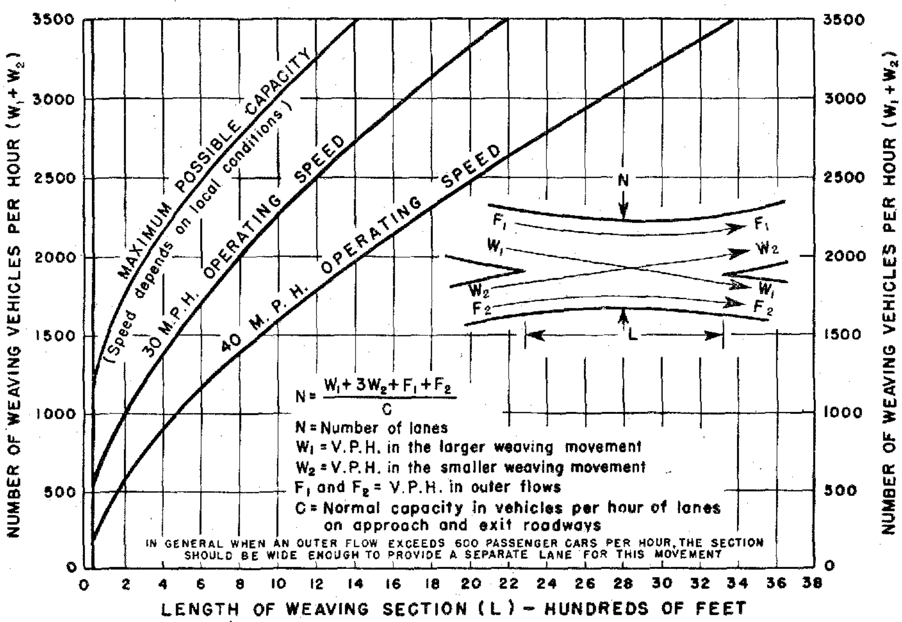


Figure 29.—Operating characteristics of weaving sections.

proximately triples the length of section required and doubles the number of lanes required for the weaving vehicles.

Any weaving section, regardless of its length or number of lanes, will become badly congested when the number of weaving vehicles approaches the possible capacity of two traffic lanes. Operating conditions will seldom be entirely satisfactory unless the traffic on the approach roadways is well below their practical capacities and the weaving section has one more lane than would normally be required for the combined traffic from both approaches. For this reason, weaving sections are considered practical only where the two intersecting one-way roadways each carries less than the normal capacity of two lanes of a one-way roadway and the total number of vehicles required to weave does not exceed 1,500 per hour. In computing capacities, allowance must be made for trucks, lanes of substandard width, etc., on the same basis as in the case of multilane roadways.

Ramps and their terminals

The efficiency of traffic movement on freeways or expressways and the extent to which their potential capacities can be realized depend directly on the adequacy of the facilities that are provided for entering and leaving these highways. Improperly planned entrances can seriously limit the traffic volumes that can use an expressway, and exit facilities incapable of accommodating vehicles leaving the highway at one point, even though the number is relatively few, can cause complete congestion of all traffic.

The capacity of a ramp is affected by the character of traffic, gradient, width, curvature, and the speed at which vehicles operate. The sharp curvature on most ramps usually limits the possible capacity to that attained on a tangent section at speeds below 20 miles per hour. At the higher speeds, drivers find it difficult to stay within their lane and have a tendency to maintain a somewhat greater headway than is normal on tangent sections. This happens even on ramps with lanes wider than 12 feet.

Except on ramps having extremely long radii, and on direct connections having a low degree of curvature, lane capacities of the ramp itself, when the entrance or exit does not govern, are usually of the order of 1,200 passenger cars per hour. Thus a ramp having a nominal width of two lanes (usually 28 or 30 feet) should accommodate about 2,400 passenger cars at an average speed of 12 to 15 miles per hour. Actual examples of ramp movements of this magnitude are rare, indeed, because few of the terminals are so planned that traffic entering and leaving the ramp can do so with the necessary freedom of interference by traffic on the through highways or streets.

Even on some of the most modern facilities, there is a tendency for traffic to move in a single line at one or two points on the ramp. The point of constriction is usually at either the entrance or the exit to the ramp. Under such conditions the possible capacity of the ramp will be about 1,200 vehicles per hour. This probably accounts for the common belief that the capacity of any ramp will not exceed 1,200 to 1,500 vehicles per hour and therefore the ramp should be tapered to confine vehicles to one lane as they enter a through highway. However, there is little reason to think that ramp terminals cannot be so planned that much larger volumes of traffic can be handled with ease. Further, there are a few existing facilities where much higher volumes have been observed.

Traffic approaching a ramp leading to an expressway and traffic on a ramp leading from an expressway must oftentimes pass through an intersection at grade in the immediate vicinity of the ramp. The volume of traffic that can be accommodated by the ramp is then dependent on the capacity of the nearby intersection. When this is the case, the information on intersection capacities should be applied in estimating the maximum volume of traffic that can enter or leave the ramp.

The capacity of a ramp may be limited by either the width and alinement of the ramp, or by traffic and physical conditions at either terminal. Some of the more important facts concerning ramp capacities are summarized as follows:

1. With the curvatures and traffic conditions that are generally present at ramp locations, it is usually difficult to obtain better than the equivalent of single-lane operation on the ramp. With such operation, the ramp capacity will not exceed 1,200 passenger cars per hour normally, with a possible maximum of 1,500 passenger cars per hour when vehicles can keep moving at a speed of 15 to 20 miles per hour (minimum radius about 100 feet). Serious consideration should be given to the provision of additional ramps when the traffic demand exceeds 1,200 vehicles per hour on any one ramp, unless conditions required for safe two-lane operation can be satisfied. The limit of 1,200 vehicles per hour is for passenger vehicles. The figure should be lowered to compensate for the effect of such commercial vehicles as may be present. As a minimum, each commercial vehicle with dual tires has the effect of two passenger cars. Conditions that must be present to accommodate 1,200 passenger vehicles per hour are:

(*a*) Adequate ramp width for off-tracking and turning of commercial vehicles.

(*b*) Adequate surface or shoulder width for disabled vehicles, especially on "up" ramps.

(*c*) Adequate speed-change areas, or excess capacity of the roadways connected by the ramp.

2. It is possible for a ramp and its terminals to handle traffic volumes exceeding 1,200 vehicles per hour under certain conditions. The following are some of the conditions that must be satisfied:

(*a*) Adequate surface width and radius of curvature (at least a 28-foot surface and a minimum radius of about 200 feet).

(*b*) At least one lane on each through highway entirely free of traffic other than that using the ramp, and a second lane on each through highway sufficiently free of through traffic to accommodate that portion of ramp traffic in excess of 1,200 vehicles per hour. Generally, the exit and entrance to the ramp must have design characteristics similar to those at a **Y** intersection of two one-way roads.

3. In considering the availability of space in the through-traffic movement into which vehicles from the ramp may enter, the following factors are important:

(*a*) At traffic volumes below 1,000 vehicles per lane per hour on a multilane highway, there is a marked tendency for vehicles approaching a ramp discharge point to shift away from the lane used by ramp traffic, thereby providing a better opportunity for vehicles to enter the through highway. When the volume on the through highway exceeds 1,000 vehicles per hour per lane, this tendency to shift away from the lane adjoining the ramp does not occur and traffic maintains approximately the same distribution between the lanes at the ramp terminal as on sections where there are no ramps.

This is particularly true where there are stop signs at the ramp exit. Where there are acceleration areas without stop-sign control of vehicles from the ramp, a somewhat higher percentage of the through traffic will use the lane farthest from the ramp than is normal at locations remote from the ramp. (See figs. 30, 31, and 32.)

(*b*) There is a tendency for traffic to distribute itself in all lanes of a through highway during heavy traffic flow, and many of the openings between vehicles in the nonadjacent lane or lanes are shielded against occupancy by vehicles entering from the ramp. As a practical matter, it is impossible to fill all the available openings between cars on the through highway unless there are suitable acceleration areas for merging. The volume of traffic that can enter from a ramp will seldom equal the amount by which the expressway is below full capacity. The only exceptions to this statement occur where there are acceleration areas or added lanes beyond the entrance turn. (See fig. 33.)

4. Where points of access and egress to and from an expressway are closely spaced, the resulting interchange of traffic between lanes may cause certain

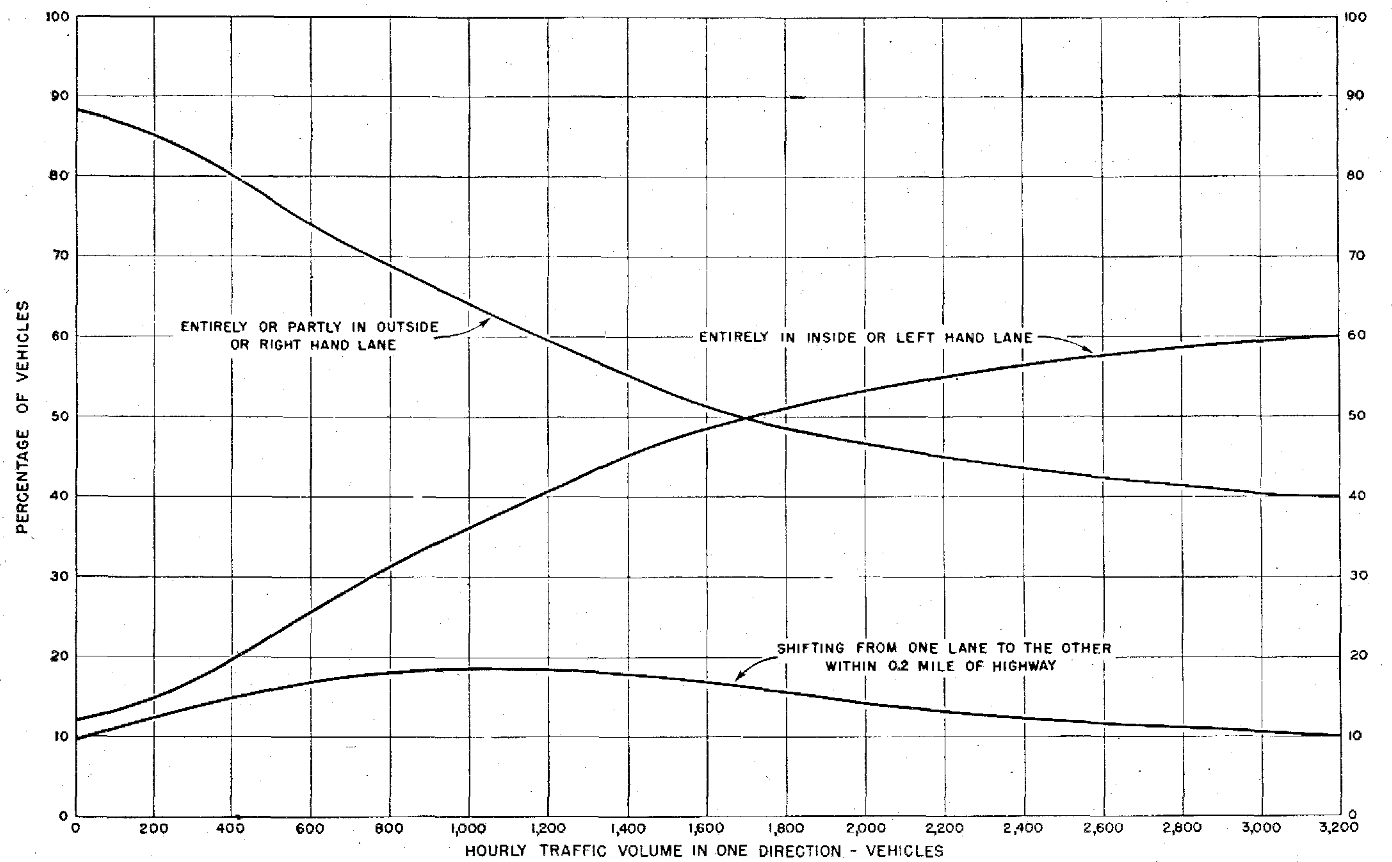


Figure 30.—Distribution of vehicles between traffic lanes on four-lane highways, at points removed from the influence of intersections or ramps, during various hourly traffic volumes.

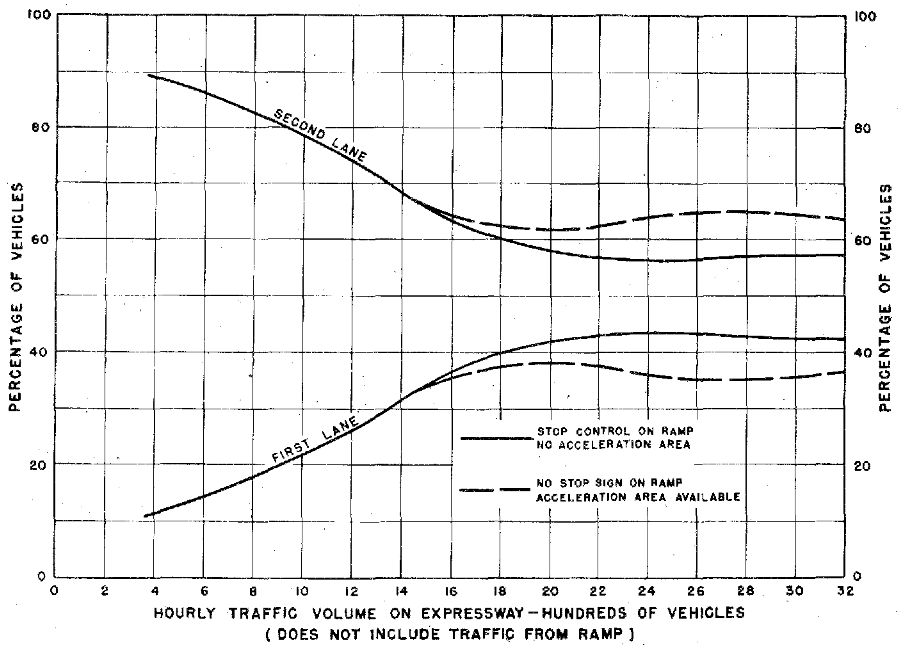


Figure 31.—Distribution of traffic by lanes on a four-lane expressway at approach to ramp where heavy volume enters the expressway on the right.

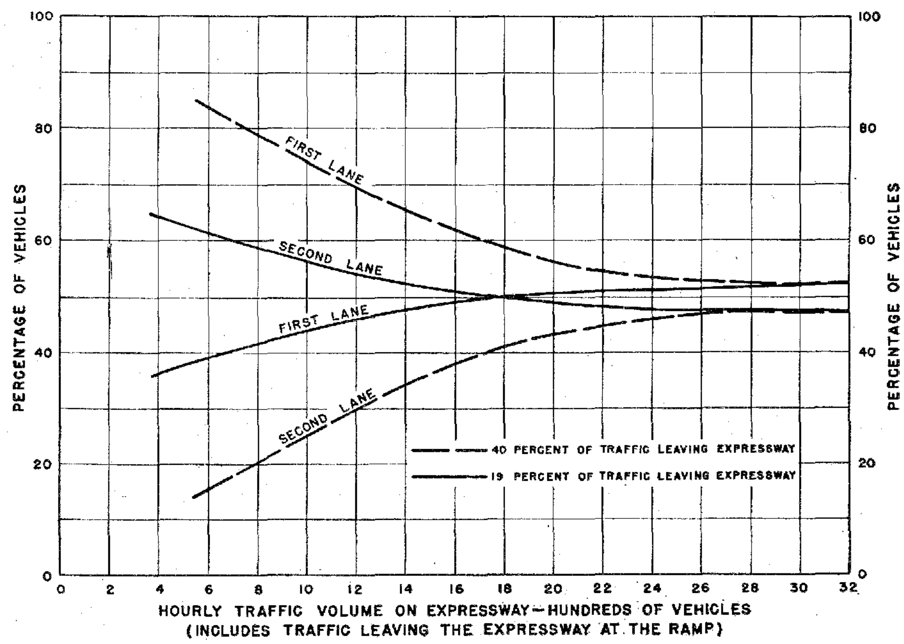
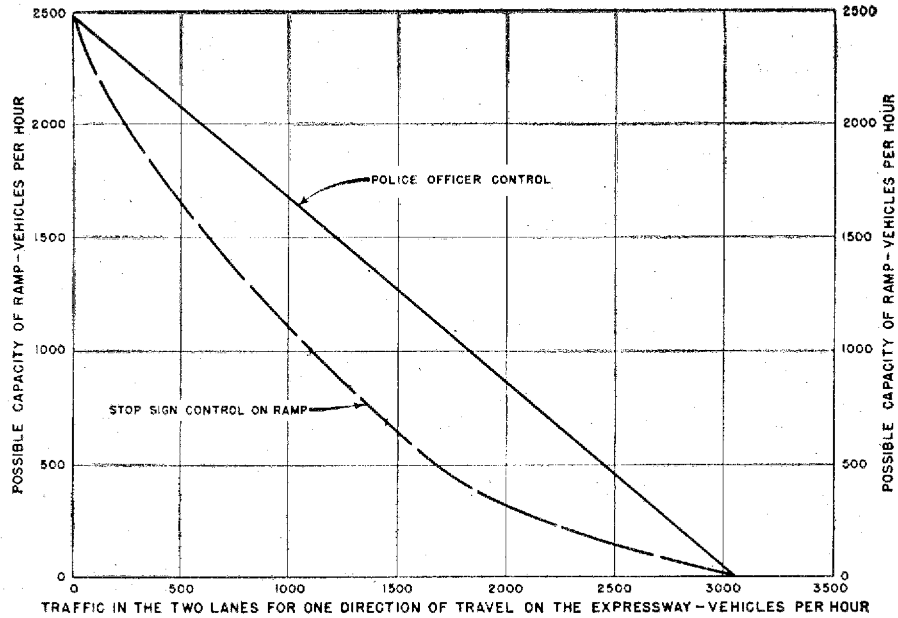


Figure 32.—Distribution of traffic by lanes on a four-lane expressway at approach to ramp where heavy volume leaves the expressway to the right.



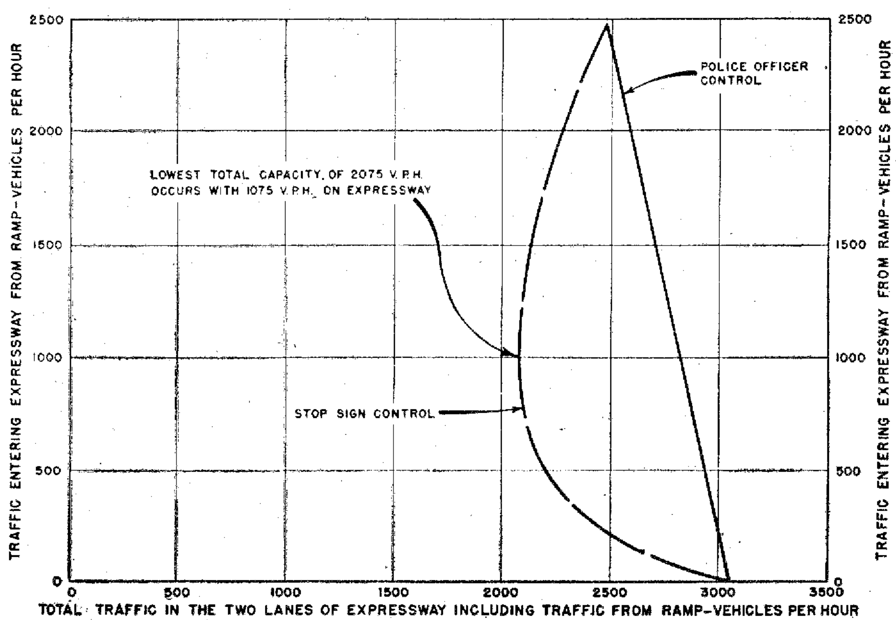


Figure 33.—Variation in ramp capacity with volume of traffic on expressway (ramp 20 feet wide; no acceleration area).

lengths of the expressway to become weaving sections and in that way affect the capacity of the expressway and the ramps.

5. In selecting the hour of peak traffic movement, a knowledge of the distribution of traffic between the ramp and the expressway is of utmost importance. An hourly pattern for traffic using a ramp is of little worth without a similar pattern for the expressway or other through street.

6. The number of vehicles that can enter an exit ramp is affected by the volume of through traffic using the right lane. Many slow-moving passenger cars and most commercial vehicles use this lane, thereby occupying space that might be utilized by departing vehicles. For most installations, the volume of traffic using an exit ramp cannot exceed 1,200 passenger cars less the number of through vehicles occupying the outside lane. This number may be reduced by instructions properly displayed on signs.

If an exit ramp is to accommodate more than 1,200 passenger cars an hour, the conditions enumerated under item 2 above must be satisfied.

Relating Hourly Capacities to Annual Traffic Volumes

Capacities are expressed as numbers of vehicles per hour, but this should not be interpreted as meaning that a highway can accommodate 24 times the hourly rate during any day. Traffic volumes are much heavier during certain hours of the day or year than at other times, and it is for these peak hours (except for the infrequent extremes) that highway standards should be developed. Since annual average daily traffic volumes are much more commonly known than peak hourly volumes, a means of relating the two is desirable.

For the United States as a whole, traffic on the maximum day is normally 233 percent, and in the maximum hour 25.4 percent, of the annual average daily traffic. It is uneconomical to design the average highway for a greater hourly volume than that which is exceeded during only 30 hours each year, and little will be saved in the construction cost and a great deal lost in expediting the movement of traffic if the highway is designed to accommodate fewer vehicles than the volume exceeded during the 50 highest hours of the year. The relation between peak hourly volumes and annual average daily traffic for the average location in the United States is shown in figure 34.

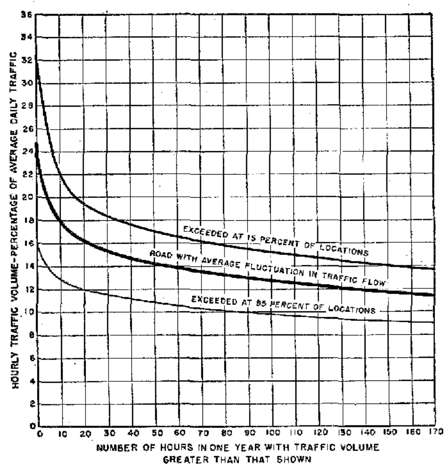


Figure 34.—Relation between peak hourly flows and annual average daily traffic on rural highways.

The variation in traffic flow between locations is such, however, that detailed data are necessary for a complete engineering analysis of the traffic facilities required at any particular location. The thirtieth highest hour as a percentage of the average daily traffic ranges from 8 to 38 percent, with an average of about 15 percent for rural locations and about 12 percent for urban locations. (See fig. 35.)

For any particular location, the relation between the thirtieth highest hour and the annual average daily traffic remains substantially unchanged from year to year, as is evidenced by figure 36, which illustrates this relation during different years for 23 traffic counter stations dispersed throughout the United States.

If the Nation-wide percentage relation-

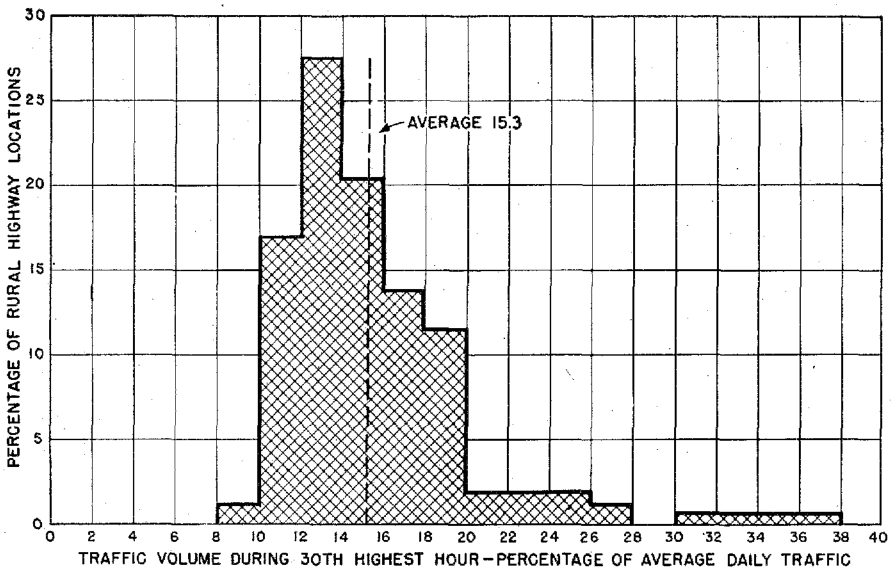


Figure 35.—Distribution of locations by percentage of average daily traffic during thirtieth highest hour of the year.

ships between the thirtieth highest hourly volume and the average annual daily traffic volume are applied to the practical hourly capacities, the capacities of two- and four-lane highways on an annual basis are as shown in table 7. It should be obvious that volumes of the magnitude shown in this table are seldom achieved without exceeding the practical capacity, because the high design standards upon which they are based can be economically justified in rare cases only. Particularly is this true for two-lane roads, the capacities of which are very sensitive to restrictive sight distances. In rolling terrain the alinement may be such as to cause a reduction of 50 percent or more in the average daily volumes for two-lane roads as shown in table 7. For any specific highway, an evaluation of the several factors affecting capacity must precede the computation of a reasonable value for the annual average daily traffic volume.

Table 7.—Average annual daily traffic volumes corresponding to the practical capacities of different types of highways as based on the Nation-wide average relationship between the thirtieth highest hourly volume and the average annual daily traffic volume [1]

Type of traffic	Average annual daily traffic volume, in vehicles per day					
	2-lane rural roads		4-lane rural roads		4-lane urban expressways	
	In level terrain	In rolling terrain	In level terrain	In rolling terrain	In level terrain	In rolling terrain
Passenger vehicles only	5,750	5,750	19,250	19,250	37,500	37,500
90 percent passenger vehicles and 10 percent commercial vehicles	5,200	4,450	17,500	14,800	34,000	29,000
80 percent passenger vehicles and 20 percent commercial vehicles	4,800	3,600	16,050	12,000	31,000	23,500

[1] Except for the presence of commercial vehicles, roadway and traffic conditions are assumed to approach the ideal, including 12-foot traffic lanes, tangent alinement, and uninterrupted flow.

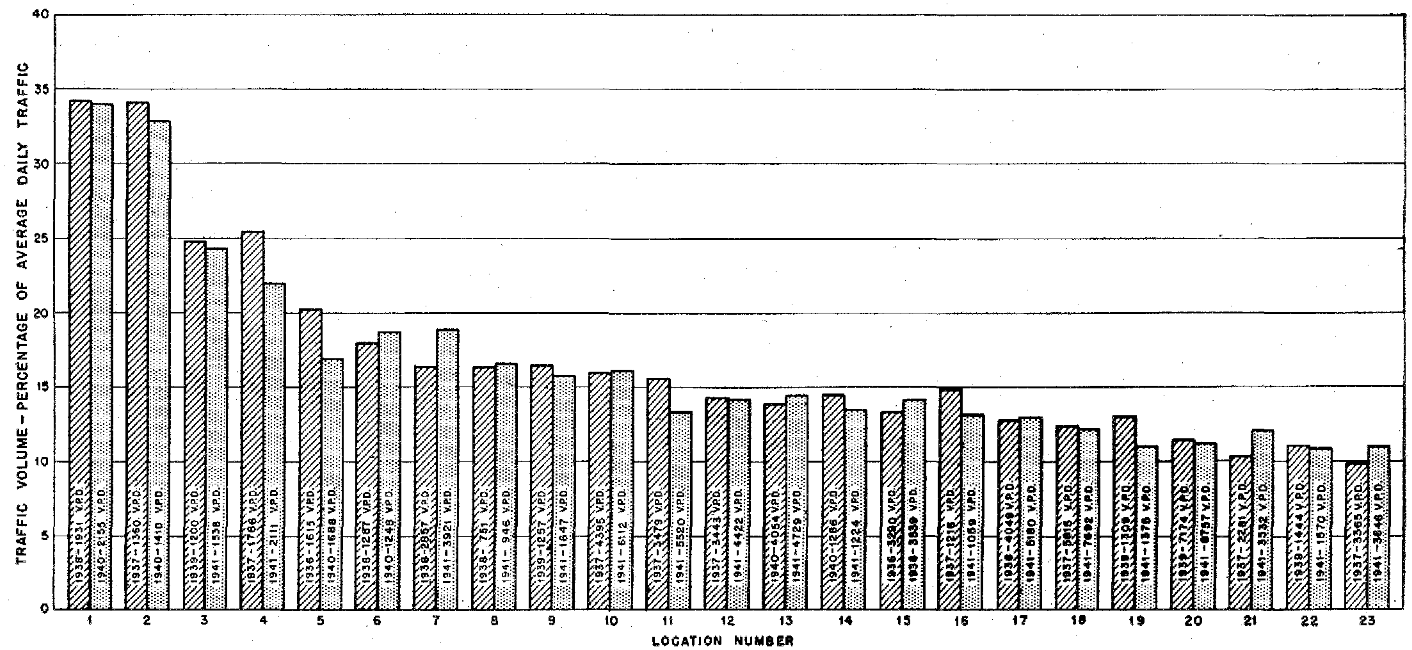


Figure 36.—Comparison of thirtieth highest hourly volumes for two years at identical locations.

ACCEPTED STANDARDS OF GEOMETRIC DESIGN

Geometric design as practiced by the several State highway departments and other designing agencies is not completely uniform. There remains a considerable variety in the laws of the States limiting the sizes and weights of vehicles, and the differences in these respects have an influence upon the decisions of highway designers. There are differences in the financing ability of the various governments and these too modify the standards of roads as built. Moreover, there are differences in the interpretation of experience and the evidence of research, and these are reflected in the variety of design practice.

Within limits, this variety is accepted as unavoidable by the Public Roads Administration, and tolerated in its approval of plans developed by the initiating State agencies for Federal-aid improvements. The strongest force tending to level these differences is the standardizing influence of technical committees of the American Association of State Highway Officials. In this association, all State highway departments and the Public Roads Administration hold membership and join in the deliberations of its committees.

Standards proposed and revised from time to time by these committees are recommended to the association and in turn submitted to the membership for adoption by letter ballot. Each member department, including the Public Roads Administration, is entitled to one vote. Upon approval by a required majority, a standard thus submitted is declared "adopted" and becomes a standard of the association.

Maximum Sizes and Weights of Vehicles

Following this process, the association has adopted a standard or policy concerning the maximum sizes and weights of vehicles that should be permitted to operate, and has recommended this policy for uniform adoption by law in the several States. While this policy takes into account the relatively low standards of a large part of the existing highway development as a condition modifying the present feasibility of accommodating the operation of vehicles, and is not, therefore, intended to constitute, unmodified, a basis for the design of new highways and structures, it nevertheless has an influence upon the design practices employed. It is appropriate, therefore, at this point, to introduce the various limits adopted.

They are:

Height

For the maximum height of vehicles, 12½ feet.

Width

For the maximum width of vehicles, 96 inches. (The policy includes a recommendation that this limit may be increased to 102 inches if and when the width of existing highways is sufficient to justify the change.)

Length

For the maximum length of—

Single trucks and two-axle busses, 35 feet.

Three-axle busses, 40 feet.

Tractor-semitrailer combinations, 50 feet.

Other combinations of vehicles (not more than two units), 60 feet.

Weight

For the maximum load on one axle, 18,000 pounds.

For the maximum gross weight of vehicles and combinations, and the weight permissible upon any group of axles of the vehicles or combinations, various amounts as given in a table relating permissible weight to the spacing of axles, measured in feet, as follows:

Distance between the extreme axles of any group of axles (feet)	*Maximum weight permissible on all axles of the group (pounds)*
4	32, 000
5	32, 000
6	32, 000
7	32, 000
8	32, 610
9	33, 580
10	34, 550
11	35, 510
12	36, 470
13	37, 420
14	38, 360
15	39, 300
16	40, 230
17	41, 160
18	42, 080
19	42, 990
20	43, 900
21	44, 800
22	45, 700
23	46, 590
24	47, 470
25	48, 350
26	49, 220
27	50, 090
28	50, 950
29	51, 800
30	52, 650
31	53, 490
32	54, 330
33	55, 160
34	55, 980
35	56, 800
36	57, 610
37	58, 420
38	59, 220
39	60, 010
40	60, 800
41	61, 580
42	62, 360
43	63, 130
44	63, 890
45	64, 650
46	65, 400
47	66, 150
48	66, 890
49	67, 620
50	68, 350
51	69, 070
52	69, 790
53	70, 500
54	71, 200
55	71, 900
56	72, 590
57	73, 280

Classification of Traffic

With these proposed limits of the size and weight of vehicles in mind, and with due regard to the reservations expressed as to their bearing upon highway design, we may now proceed to a consideration of some of the standards of geometric design.

Basic to the consideration are certain broad definitions of the type, volume, and speed of traffic contemplated and differentiated in the standards.

These definitions are contained in the *Policy on Highway Classification* of the American Association of State Highway Officials. They include type of traffic, traffic density, and design speed.

Type

The type of traffic is classified by the percentage of passenger cars and commercial vehicles and affects such elements involved in the geometric design as traffic lane widths, capacity of the traffic lanes, maximum radius of curvature, especially at intersections and on ramps, and maximum gradients.

Density

The traffic density assumed for purposes of design is that hourly traffic volume that is expected to be the thirtieth highest hourly volume during the year for which the road is designed.

Speed

The design speed is the maximum approximately uniform speed which can be adopted safely by the faster group of drivers during periods of low traffic volume, excluding the small percentage of reckless drivers. The standards are differentiated for design speeds of 30, 40, 50, 60, and 70 miles per hour. The design speed is selected for correlation of those geometric features such as curvature, superelevation, and sight distance, upon which the safe operation of vehicles is dependent.

Closely related to the design speed, although not included in the association's policies but rapidly coming into general use, is the term operating speed. It is the highest average speed, exclusive of stops, at which a driver can travel on a roadway under prevailing traffic conditions without at any time exceeding the design speed. Operating speed varies for any given road, being low when traffic is heavy and approaching design speed when traffic is light.

Modified as necessary by these basic definitions of traffic conditions, the principal geometric design standards are described in the following sections.

Alinement

The alinement that is selected for a highway determines how effectively and safely the completed facility will meet the demands of traffic. Alinement between control points should be of as high standard as is commensurate with the topography and the existing traffic, and with the probable future traffic, in order that future improvements may be made with a minimum of investment loss due to obsolescence. Sudden changes between curves of widely different radii or between long tangents and sharp curves should be avoided by use of curves of gradually increasing or decreasing radii; avoiding, however, an appearance of forced alinement. A curve at the end of a long tangent is definitely more hazardous than the same degree of curvature associated with a series of curves. It is essential to select an alinement free from sudden changes that come as a surprise to the operator. In relatively level topography, the use of long curves of large radii should be preferred to long tangents connected by relatively sharp curves. Where horizontal curves occur on grade summits, the vertical sight distance should exceed the horizontal sight distance.

Superelevation

Maximum superelevation of 0.12 foot per foot is recommended by the American Association of State Highway Officials. Where snow and ice conditions prevail, 0.08 foot per foot is the maximum that should be used. In recent practice, superelevations of 0.16 foot per foot have been found to be very satisfactory on ramps at interchanges, especially on the down ramps where design must generally provide for higher speeds than on up ramps. In obtaining superelevation, it is desirable that the slope of the outer edge of pavement with respect to the profile of the center line should not be greater than 1 in 200.

Curvature

Wherever feasible the flattest curvature possible should be used. Design policies of the American Association of State Highway Officials provide that the minimum radius of curvature shall be as shown in table 8.

Table 8.—Minimum radius of curvature

Assumed design speed	Radius of curvature	
	Desirable minimum	Absolute minimum
M. p. h.	*Feet*	*Feet*
30	290	230
40	520	410
50	820	640
60	1, 150	960
70	1, 910	1, 430

The absolute minimum radius is based upon a practical maximum superelevation, and a safe value for the side friction factor of 0.16 for speeds up to 60 miles per hour and 0.14 for a speed of 70 miles per hour. The desirable minimum radius is based on the same friction factors but approximately half the maximum superelevation.

It should be recognized that the stated minimum radii are safe for the indicated speeds only when the curves are superelevated to the maximum and approached with adequate transitions. Larger radii, perhaps as large as those for the next higher 10 miles per hour, should be adopted as a minimum for entirely safe and comfortable operation.

Transitions

Transitions should be applied to all curves of such radii that the offset from the circular arc is greater than 1 foot for a transition of the required length L_s, as determined by the formula

$$L_s = \frac{1.6\ V^3}{R}.$$

In this formula, V is the assumed design speed in miles per hour and R, the radius in feet.

Where possible, superelevation should be attained within the limits of the transition, which should be of such length that the slope of the outer edge of pavement with respect to the profile of the center line is no greater than 1 in 200.

Minimum length of curve

For small deflection angles the curve should be long enough to avoid the appearance of a kink. The curve should be at least 500 feet long for a deflection angle of 5 degrees and should increase 100 feet in length for each decrease of 1 degree in the deflection angle.

Grades

Agreement has not been reached on the maximum grade or the length of sustained grade to be used for various combinations of terrain and traffic density. The information shown on pages 71–77 is, however, useful in determining the maximum length of grade that will reduce truck speeds to values that are objectionable to the operators of passenger cars. These data are also useful in determining when added lanes should be provided on long grades.

On long grades, it is preferable to break the sustained grade by short sections of lesser grade, rather than to lay a uniform sustained grade that may be only slightly below the allowable maximum, provided the break in grade will not affect the length of highway on which passing maneuvers can be performed safely. Secondary dips in the profile, in which vehicles may be hidden from view, should be avoided. Where it is found that grades less than the maximum may be obtained over a considerable length of a project, but there are maximum grades of sufficient length to slow down loaded vehicles to a crawl speed at certain places, provision of additional lanes for slow-moving vehicles should be considered.

While the association policy does not particularize, it is known that trucks and combination units with their normal loadings are appreciably slowed down by gradients, of sufficient length, as low as 3 percent. Table 3 (page 76) shows that trucks are reduced to speeds so low as to prevent satisfactory passenger-car operation even when the steeper grades are short in length.

Sight Distance

Sight distance is the length of roadway visible to the driver of a passenger vehicle at any given point on the roadway when the view is unobstructed by traffic. For purposes of design and to determine operating conditions on a highway, sight distance is divided into two categories—stopping sight distance and passing sight distance.

Stopping sight distance

Stopping sight distance is the distance required by the driver of a vehicle, traveling at a given speed, to bring his vehicle to a stop after an object on the roadway becomes visible. The driver should have such sight distance at all times. The American Association of State Highway Officials uses a height of 4 inches for the object on the roadway, on the assumption that any object lower than 4 inches will not be a serious obstruction if it is hit. Stopping sight distance is therefore measured from the driver's eyes, which are assumed to be 4½ feet above the pavement surface, to an object 4 inches high on the road.

Passing sight distance

Passing sight distance is the minimum sight distance that must be available to enable the driver of one vehicle to pass another vehicle safely and comfortably, without interfering with the speed of an oncoming vehicle traveling at the design speed should it come into view after the overtaking maneuver is started. According to the American Association of State Highway Officials, the sight distance available for passing at any place is the longest distance at which a driver whose eyes are 4½ feet above the pavement surface can see the top of an object 4½ feet high on the road.

While stopping distance is necessary continuously on all types of highways, passing sight distance is necessary only on two-way roadways with two or three lanes.

Minimum sight distances recommended by the American Association of State Highway Officials are shown in table 9.

Table 9.—Minimum sight distances

Design speed	Sight distances				
	Stopping: 2-, 3-, and 4-lane highways	Passing			
		2-lane highways		3-lane highways	
		Desirable	Absolute	Desirable	Absolute
M. p. h.	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
30	200	600	500	-----	-----
40	275	1,100	900	-----	-----
50	350	1,600	1,400	1,100	900
60	475	2,300	2,100	1,500	1,300
70	600	3,200	2,900	2,000	1,800

Recent studies

Recent studies have shown that the stopping sight distances listed in table 9 are not adequate for many vehicles in actual use at the present time. If adequate stopping distances are to be provided for all passenger cars, other than the 10 or 15 percent with brakes in very poor condition, stopping sight distances 20 to 30 percent higher than those in table 9 must be provided. Trucks and combination units require much longer distances in stopping than do passenger cars at corresponding speeds. A stopping sight distance which is adequate for a passenger car traveling 70 miles an hour is not adequate for combination units, with normal loads, above about 50 miles per hour.

Results of recent studies of the manner in which drivers perform passing maneuvers on two-lane roads show that most drivers base the decision to begin passing on the distance they can see the road surface ahead rather than the distance to a point 4½ feet above the road surface. Unless a driver is completely familiar with the profile of a route, he cannot be sure that there is no approaching vehicle on the road surface that is not visible in a short dip in the road ahead. It is only when a vehicle is in view that he has any idea as to how far it is to a point 4½ feet above the road surface on a vertical curve.

At any given point on a highway, a driver is not aided greatly by sight distance in excess of 2,000 feet. For this reason and also because a large majority of passed vehicles move at slow speed and may be passed in a short distance, the percentage of highway on which a sight distance of 1,500 feet or more is available can be used as a criterion of the sight distance adequacy of two- and three-lane highways. A more complete discussion of sight-distance requirements as related to traffic volume is presented on pages 79–80.

In rough terrain requiring large expenditures to produce the required percentage of passing sight distance, construction of a four-lane highway is sometimes the best solution. In modernization of old two- and three-lane roads, widening to four lanes is often preferable to extensive work in lengthening sight distance to required standards.

Many of our early highways were designed using a maximum grade, a maximum curvature, and other fixed standards. To avoid exceeding fixed maximum grade, it has sometimes been necessary to introduce added distance and curvature which has resulted in a highway that would not accommodate traffic as effectively as one with somewhat steeper grades but better alinement. It is not sufficient to consider various elements of design, such as gradient, curvature, and sight distance, independently. They must be considered in combination to obtain the alinement and profile over which vehicles can operate most efficiently and safely.

Highway Cross Section

Width of surfacing

Design policies of the American Association of State Highway Officials provide for varying the width of surfacing on two-lane highways with the type and volume of traffic and the assumed design speed. The widths for various assumed conditions are given in table 10.

Table 10.—Minimum widths of surfacing for two-lane highways

Assumed design speed	Vehicles per hour			
	5 to 30	30 to 100	100 to 200	More than 200
M. p. h.	*Feet*	*Feet*	*Feet*	*Feet*
30	[1] 16 to 20	18 to 20	20	[1] 22
40	16 to 20	18 to 20	20 to 22	[1] 22
50	18 to 20	20	20 to 22	22 to 24
60	20	20 to 22	22	22 to 24
70	20	20 to 22	22 to 24	[1] 24

[1] Where shoulders flush with the pavement and capable of supporting vehicles at all times are provided, and trucks are not a factor, pavements 2 feet less in width may be used.

From the discussion (pp. 66, 78) regarding traffic lane width, it is apparent that lane widths of less than 11 feet are undesirable and that lane widths of 12 feet are preferred, especially where the normal percentage of trucks is present. For the National System of Interstate Highways, the association policy permits lanes as narrow as 11 feet only where the traffic volume per lane during the thirtieth highest hour of the year is less than 200 vehicles.

Ninety-five percent or more of the rural roads of the United States are two-lane roads. Pavements of more than two lanes are being constructed as the need for capacity greater than that of a two-lane pavement is determined. When traffic rises above the capacity of a two-lane pavement, opinion predominantly favors the construction of a four-lane pavement, divided whenever feasible.

Divided highways

On divided highways, the width of median strip required to provide protection for left-turning at grade crossings is at least 25 feet for passenger vehicles and 40 feet for trucks. Median strips of these widths continued between intersections also provide positive protection against conflict of opposing traffic, and reduce the effects of headlight glare to a minimum. Narrower medians are frequently used, but medians less than 4 to 6 feet are considered little more than center-line stripes. The narrower the median the longer must be the opening in the median to give protection to vehicles making left turns to and from intersecting roads at grade. Medians of intermediate widths—14 to 16 feet—are being used more and more. These dimensions are sufficient to provide many of the separation advantages for opposing traffic and at the same time permit inclusion of a median lane at cross roads. Usually this median lane is an extra lane entirely within the normal width, on which vehicles leaving the through lanes can decelerate and pause in a protected area to await an opportunity to turn to the left on the cross road.

At points other than at crossings, the median strip should be at least 10 or 12 feet in width to permit vegetative growth. If this is not possible, there is little advantage in a width over 4 to 6 feet. Raised median strips in no case should be less than 4 feet in width and highways with flush median strips less than 4 feet in width should not be considered divided highways.

Divided highways need not be of constant cross section. Median strips may vary in width; the roads may be at different levels; and superelevation may be effected separately on each pavement. In rolling terrain this type of design results in substantial savings in construction and maintenance costs. Where constrictions make it desirable to narrow the median or where intersections make it desirable to widen on tangent alinement, the change should be effected by long reverse curves, preferably of 5,000-foot radius or more, which may be without superelevation or transitions. Where such changes in width are desirable on curves they should be acomplished, if possible, by changing the curvature of one or both roads.

Parking lanes

In addition to to pavement lanes for the use of moving traffic, some highways include parking lanes adjacent to those provided for the moving traffic. In urban and suburban locations the parking lane often includes the gutter section of the roadway and varies in width from 6 to 8 feet. The greater width is desirable; and even with an 8-foot parking lane the traffic lane adjacent to it should be somewhat wider than usual because of the fact that moving traffic will not drive close to parked vehicles. For this reason, parking lanes are frequently paved 10 feet wide but are marked for parking 8 feet wide.

An urban street with parking in the downtown area will only accommodate about 50 to 55 percent of the traffic that the same width of street without parking will accommodate. Eliminating parking from both sides of the street will increase its capacity nearly 100 percent, regardless of the width of the street.

Crowns

The crown, or cross slope, of our pavements has varied through the years. Early roadways had rather steep crowns, one-half inch or more per foot; but as the type of pavement has improved and construction materials, techniques, and equipment have permitted closer control, the amount of crown has been decreased. High-type pavements with good control of drainage now have crowns as low as one-eighth inch per foot. This flat cross slope has been found to be satisfactory when little or no settlement of the pavement is to be expected and the drainage system is of sufficient capacity to keep the flow of water off the travel lanes. When four or more traffic lanes are used it is considered desirable to provide a steeper slope on the outer lanes to expedite the flow of water from the traveled roadway surface.

Shoulders

Shoulders are provided to furnish additional support to the pavement, and for the emergency accommodation of disabled or otherwise stopped vehicles. They increase the effective surface width for traffic. Shoulders that will accommodate disabled vehicles and that may be used by moving vehicles in cases of emergency, during any weather conditions, are essential for safety on main highways. Adequate shoulders are also essential to realize the full capacity of the surface width. Without adequate shoulders, one disabled vehicle can reduce the capacity of both two-lane and multilane highways during peak periods by as much as 60 percent. There is at least one disabled vehicle for every 10,000 vehicle-miles of travel on main highways. Without a place of refuge outside the traffic lanes, one disabled vehicle can reduce the capacity of a highway by more than one lane, especially if the lanes are less than 12 feet wide. The disabled vehicle blocks one lane and reduces the capacity of adjoining lanes by restricting speeds.

The maximum capacity of a traffic lane with vehicles moving at 20 miles per hour is only 87 percent its capacity at 30 miles per hour. At 10 miles per hour a lane has only about 50 percent of its 30-mile-per-hour capacity. A minor accident which causes a reduction in speed can result in complete congestion when a facility is operating near its capacity. Shoulders 10 feet wide are desirable and 8 feet should be the minimum. Shoulders as small as 2 or 3 feet wide have been used in the past, but even under the most extreme conditions, at least a 4-foot shoulder should be provided.

The cross slope of the shoulder should be greater than that of the pavement. A shoulder with a high type of surfacing should have a cross slope of approximately one-half inch per foot; a turf shoulder may have a slope as much as 1 inch per foot; this rather steep cross slope being necessary to carry water away from the pavement.

Curbs and gutters

Curbs are seldom used on rural roads; but they are generally a part of urban or suburban roadways. The design of curbs varies from a low, flat, lip-type to a vertical, or nearly vertical, barrier-type. When a barrier, or nonmountable, type of curb is used, it should be offset a minimum of 2 feet from the edge of the through traffic lane. When curbs are located adjacent to the through traffic lane, the longitudinal drainage is on the roadway pavement. The curb and gutter may be constructed as a unit and placed adjacent to the roadway pavement. When a high-type surfacing is used on the shoulders, the curb is often located on the outer edge of the shoulder.

Drainage ditches

Ditches are provided to collect and direct the flow of surface drainage along and away from the pavement. They should be low enough to drain water from under the pavement. The profile gradient of the ditch may vary considerably from that of the adjacent pavement. This permits the use of very flat or level profile on the pavement and provides adequate drainage by the use of a steeper gradient in the ditch section. A rounded ditch section has been found to be superior to a V-type of ditch which is subject to severe washing action.

Side slopes

The side slopes of fills and cuts vary with the type of material and geographic location. Cut slopes in solid rock are commonly vertical or nearly so; in unstable material they may be as flat as 1 to 3 or 4. Earth slopes as steep as 1 to 1 are rarely satisfactory and involve expensive maintenance. With present-day construction equipment the flatter slopes are being used extensively. These flat slopes result in a pleasing appearance and are less expensive to maintain than the steeper slopes. Flat slopes should always be used when the depth of cut or fill is small. The transition from a cut to a fill section should be gradual and extend over a considerable length of roadway. Ample rounding should be provided at the intersections of the slope with shoulder and original ground.

Other features of multilane roads

The design of multilane highways and expressways includes other cross-sectional elements, such as outer separators, lateral or frontage roads, and border strips. The width and type of separator between the through pavement and the lateral or frontage road is controlled by the width of available right-of-way, location and type of overpasses or underpasses, and many other factors.

Existing streets adjacent and parallel to a new facility may serve as frontage roads, or new parallel roads may be required. Where feasible, frontage roads should be designed for one-way traffic only. When used for two-way operation they not only complicate traffic operation at the intersecting streets, but also create a very dangerous situation at the intersection with the on and off ramps.

The border strip is that portion of the highway between the outer curb of the through roadway or frontage road and the right-of-way line. It is generally used for the location of utility poles and a grass plot. Highways involving these last mentioned elements of the cross section are special cases and receive special consideration at the time of their design.

Right-of-way

In general summary, most two-lane highways have been developed on rights-of-way from 60 to 80 feet wide, plus additional widths needed for high cuts and fills. In many States, however, important two-lane highways are being designed on rights-of-way of 100 to 150 feet. Such sections are found economical, especially in the prairie States where flat, rounded slopes not only provide a safer, better highway, but result in very low costs for maintenance and for snow removal during winter. Divided highways are designed on rights-of-way from 100 to 200 feet, and upward to 300 feet.

Control of Access

A major item in the location and design of highways is the spacing and design of access connections, i. e., control of access. The importance of this feature is now recognized, but many obstacles have retarded its adoption in many States. It is known that the safety, mobility, and efficiency of any highway will vary greatly with the conditions under which traffic operates. Operation is affected appreciably by interference from the roadsides and from traffic entering or leaving at driveways and cross roads. To preserve and protect the highway as an efficient means of transportation, the number of individual connections to it (access connections) should remain at the practicable minimum, and their type and design should be commensurate with the importance of the highway. This can be accomplished by legal means, through the obtainment of ownership or easements over strips adjacent to the highway; or it may be done by physical means, such as the termination of cross roads or development of parallel frontage roads. Expressed otherwise, it can be done by any and all types of control that will prevent indiscriminate access to the through lanes, especially from new roadside businesses whose very existence is brought about by the highway. Experience is replete with examples of well-designed highways in which obsolescence begins, capacity decreases, and accidents increase from the time they are opened to traffic because of the increasing interference due to uncontrolled development of the roadsides. On the other hand, controlled-access highways 25 years old and older are as efficient today as when they were constructed.

In its design details the problem of access control is not especially difficult, as each access is a form of intersection for which design standards are well established. In the ultimate form of a freeway, the highway with complete control of access has connections spaced as the engineer determines, and all cross roads are separated in grade from the pavements for through traffic. At the other extreme, a preference street in an urban area has a minimum of control of access. Through traffic is given preference by the use of stop signs at each cross street. But each street crosses at grade and in addition there are numerous private driveways, alleys, etc., between cross streets, each of which decreases the efficiency of operation. It is evident that freeways can be justified in many cases, especially in or near metropolitan areas. But for financial reasons, the vast majority of mileage and expenditure to be made in present and future highways will be for types intermediate between that of the preference street and the freeway.

Intersections

Intersection designs and standards for them are best considered in three groups: (1) Intersections at grade; (2) rotary intersections; and (3) grade separations and ramps. Standards for these groups are recommended in detail in publications of the American Association of State Highway Officials: *A Policy on Intersections at Grade; A Policy on Rotary Intersections; A Policy on Grade Separations for Intersecting Highways;* and the *Manual on Uniform Traffic Control Devices.*

Intersections at grade

Figure 37 illustrates the major types of intersection design treatment at grade; namely, all-paved intersections, intersections with separate turning lanes, and flared intersections. The all-paved intersection includes simple corner rounding. Use of separate turning lanes produces the "channelized" intersection with islands between the lanes. Addition of extra pavement widths at the beginning and end of intersection curves is the flared treatment, in its most common

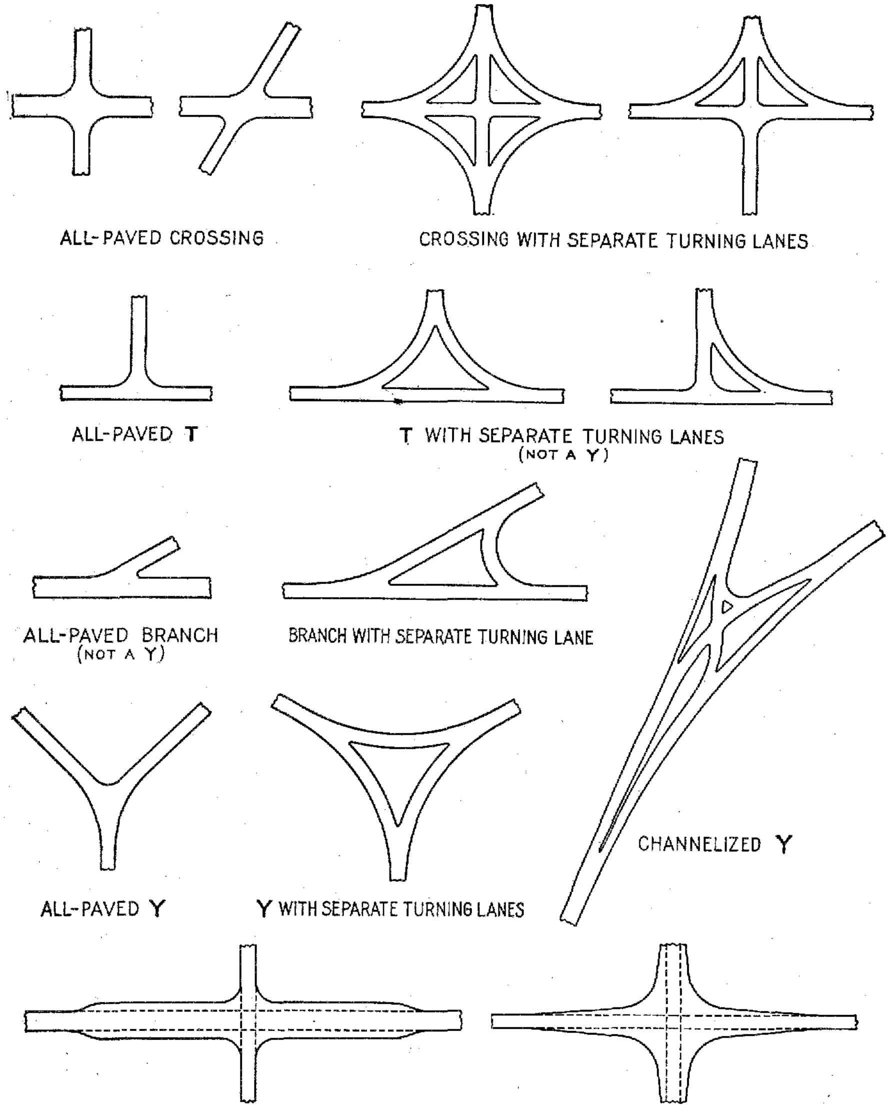


Figure 37.—Types of intersections at grade.

form, known as speed-change (or acceleration and deceleration) lanes. A proper combination of these elements produces the intersection at grade to best fit particular traffic and site controls.

The discussion on page 80 includes information relative to the traffic capacity of various intersections. More detailed information on this subject can be obtained from the material published by the Committee on Highway Capacity of the Highway Research Board.

Rotary intersections

Rotary intersections are those in which all traffic merges into, and emerges from a one-way road around a central island. They are a form of channelized intersection. Because of the relatively large area required for their development, the extra travel distance within them, the necessary speed reduction on the part of all entering vehicles, and the limited capacity of the weaving sections, rotaries are not being designed today except in special instances. It is found possible to handle greater volumes than formerly was thought feasible in at-grade intersections, combining channelization and traffic signal controls. It is found that partial-cloverleaf grade separations are comparable in over-all development and operating costs to rotaries properly designed. Thus the range of traffic volume conditions wherein a rotary is considered most suitable has narrowed considerably during the last decade. Many existing rotaries in urban and surburban areas have been made operatable under increasing traffic volumes only through installation of traffic signal controls and stop-and-go operation, for which their over-all shape is poorly suited. Others have been rebuilt to carry heavy through traffic streams directly through on a viaduct or subway facility.

In the design of a rotary intersection, proper consideration should be given to the following items:

1. Design speed of the rotary consistent with highway speeds.
2. Adequate length between radial roads; i. e., the weaving length.
3. Suitable minimum radius of central island.
4. Adequate width of rotary roadway.
5. Proper design and location of directional islands in the radial road.
6. Careful warping of pavement cross slope to provide superelevation and minimize throw at the crown line.
7. Inclusion of good sight distance and reasonably flat grades.
8. Curb sections on islands.
9. Proper use of signs throughout.

The above and other pertinent design elements are treated in detail in the American Association of State Highway Officials *Policy on Rotary Intersections.*

Grade separations and ramps

When a grade-separation structure is used in an intersection to place the through roadways at different levels, with uninterrupted traffic flow on both, the volume of traffic that can be passed through the intersection can be made to approach the sum of the open-road capacities of the intersecting highways. Moreover, with proper attention to the location and design of connecting roadways (i. e., ramps) for the interchange of traffic, all traffic can proceed through the intersection with little or no interference. In the United States there is now a considerable usage of all types and forms of grade-separation ramp layouts, and plans under preparation include even greater emphasis on such layouts.

The grade separation plan most commonly used for rural and suburban intersection conditions, and accordingly in use in nearly all States, is the cloverleaf or partial cloverleaf. As shown in figure 38, the cloverleaf (sometimes called a full cloverleaf) is a plan with a single separation structure and with ramps for both directions of travel in each of the quadrants. All left turns are made without direct crossing of traffic, by means of exit to the right, a curve around to the right (270°), and entrance from the right of the through road. The partial cloverleaf is the same type of layout, but usually with ramps in only two or three quadrants, as shown at the top of figure 38. This ramp pattern results in left turns on one or both of the through roads, depending upon the ramp locations and design.

With the current emphasis on improvement of urban arterial routes, considerable use is being made of the "diamond" ramp pattern, as shown in figure 39. In basic form, this plan has a single separation structure and a one-way ramp in each quadrant, with left turns in both directions on the minor or cross road. This pattern of ramps well fits a relatively narrow right-of-way condition as usually found in urban areas. Likewise, the left turns at grade are consistent with the normal street intersections to be found along the cross street. With parallel frontage roads, the ramp locations may be varied considerably from the truly diamond shape, as shown in the

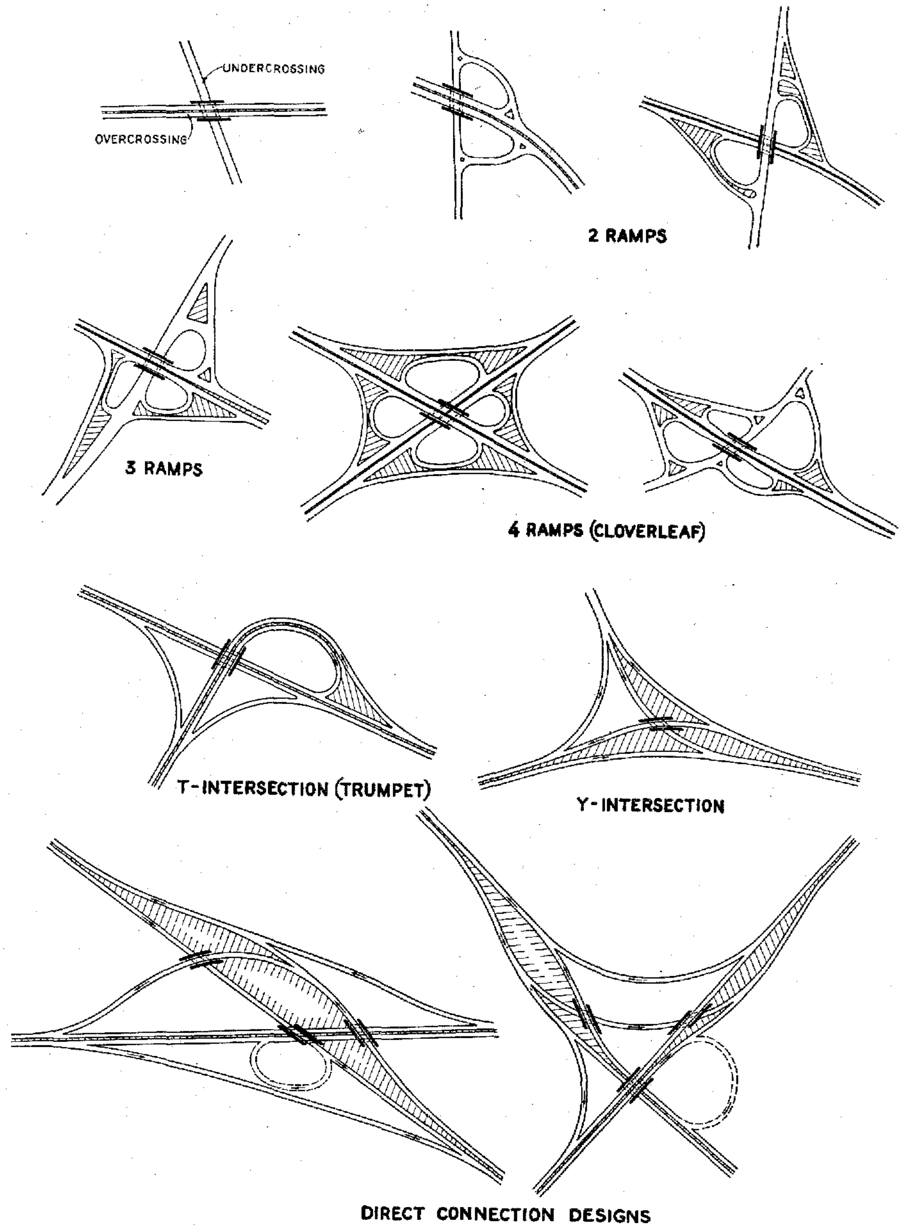


Figure 38.—Types of grade separations (diagrammatic).

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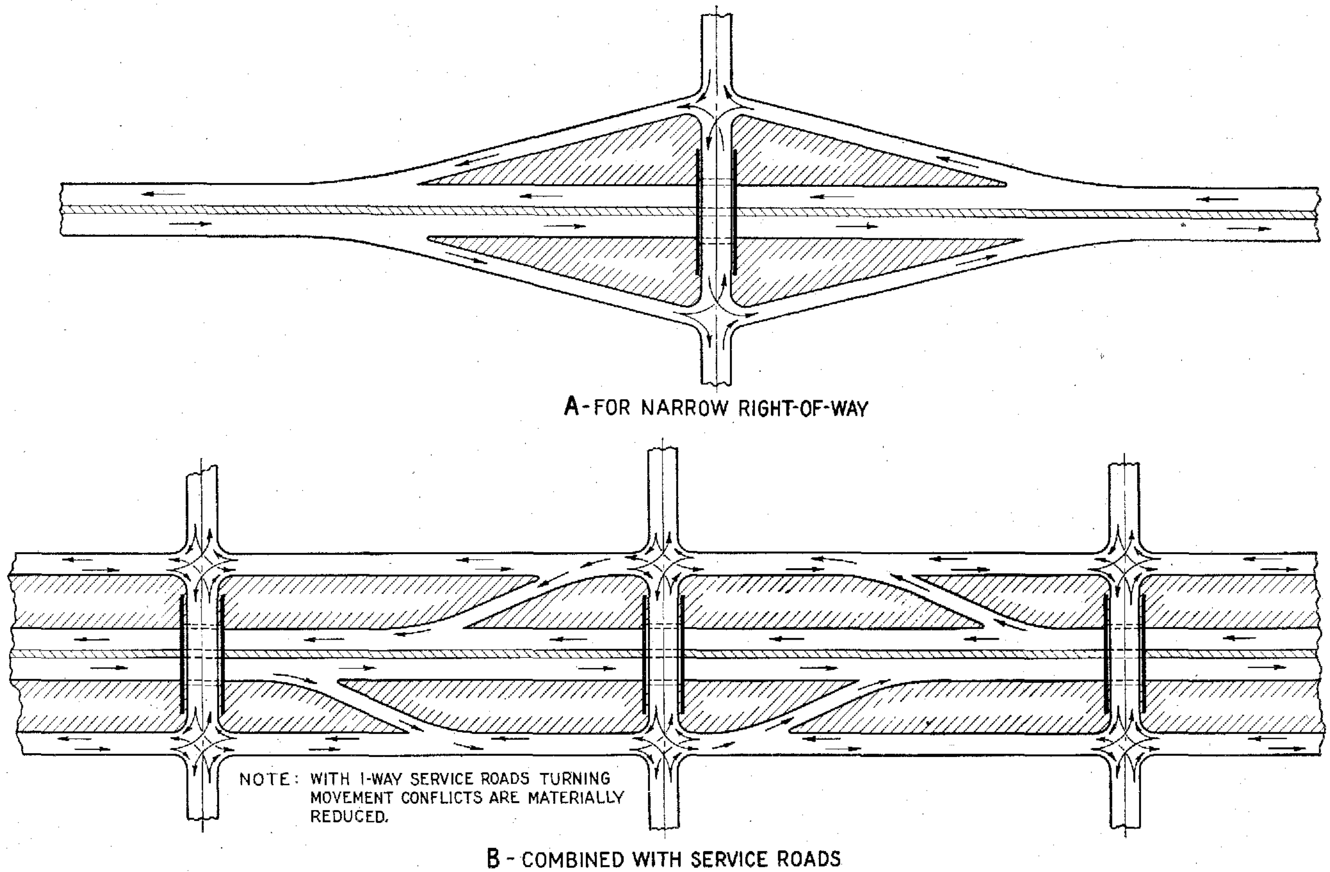


Figure 39.—Use of one-way ramps (diagrammatic).

lower part of figure 39, to fit the site conditions.

Signs, Signals, and Markings

The accepted standards for traffic signs, signals, and markings are set forth in detail in the *Manual on Uniform Traffic Control Devices*. This publication, prepared by representatives of the American Association of State Highway Officials, the Institute of Traffic Engineers, and the National Conference on Street and Highway Safety, contains criteria for the installation and use of all recognized control devices and prescribes the essentials of their design. It is in general use by all highway agencies. A primary intent of the manual is to obtain greater uniformity and effectiveness in these important auxiliaries to safe, efficient highway transportation.

Though signs, signals, and markings are, in a strict sense, relatively minor appurtenances to a highway, they often have a profound effect on traffic movement, and consequently should always be integrated with highway design considerations. In the preliminary processes of design, it is advisable to visualize the future operating condition and the probable need for traffic-control devices, so that adequate provisions for them may be made in the roadway layout. This joint consideration of design and control requirements at the planning stage frequently leads to design changes that lessen restrictions on traffic movement.

Urban Arterial Highways

As yet, there are relatively few nationally recognized standards for urban arterial highways. Most of the values and dimensions mentioned heretofore in this summary were derived for, and are applicable to rural conditions. For highways in urban areas, the upper or desirable design controls are greatly needed because of the high traffic volumes. But on the other hand, because of limited rights-of-way, extensive urban developments, established patterns of operation, and economy in the city, it often is necessary to scale down design standards.

In the absence of developed standards for urban areas, the complexity of urban design can be indicated by citing the following elements wherein there is significant differences between rural and urban design:

1. Control of access is needed in urban highways to a much greater extent than on rural highways, where natural points of access are infrequent.

2. Stage construction, as known in rural areas, may be impossible in urban areas because of the existing traffic to be handled. Maintenance of existing traffic and service to existing developments may greatly affect the highway location and design.

3. Alteration and replacement of all types of utilities is an expensive and far-reaching problem in urban areas.

4. Design of drainage facilities for urban highways requires a substantially different type of analysis, and involves a much greater proportion of total cost.

5. Factors of traffic distribution during the year, the month, and the day may be appreciably different than in rural areas. These factors materially alter the peak-hour design loads and, accordingly, the type and extent of highway facilities required.

6. Lane and pavement widths must be a compromise between the known desirable values and the severe limitations of space that can be made available.

7. Shoulders are needed most on urban highways where high peak-hour volumes occur daily, yet in these areas they are difficult of attainment.

8. The combination of elements in the highway cross section must be adjusted to fit the right-of-way that can be extracted from the existing urban development.

9. Mass-transit vehicles (busses, trolley busses, and streetcars) also must be considered in the over-all transportation facility, sometimes at the expense of full mobility for through traffic.

10. Street lighting usually is included in an urban facility.

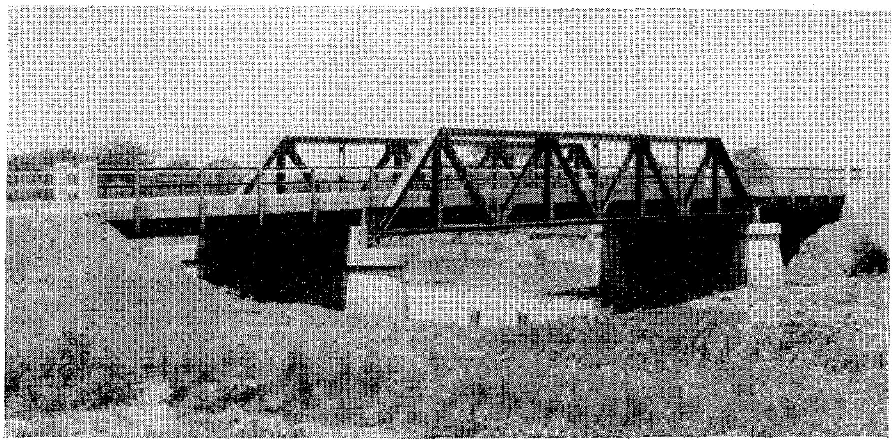
11. Because of the frequency of cross streets and other access connections, there is need for utilization of all types of traffic-control devices (signs, pavement markings, traffic signals, islands) and police-officer control.

12. With concentrated development along them, greater attention must be paid to esthetics in urban highways. This calls for adequate right-of-way, flat slopes and rounded cross section, appropriate landscaping, and architectural treatment to obtain pleasing structures: in short, a green-belt development to the extent feasible within the available right-of-way.

STANDARDS OF DESIGN FOR BRIDGES AND CULVERTS

In the United States, bridges of a length of 20 feet and less between abutments are called culverts. The term "bridge" is reserved for structures more than 20 feet in length between abutments.

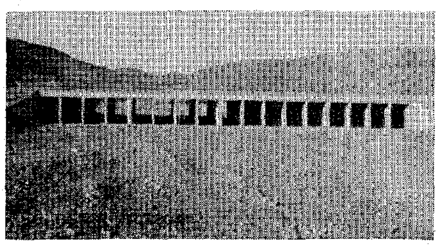
In general practice, bridges of a length of 50 feet and less are termed "short bridges." In the standards adopted for the interstate highway system, however, the term "short bridge" is applied to bridges of a length of 80 feet and less between abutments.



Bridge types: A pony truss.

Location and Design

All culverts invariably, and all bridges wherever feasible, are located to fit the general alinement and grade of the highway of which they form a part. Where structural or architectural considerations make it desirable to adjust the alinement and grade of the highway to a particular bridge location, standards of road alinement govern the character of the adjustment.



Bridge types: Multiple box culvert.

Width

The width of bridge roadways is generally not less than 6 feet greater than the width of the approach pavement. If the lane width of the approach pavement exceeds 12 feet or if safety curbs are provided on the bridge, the bridge roadway width should exceed the width of the approach by at least 4 feet. If both conditions exist, the bridge roadway width should exceed the width of the approach pavement by at least 2 feet.

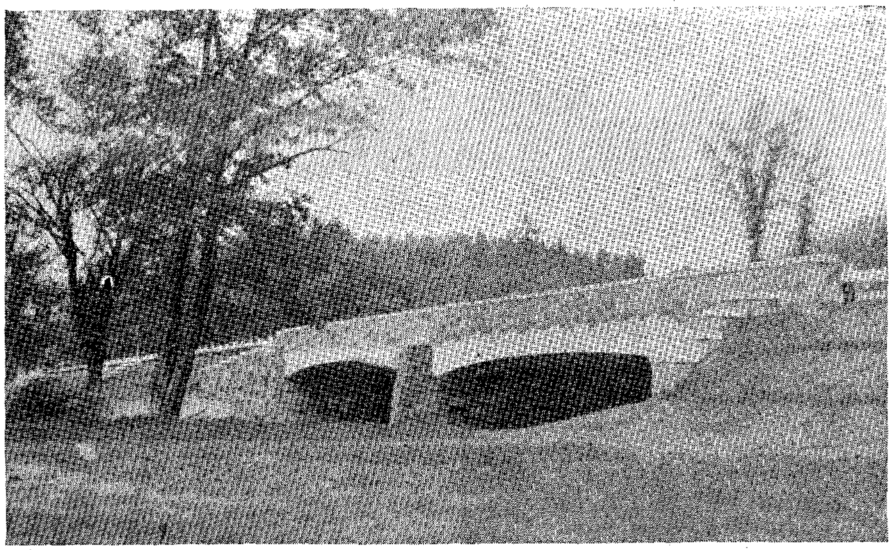
On short bridges the width of the bridge roadway is made the same as the combined width of the pavement and shoulders of the approach highway. The same rule holds for the clear width at culverts.

Vertical clearance

Vertical clearance on bridges is generally not less than 14 feet. The same clearance is generally provided at all points vertically over the pavement, but may be reduced to not less than 12½ feet over the outer edges of the shoulders of the lower highway.

The H-S loadings consist of a two-axle tractor-truck with a single-axle semitrailer or corresponding "lane loading." Numbers following the H and S indicate the gross weight in tons of the standard tractor-truck and semitrailer respectively, as H15–S12 or H20–S16. The distance between the front and rear axles of the tractor-truck is invariably 14 feet. The distance between the rear axle of the tractor-truck and the semitrailer axle varies from 14 to 30 feet, the spacing used being that which produces the maximum stress.

The rear axles of the H trucks and the



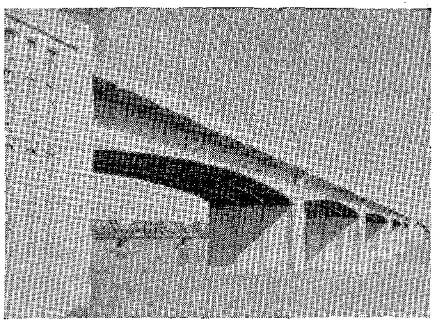
Bridge types: Stone-faced two-span continuous rigid frame.

Design Live Loadings

Bridges and culverts are designed to support standard live loadings specified by the American Association of State Highway Officials. Two systems of loading are specified, designated respectively as H loadings and H-S loadings.

H and H-S loadings

The H loadings consist of a two-axle truck or corresponding "lane loading," the latter consisting of a specified uniformly distributed load and a concentrated load equivalent in their effect to the specified trucks. A number following the H designation, as H15 or H20, indicates the gross weight in tons of the standard truck used in the loading. The distance between the two axles of the standard truck is invariably 14 feet.



Bridge types: Continuous steel girder spans.

tractor-trucks of the H-S series are invariably loaded with four-fifths of the gross weight of the truck or tractor-truck. The load on the axle of the semitrailer of the H-S series is invariably the same as that on the rear axle of the tractor-truck. Thus, the axle loading of the H20 truck is 8,000 pounds on the front and 32,000 pounds on the rear axle. On the H15 truck the front axle is loaded with 6,000 pounds, the rear with 24,000 pounds. Similarly, the axle loading of the H20–S16 combination is 8,000 pounds on the front axle and 32,000 pounds on the rear axle of the tractor-truck and 32,000 pounds on the semitrailer axle.

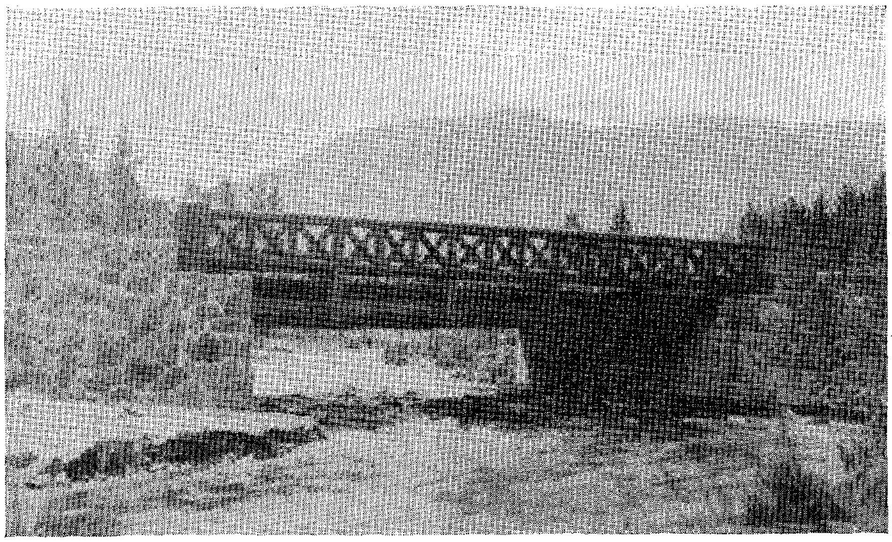
Choice of standard loading

The choice of the standard loading appropriate for the design of a particular bridge depends upon the estimate of the traffic that will develop within the life of the bridge and varies with the highway system on which the bridge is located. Bridges on the interstate highway system are currently being designed for H20–S16 loading. The great majority of bridges constructed on the Federal-aid system have been designed for H15 loading, but there has been a tendency in recent years to adopt the heavier H20 loading for bridges in this system.

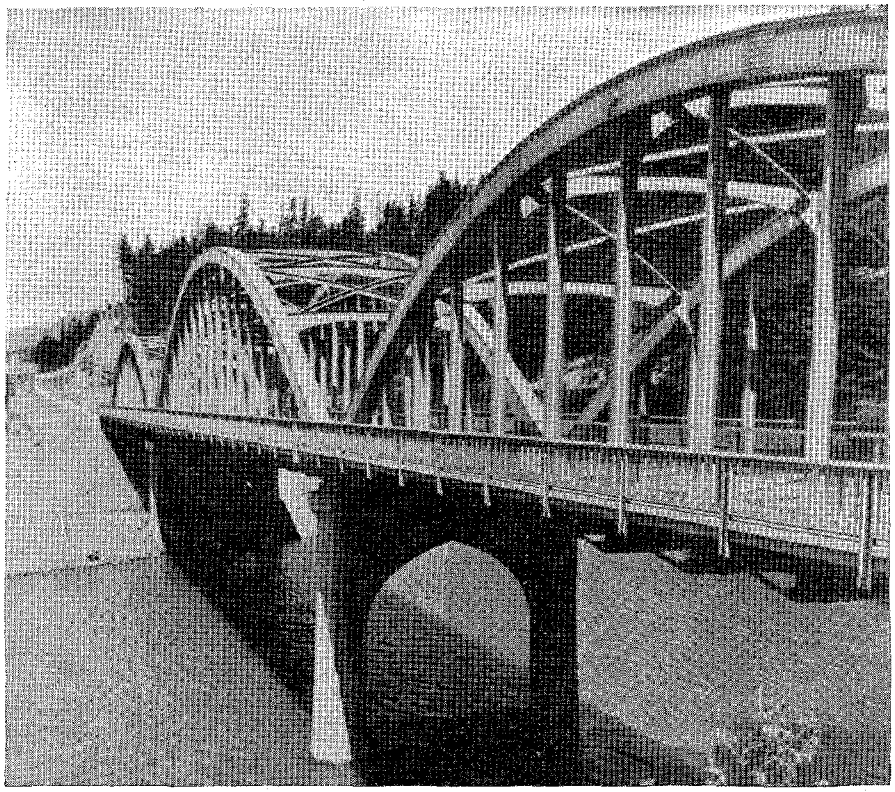
The number designations of the standard loadings have contributed to a widespread erroneous belief that the bridges correspondingly designed are limited in their design capacity to the support of vehicles of the indicated weight in tons. This is true only with respect to vehicles of the same wheel base as the standard vehicle. Substantially heavier vehicles may occasion no greater stresses in bridges of moderate spans if the wheel base is enough longer than that of the standard vehicle to materially reduce the rate of loading.

Also, it is to be remembered that though an occasional heavy vehicle may cause higher stresses, if the repetition of such loads is infrequent, the stresses occasioned may approach the yield point of the material composing the structure without danger. Thus, an H20–S16 bridge will carry safely an occasional load approximating H40–S32 loading.

It is being increasingly realized that additional carrying capacity is cheap. If present conditions are satisfied by an H10 bridge, a slight additional expenditure, usually well under 10 percent, will



Bridge types: Rustic timber span in a park area.



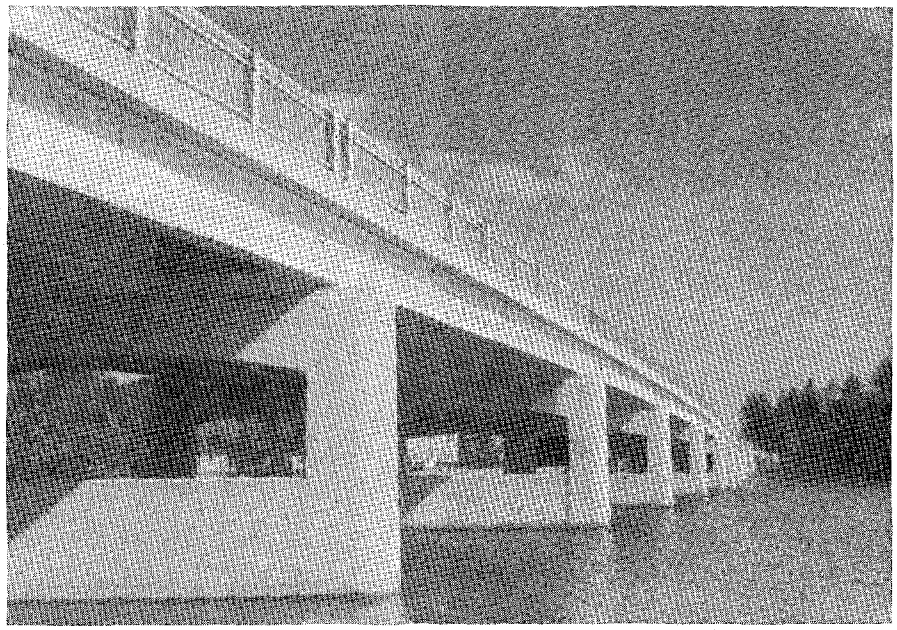
Bridge types: through tied-steel arch.

provide a structure designed for H15. For an expenditure of about 10 percent it is usually possible to increase the capacity of an H15 bridge about one-third to H20–S16.

Common Bridge Types

The types of bridges generally used are: culverts, pile trestles, viaducts, slabs, beams, girders, frames, arches, trusses, suspension, and movable spans. Some of these types, such as the beams, girders, frames, and trusses, are frequently varied in the manner of support used, such as simple, cantilevered, or continuous. The cantilevered support naturally lends itself to longer spans than the simple beam. Likewise the continuous beam is more economical of material than the simple beam, but it is necessary that the foundation for continuous bridges be restricted in the possibility of settlement, a limited amount of which would not so seriously damage the simple or cantilevered-and-suspended span bridge. Continuous construction has come strongly into the bridge field during the past few years for all materials. Continuous beams and girders are among the most common types of bridge structures today.

For steel work, the beam and plate girder types can be fabricated at minimum cost, and painting and maintenance costs are also low. Owing to their compactness and simplicity these structures are better able to resist shock, vibration, overstress, and damage due to accidents. Except for unusual conditions the erection cost for beams and girders is decidedly less than for trusses.

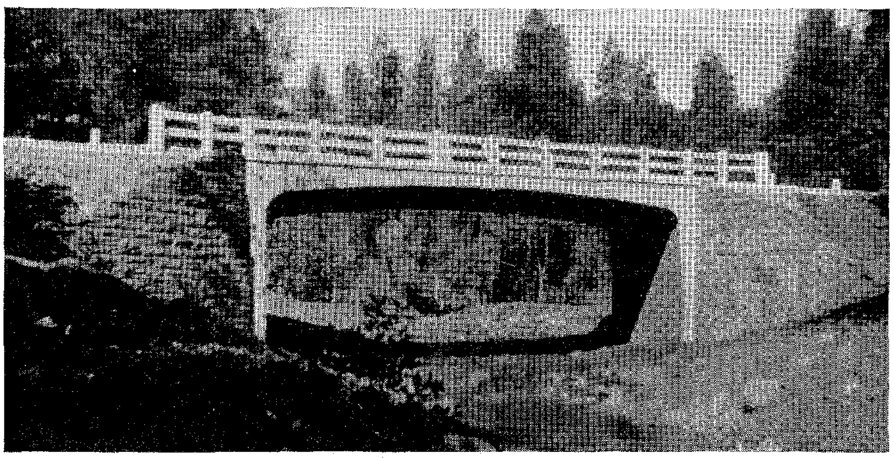


Bridge types: Continuous I-beam spans.

Culverts are generally constructed of either concrete or corrugated sheet metal. These structures normally furnish the ultimate in economy of first cost. They may be designed to suit practically all locations where the required area of waterway is not large. The roadway may be carried directly on the culvert slab or on an earth fill at any desired height.

Of the usual bridge types, the pile trestle is the most economical and serviceable and the most rapidly constructed for bridges of the greater lengths. The pile trestle may utilize various types of superstructures, such as slabs, beams, or girders.

Viaducts are a special type of trestle suitable for the crossing of deep valleys



Bridge types: A concrete rigid frame.

where the roadway is located at a considerable height, or in urban areas where long length of a typical design is required. In these cases, piles give away to towers or bents which support girder or truss spans.

Through steel-truss spans are not used as frequently today as they were two decades ago, because of a unit cost greater than that for girder bridges, and especially on account of the impracticability of widening most through bridges. One of the principal advantages of the deck type of bridge is the fact that it may be widened in the future when an increase in volume of traffic necessitates such a change. The through truss bridge still has a field of usefulness in localities where the transportation and erection of heavy girders would be impracticable. The field of usage for the low or pony truss bridge has been severely narrowed.

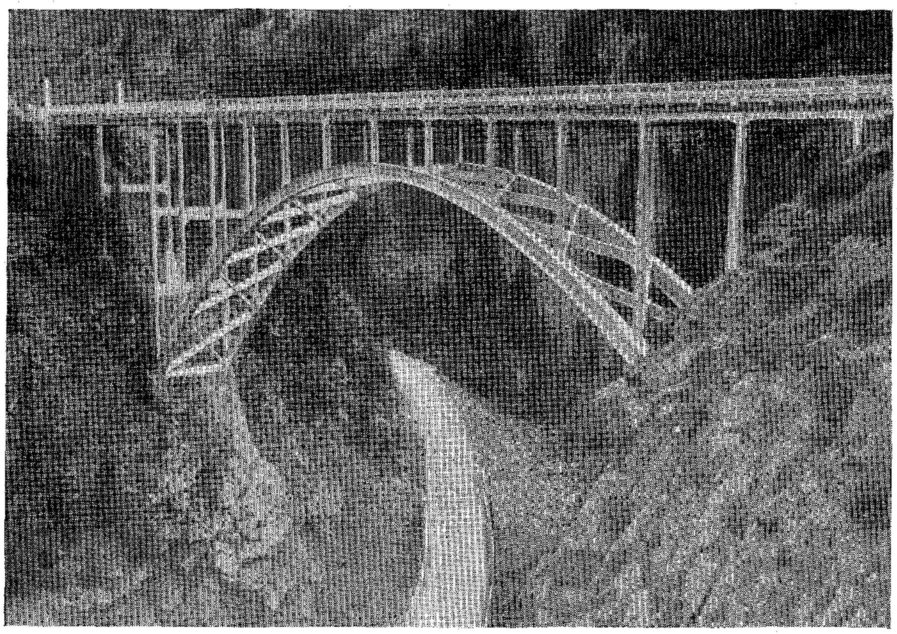
Deck truss bridges are used where the underclearance requirements permit.

The following will give an idea of the approximate maximum span lengths for the various types:

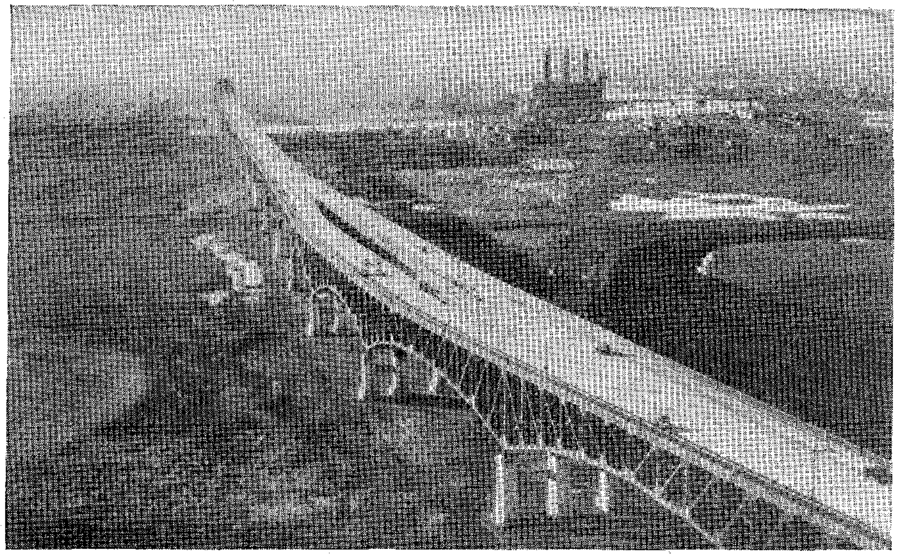
	Feet
Timber stringer	22
Timber truss	80
Timber arches	180
Concrete slabs, continuous	45
Concrete rigid frames	75
Concrete simple girders	50
Concrete girders, continuous	100
Concrete arches	460
Steel simple beams	70
Steel continuous beams	100
Steel rigid frames	100
Steel simple girders	125
Steel continuous girders	300
Steel simple trusses	600
Steel continuous trusses	850
Steel cantilever trusses	1,400
Steel arches	1,650
Suspension bridges	4,200

Materials Used in Bridges

The materials principally used in the construction of highway bridges are timber, stone or concrete masonry, and steel, or a combination of these materials.



Bridge types: Deck steel arch.



Bridge types: Elevated highway in an urban area.

Timber is used for foundation piles, cofferdams, falsework, forms for concrete, and for superstructures, including floors and railings. Owing to its rapid deterioration when exposed to the elements, timber is used very largely for temporary structures, although preservative treatment greatly enhances its useful life. Timber piles under water are not subject to weathering conditions.

Stone masonry is used for culverts, arch bridges, and for facing concrete structures where architectural treatment is of prime importance, as in park and urban areas. Its cost is considered prohibitive for general bridge work. The greater proportion of bridges are constructed of reinforced concrete or steel. Plain or unreinforced concrete is used for parts of substructures and sometimes for small arch culverts. Otherwise, all concrete used in bridge construction is reinforced with steel bars. Steel and concrete are closely competitive in cost and the choice is determined largely by the availability of local materials and transportation costs.

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Part 3

LOCATION AND DESIGN

LOCATION OF HIGHWAYS

The previous discussion has been concerned with the grouping of highways into systems rationally related to function and the portionment of governmental responsibility for administration, and with the standards of what has been termed the geometric design of highways and bridges essential to the proper accommodation of their determined probable usage by traffic in specific volumes, composed of vehicles of definite characteristics, operated at assumed desirable speeds.

We now turn to matters concerned with the specific location of highways within the determined systems and the design of the physical features of the highways, including their drainage, foundations, and surfaces. In these respects the guiding purposes are:

1. To place the highway in optimum conformity with its terrain and adjoining land uses;
2. To protect the highways and bridges against the destructive action of water; and
3. To provide foundations, structures, and surfaces which, at an optimum combination of construction and maintenance cost, economically related to the value of the transportation service to be afforded, will have the strength to resist anticipated traffic and natural forces.

In approaching these phases of the discussion it is logical to begin with a consideration of the objectives and methods of location as they are viewed and practiced in the United States.

First, it should be borne in mind that many miles of highways, especially in the more fully developed areas of the country, are now substantially fixed in their existing locations. Reconstruction of these highways occurs periodically in projects a few miles in length, with no choice of new location at all. When short sections of such highways are relocated to correct local deficiencies of alinement, the objectives are the same as those which are sought in more extended new location or relocation, but the methods are, generally, the familiar methods of ground surveying.

Location Objectives

Modern American highways, in contrast with those in some other countries, are designed almost exclusively for motor vehicles. Our main reason for relocating and reconstructing the average primary highway is the fact that it has become obsolete for use by existing volumes and types of motor traffic. The main objectives of new highway location include the following, among others:

1. A location is desired which will, as far as possible, provide at lowest possible cost permanently optimum operating conditions for a gradually developing stream of composite traffic [1].[2]

2. This means a location which meets standards of grade, alinement, and sight distance based on actual existing and probable future traffic over a period of at least 25 years.

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[2] Numbers in brackets refer to numbers in the Bibliography, page 172.

3. A location to standards which will permit operation of vehicles at a constant average design speed, without gear shifting in ascent or braking in descent.

These objectives and others of equal importance require complete topographic and land use information between the terminal points selected before the highway location survey begins. The final objective of such a survey will be the use of such complete information in obtaining the best possible permanent location of the highway, considering the standards of construction believed justified by future traffic.

Reconnaissance Surveys

Modern American practice in highway location involves four typical stages [2] which may be briefly described as:

1. Reconnaissance of the region or general area through which a proposed new or relocated highway is to pass.
2. Reconnaissance of possible alternate routes indicated by existing regional maps and supplementary regional surveys. In this second step best locations are selected for:
3. Preliminary location surveys.
4. Final location surveys and preparation of plans are the culmination of the highway location process.

Reconnaissance of the region

The first stage of highway location is the determination, not of a single route or highway location, but of all feasible routes in the region through which the proposed new or relocated highway will pass. This survey stage is largely based on existing maps where available, supplemented by aerial photographs and mosaics obtainable from various sources.

Reconnaissance of alternate routes

The second stage has as its purpose the selection and comparison of a series of possible alternate routes. As now carried out by aerial survey methods, this reconnaissance usually covers a series of strips or zones of land from 1 to 5 miles, or more, in width. Best adapted for such aerial coverage are strip photographs at scales of from 400 to 600 feet per inch. In highly developed suburban or urban areas photogrammetric maps made from such photographs to scales as large as 200 feet per inch, with a contour interval of 5 feet, have been used. In very heavy, mountainous topography such large scale maps are often useful, both in this stage and in the preliminary location stage following. Under usual conditions, in open, undeveloped country, photogrammetric contour maps at a scale of 400 to 500 feet per inch, with a 10-foot contour interval, are satisfactory.

Aerial surveys

Main features of aerial surveys for alternate route reconnaissance may be summarized as follows:

1. Flight lines are laid out covering a series of strips or zones of land from 1 to 5 miles wide containing possible alternate routes. The small-scale topographic maps or mosaics, mentioned under stage 1, are used for this purpose.
2. The strips shown on the small-scale mosaics or maps are flown over and photographs are taken at desired scales, preferably 400 to 600 feet per inch. These photographs will normally have about 55 percent overlap along the strip, with 25 to 35 percent of side lap.
3. The photographs are examined under the stereoscope, and ground traverses and base lines are run to locate control points, such as road intersections, building corners, and the like. These control points, to be usable, should be easily recognized both on photographs and on the ground.
4. After ground control surveys are run and bench marks established by level parties, these known control points are located on base map sheets.
5. Photogrammetric maps can then be made, within the scale limits mentioned, by commercial mapping organizations. Costs of such mapping at 500 feet per inch and 10-foot contour interval in 1945 were in the neighborhood of 50 cents per acre, a map of 200-foot-per-inch scale and 5-foot contour interval costing about $1.00 per acre.

Points of importance are: (1) that such maps must be *correct up to the minute*; (2) that they must be accurate in horizontal measurement to the limits of accurate measurement at the scales provided; and (3) that contours can be provided with elevation accuracy on 90 percent of areas covered to within half the contour interval.

The usual final operation in this stage of reconnaissance will be the selection of the most direct and economical route for the preliminary surveys to follow.

Ground reconnaissance

The above description of aerial survey procedures should not be understood to imply that *ground* reconnaissance is not of great value. By ground processes, however, only the individual locator can retain full knowledge of the strips over which alternate routes will pass. In rough topography, or in developed suburban or urban areas, the vision of the reconnaissance party on the ground is limited and many details must be supplied by memory and from field notes. *Reconnaissance by aerial methods*, in contrast, removes the possibility of individual errors in judgment. Alternate routes shown on paired photographs under the stereoscope and on good photogrammetric maps are recorded in every detail. With such paired photographs and the contour maps made from them, there should be no possibility of doubt that the best and most economical route has been selected for preliminary location survey.

Preliminary Location Surveys

Let it now be assumed that three or more alternate routes have been selected and mapped for study. Assume, also, that there are overlapping strip photographs at a 500-foot per inch scale (1:6,000) and a photogrammetric contour map at this same scale with 10-foot contour interval. A trial line can now be laid down on the map, with a spline, which will follow in very close approximation such a line staked on the ground. Such a line will readily avoid badly *drained ground*, impassible rough topography, valuable buildings, or other obstacles. The line will cross streams at points seen to be reasonably practicable as bridge sites. In cases of doubt, questioned points can be identified on paired photographs under the stereoscope and examined in detail on the ground. Finally, from such photographs and maps, rough estimates of excavation yardage, *bridge and culvert construction costs*, and the like can be made. The usual result of such calculations in open undeveloped country will be to make possible selection of a single, best, and most economical line location on the contour map. This selected preliminary location will then be ready for preliminary survey.

The preliminary location survey will usually require *aerial photography* on a strip ¼ to 1 mile wide. Details such as fence lines and property line corners must be identifiable and accurate estimation of excavation yardage will be necessary at this stage. Location of points of curvature and points of tangency on the map will be required. These details will require contour map scales of from 200 to 100 feet per inch, although only in built-up suburban areas will the larger of the two scales be required. The 200 feet per inch contour map can be prepared from the 500 feet per inch photographs taken for stage 2.

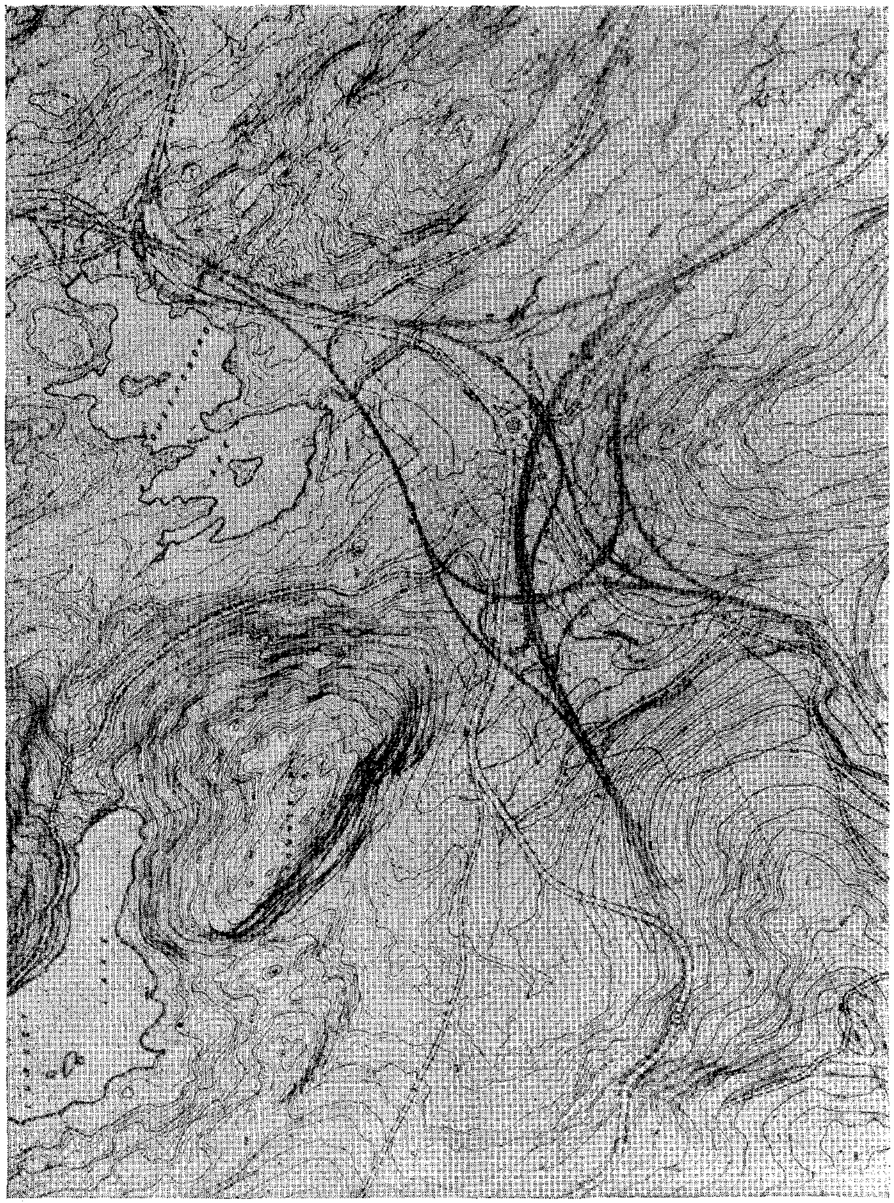
Value of aerial photography

Important points to be emphasized in the preliminary location stage are these:

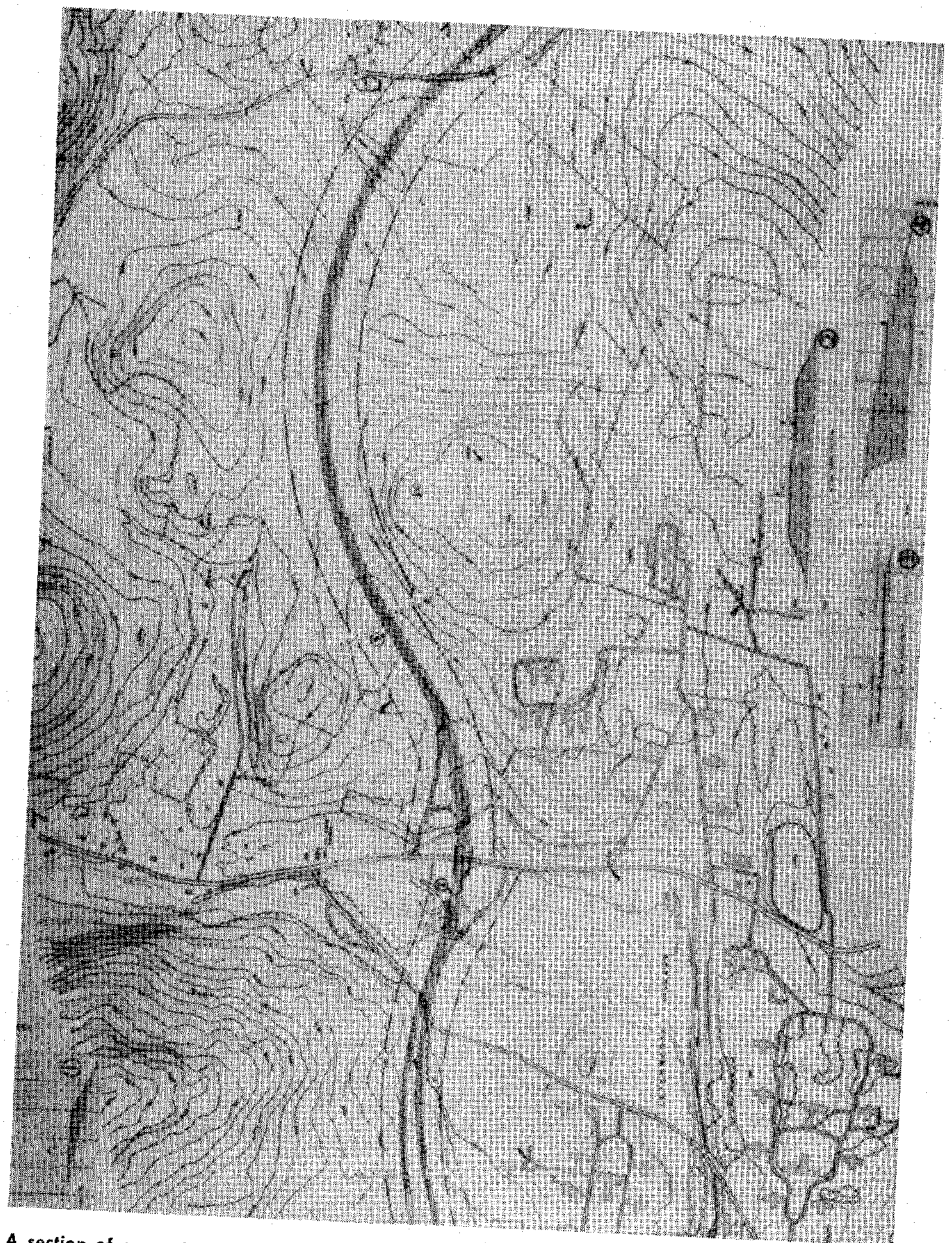
1. Previous reconnaissance stages of survey have covered wide bands or zones of ground area. The preliminary survey stage brings the zone of coverage to a strip from ¼ to 1 mile wide, on which contour lines will be obtained.

2. At the usual scale of 200 feet per inch, a line can be laid down, on the map and photographs, which can be located on the ground and, when desired, staked out.

3. At the scale of 200 feet per inch, estimates of yardage of excavation can be made for the selected line. Such es-



Preliminary location of a main intersection on a new eastern parkway. These trial lines are laid down on the photogrammetric map with a spline. As a rule, no lines need be staked out on the ground until the best of the alternate preliminary locations has been selected. Estimates of excavation yardage were made, using the 5-foot contours, and were within 5 percent of actual yardage excavated on the selected lines.



A section of an eastern parkway laid down with a spline in the 5-foot contours of a photogrammetric map made by aerial survey methods. Note that the line is complete, with points of curvature and points of tangency. This selected preliminary line can now be staked out as the final location line.

timates, when checked by cross sectioning and computation, have been within 5 percent of the actual excavation quantities.

4. Field stake-out and trial-and-error location of a series of alternate preliminary lines on the ground can be avoided by the aerial survey methods outlined.

5. By avoiding actual staking out of preliminary lines, private property owners are not unduly alarmed as they always are by ground surveys. Values of land to be acquired are not increased as they are by the usual discussion with property owners which follows the staking out of a survey line.

6. At the map scale of 200 feet per inch, the value of buildings may be appraised, property lines may be laid out from the photography, and property maps prepared.

7. On such contour maps, supplemented by stereoscopic examination of paired photographs, the road alinement can be fitted to the topography with the least possible cut and fill permitted by assumed controls of curvature, profile, and sight distance. All serious obstacles, such as rock cliffs, marshes, and bad stream crossings can be avoided before any lines are staked out on the ground.

Final Location Surveys

The final location of the preliminary line, selected either by trial and error on the ground, or by means of aerial photographs and photogrammetric maps, is a process well understood by all experienced highway engineers. The obtaining of cross-section information, the layout of sections of tangents and curves, the estimation of yardage by end-area methods, all these are familiar. The use of aerial survey methods, as now practiced by American engineers, normally terminates when the best preliminary line available between selected terminal points, and passing through selected control points, has been laid down on the ground. This best preliminary location line, with necessary minor adjustments during the stake-out process, becomes the final location line.

SOIL SURVEYING AND ITS OBJECTIVES

A soil survey forms an essential part of the preliminary engineering survey required for the location and design of a highway. It furnishes information on soil and ground water conditions that must be considered in the reasonable and economic design of a road passing through a variety of different terrain conditions.

Soil Information

Soil surveys conforming to these requirements include: (1) the exploration of the site, (2) the classification of soils in place, (3) the preparation of soil profiles and cross sections showing critical depths to bedrock, water table, or the area and extent of adverse ground conditions such as swamps and peat bogs, (4) the selection of representative samples of soil and construction material (sand, gravel, or rock) for laboratory testing, (5) the study of existing pavement design and the correlation of pavement performance with similar soil conditions found in the area being surveyed, and (6) the reduction of this information to engineering recommendations.

This type of soil information is a major prerequisite to the systematic planning and construction of a road. It becomes even more essential when the engineering problems associated with the construction of secondary roads are considered. The economic factor in this case requires that roads be designed and located to take advantage of any cost reduction that may result from the use of local materials and alinement over the most favorable subgrade conditions.

The major part of the soil survey work, with the exception of the reconnaissance study of available geologic and agronomic data, must be accomplished in the field. The costs of testing and the time required for the testing of soils in the laboratory restricts the number of samples that can be tested for a particular project. Consequently, emphasis must be given to engineering appraisal of soil conditions in the field, especially the behavior of pavements that have been built over similar soil conditions.

Several of our States have published technical manuals [3], [4], [5], to assist in the recognition of soils on the basis of their physical and environment characteristics. The essential considerations for the in-place classification of soils are outlined in the standard test methods [6], [7], used by the State highway departments. A study of these soil survey methods will show that the soils are identified and grouped on the basis of the soil-profile characteristics.

It is indicated that soils grouped on the basis of significant soil profiles will, within practical limits, reflect changes in texture and drainage conditions existing in the landscape. The soil profile development changes with each significant combination of the soil-forming factors such as parent material, relief, climate, organisms, and time. Parent material as used in this discussion refers to either weathered rock, unconsolidated sediments, or transported materials such as wind, colluvial, or glacial deposition.

A recent Nation-wide study of soil practices [8], shows that 20 States follow the soil survey method of the American Association of State Highway Officials, T 86–42 [7], and 16 other States use this method in part or with some modification. County agricultural soil maps (soils classified by soil-profile characteristics) are used by 28 States as a means for obtaining the area concept of general soil conditions for the preliminary planning of detailed engineering soil surveys, and for the location of suitable construction materials in the vicinity of proposed road projects. Aerial photographs are used by nine States to study soil conditions and to identify areas likely to contain granular materials for construction and maintenance purposes.

Subsurface Exploration

The determination of depths to solid rock and the classification of soils and underlying strata with respect to their relative degrees of compaction are major engineering problems in areas where deep cuts and fills are required to obtain satisfactory road alinement, or where subsurface information is needed for the foundation design of large structures.

Borings

Subsurface exploration by auger borings usually is limited to about 30 feet in areas where rock or the presence of numerous boulders do not hinder operations. Below this depth, wash boring rigs, churn drills, or rotary drills are ordinarily used to obtain the essential design information. As a result of the high costs of deep borings there has been an increased use of geophysical methods [9], [10], to obtain supplemental information to control the number and location of the deep drill holes required for subsurface studies.

Two geophysical methods of subsurface exploration are used for such preliminary investigations.

Seismic exploration

One, the refraction seismic method, depends upon differences in the velocity of propagation of sound or seismic waves through the various materials making up the earth's crust. Such wave velocity depends upon the density and the elastic properties of the soil and rock formations. Small charges of dynamite, exploded at selected points, set seismic waves in motion and their time of arrival at properly spaced sensitive detectors is obtained.

Earth-resistivity method

The other method, the earth-resistivity method, depends upon measured differences in the electrical resistivity of the various soil layers and rock formations. The soil resistivity depends upon an electrolytic action of moisture and salts in solution. Dense materials such as solid rock, having limited pore space for accommodating moisture, usually have a high resistivity, whereas most clay soils have quite low resistivities.

Each method has some limitations. The seismic test is definite in the identification of a subsurface contact between solid rock and various types of overburden, but it is less definite than the resistivity test in distinguishing between clay and coarse sand and gravel. Calibration of the seismic test against revealed subsurface conditions, such as exposed cut slopes, drill hole records, etc., is desirable for best results in a particular locality. On the other hand, the resistivity test is influenced by stray ground currents and sometimes by a close similarity between the resistivities of the materials involved at a particular location. Resistivities of both soil and rock formations may vary considerably from place to place, and calibration tests over outcrops or known subsurface conditions are a prerequisite to an intelligent interpretation of earth-resistivity data. An improved empirical method of interpretation of the data, made available in recent years [11], has made this method more useful to the engineer.

Application of geophysical methods

Even with these limitations, geophysical methods are an aid to the preliminary reconnaissance of proposed construction sites. The most advantageous points to locate deep drill holes to obtain the maximum amount of test data for design purposes ordinarily can be found by the use of these methods of subsurface exploration. It has also been indicated [12], [13], [14], [15], that test data from a few well-placed drill holes or test pits can be expanded by the use of such methods so that areas of considerable size can be explored quickly and at low costs, and that they can be used for the location of granular materials for highway construction in areas where surface indications are few or unreliable.

Identification Tests for Soils

The standard tests used for identification of soils and the determination of their physical characteristics are as follows:

Test	*Physical characteristic*	*A. S. T. M. method*	*A. A. S. H. O. method*
Preparation of soil samples.	------------	D 421–39	T 87–42
Mechanical analysis (MA).	Grain size--	D 422–39	T 88–42
Liquid limit (LL)-	Plasticity--	D 423–39	T 89–42
Plastic limit (PL)-	--do--------	D 424–39	T 90–42
Plasticity index (PI).	--do--------	D 424–39	T 91–42

Preparation of soil samples

Sieve and hydrometer analyses are made on a fraction of the air-dried soil sample passing the No. 10 sieve. A sieve analysis is also made of any material that may be retained on the No. 10 sieve. The identification tests are made on the fraction of the air-dried sample passing the No. 40 sieve.

Mechanical analysis

The mechanical analysis of soils determines the size and grading of the particles. The grain sizes of the particles retained on a No. 200 sieve are determined by sieve analyses. The sizes of the soil particles passing a No. 200 sieve are determined by hydrometer analyses, the method of which is based upon the fact that particles of equal specific gravity settle in water at a rate which is proportional to the size of the particle (Stokes' law).

Liquid limit

The liquid limit is defined as that moisture content, expressed as a percentage by weight of the oven-dry soil, at which the soil will just begin to flow when jarred slightly. According to this definition, soils at the liquid limit have a very small but definite shear resistance which may be overcome by the application of a little force. At the liquid limit, the cohesion of the soil is practically zero.

Plastic limit

The plastic limit is defined as the lowest moisture content, expressed as a percentage by weight of the oven-dry soil, at which the soil can be rolled into threads one-eighth inch in diameter without breaking into pieces. Soil which cannot be rolled into threads at any moisture content is considered nonplastic. A sample having a moisture content above the plastic limit can be rolled into threads one-eighth inch in diameter without crumbling under the pressure exerted by the hand. When the moisture content of the soil has been reduced by evaporation to the plastic limit or below, the soil thread will crumble.

The plastic limit is, therefore, the moisture content at which cohesive soils pass from the plastic to the semisolid state. It is also the moisture content at which the coefficient of permeability of homogeneous clays becomes practically equal to zero [6].

Plasticity index

The plasticity index is defined as the difference between the liquid limit and the plastic limit. It is the range of moisture content through which the soil is plastic. When the plastic limit is equal to, or greater than the liquid limit, the plasticity index is zero. When the plastic limit cannot be determined, the plasticity index is designated by the letters NP (nonplastic), to indicate that the soil is entirely lacking in plasticity [6].

Classification of Soils

The soil classification system most commonly used by highway engineers in the United States was originally presented in the June and July 1931 issues of *Public Roads* [16]. A revised version of the system was published in the February 1942 issue of the same publication [17]. In 1943 a committee of the Department of Soils Investigations of the Highway Research Board was appointed to investigate classifications of soil. In 1945, this committee published a classification which is a revision of the original *Public*

Roads version [18]. This system is being used by the Public Roads Administration and by a number of State highway departments.

Based upon their field performance, soils have been classified by this latter system in seven groups designated as A–1 to A–7, inclusive. This classification, with the limiting test values, is shown in table 11.

A description of the various groups and subgroups follows:

Granular materials (containing 35 percent or less passing No. 200 sieve)

Group A–1. The typical material of this group is a well-graded mixture of stone fragments or gravel, coarse sand, fine sand, and a nonplastic or feebly plastic soil binder. However, this group includes also stone fragments, gravel, coarse sand, volcanic cinders, etc., without soil binder.

Subgroup A–1–a includes those materials consisting predominantly of stone fragments or gravel, either with or without a well-graded binder of fine material.

Subgroup A–1–b includes those materials consisting predominantly of coarse sand either with or without a well-graded soil binder.

Group A–3. The typical material of this group is fine beach sand or fine desert blow sand without silty or clay fines or with a very small amount of nonplastic silt. The group includes also stream-deposited mixtures of poorly graded fine sand and limited amounts of coarse sand and gravel.

Group A–2. This group includes a wide variety of "granular" materials which are at the border line between materials falling in groups A–1 and A–3 and the silt-clay materials of groups A–4, A–5, A–6, and A–7. It includes all materials containing 35 percent or less passing No. 200 sieve which cannot be classified as A–1 or A–3 due to fines content or plasticity, or both, in excess of the limitations for those groups.

Subgroups A–2–4 and A–2–5 include various granular materials containing 35 percent or less passing No. 200 sieve and with a minus No. 40 portion having the characteristics of the A–4 and A–5 groups. They include such materials as gravel and coarse sand with silt content or plasticity index in excess of the limitations of group A–1, and fine sand with nonplastic silt content in excess of the limitations of group A–3.

Subgroups A–2–6 and A–2–7 include materials similar to those described under subgroups A–2–4 and A–2–5 except that the fine portion contains plastic clay having the characteristics of the A–6 or A–7 group.

Silt-clay materials (containing more than 35 percent passing No. 200 sieve)

Group A–4. The typical material of this group is a nonplastic or moderately plastic silty soil, usually having 75 percent or more passing No. 200 sieve. The group includes also mixtures of fine silty soil and up to 64 percent of sand and gravel retained on No. 200 sieve.

Group A–5. The typical material of this group is similar to that described under group A–4, except that it is usually of diatomaceous or micaceous character and may be highly elastic as indicated by the high liquid limit.

Group A–6. The typical material of this group is a plastic clay soil usually having 75 percent or more passing No. 200 sieve. The group includes also mixtures of fine clayey soil and up to 64 percent of sand and gravel retained on No. 200 sieve. Materials of this group usually have high volume change between wet and dry states.

Group A–7. The typical material of this group is similar to that described under group A–6, except that it has the high liquid limits characteristic of the A–5 group and may be elastic as well as subject to high volume change.

Subgroup A–7–5 includes those materials with moderate plasticity indexes in relation to liquid limit and which may be highly elastic as well as subject to considerable volume change.

Subgroup A–7–6 includes those materials with high plasticity indexes in relation to liquid limit and which are subject to extremely high volume change.

Table 11.—Classification[1] of highway subgrade materials

[With suggested subgroups]

General classification	Granular materials (35 percent or less passing No. 200 sieve)							Silt-clay materials (more than 35 percent passing No. 200 sieve)			
Group classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5, A-7-6
Sieve analysis: percent passing:											
No. 10	50 max.										
No. 40	30 max.	50 max.	51 min.								
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 40:											
Liquid limit				40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		NP	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.[2]
Group index[3]	0		0	0		4 max.		8 max.	12 max.	16 max.	20 max.
Usual types of significant constituent materials.	Stone fragments, gravel and sand.		Fine sand.	Silty or clayey gravel and sand				Silty soils		Clayey soils.	
General rating as subgrade	Excellent to good					Fair to poor.					

[1] *Classification procedure:* With required test data available, proceed from left to right on above chart and correct group will be found by process of elimination. The first group from the left into which the test data will fit is the correct classification.

[2] Plasticity index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity index of A-7-6 subgroup is greater than LL minus 30.

[3] See group index formula and fig. 40 for method of calculation. Group index should be shown in parentheses after group symbol as: A-2-6 (3), A-4 (5), A-6 (12), A-7-5 (17), etc.

Group index

The following formula for a "group index" was devised for approximate within-group evaluation of the "clayey granular materials" of the A–2–6 and A–2–7 groups and the "silt-clay materials" of the A–4, A–5, A–6, and A–7 groups:

Group index$=0.2a+0.005ac+0.01\ bd$, in which

a=that portion of the percentage passing No. 200 sieve greater than 35 and not exceeding 75, expressed as a positive whole number (1 to 40).

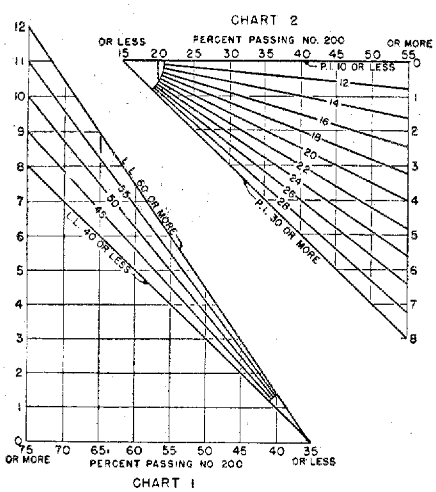
b=that portion of the percentage passing No. 200 sieve greater than 15 percent and not exceeding 55 percent, expressed as a positive whole number (1 to 40).

c=that portion of the numerical liquid limit greater than 40 and not exceeding 60, expressed as a positive whole number (1 to 20).

d=that portion of the numerical plasticity index greater than 10 and not exceeding 30, expressed as a positive whole number (1 to 20).

Charts for graphical determination of group index are shown in figure 40.

The formula will give values ranging from a fraction of 1 to 20, and is so weighted that the maximum influence of each of the three variables is in the ratio of 8 for percent passing the No. 200 sieve, 4 for liquid limit, and 8 for plasticity index.



GROUP INDEX = SUM OF READINGS ON VERTICAL SCALE OF CHARTS 1 & 2

Figure 40.—Group index charts.

Under average conditions of good drainage and thorough compaction, the supporting value of a material as subgrade may be assumed as in inverse ratio to its group index: that is, a group index of 0 indicates a "good" subgrade material and group index of 20 indicates a "very poor" subgrade material.

Definition of gravel, sand, and silt-clay

The terms "gravel," "coarse sand," "fine sand," and "silt-clay," as determinable from the minimum test data required in this classification arrangement and as used in the descriptions of the various groups, are defined as follows:

Gravel—material passing sieve with 3-inch square openings and retained on the No. 10 sieve.

Coarse sand—material passing the No. 10 sieve and retained on the No. 40 sieve.

Fine sand—material passing the No. 40 sieve and retained on the No. 200 sieve.

Combined silt and clay—material passing the No. 20 sieve.

Boulders (retained on 3-inch sieve) should be excluded from the portion of the sample to which the classification is applied, but the percentage of such material, if any, in the sample should be recorded.

The term "silty" is applied to fine material having plasticity index of 10 or less and the term "clayey" is applied to fine material having plasticity index of 11 or greater.

By keeping the above terms and the group test limits in mind, it is possible, with some practice, to make fairly close approximations of the correct classifications by visual examination and handling of the materials in a damp condition.

Investigation of Soil Foundations

The investigation of soil foundations for bridges and embankments may be divided into three parts, as follows:

1. Field exploration and sampling.
2. Laboratory testing of samples.

3. Analysis of field and laboratory data.

In the field exploration of soils, a study of the geology of the area in which the structure is located is often made as an aid in planning the details of the investigation. The purpose of the field exploration is to establish horizontal and vertical limits of the soil layers and to obtain samples that can be used for laboratory testing. Examinations are made by digging test pits or making borings.

Test pits

Test pits are open excavations large enough to permit a man to enter and examine formations in their natural condition. They are by far the most accurate means of determining the in-place character of materials but they are also the most costly. The densities and moisture contents of undisturbed soil samples properly taken from pits are more likely to be representative than those taken by any of the drive-tube methods. On account of the cost, the method is used only when boring methods are considered unsatisfactory.

Borings

Subsurface investigation by means of borings consists of drilling down to the desired depth, removing the material penetrated so that it may be examined at the surface, recording the elevation at which changes in material are found, obtaining samples in disturbed or undisturbed condition from the different strata, and preparing a log or chart of the boring data. Borings may be classified as follows:

1. Soil-auger borings.
2. Wash borings.
3. Churn-drill borings.
4. Rotary-drill borings.
5. Core borings.

The most widely used method is the "wash boring." In this method the penetrated material is removed from the cased hole by means of water. One of two methods may be used, depending on the manner of taking samples. In one method, samples are recovered from the wash water. Samples obtained by this method are suitable for visual examination only.

In the second method, sampling for visual examination is done by driving a section of pipe or a special sampling tool into the soil and extracting a core that has not been cut up and mixed with water. The washing is merely a means of removing the material penetrated by the casing and is not a method of sampling.

Undisturbed samples

Undisturbed samples of soil are taken for the purpose of making laboratory tests to determine soil consolidation characteristics, compressive, and shearing strengths. A core of soil, 18 to 24 inches long, is generally required. The practice of taking samples 2 inches in diameter with thin-walled tubing (Shelby tubing) as a part of the wash-boring operation has become widespread during the past few years. Most authorities agree, however, that samples 4 to 5 inches in diameter are less disturbed by the driving of the sampler and, therefore, are more suitable for testing purposes.

The taking of undisturbed samples involves drilling, forcing the sampling device into the hole, removing, and preserving the sample.

The sample is usually preserved by sealing it in a container with paraffin to prevent changes in moisture content. It should be so packed that the structure will be preserved in shipment.

Undisturbed soil samples can be obtained by drive-tube methods only from fine-grained plastic soils. The presence of granular material in soils prevents the driving of sampling devices without disturbance.

Laboratory testing

In addition to the liquid and plastic limits and the grain size, the shear strength determined by direct shear or by the triaxial compression method, the compressive strength, and the consolidation characteristics are used in the evaluation of soils for foundation purposes.

The direct shear test is made to determine the cohesion and angle of internal friction of fine-grained soil samples. The apparatus used in the Public Roads Administration laboratory (fig. 41) consists of an upper frame that is stationary and a lower one than can be moved in a horizontal direction. The sample is located between two porous stones which serve as drains during the consolidation

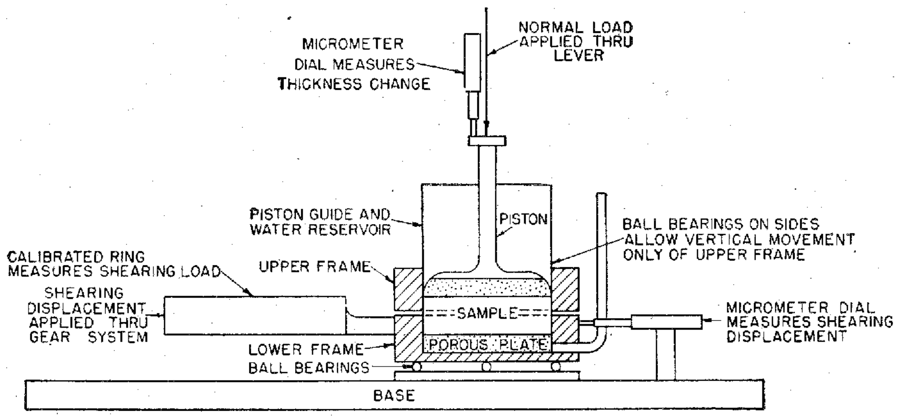


Figure 41.—Direct shear device.

of saturated samples. Before the sample is subjected to shear, a vertical load is applied to the upper stone. The shearing force and the corresponding displacement are recorded. From these data, values of the cohesion and the coefficient of internal friction are obtained.

In the triaxial compression test, the stresses at a point in a loaded soil mass are simulated in a cylindrical sample by applying normal stresses to its faces by means of an apparatus such as is shown in figure 42.

The sample is placed in a rubber membrane, which is clamped to two rigid end plates, the lower of which is connected to a drain. (If desired, the drain may be closed to prevent drainage from the sample.) The lucite cylinder and loading head are assembled and tightened. The head of the testing machine is brought just in contact with the piston. A lateral pressure is applied in the chamber around the sample, the piston is displaced at a constant rate, and the reaction and displacement are recorded. The test is continued until the reaction becomes constant or diminishes. Separate samples are tested with different lateral pressures to evaluate the effect of the variable.

From the data obtained in the triaxial test, the cohesion, angle of internal friction, and modulus of elasticity are computed.

In the consolidation test an undisturbed sample of soil is compressed between two porous stones (fig. 43). The load is applied axially and the sample is confined laterally. The loadings are selected so as to include stress conditions anticipated in the material in the soil profile due to the weight of the overbur-

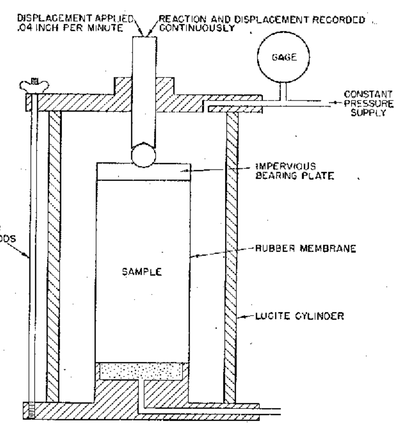


Figure 42.—Essentials of triaxial compression test.

den and the structure. The test loads are applied in increments. Each load is maintained until the change in thickness does not exceed 0.01 percent of the thickness per hour. After each application of load, gage readings are taken at regular time intervals from which the amount and rate of change in thickness can be calculated.

Analysis of test data

The test results obtained in the shear and consolidation tests are used in the calculation of the theoretical bearing capacity of soils in embankment and bridge foundations and in estimating the amount and rate of settlement in such structures due to soil consolidation or displacement. In the complete analysis of a foundation problem, there are many complicating conditions that must be given consideration in arriving at a solution.

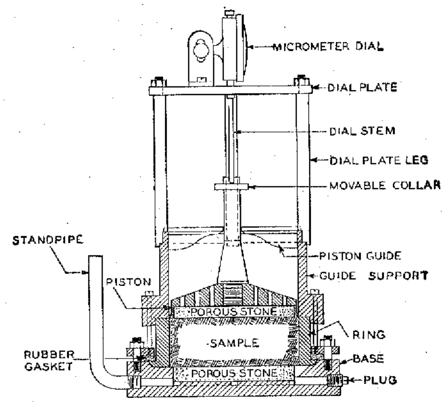


Figure 43.—Consolidometer.

Detailed discussions of the investigation and analysis of soil foundation problems may be found in references [6], [19], [20], and [35–57].

HIGHWAY DRAINAGE

Drainage of highways involves removal of stormwater falling on or draining across the highway, and removal of detrimental amounts of subsurface water which can be drained by gravity flow.

Adequate provision for handling stormwater run-off requires thorough study, beginning with the location of the highway, so as to avoid unnecessarily difficult drainage problems, and continuing through the design of culverts, bridges, and open channels, to the proper maintenance of these facilities after they are constructed.

Objects of Drainage Design

Generally speaking, it is not expected that the ordinary highway will be constructed so that no part of it will be flooded by any storm which might occur during the existence of the highway. Rather, the attempt is to provide facilities which will handle the stormwater flow of frequent storms easily and which can handle the less frequent storms without excessive damage to the highway or to developments affected by the inadequacy of the highway structures to handle the extreme storms. Highways carrying very heavy traffic flows in metropolitan areas, and highways having high strategic importance in the transportation system, will justify the larger expenditures for drainage facilities necessary to keep them in operating condition despite climatic conditions.

Expressed in another way, drainage facilities for ordinary highways ought to be designed so that the ultimate cost, including cost of construction and maintenance, will be a minimum. Since maintenance costs directly connected with drainage are a large item in the maintenance budget, and vary within wide limits depending on the care with which the drainage system is designed, it is always worth while to give close attention to drainage design.

The paragraphs which follow are intended to illustrate briefly the most advanced practice in estimating rates of run-off and providing for the handling of stormwater on highways.

Estimating peak rates of run-off

The logical procedure in drainage design is first to estimate the magnitude and frequency of peak rates of run-off. A first-hand knowledge of local run-off characteristics based on years of experience is always desirable. Good records of stream flow, particularly with respect to stage and discharge of annual floods, provide means for estimating the magnitude and frequency of floods on the streams gaged and, to a lesser extent, on streams similarly situated but not gaged. Flood-flow formulas as published in engineering handbooks are useful as a guide to judgment in the absence of any stream-flow measurements, but should be used with caution, since each was developed with respect to a given area or region, and is of doubtful validity outside that area. The science of hydrology has not developed to the point where it is possible to estimate magnitude and frequency of flood peaks solely from measurable characteristics of the drainage area and knowledge of climatic conditions.

In constructing roads in undeveloped territory the highway engineer is confronted with making decisions as to flood probabilities on the basis of the evidence of previous floods which he can see on the ground. In doing this his judgment will be the better if he has studied the hydraulics of rivers in an area where basic data are available, for he will better be able to interpret the significance of bank erosion, stream-bed sediment characteristics, and evidence of previous highwater marks, not readily discernible to the untrained observer.

Designing Waterways for Bridges

In building across any stream the extent to which the cross section of flow at flood stages is contracted by the waterway provided is very important. On streams in mountainous terrain, with relatively high velocities, it is advisable to bridge the entire width of the flowing stream, placing as few piers in the stream as is economically feasible. The stream is usually confined between high, rocky banks which lend themselves to this type of construction. When the stream emerges into a broad, flat valley on a gradient producing only moderate velocities, the flood waters usually overflow the banks and spread out over the valley. Velocities in the over-bank flow are relatively low and a major part of the discharge is carried within the banks of the normal stream channel. In that case, the bridge need extend only part of the distance across the flood plain, the rule to follow being to avoid creating excessive backwater.

Backwater

Backwater, in the sense here used, is the additional depth of flow, above normal depth in the unobstructed channel, required to build up enough head to give the increased velocity necessary to pass the water through the small cross section under the bridge. For ordinary purposes it may be estimated as the difference in velocity heads for the area under the bridge (at a stage determined by the downstream channel depth for a given discharge) and for the area immediately upstream from the bridge. Since the latter is affected by "backwater" the answer must be obtained by trying successive values of upstream depth until the equation balances [58]. The upstream area should be only that area in the immediate vicinity of the bridge opening in which there can be a substantial velocity component in the direction of flow through the bridge. An allowance may be made for eddy losses and friction losses through the bridge opening by adding an arbitrary percentage to the velocity head under the bridge.

Reduced to a more simple concept, the increase in velocity of flow necessary to pass the flood discharge through the bridge opening should be small. For example, if the normal mean velocity of the unobstructed stream is 5 feet per second at flood stage, a contraction which would increase this velocity to 6 feet per second would not be objectionable since the increase in velocity head would only be $6^2/2g - 5^2/2g = 0.17$ feet. If eddy losses are assumed as 10 percent of velocity head under the bridge, then backwater becomes about $0.17 + 0.06 = 0.23$ feet or roughly 0.2 feet. On the other hand, if a shorter bridge opening forces acceleration of the velocity to 10 feet per second, then the backwater becomes roughly 1.5 feet and is of significant amount. The designer must then decide whether possible damage on the flood plain upstream from the bridge warrants increasing the length of the bridge, and also whether the foundations of the structure are safe against the inevitably deeper scour caused by the increased velocity (assuming the stream bed to be composed of erodible materials).

Overflow channels

On low-traffic roads, where it is not essential that the road be kept open to traffic at flood stages, economy in the cost of the stream crossing can be obtained by building the superstructure of the bridge with clearance above the design flood stage and leaving the approach roadways below flood stage. If the overflow section is of sufficient length it acts as a safety valve or spillway, relieving the bridge waterway of part of the flood discharge. This type of design is applicable to situations where a considerable part of the flood flow is outside the banks of the main stream and the cost of providing a bridge for the entire flood would be excessive. The embankment overflowed need not suffer severe damage if the slopes and shoulders are covered with a dense growth of grass [59], [75].

When the flood plain is very wide there are usually defined overflow channels for which relief bridges must be provided. These structures should be long enough so that they can handle their share of the discharge in the flood plain without excessive backwater. It is inadvisable to provide small openings sufficient only to drain off the water trapped upstream from the highway embankment, because during the rising stage these openings are subject to excessive head, and severe scour will occur in the stream bed through the opening, or, in the case of culverts, at the outlet. On the other hand, there is also a danger of the river channel shifting to the relief opening if the latter is relatively long and the river is of the meandering type.

Unless the superstructure is deliberately designed to be submerged by major floods, adequate clearance should be provided to pass the type of drift usually encountered on the stream.

An extensive channel change to provide a better crossing for the highway should be examined critically, particularly if it involves a substantial increase in the gradient of the stream. Disturbing the equilibrium of an existing channel is likely to have consequences reaching beyond the limits of the channel change itself. This is a problem requiring analysis by an expert on river hydraulics.

Peak run-off

As the drainage areas intercepted by the highway become smaller the stream gradients and the mean velocities usually become greater, although the total discharge usually becomes less (about in proportion to the square root of the drainage area, other factors remaining constant). Figure 44 illustrates a simple method of estimating peak rates of run-off on areas up to 10,000 acres. This is as good as any empirical formula available for general use. A curve is selected by reference to the tabulated drainage characteristics or the peak flow is interpolated between two curves presumed to encompass the particular situation, in any case reading the discharge directly from the drainage area in acres. This value can then be adjusted in the proportion that the 1-hour rainfall in the vicinity bears to 2.75 inches per hour. This correction is only relative, since the intensity of run-off is affected by many factors in addition to the intensity of rainfall,

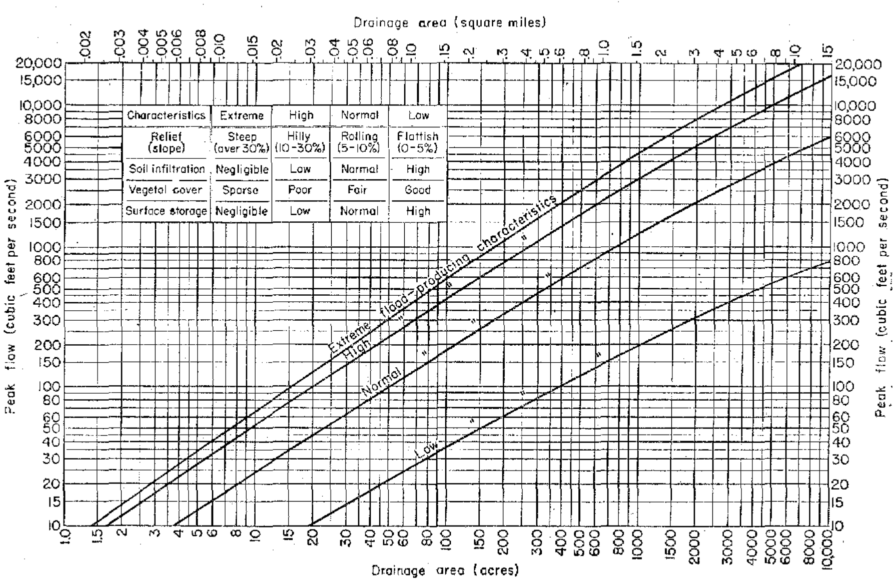


Figure 44.—Peak run-off for storms of 25-year frequency having one-hour rainfall of 2.75 inches.

and can be made only if rainfall intensity records are available [60].

The engineer can tie into this chart by making approximate measurements of floods on small drainage areas and plotting these points on the chart as indexes of the run-off characteristics for those areas. The result will not have much reliability until observations have been made over a period of several years of normal rainfall, and then it should be recognized that it is very probable that the observed maximum may sometimes be exceeded by a wide margin. The measurement of the discharge can be done by selecting a reach of channel of uniform cross section and reasonably straight alinement, measuring the average cross-sectional area up to the high-water mark, and computing the discharge by the Manning formula, using an appropriate value of roughness coefficient. Computations can be facilitated by using hydraulic tables [61], [62], [63].

Figure 44 may also be used for estimating peak rates of run-off in roadside drainage channels, as the first step in determining the need for protection against erosive velocities. Experience in regions where there is sufficient rainfall to support a good turf-forming grass has demonstrated that channels carrying only stormwater flow can be protected by sod laid in the newly constructed channel. The sod will withstand velocities from 4 to 8 feet per second, depending on the kind of grass. A simplified technique for hydraulic design of such channels is contained in an article published in the March 1942 issue of *Public Roads* [64].

Flow of Water Through Culverts

In providing for crossings of small streams, culverts are commonly used instead of bridges. The same basic principles of hydraulics apply, in that the cross section of the flowing water is contracted, with the result that the velocity must be increased. The culvert, whether a pipe, a box, or a multiple of either type, usually requires more change in velocity than a bridge, and can stand higher velocities because the flow is completely enclosed instead of being carried on an erodible stream bed as is commonly the case with a bridge. In erodible stream beds, the jet emerging from a culvert outlet almost inevitably scours a hole since the velocity is higher than the normal velocity in the unobstructed channel. If the apron at the outlet has an adequate cut-off wall the hole does not endanger the structure unless excessively high velocities are developed. In the latter case some form of energy dissipator is advisable [65] because the scour hole may enlarge and cause damage to the highway embankment beyond the limits of the culvert headwalls.

Culverts also differ from bridges in that they are rarely designed to flow partly full with sufficient clearance to pass drift. Most highway departments intend that culverts should operate with the headwater elevation about at the crown of the entrance for the design discharge. The California Division of Highways, which has studied this problem extensively, recommends that the culvert should flow just full at the entrance for the 10-year flood, and should operate under head without serious damage to the highway for the 100-year flood [66].

Two-part design problem

In the past, the Talbot formula (found in most highway engineering texts), which gives the square feet of waterway as a function of the drainage area in acres, applying a coefficient which is supposed to allow for differences in rainfall and run-off characteristics, has been widely used. As a "rule of thumb" this formula is still a good guide, particularly when the user has had many years of experience in a given locality and has had the opportunity to observe how culverts so designed have operated during flood run-off. The element of judgment is so large, however, that the novice is likely to err widely, particularly if run-off characteristics are abnormal, or the culvert installation is unusual.

The present trend is to divide the problem into two distinct parts (1) estimation of the peak rate of run-off for design purposes, called the "design discharge" and (2) design of the culvert by hydraulic methods to carry that design discharge within the limits set up for headwater elevation and outlet velocity. The run-off chart (fig. 44) affords the simplest, and probably the best available means of estimating the peak rate of run-off.

Attention is called to the fact that the design discharge on small drainage areas is of very limited duration, a few minutes for the discharge from one acre and probably less than an hour for any culvert. Where ponds exist on the drainage area the peak of the hydrograph will be lower and flatter than on areas having no pondage.

Hydraulic design of culverts

The designer needs to know how high the water surface will rise at the entrance to the culvert when flowing at the design discharge. This headwater (HW) elevation depends on the size of the culvert entrance alone if the barrel and outflow channel can carry the water away faster than the entrance can admit the flow [67].

For example, if the design discharge for a 36-inch concrete pipe is 20 cubic feet per second and the fall in the pipe is 0.02 foot per foot, then figure 45 incates that the pipe will flow at a depth of about 1.0 foot after normal flow has been established some distance from the entrance, provided the tailwater (TW) elevation does not submerge the outlet and force the pipe to flow full. Note, also, that the velocity at the outlet will approach 10 feet per second (if the pipe is long enough and the outlet channel does not cause backing-up). Actually, since the velocity is greater than the critical velocity, which is read from the dotted curve to be 6.0 feet per second for this discharge, the TW could rise almost to the crown of the pipe without affecting the depth of flow inside the barrel.

If the slope of the pipe is as flat as 0.001 foot per foot the barrel must flow full, since figure 45 indicates that the maximum capacity of a 36-inch pipe on that slope is about 18 cubic feet per second (not under head). For grades between 0.001 and the critical slope of about 0.005, the profile of flow in the barrel can be affected by the TW elevation. For example, the normal depth of flow for 20 cubic feet per second on a 0.002 slope is 2.0 feet; if the TW depth at the outlet exceeds 2.0 feet measured from the pipe invert, then the depth of flow in the pipe will not drop down to an elevation less than the TW elevation.

Types of flow

Flow through ordinary culverts may be classified into three types depending on where the control determining the HW elevation lies. Figure 45 provides the means for classification after which figure 46 [3] or figure 47 may be used to estimate the HW elevation. The dotted line in figure 45, labeled "critical", is the key to the classification. The criteria are as follows:

1. If the discharge ordinate intersects the line for the slope of the pipe at a point above the dotted line, the control lies at the entrance and figure 46 applies, provided TW does not submerge the outlet.
2. If the discharge ordinate intersects the line for the slope of the pipe at a point below the dotted line, the control is somewhat indefinite, but for practical purposes the HW elevation estimated from figure 46 may be used, provided TW does not rise substantially above the normal depth read from figure 45 at the point of intersection of discharge and slope.
3. If the discharge falls to the right of the hooked end of the slope line, the pipe must flow full and figure 47 applies.

Figure 46 is strictly applicable only to entrance control on a round pipe whose inner surface meets the outer face of the headwall in a 90° angle to form what is commonly called a square-edged entrance. Experiments now in progress indicate that for any headwater elevation above the crown of the pipe a relatively large increase in discharge can be obtained by rounding off this square corner. Conclu-

[3] Fig. 46 is adapted from The Hydraulics of Culverts by F. T. Mavis, as published in *Concrete Pipe Lines* by the American Concrete Pipe Association.

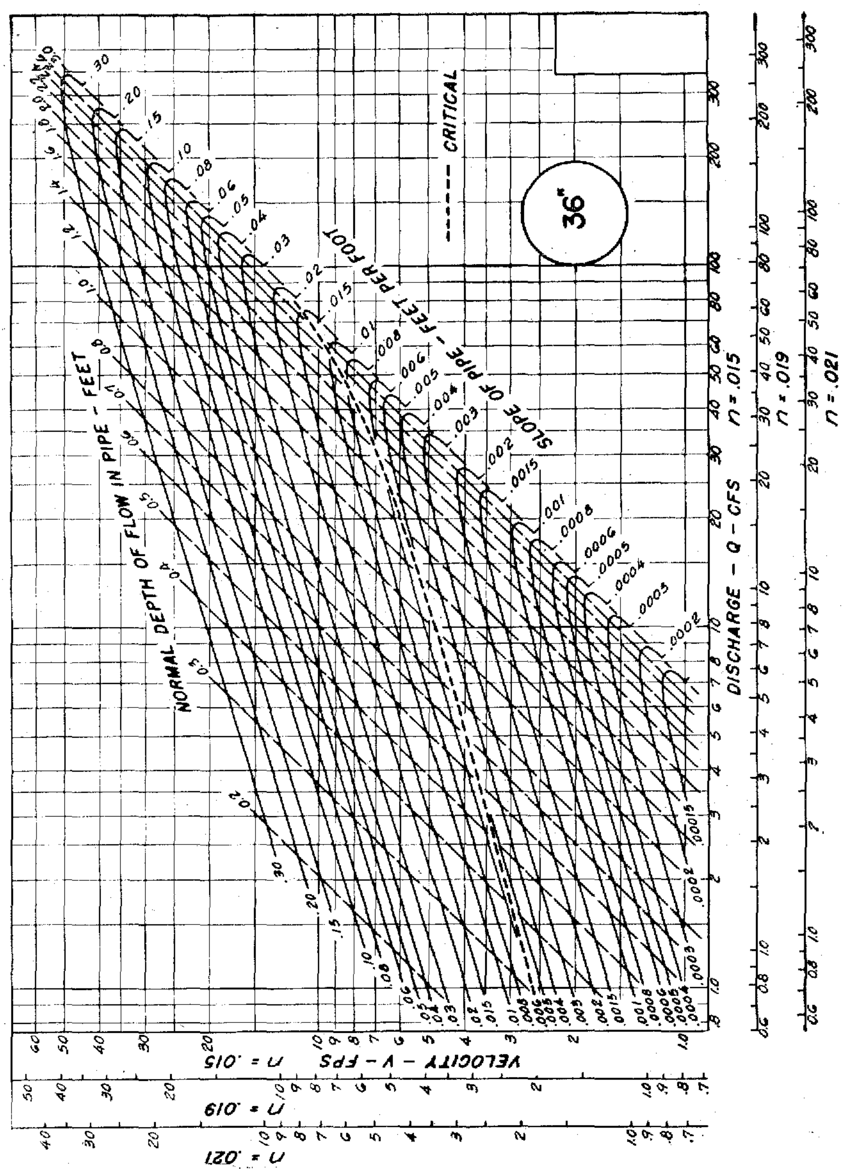


Figure 45.—Pipe flow chart; 36-inch diameter.

sive results for entrances other than square-edged are not yet available.

For example, a 36-inch concrete pipe on a 0.02 slope would operate with entrance control at 20 cubic feet per second since the discharge ordinate in figure 45 intersects the slope line above the dotted line for critical depth. Thus from the first criterion above, figure 46 is applicable for estimating HW elevation. A straight-edge laid across figure 46 through $D=36$ and $Q=20$ intersects H/D at 0.72 from which $H=0.7\times3=2.1$ feet measured from the invert. This is below the crown of the pipe so the answer is substantially correct whether the entrance corners are square or rounded.

But if the discharge had been 80 cubic feet per second on the same slope, the pipe would still not flow full at the out-

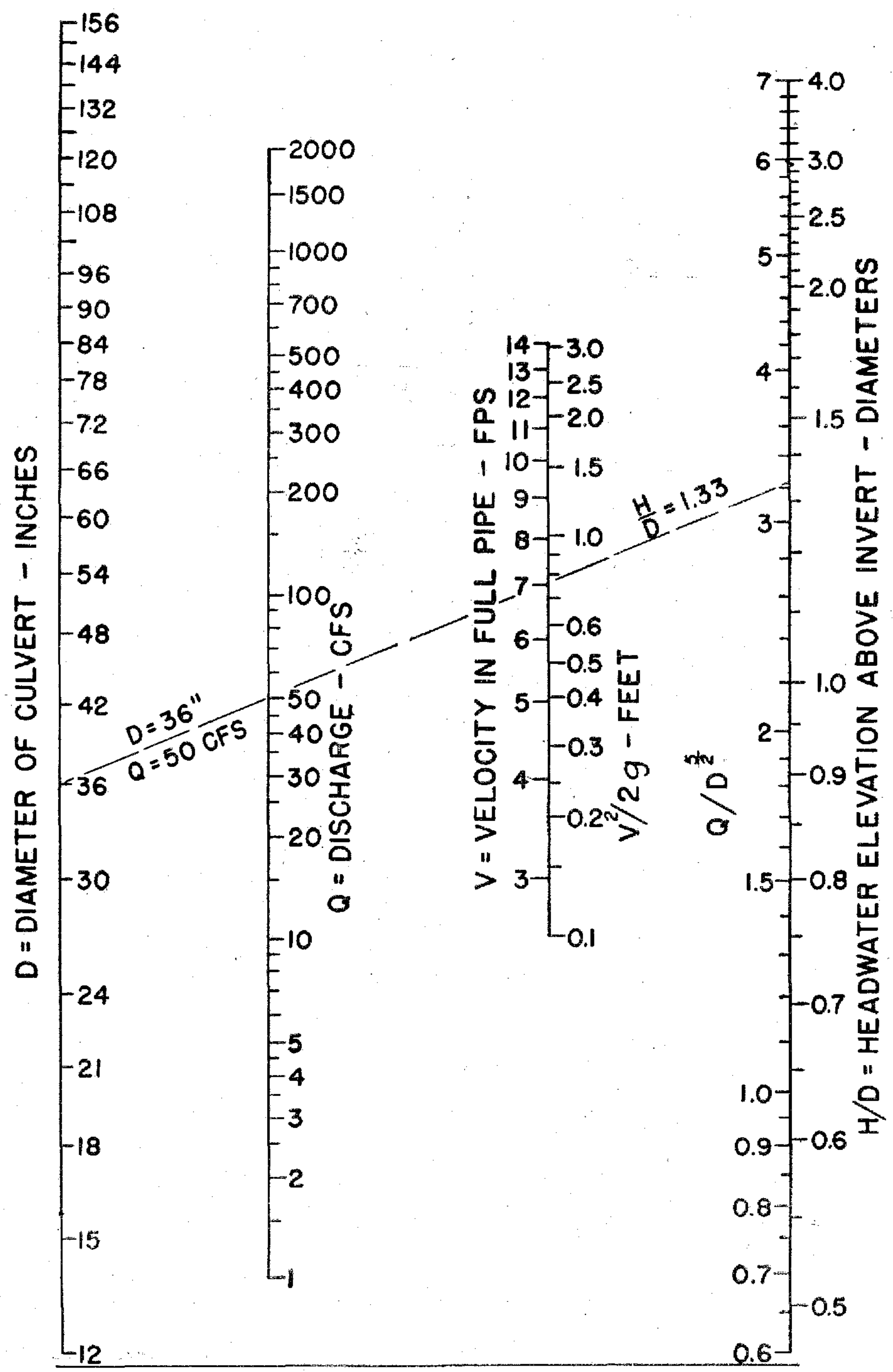


Figure 46.—Nomograph for pipe culverts not flowing full (applies only to square-edged entrances).

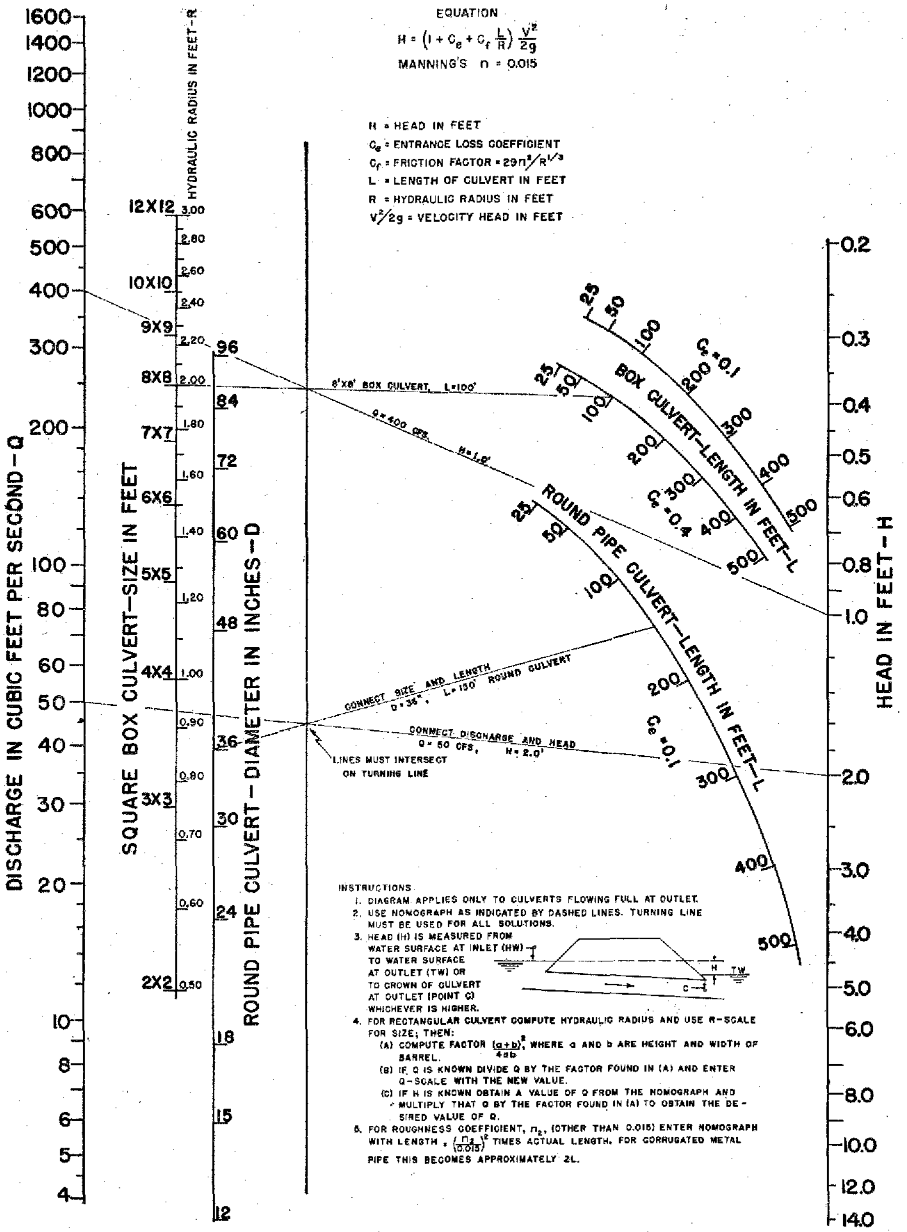


Figure 47.—Nomograph for culverts flowing full.

let and H/D would be 2.3 making HW elevation 6.9 feet above the invert. In this range of H/D figure 46 is correct only for a square-edged entrance. Actually, with the bell-end of a concrete pipe placed flush with the face of the headwall, as is usually the case, the HW elevation would probably be substantially less than 6.9 feet because the recess in the bell has the effect of eliminating the square corner between the inside wall of the pipe and the headwall.

With culverts flowing full, figure 47 provides a simple method for estimating the total loss of head. This head loss must then be added to the TW elevation to obtain the HW elevation unless the TW is below the crown of the pipe at the outlet, in which case the head loss would be added to the elevation of the crown of the pipe.

In order to estimate the TW elevation in the outlet channel, charts similar to figure 48 may be used, provided the cross section and gradient of the channel are reasonably uniform, and provided further that there is no flood stage in the main stream into which the channel discharges, sufficient to cause backwater at the culvert outlet. In the latter case, of course, the elevation of the flood stage determines the TW elevation on which the HW elevation would depend.

If a discharge of 20 cubic feet per second is assumed for a channel of the cross section indicated in figure 48, the depth of flow would be about 1.2 on a 0.01 slope, or 2.0 feet on a 0.001 slope. The latter depth would have no effect on the 36-inch pipe laid on a 0.02 slope, nor would it affect the HW elevation of the same culvert on a 0.001 slope, since the TW does not rise above the crown of the pipe. If a flood stage of 4 feet above the invert of the outlet existed at the time the culvert was discharging 20 cubic feet per second, then, from figure 47, the HW elevation would be 0.3 foot higher than the flood stage at the outlet (assuming a culvert length of 150 feet). A 24-inch concrete pipe of the same length would have caused 2.2 feet of backwater for the same discharge.

The Public Roads Administration is preparing a full series of pipe and open-channel flow charts similar to figures 45 and 48, which will be accompanied by a text explaining how these charts and other hydraulic techniques may be applied to practical design problems.

Subsurface Drainage

Problems in subsurface drainage are less subject to hydraulic analysis than problems of the removal of storm water on the surface. The very existence of the problem is sometimes unsuspected until the contractor opens up a deep cut, or even later when an apparently good base course begins to fail under traffic because of an excess of water. The former situation results from excavating below the ground-water table and may require only provision for conveying the outflow in an open channel to the mouth of the cut. More frequently, however, the water-bearing stratum may extend below the subgrade and, depending on the nature of the subgrade soil, may require installation of an intercepting drain pipe in a deep, pervious backfilled trench. In the absence of a natural water-bearing stratum the latter case of base-course failure may result simply from the leakage of surface water in the base course along the edges of the pavement or through cracks or joints in the pavement.

Subsurface drainage is usually tied in closely with the stability of subgrades, base courses, and embankment or cut slopes and therefore must be studied along with the soils problems. Hydraulic design comes in primarily with respect to permeability of the soil strata, the base courses, and the filter material placed around the drain pipe. The rate at which water can be drained by gravity in nearly all cases, excepting springs, in open-fissured rocks, or very pervious gravels, is so slow that a 6-inch drain is generally as large as is needed, unless the length of the line exceeds a thousand feet, more or less, or the gradient is extremely flat.

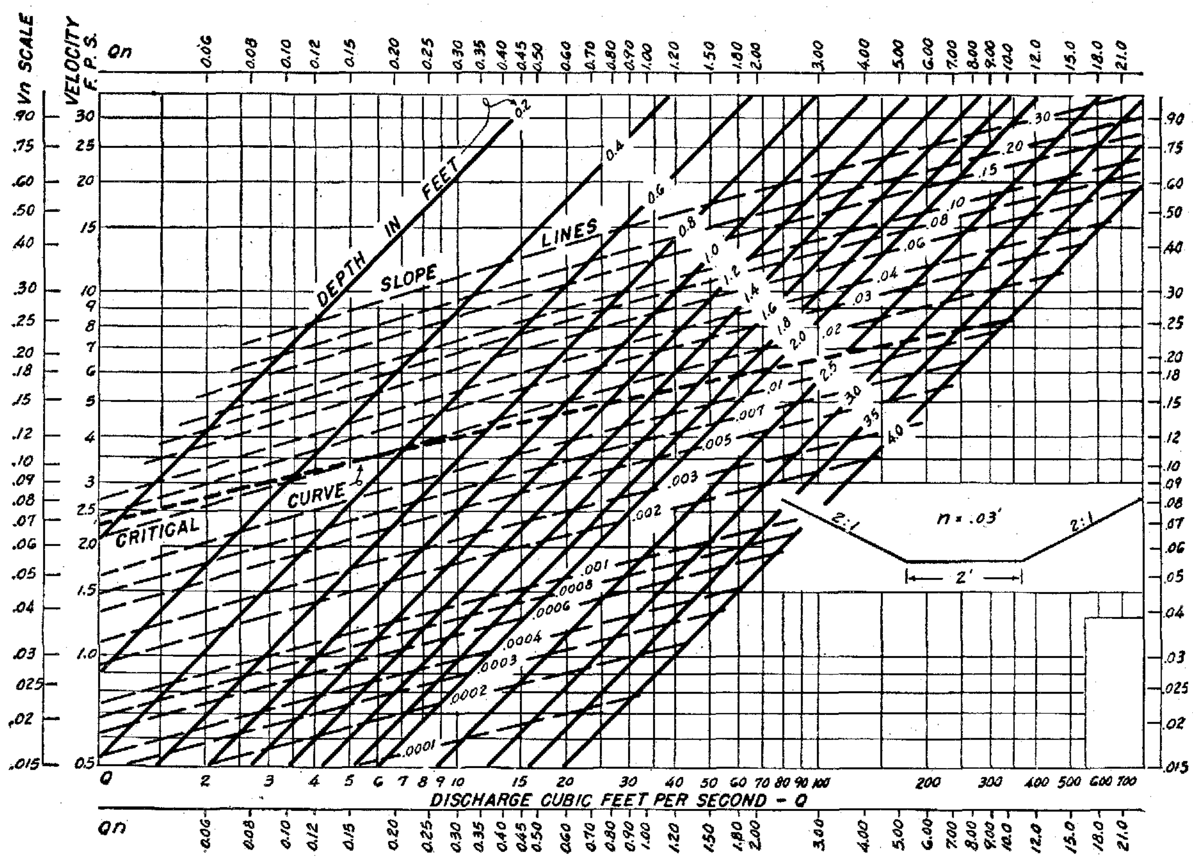


Figure 48.—Channel chart (2:1 side slopes, bottom width 2 feet).

Backfilling

The most important considerations are placing the drain in the position where it can accomplish the desired purpose, and backfilling the trench with a filter material which will not clog on the one hand or be washed away into the drain pipe on the other. For the majority of fine-grained sandy and silty soils a concrete sand (sand having the gradation required for portland cement concrete) forms a satisfactory filter (or backfill) material, provided the openings in the drain pipe are equal to or less than half the size of the screen opening which will pass 85 percent (by weight) of the filter material. The filter material must be so graded that the maximum size of the finest 15 percent is equal to or less than five times the maximum size of the finest 85 percent of the soil being drained. To permit free drainage of water through the filter the maximum size of the finest 15 percent of the filter material should be equal to or greater than five times the maximum size of the finest 15 percent of the soil being drained. Percentages are by weight [68], [69].

Intercepting drains

If the subsurface drain is intended to intercept movement of ground water into the face of a cut, or into the subgrade of the roadway, it is necessary first to locate by borings the interface between the water-bearing stratum and the less pervious stratum lying beneath it, and to determine the direction in which the water normally flows. The stratum may be under pressure, so the dip of the bed does not necessarily prove the direction of water movement. The subsurface drain should be located, if feasible, so as to intercept the ground water before it reaches the part of the highway which is to be protected; generally the trench should be recessed slightly into the less pervious stratum underlying the water-bearing stratum. A method has been developed of jacking perforated drain pipe into holes drilled into the face of cut slopes requiring drainage [70].

Experience has indicated that a pervious base course which does not extend laterally to a face permitting gravity drainage must be provided with a longitudinal subsurface drain to remove water which may enter from the surface. Such infiltration can occur with any type of pavement [68]. The need for a positive outlet for the base course is particularly acute where the longitudinal gradient of the road is less than one percent either continuously or at sag vertical curves [71]. The presumption is that the base course is placed on a soil which will not drain freely, and which would be adversely affected in its load-bearing characteristics by water impounded in the base course.

STABILIZATION OF EMBANKMENTS AND SUBGRADES

The stability of an embankment or subgrade is dependent upon the shearing resistance of the soils of which they are composed. Shearing resistance consists of two properties—internal friction and cohesion. These combined properties of a given soil are affected by the amount of voids in the soil and the amount of water within these voids. A soil mass containing a high percentage of voids will become very unstable when exposed to high moisture conditions. Conversely, a soil mass containing a low percentage of voids will resist the entrance of water and will, in turn, be much more stable than the soil mass containing the higher percentage of voids. Any process which reduces the amount of voids in a soil mass may be called densification.

Compaction of embankments

The most economical and feasible method of improving the supporting power of subgrades and embankments is densification by compaction.

However, compaction cannot be considered a cure-all for obtaining satisfactory subgrades and embankments. Rather, compaction should be considered as an economical means of improving most subgrade or embankment soils. Some types of soil are expansive and may swell when subjected to adverse moisture and temperature conditions even though well compacted.

Moisture-density relations

The density to which any given soil can be compacted depends upon its moisture content and the amount of compactive effort expended upon it. A change in either moisture content or compactive effort produces a change in density. This relationship is utilized to produce soil masses of high density with the least compactive effort.

If a given soil in an air-dry condition is placed in a container and submitted to a definite compactive effort, a certain density (usually measured in pounds per cubic foot) will be obtained. If a small percentage of water is added and the soil is again compacted with the same amount of effort, a greater density is obtained. By repeating this procedure, using the same compactive effort, but increasing the moisture each time, a moisture content will be found for which the density of the soil is a maximum. The moisture in the soil at maximum density is called the optimum moisture content for this compactive effort. If the test is repeated, using a greater compactive effort, a higher maximum density will be obtained at a lower optimum moisture content. On the other hand, if a smaller compactive effort is used, a lower maximum density will be obtained at a higher optimum moisture content. For a given soil, therefore, there are as many "maximum densities" and "optimum moistures" as there are compactive efforts used.

Determination of the moisture-density relations of soil is comparatively simple, involving only procedures for determining unit weight and moisture content of samples subjected to a definite compactive effort. Method T 99–38 of the American Association of State Highway Officials [7] is the one most commonly used by highway engineers. The optimum moisture content is that which gives the greatest weight per cubic foot.

Granular stabilization

Granular-stabilized roads are those which have been made usable in all weather by means of a mixture of soil and aggregate [26].

The significant parts of a soil-aggregate mixture for stabilized road use are the granular fraction and the fine-soil fraction consisting of silt and clay.

Granular fraction.—With the possible exception of mica flakes and peat particles, all materials retained on the No. 200 sieve can be considered suitable granular material. In selecting the source, consideration should be given to the durability of the material.

Fine-soil fraction.—That portion of the material which passes the No. 200 sieve is responsible for the muddy condition of the road observed in wet weather. It consists principally of silt and clay.

Silt.—Silt includes the coarser grains of the fine-soil fraction and can be readily distinguished from clay by its grittiness if a tiny amount is placed in the mouth and bitten between the teeth. Silt alone can become very unstable when wet but does not produce a sticky mud.

Clay.—Clay particles are smaller than silt particles and give no sensation of grittiness when bitten. It is the clay particles which become cohesive when wet and therefore produce tenacious mud.

The process of granular stabilization may be used for constructing either surface or base courses. Design recommendations for base courses are different from those for surface courses because the functions of the two courses are not the same.

More clay is used in the surface course because it must (1) have resistance to traffic abrasion, (2) shed a large portion of the rain that falls on the surface, and (3) have sufficient capillarity to replace surface evaporation so that the clay will retain its binding properties. Base courses are protected by a surface which gives protection from traffic abrasion, sheds rain, and prevents surface evaporation.

Generally, granular mixtures which are designed for surface courses fail when covered with an impervious surface. The larger percentage of clay which is necessary to satisfy the requirements for a surface course will soften when surface evaporation is arrested by an impervious wearing course and the entire mass will lose stability.

Thus, to control the above conditions, the factors in the design of granular stabilized roads are gradation, resistance to abrasion, and the plasticity characteristics of the mixture. Specifications for both base and surface courses may be found in the standard specifications of the American Association of State Highway Officials [27].

The design of soil-aggregate mixtures are described in references [6], [26], and [27].

Chemical treatment for stabilization

Admixtures of a chemical nature may be used with well-graded soil-aggregate mixtures to improve their performance, or with fine-grained soils where no aggregates are available to change their physical properties, in such a manner as to make them more suitable for use as base courses.

Calcium chloride, sodium chloride, lignin, etc., and small percentages (1 to 2 percent) of bituminous materials may be used with the granular mixtures [26], [28], [29]. These chemicals must be used with well-graded materials if they are to be successful. Stability is provided by the granular particles. The function of the admixtures is to maintain the materials at or near the moisture content of maximum stability.

Portland cement is used to stabilize fine-grained soils on highways which carry light to medium traffic. Protective surface courses are usually used to minimize the effect of traffic abrasion.

The design of soil-cement mixtures is based on standard freezing and thawing and wetting and drying tests [7]. One set of laboratory samples is subjected to designated periods of wetting and drying and another set is tested by alternate freezing and thawing. In both types of test the samples are brushed, at designated intervals, with a wire brush and a record made of the material removed. At least three, and sometimes four percentages of cement are used in the testing program. The smallest amount of cement which results in a negligible loss of material at the completion of 12 cycles of freezing and thawing or wetting and drying is selected for construction purposes [30].

Bituminous stabilization

Bituminous stabilization of fine-grained soils is in the development stage. Suitable test methods are under discussion and experimentation, and requirements vary greatly with climate, topography, drainage conditions, etc., as well as with proposed service [29]. Depending upon their significant properties, the materials may consist of the natural soil in the roadbed with or without granular admixture, or may be obtained elsewhere and hauled to the roadbed. Bitumen may be added by mixing on the roadway with blade graders or traveling mixing plants, or at the source of supply by a stationary plant. This soil-bituminous mixture should be thoroughly consolidated on a prepared subgrade by rolling in accordance with the specifications.

The use of resinous waterproofing agents is even more in the experimental stage than is the use of bituminous materials. Tests in the laboratory indicate that certain resins have decided possibilities in waterproofing soils even though present in very small amounts. Experimental sections of road have been built but none of them is of sufficient age to permit drawing conclusions.

TYPES OF ROAD SURFACES AND PAVEMENTS—THEIR USES AND DESIGN

Low-Type Surfaces

About half of the total road mileage in the United States is unsurfaced. Many of these roads, because of their minor importance, will never be improved with more than low-type surfaces of sand-clay mixtures or gravel or crushed stone. Such surfaces, if well built, are quite adequate for low volumes of traffic.

Sand-clay surfaces

In areas where gravel or crushed stone is expensive a sand-clay road constructed by methods approximating the method of granular stabilization, previously described, is relatively economical. Such a surface may also be constructed as a first stage of improvement in the expectation that it will become the sub-base for a better surface to be built in time. Under proper maintenance and light traffic it has proved very satisfactory.

The sand should be composed of hard, sharp, and durable particles. The binder should have a plasticity index not less than 4 or more than 9.

The mixture should approximate the following grading limits:

Requirements	*Percentage by weight*
Passing 1-inch sieve	100
Passing No. 10 sieve	45–100

The fraction passing the No. 200 sieve should not exceed 25 percent of the total soil mortar. The surface must shed a large portion of the rain water if it is to prove satisfactory. Special attention should therefore be given to the compaction of the material to a suitable density and to the shaping to a satisfactory crown.

In its simplest form the sand-clay surface is formed of a layer of selected natural soil consisting of a mixture of clayey or silty material and sand. In this form it is generally called a top-soil surface, from the fact that the material is often stripped from the surface of nearby land. If necessary separate sandy and clayey materials are distributed over the subgrade in the necessary quantities, and mixed in place by plowing, harrowing, and blading. If the surface resulting from the original construction is not uniformly satisfactory, it may be improved by addition of a suitable natural or manufactured stabilizing material as a maintenance operation.

Gravel surfaces

Gravel surfaces, as they are built in the United States, generally consist of particles or fragments of stone or gravel as a coarse aggregate and a filler of sand or other finely divided mineral material. The size of the coarse aggregate may vary from 1½ inches to that just retained on a No. 4 sieve. The portion passing a No. 4 sieve is considered filler. Oversize material encountered in deposits from which the surface course is produced may be removed by screening or crushed to the desired size.

The composite surface course should be free from vegetable matter and lumps or balls of clay and should meet requirements previously determined for durability and gradation. If filler is necessary in addition to that naturally present, it should be blended with the coarse material on the road or at the screening plant.

A crushed gravel or crushed stone surface course is constructed similarly, except the coarse aggregate is gravel or stone material that has been crushed to desirable sizes and recombined in appropriate proportions of the several sizes.

Types of Bituminous Material and Their Uses

By definition, in the United States, that portion of tar, petroleum, asphalt, or asphaltic material that is soluble in carbon disulfide is designated as bitumen. The bituminous materials used in the construction of highways in this country are asphalts, liquid asphaltic road materials, asphaltic emulsions, rock asphalts, and road tars [7], [77], [79–83].

Asphalts

Asphalts are solid and semisolid cementitious materials that gradually liquefy when heated and are composed entirely or essentially of bitumen. The majority of asphalts in use in this country are produced by the refining of petroleum. Native asphalts, such as Trinidad and Bermudez, are refined and fluxed for use as road binders.

The solid asphalts, when powdered, are used with suitable fluxing oils for the construction of seal coats and cold-lay bituminous concretes. Pretesting of the powdered asphalt and flux, intended for use, is necessary to insure that the constituents will blend readily to a homogeneous adhesive asphalt cement under traffic and normal atmospheric temperature.

The softer grades of semisolid asphalts are used for hot surface treatments and in the construction of seal coats. The intermediate grades are used as binders in the construction of penetration macadam and bituminous concrete pavements. The harder grades are used in hot-mix pavements such as bituminous concrete and sheet asphalt. The selection of the most suitable grade of semisolid asphalt for a particular type of construction is based on the probable traffic density and the normal climatic conditions to be met.

Liquid asphaltic materials

Liquid asphaltic road materials are sometimes produced from petroleum either by dehydration or by distilling off the lighter constituents. Generally they are prepared by blending suitable grades of asphalt with certain petroleum distillates to obtain fluid materials that have the proper consistency and volatility for the construction of particular types of bituminous road surfaces. Liquid asphaltic road materials are classified as rapid, medium, and slow curing. Each class is produced in six grades, based on the amount of diluent used and the range in consistency as determined by the Furol viscosity at stipulated test temperatures.

Rapid curing materials (RC) are produced by fluxing asphalt, generally of the 85/100 penetration grade, with petroleum distillate such as naphtha or gasoline. The volatility of this type of diluent permits the early development of a residual binder that approaches the consistency of the asphaltic base material used in the manufacture of these products. These materials are used in cold and hot surface treatments and as tack coats. They are used in road mixing of fine-graded aggregates containing little dust and with aggregates of the macadam type. The more viscous grades are used in plant mixes with similar types of aggregates.

Medium curing materials (MC) are produced by fluxing asphalts of the 85/100 penetration grade with petroleum distillates of the light fuel oil type. Medium curing materials lose their volatile matter more slowly than do the rapid curing materials and the resulting asphaltic residues are generally softer than the base asphalts used in their preparation. The lighter grades of these materials are used for priming. The intermediate grades are used for road mixing with dense-graded aggregates containing a high percentage of material passing the No. 200 sieve. Plant mixes of dense-graded aggregate containing some material passing the No. 200 sieve are prepared with the two most viscous grades of MC material. These grades are also used in hot surface-treatment work.

Slow curing materials (SC) may be either crude or partially refined petroleums of low volatility. Generally, they are produced by blending asphalts of various consistencies with relatively nonvolatile petroleum distillates such as gas oil. Materials of this grade from various sources may have a relatively wide range in volatility but the residual binder seldom approaches the consistency of a soft asphalt. Various grades of this type of material are used as dust layers, mulch treatments, and in road and plant mixes with aggregates containing considerable dust, especially where it is contemplated that the road surface may need reprocessing. The heavier grades are used also as binders in hot surface treatments.

Emulsions

Asphaltic emulsions used in road construction are usually of the oil-in-water type. They are manufactured in three classes, depending on the speed at which the asphalt globules coalesce. Quick-break or quick-setting emulsions are used for surface treatment and penetration macadam. Medium-break emulsions are used as binders in road- or plant-mix using macadam-type aggregate. Slow-break emulsions are used generally in road- or plant-mix construction with graded aggregates containing a high percentage of fines and dust, and also in soil stabilization work.

Emulsions in which globules of water are dispersed in the asphaltic material are known as water-in-oil or inverted emulsions. Materials of this type, containing from 8 to 16 percent water and prepared with cutbacks, RC–2 and RC–3, are used in some areas for surface treatments and open-graded aggregate mixtures. They are considered to be efficient binders, especially with moist aggregates.

Road tars

Road tars, used in this country, are prepared from tars produced by the destructive distillation of coal in gas works and coke ovens and from tars produced by the decomposition of petroleum or petroleum distillates when these materials are used as enriching agents in the manufacture of carburetted water gas. The tars from these sources are refined and are then combined with tar distillates or very fluid water-gas tars to make the various grades of road tars in general use.

The lighter grades of road tars are used as primes and for cold surface treatments. The somewhat more viscous grades are used for road-mix construction. The less viscous grades of the hot-application tars are used in hot surface treatments and in hot-mix, cold-lay mixtures with coarse aggregates. The most viscous grades are used in penetration macadam and bituminous concrete.

Rock asphalts

Rock asphalts, which are found in various sections of the United States, are limestones and sandstones naturally impregnated with liquid, semisolid, or solid asphalts. The amount and consistency of the binder in these asphaltic rocks determine the type of processing and the type of construction. These materials generally require crushing. Some of them are used without further processing. Generally, however, they are blended with asphalt or flux, or with nonbituminous aggregate. Rock asphalts are used as seal coats and as hot- or cold-laid wearing courses.

Aggregates for Bituminous Construction

Aggregates may be grouped in two general classes: Those that are manufactured from quarried stone or by crushing and screening gravel or slag to meet specifications for standard paving mixture types; and those that are used, after a minimum of processing or as found in pits or stream beds, for low-cost and intermediate types of construction [7], [78], [83–87].

Generally the type of construction, selected on the basis of the type and amount of traffic to be served, dictates the quality and grading requirements of the aggregate, although there are several sections of the country where this general rule does not apply because of the lack or scarcity of good aggregate supplies. In such instances, ingenuity and resourcefulness are required on the part of the engineering staff to devise satisfactory highways from whatever materials may be available.

Ideal aggregate

Without regard to availability, cost, etc., the ideal aggregate for bituminous construction would have the following characteristics:

1. Strength and toughness.
2. Good crushing characteristics which would result in the production of a high percentage of chunky particles and a minimum of flakes and slivers or unduly thin and elongated pieces or dust.
3. Low porosity. (Porosity should not, however, be completely lacking.)
4. Hydrophobic characteristics.
5. Particle size and gradation appropriate to the type of construction.

All of the above characteristics except size and gradation and, to some extent, crushing characteristics, must necessarily be inherent in the aggregate selected if the finished product is to be of the highest quality. The processing required in producing the so-called manufactured aggregates consists mainly of crushing and screening to produce the particle sizes and gradings required for the various types of construction, and of washing the crushed product to remove undesirable materials such as clay, loam, organic material, and excessive amounts of rock powder.

In selecting aggregates from local sources for low-cost and intermediate types of construction, it is often possible, and always desirable, to maintain just as high quality standards as for the more expensive types. As a practical matter, however, it is often necessary to waive one or more of the requirements, in part at least, for considerations of economy or availability. Often, where this is necessary, it is possible to compensate for the reduction in quality of the aggregate by slight modification of the grading and mixture design.

For instance, it is generally required that the Los Angeles abrasion loss on aggregate for surface treatment or macadam should not exceed 35 and 40, and on aggregate for high type of mixed surfacing should not exceed 40 or 45 percent. However, aggregate not meeting these requirements for hardness can be used if the type of construction will permit increasing the percentage of fine material to produce a cushioning effect on the coarse aggregate and protect it from degradation during compaction.

Low porosity

Low porosity is an important property of aggregate for bituminous work regardless of the class of construction. High porosity, evidenced by high absorption, will generally increase the cost of the pavement because of the higher bitumen requirements. No allowance in extra bitumen is necessary when the absorption of the aggregate is 1 percent or less and this amount of porosity is desirable since it aids adhesion of the bituminous film. However, when the absorption of the aggregate is over 1 percent, an allowance should be made in the bitumen requirements to compensate for it.

Resistance to stripping

Resistance to film stripping, or hydrophobic quality, is important for all aggregates for bituminous work. This property is difficult to measure accurately and the factors that affect it are not fully understood although it is thought that both surface chemistry and surface texture or porosity are involved. In recent years several chemical treatments and proprietary compounds have been developed to improve the adhesion of bituminous material to the aggregate particularly where tests show the aggregate to be hydrophilic, or especially susceptible to film stripping in the presence of water. Some of these so-called anti-stripping compounds and treatments seem to be very effective in the early stages of service when used in connection with liquid asphaltic materials. They should be of special value on winter and spring maintenance work because there are some of them that make possible the coating of wet aggregate and the adhesion of bituminous patches to wet pavements. The permanence of these benefits has not as yet been established but, regardless of their permanence, the most effective of these materials have a definite value.

Particle size and grading

The maximum particle size and the grading of the aggregate are factors that have a most important bearing on the appearance, strength, and durability of the bituminous pavement. Surface treatments, for example, may vary considerably in thickness depending upon the specification requirements for quantity of binder and cover; but a fundamental requirement for the aggregate is that the first or main stone course should be composed of uniformly sized particles, the diameter of which is approximately the same as the thickness of the proposed surface treatment.

For dense mixtures, on the contrary, the aggregate is graded in size from that of the largest particles to dust, and the distribution of the size fractions is such as to produce a dense finished pavement. If the largest particles are too coarse or if an excessive percentage of coarse particles is present the mixture will have a tendency to segregate during handling and laying operations and the result will be an unsightly surface finish and poor sealing. Generally, mixtures in which the maximum size of the aggregate particles is ¾-inch or less will not show objectionable segregation. If, on the contrary, the maximum size is 1 inch or more, segregation is difficult to avoid unless the mixture is heavily sanded.

Stability

Workability and surface finish, while important, are secondary to considerations of stability, or strength to carry the traffic load without shoving or rutting, and high density to promote durability. These factors are, to a large extent, influenced by the grading of the aggregate. Grading requirements for such mixture types as sheet asphalt, bituminous concrete, and dense-graded road mix are well established and are to be found in the standard specifications of the State highway departments, engineering agencies of the Federal Government, and in the handbooks and manuals of various technical organizations and producers of road materials.

These more or less fixed requirements constitute the factor that generally necessitates special manufacturing or processing of commercial aggregates. They are well justified where the construction is of the highest type, as for city streets and main highways, since they tend to result in a good degree of uniformity of the finished product under adequate inspection control. There are, however, frequent instances in low-cost work where it is impractical to bring the grading of the aggregate into exact compliance with standard requirements. In such cases it is frequently possible to obtain sufficient density and stability by blending aggregates from two or more neighboring pits or even from different parts or levels of a single pit on the basis of preliminary laboratory studies of the specific materials involved and without regard to set grading requirements. This is a highly important phase of highway development, since it encourages the fullest utilization of local materials and makes it possible to build reasonably good roads where funds are limited and where supplies of standard materials are scarce or expensive.

Fillers

Rock powders or fillers are generally used in dense-graded aggregate mixtures to improve both density and stability. Limestone dust, having about 85 to 95 percent passing the No. 200 sieve, is the most widely used of the fillers. However, there are other powders that are used successfully. These include portland cement, slate dust, blast furnace slag dust, some trap-rock dusts, and "fly ash" from steam power plants. Two quality attributes are necessary: (1) that the dust shall be hydrophobic in character, and (2) that it shall be fine enough so that most of it will pass the No. 200 sieve and graded so that an appreciable portion will be even finer.

Types of Bituminous Surfaces and Their Uses

In order to meet the many different requirements of service under a wide range of climatic conditions and to compensate for deficiencies or exploit special qualities of the aggregates and bituminous materials most conveniently and economically available, many types of bituminous construction have been developed. These types are classified as follows:

1. Surface treatments and seals.
2. Rock asphalt.
3. Penetration macadam.
4. Mixtures:
   (*a*) Those that are laid hot:
      (1) Dense-graded bituminous concrete.
      (2) Open-graded bituminous concrete.
      (3) Sheet asphalt.
      (4) Sand asphalt.
   (*b*) Those that are laid cold:
      (1) Dense-graded road mix.
      (2) Open-graded road mix.
      (3) Dense-graded plant mix.
      (4) Open-graded plant mix.

Specifications covering, in detail, the requirements for materials and construction procedures for these types have been prepared by the State highway departments, Federal agencies, and trade and technical associations, and are readily available [84–86]. Accordingly, only broad distinctions and a few of the considerations leading to the choice of specific types will be discussed here.

Surface treatments and seal coats

Seal treatments are intended primarily to protect or enliven already existing bituminous surfaces. They consist essentially of a single application of bituminous material and a cover of relatively fine aggregate such as sand or stone screenings.

Light surface treatments are used where improvements in textural qualities are needed to provide resistance to skidding and better visibility for night driving. The cover aggregate used for this purpose is a one-size material, somewhat coarser than that used in seal treatments.

Heavy or multiple surface treatments are used on old surfaces when it is desired to add appreciable thickness or to improve riding qualities. They are also used as the wearing course on newly constructed, primed bases composed of such materials as stabilized soil, gravel, and water-bound macadam.

The single-application treatment, as its name implies, consists of one application of bituminous material and one application of cover aggregate of a size to give the desired thickness.

The multiple-application treatments involve from two to four spreads of aggregate, the first of which is of such size and quantity as to determine essentially the thickness of the completed wearing course. The succeeding spreads are of progressively smaller size and quantity to provide key, choke, and seal. Each spread of aggregate is preceded by an application of the selected bituminous material in appropriate quantity and is followed by rolling. The total amount of bituminous material in the finished wearing course will vary from 7 to 10 percent of the dry weight of the total aggregate. A convenient method of estimating quantities is to allow 0.1 gallon of bituminous material for each 10 pounds of cover aggregate. The procedure requires some modification to prevent flooding when bituminous materials of low viscosity are used.

Penetration macadam

Penetration macadam, widely used in former years, is now limited to localities where especially tough, durable aggregates abound and where the peculiar requirements for the building of smooth-riding surfaces of this type are well understood. Penetration macadam is usually laid on bases consisting of old or new water-bound macadam or gravel. The coarse aggregate is essentially one-size material, the largest particles of which closely approximate, in diameter, the thickness of the completed wearing course. This aggregate is first rolled to produce initial interlocking, after which the first application of bituminous material is made. Smaller aggregate, called keystone, is then spread and rolled. The final, or seal application of bituminous material is then made and covered with small, one-size aggregate.

Some modification with respect to the size of keystone and to the order of applying the first increment of bituminous material is necessary, when emulsions, tars, or other materials of low viscosity are used, to prevent flooding the bottom portion of the course. Great care must be used in each step of the construction, particularly in spreading and rolling the coarse aggregate, to obtain smooth riding qualities.

Plant-mix bituminous mixtures

The preparation of bituminous mixtures in stationary plants permits close control of temperature, moisture content, and mixture composition. For roads carrying heavy traffic, the relatively high cost of plant mixing is considered to be justified by the quality and uniformity obtained.

Among the types of plant mixtures that are extensively used are the following:

1. Bituminous concrete.
2. Sheet asphalt.
3. Sand asphalt.
4. Mixtures containing liquid bituminous materials.

Bituminous concrete and sheet asphalt are the highest types of bituminous construction. Bituminous concrete can be designed to carry the heaviest traffic and is eminently suitable for use on the most important highways. Sheet asphalt, while not as stable as bituminous concrete, is held in high regard for the paving of city streets because of its excellent appearance and superior riding qualities. It is laid as a wearing course on a binder course of bituminous concrete.

Sand-asphalt and the graded mixtures containing liquid bituminous materials are similar in appearance and general characteristics to the two types described above, but are built under less exacting specification requirements for less rigorous service, and are widely employed where it is desired to obtain the greatest possible use of local materials.

Bituminous concrete, sheet asphalt, and sand-asphalt contain binders of penetration grades and consequently are mixed hot. Mixtures containing liquid bituminous materials, on the other hand, are mixed at only slightly elevated temperatures. Recent developments in mechanical equipment have resulted in improved control of proportioning and mixing operations. The development of highly efficient spreading and finishing equipment has resulted in the almost universal abandonment of hand raking and finishing.

Traveling-plant or road-mix bituminous mixtures

The traveling-plant or road-mix type of bituminous construction owes its early development to the need in certain areas for extensive mileages of road improvement with an absolute minimum of funds and the consequent need for the fullest exploitation of local aggregates and the simplest and least expensive construction equipment.

The development of many successful types of traveling plants has brought about improved processing and control of proportioning as well as substantial economies.

The major portion of the construction of this type utilizes aggregates from natural banks and pits or from the roadway itself. The bituminous materials used are of the liquid type, the class varying with the character and gradation of the aggregate and the climatic conditions.

The mixing may be done in place on the roadway with disks, harrows, and blade machines, or with powerful pugmill or shredder-type mixing machines. In other cases, the previously blended and windrowed aggregates are picked up by a traveling plant which then adds the bituminous material at a controlled rate, does the mixing, and deposits the finished mixture in a windrow behind the machine. Laying and leveling are usually done with blade graders. Compaction, which was formerly left to traffic, is now usually accomplished with either rubber-tired wobbly wheel rollers or flat-faced, steel-shod rollers, with the result that both durability and riding qualities have been improved.

Many of the roads on which these surfacing types were originally constructed have, as a result, increased so much in use and value that more substantial construction has been necessary, but there are thousands of miles of the characteristic road-mix type in use. Many of them have paid for themselves in reduced maintenance costs alone.

The Design of Bituminous Mixtures

The functional role of a bituminous pavement, considered as an element of the highway structure as a whole, determines the primary factors that govern the design of the bituminous mixture. Such a pavement performs a twofold function: It distributes the loads imposed by traffic to the underlying base; and, at the same time, provides a protective waterproof covering for the base.

The successful performance of these functions requires that the bituminous mixture, of which the pavement is composed, be possessed of certain qualities. Although the bituminous pavement sometimes consists of two parts, a base course and a surface or wearing course, in most of such cases the basic qualities desirable in one course are equally desirable in the other.

Stability requirements

A bituminous pavement must be able, without permanent deformation or internal displacement, to transmit wheel loads to the underlying base. The bituminous mixture must therefore be stable, and this quality of stability is of prime importance in design. Of a number of factors influencing the stability of a mixture, the following are considered to be of special consequence:

Gradation of the aggregate.—The stability of a bituminous mixture is very closely related to the density of the mineral aggregate, and the potential density of the aggregate is largely a function of particle-size distribution. The stability of a mixture containing an aggregate that is well-graded from coarsest to finest particles will be greater than that of a comparable mixture containing a poorly graded aggregate.

The shape and hardness of the aggregate particle.—Rough, angular particles are more effective than smooth, rounded particles in the development of a high degree of stability. If soft, easily crushed aggregate is used, the particles may crush under the weight of traffic to the extent that the spaces between the particles become too small to contain the bituminous binder. Such a condition eventually results in pavement instability.

The quantity and consistency of the bituminous binder.—In certain types of mixtures, stability is affected by the consistency of the binder, with the binders of higher consistency producing mixtures of greater stability. The requirements for quantity of binder differ for different types of mixtures, but the use of a quantity greater than the gross volume of spaces between the aggregate particles after compaction is to be avoided in any type of mixture for use in roadways.

The degree of compaction.—The formation of a multiplicity of points or surfaces of contact between the bitumen-coated particles is essential in the development of stability. While aggregate-gradation and particle-shape are predisposing factors, compaction is required to establish the maximum number of these contact points or planes. The degree of compaction depends upon the type of compactive effort, the viscosity of the binder, and other influences.

Durability requirements

A bituminous pavement must be durable as well as stable. That is, it must be resistant to adverse effects of water, air, and extremes of heat and cold:

1. The bituminous mixture, when compacted, must be sufficiently dense to minimize the intrusion of water in order not only to protect the underlying base from damage, but also to prevent damage to the bituminous surface itself. In this regard, the size of the individual voids in the mixture may be more important than the total percentage of voids. An aggregate of small maximum size having a high void content may be more effective in reducing penetration of surface water than a more coarsely graded aggregate having a lower void content.

Some types of aggregates have a tendency to lose bituminous coatings in the presence of water, and where such aggregates must be used, particular emphasis on denseness is essential in design. In some cases, bituminous binders treated with additives to increase adhesion to the aggregate particles in the presence of water are used to good advantage.

2. Exposure to air is conducive to progressive hardening of the bituminous binder by oxidation. The rate of hardening is partially dependent upon certain properties of the bituminous binder, some binders being characteristically more resistant to oxidation processes than others. The extent of hardening is partially dependent upon the accessibility of air to the interior of the pavement, the extent being greater and the rate being faster in pavements of low density where air has easy access. On pavements of such type, seal coats are often effective in retarding hardening of the binder. Excessive hardening results in surface abrasion, cracking, and eventual disintegration of the pavement.

3. The temperature conditions to which the pavement is subjected influence the design of mixtures. Whether the pavement will be exposed to very high or very low temperatures, or to extremes of both heat and cold, must be taken into account. In hot climates the use of soft binders and high bitumen contents tends to cause instability of the mixture. In cold climates the use of soft binders and relatively rich mixtures reduces the tendency of pavements to crack.

It should not be inferred from the foregoing that stability and durability are complementary. Mixtures designed for high stability are not of necessity highly durable, or vice versa. On the contrary, in many cases the opposite relation will obtain. For example, a mixture consisting of a small proportion of bituminous binder of relatively high consistency and a densely graded aggregate containing a high percentage of clay may be highly stable, yet be so prone to crack in cold weather and so susceptible to water action as to be totally lacking in durability. Good design practice recognizes the desirability of both stability and durability, yet it is often necessary to strike a balance between the two qualities.

Although stability and durability are two most important elements in bituminous mixture design as it relates to pavement performance, other considerations must be taken into account. For economic reasons, selection of aggregates is very often limited to those available locally, and the individual properties of these aggregates may affect the mixture design materially. Again, the design requirements for a pavement in a heavily travelled urban street are necessarily different from those for a light-traffic, farm-to-market road. The types of paving equipment available in the area, local preferences for certain pavement types, the need for providing a surface texture of especially high resistance to skidding: these are typical of the special matters that must often be considered in designing bituminous mixtures [84].

Structural Design of Nonrigid Pavements

Prior to World War II, the design of pavements of the nonrigid type was based almost entirely upon the experience and judgment of the engineer. There were several reasons for this: (1) The method appeared to be giving satisfactory results under the traffic conditions prevailing at that time; (2) basic knowledge necessary for the development of scientific methods of design was lacking; and (3) the general use of stage construction did not seem to lend itself readily to the possible utilization of scientific methods of design.

Empirical design

A great deal of new and pertinent information regarding the design of this class of pavements was developed during the war in connection with the airport construction program. It was indicated that thickness design procedures of an empirical nature might be used to great advantage in the construction of highway pavements of the nonrigid type. For example, the program focused attention on the practicability of utilizing the results of small-scale strength tests of the subgrade soil for estimating the thickness of pavement required. As a result some 20 of the State highway departments have developed empirical design procedures that are being given a thorough trial in practice. These procedures are such that they serve to eliminate to a large extent the element of personal evaluation of a given set of conditions. The principal deficiency of the experience-judgment method was that the answer invariably reflected the opinion of an individual whose appraisal of a given set of conditions may have led to the use of thicknesses considerably greater or less than necessary. Because of the tremendous increase in cost of road building and the greater volume of work under way, particularly in the field of secondary road improvement, the adoption and use of orderly design procedures merit serious consideration.

C. B. R. test methods

In the discussion that follows certain information regarding a number of the thickness design procedures that have been developed for highway loading conditions has been assembled (see table 12). Five out of the eleven methods listed employ the California Bearing Ratio (C. B. R.) test. This test is made with a penetration piston, 1.95 inches in diameter, so loaded that it penetrates the material at a rate of 0.05 inch per minute. The results of the test are expressed as a percentage of the standard stability value for graded crushed stone. In some cases the test is made on the material in place, in others upon molded specimens of the soil prepared at the density and moisture content anticipated in the field. In other cases the test is performed upon specimens soaked in the standard C. B. R. mold for 4 days. Two of the methods utilize plate-load tests; two determine thickness upon a basis of the gradation of the soil and upon other of the soil test constants. One method relies on information disclosed by detailed soil surveys to determine the thickness of pavement needed.

The methods of approach used in developing the Australian [88], California

Table 12.—Character of principal procedures for design of thickness of nonrigid pavements

Method	Basis of thickness design	Subgrade correlation tests	Traffic factor
Australia	Soil character	Grading LL, PL, LS	Wheel load.
California	Design curves	CBR	Do.
Canada	$t=65 \log \frac{P}{s}$	Plate bearing, CBR., CB, HP, triaxial shear.	Do.
Colorado	Design curves	CBR, grading LL, PL	Volume.
Group Index	Soil character	Grading LL, PL	Do.
Kansas	$t=\left[\sqrt{\left(\frac{3\ Pmn}{2\pi\ C\ s}\right)^2-a^2}\right]\left[\sqrt[3]{\frac{C}{C_p}}\right]$	Triaxial shear	Volume and wheel load.
Michigan	Soil survey data		Volume.
Minnesota	Design curves	CBR	
North Carolina	$t=a\sqrt{\frac{p}{s}-1}$	Plate bearing	Wheel load.
New Mexico	$t=1.2\sqrt{\frac{P}{s}}-0.27\sqrt{A}$	CBR	Do.
Wyoming	Design curves	CBR	Volume and wheel load.

t=pavement thickness.
P=wheel load.
s=subgrade bearing (except in Kansas formula).
s=permitted deflection of pavement (in Kansas formula).
m=traffic coefficient.
n=saturation coefficient.
C=subgrade modulus of elasticity.
C_p=pavement modulus of elasticity.
a=radius load contact area.
A=area load contact area.
p=unit contact pressure.
CB=cone bearing.
HP=Housel penetrometer.
CBR=California bearing ratio.
LL=Liquid limit.
PL=Plastic limit.
LS=Lineal shrinkage.

[89], and Minnesota [90] procedures of design were basically similar. Each involves the study and sampling of roads in service at locations where they have given both good and bad performance, and the correlation of test values of the subgrade with the thickness of pavement. A somewhat similar method of approach was used in developing the Group Index method [91] of estimating thickness.

Development of method

In the development work on the California and Australian methods, roads that had carried different weights and volumes of traffic were included, providing in the initial studies some pertinent information with respect to the influence of traffic. This method makes it possible to obtain also useful information with respect to the condition (density and moisture content) of subgrade soils, information which in the final analysis constitutes the factual data necessary for the design of the thickness of pavement.

The California and Minnesota methods provide for the determination of the "strength" of the subgrade soil by means of the C. B. R. test and the selection of thickness from empirically developed design curves (C. B. R. versus thickness). The methods differ in that the former provides for C. B. R. determinations upon soaked specimens of the subgrade soil compacted under the static load of 2,000 pounds per square inch while in the latter the tests are made upon undisturbed specimens of the subgrade or upon specimens of the material compacted at field moisture and density.

The Australian method makes use of results of the standard physical soil tests in estimating the thickness of pavement required for either normal traffic conditions (9,000-pound maximum wheel load) or heavy traffic conditions (13,500-pound load). Thickness is estimated by a "Grading Rule" or a "Soils Moisture Relations Rule." For certain conditions the first rule is used and for others the second. For most conditions both rules are applicable and give essentially the same results.

Group Index method

The Group Index method of estimating thickness also utilizes soil test data. Numerical values of the index represent the thickness of the sub-base portion of the pavement. In a discussion of the application of this method, D. J. Steele [91] shows graphically thicknesses of the surface-base and of the sub-base components of the pavement for three traffic densities and for four subgrades. For light, medium, and heavy traffic the thickness of the surfacing plus the base are given as 6, 9, and 12 inches respectively. For subgrades classed as good (group index 0 to 1) no sub-base is required; for subgrades classed as fair (group index 2 to 4) 4 inches of sub-base is indicated; for poor subgrades (group index 5 to 9) a sub-base thickness of 8 inches; and for very poor subgrades (group index 10 to 20) a sub-base thickness of 12 inches is indicated as being necessary by this method of design.

Strength-test methods

The Canadian [92], Kansas [93], North Carolina [94], and New Mexico [95] methods of design utilize formulas for converting strength test values of the subgrade soil into pavement thickness. In all four, the thickness of pavement is expressed in terms of the wheel load and the subgrade strength. The Canadian formula is based upon the results of plate-load tests of pavements having cohesive subgrades. The triaxial thickness formula (Kansas) [93] is based upon elastic theory. The North Carolina formula was developed by Vokac from theoretical considerations, and the New Mexico formula was developed upon a basis of certain assumptions with respect to the effective tire contact area and angle of load distribution. The Canadian and Kansas formulas have considerable background, the former being based on comprehensive load test data while the latter has been used with apparent success for a period of about 4 years.

Numerical rating systems

The Colorado [96] and Wyoming [97] methods involve the conduct of a subgrade strength test (C. B. R.) and the conversion of strength values so determined to thickness of pavement by means of a series of empirically developed design curves. The Colorado method also utilizes values of the group index as a supplement and check of the C. B. R. values. Both of these methods are unique in that they provide for a consideration of the variables entering into the problem by means of a numerical rating system. The Wyoming method considers the items of precipitation, elevation of the water table, frost action, appraisal of subgrade environment, and traffic. The Colorado method considers frost conditions, moisture conditions, and traffic. With both methods the C. B. R. test is made according to the California procedure upon soaked specimens of the material. While this procedure of making the strength test would seem to provide for the most adverse condition of the soil, the numerical system of rating those factors that influence the condition of the soil permits an adjustment of the strength values obtained with "soaked" specimens to compensate for the conditions actually prevailing.

Field studies

The Michigan [98] method of arriving at the thickness of pavement required for different conditions is based upon the combined judgment and experience of a staff of engineer-soil specialists. Field studies rather than laboratory studies and testing are emphasized in this design procedure. Detailed soil surveys are made, utilizing the pedological profile system of classification. Soils engineering data have been compiled for each of the soil groups, data which provide information relative to the grade line, elevation of the water table, ditches, cross section, and required thickness of the sub-base, base, and surface portions of the pavement.

Comparison of methods

Figure 49 shows graphically how certain of the methods of design provide for increasing the thickness of pavement with wheel load. The report describing the

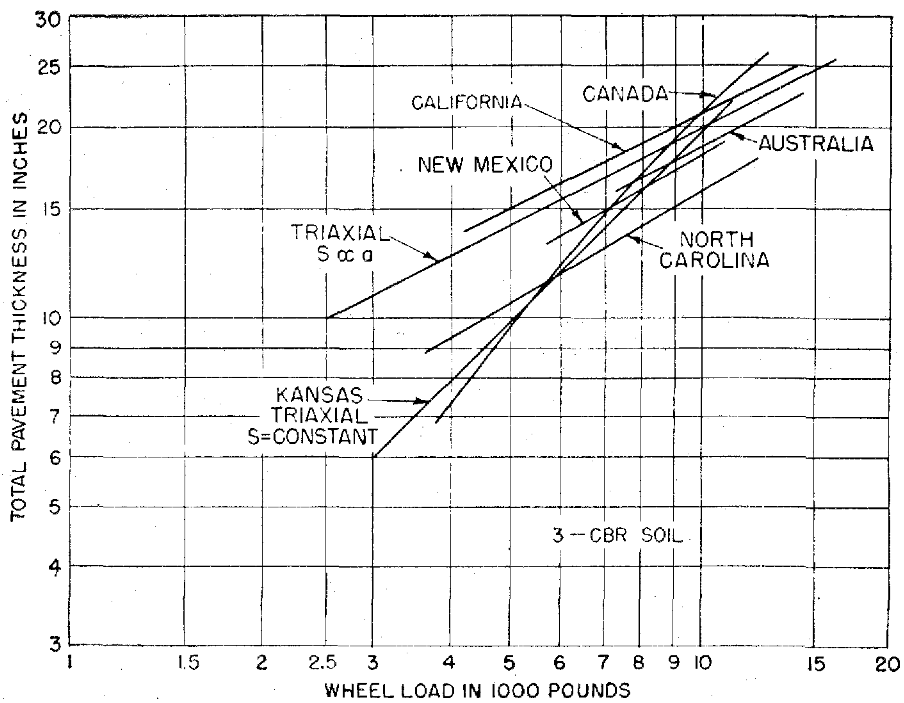


Figure 49.—Load-thickness relations for highway loading.

Minnesota method makes no mention of the wheel load or traffic factor. The Colorado, Wyoming, Michigan, and Group Index methods consider the volume of traffic rather than the magnitude of the wheel load. The numerical values of thickness represented by the seven relations in figure 49 are for the most part qualitative rather than quantitative, although they are intended to represent thicknesses that the various methods would require for a soil having a C. B. R. of 3. The values used in plotting the Canadian relation were obtained directly from charts in the published report.

According to the data in figure 49, five of the methods (Australian, California, North Carolina, New Mexico, and the triaxial) would provide for increasing the thickness of pavement with load approximately as the diameter of load contact area or as the square root of the wheel load. The two other methods (Canadian and Kansas triaxial) would provide for increasing pavement thickness at a much more rapid rate—almost directly with increase in wheel load. The difference between the Kansas triaxial formula relation and the other triaxial relation is due to the fact that in the former s, the permitted deflection of the pavement, is assumed to be constant irrespective of the wheel load whereas in the latter permissible deflection is assumed to vary as a, the radius of the load contact area, or directly as the square root of the wheel load.

Lack of agreement

The significant deduction to be drawn from the data in figure 49 is that there is apparently a considerable lack of agreement among the seven methods as to the extent to which the pavement thickness should vary with the wheel load. Assuming that, for a soil having a C. B. R. value of 3 and a 10,000-pound wheel load, the required thickness of a pavement is 24 inches, the thickness required for a 5,000-pound wheel load would be 17 inches by five of the methods and 12 inches by the other two. Or, stated another way, if it is assumed that the thickness required for a 5,000-pound load is 12 inches, five methods would require only about 17 inches for a 10,000-pound load as compared with 24 inches required by the other two methods. These indicated differences in pavement-thickness requirements for different wheel loads in the case of the two groups of methods cited are by no means insignificant.

Effect of traffic

In connection with the question of the extent to which the thickness of flexible pavements should vary with wheel load there is a growing tendency to give more consideration in design to the volume of traffic than to the magnitude of the permissible wheel load. This is evident from a study of the methods of design listed in table 12. Wyoming, for example, converts the number of commercial vehicular loads to equivalent repetitions of a 5,000-pound wheel load, values which are employed in their method of estimating thickness. Colorado considers traffic in terms of number of vehicles per unit of time. Kansas considers both the volume of traffic and magnitude of the anticipated wheel load. Michigan considers the volume of traffic as a guide to the selection of the type and thickness of the bituminous surfacing for gravel bases, i. e., for roads carrying 500 to 1,000 vehicles per day bituminous-concrete surfaces are used, and for roads carrying 50 to 200 vehicles per day surface treatments only are employed.

The effect of traffic on a bituminous pavement is known to be beneficial rather than harmful providing the average wheel load is not excessive or is within the safe bearing capacity of the structure and providing that the traffic is reasonably well distributed over the road surface. The action of such traffic tends to increase rather than decrease the strength of the pavement by reason of its compactive effect. On the other hand, a road whose strength is inadequate to carry an excessive wheel load may be damaged seriously by the passage of a few such loads or the structure may be disrupted to such an extent that normal traffic loads will later have an adverse effect. It is true that the volume of traffic constitutes a rough index of the number of heavy wheel loads. Thus the method of basing the design of this type of pavement upon the volume of traffic, to a certain extent at least, considers the magnitude of the wheel load.

Quality versus cost

In the field of secondary pavements, the problem is to provide as much inherent strength in the structure as possible with available funds. Some sacrifices have to be made with respect to the thickness and quality of those components adjudged necessary for primary pavements or else there could be no real secondary type roads. To illustrate, the practice as reported in Michigan involves the use of the same basic standards of design for all bituminous roads insofar as the base and sub-base are concerned. The difference between what Michigan apparently considers a secondary type road and a primary road rests principally in the wearing surface, i. e., bituminous treatments for secondary and bituminous concrete for primary pavements. Where funds are not available to follow such a practice in building secondary roads some other concessions in design must be made; that is, either the thickness of the base and the sub-base must be reduced or materials of a lower quality must be used. Where economies might best be effected is a controversial question. It would appear, however, that savings in the initial cost of improvement should rest primarily in reduced thicknesses of the base and the surface rather than in the elimination of the all-important sub-base course or even in the reduction of its thickness. Of course, if it is considered that a secondary road need not be built to the same standards of grade and alinement as a primary road a great difference in overall cost could be effected.

Current research

There are many aspects of the problem of structural design of nonrigid pavements that are still in need of investigation. More work should be done in an effort to develop and perfect methods of test that will permit a factual rating of all of the constituent materials with respect to their ability to support and distribute loads.

Another part of the problem greatly in need of systematic study concerns the effect of vehicular traffic upon bituminous pavements. Controlled moving-load tests should be conducted upon experimentally built sections of pavement as well as upon selected sections of pavement in service.

The problem should also be reapproached from the viewpoint of pure research. More basic knowledge is needed as to the precise manner in which plastic materials react to quickly applied loads. More basic knowledge is needed also regarding those properties of plastic materials that contribute to adequate performance in road structures.

A great amount of research work is now under way in this field. The activities of the State highway departments that have interested themselves in the problem to the extent of developing systematic design procedures represent one important type of research. Every road built according to a definite design procedure is potentially a test road. If complete records of its condition and performance are maintained valuable information will result.

Cooperative study

A study of the structural design of nonrigid pavements is now being conducted as a cooperative undertaking by the Public Roads Administration, the Highway Research Board, and the Asphalt Institute. The plan, scope, and objectives of the investigation have been described in detail elsewhere [99] and will not be restated here. The results of the investigation should yield definite information on many phases of the problem mentioned before in this discussion. For the particular materials used in the construction of the pavement sections, the tests under way should result in the development of factual data on load-pavement thickness relations. Also, information should be obtained relative to the effect of various moving-load traffic patterns upon different thicknesses of pavement.

Many other agencies are now engaged in studies of some part of the general problem. These include the Civil Aeronautics Administration, the Army, and the Navy, in this country, and the Department of Transport of Canada. The combined efforts of all these agencies should, in due course, result in the development and use of standardized design procedures for pavements of the nonrigid type.

Portland Cement Concrete and Its Uses

Portland cement concrete has been used extensively in the United States for many years as a paving material and in the construction of bridges. In both cases concrete of the highest quality is demanded, quality in this case including not only strength but durability as well. In this respect, highway concrete differs from structural concrete used in buildings, much of which is protected from the weather.

Concrete pavements, in particular, probably are called upon to resist not only as severe but also as great a variety of destructve forces as any type of structure in which this versatile engineering material is used. For example, a pavement must possess not only sufficient strength to resist the forces due to traffic loads without structural failure, but the concrete of which it is composed must also be sufficiently durable to insure reasonable permanence under the prevailing weather conditions. The destructive forces which result from large and rapid changes in temperature and moisture, including the effects of alternate freezing and thawing, produce not only direct tensile and compressive stress, but also induce complex stresses or "weathering effects" which sometimes result in partial or complete disintegration, to resist which we strive to produce what we call "durable" concrete.

Materials for Concrete

It should be obvious that in order to insure concrete meeting such rigid requirements great care must be exercised in selecting not only the best materials but also in seeing to it that the methods of combining these materials, as well as the various construction operations — placing, finishing, curing, etc., are so conducted that uniform concrete of the required quality will be obtained. In this discussion, brief reference to current specification practice in this country, both as regards materials and construction methods, will be made. Attention will also be called to the efforts which are constantly being made to improve materials and methods in an effort to obtain concrete which will more adequately fulfill the exacting requirements of highway use.

Portland cement

The standard specifications of the American Association of State Highway Officials [7], [100] recognize five types of portland cement. Of these, type I is a general-purpose cement having few chemical limitations and minimum physical test requirements; type II, a moderate heat-of-hardening and moderate sulfate-resisting cement; type III, a high-early-strength cement; type IV, a low-heat cement, and type V, a sulfate-resistant cement. Except where high early strength is required, most specifications for highway work refer to either type I or type II.

Some engineers prefer type II cement because of certain chemical limits which restrict the formation of tricalcium silicate and tricalcium aluminate to maximum values of 50 and 8 percent, respectively. Whether such restrictions actually insure greater durability under severe weather conditions, as some engineers believe, is a moot point. They do, of course, insure a somewhat slower hardening cement. The specification has the further advantage over type I of providing greater uniformity in composition. All specifications insure soundness through the use of an autoclave (high pressure steam) test. Although this test is generally considered as a great advance over the old pat test, there are many engineers who feel that the maximum value of 0.5 percent for expansion permitted by the standard specification may be too high. A value of 0.2 is sometimes used.

Restriction of alkali

There has recently appeared in specifications for portland cement a requirement that the percentage of sodium oxide plus the percentage of potassium oxide, when calculated as sodium oxide, shall be limited generally to a maximum of 0.6 percent. This restriction on the total alkali is imposed only in cases where it is anticipated that certain types of aggregates which react chemically with the alkalies in the cement may be encountered. It has been determined quite definitely that when such a reactive combination exists in concrete, delayed expansion, followed sometimes by complete disintegration, will almost surely result.

Air-entraining cement

The recent discovery that the workability and durability of portland cement concrete can be significantly improved by the introduction into the mixture of about 5 percent of air in the form of minute disconnected bubbles has profoundly affected the technology of cement manufacture. This action is known technically as "air entrainment" and this particular type of concrete as "air-entraining concrete." In order to fulfill demands for air-entraining concrete, manufacturers are now producing cement in which sufficient air-entraining material has been interground to produce the required air content of the concrete. Standard specifications of these air-entraining cements have been developed. These are similar to the specifications for plain or non-air-entraining cement except for a provision limiting the amount of air which must be entrained by a standard mortar. The specified value is now 18 ± 3 percent. This amount of air in the test mortar will yield about 5 percent air in the concrete under average conditions. At the present time two commercial air-entraining additions are recognized as acceptable for intergrinding: Vinsol resin, a product of the distillation of pine wood; and Darex, which is defined as a triethanolamine salt of a sulfonated hydrocarbon. Other materials are also available, some of which are probably satisfactory.

The extent to which air-entraining cement is now used in concrete [101], [102] is indicated by the fact that last year from one-quarter to one-third of all the portland cement manufactured in the United States was of this type.

Air entrainment in mixing

Air entrainment in concrete can also be secured by adding the required amount of air-entraining material directly to the concrete at the time of mixing. Many engineers prefer this procedure, feeling that it permits of closer control of air content than when air-entraining cement is used. In any event, the end result is the same, provided an air content of not less than 3 nor more than 6 percent is obtained. Both Vinsol resin and Darex, the nationally approved air-entraining materials, are marketed commercially for use as admixtures—that is, for addition directly to the concrete at the time of mixing—as well as for intergrinding with cement. Other admixtures are also on the market, many of which are probably satisfactory. Standard procedures have been developed for evaluating proposed materials of this type.

Air-entraining concrete is probably here to stay. The improvement in workability with corresponding reduction in bleeding and segregation is so marked as to make this development highly attractive even without the improvement in durability which is obtained. There is some loss in strength but with a properly designed mix this slight disadvantage is more than balanced by the advantage of increased resistance to freezing and thawing and to the action of salts used for ice removal on pavements.

Aggregate quality

Most specifications for aggregates contain provisions which insure that the material will have sufficient structural strength and soundness for the purpose intended. Strength is usually measured by means of the Los Angeles abrasion test, which has largely replaced the old Deval abrasion test used for so many years to measure the quality of road-building rock. Soundness is determined by means of the sodium-sulfate or magnesium-sulfate test, supplemented by freezing and thawing tests in certain instances. In the case of both the abrasion and soundness tests, the appropriate test limit for any particular specification will, of necessity, be based on the quality of the available materials. Moreover, the area of availability, in most cases, is strictly limited because of the high cost of transportation. In general, specification limits are set so as to insure the use of the best available materials, with a maximum limit, usually not exceeded except in special cases, of about 50 percent Los Angeles abrasion loss and about 15 percent sodium-sulfate soundness loss.

Alkali reaction

Until a few years ago it was generally believed that concrete aggregates were inert to chemical attack by the cement. As already indicated, it has now been determined [103] that certain otherwise entirely satisfactory aggregates may contain substances in varying amounts which will react chemically with the alkalies in the cement. The compounds which are formed within the concrete expand in volume, causing surface cracking, followed, in many cases, by complete disintegration. Materials which are believed to act in this way include certain forms of opaline silica usually occurring in chert, and certain types of altered igneous rock such as altered andesite. This trouble was first noticed in certain of our Pacific Coast States and later in the Rocky Mountain region. However, evidences of failure due to chemical reaction have recently been discovered in the southeastern part of the country, so that the trouble may be more widespread than was at one time thought probable. Both petrographic and physical tests are now being used in an effort to determine whether a proposed aggregate is reactive with cement. If evidences of reactivity are found and the material must be used, there are two courses open. One is to require that the total percentage of the alkalies, Na_2O+K_2O, shall be limited to an amount which will be harmless, and the other is to mix with the concrete some material which will react immediately with the alkalies in the cement, thus rendering them harmless. This latter procedure is still in the experimental stage.

Aggregate grading [104]

When the coarse aggregate exceeds about 1 inch in size, it is customary to specify that the material be shipped to the job and stockpiled in at least two separate fractions. For example, when the maximum size is 1½ inches, the usual separations are No. 4 to ¾-inch and ¾ to 1½ inches. The practice of batching separated sizes of coarse aggregate contributes a good deal to the uniformity of the mixture and it is believed that the slight additional cost is well justified. Sand, or fine aggregate, usually is not separated into sizes but is furnished as a graded material, ranging in size from No. 4 maximum, down to No. 100. Within this range of size rather coarse sands are preferred. Most specifications, however, permit a rather wide range in grading in order to make the best use of locally available materials. National standard specifications show a range in the amount passing the No. 16 (0.047-inch opening) sieve of from 45 to 80 percent, in the amount passing the No. 50 (0.012-inch) sieve of from 10 to 30 percent and in the amount passing the No. 100 (0.006-inch) sieve of from 2 to 10 percent. It is required that at least 2 percent pass the No. 100 sieve in order to provide sufficient fines for workability. The sand also must be clean and free from organic matter. It must also be sound and be composed of fragments having adequate structural strength.

Concrete Mixture Proportion

There are two general methods in current use for specifying mixture proportions for concrete pavements, the so-called "strength-design" method and the method of fixed proportions [105].

Strength design

In the first case the mix is designed so as to produce concrete having a specified flexural strength (modulus of rupture) based on laboratory tests made on concrete containing the same materials as are to be used in the work. Under this procedure the proportions and, consequently, the cement content may vary considerably from job to job, due to variations in the materials. This is, theoretically, the preferred procedure, in that it should result in more economical use of the available materials than is possible with the method of fixed proportions. Its disadvantage lies in the fact that it requires a large amount of carefully conducted laboratory work. Therefore, this method should not be attempted unless adequate laboratory facilities and trained personnel are available.

Fixed proportions

In the method of fixed proportions, quantities are usually stated in pounds of fine and coarse aggregate per bag (94 pounds) of cement. Volumetric proportions are rarely used, principally because volumetric batching is no longer permitted, all aggregate batching now being done by weight. In many cases, particularly in the northern States, where winters are severe, a maximum limit on the water-cement ratio, usually 6.0 gallons per bag, is imposed. To illustrate the method of fixed proportions, the following is quoted from the current specifications for concrete pavement of the American Association of State Highway Officials: Cement, 94 pounds; sand, 175 pounds; small size gravel, 140 pounds; large size gradve, 215 pounds; maximum water-cement ratio, 6.0 gallons per bag. This proportion is based on the use of rounded gravel.

Crushed aggregate

When angular crushed stone or slag is used as coarse aggregate it is customary to increase the sand content about 15 percent to compensate for the harsher aggregate. A corresponding reduction in the amount of coarse aggregate is also made. This is done so that the total absolute volume of the aggregate will remain constant, a condition which is necessary if the yield (amount of cement in a cubic yard of concrete) is to remain constant. The weights shown in the example are also based on an assumed specific gravity of 2.65. When aggregates having other specific gravities are used, it is necessary to adjust the weights in order to maintain the same absolute volume. This can be done by simple proportion.

In the above example, the proportions are such that concrete having a cement content of about 6 bags per cubic yard will be obtained. It has been found by experience that this cement content will ordinarily insure strengths which will at least equal the American Association of State Highway Officials' minimum requirement of 550 pounds per square inch modulus of rupture at 14 days, for concrete designed for strength. This will be true even for combinations involving relatively low-strength materials provided, of course, that these meet the basic specifications for the cement and aggregates. The specification is, therefore, safe. When high-strength materials are available, these same proportions will yield concrete having strengths considerably in excess of the minimum requirements, thus illustrating the technical superiority of the strength-design method. However, for ordinary work, the method of fixed proportions should prove satisfactory, provided the base proportions are so set as to insure at least the minimum required strength with the poorest of the available materials, even though other possible combinations of materials might give substantially higher strengths.

Consistency

The consistency of the concrete must also be stated. Consistency is usually specified in terms of slump, which will vary with the method of placing. For concrete pavements it is customary to specify a slump of from 2 to 3 inches in the case of concrete to be placed by means of an ordinary power-driven screed and from 1 to 1½ inches in the case of concrete to be consolidated by vibration. The slump test, although not a test for workability, is an excellent test for relative consistency and should always be used, particularly in cases where it is difficult to control the water content directly.

Air entrainment

The introduction of air entrainment has posed new problems in mix design. For example, the mix proportion just cited is for plain concrete which will contain, on an average, about 1 percent air. When either an air-entraining cement or an air-entraining admixture is used, the amount of air is increased to about 5 percent. This will, of course, slightly increase the yield of concrete per bag of cement, with resulting loss in strength. However, an approximately constant yield may be retained without sacrificing workability by reducing the sand content by an amount equal to about 3 percent of the weight of the combined aggregate, or about 16 pounds in the case of the illustration previously cited. This would make the adjusted proportions: 94 : 159 : 140 : 215. This adjustment will also tend to equalize the strength, although experience indicates that there may be some residual loss in strength even with the reduced sand content. It should, of course, be emphasized that adjustments of this type merely serve to establish a trial mix which must be checked for yield and further adjusted, if necessary, in the field, using a full-size batch and exactly the same materials and mixing equipment as will be used in the work.

Structural Concrete

The discussion of concrete as a highway material has so far been confined largely to its use in pavements. However, most of the discussion, at least insofar as it concerns materials, will apply also to concrete used in bridge construction. Complete specifications for bridge concrete are given in the Public Roads Administration's *Specifications for Construction of Roads and Bridges in National Forests and National Parks (FP-41)* [106]. These specifications contain requirements for materials, proportioning, and construction methods, including erection of false work and forms; handling, measuring, and batching materials; placing; finishing; and curing. There are also sections on forming joints, depositing concrete under water, and cold-weather concreting.

Proportioning

These specifications, in the requirements for proportioning concrete for bridges, provide for several classes, depending upon the part of the structure in which the concrete is to be used. Cement contents range from 4 to 7 bags per cubic yard, depending upon the strength required, degree of exposure, etc. Proportions are not stated directly but must be determined in each case by the engineer, using trial mixes containing the same cement and aggregate as will be used in the work. The final mix must be so adjusted as to fulfill the requirements of a master table which gives, for each class, the required cement content, the maximum water content, and the consistency as measured by slump. This method of mix design has an advantage over the method of fixed proportions in that it makes it possible for the engineer, within the limits imposed by the master table, to adjust his proportions in accordance with the characteristics of the materials he will actually use in the work.

This method of proportioning is not theoretically as sound a procedure as the method of strength-design. However, bridge structures are designed on the basis of compressive strength and compressive strength is not affected nearly as much by type of aggregate as is flexural strength. For this reason this type of specification will result in lesser variations in compressive strength than in flexural strength. Furthermore, the same practical objection as regards the large amount of testing which is required under the method of strength-design applies here as in the case of pavement concrete. All in all, it is believed that the Public Roads Administration's specification is the nearest practical approach to the ideal that has as yet been developed.

Durability

In a properly designed bridge there is little danger of structural failure provided the concrete has reasonable uniformity and meets the design-strength requirements. However, as previously stated, adequate strength does not necessarily insure adequate durability, a property which is extremely important, especially in the case of bridges exposed to severe weather [107]. This applies particularly to concrete in the thin, exposed sections of the superstructure, such as curbs, handrails, rail posts, end posts, etc. Every effort should be made to insure the most careful fabrication of each unit of such exposed sections. Meticulous attention to every detail of construction is necessary, as there is little factor of safety against failure due to weathering.

It is believed that air entrainment will materially improve the durability of concrete structures which are subject to severe weathering. The benefits are both direct and indirect. In the first place, the incorporation of entrained air will, in itself, greatly increase resistance to alternate freezing and thawing. In addition, we have the indirect benefits which result from the added plasticity and homogeneity of this type of concrete. These tend to reduce segregation and water-gain and thereby make it possible to place more uniform concrete in the structure. This is a matter of the utmost importance, particularly in deep sections where there is a tendency for water-gain to develop at the top of each successive lift.

Vibration

Vibration [108] is employed extensively for placing bridge concrete. For this purpose, internal tube or spud vibrators are used. These operate at frequencies ranging from 5,000 to 9,000 revolutions per minute. Vibrators, if properly used, are very effective in consolidating concrete. However, they must be used strictly for this purpose and not to assist in distributing the concrete in the form, as is sometimes done. Vibration tends to reduce somewhat the amount of air in air-entraining concrete. This can be corrected by determining the air content of a specimen which has been compacted by vibration under as nearly as possible the same conditions as in the work and adjusting the amount of air-entraining agent accordingly. For best results it is recommended that both air entrainment and vibration be employed in all work subject to severe weathering and that the vibration be employed in all cases where more than 50 cubic yards of concrete are required.

Curing

The thorough curing of all bridge concrete is very important. Specifications usually require that all horizontal surfaces be covered with wet burlap, cotton mats, etc., for a period of at least 7 days and that the surface be kept thoroughly wet for this period. Wet straw or wet earth may be substituted for the fabric coverings as soon as the concrete has hardened sufficiently to prevent marring the surface. All vertical surfaces, after removal of the forms, should be kept thoroughly wet for the same period, either by sprinkling or by covering with wet burlap, cotton mats, or other suitable fabric. Wood forms, if allowed to remain in place during the curing period, must be kept thoroughly wet.

Structural Design of Rigid Pavements

In the United States, constantly increasing attention is being given to the development of more rational methods for the structural design of pavements, whether of the so-called rigid type built of portland cement concrete or of the nonrigid type built with graded granular materials and bitumen.

As with any problem in structural design, the method must consist of an appraisal of the forces to which the pavement is subject, and consideration of so proportioning the pavement structure as to give it the best chance to resist the effects of those forces for long periods of service.

Load

Research has demonstrated that insofar as the structural design of a pavement is concerned, it is the load imposed by a single wheel that must be considered. As motor vehicles are usually designed, the load at the other end of the axle or that of an adjacent axle does not materially increase the stress caused by the given wheel [111].

The heaviest wheel load permitted by law, in most States, is 9,000 pounds. A few Eastern States permit 11,200 pounds and five States have no wheel or axle load limitation [112]. These legal limitations are not always observed, however, and wheel loads in excess of the legal wheel load must be expected at times on almost any highway pavement.

A motor vehicle in motion develops forces or reactions between the wheel and the pavement which exceed in magnitude that imposed by the same wheel at rest. The magnitude of this "dynamic increment," as it has been termed, has been found to depend principally upon the roughness of the road, the static wheel load, the softness or degree of cushioning afforded by the tire, and the vehicle speed. The total dynamic reaction may range upward from the static wheel load to as much as twice that load or even more [113].

Although there is evidence that the effects of these dynamic or impact forces on pavement structures are not as great as their magnitudes might suggest, the adverse effect of impact forces on both the pavement and the vehicle is well recognized. Every effort is made to construct and maintain pavement surfaces that are as smooth as possible as a preventive measure to control these destructive forces.

Width

As previously described, pavement width is commonly defined in terms of a number of lanes and the currently accepted idea of what constitutes a safe lane width.

This leads to the construction of concrete pavements as a series of parallel strips, each one lane in width (now commonly 10, 11, or 12 feet).

The design of the cross section has undergone several marked changes. Originally concrete pavements were thicker along the center line than at the edges, following the pattern of the old macadam surface. Later, for simplicity, some were built of uniform thickness. The advent of the heavy truck with solid-rubber tires, crowded to the outer edge by insufficient pavement width, brought about an epidemic of corner breaks along the outer edges of these pavements of uniform thickness. This led to the development of the thickened-edge cross section, which has been widely used over the past 25 years.

Thickness

Research has shown that, insofar as load stress is concerned, the thickened-edge cross section is an efficient one. Further study, however, developed a knowledge of temperature stresses which has led to the conclusion that, when the combined effects of load and temperature are considered, the pavement slab of uniform thickness is at least as effective as the thickened-edge cross section [114]. This conclusion, coupled with the fact that with the present wider pavements and higher operating speeds, the wheels of heavy vehicles no longer travel along the extreme edges of pavements, justify the current trend toward a more general use of the pavement of uniform thickness.

In practice, concrete pavement slabs in the United States range in thickness from 6 to 10 inches, approximately. Westergaard [115], [116] has developed analyses of the load-stress relation in concrete pavement slabs that take into account the effects of position of the load, area of tire contact, the stiffness of the subgrade support, and the various physical characteristics of the concrete itself. These analyses are useful in explaining the observed structural behavior of pavements in service and for many other purposes. However, for reasons that are beyond the scope of this discussion, they have not been applied to specific structural design problems up to the present time.

Within the thickness limits mentioned, that is, 6 to 10 inches, an attempt is made to select a thickness value that takes into account, at least to some extent, the degree of subgrade support expected at a particular location and to adjust the thickness to conform to the anticipated traffic, particularly heavy-axle-load traffic. These adjustments are not by any means precise, being based on experience and judgment. However, the practice does lead to the use of lighter designs where subgrade conditions are considered favorable and traffic is moderate and to heavy designs where service is more severe.

Crack control

It has long been known that portland cement concrete expands and contracts with rise and fall of temperature and that, like wood and other materials, it swells in the presence of moisture and shrinks upon drying. The concrete in a pavement is usually exposed to severe conditions of temperature and moisture change. Restraint, due to slab weight and subgrade resistance, tends to prevent the natural tendency of the concrete to change in volume, with the result that high stresses are developed and the concrete cracks. Irregular cracks are unsightly and difficult to maintain. It has been general practice to subdivide the pavement into panels or slab units of limited dimensions by means of joints, in an effort to control this cracking tendency. Research has shown the general magnitude and extent of the forces that tend to produce cracking in concrete pavements and has provided an explanation for much of the structural behavior that has been observed in pavements in service [114], [117].

Center-line joints

To control the irregular center cracking that occurred longitudinally when pavements were laid in integral widths of 16 and 18 feet, a plane of separation was introduced along the center line. This structural change effectively controlled center cracking although the reasons were not thoroughly understood until many years after the change was introduced. This joint, the primary function of which is to relieve a stress caused by certain temperature conditions, is now in universal use.

The design may take any one of several forms but the essential is that a structural hinge be created along the center line of the pavement. The separation may be caused by a deformed metal plate or it may be a crack induced by deeply grooving the surface at the time of construction. Almost always the abutting slabs are tied together by steel bars placed across the joint. A common design for this detail provides ½-inch diameter deformed steel bars, about 3 to 4 feet long, spaced from 2½ to 5 feet apart [118]. Its function is to prevent opening of the longitudinal joint.

Expansion control

If concrete is subjected to a temperature above that at which it hardened it tends to assume a length greater than it had initially. If restrained from lengthening, compressive stresses of considerable magnitude are developed in the concrete. Since a pavement slab under compression acts somewhat as a column of extreme slenderness, failure will usually occur by buckling causing what has been termed a "blow-up." Some provision for expansion is necessary if blow-ups are to be prevented.

Heretofore, it has been usual practice to provide for relief of compressive stress by providing expansion space at intervals of 100 feet or so. This usually consists of an opening ¾ to 1 inch in width completely across the pavement and to its full depth. To prevent the entrance of foreign matter, the opening is filled with compressible material of some sort. Frequently this filler takes the form of a premolded board or strip set on edge on the subgrade at the time the concrete is placed and left in place to form the joint.

Currently there is a trend away from the use of expansion joints at such close spacing, and research has indicated that where pavements are subdivided into relatively short panels by contraction joints the need for expansion joints is greatly reduced if not eliminated [119].

The desire to reduce the number of expansion joints springs from the difficulties that attend their construction and maintenance.

Contraction joints

Concrete contracts with a decrease in temperature. Since it is a material with a low tensile strength, a continuous length of pavement tends to crack into relatively short slabs as it contracts. Plain concrete slabs 15 to 20 feet in length appear to be able to withstand the forces of service without cracking, and research has indicated that combined stresses are controlled within reasonable limits in slabs of this dimension [114]. Thus, if the individual panels of a concrete pavement are 11 to 12 feet wide (one lane width) and 15 to 20 feet long, they may be expected to remain structural entities without the use of distributed reinforcement, provided of course that they are of adequate thickness.

Contraction joints are usually constructed by forming a deep groove transversely of the pavement at the designated location with the expectation that the weakened section thus formed will develop by cracking into a full plane of separation. This is usually referred to as a "plane of weakness" or "dummy" joint, and is the same type of construction that was referred to in connection with the discussion of longitudinal joints.

Load transfer

Load-transfer systems are used to develop shear resistance at the joints in concrete pavements by making both slab edges share the load that is imposed by the wheel of a vehicle. This shear resistance may be for the purpose of reducing stress in the loaded slab edge, for the purpose of reducing vertical movements of the slab edge as the load passes over the joint, or for the purpose of maintaining surface alinement at the joint. These systems usually comprise an assembly of closely spaced steel dowels or other shear-resistant units anchored in one slab and extending into or under the adjoining slab. They are rather costly, cause some construction difficulties when installed properly, and are subject to deterioration from exposure. However, they are a necessary feature of concrete pavements as ordinarily constructed [120], [121]. They are required at expansion joints by most, and at contraction joints by about one-half of the States [118].

A typical load-transfer system consists of an assembly of steel dowels ¾ to 1 inch in diameter, 18 to 20 inches in length, spaced 12 to 15 inches apart, held rigidly in a frame that can be alined on the subgrade at the prescribed location and left in place as the concrete is placed around it. For expansion joints the premolded filler material is incorporated as a part of the assembly and an expansion cap is provided at the free end of each dowel. For contraction joints no filler is used and the expansion caps are omitted.

Reinforcing steel

Steel as used for the reinforcement of highway pavements adds but little to the flexural strength of the slab. It is neither adequate in amount nor is it well placed to serve such a purpose. It functions rather to insure structural integrity, first, by assisting in the creation of a sound structural unit by preventing localized shrinkage during hardening and, second, by holding tightly together the parts of a slab unit should a crack occur. Reinforcement for this purpose consists of relatively light members, rather closely spaced. It may be either mats of small bars or welded wire fabric. High yield-point steel has obvious advantages for this purpose. The usual practice is to place the steel 2 to 3 inches below the finished pavement surface.

When steel reinforcement is used, the spacing of the transverse contraction joints is increased by an amount which is proportional to the amount of longitudinal steel in the reinforcement. Slabs over 1,300 feet in length, reinforced with 1.8 percent of longitudinal steel, laid experimentally show no open transverse cracks after nearly 10 years of heavy traffic service [122]. Slab lengths of 60 to 100 feet are more commonly used for reinforced pavement with a much smaller amount of reinforcement.

Distributed reinforcement is used at least for certain locations by a majority of the States. A considerable number of States use reinforcement in all concrete pavement. Only a very few never use it.

Recently two experimental pavements have been built, one in New Jersey and one in Illinois, in which longitudinal steel was used continuously over lengths of 1 mile in the New Jersey pavement and 3,500 feet in the Illinois pavement. Different sections contain different amounts of longitudinal steel within the range 0.3 to 1.0 percent. The purpose is to learn whether or not it is practicable to build continuously reinforced concrete pavements without transverse joints.

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Part 4

CONSTRUCTION AND MAINTENANCE

HIGHWAY CONSTRUCTION

When detailed plans and specifications for a highway project are completed, funds assigned for construction, and necessary steps taken toward acquirement of rights-of-way, the project is ready for the attention of the construction division of the highway department.

The Contract System

About 95 percent of construction under State highway department supervision is done under the contract system; that is, the work is given to the firm in the construction business that offers to do it at lowest cost. Only about 5 percent is done by forces organized and equipped by the highway department.

The first step by the construction division is issuance of a call for bids. Notice to contractors is given in appropriate publications two weeks or more in advance of the date set for considering bids.

Preparation of bids

Prospective bidders are furnished plans, specifications, and bidding sheets prepared by the highway department. These documents are specific and a prospective bidder must exercise his best judgment in estimating what the cost of supplying materials and performing the construction items will be. The engineers are willing to supply all available information. The contractor knows that there can be no departure from the provisions prescribed in the contract document and that the primary advantages one bidder has over another are individual ingenuity and more effective management.

On Federal-aid work the bidding must be open to contractors from all parts of the country and there must be no discrimination against the products of other States in procurement of materials. This policy is followed quite generally on all classes of highway work.

Qualifications of contractors

It is now the general practice to require that a contractor establish that he has the experience and resources to undertake a given project before his bid can be considered. A prospective bidder must submit a detailed statement of his financial resources, amount of equipment, and experience in construction work. Sometimes this information accompanies a bid, but more often it is submitted to the highway department annually. The highway department evaluates these statements and determines the type and maximum value of the work that the contractor should undertake. Generally he will not be considered for an award in higher amount.

Sealed bids are submitted to the highway department accompanied by guarantees to insure acceptance of the contract if award is offered. At a prescribed time the bids, indicating the contractor's price for each item of the contract, are opened publicly and read. The total bid of each contractor is then computed and award is usually made to the lowest bidder. Before a contract is made he is required to furnish a bond from a reliable surety, guaranteeing proper performance of the work and the payment of obligations incurred on the work.

Time limits established

After execution of the contract, the contractor is ordered to begin work upon a specific date and he must complete all operations within the time specified in the contract. Failure to complete the work within the time limit will subject the contractor to assessment of damages if there are no extenuating circumstances.

Contractors are usually paid monthly for 90 percent of the work accomplished. Ten percent is retained to insure completion of the job. Upon satisfactory completion, the contractor is paid in full.

As the date for beginning work approaches the highway department assigns a project engineer to the job, with assistants and inspectors as may be needed. It will be the duty of this force to see that the work is performed in accordance with the plans and specifications.

Within the limits stipulated in the contract and specifications the contractor is at liberty to assemble his crews, purchase materials and supplies, assemble equipment, arrange for necessary finances, plan the work, and proceed with operations according to the dictates of his judgment.

New methods encouraged

New methods of performance are encouraged. Specifications are usually sufficiently flexible to permit the use of new types of equipment that will result in more economical performance. It has often happened that development of new and improved types of equipment has caused a lowering of costs in spite of more rigid design requirements and improved specifications to meet the increasing traffic requirements.

Up to this point discussion has related to steps taken by the State in selecting a contractor and in controlling his work. Attention is now directed to problems of the contractor. These are just as important to the engineer as any other phase of the work, since efficient performance at low cost produces work of good quality and will result in lower prices on future work.

Job Management

Most successful contractors prepare a tentative plan of operation in conjunction with their bid computations. On large and complicated projects this procedure is quite desirable and the proposed plan of operation is sometimes required to be submitted with a bid. If not made previously a plan of operation should be prepared immediately upon award of a contract. This plan is, in effect, a job schedule, to be used as a guide in ordering materials, supplies, and equipment, and in meeting labor requirements.

The best computations and plans can go for naught if project supervision is inadequate to carry them out. In recent years it has become the practice of many contractors to employ experienced supervisory personnel on an annual basis. The practice entails salary payments during winter shut-down and between jobs but it is believed to be profitable. Some contractors employ equipment operators and mechanics for their full time. Such men are kept busy repairing and overhauling equipment as necessary.

A project supervisor should delegate authority to trained assistants, maintain the proper flow of materials and supplies to the job, establish efficient operation of equipment, and keep progress on each part of the work in harmony with the over-all job schedule. An additional requisite, one that has become quite important in recent years, is ability to improvise methods when unforeseen conditions arise.

Supervisory personnel must be able to understand plans, interpret the intent of specifications, and look upon attainment of the final result from the engineer's point of view, as well as that of the contractor.

Equipment

There are many different models and makes of most types of highway construction equipment. Each machine is designed for specific limited uses. When a selection as to size and type has been made, the choice as to make is often a matter of personal preference. Most manufacturers will offer a variety of models, each suited to particular conditions.

Selection of power unit

The choice of type of power in a machine is important for several reasons. A matter to be considered is the availability and cost at the job site of the fuel used. Each type of power unit has particular advantages and disadvantages. Most large manufacturers of earth-moving equipment furnish their more popular models with a choice as to gasoline or diesel power units. During the past 10 years diesel power has become more and more popular. This has been due, no doubt, to the steady advance in the design and efficiency of the engine as well as to its lower fuel cost.

Standardization

It is good practice, when selecting equipment, to standardize on one make and type of power, to the extent possible. With some planning, it may be possible to obtain tractors, patrol graders, power shovels, rock crushers, and road rollers, with the same make, type, and model of power unit. With identical power units, the problem of repair parts and mechanical servicing is simplified. Standardization is a major consideration when equipment is to be used at a great distance from the source of spare parts and service facilities.

Relation to the job

After a choice of type and make has been made, it is necessary to determine the size most suited to the job contemplated. This choice is quite important from many angles. Equipment for grading can be too large for a specific job, as well as too small. Consideration must be given to the plans for the proposed work, mainly from the standpoint of roadway width. Equipment should be selected that is adapted to working within the width of the roadway. The topography of the country, as well as character of the material to be excavated, should also be considered. It is seldom desirable to use large equipment on work where it cannot operate efficiently. It is equally important not to place small equipment on work where great strain and overloading will cause excessive wear, which in turn will involve high operating and repair costs.

Quite often there is a tendency, especially in the use of large equipment, to over-rate its performance. For instance, it may appear to save time and expense by not drilling and blasting a material that can be moved without this added work. In many cases, however, actual costs may be reduced by blasting, as excessive wear and tear, break-downs, and slow progress are avoided. Rock excavation generally requires equipment differing from that used in earth excavation. Equipment should be used that is best adapted to the length of haul that predominates on the job. Final costs are affected materially by the proper choice and use of equipment.

The performance of the operator of a machine is a large factor in obtaining economical use. When possible, skilled operators should be employed. When this is not practical a thorough schooling in the operation and care of equipment should be given the men employed. For this purpose one or two experienced operator-instructors should be employed. Expensive machines should never be placed in the hands of men ignorant of their care and use.

Equipment maintenance

Care in the repair and maintenance of equipment is directly reflected in final costs and work accomplished. All manufacturers furnish operating and maintenance manuals containing specifications for each machine. These instructions are the result of a great deal of study and operating research. They are prepared with the intent to indicate how maximum performance may be obtained. Short-cuts or deviations from the recommendations are usually poor practice. If a difficult problem in maintenance or repair presents itself, it is good practice to ask for advice or instructions from the authorized dealer or manufacturer. Use of equipment after one or more parts become worn or defective is poor economy. Each working part has a definite function in the efficient operation of the whole unit. The failure of one part, while it may not completely disable the machine, throws undue strain and wear on the other parts. Continued operation may result in a serious break-down with added expense for repairs.

Clean fuel is necessary in the operation of all equipment, especially where diesel power is used. Foreign matter in the fuel will clog the injection system, causing expensive delay in operation, as well as repairs. It is good practice to strain all fuel as it is poured into the fuel tank on the equipment. This is especially recommended when fuel is supplied from iron or steel drums. Lubricating oil and greases used should be those recommended by the manufacturer. Different types and grades of grease are often used on one piece of equipment and it is important that the servicing be done properly. Frequency of lubrication is governed somewhat by the conditions on the job. Extremely dry or wet material, abrasive material, and rock excavation, all have damaging effects on equipment. Proper lubrication can keep wear to a minimum. Tires should be kept inflated at the recommended pressure to obtain maximum life. All equipment should be protected from the weather when not in use on a job.

Storage

Under adverse conditions, machinery will deteriorate as quickly in storage as in service. Equipment should never be stored for any length of time without protection against sun, rain, salt air, and dust. The equipment should be thoroughly cleaned, well greased, and painted, if possible. When painting is impracticable, it is good practice to cover all exposed surfaces with a film of oil or grease. Numerous preservative coatings were developed during the war and it is probable that they will soon be available commercially. The power plant in stored equipment should receive prestorage care if permanent damage is to be avoided. Additives are available for mixing with lubricating oils to prevent the pistons from sticking. Radiators should be flushed and drained, and batteries removed and stored. All rubber-tired equipment should be placed on blocks so as to take the weight off the tires. When power equipment is to be stored for a short period, and the expense of elaborate prestorage care is not justified, it is good practice to run all engines at idling speed for a period of at least one-half hour, every week or two.

Construction Operations

Certain observations may be made that have application on nearly all highway construction jobs. On most work one machine, generally the one that costs the most to buy and operate, controls the rate at which work may be done. In grading with a power shovel, trucks can haul away only what the shovel digs. Work of the shovel can be obstructed but no amount of excess capacity elsewhere can increase its production beyond an amount fixed by its size and characteristics. At bituminous and concrete mixing plants the mixer is the key machine. At a quarry the rock crusher will control the daily output.

The key machine

The job manager should pattern his organization to get the maximum output from the key machine. If it breaks down, all production stops, but costs will continue to accumulate. Spare parts should be immediately available. If the job is remote from where parts can be obtained, those parts most likely to be needed should be taken along.

If the key machine stops producing because the flow of materials to it is inadequate or because the output cannot be handled, there is generally a loss far greater than the cost of correcting the deficiency. The key machine should be fully served at all times.

Hauling

Hauling with trucks is an important operation on a large portion of highway jobs. The distances through which materials must be hauled vary as the job progresses, and this complicates the problem of determining the number of hauling units to be supplied. A number sufficient to keep the job going at full efficiency on hauls well beyond the average haul distance should be supplied, with some reserve for use in case of breakdowns. For hauls much in excess of the average for the job, careful estimates should be made to determine whether it is best to supply hauling units that will be needed only a part of the time or accept the loss resulting from idle time of the key machine. The value of the additional trucks as replacements for those that may break down should not be overlooked.

The character of surface over which hauling is to be done, the manner in which it will be maintained, and steepness of grades are important considerations. Where rough, poorly maintained surfaces reduce speed to 8 or 10 miles per hour the number of units required will be increased.

Practice has not been standardized as to size of truck. Personal preference usually governs the decision. However, on the longer hauls the larger units offer an economic advantage.

Grading and Drainage

Study to determine the equipment most suited for a given grading job begins with the examination of the plans, which show quantities to be moved, length of haul, and a typical cross section. This is followed by a field inspection. Engineers are consulted as to character of the soil and rock formations. These steps are taken by a contractor before bidding on a job. From the facts developed he determines if it is wise to undertake the work with equipment already owned or with some new equipment. In a foreign country where work is done under another system, the problem would be unchanged. Under any system the speed and cost of work done will be affected by the judgment used in selecting equipment.

Production-line grading

Management should plan grading operations to resemble a production line as closely as possible. At the head of this line will be found the clearing and grubbing crew. Their function is to clear all growth from the projected roadway. The size of this crew, and the equipment used by it, are governed by the topography and growth. Where heavy growth and large trees are present, large tractor-bulldozers are needed. Specifications usually provide that all debris must be burned.

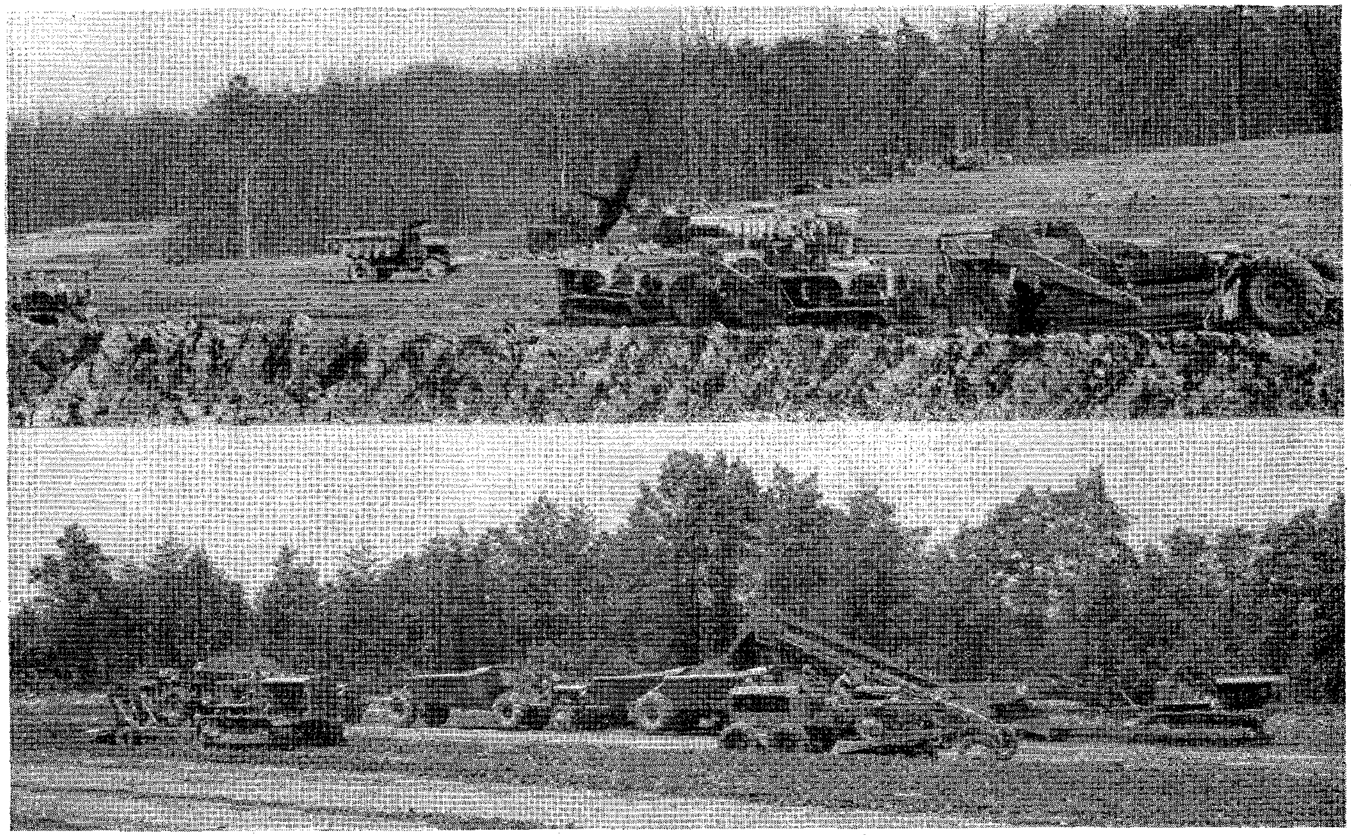
Following behind the clearing crew comes the pilot grading crew, or pioneering crew as it is sometimes called. Their work consists of opening a tractor road within the cleared area so that equipment may be placed at different working points. Often, a culvert crew will follow closely behind, installing those culverts that can be placed ahead of grading work. If rock is to be excavated by blasting, a drilling and blasting crew comes next. This crew will do all such work ahead of earth grading, except where rock excavation is of such magnitude that the drilling and blasting must be carried on simultaneously with earth excavation.

On large projects, numerous grading crews will work simultaneously at various points. Guided by the project plans, haul limits are established and the excavated material is placed to build up the embankments, or wasted as may be required.

Culverts

Culverts may be installed in conjunction with excavation and embankment placement, as well as ahead of such work. Topography and character of design govern this operation to considerable extent.

Following closely behind excavating machines, comes the finishing and cleanup crew. By hand work and with machines, this crew brings the roadway to the shape and grade required by the plans, smooths the slopes, shapes the ditches, and removes all debris. The



Typical mechanized grading jobs. Above: Tractor-drawn scrapers operate in the foreground while a power shovel loads trucks in the rear. Below: A tractor-towed elevating grader fills wheeled tractor-wagons. In the foreground, a rooter (left) and a motor patrol grader (right) aid in the work.

motor-patrol grader is the most widely used machine on such work and an experienced operator can accomplish with it most of the work formerly done by hand labor. Because of wide variations in character of grading jobs and in equipment it is not possible to give all of the possible combinations of equipment that may be used. However, the following suggestions may be helpful.

Rock excavation

Drilling and blasting equipment with accessory tools for sharpening drill steel and maintaining portable air compressors are needed for rock excavation. Air compressors should be capable of producing 100 cubic feet of air per minute for each drill. About one pound of blasting powder will be needed for each cubic yard of rock excavation. Power shovels are preferred for loading blasted rock. Those having a dipper capacity of 1½ to 2½ cubic yards are best suited for rock work. Hauling units should be selected according to length of haul. Large crawler wagons pulled by crawler tractors are suitable for hauls of moderate length in rough terrain. Rubber-tired tractors towing rubber-tired wagons are best on long hauls. Dump trucks of the larger sizes may be used, especially when the haul distance is exceptionally long. Use of small dump trucks with a large shovel is not good practice. A shovel will excavate between 50 and 100 cubic yards per hour, per cubic yard of capacity, and sufficient hauling equipment should be available to keep it in continuous operation.

Earthwork

Topography and length of haul are important considerations in earthwork. On heavy work with short haul and steep grades, self-loading scrapers towed by crawler tractors are desirable. Bulldozers or pusher tractors or both are necessary to open cuts and assist in scraper loading. A good balance is maintained with one dozer for every two tractor-scraper units or one dozer and one pusher for every three tractor-scraper units. Self-loading scrapers towed by two- or four-wheeled rubber-tired tractors should be used on the longer hauls. Pusher tractors are recommended to assist in loading these units. Scarifiers should be used to loosen the material whenever it is too hard and tough to be readily loaded by pulling and pushing tractors. Elevating graders and rubber-tired tractor-wagon hauling units are quite often used in flat terrain where large quantities of easily worked soil must be hauled some distance.

Compaction of fills

In the early years of highway construction, soil was placed in fills without compaction other than that resulting from movement of hauling equipment. Settlement often took place over a period of years, delaying surfacing with rigid pavements and causing serious trouble with all types of surfacing. It is now the practice to spread the soil in layers and thoroughly compact it.

As soil is dumped at the fill by the hauling units it is spread in an even layer by bulldozers or graders.

The maximum thickness of the layer that may be compacted in one operation is usually set by the specifications, and on most work is 6 inches of compacted depth. Some soils will not compact uniformly to this depth under certain types of rollers and thinner layers must be used. The thickness for each soil must be determined by trial and error since no laboratory test has been devised to give this information. Several small areas of soil layers of different thickness should be brought to optimum moisture content and rolled to determine the greatest thickness that can be compacted to desired density and the number of roller trips required to produce that density.

Types of rollers

The type of roller used to compact embankment is not important if the required density is obtained and satisfactory construction progress is maintained. Sheepsfoot or tamping rollers, smooth-faced rollers, and rubber-tired rollers have been used with success.

The sheepsfoot or tamping roller is used extensively. These rollers vary in design from small single-drum rollers to the large double-drum type used on large dams, and the compaction pressures range from 90 to 675 pounds per square inch. One of the chief advantages of this type of roller is that the unit load on the feet may be increased or decreased by variations in the ballast in the drum.

Tamping rollers should be of the twin cylinder type with a frame and tongue that can be attached to a tractor in such a manner that the entire device may be either pulled or pushed in operation. The frames for the two rollers should be pivoted so as to permit the rollers to adapt themselves to uneven ground surface and to rotate independently of one another. Cleaning teeth should be attached to the frame at the rear to prevent accumulation of soil between the tamping feet. The tamping feet should be placed in staggered rows.

Compaction by hauling units

Embankments and subgrades may be compacted to satisfactory densities by the passage of modern hauling equipment over soil layers during the process of construction. However, distribution of equipment over the area to be compacted is difficult to control. Uneven distribution may result in a lack of uniformity in the density and moisture content of the soil in the finished embankment.

Sub-Bases

In general a sub-base consists of a layer of rocky or sandy material placed upon the roadbed to a required depth as support for surfacing. This work is sometimes done along with the grading work and sometimes as a part of surfacing operations. When suitable material will be excavated in grading, the work is included in grading operations. Where a layer of crushed stone or gravel from an outside source is to be placed it is usually done as a part of surfacing.

Placement of sand or gravel sub-base to support concrete pavements is commonly made a part of the paving work. Placement is usually made just prior to pouring of the concrete and the material is usually from the same source as the concrete aggregates.

Equipment

Most of the equipment required in constructing a sub-base will be available in connection with grading or surfacing work. A shovel and hauling units used for grading may be used to load and deliver selected material. If gravel surfacing is to be placed, the gravel producing unit and hauling equipment may be used on the sub-base work. Special equipment has been developed for mixing the stabilizing agent with the aggregate. This equipment is quite efficient and should play a major role in a more widespread use of this type of construction.

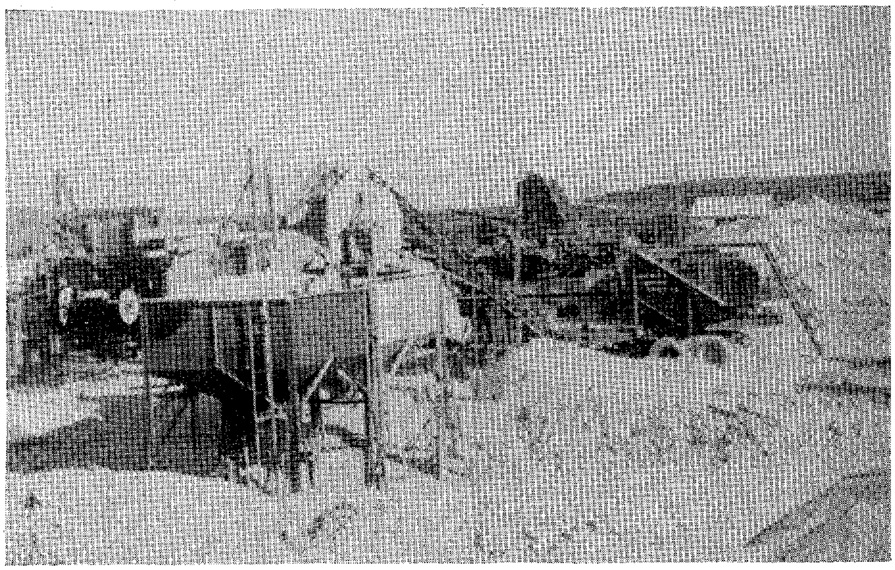
Gravel and Crushed-Stone Surfaces

A gravel or crushed-stone surface may consist of a base course, usually of rather open texture, and a surface course graded to give a dense mixture. For this, as well as for other types of surfacing, the plans and specifications will indicate the type and gradation of materials to be used in the different courses, as well as their depth.

Sources of materials

Aggregates for surfacing are sometimes produced by the contractor from natural deposits within a reasonable haul distance of the job and are sometimes purchased from commercial plants engaged in the production of aggregates for general use. Consideration of the quality of materials from the different sources and cost delivered on the road govern the choice. The contractor is often influenced by whether or not he owns equipment suitable for aggregate production. Absence of suitable local materials may leave no choice other than purchase from a commercial plant, shipment by rail, and delivery on the job by truck.

When materials are produced locally it may be necessary to crush and screen river or bank gravel, or it may be neces-



A typical semiportable crushing and screening plant.

sary to drill, blast, and crush ledge rock. Development of portable and semiportable crushing and screening plants has caused a steady increase in roadside production of materials where deposits of gravel or ledge rock are close at hand.

Synchronized operations

When aggregate is produced locally the surfacing operation is patterned to synchronize with the most efficient output of the crushing and screening unit. In some gravel deposits only screening is required. In others the entire product of the crusher may be used without screening. Synchronization of operation is of vital importance, as the cost of operating a plant remains about the same whether it is producing at full capacity or at a lower rate. Deficiency in hauling or placing equipment or in supplying material to the crusher, lowers the rate of production at all places on the job and increases costs.

When material is produced at a plant near the job, it is the responsibility of the engineer, or one of his assistants, to make gradation tests on the materials as they come from the plant. Close cooperation between the engineer and the plant supervisor is of vital importance in gradation control. Adjustment of the crusher or screens, as indicated by the tests, should be made whenever needed.

The manner of placing surfacing material on the roadbed will vary with the type of construction. The specifications will state the limiting conditions as to types and sizes of equipment to be used, and limits governing processing, mixing, and rolling for compaction. Such conditions must be considered when assembling equipment for construction.

Placement

Whatever the source of surfacing material, a fixed rate of delivery to the job is desirable. Methods of placing aggregate will usually be prescribed in the specifications. The bituminous paving machine is frequently used to spread large aggregate in water-bound macadam construction. Spreader boxes, easily attached to the rear of dump truck bodies and giving quite accurate control of width and depth of spread, are in general use. Where mixing of dry aggregates on the roadway is necessary, the motor-patrol grader can accomplish this operation by moving the material back and forth across the roadbed. Traveling aggregate-mixing machines are also available for mixing on the road. Final spreading and finishing is done with the motor-patrol grader. Power rollers, of various weights, are used for final compaction. Vibrating-tamping machines, to replace the rolling, are being developed and may soon be in general use.

Surface Stabilization With Salts

Granular road surfaces such as sand-clay, gravel, and crusher-run materials frequently become loose and dusty under traffic. This may happen when a base is placed and left for a period of months before adding a bituminous surface or when the volume of traffic does not justify bituminous surfacing.

Under such conditions the character of the surface may be temporarily improved by the addition of calcium chloride or sodium chloride. If surfacing material is mixed on the roadway the salt is evenly distributed by a mechanical spreader during the mixing process. Calcium chloride is applied at the rate of one-half pound per square yard per inch of compacted thickness, and sodium chloride at double that rate. Layers should not exceed 3 to 4 inches in processing. Thorough mixing should follow the application.

When crushed aggregate or gravel is used for surfacing and road mixing is not required the salt may be applied to the surface after the final spreading. Application should be in the morning during relatively high humidity or following a rain while the road surface is still drying out.

Densities for consolidated surfaces containing the chemicals are high, and dry weights are often as much as 150 pounds per cubic foot.

Soil-Cement Surfaces

Soil-cement surfaces may be constructed where the natural surface soil is of a suitable character, as shown by laboratory tests, or may be made so by addition of granular material.

If the natural material is suitable it should be scarified to a depth of 6 inches and pulverized by harrowing. If sand is to be added, its thickness and the depth to which the surface should be scarified will be indicated by tests.

Spreading the cement

In any event, a completely pulverized and uniform mixture of the correct thickness should be produced. Cement is then distributed over the surface. On many projects sacks of cement have been placed, with appropriate spacing, dumped on the surface, and spread with hand tools. This method does not give uniform distribution. Mechanical spreaders are coming into use that give much superior results. The amount of cement used will vary from 6 to 14 percent by volume.

After distribution of the cement, it is thoroughly mixed with the soil by disk harrows. In some cases, a traveling mixing plant is used.

Moisture control

Tests are made to determine the amount of moisture in the soil as an indication of the amount to be added to obtain the optimum for compaction. This amount will be sufficient to hydrate the cement. When it is necessary to add water, a pressure distributor is used and the mixing is continued to make the water content uniform.

A sheepsfoot roller is used for the initial compaction. The surface is then given a final blading and smoothed out with a tandem roller.

The surface should be kept free from traffic until the cement has sufficiently set. During this period, the surface should be covered with straw, wet burlap, or other satisfactory material, to prevent too rapid evaporation.

Soil-cement surfaces are smooth but lack wear resistance and it is now common practice to apply some form of bituminous treatment.

Bituminous Surfaces

The types of bituminous construction most generally used are of five general classes: (1) Surface treatment, (2) penetration macadam, (3) road mix or mixed-in-place, (4) traveling plant mix, and (5) stationary plant mix. Frequently, a pavement in which one type is used will also involve the use of another type. A road mix of open-graded aggregate will require a surface treatment or a seal coat. The seal coat may be a surface treatment or mixed-in-place or plant-mixed material.

The particular type used for a given set of conditions is influenced primarily by the thickness of the surface course required, the materials and equipment available, the extent of control necessary, and relative costs.

General types of construction commonly used may be preceded or followed by other treatments as an integral part of the construction or as supplemental treatments designed to provide specific characteristics. Among such treatments are primes, tack coats, and seal coats.

Relation of thickness to selection of construction *method*

The thickness of bituminous surfacing required and the equipment available will have the greatest influence on the method of construction to be used, whereas the classes of materials available will have the most influence upon the selection of the type to be used.

The surface treatment method is the simplest and most economical method of constructing a bituminous surface course not greater than 1 inch in thickness. Courses greater than 1 inch in thickness are usually constructed by some form of mixing method or by penetration. Road-mixed mats can be mixed, spread, and compacted in depths greater than 1 inch and with aggregate up to 1 inch in maximum size. They are usually constructed to depths not in excess of 2½ or 3 inches. Loosely bonded surface materials such as sand, however, are frequently mixed in place to depths as much as 6 inches. Bituminous concrete can be consolidated in layers up to 3 inches for coarse mixtures and up to 2 inches for finer mixtures. Penetration macadams are usually built not less than 2½ inches thick since the maximum sizes of stone required for good interlocking will normally be greater than is ordinarily permitted in mixing methods. Moreover, the penetration course must be of adequate thickness and the void spaces must be sufficiently great to permit entrance of the bituminous material to waterproof the structure and assist in holding the aggregate particles together.

Schedule of operations

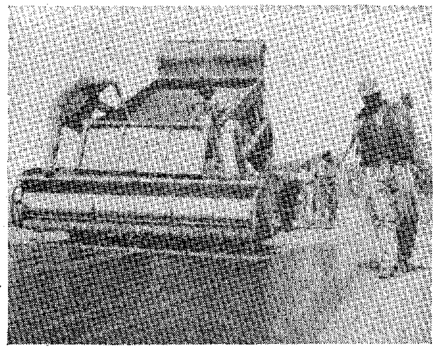
In all bituminous work, operations must be scheduled with considerable care, and this is particularly true when hot materials are prepared. There are rigid requirements as to the time in which different operations must be performed. The entire job must be manned and equipped to meet these requirements without strain.

Preparation of the roadbed is the first step in surfacing. Considerable care is justified on such work as smoothness of the finished pavement depends in large measure upon an even and smooth roadbed. Men skilled in the operation of patrol graders are indispensable in producing desired results.

Bituminous Surface Treatment

Surface treatment is used to form a relatively inexpensive wearing course for any type of stable base. A variety of materials, as well as construction procedures, are used.

Disregarding minor refinements, the general practice in the construction of surface treatments is, first, to prime the base with a liquid bituminous material of low viscosity and, after this has penetrated and dried, to make an application of heavier bituminous material. This is covered immediately with clean, coarse, one-size aggregate, which is rolled. In some instances this may complete the construction, but usually a second coat of bituminous material is applied and



Bituminous material has been applied and is being covered with stone chips, using a box spreader.

covered with or mixed with a small amount of finer aggregate. A seal coat of bitumen and fine aggregate may be applied shortly afterwards or it may be delayed until the approach of the winter season.

Character of finish

The resulting treatment will have about the same thickness in inches as the maximum dimension of the coarse aggregate. The character of the finish will depend upon whether a single application of coarse aggregate is used or whether a second application of fine aggregate is made to fill some of the surface voids. The coarse aggregate seldom is manipulated or mixed with the bituminous binder. Subsequent treatments and seals may be applied with or without mixing. When the fine surface-aggregate and bitumen are mixed, the finished surface will be black. When they are not mixed, the resultant color is that of the aggregate used in the final application.

The foregoing description applies to what are commonly referred to as "single" and "double" surface treatments, depending upon whether one or two applications of aggregate are used. Obviously a number of applications of bitumen followed by aggregate of suitable size can be made when it is desired to construct a surface of greater thickness than that resulting from a single or double treatment.

Bituminous Penetration Macadam

Bituminous macadam bases and surfaces are constructed by spreading and compacting a layer of aggregate and then applying bituminous material, and adding additional layers until the desired thickness of base or surface has been obtained. This will usually be not less than 3 and may be as much as 6 inches.

In this type of construction the required stability is obtained by the interlocking of the aggregate, while the bituminous material serves primarily as a waterproofing agent. Stability is acquired by proper selection of the aggregate and by compacting it until no further movement occurs. The aggregates for each layer are usually one-size materials, the coarsest of which is placed first. Its size will depend upon the thickness of the course desired. When this material has been compacted thoroughly and the bituminous material has been applied, smaller size aggregate is then keyed into the surface voids of the larger material by rolling. Thorough rolling is recommended to insure against future movement that would destroy surface smoothness.

Since the stability is primarily dependent upon the interlocking of aggregate, crushed stone and slag are most generally specified for this type of construction.

Mixed-in-Place Bituminous Bases and Surfaces

The road-mix or mixed-in-place method of constructing bituminous bases and surfaces can be employed advantageously (1) when the aggregate to be used is that already in place, (2) when the existing aggregate is to be supplemented by the addition of selected aggregate to provide the grading required or to produce a base or surface of the thickness desired, and (3) when the existing aggregate is to serve as a base or foundation course and all of the aggregate to be used in the mixture is to be brought in.

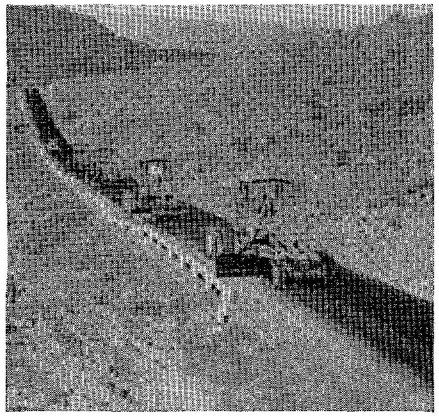
Adapted to sandy soils

The road-mix method is well adapted to surfacing where the natural soil is predominantly sandy. Generally the soils are loosely bonded sands and are not sufficiently well graded to provide good stability. Their load-carrying ability when the particles are bound together by some agent is definitely demonstrated by their good behavior in moist or wet weather. This binding can be made relatively permanent either by the addition of a suitable bituminous binder or by first improving the grading with selected mineral aggregate and then adding the bituminous material. Bituminous treatment of sand in place may be employed for the purpose of providing a foundation upon which to lay a wearing surface, or it may be made to serve as the wearing surface with the untreated material below it acting as the foundation or base.

Preparation of aggregate

The first operation in the road-mix method of construction is to prepare the aggregate. If the material in place is to be used alone, the surface may be scarified to the depth required for the finished thickness. Disks, spring-tooth harrows, blades, and similar devices are then used to reduce the scarified material to a uniformly loose condition. If new material is to be added, it is dry-mixed with this loose aggregate until the combined material is uniform in grading. When all of the material is to be brought in, the existing surface is not disturbed except for necessary reshaping.

When the aggregate has been properly prepared, it is spread out to a level course and the bituminous material is then applied in one or more increments by pressure distributors. After each application of bituminous material the aggregate and bitumen are turned with disk harrows and, after the total amount of bituminous material has been applied and the disking has been done, the materials are mixed by repeated turnings, with disk and spring-tooth harrows, pulled and self-propelled blade machines,



Patrol graders mixing bituminous material with aggregate. A windrow of partly mixed material in the center of the road is being bladed back and forth.

or by some type of portable mixer that completes the mixing operation by passing over the materials. When the mixing operation has been completed, the mixture is spread and compacted.

Continuous operation

Bases, surfaces, and in some instances combined bases and surfaces can be constructed as a continuous operation. For example, if the existing soil appears satisfactory as aggregate for base and surface, it can be mixed with bitumen to a depth equivalent to the total thickness of the base and surface courses. Since the bitumen content of the base course will normally be less than that of the surface portion, the entire depth can be mixed with the bitumen required for the base portion. When this has been done and the mixture has been spread and compacted, the upper portion of the mixture can be loosened to a depth equivalent to the desired thickness of surface course and additional bitumen applied to raise the percentage to that necessary for the surface course.

Another method of constructing the surface course integrally with the base is to enrich the upper portion by applying a small amount of rapid-curing material that will penetrate into the mixture and form a relatively thin surface course which is actually a part of the base but is sufficiently rich to resist abrasion. It may be desirable to place a surface course composed of bitumen and graded stone, slag, or gravel on the mixed base. In this case the surface may be constructed by the surface-treatment method except that no prime is required and a high-viscosity bituminous material should be used to prevent its penetration into the bituminous base.

The procedure for mixing in place just given is equally applicable when the aggregate is brought in. In such instances, however, there is a tendency towards the use of the plant-mix methods because of the possibility of greater uniformity and control. Practically any gradation and type of nonplastic material can be used as aggregate provided the purpose it is to serve is kept in mind.

Types of bitumen

Regardless of the type of aggregate used, the bituminous materials suitable for this type of construction are necessarily liquids that will remain fluid at air temperature sufficiently long to permit completion of the construction operations. Asphalts, tars, and slow-breaking emulsions may be used.

The percentage composition of mixed-in-place bases and surfaces varies so widely in actual practice as to render meaningless a statement of satisfactory limits. However, regardless of whether the aggregate used is that already in place or is to be brought in, the bitumen content should be based upon its gradation, the consistency and type of bitumen used, and whether the mixture is to serve as a base or as a wearing course.

Compaction

The compaction of mixed-in-place material varies considerably, but some type of compaction is usually required. Preliminary compacting is sometimes done as a construction operation and traffic is depended upon to develop the final compaction.

A variety of types of compacting equipment is used. Self-propelled two-wheel or tandem type rollers as well as the three-wheel type are used for compacting the same type of mixtures and it is frequently required that both types be used on the same project. Rollers of these types are satisfactory for compacting courses not over 3 inches thick. Where depths greater than about 3 inches are to be compacted in a single operation, some type of pulled roller is generally used. Among these are smooth-faced rollers, pneumatic-tired multiple-wheel rollers, and sheepsfoot rollers. A description of the various rollers is given in the discussion of equipment.

Volatile materials

Special consideration should be given to the compaction of mixtures in which the bituminous material is a liquid that contains volatile materials, such as cutback liquid asphaltic materials, tars, and asphaltic emulsions. The volatile portion of such materials serves no useful purpose after the mixture is prepared and placed. It must be removed if the bituminous material is to develop the natural cementing properties of which it is capable and the mixture stability expected. Dissipation of the volatile material after the mixture has been compacted is a very slow process and consequently it should be eliminated as far as possible before compaction begins. This can be accomplished by continued manipulation if blades, drags, and similar equipment are used. When the traveling-plant method of mixing is used, the bituminous material need not contain as much volatile material for the mixing operation. Regardless of the method of mixing, the mixture should be manipulated until it is just sufficiently workable to permit satisfactory placing. When it is in this condition, compaction can be begun.

The amount of compaction that can be obtained is influenced primarily by the grading of the aggregate but it is dependent upon many other factors such as the weights of compacting devices, workability of the mixture, and atmospheric conditions. A density close to the maximum theoretical density should be required. The manner in which it is to be obtained should be based on experience and the judgment of the engineer.

Traveling-Plant Methods of Constructing Bituminous Bases and Surfaces

As an outgrowth of the mixed-in-place method of construction, traveling mixing plants have been developed. The machines were designed to replace the distributors and various mixing devices by proportioning and mixing the bitumen and aggregate in a single continuous operation. They are adapted to the same conditions as is the road-mix method and the preliminary operations up to the application of bitumen are the same for both methods. However, when the traveling mixer is used, the prepared aggregate is windrowed instead of being spread out. The windrowed material is picked up, fed continuously through the plant, mixed with the bitumen, redeposited in a windrow, and then spread and compacted as in the road-mix method.

Batching method

Several types of traveling plants are available. All are self-propelled and have continuous, pug-mill mixers. Proportioning is automatically done by the batching method or by the continuous process. In the batching method, the aggregate is continuously fed into the batch hopper. When the desired weight of material has been deposited, the hopper is tripped and the aggregate falls into the end of the mixing chamber. At the same time, the bitumen, which has been pumped into a reservoir, is sprayed over the aggregate. The twin-pug paddles pick up the bitumen and aggregate, mix them thoroughly, and at the same time force the mixture toward the rear of the chamber from which it is discharged.

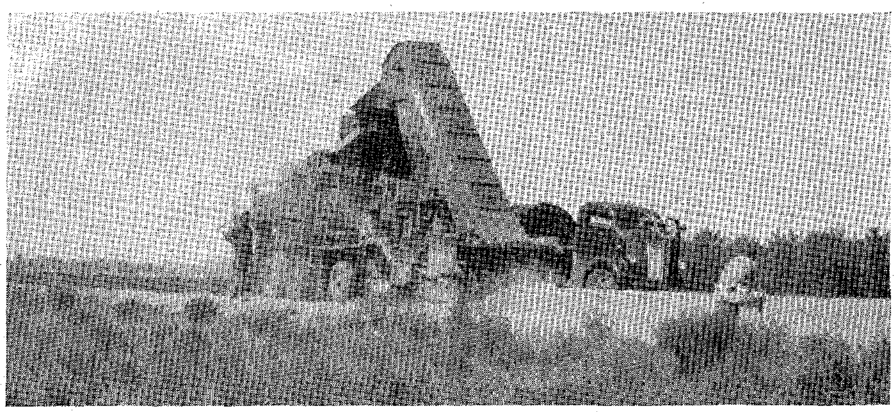
Continuous proportioning

In continuous proportioning, the aggregate is fed from a storage bin or hopper through a calibrated gate to a traveling conveyor that carries it to the mixing chamber. The bitumen is pumped continuously into the mixing chamber through a gage set to deliver the required amount. The operation of the pump is synchronized with the aggregate conveyor so that the composition of the mixture is not affected by variations in the speed of the driving mechanism.

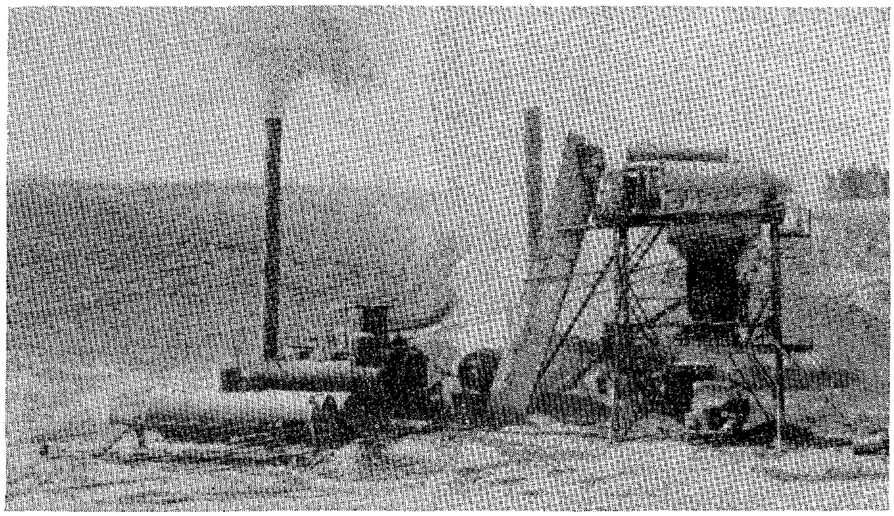
The factors affecting the type and quantity of bitumen, the necessity of curing the mixture, and the methods of compaction described for the road-mix method are equally applicable to the traveling-plant method.

Advantages of traveling plant

Satisfactory results can be obtained by either method of construction but the traveling plant has some advantages over manipulating the materials in place: (1)



A traveling mixing plant.



A typical plant for preparing hot bituminous mixtures.

More accurate control of bitumen content is possible; (2) heavier grades of a given type of bituminous material can be used; (3) a more uniform thickness can be obtained; (4) delays caused by inclement weather will be of shorter duration, and (5) the likelihood of partially mixed material getting wet is eliminated.

Delivery and Application of Bituminous Materials

Equipment used in heating, transporting, and storing liquid bituminous material is quite important and must be suited to the type of material and conditions surrounding the job. In this country very little packaged asphalt is used. Delivery to the job is made in insulated railroad tank cars and tank trucks from refineries or storage places. Hot oil is shipped at a specified temperature. When reheating is necessary to bring the material to the temperature required for use, facilities must be provided. Railroad tank cars are fitted with steam coils and the material may be reheated by circulating live steam through them. Portable heaters are used to generate steam and are suitable for use with tank cars or storage tanks equipped with steam coils. At large mixing plants it is customary to install sufficient storage tanks to assure a supply of bituminous material at all times.

Distributors

An asphalt distributor is required for most types of bituminous construction. This is a highly efficient piece of equipment. Those in most common use have a capacity between 1,000 and 1,200 gallons, are truck mounted, have built-in tank heating coils, and pressurized discharge. They are equipped with a device registering travel speed in feet per minute that is used as a guide in obtaining the required application per square yard.

Compaction in Bituminous Construction

Specifications for practically all types of bituminous construction include requirements for the compaction of the mat or mixture and surface rolling to obtain the required density and smooth-riding qualities.

Adequate density and surface smoothness can be obtained by several means. Compaction by traffic is used to a limited extent on minor highways. The principal objection to it is the uneven distribution of the wheel movements.

Rollers

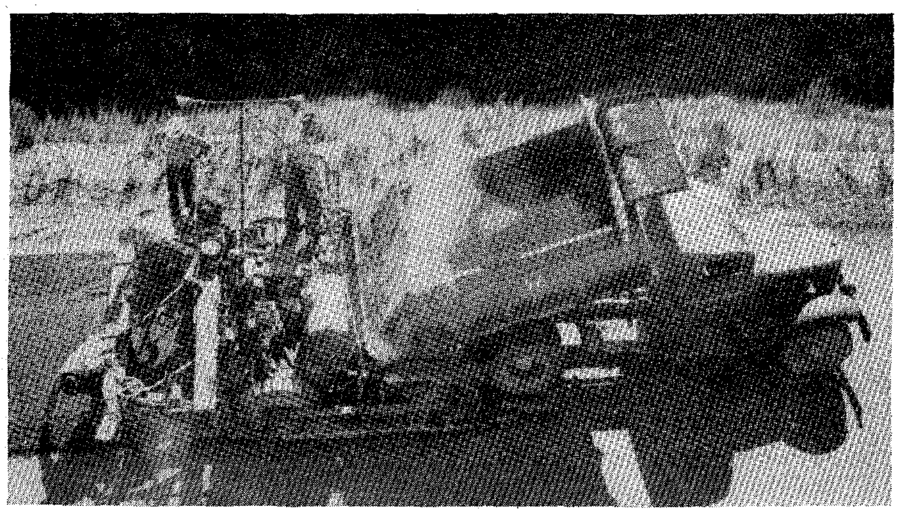
Self-propelled rollers have been used for years in bituminous construction. They are of two general types, commonly referred to as the two-wheel or tandem and the three-wheel or macadam rollers. The two rolls of the tandem type are of the same width but of different diameters. The three-wheel type has a wide but relatively small diameter front wheel and two narrow rear wheels whose diameter is usually much greater than that of the front wheel. In principle, rollers of these types are the same as those in use for years but improvements have been made which have increased their practicability and efficiency. One rather recent development has been the addition of an auxiliary roller on which practically the entire weight of the machine can be concentrated if necessary to reduce high spots. In the three-wheel type of roller, this auxiliary roll is mounted between the front and rear rolls in some types and behind the rear wheels in others. In the tandem types the third roll is usually the same size as the front one and is attached to the front of the frame.

Another development is the variable-weight tandem roller. In this type the rolls are hollow, closed cylinders that can be partially or completely filled with water for added weight if desired. They are listed according to their variations in weight, as 4 to 8 tons, or 10 or 15 tons, etc. Rollers of this type are more adaptable to various uses than are those of a fixed weight.

Both tandem and three-wheel rollers can be obtained in sizes ranging from about 3 to 20 tons, gross weight.

In addition to the self-propelled rollers just described, various types of pulled rollers are used for compacting. One of these, the pneumatic-tired, multiple-wheel roller, is an outgrowth of compacting by traffic and construction equipment. This roller consists of a heavy box-like frame supported by two sets of truck wheels having pneumatic tires.

The particular type and weight of roller required will depend upon local conditions and upon the type of construction. The amount and method of compaction should be stated definitely in the specifications.



Bituminous mixture has been prepared at a central plant and is being spread with a bituminous paver.

Portland Cement Concrete Construction

The satisfactory performance of a concrete pavement depends as much upon the construction methods used as upon the materials. Most of the construction operations, including the handling and batching of the materials and the mixing, placing, and finishing of the concrete, have been standardized for many years and are highly mechanized. The rate at which the mixer operates sets the pace for all operations. Its capacity governs the size and output of all parts of the organization.

Construction equipment

In addition to the equipment required for handling and batching materials, the usual construction equipment includes a power subgrader, a mixer having a capacity of one cubic yard or more, a power-driven machine for spreading the concrete, a power-driven finishing machine for smoothing off the concrete, and a power-driven longitudinal float for taking out transverse irregularities left by the finishing machine.

Detailed procedures for constructing concrete pavements in accordance with current American practice are given in specifications prepared by the American Association of State Highway Officials. These specifications are in such detail as to require little additional explanation.

Finishing

Alternate procedures are acceptable for many of the operations. For example, the specifications provide three alternate procedures for finishing the pavement surface: (1) Finishing by hand, to be used only in places where mechanical finishing is impractical; (2) machine finishing, with a standard power-driven finishing machine; and (3) consolidation, by means of high frequency vibration applied either to the surface of the concrete or internally. Either standard finishing machines with vibrators or similar machines equipped with one of the types of vibrators specified may be used. However, the proportions and consistency of the concrete should be adjusted according to the method of finishing used. Experience has shown that the amount of sand may be reduced and a somewhat drier mix may be used in mixtures that are to be vibrated. Internal vibration of pavement concrete, except along longitudinal and transverse joints, has not always proved entirely satisfactory because the equipment now on the market cannot always be depended upon to consolidate properly the harsher mixes in which certain types of stone are used as coarse aggregate.

For surface finishing, there are two alternate procedures. In the first, the surface is finished with a canvas belt, usually operated by hand. In the second, the surface is given a broomed finish. This latter operation is so conducted as to produce transverse corrugations in the surface, closely spaced and not more than one-sixteenth inch in depth, without unduly roughening or tearing the surface. The broom is operated by means of a long handle and is usually about 18 inches wide, with fibers about 4½ inches long.

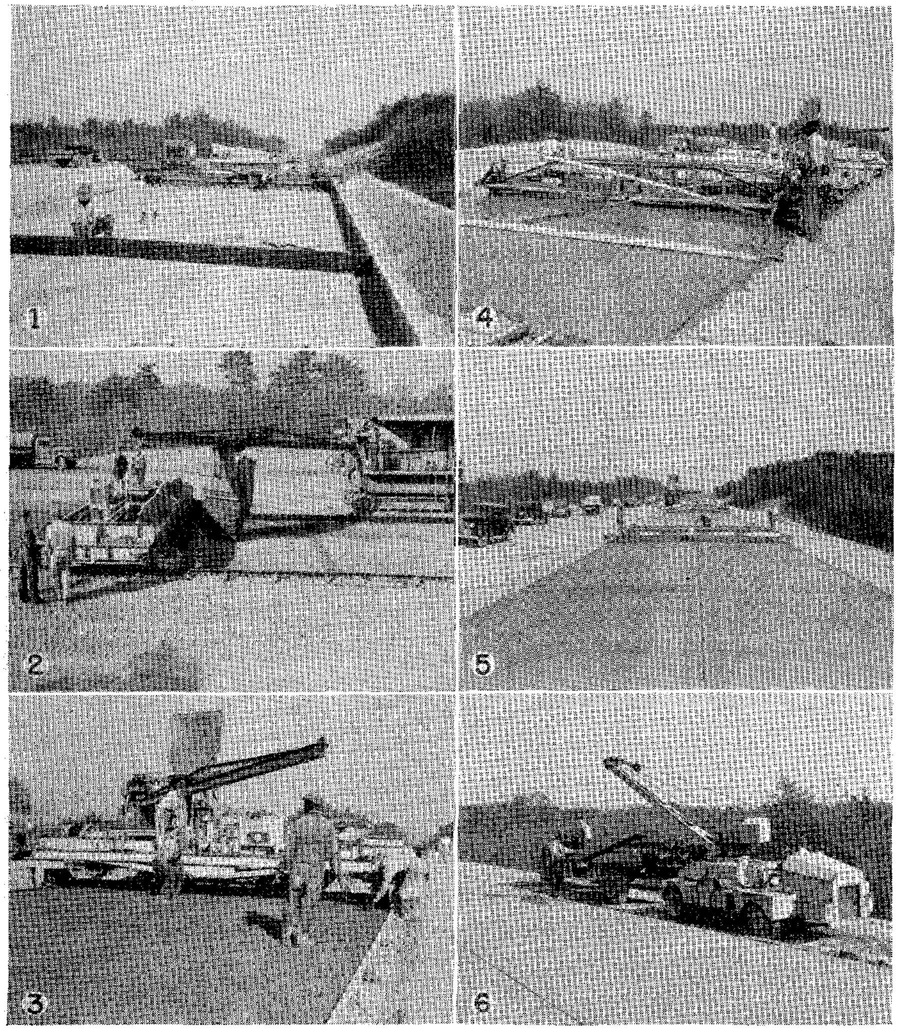
Curing

Several alternate procedures for curing are specified. These include the use of cotton or jute mats, waterproof paper, wetted earth, straw curing, or spraying with impervious membrane sealing compounds. All of these methods are in use. However, one of the most popular methods at the present time appears to be the application of colorless membrane sealing compounds. Numerous materials are now available for this purpose and appear to give reasonably satisfactory results if means are provided for applying the compound uniformly to the surface of the pavement. Hand sprays were formerly used but these are rapidly being replaced by multiple-spray devices mounted on frames which ride upon the forms.

Standard specifications for determining the efficiency of sealing compounds are available. Although the use of membrane compounds is very popular, curing with cotton or jute mats is still preferred by many engineers because the mats not only protect the concrete from drying but also supply additional moisture for hydration. They also have a definite insulating effect against sudden changes in temperature. Standard specifications for cotton mats, as well as for waterproof paper and membrane compounds, are available.

Ready-mixed concrete

The use of ready-mixed concrete is steadily on the increase. By ready-mixed concrete is meant (1) concrete which is proportioned and mixed in a central plant and hauled to the site of the work in an agitator truck, (2) concrete which is proportioned and partially



A concrete paving job. (1) A subgrade machine levels the subgrade and windrows excess soil outside the forms. In the foreground, an expansion joint is being set. (2) A finisher waits to spread concrete being dumped by the mixer. (3) Steel reinforcing is laid, to be followed by more concrete. (4) Finishing and floating operations. (5) Joints are cut and finished by hand from a moving bridge. (6) Forms are removed from the hardened pavement.

mixed in a central plant and then transported to the site of the work in a truck mixer, the mixing being completed enroute, or (3) concrete which is proportioned in a central plant and mixed in a truck mixer enroute to the site of the work. All three methods are in use. The use of ready-mixed concrete has certain advantages over mixing at the site. The proportioning plant is usually a fixed plant with adequate equipment for measuring materials and can be subject to close supervision. In constructing a road surface it also does away with operation of a mixer on the subgrade. The principal difficulty is in controlling the water content of the concrete. Adequate water control devices should be insisted upon and careful control of the consistency of the concrete as delivered to the work should be exercised.

On jobs where only a moderate amount of concrete is needed for small culverts and headwalls there is considerable economy in buying ready-mixed concrete from a commercial supplier but the procedure is by no means limited to small structures.

Efficiency of Construction Operations

The superintendent of a highway construction job will seek to get the maximum amount of work done. Success in this direction will depend upon accurate knowledge of the time it should take to perform each detailed operation and what the consistent output on the job as a whole should be.

As an example of how a superintendent should seek to obtain efficiency, assume a grading job with a power shovel capable of handling 100 cubic yards per hour. Hauling and spreading units have been provided to handle this output, yet actual production is only 75 cubic yards per hour.

Responsibility for the lost production falls squarely upon the superintendent. He has been provided with a 100-cubic-yard outfit that is operating at only 75 percent efficiency. It is his duty to find the trouble and correct it.

Shovel speed

The number of places to look is not large. The superintendent examines them, starting with the shovel. Here there are two possible difficulties. The operator may be wasting time taking more than an average of slightly less than 2 minutes to load a truck. On this job the operator should be able to load at a rate of one dipperful in slightly less than one-half minute. When this rate is not maintained it may be because the operator lacks skill and energy or it may be because the trucks are not getting into loading position promptly. If time is being wasted, it may be that all that is required is to have the operator correct faulty practices. A more usual solution of the poor-operator problem is to find and employ a better one.

Size of loads

A second thing to look for at the shovel is the size of the loads the dipper is picking up. A shovel operator who consistently fails to dig full loads can cause a big loss because when the loads he puts into a truck are short, the truck—which is usually given a definite number of dipperfuls—goes light to the dump. As it costs as much to haul a partial load as it costs to haul a full load, and cost of shovel operation is not lessened by taking partial loads, cost rises above the planned figure. It may be that the shovel is not digging from the right position—that is, it may be too close to the face or too far from it. The digging teeth may be badly worn and need replacement.

Sometimes an operator spends too much time on final touching up of the ground over which he is working. Time should not be wasted on touching up that can be done better by a bulldozer. It is good practice to run the bulldozer back from the dump every 2 hours or so to clean up around and back of the shovel. Usually the bulldozer will have plenty of time for this.

Hauling

If the trouble is not at the shovel it is likely to be in the management of hauling. Too little room may be available at the shovel for turning trucks, or after turning they may have to back too far to the loading position and thus delay the shovel operator. Frequent and careful attention should be given to how the trucks are handled at the shovel. Suppose the trucks should be making a round trip every 6 minutes, but, because 1 minute is lost in maneuvering at the shovel the trip time becomes 7 minutes. If five trucks are in use the hourly output falls from 50 to 43 loads—a loss too large to ignore.

A common case of inefficient operation is the condition of the ground over which hauling is done. Scheduled speeds cannot be maintained over rough or muddy ground. A patrol grader should be kept constantly at work on ground over which hauling is being done. If the ground is so wet that deep ruts will form, work should be suspended. Ruts formed are hard to eliminate, cause additional wear of equipment, and cut down hauling speed.

Occasionally time is lost in turning around at the dump. This is apt to occur only when the width of fill is less than 20 feet. When it does occur careful attention should be given to developing means of eliminating or reducing the delay.

Job practices

Finally, production may be falling behind because of job practices. Assume that the production schedule calls for 8 hours of production per day. This means 8 hours of actual work—not just 8 hours spent on the job. If it becomes the practice to stop units to grease them during working hours, to go to the material yards for gasoline, production time is lost. Jobs have been observed where 5 percent, and even 10 percent of working time was lost because of avoidable delays.

Such practices tend to grow without full appreciation of their significance. Often labor is blamed for lack of progress when the fault lies with management.

This example of where to look for trouble on a power-shovel grading job has been selected as typical of the method of examining performance on all classes of highway work. Construction men should appreciate that each construction item—grading, quarrying and crushing stone, laying asphalt pavement, laying concrete pavement—involves a series of operations, and that delay at any place in the series affects the entire series. An organization that has been correctly designed can be made to produce as planned and should be made to do so.

Field and Laboratory Control of Materials and Processes

The purpose of laboratory and field control of materials and processes is to insure that a structure will be built according to the prescribed plans and specifications. The extent of control required depends upon the nature of the work, the specification requirements, and conditions peculiar to the job. Normally it includes tests and inspection of materials; assembling, preparing, proportioning, and mixing them; and placing and finishing them in accordance with specified or implied directions.

Various plans are used for the control of materials. They may be tested at the source of supply, in a central or control laboratory, or on the job. Testing is generally done at the source of supply if the quantity of material being furnished justifies sending an inspector to the producer's plant and if testing facilities can be made available. This practice has definite advantages: It prevents unsuitable material from reaching the job and becoming the subject of dispute; it relieves the job inspector from unnecessary routine work that can be done elsewhere; and it eliminates a possible source of delay to the contractor.

Central laboratory

Over-all control of materials and final decisions on their acceptability is the responsibility of the central or control laboratory, which should be equipped to conduct all tests required by the specifications and should be manned by trained and skilled operators. Normally, the testing of materials in such a laboratory is done in accordance with the methods stated in the specifications, which generally are those of a recognized technical society such as the American Society for Testing Materials or the American Association of State Highway Officials. Such test methods have been carefully standardized and precisely described so that concordant results can be obtained wherever performed, providing the testing is accurately done by trained operators. Additional tests, developed by research but not necessarily adopted as standard, are sometimes included in specifications to insure closer control of materials (or combinations of materials) than is afforded by the standard routine tests. Experience has shown these tests to be necessary, in some instances, in order to obtain satisfactory results.

Judgment and experience needed

Normally, specifications prescribe the manner in which materials are to be used on the job. Some provisions, however, require that certain operations be performed "to the satisfaction of the engineer" or "as directed by the engineer." Obviously such clauses place reliance solely upon the judgment of the engineer for fulfillment according to the spirit of the specifications. It is essential that the engineer have the training, experience, and judgment necessary for the intelligent use of this authority.

The actual operations by the engineer or inspector on a given job are implied directly or indirectly by the specifications. The more definite the specifications, the more definite will be the duties of the engineer and the more closely will the work be controlled. On some types of construction it is frequently desirable and more economical to permit use of alternate materials and methods so that only general terms can be used and the desired end results specified. This in turn necessitates placing greater reliance upon the inspector for proper selection and control of materials so as to produce the most satisfactory results. On the more closely controlled types of construction the duties and responsibilities of the inspectors, while numerous, are specific and require more routine testing than exercise of judgment. Control consists of: first, complete examination of all materials prior to use, for compliance with the specifications; and, second, proper use of the materials on the job, as determined by tests or by the judgment of the inspector.

Bituminous construction

Types of bituminous construction range from the placing of a single application of bituminous material on a bituminous or a nonbituminous base or surface to the fabrication and placing of a carefully designed and closely specified bituminous mixture. For the purposes of discussion it will be assumed that all materials have been tested and approved before reaching the job, and that the central or control laboratory has provided the engineer with such data and information regarding the materials as may be necessary for proper manipulation without injury or damage in the course of construction. This will apply particularly to bituminous materials that may be damaged by overheating or may become a fire hazard if not handled properly.

Regardless of the type of surfacing under construction, there are certain basic duties which the engineer must perform. Before actual operations begin, he must be sure that the materials to be incorporated in the road are in good condition upon arrival at the job. Aggregate should be examined to see whether it has been damaged or contaminated while en route. Bitumen shipments should be similarly examined. All equipment specified to be used on the job must be checked. This includes calibration of all weighing, measuring, recording, and timing devices; checking screens, bins, driers, and mixing devices as to size, design, and condition; and examining spreading, compacting, and other required equipment for compliance with the specifications as regards type and mechanical condition.

The engineer must also check the existing surface or base, prior to placing any material upon it, to see that it conforms to the specifications. This includes checking the grade and cross section if required, examining for cleanliness, density, freedom from moisture, and other conditions covered by the specifications. This is a continuing duty to be performed as frequently as the situation requires and, as it involves the exercise of good judgment, it should be the responsibility of an experienced engineer.

Primes, tack coats, surface treatments, and seal coats

The engineer must see that bituminous material is applied in the amount and at the temperature specified; and that aggregate, if used, is spread uniformly in the amount specified. The volume of bitumen in the distributor should be measured before and after each load of material is applied and the temperature should be recorded. These data are necessary for calculating the amount used and the rate of application.

The rate of application is normally specified as a range within which the engineer decides upon the exact amount to be used. For example the specifications may direct that a prime coat be applied at a rate between 0.25 and 0.35 gallon per square yard. A trial application of the average amount specified will be made and, after observing the results obtained, the engineer must promptly decide what amount will be needed to provide a thorough prime coat without waste of material. Too rapid absorption of the priming material may indicate use of too little material or that a heavier grade should be used. Delay in absorption may indicate the opposite; that is, the amount applied may have been too great or the grade used too heavy. Applications of smaller amounts, or in increments, may be necessary to obtain the desired results.

In applying materials for surface treatments, followed by a cover of mineral aggregate, the method of control will be similar. In this case, however, the rate of application of bitumen is based upon the amount required to bind the cover in place. In surface treatments it is necessary to prevent overlapping of successive loads of bitumen and thereby prevent development of rough riding surfaces at junction points. Placing of cover aggregate requires measurement or weighing of increments and spreading them over measured areas. The specifications frequently require this operation to be done "uniformly" or "in a workmanlike manner" and consequently the engineer must have the training and experience to enable him to decide how these requirements are to be met.

Bituminous macadam

In addition to considerations already discussed, the engineer's duty in the construction of macadam is to insure that the different courses are placed to the specified thickness, that they are thoroughly compacted until no further consolidation can be obtained, and that the resulting surface smoothness is within the tolerance permitted by the specifications. This entails close observation of rolling and almost continuous use of the straight edge and template. Defects in a given course cannot be remedied easily or compensated for in subsequent courses. The engineer should require that each course be completed properly before operations begin on the next course. Control of bitumen applications is, for all practical purposes, essentially the same as in surface treatments.

Road-mix construction

Specifications for road-mix surfaces are normally rather general except in the matter of bitumen content and moisture, and the results obtained depend to a great extent upon the judgment of the engineer. Routine tests of aggregate grading, moisture contents, and percentages of bitumen, as required by the specifications, are made; but because of the speed of construction the results of such tests serve primarily to substantiate the engineer's judgment and to provide information for future reference. The engineer must observe mixing operations almost continuously and be capable of deciding promptly when a mixture is thoroughly mixed, when the bitumen content is satisfactory, when the moisture content is not excessive, and when the mixture is in the proper condition for spreading and compacting.

Traveling-plant construction

In some traveling plants the aggregate and bitumen are mechanically proportioned as desired, and control is thus constantly exercised. In other plants, the bitumen is applied at a constant rate which is dependent upon the forward movement of the machine—the uniformity of the mixture therefore depending upon the uniformity of the windrowed material.

Judgment in controlling the mix is influenced by a few routine tests, but depends chiefly upon ability to decide promptly when adjustments should be made. Normally, progress is so rapid that changes must be made on the basis of visual observations rather than on routine tests.

Plant-mix construction

The results demanded in plant-mix construction are more exacting than in other types of bituminous construction and consequently the controls governing mixing, laying, and finishing are more definitely specified. The exercise of control requires considerable routine testing on the job.

Routine testing can be done by an operator of limited experience provided he is adequately supervised. Proper use of the tolerances permitted by the specifications requires the exercise of good judgment if the best results possible under the specifications are to be obtained. For example, specifications permit slight tolerances in grading of aggregates, in the composition of the mixture, and in the mixing temperatures, in the case of hot mixtures. The bitumen content required is affected by the grading of the aggregate and both the grading of the aggregate and the temperature affect the workability of the mixture and its resulting density in place. It is essential that the engineer know what effect a minor adjustment may have on the overall results.

Spreading and finishing are affected by the composition and temperature of the mixture and the results obtained may indicate minor adjustments in preparing the mixture. The same factors also influence the method, time, and amount of rolling required. Control of all these features is essential for best results. Since most of them depend upon visual observations, experience, training, and good judgment on the part of the engineer are required.

Concrete construction

Control of concrete construction requires extensive preliminary study in the control laboratory, close and continued cooperation between the laboratory and the job, control testing on the job, and close observation of all construction details. There should be close cooperation between the engineers at the materials plant and on the job site.

It is the responsibility of the central or control laboratory to design the concrete mixture according to limits set by the specifications and so that the finished product will have the physical properties contemplated in the design. Assuming that the individual materials are satisfactory, this will include a determination of the best combination or combinations of cement, aggregates, and water, a determination of the proper consistency, and the development of information as to variations that may be permissible and still produce uniformly satisfactory results. The effect of variations in composition upon the final results can be determined only in the laboratory and therefore the information supplied to the field laboratory should be very definite.

Job control will be based primarily upon instructions from the laboratory but will be influenced, within limits, by the particular conditions existing. Routine tests are fairly well standardized and are a fixed assignment. Knowledge and experience is required, however, in the inspection of the condition and handling of materials, in the inspection of fabrication processes, and in determining the apparent quality of the mixture. The physical properties that will develop cannot be determined by visual inspection, but the experienced engineer will note the consistency, uniformity, and general appearance and must make such minor adjustments as may be permissible and necessary very promptly to prevent the use of nonuniform or unworkable material.

Timing of operations such as mixing, transporting, and finishing is very important. If such operations are not properly timed, the results will be unsatisfactory and may make it necessary to remove and replace concrete. The chief requisite for proper control is a thorough knowledge of the specifications, experience, good judgment, and ability to make decisions promptly. Dimensional and quantitative factors can be measured, but judgment and experience are required in making many decisions that greatly affect the results. The engineer must decide whether the forms are properly alined; when the subgrade is properly prepared, compacted, and moistened; whether reinforcing steel, if used, is in satisfactory physical condition and properly placed; whether the mixture has the consistency and other detectable physical properties it should have; whether it is placed correctly and is manipulated and finished properly and at the correct time.

Construction with soils

Construction in this category includes fills, embankments, subgrades, bases, and surfaces composed chiefly of natural soil with or without the addition of granular materials such as sand, gravel, stone, and slag. Extensive field and laboratory work should precede the preparation of specifications for soil and soil-aggregate construction.

The field work consists of determining the location and amounts of the soils of various types on the site, adjacent to it, and in areas likely to become sources of supply. Moisture and drainage conditions must be thoroughly examined, not only as they exist but also as they may be affected by the proposed construction. Extensive sampling of materials and the preparation of soil-profile maps are also essential preliminary studies.

The properties of the soil and other materials are determined in the laboratory by routine and special tests, and mixtures of materials are designed to have the properties required for satisfactory behavior in the structure. For example, moisture control and compaction are essential in placing soils so as to develop load-carrying capacity and resistance to the effects of excess moisture. It is imperative that the required density be determined and that the moisture content required to obtain that density be established. This information is used in specifying construction controls. The laboratory specialists must designate the materials to be used in a particular location, and also those materials existing on the site to be removed and replaced with specified materials. Where drainage systems are required to maintain stability, they must be located and designed.

Control of materials and processes during construction involves continued testing of materials for gradation and plasticity constants, and determination of moisture contents and densities, to insure that each layer or course as completed has the physical properties required by the specification. Since consolidation or compaction is almost a continuous operation, the engineer must have a good knowledge of soil behavior to determine, approximately, when the proper degree of consolidation has been attained and then corroborate his judgment by test measurements.

HIGHWAY MAINTENANCE

Some 327,000 men and over 300,000 major mechanical units are stationed along the Nation's highways and city streets to keep them in the proper condition for safe and unobstructed movement of vehicles.

The Size of the Job

Prompt and constant action is essential in repairing the pavements over which roll vehicles of considerable weight, at high speeds and under all weather conditions, carrying people, food from farms, and raw materials to and finished products from our factories.

Gradual deterioration, sudden failures, damage by storms, and chance obstructions are all road hazards that cause personal injury and damage or delay in transportation of commodities. Well-kept roads are necessary to our national economy.

It is sometimes said that the most permanent thing about a highway is the cost of keeping it up. The expenditure in 1947 for road maintenance by State and local governments is estimated at $967,000,000. In contrast to construction, where most of the work is done under contract by private organizations, highway maintenance is generally performed by labor hired by agencies of State and local governments, and with equipment owned by them.

Of the average dollar expended for maintenance, 48 percent goes for direct labor on the road; 18 percent for materials; 26 percent for cost of equipment, including depreciation and operating costs; and 8 percent for administration.

Organization

In a typical State highway department all maintenance and minor betterment activities are directed by a highway maintenance engineer at headquarters The State maintenance engineer's duties are to participate with the chief engineer in developing general maintenance policies for the approval of the highway commission and in directing execution of such policies by the field organization.

Annual program

Annual programs of work are prepared at headquarters each fall for the coming year. Each district maintenance engineer submits a detailed estimate of the funds needed in each county and on each route for the coming year. Allotments are based on condition of pavement, traffic carried, previous maintenance operations, imminence of resurfacing or other improvement, priority suggested by field supervisor, and complaints received from highway users. A tentative program is prepared and checked against the construction program to avoid expenditures on highways soon to be reconstructed. After appropriate revision it is approved as the authorization for the year.

Districts

A State is generally divided into eight to twelve geographic districts, each in charge of a district engineer. The line of authority is from the State maintenance engineer to the district maintenance engineer, to maintenance superintendents, gang foreman and sectionman or patrolman, skilled and common labor.

In one State where the highway department is responsible for maintenance of 40,800 miles of roads, the State is divided into districts consisting of several counties, each in charge of an engineer who directs a maintenance superintendent in each county.

The superintendents have their offices in buildings where maintenance equipment and materials are stored, and there is space for repairing equipment. Modern maintenance buildings have been constructed in each county. The equipment depot is centrally located and on the average 600 miles of road are maintained.

This State highway department employed 66 maintenance superintendents with 192 assistant superintendents. There were 11,978 maintenance employees.

In the Oregon organization, shown in figure 50, field operations are directed through an equipment engineer, five division engineers, one office engineer, a sign engineer, a radio engineer, and a ferry superintendent.

Maintenance patrols

Repairs on the highways are made by both patrol and gang methods. A normal patrol section consists of from 10 to 40 miles of highway, depending upon the amount of work to be performed. Each section is assigned to a patrolman with from one to three assistants. This crew is responsible for normal hand patching, reconditioning short stretches (300 feet or less), ditch cleaning, shoulder repairs, and cleaning and mowing the roadside. Frequent patroling of the roads is required so that defects may be noted as they occur and plans made for correction.

Many States have special gangs to travel over the State and do work beyond the capacity of the patrol crew. Such forces do surface reconditioning where the area to be worked on is large. A traveling party may consist of about 15 men and have 4 or 5 power patrol graders, 4 or 5 trucks, a bituminous distributor (800 to 1,200 gallon capacity), disks, power brooms, a roller, and small tools. At times a special gang and patrol force will work together. Gang crews are used for adding gravel to the surface, centerline painting, weed eradication, bridge repair and painting, and other work requiring special equipment or skill.

County organizations

The maintenance organizations of counties to care for the local roads are organized along the same lines as a subdivision of the State organization but

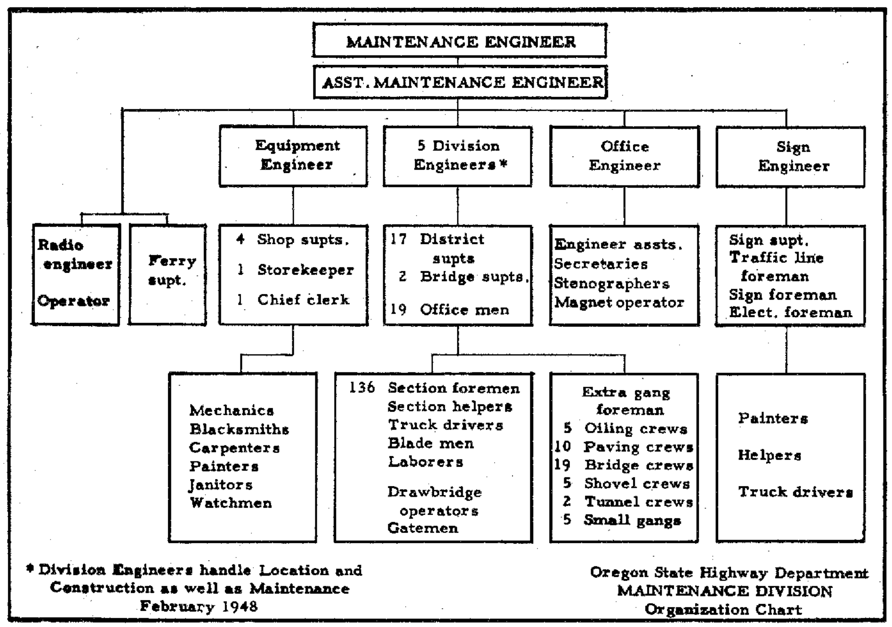
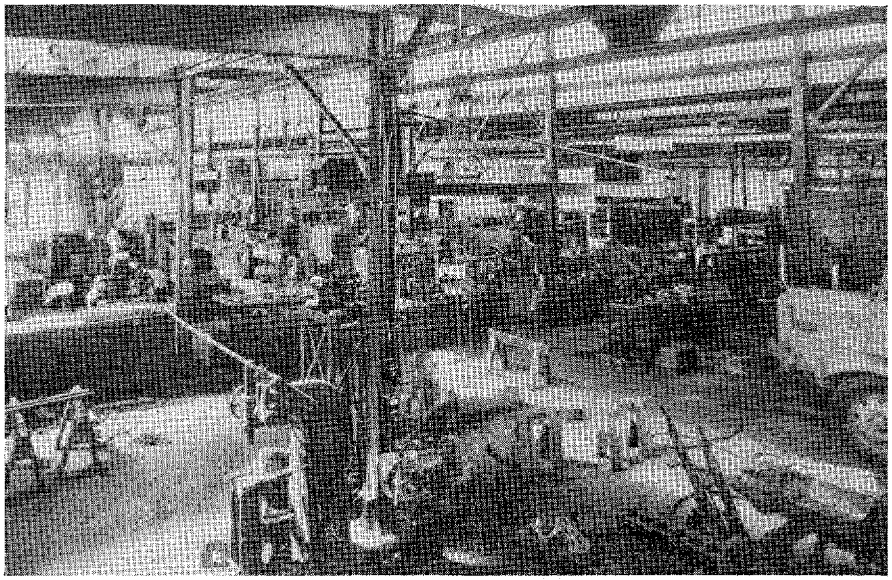


Figure 50.—Organization of maintenance division of Oregon Highway Department.



Equipment maintenance shop of the California Division of Highways at Sacramento.

they generally operate on a smaller scale.

Cities

The larger cities have large maintenance organizations. The following description of the organization for a city of one million population is typical. A superintendent directs the work which is divided into three branches:

1. An assistant superintendent with 15 men inspect work done under contract in repairing concrete roadways, alleys, and sidewalks.
2. An assistant superintendent with 4 inspectors, 12 foremen, and 80 laborers make repairs to bituminous roadways and inspect that done under contract.
3. An assistant superintendent with 1 principal assistant, 11 mechanics, 70 truck and passenger-car drivers, and 16 laborers are assigned to shops and 119 pieces of major equipment.

Maintenance of bridges is performed by a crew of 2 foremen and 15 skilled laborers, under the direction of the engineer of bridges.

These men are at times assigned to street cleaning, and repair of culverts and traffic signs. The organization maintains 995 miles of city streets.

The Equipment Section

The practice of the States in procuring maintenance equipment and materials and in making major repairs varies. The most common practice is to concentrate the administration, procurement, main stockroom, and major repair shops at one location. This location should be near the center of operations. Here should be located the office of the State equipment engineer with an office force sufficient to keep records on the assignment and mechanical performance of all equipment. A central parts warehouse should also be located here with a well-stocked and perpetual-inventoried supply of parts and replacement units for all types of equipment owned. A well-trained parts superintendent should head this organization and should be responsible for procuring all necessary parts.

Central repair shop

The central or major repair shop should perform all major overhauls; should inspect all motorized equipment at least once a year; and should have sufficient machine shop, welding, blacksmith, tire repairing, and painting equip ment to do major rebuilding.

The equipment maintenance garage of the Massachusetts Department of Public Works is typical. It has over-all dimensions of 300 by 300 feet and covers 2 acres of land. It is the principal service shop for 2,150 major pieces of equipment.

Equipment arriving at the central shop for repairs is checked into the garage at an office to the left of the entrance. It is then moved along the right-hand aisle, stopping along the way, if necessary, at the washstand, and finally reaches a truck, tractor, or machinery repair stall along the rear of the building.

There it may be dismantled and heavy parts carried by an overhead monorail to one of the various specialty shops for overhauling. Stalls are separated from each other by a low wall so that upon completion of a job the mechanic may wash down his stall without interfering with work in the adjacent areas.

The stockroom furnishes spare parts from stock stored within a room in the central area of the building. The monorail is available to handle the heavier parts.

Sandblasting and steam-cleaning facilities are provided adjacent to the paint shop.

Each piece of equipment is tested and inspected at the right of the exit before it is permitted to leave the garage.

Office space for the administrative and clerical force is provided on the second floor of the building.

Additional storage is provided around the outside of the yard in covered stalls which protect equipment from weather while awaiting repairs.

District shops

This type of central shop is often supplemented by smaller shops strategically located throughout the State and equipped to perform small repair jobs.

Several States, because of their size, prefer to have a number of district shops rather than one central shop.

The highway maintenance shop at Rapid City, S. Dak., shown in figure 51, is a small unit which services the equipment for a district having 1,300 miles of low-type bituminous or gravel roads.

Maintenance Operations

The distribution of maintenance expenditures on different parts of a highway is shown in the following tabulation, based on analysis of a large volume of data from all parts of the country:

	Percent
A. Traveled way—surface	48
B. Shoulders	10
C. Drainage—ditches, culverts	10
D. Roadside—mowing, erosion control, vegetation, footpaths, recreation areas	8
E. Traffic service — guardrail, signs, signals	5
F. Snow and ice control	10
G. Bridges—superstructure, substructure, stream bed, signs	7
H. Special service — permits, load limitations, detours, public relations	2

The following outline lists most maintenance operations:

A. Traveled way

1. Repairing small surface failures by patching with materials similar to those used in original improvement.

2. Repairing large or extensive surface failures by scarifying, reshaping, and re-treating, adding new materials if necessary.

3. Dragging and blading soil, gravel, or similar surfaces:

(*a*) Maintaining proper crown and cross section.

(*b*) Adding new material when necessary.

4. Stabilizing soil-aggregate surfaces through light bituminous or chloride applications to check dust or the loss of materials.

5. Applying bituminous surface treatment to bituminous pavements when it is necessary to:

(*a*) Seal against water penetration.

(*b*) Renew the binder in a surface that shows signs of oxidation.

6. Filling joints and cracks in portland cement concrete and block pavements.

B. Shoulders

1. Dragging and blading.
2. Sloping away from pavement at least 1 inch per foot.
3. Stabilizing with granular materials if necessary.
4. Mowing grass shoulders and keeping them level with the surface to avoid retarding surface drainage.

C. Drainage facilities

1. Cleaning ditches and culverts periodically to provide free and unobstructed run-off.
2. Keeping side ditches clear and well below the road surface to prevent subgrade or sub-base weakness.
3. Cleaning drain-off ditches frequently to remove vegetation, debris, and other obstructions.
4. Drainage of road right-of-way as an aid to public health.

D. Roadsides

(Maintenance of that part of right-of-way area not used for traveled way or drainage facilities.)

1. Prevention of erosion of slopes, embankments, and the roadside area by rounding and flattening affected areas, stabilizing soils, seeding, mulching, sodding, or planting proper types of vegetation.
2. Cutting and removing grass, vines, brush, and trees to provide sight distances, open vistas, and to protect the roadway.

E. Traffic service (safety measures)

1. Repairing, painting, and preserving guardrail.
2. Signs and markings for the direction, warning, and regulation of traffic are installed, repaired, painted, and properly maintained.
3. Traffic signals are inspected, checked periodically, and maintained in good condition at all times.

F. Snow and ice control

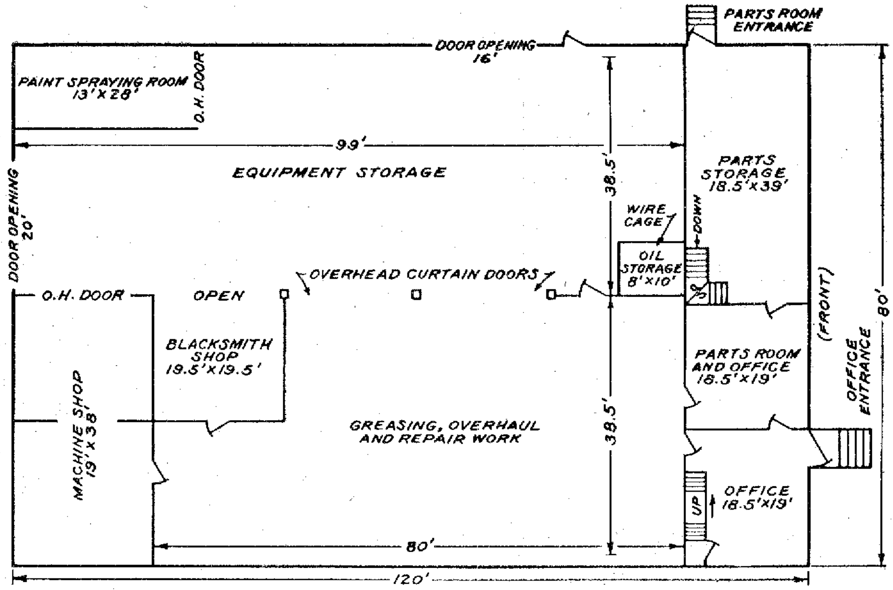
1. In the northern States a program is prepared showing priority of routes to be cleared of snow.
2. Equipment must be serviced and dispatched to winter stations.
3. Gravity-feed sand bins must be erected and abrasives for ice treatment stock piled.
4. Snow fence to check drifting must be erected.
5. Preliminary arrangements must be made for weather reporting and alerting maintenance employees at any time.
6. Snowplowing.
7. Treatment of ice-covered pavements.
8. Marking of drainage facilities and thawing of frozen culverts.

G. Bridges

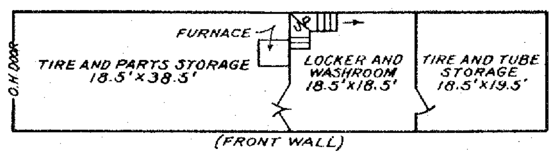
1. Superstructures are repaired, painted, and cleaned as required. Bridge decks must be repaired and replaced. Truss members damaged by collision require attention. Disintegrated concrete surfaces must be patched. A troublesome item is the repair of expansion elements that have not functioned properly.
2. The substructure should be inspected periodically, and abutments and supports repaired when necessary. Timber bulkheads must be repaired or replaced. Piling exposed to the erosive action of the stream, corrosive action of the earth, and attack by organisms must be watched, and replaced when necessary.
3. The stream bed should be cleaned, and obstructions removed to provide free flow of water and protection from scour.
4. Signs should be installed and maintained to show approaches to the bridge, the load limit, width, vertical clearance, and any restrictions imposed.

H. Special Services

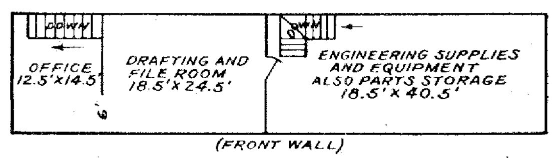
1. Control of work done within the right-of-way limits by individuals or corporations by issuance of permits is necessary for the protection of the highway and highway users.
2. The requirement of a special permit for transportation of loads of excessive weight, width, height, or length; and load limitation during rainy seasons are standard protective measures.
3. Properly maintained and well-marked detours are essential in good



MAIN FLOOR PLAN



FLOOR PLAN OF BASEMENT AT FRONT OF BUILDING



FLOOR PLAN OF MEZZANINE AT FRONT OF BUILDING

Figure 51.—A typical district maintenance shop.

maintenance practice. They promote good public relations and aid in highway safety.

4. First-aid training of maintenance employees makes possible a valuable service in case of accidents.

5. Maintenance and repair operations should be performed with due regard for safety of the State employees and the traveling public. Good public relations are very desirable at all times.

Soil-Aggregate Surfaces

Soil-aggregate surfaces constitute by far the largest class of roads. Maintenance of them consists of: (1) Dragging and blading; (2) patching and repairing soft and unstable areas; (3) scarifying, reshaping, and restoring losses of material; (4) applying dust palliatives; and (5) bituminous surface treatment.

The most important maintenance op-

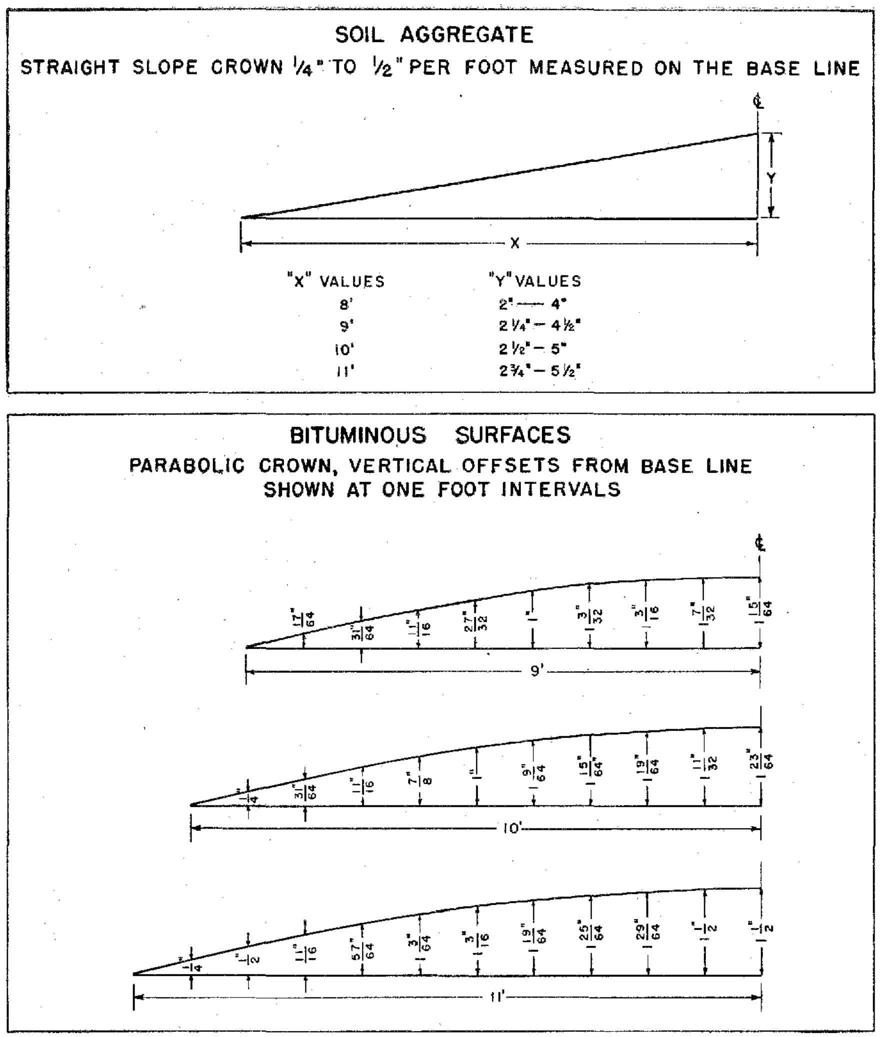


Figure 52.—Standard crowns.

erations—dragging and blading—should be performed soon after a rain when the surface materials are moist and more readily compacted. This work, when performed on a dry and dusty surface, may do harm, due to loosening of surface materials and loss by wind and traffic. It may increase the amount of dust, thereby creating a traffic hazard. Conversely, roadbed shaping should be avoided when the surface is excessively moist, since traffic will cause rutting and a resultant loss of crown.

Maintaining crown

Maintaining a crown is of primary importance. The slope of the surface depends upon: (1) the type of surface, (2) the steepness of grade, and (3) whether the section is in cut or fill. A porous, sandy soil requires less crown than a clay soil for the reason that granular materials absorb moisture without being softened. This may also be true of other untreated surfaces. On steep grades, surface water drains off more readily. In fill sections, where shoulders are narrow, the matter of traffic safety should be considered. The crown may vary from one-fourth to one-half inch per foot, depending on the factors enumerated. Figure 52 illustrates the standard crowns for pervious and impervious soil-aggregate surfaces and for bituminous-treated surfaces.

In natural soil roads, boulders and large rocks have a tendency to work to the surface. These should be removed or hand-knapped as soon as observed.

Unstable areas

A few soft and unstable areas may develop in a surface, the greater part of which remains in good condition for the greater part of the year. Usually the failures may be attributed to (1) improper surface or subsurface drainage, (2) poor gradation or mixture of materials, and (3) inadequate foundation.

Proper surface and subsurface drainage should be provided, if needed, before the surface is repaired. Surface drainage can be remedied by providing the proper crown. Excessive moisture in the subgrade may occur in the spring or after a long, rainy period, producing subsurface failure. The condition may be remedied by the installation of side or lateral drains to intercept the free water and also effect the lowering of the ground water level.

Repairing of extensive disintegration may be accomplished by scarifying and reshaping. Proper mixing of materials added to the surface should be effected before compaction is begun.

Dust palliatives

Highway users object to the dusty condition of plain soil-aggregate surfaces and a palliative is generally applied by maintenance forces when the traffic exceeds 50 vehicles per day.

The primary purposes in applying dust palliatives are: (1) Abatement of the dust nuisance to traffic and on property adjacent to the highway, (2) provision of additional superficial bond, and (3) conservation of surface material.

Three substances are commonly used as dust layers: (1) Calcium chloride, (2) sodium chloride, and (3) bituminous materials.

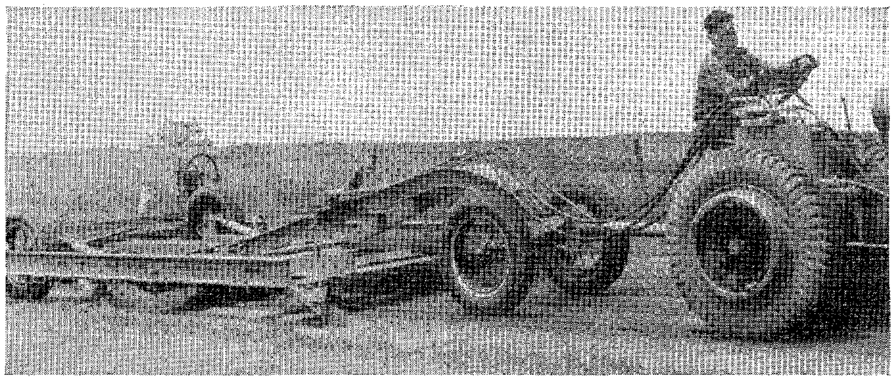
Calcium chloride is most generally used because of its deliquescent characteristics, or ability to absorb moisture from the air, and ease of application.

Sodium chloride may be used as a dust layer. This chemical (common salt, usually in coarse crystals) will not absorb moisture from the air except under certain conditions, and then slowly. The principal stabilizing action of sodium chloride is by the recrystallization of the salt in the surface layer when the road surface loses moisture.

Bituminous materials are frequently used. Certain grades of liquid bituminous materials are suitable. The bitumen should have sufficient "body" to bind the fines in surface aggregates for a reasonable period. These materials may be tars (RT–1 and RT–2), slow-curing road oils (SC–0, SC–1, and SC–2), medium-curing cutback (MC–0 and MC–1), and diluted emulsified asphalt (SS). The dilution should be three parts of water to one part of emulsified asphalt. The type and grade of bitumen to use, and the rate of application, will depend upon the condition and density of the road surface. Tar is recommended for granular surfaces only and is not suited for laying dust on earth roads. As a general rule the amount of bituminous material applied should be increased as the surface density decreases. The quantity varies from 0.10 gallon per square yard on dense surfaces to 0.25 gallon per square yard on those of open texture.

Bituminous surface treatment

In the maintenance of soil-aggregate surfaces, a distinction is made between the application of small quantities of bituminous material for dust control and a larger application of a different kind of bituminous material. The latter is called a "surface treatment." It provides more stability than a bituminous dust palliative, yet is not equivalent to a bituminous mat. The bituminous materials are applied in relatively small quantities to the stabilized soil or coarse aggregate surfaces as a prime, protec-



The road maintainer is a useful machine in maintaining soil-aggregate surfaces and in finishing some types of mixed-in-place surface treatments on low-type bituminous surfaces.

tive, or seal coat. When the treatment is of sufficient thickness to distribute a portion of the weight of a vehicle, then it should be classified as a bituminous mat. If the thickness of the wearing course is less than 1 inch, it is classified as a bituminous surface-treated, soil-aggregate road. A thickness of 1 inch or over is classified as a bituminous wearing course.

The condition of the soil-aggregate surface to be treated is an important consideration. The subgrade and surface course should be of sufficient strength to support the traffic loads and should be well drained. Sand-clay and stabilized soil mixtures should be tested for plasticity index and liquid limit as indications of the probable effect of moisture on the surface binder. The bituminous mat will retard evaporation and if excessive moisture accumulates beneath it disintegration of the mat will occur. If the road surface does not have grading and plasticity characteristics conforming to base-course requirements, it should be scarified and materials incorporated to correct the deficiencies before applying the bituminous materials.

Classification of Bitumens

In the discussion of design it has been stated that asphaltic materials for surface treatment are of three types: (1) Hot or penetration grade asphalts, (2) liquid asphalts, and (3) asphaltic emulsions.

The hot asphalts (heated before use), also called asphalt cements, are semisolid natural materials or, more commonly, residuals from the distillation of asphaltic base petroleum.

Liquid asphalts are classified according to their curing properties: (1) The RC or rapid-curing type, (2) the MC or medium-curing type, and (3) the SC or slow-curing type. The RC materials are produced by combining asphalt cements with gasoline or naphtha, and MC materials by combining asphalts with kerosene or light fuel-oil distillates. The SC materials are asphaltic residual oils or blends of such oils with distillates that do not volatilize readily.

Asphaltic emulsions are produced with the aid of emulsifying agents by vigorously stirring heated asphalt cements of various grades in water to form suspensions of minute globules of asphalt in the water.

Tars for surface treatment are of two types: (1) Straight run or blended tars, ranging in viscosity grade from RT–1 to RT–12, and (2) tar cutbacks, grades RTCB–5 and –6. They are produced by refining and blending the condensates resulting from the destructive distillation of coal and those resulting from the manufacture of carbureted water gas. The use of tars, particularly those in the lower and intermediate viscosity ranges, is extensive in areas where they are available at moderate cost.

Table 13 shows the principal uses of the various grades of tars and asphalts in maintenance operations. The left-hand column lists classes of work, and cross marks indicate the grade of bitumen that may be used.

The size of aggregate used in a bituminous surface is influenced by its quality. Good aggregates are scarce in some sections of the country. For this reason practice of the various States as to size of aggregate used varies considerably. Table 14 gives the standard sizes recommended by the American Association of State Highway Officials.

Bituminous Surfaces

Maintenance of bituminous surfaces requires timely action along five lines:

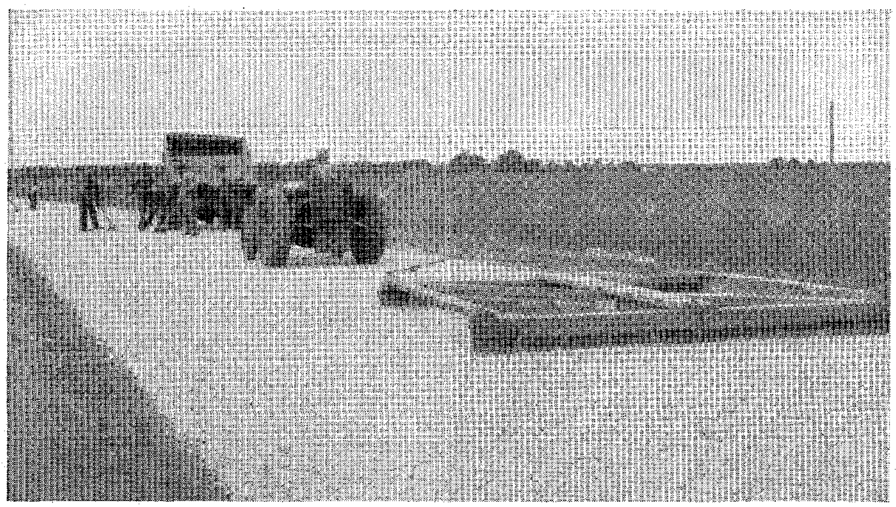
1. Patching.
2. Paint-patching.
2. Scarifying.
4. Resealing.
5. Non-skid treatment.

Patching of holes that form in the surface should be preceded by a determination of the cause of the failure. The cause may be poor drainage, insufficient base, or poor subgrade. The cause should be removed if possible. Temporary patching may be desirable during unfavorable weather; when the subgrade material is undergoing consolidation; or for similar reasons.

When it is necessary to patch with bituminous materials in wet weather, the use of additives, either in the bitumen or as a coating on the aggregate, may be desirable. This should be done only when laboratory tests indicate that an additive is needed to obtain a satisfactory coating on the moist aggregate.

Seal coats

Areas which are beginning to crack or ravel may be sealed by applying thin coats of bitumen and covering with suitable aggregate. Thin layers of premixed material are also used for this purpose. Intermediate or high-type bituminous surfaces, which have disintegrated to a depth too great for restoration by a seal coat, should be repaired by trimming the affected area to form a rectangular hole with vertical sides. The hole is then filled in tamped layers by the penetration method or with premixed material. The material used to patch high-type pave-



Uniformity of spread of aggregate, commonly accomplished by use of a broom drag, is important in surface-treatment work on bituminous surfaces. Final touching is being done by the men in the background.

Table 13.—Principal uses [1] of various grades of tars and asphalts in maintenance operations

Class of work	Grade of bitumen: Slow curing road oils						Medium curing cutback asphalts						Rapid curing cutback asphalts						Emulsified asphalts					
	SC-0	SC-1	SC-2	SC-3	SC-4	SC-5	MC-0	MC-1	MC-2	MC-3	MC-4	MC-5	RC-0	RC-1	RC-2	RC-3	RC-4	RC-5	RS-1	MS-1	MS-2	MS-3	SS-1	SS-2
1. Dust palliative, on dirt or dirty aggregate:																								
A. Natural soil	X	X					X																	
B. Gravel, stone, etc.			X					X															X[2]	
2. Soil stabilization, base									X						X									X
3. Blotter or mulch treatment, excess of fines			X																				X[2]	
4. Priming:																								
A. Tightly bonded surface							X	X											X					
B. Loosely bonded fine agg. surface								X	X														X[2]	
C. Loosely bonded coarse agg. surface									X										X					
5. Tack coat:																								
A. Bituminous surface														X	X				X					
B. Brick and concrete									X						X				X					
6. Surface treatment, seal or skin: [3]																								
A. Without cover													X											
B. Coarse sand cover									X	X				X	X				X					
C. Clean ¼ in. aggregate cover									X	X	X			X	X				X					
D. Clean ½ in. aggregate cover										X	X	X			X	X			X					
E. Clean ⅝ in. aggregate cover										X	X	X				X	X		X					
F. Clean ¾ in. aggregate cover											X	X					X		X					
G. Graded gravel aggregate									X	X									X					
H. Gravel mulch			X						X														X[2]	
7. Dragged leveling course:																								
A. Open graded aggregate										X	X	X				X	X			X	X			
B. Dense graded aggregate									X	X	X												X	
8. Road mix:																								
A. Open graded aggregate:																								
1. Sand										X				X	X					X				
2. Max. dia. 1″, high percent passing 10 mesh										X	X													
3. Macadam aggregate															X	X				X				
B. Dense graded aggregate:																								
1. High percent passing 200 mesh			X	X	X				X															
2. Max. dia. 1″, medium passing 200 mesh				X	X				X	X														

Class of work	Grade of bitumen: Tars														AC asphalt cements: Penetration—							
	RT-1	RT-2	RT-3	RT-4	RT-5	RT-6	RT-7	RT-8	RT-9	RT-10	RT-11	RT-12	RT CB-5	RT CB-6	50-60	60-70	70-85	85-100	100-120	120-150	150-200	200-300
1. Dust palliative, on dirt or dirty aggregate:																						
A. Natural soil	X																					
B. Gravel, stone, etc.	X	X																				
2. Soil stabilization, base	X	X	X	X	X	X																
3. Blotter or mulch treatment, excess of fines				X	X	X	X															
4. Priming:																						
A. Tightly bonded surface		X	X																			
B. Loosely bonded fine agg. surface		X	X	X																		
C. Loosely bonded coarse agg. surface			X	X																		
5. Tack coat:																						
A. Bituminous surface						X	X	X	X	X												
B. Brick and concrete			X	X	X		X	X	X	X												
6. Surface treatment, seal or skin: [3]																						
A. Without cover			X	X	X	X																
B. Coarse sand cover				X	X	X	X	X	X													
C. Clean ¼ in. aggregate cover					X	X	X	X	X	X												
D. Clean ½ in. aggregate cover							X	X	X	X												
E. Clean ⅝ in. aggregate cover								X	X	X	X											X
F. Clean ¾ in. aggregate cover									X	X	X	X								X	X	
G. Graded gravel aggregate					X	X	X	X	X													
H. Gravel mulch					X	X	X	X														
7. Dragged leveling course:																						
A. Open graded aggregate						X	X	X	X	X												
B. Dense graded aggregate						X	X	X	X													
8. Road mix:																						
A. Open graded aggregate:																						
1. Sand						X	X	X														
2. Max. dia. 1″, high percent passing 10 mesh						X	X	X	X													
3. Macadam aggregate							X	X	X	X												
B. Dense graded aggregate:																						
1. High percent passing 200 mesh					X	X	X	X														
2. Max. dia. 1″, medium passing 200 mesh						X	X	X	X													

9. Bituminous (hot penetration) macadam:																																														
A. Warm climates																																				X						X				
B. Northern climates, summer																																				X						X	X	X		
C. Northern climates, cool weather																																			X	X						X	X	X		
10. Cold penetration macadam																		X[4]	X										X	X	X															
11. Seal coat, new construction											X	X				X	X	X	X											X	X	X	X	X	X	X						X	X	X		
12. Cold patch:																																														
A. Open graded aggregate										X	X				X							X															X	X								
B. Dense graded aggregate				X	X	X			X	X		X																									X	X								
13. Plant mix, cold laid:																																														
A. Open graded aggregate:																																														
1. Sand															X	X																X	X	X												
2. Max. dia. 1″, high percent passing 10 mesh												X				X					X											X	X	X												
3. Macadam aggregate																	X	X				X											X	X	X											
4. Macadam aggregate, liquefier type																																										X				
B. Dense graded aggregate:																																														
1. High percent passing 200 mesh					X	X				X	X												X								X	X	X													
2. Max. dia. 1″, medium percent passing 200 mesh											X	X											X								X	X	X	X												
C. Primer to be followed with soft AC							X																																							
14. Plant mix, hot laid:																																														
A. Sheet asphalt																																							X	X	X	X				
B. Bituminous concrete																																			X	X			X	X	X	X	X	X	X	
C. Medium hot, class F												X						X													X	X	X	X				X								
D. Medium hot, oil-aggregate					X	X																																								
15. Crack filler																	X	X	X					X[5]											X	X		X	X	X	X	X				

[1] Usually, for any particular project, any one of two or more different grades of bituminous materials may be used with satisfactory results. However, this is not always true as the kind of aggregate may dictate the particular grade of bituminous material that will give best results. Generally the heaviest grade of bitumen that can be readily incorporated with the aggregate being used and which produces a mix that can be readily and uniformly spread will result in the most service for the money expended.

Frequently, on account of its slower drying character, MC material of one number higher grade than RC used on similar work would be used on road-mix or cold plant-mix construction.

[2] Emulsified asphalt to be diluted, 3 parts emulsion to 9 parts water.

[3] The size of aggregate cover influences grade of bitumen to be selected. However, the quantity of bitumen desired may determine its grade.

[4] Modified type penetration macadam, RC–5 applied hot.

[5] To be mixed with sand but producing a flowable mix.

Table 14.—Standard sizes of coarse aggregate

Size No.	Nominal size square openings	Amounts finer than each laboratory sieve (square openings), percent by weight													
		4 inches	3½ inches	3 inches	2½ inches	2 inches	1½ inches	1 inch	¾ inch	½ inch	⅜ inch	No. 4	No. 8	No. 16	No. 100
1	3½ to 1½ inches	100	90–100		25– 60		0– 15		0– 5						
2	2½ to 1½ inches			100	90–100	35– 70	0– 15		0– 5						
24	2½ to ¾ inch			100	90–100		25– 60		0– 10	0– 5					
3	2 to 1 inch				100	90–100	35– 70	0– 15		0– 5					
357	2 inches to No. 4				100	95–100		35– 70		10– 30		0– 5			
4	1½ to ¾ inch					100	90–100	20– 55	0– 15		0– 5				
467	1½ inch to No. 4					100	95–100		35– 70		10– 30	0– 5			
5	1 to ⅜ inch						100	90–100	40– 75	15– 35	0– 15	0– 5			
57	1 inch to No. 4						100	90–100		25– 60		0– 10	0– 5		
6	¾ to ⅜ inch							100	90–100	20– 55	0– 15	0– 5			
67	¾ inch to No. 4							100	90–100		20– 55	0– 10	0– 5		
68	¾ inch to No. 8							100	90–100		30– 65	5– 25	0– 5		
7	½ inch to No. 4								100	90–100	40– 70	0– 15	0– 5		
79	½ inch to No. 8								100	90–100	40– 75	5– 25	0– 5		
8	⅜ inch to No. 8									100	85–100	10– 30	0–10		
9	No. 4 to No. 16										100	85–100	10–40	0–10	
10	No. 4 to 0 [1]										100	85–100			10–30

[1] Screenings.

ments should be the same as that in the original surface.

Paint-patching or seal-patching is a form of preventive maintenance applied to small areas that show signs of deterioration. A thin surface treatment of bitumen is applied and covered with fine stone chips, pea stone, or coarse sand and then rolled with a light roller.

Low-type surfaces with extensive areas in bad condition should be scarified and reworked. The reworked surface is sealed with bituminous material.

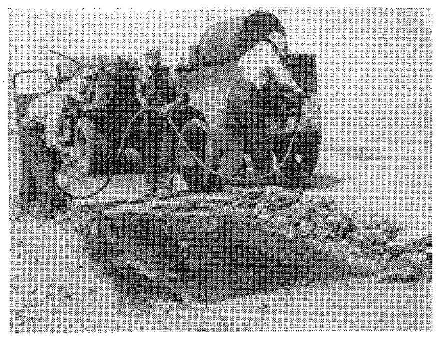
Types of treatment

Nearly all types of bituminous surface need at least a fresh seal coat from time to time as the bitumen oxidizes and small cracks form, permitting moisture to enter the surface. One of three types of surface treatments may be applied:

1. Light surface treatment consisting of a single application of a bitumen with or without a mineral aggregate cover. The work is sometimes called seal-coat application.

2. Heavy surface treatment consisting of single, double, or triple application of bitumen, each with a mineral cover of coarse-graded aggregate. This work is sometimes called penetration-type surface treatment, armor coat, or oil-mat treatment.

3. Drag surface treatment consists of applying a prime or tack coat to the prepared surface, spreading mineral aggregate, applying the bituminous binder, and manipulating the course to form an intimate mixture of aggregate and bitumen. Such work is sometimes called a retread treatment.



In patching high-type bituminous surfaces, deteriorated material is excavated as shown and a tack coat is usually applied to seal off moisture. The hole is then filled with a mixture similar to the original surfacing.

Slipperiness

Slipperiness in a bituminous pavement usually results from an excess of bitumen at the surface. Prompt action should be taken to correct slipperiness. A modification of the surface-treatment process has been used successfully. A light oil is applied and covered with angular aggregate to roughen the surface. In severe cases a drag treatment or a complete reworking of the surface may be required.

Extensive need of repairs to a high-type bituminous surface is often the result of inadequate base or sub-base or a poor subgrade. When failures are due to such causes, it is necessary to rebuild the entire area affected, from the foundation up. Frequently it is necessary to install additional drains to remove excess moisture. In old pavements failure may result from oxidation of the bitumen.

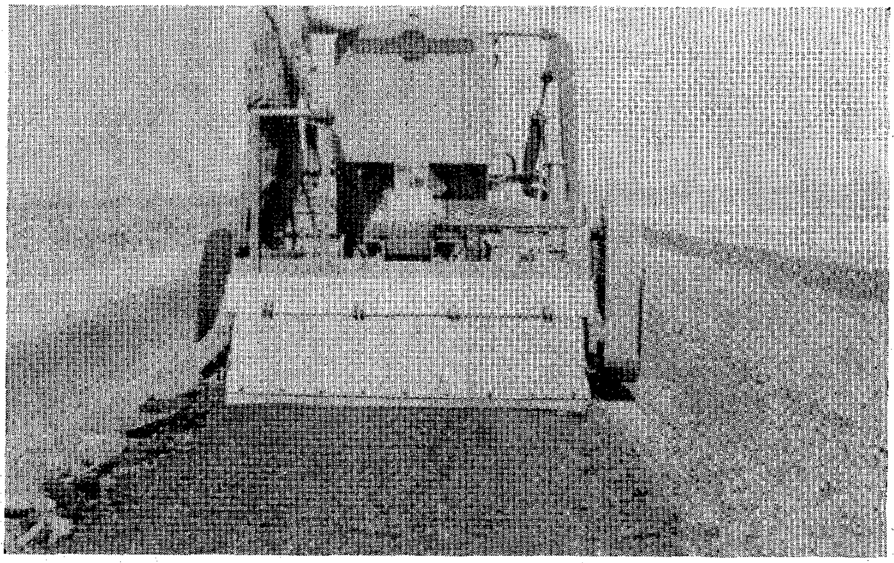
Portland Cement Concrete

Maintenance of cement concrete pavements consists, in greater part, of filling and sealing joints and cracks, generally with asphaltic cements, and the drainage of excessive moisture from the subgrade by the installation and maintenance of proper drainage facilities. Free water in the subgrade in sufficient quantity and in combination with unfavorable soils tends to produce so-called "pumping" at the joints, and the pavement cracks under the action of heavy traffic loads.

All breaks in the surface must be repaired promptly. On spalled, scaled, or cracked areas where only the surface is affected, a bituminous application, covered with stone chips, may be applied. Where thicker patching is necessary, bituminous premixed materials are used. Small areas of badly disintegrated or broken concrete are usually cut out to full depth and replaced by properly reinforced new concrete. Settlement of slabs, generally caused by subgrade failure or by "pumping," can be rectified by mud-jacking the slab back to proper elevation. This involves drilling holes in the pavement and pumping under it a slurry of loam, cement, and water, or of asphaltic materials. Expansion of the concrete may cause shattered areas which must be replaced either by new cement concrete or bituminous mixtures.

Materials

As an economy measure local materials are used wherever they are available



Bituminous-treated gravel surface being broken up by one pass of scarifier and pulverizing machine. Large pieces of surface material at left of machine will be broken up to proper size on next trip, which overlaps previous pass. Tractor pulled, the machine operates at 1 1/2 miles per hour, pulverizing a 6-foot strip to a depth of 6 inches.

and of satisfactory quality. Maintenance engineers examine prospective sources of materials and submit samples to the testing engineer for analysis and a report as to whether they meet the requirements of established specifications.

The following, based on Nation-wide averages, is an indication of the quantities and kinds of materials used annually in the maintenance of 1,000 miles of representative State highways of which 17 percent are unsurfaced; 25 percent soil-aggregate (gravel or equivalent); 31 percent low- and medium-type bituminous; and 27 percent are high-type pavement:

Material	*Quantity*
Crack seal (gallons)	16, 519
Bituminous mix (tons)	927
Bituminous material, liquid (gallons)	249, 199
Cement (barrels)	628
Chlorides (tons)	153
Stone (tons)	11, 238
Gravel (tons)	19, 337
Sand (tons)	2, 742
Paint (gallons)	4, 259
Lumber (Mbf)	97
Pipe (linear feet)	1, 777
Traffic signs	1, 981

Maintenance Equipment

Highway maintenance work is highly mechanized. Development of mechanical aids has been gradual as the necessity arose for doing more work with limited forces.

Suitability of equipment

The problem of determining the most suitable equipment for accomplishing a specific operation includes consideration of the utility of the equipment in other operations. A committee of the Highway Research Board has obtained from the 48 State highway departments, views as to the suitability of equipment for different purposes. Table 15 lists the recommendations concurred in by a majority of the highway departments regarding the most suitable types of equipment for the performance of each of 39 highway maintenance operations, classified according to highway elements.

Automobiles and trucks

One piece of essential equipment, not listed in the table, is the automobile. It is used in the supervision and inspection of road operations and in the transportation of workers. In the last few years some highway departments have installed two-way radiotelephones in supervisor's cars, trucks, and snow-removal equipment. These installations are particularly useful during floods and heavy snowfalls.

A widely used piece of equipment is the light truck of 1½ or 2 tons capacity. They are used in hauling material to stock piles for both summer and winter maintenance, placing abrasives on icy pavements, and in delivering bituminous patching material directly to the place of use. They are also used on shoulders, on the roadside, in the hauling of riprap and other protective material, and in painting and erection of road signs. They have general utility in hauling men to work and in pulling road drags or tow-type graders, although the latter use may cause excessive wear.

Heavier trucks are generally used for winter snow plowing and in transportation of crushed stone, gravel, borrow material, and other materials where there is a haul of some length.

The heavy-duty trailer for transporting equipment and various heavy loads relatively long distances is very important in mechanized maintenance. It is particularly useful when heavy equipment must be assembled to meet an emergency such as a slide or washout. The trailer is usually towed by truck. If considerable use is made of a trailer, the tractor-truck semitrailer combination is a desirable unit.

Drags and graders

The road drag is used almost exclusively for filling in ruts and smoothing surfaces. The road maintainer performs the same work and, in addition, mixes surface materials more intimately and thus, under certain conditions, produces a more stable surface. Since the maintainer is wheel-mounted, it is more portable than the drag.

The road grader has long been one of the most important pieces of maintenance equipment. It is used extensively for maintaining soil-aggregate surfaces, low-type bituminous surfaces, shoulders, roadsides, and drainage channels. The grader is especially useful in establishing and maintaining a crown on soil-aggregate surfaces. It is adaptable to earth-moving and grading work, for scarifying road surfaces, trimming slopes, and removing snow and ice.

Both self-propelled motor graders and tow graders pulled by a truck or tractor are used. The tractor may be either of crawler or wheel type. Each machine will perform work similar to that accomplished by the drags and maintainers and has other uses.

Loaders

The loader is useful where either aggregates or earth is to be placed in trucks. Certain types are adaptable to loading while in motion. Belt, bucket, and scoop types are in use. This machine is useful in surface, shoulder, roadside, and drainage work in loading excess shoulder and ditch materials, and in removing snow and ice. In the last few years highway departments have made much greater use of loaders.

Power shovels

The power shovel with its several variations—the dragline, clamshell bucket, and crane—is used primarily for loading earth and handling material. It is used for heavy work such as removal of debris after floods, hurricanes, and tornadoes, and for removal of landslides which occur frequently in mountainous areas. In normal work it is sometimes used in the repair and maintenance of the traveled way, shoulders, roadsides, and for snow removal.

The ½-cubic-yard capacity, crawler-mounted shovel is preferred for use in maintenance; however, the truck-mounted shovel has greater mobility and does not require a separate auxiliary piece of equipment—the trailer—for transportation.

Spreaders

A variey of devices are available for attachment to trucks for uniform spreading of aggregates on surfaces and shoulders and in applying abrasives to icy pavements. They are particularly useful in surface-treatment work. Specially designed spreaders are used in applying chemicals to soil-aggregate surfaces.

Rollers

The 3-wheel steel roller is suitable for practically all of the rolling required in maintenance. The 10-ton roller is suitable for soil compaction and for rolling aggregate courses. The 5- to 8-ton tandem steel-wheel roller is popular for compacting patches. The pneumatic-tired roller is used for compaction of bituminous surfaces when the depth of retreatment is 1 inch or more.

Bituminous equipment

A bituminous distributor is essential in the maintenance of bituminous surfaces. Surface treatments must be applied at suitable intervals. The distributor should be truck-mounted, have a capacity of 800 to 1,200 gallons, and be equipped with a power spray that is readily controlled.

Bituminous kettles are used extensively in maintaining bituminous surfaces of all types, and in filling joints and cracks in portland cement concrete surfaces and in block pavements.

The kettles are used to heat bituminous materials to the desired temperature and are equipped with discharge valves. Frequently a kettle is equipped with a pressure spray device for applying bitumen.

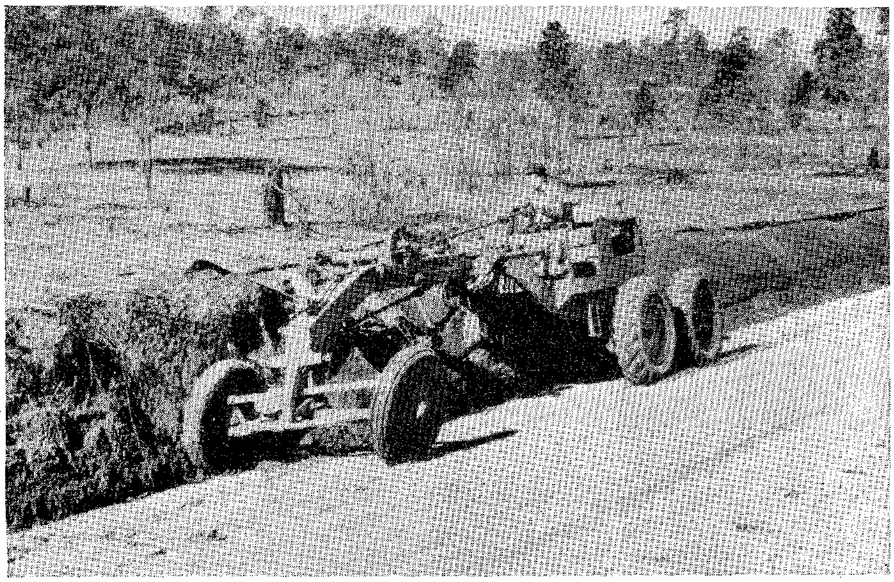
Tractors

Tractors are used in a variety of maintenance operations. Both the crawler and wheel type are used. The crawler type with dozer attachment is principally an earth mover, but it may be used to tow scrapers, graders, and rooters. Snow-plowing attachments are available so that the tractor may be used to remove snow.

Table 15.—Equipment classification by type of surface and miscellaneous work

Type of equipment	Traveled way												Shoulders			Roadsides				Bridges			Miscellaneous structures				Snow and ice removal				Trees and shrubbery			Signs, signals, and safety devices					
	Earth or natural soil	Oiled earth—Penetration or mulch	Gravel or crushed rock	Oiled gravel, penetration, pen. seal	Bituminous road mix	Bituminous plant mix	Water-bound macadam	Bituminous macadam	Armor coat, seal coat, retread, etc.	Asphaltic concrete	Portland cement concrete	Brick or block	Native material	Imported material	Surfaced shoulders	Dikes, berms, and gutters	Drainage control	Slides and washouts	Control of weeds and vegetation	Sandblasting	Painting	Repairing	Retaining walls, riprap, slope paving	Bank protection, cribs, subdrains	Culverts	Right-of-way fence	Snow removal	Snow fences	Sanding icy pavement	Ice removal	Watering	Pruning, tree surgery	Pest control	Guardrail, guide posts	Signs and signals	Pavement markings and markers	Traffic striping	Barriers, barricades, traffic control	Lighting installation
Compressors, air:																																							
105-cubic-foot capacity	X		X								X	X						X	X			X	X																
210-cubic-foot capacity																				X	X																		
315-cubic-foot capacity																				X	X																		
Disks:																																							
Road type, heavy duty					X																																		
Motor grader attachment					X				X																														
Orchard type					X																																		
Distributors (bituminous):																																							
300- to 600-gallon trailer						X			X	X					X																								
800- to 1,200-gallon truck		X		X	X	X		X	X	X					X				X																				
Dozers: Angle and bulldozers	X		X													X		X																					
Graders:																																							
Motor grader, 35 to 55 horsepower with 10- to 12-foot blade	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X									X			X									
Motor grader, 60 plus horsepower with 12- to 14-foot blade	X	X	X	X	X	X	X	X	X				X	X	X	X	X	X									X			X									
Blade, tow type 8- to 12-foot	X	X	X	X	X								X		X	X	X	X						X															
Heaters:																																							
Tank car, steam		X		X	X	X		X	X	X															X														
Booster, retort									X																														
Kettles (2-wheel trailer mount):																																							
Asphalt heating, 100- to 300-gallon capacity				X	X	X		X	X	X	X	X			X																								
Asphalt heating, 300- to 550-gallon capacity						X																																	
Loaders:																																							
Belt conveyor (stationary loading)	X	X	X	X	X	X		X	X	X	X	X		X	X														X										
Belt conveyor (travel type)	X	X	X	X	X	X		X	X	X	X	X		X	X			X																					
Belt conveyor (motor grader attachment)	X	X	X	X	X	X		X	X	X	X	X		X	X			X																					
Bucket conveyor			X	X	X	X			X																														
Tractor front-end																		X																					
Maintainer:																																							
2 blade, pneumatic-tired			X																																				
Home-made drag			X										X	X	X																								

Mixers:																																							
Bituminous				X	X	X		X	X	X																													
Concrete											X											X	X	X	X														
Mowers:																																							
Tractor type													X	X		X			X																				
Tow type													X	X					X																				
Mud-jack											X																												
Plant: Gravel producing			X												X																								
Plows, snow:																																							
One-way type																											X												
Reversible type																											X												
V-type, on truck																											X												
Rotary type																											X												
V-type, on motor grader																											X												
V-type, on tractor																											X												
Pumps:																																							
Centrifugal, 2- to 4-inch diameter																						X	X								X								
Diaphragm, 4-inch diameter																						X																	
Rollers:																																							
Pneumatic				X	X	X			X	X					X																								
Three wheel, 5 to 10 tons		X	X	X	X	X	X	X	X	X		X		X	X																								
Power portable, 2½ tons minimum				X	X	X		X	X	X					X																								
Tow type, portable, 2 to 5 tons				X	X	X			X	X					X																								
Tandem, 5 to 10 tons				X	X	X		X	X	X																													
Scraper: Carry-all, 5- to 7-cubic yard capacity			X													X																							
Shovels:																																							
Crawler type, ½-cubic yard capacity	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X					X	X					X										
Truck mount, ½-cubic yard capacity	X	X	X						X				X	X		X	X	X					X	X															
Truck mount, ⅝-cubic yard capacity		X	X																				X	X															
Spray rig: High pressure, 200 to 400 gallons																																	X						
Spreaders, sand or chip:																																							
Hopper type with feed roll				X	X			X	X						X																								
Gravity type				X	X	X		X	X	X																													
Rotary disk type		X				X			X																				X										
Sweepers (brooms):																																							
Tractor attachment, rotary		X		X	X	X		X	X	X																													
Power driven, rotary				X	X	X			X																														
Sprocket driven, rotary		X		X		X			X																														
Drag type		X	X		X	X		X	X						X																								
Tanks:																																							
Oil supply, 800- to 2,000-gallon capacity					X	X			X																														
Oil storage, 10,000- to 14,000-gallon capacity								X																															
Water, 700- to 1,000-gallon capacity	X	X	X				X	X																							X								
Tractors:																																							
Track-laying type 25 to 95 horsepower	X	X	X	X	X								X		X	X	X	X						X															
Wheel type, 15 to 45 plus horsepower	X	X	X				X						X	X	X	X			X																				
Traffic stripe machine:																																							
Truck push type																																					X		
Hand propelled type																																					X		
Trucks:																																							
Dump body, 1½- to 2-ton capacity	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X		X		X	X	X	X	X	
Dump body, 3- to 6-ton capacity	X	X	X	X	X	X	X	X	X	X	X			X				X											X										
Dump body, 2- to 5-ton capacity, 4 wheel drive	X		X				X																				X												
Express body, ½- to ¾-ton capacity	X	X	X			X	X	X	X	X	X								X	X	X	X	X	X	X	X						X	X	X	X	X	X	X	X
Stake body, 1½- to 3-ton capacity																				X								X				X	X		X	X	X	X	
Welding generator: 200 to 300 amperes																						X																	



Motor-patrol grader shaping an eroded embankment.

The wheel tractor is faster moving and usually of lighter weight. It is extensively used with an attachment for mowing the roadside. Other attachments include front-end loaders, hoists, and rotary brooms, all of which are useful.

The air compressor with air-operated tools is used in removing pavement, tamping backfill, and drilling holes. The disk harrow is used for disking and mixing surface materials, particularly low-type bituminous surfaces. It may be attached to a motor grader or may be pulled by a truck.

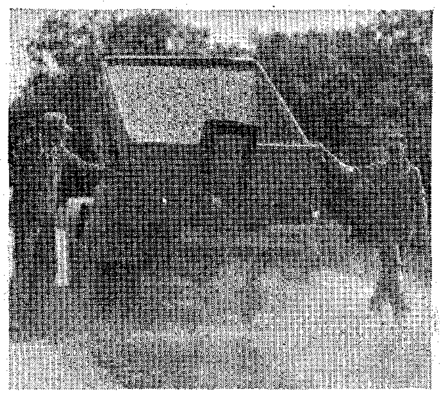
Mixers

Bituminous and concrete mixers are used to mix aggregate with the cementing agent. A single mixer is sometimes used to make both bituminous and portland cement mixtures when they are needed in small quantity. However, the machines for mixing the two types of surfacing material in large quantity are quite different in character.

In the maintenance of bituminous surfaces, it is common practice to prepare mixtures for use in patching and store them until needed. A popular machine for producing cold mixtures produces batches of from 10 to 14 cubic feet. The larger size will produce 150 tons a day. This machine will mix aggregate with all standard types of cold-mix binders, including emulsions, cut-back asphalts, powdered asphalts, or tars. Another type of equipment for producing bituminous mixes for maintenance work is provided with heating and drying apparatus for producing hot bituminous concrete. The capacity of this machine is from 10 to 20 tons per hour, depending upon the time required to dry the aggregate. Each of the above pieces of equipment is self-contained and portable. Erection and dismantling can be accomplished in a short time. Mixtures can be produced that will remain workable for several days or, if necessary, for several weeks.

Crushers

Aggregate-crushing plants are operated by many highway departments. There are a number of types of crushers; the jaw crusher, the roller crusher, the cone-type crusher, the gyratory crusher, and the hammer pulverizer. The selection of the type depends upon the type of material being crushed, the size of the finished aggregate desired, and whether large or



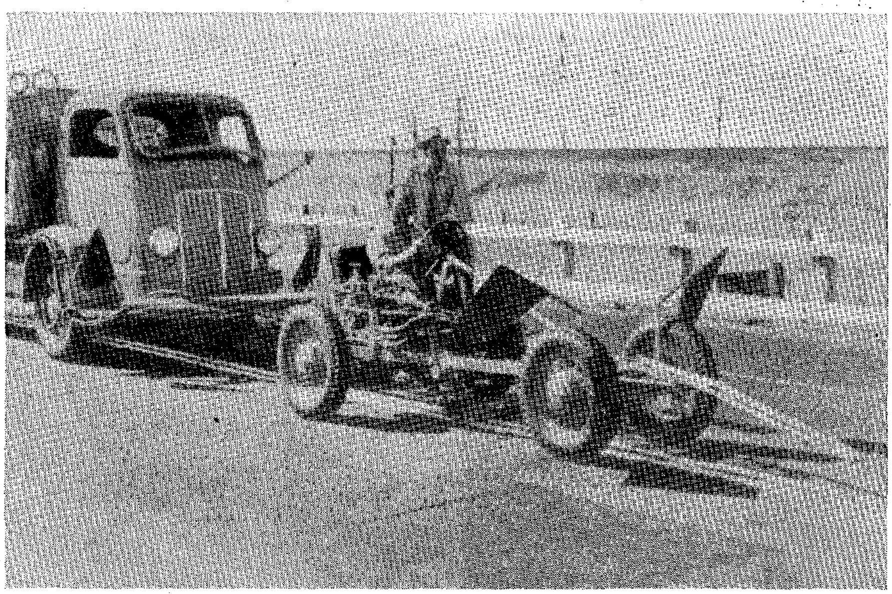
Aggregate spreading machine used in bituminous surface treatment and in ice treatment operations.

small quantities are to be produced. When crushed, the aggregate is usually screened into various sizes. Portable crushing, screening, and loading plants are useful in producing aggregates for the maintenance of certain types of soil-aggregate surfaces and for all types of bituminous surfaces. Aggregates are also used in maintaining portland cement concrete surfaces and shoulders.

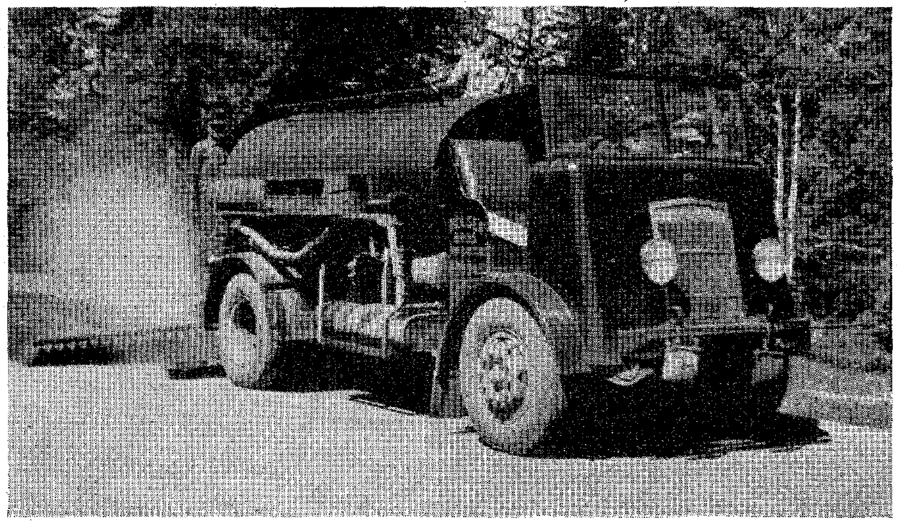
Pavement-marking machines

Pavement-marking machines of a variety of types are used to place lane markings on all types of surface sufficiently smooth and firm to retain the marking. Machines should be able to paint double-stripe solid or broken lines in white or yellow. A machine recently developed is described as follows: The apparatus is mounted on a 2-ton truck with a steel body. An **A** frame extends 15 feet in front of the truck to which it attached a swivel-mounted guide wheel to be used in guiding the truck. Two 60-gallon tanks supply the paint. A converted 100-horsepower V–8 gasoline engine provides compressed air.

The spraying unit is placed on a 2-wheel trailer and is operated at 60-pound pressure. Three stripes can be painted simultaneously, using two different colors of paint if desired. Width of stripe can be varied from 4 to 6 inches or a single 18-inch stripe can be applied. On both sides of each spray nozzle there are flattened funnels that direct blasts of air against the pavement to confine the spray of paint within the width desired. This



Pavement-marking machine painting a double line.



Pressure distributor applying bitumen during surface treatment operations.

machine operates at speeds of from 10 to 20 miles per hour.

There are several highly useful maintenance machines not listed in the table. One such machine is the electro-magnetic "nail picker" which is used by many highway departments having a large mileage of soil-aggregate surfaces. Nails, tacks, and pieces of metal are dropped on these surfaces and must be removed mechanically. The saving to the road user in reduction of tire damage far exceeds the cost of the equipment and its operation.

Asphalt equipment

Several types of mechanical equipment are used to prepare liquid asphalts when they cannot be obtained readily from commercial sources. These machines consist of a series of pipes and valves through which liquids are pumped and mixed with asphalt cement. The mixing process is carried on at a relatively low temperature and the liquid material is stored in convenient tanks. The manufacturing process can be performed near the maintenance job. The principal liquid asphalts so manufactured are asphalt emulsion, in which water is mixed with the asphalt cement, and cut-back asphalt, in which a light distillate is used to convert the asphaltic cement to a fluid. The liquid asphalts thus produced can be used on all types of operations involving maintenance of bituminous pavements.

Bridge Maintenance

Bridge maintenance is a special field of operation that is handled by traveling crews of highly skilled workmen well equipped with portable apparatus. Crews perform such duties as cleaning steel by sand blasting, painting by hand and by spraying, and strengthening or replacing damaged bridge members. Some of these crews have equipment that is equal to or better than that found in the average small machine shop.

The State of Florida operates what they call a heavy bridge-maintenance repair unit. It consists of a service truck, an equipment truck, and a personnel trailer. The service truck is equipped with a power take-off and a boom. The 2-ton equipment truck has a completely enclosed metal body. It has "roll-top" sliding doors on the sides and hinged doors on the rear. The truck is equipped with a 300-ampere arc-welding outfit, a 9-inch lathe, a drill press, compartments for small tools and supplies, an acetylene cutting and welding outfit, a beam light, a bench vise, and a pipe vise. There are also a 105-cubic foot air compressor, air tools, and a hose reel.

Snow Removal

Snow removal is an important operation for all maintenance forces in the northern half of the United States. All main highways and most of the surfaced secondary roads are kept open for travel. As the season of icing and snowfall approaches the maintenance department gets its snow removal and ice treatment equipment in order. Snowplows are mounted on trucks, sand or cinders for use on slippery surfaces are stockpiled, and personnel are given specific assignments to carry out.

The department must be ready for instant action at whatever hour a storm begins. Under permanent arrangements with weather bureaus the maintenance authorities are notified of approaching storms and their probable intensity. Removal of snow begins when the depth is only 1 or 2 inches and continues until snowfall ceases and roads are clear. Men work day and night that traffic may resume its movement.

Snowplows

Several types of snowplows are used to remove snow from the highway. For light work, graders and light blade-type displacement plows are adequate. V-type and side-wing displacement plows are suitable for moderately heavy work. For extremely heavy work rotor-type plows are generally used. The displacement-type plow pushed by trucks is the most widely used type of machine.

Light V-shaped and blade displacement plows are often used to open the traveled way for traffic, followed by rotary units which blow the snow clear of the roadway. Rotary plows and heavy tractor-propelled V-plows are used extensively in deep drifts on mountain passes. Use is also made of side-wing plows and slice bars for cutting down snow banks in deep drifts.

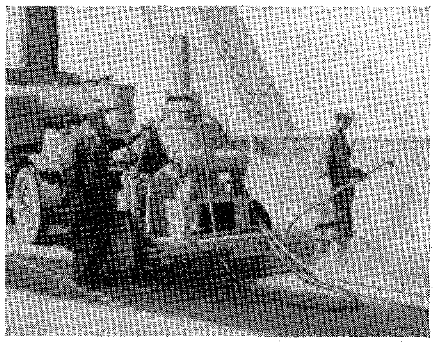
Although the primary purpose of snow removal is to enable traffic to move with facility and safety, prompt removal also helps to preserve the road surface and shoulders.

Draining the roadway

The snow should be pushed back from the shoulders to facilitate the flow of water from melting snow into drainage channels. Failure to remove snow from the shoulders, and allowing a thin cover of snow or ice to remain on the surface, results in erosion on low and intermediate-type surfaces and loss of supporting value. The water from thawing snow and ice frequently runs along the edge of the pavement, softening the shoulders and allowing seepage under the pavement and into the subgrade. This excess water may serve to build up ice layers, with resulting frost heave, and often cannot drain away through the ground because of an impervious layer of frozen soil below. The weakened road may quickly fail under traffic, especially at the edges of flexible-type surfaces. It is now generally recognized that it is less expensive maintenance for snow-removal crews to preserve the road by draining the traveled way during each thaw than to repair winter-damaged surfaces and shoulders.

Sanding

Highways frequently become covered with ice or a thin layer of packed snow, rendering them impassable or extremely dangerous to traffic even at slow speeds. This can be remedied by spreading sand or cinders over the ice, thus restoring



A steam-cleaning unit preparing steel for painting. Three such units are used on the Bay Bridge at San Francisco, Calif.

traction. For pavements other than portland cement concrete the abrasive is commonly mixed with calcium chloride or sodium chloride.

Cinders are preferred to sand by some States, but are usually not available in sufficient quantities. The chemicals are used to assist in partially embedding the abrasives by temporarily lowering the freezing point.

The sand and chloride are generally mixed and stock-piled at convenient points or sheltered in bins to prevent the weather from dissipating the salt and to keep the materials from becoming caked. Wherever possible the bins are placed in positions that will expedite handling of materials by gravity loading. Spreading is performed from trucks either by hand shoveling or mechanical spreaders, and directly from stock piles on short and isolated sections. Because of the cost, treatments are largely limited to steep grades, curves, grade crossings, intersections, and other dangerous places where accidents are most likely to occur.

Equipment Needed for Road Systems

Reports have been obtained as to the equipment used by State highway maintenance organizations and the mileage of highway maintained. These data have been analyzed to estimate the average amount of equipment used to maintain 1,000 miles of primary or main highways. Similar analyses have been made for secondary roads from data provided by 28 counties selected as having high quality of maintenance performance. Results are shown in table 16. The values of equipment given are present replacement costs.

The mileages of different types of highway surface composing each 1,000 miles are shown in table 17. These are proportionate to the mileages of actual surface

Table 16.—Equipment used to maintain 1,000 miles of highways by the average State highway maintenance department and the average of 28 selected county maintenance departments [1]

Type of equipment	Secondary road system (county)		Primary road system (State)	
	Number of units	Estimated cost new	Number of units	Estimated cost new
Automobiles (including ½-ton pick-up trucks)	5	$8,000	19	$30,400
Brooms, power	----------	----------	2	2,400
Compressors, air	2	10,000	3	15,000
Distributors, bituminous	1	6,000	2	12,000
Graders, power	7	56,000	12	96,000
Graders, tow	2	6,000	10	30,000
Heaters, tank car	----------	----------	1	1,000
Kettles, bituminous	1	800	11	8,800
Loaders	1	2,500	3	7,500
Maintainers	2	2,000	1	1,000
Mixers	2	3,600	4	7,200
Mowers	3	4,500	9	13,500
Plants, crushing	1	15,000	1	15,000
Plows, snow (displacement type)	[2] 10	10,000	[2] 45	45,000
Rollers	2	10,000	6	30,000
Shovels, power (cranes, etc.)	1	13,000	2	26,000
Spreaders	2	2,000	10	10,000
Tanks, storage	----------	----------	4	4,800
Tractors, crawler and wheel	5	27,500	10	55,000
Traffic line markers	----------	----------	1	2,000
Trucks, 1½ to 2 tons	22	44,000	16	32,000
Trucks, over 2 tons	5	20,500	44	198,000
Trailers	2	5,000	3	7,500
Welding machines	1	2,600	1	2,600
Other major equipment	5	4,450	20	15,750
Total	82	253,450	240	668,450
Total annual average maintenance expenditure	----------	197,000	----------	655,000
Ratio of equipment cost new to annual expenditure	----------	1.28	----------	1.02

[1] See table 17 for break-down by types.
[2] Snowplow equipment would be used only in cold climates.

in the road system for which data were obtained.

Primary roads

An average of 240 pieces of major equipment that would now cost $668,450 is being used to maintain each 1,000 miles of our primary roads. The average annual expenditure made on this mileage, including an appropriate charge for equipment, was $655,000. An equipment investment of $1.02 is made for each $1.00 of annual primary road maintenance expenditure.

On the primary systems, 17 percent of the roads maintained are nonsurfaced, 25 percent are soil-aggregate roads (gravel or equivalent), and 58 percent are low-type bituminous surfaces or better.

Secondary roads

In the 28 selected counties, an average of 82 pieces of major equipment, at an estimated cost new of $253,450, are being used to maintain each 1,000 miles of secondary roads, with an average annual expenditure of $197,000. An equipment investment of $1.28 is made for each $1.00 of annual expenditures for maintenance. Fifty-seven percent of the secondary roads maintained are nonsurfaced, 35 percent are soil-aggregate, and 8 percent are low-type bituminous surface or better.

There is a marked difference in the rates of expenditure on primary and secondary roads. This is due to differences in types of roads maintained, the intensity of usage, and to standards of service established.

On the average, one equipment unit is provided for each 4.2 miles of primary roads. There is only one unit in use for each 12.2 miles of secondary roads in the selected counties. Outlay of equipment for secondary roads would have to be increased to maintain them in the condition that primary roads are kept.

A recent analysis of data from 402 counties is more indicative of the probable average maintenance level on secondary roads in the United States. These counties used 46 equipment units per 1,000 miles of road, or one unit per 24 miles. The estimated cost new of the 46 units was $196,190, against an average annual total maintenance expenditure of $169,000.

Economy in proper equipment

Observations of equipment performance indicate that it is possible to increase the productivity of the maintenance dollar with well selected equipment in proper working condition. Increased use of mechanical methods in performing maintenance work appears to be a principal means of catching up with present highway maintenance requirements.

A good example of the saving in cost of highway maintenance by the use of equipment rather than hand methods is illustrated in the filling of joints and cracks in portland cement concrete surfaces. One State highway department has determined that substitution of mechanical for hand methods reduced the cost of performing this work by 45 percent. The rate of output, with the same number of men, was doubled.

Another example of savings is shown in roadside and drainage maintenance. With hand labor the cost of loading material trimmed from ditches amounted to

Table 17.—Surface-type classification of average 1,000 miles of highways maintained by State highway departments and by 28 selected counties

Surface type	Secondary road system (county)		Primary road system (State)	
	Miles	Percent	Miles	Percent
Unimproved (nonsurfaced)	570	57	170	17
Soil-aggregate (gravel or equivalent)	350	35	250	25
Low-type bituminous or better	80	8	580	58
Total	1,000	100	1,000	100

from 90 cents to $1 per cubic yard. With a machine the cost was 64 cents per cubic yard. This represents a saving of approximately 33 percent.

Influence of Maintenance on Highway Design

Maintenance engineers are increasingly aware of the desirability of assembling data on maintenance experience under the wide variety of conditions that exist, analyzing the data, and reporting conclusions. Accurate comparisons of costs and effectiveness of different methods are necessary if progress is to be made. The amount of work required to maintain each particular type of surface is an important element in type selection by the highway designer. Whenever a highway is to be reconstructed the designer should not overlook the store of important knowledge on drainage, erosion, soil characteristics, and snow drifting that has been accumulated by the maintenance men. Twenty-five States now provide that the engineer in charge of maintenance shall review and criticize highway plans before they are finally approved. The maintenance engineer spends his entire time on roads in use, observing and correcting their deficiencies. He knows the weaknesses of past designs and can improve those of the future.

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