PUBLIC ROADS

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NUMEROUS GRADE CROSSINGS RETARD THE FLOW OF TRAFFIC ON THE COOK COUNTY HIGHWAYS

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THE COOK COUNTY TRANSPORTATION SURVEY

A Digest of the Report of a Study of Highway Traffic and the Highway System of Cook County, Illinois [1]

Reported by J. Gordon McKay, Chief of the Division of Highway Transport and Economics, U. S. Bureau of Public Roads

THIS article is a digest of a report containing the results of highway traffic studies in Cook County, Ill., conducted during the summer and fall of 1924 under the cooperative research agreement between the Bureau of Public Roads, United States Department of Agriculture, and the Cook County highway department.

These investigations were undertaken in order to obtain essential facts concerning traffic on the Cook County highways as a basis for planning the development of the highway system in the Chicago regional area to serve present and future traffic.

The conclusions are based upon the present density, type, loading, and distribution of traffic units on the highways in the area, upon present population and population trends, upon predicted future traffic, and upon an economic and physical analysis of other factors affecting a highway improvement program.

The full report contains the data and conclusions and presents a recommended plan of highway improvement for Cook County indorsed by the Cook County highway department, the United States Bureau of Public Roads, the Illinois Department of Highways, and the Chicago Plan Commission. This program is an integral part of the plan of development for the regional area, which includes highways and streets under the jurisdiction of the several agencies.

ANALYSIS of the present volume of traffic on the highways of Cook County, the composition of this traffic, and the expected traffic in 1930 demonstrates the need for extensive highway improvements in the county during the next few years. Highway traffic in sections of the county, particularly the zone surrounding the city of Chicago, already exceeds the functional capacity of the improved routes in these sections, and the great increase in traffic that may be expected during the next five years indicates that unless a comprehensive betterment program is initiated and substantially completed within this period, the county and the city of Chicago will suffer seriously from the lack of adequate highway facilities. The daily cost of highway congestion to the citizens of Cook County is excessive at the present time, and will become enormous by 1930, unless additional highway improvements are made in the county and the city.

It is essential to formulate a coordinated plan of highway improvement which will provide highway transportation service for present and expected future traffic. The present system of improved highways is unsatisfactory for present traffic and an analysis of the reasons for the inadequacy of the present system will be of value in developing the plan of highway improvement to fully serve present and expected future traffic.

PRESENT HIGHWAY SYSTEM INADEQUATE

The present highway system is, to a large extent, a development of a system of roads established during the period when the horse-drawn vehicle was the vehicle of highway transportation. A considerable mileage of these roads have been provided with high-type surfaces, but the locations have not been changed and the system is now inadequate for present traffic.

Population and industrial development in the county have increased markedly during the period of rapid growth in motor vehicle usage, particularly in the area adjacent to the city of Chicago. This growth, with the closely related increase in motor vehicles, has resulted in a steadily increasing volume of traffic on the highways of the county and city.

The building of highways, in spite of a continuous construction program, has not kept pace with the increasing volume of traffic. During the period 1913 to 1925 there were constructed in the county 346 miles of paved highways at a cost of approximately $10,440,000, nearly 1 mile of improved highway for every 2 square miles of area. Since 1920 the mileage of improved highway per registered motor vehicle has been steadily decreasing.

The present highway system is unable to serve the present traffic properly not only because of the lack of improved mileage but also because of the lack of adjustment of the present system to the traffic needs. The analysis of the 1924 traffic shows the importance of the city of Chicago as a source of the traffic on the highways of the county. A very large part of this traffic consists of vehicles operating between Chicago and other cities and villages in the county. As the cities and villages located within 5 miles of Chicago include 74 per cent of the total population of the county, exclusive of Chicago, it is evident that the greatest volume of traffic must be between the city and the 5-mile zone surrounding the city. There are, however, more improved highway routes leading to Chicago at some distance from the city line than there are at the city line because of the convergence of main routes as they approach the city.

LACK OF CONTINUOUS ROUTES IN CITY AND COUNTY

In the city there is a lack of continuous through routes upon which traffic can move freely and rapidly within the city and between the various sections of the city and county. The effective use of the county highway system is impaired by the lack of a sufficient number of connecting streets within the city; and this lack of coordination of county highways and city streets is an important cause of traffic congestion.

Traffic between the cities and villages of the county is second in importance to traffic between these cities and villages and Chicago. Highways connecting these cities and villages are few in number and unable to meet present traffic needs. A network of improved highways connecting them will provide routes for local traffic and relieve congestion at the city entrances by permitting through traffic to "by-pass" the city.

The traffic capacity of the present county system is also impaired by the lack of continuous, direct, improved routes. There is no continuous east-west highway across the county between the Lincoln Highway,

[1] The highway traffic studies upon which the report is based were conducted under the joint supervision of Thomas H. MacDonald, Chief of the Bureau of Public Roads and Maj. George H. Quinlan, Superintendent of Highways of Cook County. J. Gordon McKay, Chief of the Division of Highway Transport and Economics, Bureau of Public Roads, directed the work of the survey and the preparaton of the report assisted by O. M. Elvehjem, E. T. Stein, and L. E. Peabody, all of the Bureau of Public Roads, and Warner Harwood of the Cook County highway department.

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which crosses the southern part of the county, and One hundred and eleventh Street, 12 miles to the north. By the development of 7½ miles of new highway in this section it will be possible to provide five additional continuous east-west routes. A few miles of new road to close the gaps in the north-south highways will open three additional through routes. The same condition exists in other sections of the county. By paving approximately 680 miles of new highways a large number of present non through routes will be connected and converted into through routes, and the traffic capacity of the highway system greatly increased.

NATURAL AND ARTIFICIAL BARRIERS IMPEDE HIGHWAY DEVELOPMENT

The natural and logical development of the highway system has also been impeded by the presence of certain barriers and obstructions to its orderly development. These barriers are of two types—natural and artificial.

Natural barriers are limited largely to waterways, the topography in other respects being favorable to highway location. Extending southwest from the city are three parallel waterways,—the Des Plaines River, the Sanitary Canal, and the old Illinois and Michigan Canal. Bridge construction over these waterways is very expensive and has had considerable influence on highway location. At the present time there are only three locations where highways cross these waterways in a distance of 20 miles.

Lake Calumet and Wolf Lake are also serious water barriers to highway planning. The lack of connecting highways between the city and the southeastern part of the county through the area occupied by these lakes and the surrounding lowlands has compelled traffic that would enter or leave the city via such routes to use either Indianapolis Avenue or the highways west of the lake district. This results in increased motor-vehicle operating costs due to the indirect routing and also congests the present entrances to the city.

Although natural barriers to highway development in the county are few, artificial obstructions are numerous. The latter are the natural result of the growth of Chicago and the surrounding area.

Railroad trunk lines enter the city from all directions. Industrial trackage, freight yards, classification yards, and structures essential to the railroad business surround the city on all sides. These, together with industrial establishments, form complete barriers to highway routes. Highways must be constructed around rather than through such areas. Crossings at grade reduce the traffic capacity of the routes and are a constant hazard to vehicular traffic.

A similar effect upon highway development is caused by the many special-use areas which have developed in the suburban area around the city. Brickyards, quarries, golf courses, cemeteries, and other developments requiring large acreages are obstacles to the construction of through highways.

The rapid growth of population and motor vehicle registration, the decrease of improved highway mileage in proportion to motor vehicle registration, the lack of improved city connections and sufficient through routes in the city, the lack of adjustment of the present highway system to traffic needs, gaps in the present highway system, and the natural and artificial barriers to highway development are the principal causes of the inadequacy of the present highway system and of traffic congestion.

The traffic congestion results in an enormous loss of time. Its elimination would result in a great saving both to vehicle owners and the public. It is difficult to estimate the cost, but if the loss due to delays in the transportation of people and commodities and the additional use of gasoline and oil due to traffic delays could be computed the total would be very large.

During an eight-hour period at a railroad crossing on Western Avenue, where traffic exceeds 15,000 vehicles per day, the crossing was blocked an average of 17 minutes per hour, and during one hour was closed 30 minutes.

The utilization in 1924 of 418 miles of highway in the county was approximately 990,000 vehicle-miles per day. Assuming an average speed of 20 miles per hour, the daily vehicle-hours are 49,500. Assuming that each vehicle loses four minutes per hour, due to traffic congestion on the county highways caused by natural or artificial obstructions or indirect routes, there is a daily time loss to traffic of 3,300 vehicle-hours. Considering the number of persons per passenger car and the net load per motor truck, the value of this lost time is at least $3 per hour. On this basis, there is a daily net loss, due to traffic delays, of $9,900 on these 418 miles of highway. Assuming this condition to exist 300 days during the year, the annual loss is approximately $3,000,000.

Recognizing the seriousness of the situation, the Cook County commissioners requested that the United States Bureau of Public Roads cooperate with the county in an investigation of highway traffic and in the formulation of a plan of improvement.

PURPOSE OF AND SCOPE OF THE TRANSPORTATION SURVEY

The principal purpose of the survey was to determine the present and anticipate the future traffic importance of all highways in the county as a basis for the designation of the highways to be included in a comprehensive plan of improvement.

The second major purpose was to classify the selected highways in accordance with their relative traffic importance and thereby to determine the relative necessity for and order of the several improvements; after which the third purpose was to determine the most economical type, design, and width for the improvement of the several sections on the basis of the following factors:

1. Present and estimated future traffic density.
2. The average daily number of motor trucks of large, medium, and small capacity using various sections of the system.
3. Maximum wheel loads and the frequency of heavy gross loads and wheel loads.

In general, these factors govern the choice of the type of pavement and the design and width of the improvement, though the final planning of each specific improvement must consider financial and physical factors such as the cost of the improvement in relation to traffic use, topography, drainage, soil and subgrade conditions, and availability and cost of materials.

For the purpose of securing this information 73 traffic stations were located throughout the city and county. At 17 of these, motor-truck weights were recorded. Recording stations were grouped around the weight stations and the truck weights recorded at each of the latter were imputed to the surrounding stations of the former class. At all stations information as to origin, destination type of vehicle, character of load, and purpose of use was recorded for both passenger vehicles and trucks.

DENSITY OF MOTOR-VEHICLE TRAFFIC

The traffic map, Figure 1, supports the following general conclusions with respect to the density of traffic:

1. The greatest density of traffic is found on a few main routes entering the county and on the highways adjacent to the city limits of Chicago.
2. The need for improved highways is of markedly less importance in the northwestern and southwestern sections than in the western, northeastern, southeastern, south-central and north-central sections of the county.
3. As distance from the city of Chicago increases the traffic importance of the highways decreases.
4. There are five congested areas in the county, each traversed by one or more highways that carry traffic of greatest density.

On the average day 78,446 motor vehicles, approximately two-thirds of the traffic between the city and county enter or leave the city at the gateways to these five congested areas. There is a most pressing need for additional city connections to diffuse traffic between the city and county, as well as the need for additional through routes in the city. River Road and the recently completed Mannheim Road are the only north-south routes serving the territory west of the city and available for through traffic that wishes to "by-pass" the city. This road passes through thickly populated areas and now carries a heavy traffic that is hampered by intersections with important cross routes. New north-south routes traversing this area as well as east and west routes are needed to diffuse the traffic.

POPULATION AND HIGHWAY TRAFFIC

In connection with the survey an analysis of the distribution of population and the trend of population and industrial development was made. The trends of population growth in Cook County vary markedly in different sections of the county. With some exceptions the trends are similar to the distribution of present population. The areas with the lowest density of population also had the lowest rate of population change between 1910 and 1920. These areas will not produce a large amount of traffic for a considerable time. The west, northeast, and southeast sections of the county, which are adjacent to the city, have a relatively dense population which is increasing rapidly and present the greatest need for highway improvement.

On the basis of past experience highway traffic may be expected to increase even more rapidly than population. The traffic is closely related to the number of traffic units as reflected in motor-vehicle registration, and the registration is increasing more rapidly than the population. In 1914, 31,869 motor vehicles were registered in Chicago, or 1 vehicle for 75.7 persons. In 1924 the registration of motor vehicles was 305,143 or 1 vehicle for 9.64 persons.

FORECAST OF HIGHWAY TRAFFIC IN 1930

The most scientific method of future highway traffic prediction is by the projection of past traffic and motor-vehicle registration trends. In the absence of comprehensive traffic records over a number of years it has been assumed that traffic will increase at the same rate as motor-vehicle registrations, as has been found to be true in Maine, Maryland, Michigan, and Wisconsin.

An additional factor which is negligible in considering a whole State may be of considerable importance in Cook County; that is, the effect of traffic congestion upon the rate of increase of traffic. In Cook County, however, present traffic is affected by congestion, particularly on the highways entering Chicago within 5

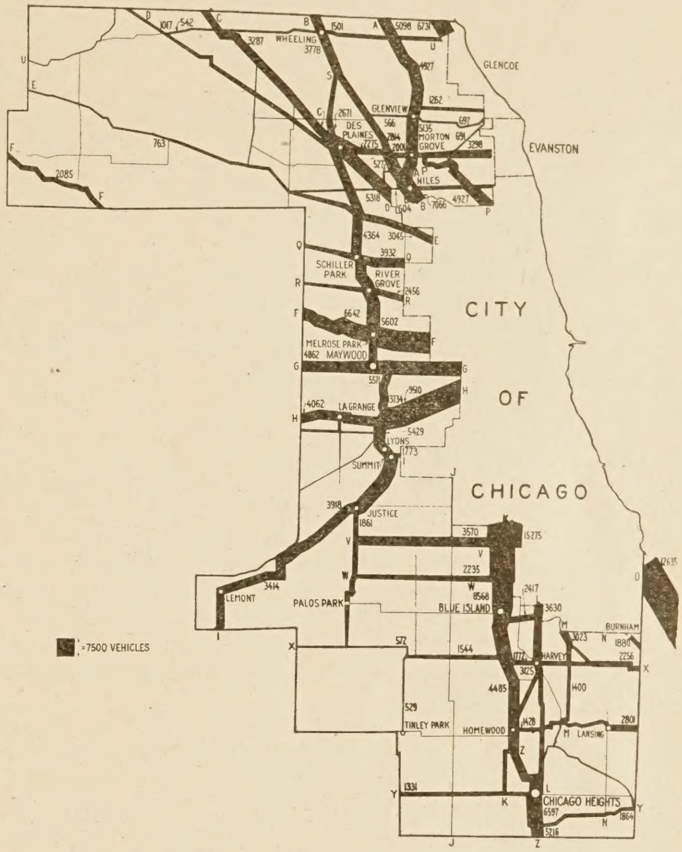

FIG. 1.—Average daily density of vehicular traffic on Cook County highways, 1924

miles of the city. Considering the increase in the number of routes planned for construction by 1930, it is doubtful if traffic congestion at that time will be more severe than it is at present, and it may therefore be assumed that the present ratio of traffic to registration will prevail in 1930.

Accurate records of motor-vehicle registration for the entire county of Cook for a series of years are not available. Such records for the city of Chicago are available, and it is necessary, therefore, to assume that the rate of increase of motor-vehicle registration for the county is approximately equal to the rate of increase within the city. The justification of this expedient is evidenced by the fact that in 1920, 88.5 per cent of the total population of the county lived within the city of Chicago. A variation in the rate of registration increase between the city and the county exclusive of the city will therefore have only a small effect upon the rate of increase for the entire county. The fact that population in the county exclusive of the city is increasing more rapidly than the population of the city will tend to make conservative an estimate of future registration based on present city registration.

Vehicles registered in the city of Chicago dominate the traffic on the highways of the county. More than 50 per cent of all trucks recorded on county highways were registered in the city, and trucks registered in the city exceeded by 65 per cent the trucks registered in the county exclusive of the city. It is probable that the distribution of passenger-car registration is quite similar.

The registration of motor vehicles in the city of Chicago from 1914 to 1924 was as follows:

Motor-vehicle registration, by years, in the city of Chicago

Year	Motor-vehicle registration	Year	Motor-vehicle registration
1914	31,869	1920	109,609
1915	42,602	1921	166,990
1916	60,072	1922	207,150
1917	73,321	1923	259,043
1918	76,567	1924	305,143
1919	93,125		

An accurate prediction of registration upon the basis of the rate of increase in the past, as shown by these records, will make possible the approximate prediction of future traffic. The predicted percentage increase in registration applied to the present traffic on the highways will give approximate figures for the future total traffic on the highways of the area.

It is not expected that this future traffic will be distributed upon the same routes as at present, owing to the development of new and auxiliary highways, suburban growth, and unusual industrial or pleasure-resort developments. Whether this future traffic can or will be carried upon existing routes or whether new routes are needed may be determined by other considerations. The traffic here predicted for a given route may be divided between the present route and one or more new routes.

Two facts increase the accuracy of such a traffic forecast based on motor-vehicle registration, namely, (1) the fact that comparatively accurate and complete registration statistics are available over a series of years; and (2) the fact that future registration is largely dependent upon future population, which can be accurately predicted for short periods of time.

Future registration is the quotient of future population and future persons per car, i. e., the ratio of population to registration. Admitting the accuracy of the population forecast, we have the problem of forecasting future persons per car.

The table below presents the population of the city of Chicago from 1914 to 1925 as reported by the United States Bureau of the Census, the estimated population from 1926 to 1930 as computed by the method of predicting population used by the Bureau of the Census, and the persons per registered vehicle from 1914 to 1924, the latter determined from the registration statistics in conjunction with the population statistics.

Past population and persons per car in the city of Chicago and estimate of future population

Year	Past population and estimated future population	Persons per car	Year	Past population and estimated future population	Persons per car
1914	2,412,218	75.7	1923	2,886,971	11.1
1915	2,464,852	57.9	1924	2,942,605	9.64
1916	2,517,486	41.9	1925	2,995,239	
1917	2,570,120	35.1	1926	3,047,083	----------
1918	2,622,754	34.3	1927	3,100,507	----------
1919	2,675,388	28.7	1928	3,153,141	----------
1920	2,728,022	24.9	1929	3,205.775	----------
1921	2,780,655	16.7	1930	3,258,409	----------
1922	2,833,288	13.7			

From this data it is estimated that there will be 4.86 persons per car in the City of Chicago in 1930. This figure was deduced by plotting years as abscissas and persons per vehicle as ordinates and projecting to 1930 a least square curve fitted to the data from 1914 to 1924. The estimated persons per car for each year to 1930 are shown in the following tabulation:

Estimated persons per car in the city of Chicago from 1925 to 1930

1925	9.07	1928	6.14
1926	7.92	1929	5.45
1927	6.96	1930	4.86

The estimated motor-vehicle registration on the basis of the above figures and the population estimate is as follows:

Estimated motor-vehicle registration in the city of Chicago, 1925 to 1930

Year	Estimated motor vehicle registration	Year	Estimated motor vehicle registration
1925	330,200	1928	513,500
1926	384,700	1929	588,200
1927	445,500	1930	670,500

The 1930 estimated registration of 670,500 vehicles is an increase of 119.7 per cent over the 1924 figure of 305,143 vehicles. This percentage increase applied to 1924 traffic on the Cook County highways gives the estimated traffic for 1930. This estimated traffic is shown graphically in Figure 2.

Figure 2 indicates the probable traffic conditions which will exist on the main highways of Cook County in 1930 unless new routes are added. Western Avenue near the city line may be expected to carry an average of 33,600 vehicles per day. At least five other routes may be expected to carry a daily average in excess of 10,000 vehicles near the city line. If the present ratio between average traffic and Sunday traffic continues until 1930, in excess of 20,000 vehicles may be expected to attempt to use each of these routes on the average Sunday. In view of the present congestion of traffic on these routes, particularly on Sundays, this great increase in traffic will result in impossible traffic conditions.

With few exceptions traffic congestion will, in 1930 as well as at the present time, even if no new routes are added, be limited to a zone approximately 5 miles in width surrounding the city. Five routes may be expected to carry an average daily traffic in excess of 10,000 vehicles throughout their entire length in the county. On the outlying sections of other routes traffic in 1930 is not expected to reach the capacity of the present highway. The northwestern and southwestern sections of the county will continue to be light-traffic areas.

THE PLAN OF IMPROVEMENT

The analysis of traffic upon the present highway system and consideration of the area and population of the area to be served has developed certain fundamental principles which must be incorporated in the plan of highway improvement. These principles may be summarized as follows:

1. The plan must be a regional plan.
2. It must provide for permanent improvements.

3. It must efficiently serve present and expected future traffic. To accomplish this, it is essential that all important sources of highway traffic be connected by direct through routes, involving:

(a) The construction of arterial highways between Chicago and the principal centers of population of the county.

(b) The connection of highways in the area surrounding the city with through city streets, which will permit traffic to move rapidly and directly to its destination.

(c) The construction of routes connecting important cities and villages in the county exclusive of the city of Chicago. These routes will also serve as "by-pass" routes for traffic desiring to avoid the city and as traffic-sorting routes in the present congested areas.

(d) The elimination of obstructions to the free and rapid movement of traffic. This involves the elimination of congestion points such as rail and highway intersections at grade, traffic "bottle necks", and sections of inadequate width.

4. The plan must provide for the acquisition of right of way for required future routes.

5. The present constructed sections of highway must, as far as possible, be utilized as the basis for the proposed plan.

1. *Necesity for a regional plan.*—In order that highway development may adequately meet the actual traffic needs of the Chicago area it will be necessary to coordinate the work of the various agencies now engaged in highway and street improvement in the area. Such coordination can not be accomplished without a comprehensive plan of highway location and construction.

The county of Cook, the city of Chicago, the State of Illinois, and the various smaller political units within Cook County are contemplating large programs of highway and street improvements. Each political unit is limited in its operations by legal restrictions. To obtain, therefore, a unified highway system it is essential that all agencies agree upon a definite improvement plan. By coordinating highway improvements according to an established plan with a known sequence of improvement, each community involved will secure the greatest possible benefit for the least expenditure The plan must serve not only the area as a whole but must also provide improved highway service for each section of the county.

In order to obtain the best results each governmental unit engaged in highway and street improvement should adopt the plan and work in harmony to complete the program of improvement. The poorest section of a highway determines the capacity of the entire route and the failure of one political unit to follow the general plan of improvement may impair highway service to an entire community.

The Chicago City Plan Commission has developed a comprehensive plan of major streets for the city of Chicago. This plan of the county highway system is coordinated with the city plan.

2. *Need for permanent high-type improvements*.—The large daily number of passenger cars and motor trucks on the highways of the county requires the best type of design and construction. The plan must therefore provide for highways which will provide efficient service to the large volume of present and expected future traffic. The additional present cost of high-type improvements will be more than equalized by savings in future highway-maintenance costs and motor-vehicle opertaing costs. Improvements must be designed to carry the expected volume of heavy truck traffic as well as the large total number of vehicles.

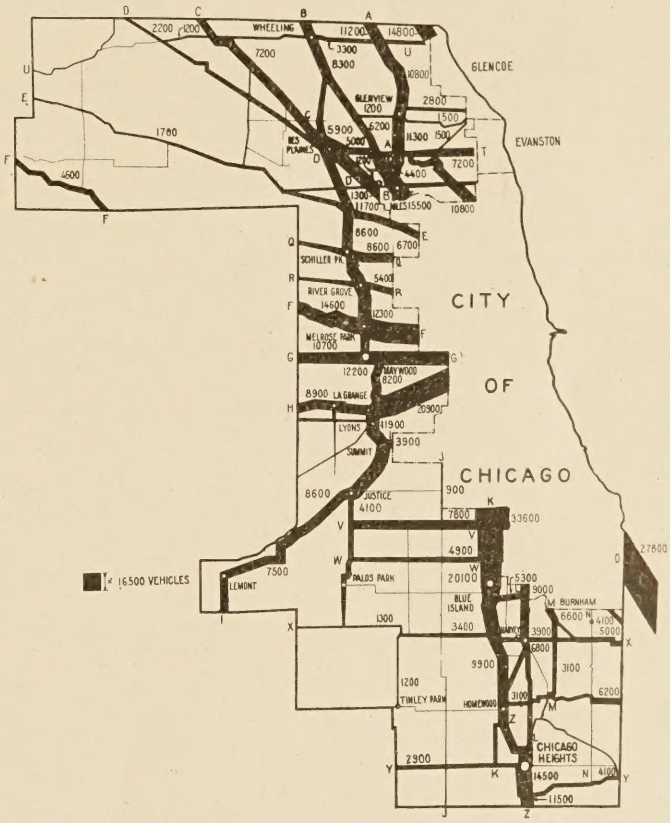

FIG. 2.—Forecast of average daily density of vehicular traffic on Cook County highways, 1930

3. *Need for a highway system which will efficiently serve present and expected future traffic.*—The present congestion of traffic on highways near the city of Chicago is evidence of the inability of the present highway system to serve present traffic. The plan of improvement must provide highway facilities which can carry the present and expected future traffic without the delays and inconveniences caused by present congestion. The analysis of traffic presented in the report indicates the need for the following types of improvements.

a. Arterial highways:

The distribution of population in Cook County and the principal sources of highway traffic indicate that the greatest need for such arterial highways is within the 5-mile zone surrounding Chicago. The primary movement of traffic on the highway system in the area is between Chicago and the belt of cities and villages surrounding the city. To provide highway service for this movement it is necessary that each of these cities and villages be connected with Chicago by one or more direct routes. A considerable part of the present traffic congestion is caused by the fact that there is at present an inadequate number of such connecting or arterial highways. Traffic from a large suburban area converges at a few points and results in severe congestion on the available routes.

b. The connection of highways in the area surrounding the city with major streets in the city:

The provision of adequate arterial highways to the city line will not eliminate congestion unless these highways are connected with additional through city streets which will permit traffic to move freely and rapidly within the city. If traffic is forced to use a few main thoroughfares within the city, it will continue to "pile up" at the present gateways to the city. The solution of this traffic problem can be found only in the coordinated construction program of the county, the city, and the large number of independent municipalities in the area.

Arterial highways are also required in the sections of the county lying beyond the 5-mile zone adjacent to the city. Present highways will, however, more nearly meet the demands of present and future traffic in this area. The widening of the present routes carrying the heaviest traffic or the provision of a few alternative routes will furnish adequate highway service for a considerable period of years.

c. Circuit and "by-pass" routes:

The rapid growth of the cities and villages in the area surrounding Chicago has greatly increased the local interchange of traffic between these communities. The present highway system does not provide adequate connections between these cities and villages. A large part of the traffic must now use the congested routes leading to the city or must enter the city and use congested city streets. Des Plaines River Road, and the newly completed Mannheim Road are the only north-south circuit routes in the section west of the city, and these routes provide highway facilities for only a limited number of communities. Traffic between Evanston and Oak Park, both cities of over 35,000 population, must either pass through the City of Chicago or must travel almost twice the required distance via Dempster Street and Des Plaines River Road.

The construction of adequate circuit routes would further relieve congestion on the arterial highways by permitting traffic destined to points beyond Chicago to "by-pass" the city, and connections between the arterial and circuit routes would permit the natural sorting of traffic outside the city and allow traffic to enter the city by the most direct route.

d. The elimination of obstructions to the free and rapid movement of traffic:

The required arterial and circuit highways will encounter many of these obstacles and must, therefore, be carefully planned in order that, so far as possible, these barriers may be avoided. In addition to obstructions caused by railway developments and special-use areas the arterial highways radiating from Chicago and the circuit routes around the city must of necessity intersect at a large number of points. Provision must be made for the crossing of these streams of traffic. This will probably involve the separation of grades at certain intersections and the planning of intersections which will involve as little congestion as possible at all intersections.

The traffic capacity of a route is also frequently reduced by narrow sections of pavement, narrow bridges, sharp curves, blind curves, street car and interurban trolley lines, the use of the highway for parking purposes and by local traffic on certain sections of the route, particularly when the route passes through the business section of a community. As far as possible such obstructions to the free movement of vehicles must be eliminated on all important traffic routes.

4. The plan of improvement must provide for the acquisition of right of way for required future use.

The normal development of an area surrounding a large center of population, such as Chicago, results in the establishment of large special-use areas through which highways can not be located. In so far as future highway needs can be predicted, adequate right of way for future improvements should be obtained prior to the establishment of these special-use areas. This procedure will not only reduce the cost of the highway system but will also provide in these areas a highway system so designed as to provide the most efficient highway service. By planning for the future development, many of the obstacles to highway improvement now existing in Cook County can be avoided in the sections of the area which are now undeveloped.

5. The proposed plan shall, as far as possible, utilize the highways already constructed.

Principles of economy dictate that where a through route can be developed by the construction of a relatively small unimproved mileage, this highway should be made a part of the proposed plan, if there is a traffic need for such a highway.

In establishing the order of improvement of the proposed plan it is obvious that improvements should be made in the order of their importance. First consideration should be given to improvements in the areas and on the routes where traffic is seriously congested. Second, the routes necessary to provide service to present traffic should be improved and, third, the highway right of way should be obtained on routes planned to serve future traffic.

In accordance with these principles a detailed plan of highway improvement has been worked out which includes the construction of pavements on approximately 838 miles of highway, of which approximately 248 miles must be opened as well as paved, and the widening of approximately 97 miles of present pavement. This mileage has been classified in four stages according to the urgency of the needed improvement.

The completion of the proposed plan of highway improvement will provide for Cook County, for the city of Chicago, and for the surrounding area a highway system which will serve the large volume of present highway traffic in the area and the expected increase of traffic in the immediate future.

The translation of the plan into actual improvements is already under way. This fact is evidenced by the construction during 1925 of a considerable mileage of urgently needed improvements in the county. Legislation enabling the cooperating agencies to carry out the proposed plan in the most efficient manner is enacted or pending.

Working agreements between the principal agencies charged with the development of the highway system have already been established. Agreements with municipalities, required for the initiation of improvement projects on certain routes, are rapidly being established and the details of a coordinated construction program are being arranged.

The execution of the proposed plan will require a considerable outlay of public funds. The plan is so arranged, both as to routes to be improved and the order of their improvement, that these funds will be placed where the greatest return on the investment will be realized. The required outlay of funds will be quickly returned in the form of reduced transportation costs, increased real-estate values, and improved highway service.

The severity of present traffic congestion in the area and the rapid increase in highway traffic, population, and industrial development in Cook County demonstrate the need for continuous and intensive study of the problem of providing highway service in order that present conditions may not recur.

EFFECTIVE WIDTH OF CONCRETE BRIDGE SLABS SUPPORTING CONCENTRATED LOADS

Reported by E. F. KELLEY, Acting Chief, Division of Tests, United States Bureau of Public Roads

IN THE DESIGN of a narrow rectangular reinforced concrete beam, subjected to concentrated loads, it is permissible to assume that the stress is constant over the full width of the beam. This assumption can not be made in the case of a wide slab where the stress varies from a maximum at the point of application of the load to a minimum at the edge of the slab. Therefore, in order to apply the rectangular beam theory to the design of wide slabs it becomes necessary to determine the width of slab, commonly called the "effective width," over which the concentrated load may be assumed as uniformly distributed.

It is the purpose of this paper to consider the data on the subject which are available and to derive working rules for distribution, suitable for use in the design of the floor slabs of highway bridges. The results of three series of tests on stress distribution have been published and these furnish the fundamental data for this study. The tests referred to are those of the University of Illinois, the State Highway Department of Ohio, and the United States Bureau of Public Roads. The conclusions based on these tests will be presented briefly in the following pages, but for complete discussions the reader is referred to the original papers.[1]

CONCLUSIONS FROM BUREAU OF PUBLIC ROADS TESTS

Of the several tests those by the Bureau of Public Roads are the most comprehensive, and these are summarized in the article published in the issue of Public Roads for September, 1918. The conclusions drawn from them may be briefly stated as follows:

Influence of slab width on effective width.—If the slab width be designated as b, the span of the slab as S, and the effective width as e, the relation between $\frac{b}{S}$ and $\frac{e}{S}$ which has been determined for a slab centrally loaded with a single load is shown in Figure 1.

Influence of two-point loading on effective width.—From tests made with two loads 5 feet apart on the center line of the slab, a loading approximating that of a single-axle load of a truck, it is concluded that the effective width equals the effective width for a single central load plus 4 feet.

Influence of eccentricity of load.—When a slab is eccentrically loaded with a single load, the effective width is the same as for a centrally loaded slab, when the distance, D, of the load from the near edge of the slab is more than one-half the effective width of the centrally loaded slab. When the distance D is less than half the effective width under a central load, the effective width equals $\frac{e}{2}+D$ where e is the effective width under a central load.

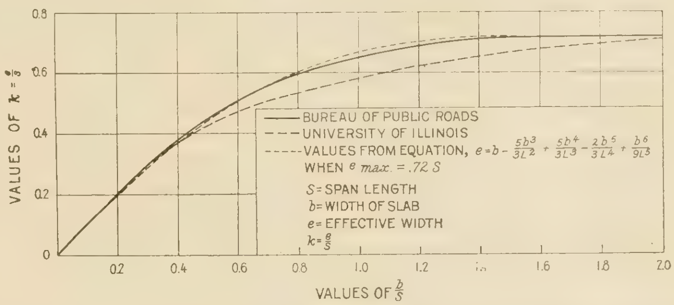

FIG. 1.—Relation between slab width and effective width as determined by the Bureau of Public Roads and the University of Illinois

UNIVERSITY OF ILLINOIS CONCLUSIONS

The results of the University of Illinois tests are given by Mr. Slater in his discussion of the earliest tests by the Bureau of Public Roads. He presents a graph showing the relation between slab width and effective width which is shown, in comparison with the same relation as established by the bureau, in Figure 1. It is apparent that the effective widths as proposed by Mr. Slater are in fairly close agreement with those proposed by the bureau, although somewhat lower. But it should be noted that both determinations of the effective width are for a load applied at a point. To provide for the fact that actual loads, such as truck wheels, have an appreciable width of bearing, Mr. Slater proposed the following rule:

$$E=2x \tan\theta+w$$

where E = effective width for load of width w
x = distance from load to near support
e = effective width for load applied at a point
S = span length

$$\tan\theta = k = \frac{e}{S} \text{ (values given by curves, Figure 1).}$$

When, therefore, $x=\frac{S}{2}$, the equation becomes

$$E=kS+w$$

In his very interesting article in the Engineering News Professor Young carries Mr. Slater's proposals somewhat further and develops equations for effective widths (fig. 2) which take into account the width and length of wheel contact area and also the direction of traffic with reference to the direction of the span of the

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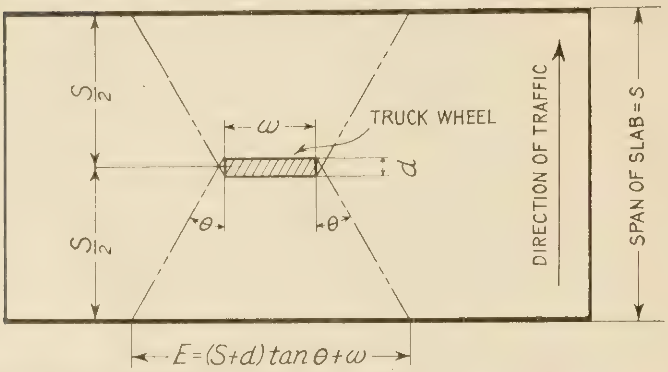
[1] *Tests of the State Highway Department of Ohio:*
Load Distribution Tests of Reinforced Concrete Slab Floors under Concentrated Loads. Bull. No. 28, State Highway Department of Ohio.
Tests of the U. S. Bureau of Public Roads:
Tests of Reinforced Concrete Slabs under Concentrated Loading. By A. T. Goldbeck. Proceedings of the American Society for Testing Materials (1913), vol. 13, p. 858–873.
Test of a Reinforced Concrete Slab. By E. B. McCormick. Journal of American Concrete Institute, May, 1915, vol. 3, No. 5, p. 195–204.
Tests of Large Reinforced Concrete Slabs. By A. T. Goldbeck and E. B. Smith. Proceedings of the American Concrete Institute (1916), vol. 12, p. 324–333.
Tests of Three Large-Sized Reinforced Concrete Slabs under Concentrated Loading. By A. T. Goldbeck and E. B. Smith. Jour. Agr. Research, Vol. VI, No. 6, May 8, 1916.
The Influence of Total Width on the Effective Width of Reinforced Concrete Slabs Subjected to Central Concentrated Loading. By A. T. Goldbeck. Proceedings of the American Concrete Institute (1917), vol. 13, p. 78–88.
Tests of a Large-Sized Reinforced Concrete Slab Subjected to Eccentric Concentrated Loads. By A. T. Goldbeck and H. S. Fairbank. Jour. Agr. Research, Vol. XI, No. 10, Dec. 3, 1917.
Reinforced Concrete Slab Bridge Design Based on Full-Sized Tests. By A. T. Goldbeck. Public Roads, Vol. I, No. 5, September, 1918.
Tests of the University of Illinois.
Discussion of Mr. Goldbeck's paper on Tests of Reinforced Concrete Slabs under Concentrated Loading. By W. A. Slater. Proceedings of the American Society for Testing Materials (1913), vol. 13, p. 874–883.
The Effective Width of Reinforced Concrete Slabs Supporting Concentrated Loads. By C. R. Young. Engineering News, July 30, 1914.

slab. When k is substituted for tan θ in these equations they become, for Cases I and II, respectively:

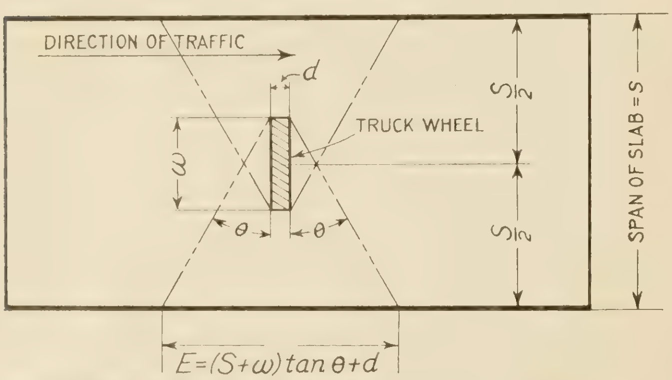
$$E = k(S+d) + w$$
$$\text{and } E = k(S+w) + d$$

and as the dimension, d, is small as compared with the width of wheel, it is advantageous, from the standpoint of simplicity, to neglect it, in which case the above equations reduce to:

$$E = kS + w \qquad \text{(Case I)}$$
$$E = k(S+w) \qquad \text{(Case II)}$$



CASE I DIRECTION OF TRAFFIC SAME AS SPAN OF SLAB



CASE II DIRECTION OF TRAFFIC PERPENDICULAR TO SPAN OF SLAB

FIG. 2.—Diagram of area of wheel contact in relation to slab

The fundamental principles underlying the determination of effective width are well stated in the paper by Goldbeck and Smith,[2] from which the following is quoted:

> The width of the slab that should be used in the rectangular-beam formulas when applied to slab design will be termed the "effective width" of the slab. It is that width over which, if the stress were constant and equal to the maximum stress under actual conditions, the resisting moment would equal the resisting moment of a slab of the same depth and full width, but having varying stress distribution. If the straight-line theory of stress distribution from neutral axis to upper fibers is assumed to be applicable to slabs, the resisting moment of a given slab is dependent on the total stress in the concrete or steel at the dangerous section. The total stress in the concrete, however, is governed by the stresses in the top fibers, and these stresses are proportional to the unit deformations. If, then, there are two slabs of equal depth, one having uniform distribution of deformations and the other a varying distribution, but with their maximum deformations identical, they will likewise have equal resisting moments if the summations of the deformations over their respective widths are identical.

[2] Tests of Three Large-Sized Reinforced Concrete Slabs under Concentrated Loading. By A. T. Goldbeck and E. B. Smith. Jour. Agr. Research, Vol. VI, No. 6, May 8, 1916.

In Figure 3, which represents a slab in position on two supports with a concentrated load P, is illustrated the method of obtaining "effective width." Strain-gauge readings are taken of the fiber deformations perpendicular to the supports, as indicated at eg. These concrete deformation values are plotted to scale, as, for instance, at fh, giving the deformation curve JHF, inclosing the area $AJHFE$. This curve shows the variation of stress from the center to each of the two free edges of the slab, and the area under the curve is a function of the total concrete-resisting moment of the slab. The area $BDGI$ (formed upon the base BD),[3] obtained by dividing the area $AJHFE$ by its maximum ordinate CH, has the same total concrete-resisting moment with the stress uniformly distributed as the whole slab, and its width BD, is that which may be effective in furnishing sufficient resistance under these conditions to carry the load. The width BD, obtained in this manner, is the "effective width."

CONCLUSIONS FROM THE OHIO TESTS

The results of the Ohio tests, in so far as they may be compared, are in close agreement with those of the University of Illinois and the Bureau of Public Roads, but the influence of slab width was not determined and, since the results may be applied only to wide slabs, their application to bridge design is limited.

However, in the published results (Bul. 28), an application of theoretical principles is developed which is worthy of careful study and which seems to the writer to offer opportunities for more extended consideration than has yet been given it.

The following is quoted from the above-mentioned bulletin:

> From the results of the tests it is known that the intensity of the resistance decreases from the load out, and that the shape of the transverse deformation curve is similar to that of the elastic line of a beam fixed at the ends. We may assume then that the elastic curve of a beam fixed at the ends and loaded as shown in Figure 4, would approach the form of the actual transverse deformation curves derived from the tests.

M_1 = moment necessary to hold the beam horiozntal at the ends.
w = maximum intensity of a reaction varying uniformly to zero at the ends.
y = deflection at any point.

W = total load $= \frac{wL}{2}$, where L is the span of the transverse deformation curve.

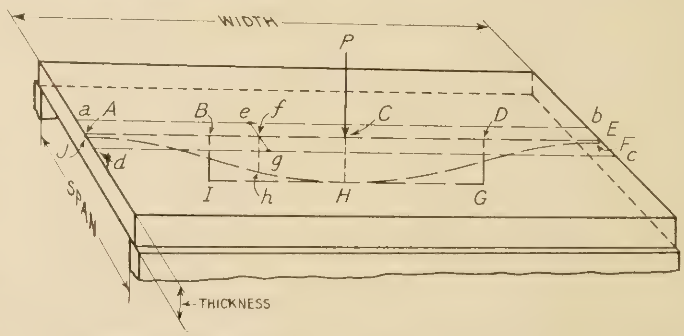


FIG. 3.—Diagram illustrating Bureau of Public Roads method of determining the effective width of a slab

The equation of the elastic line is:

$$y = \frac{W}{6EI}\left[\frac{x^5}{5L^2} - \frac{Lx^2}{16}\right] \qquad (1)$$

$$\text{When } x = \frac{L}{2},\ y = y_{\max.} = -\frac{WL^3}{640EI} \qquad (2)$$

Let b = the width of slab where b is less than L.

Then the area under the elastic line for the length b will correspond to the areas under the actual transverse deformation curves.

[3] Inserted by the editor.

$$A=2\int_{\frac{L-b}{2}}^{\frac{L}{2}} y\,dx=\frac{W}{3EI}\int_{\frac{L-b}{2}}^{\frac{L}{2}}\left[\frac{x^5}{5L^2}-\frac{Lx^2}{16}\right]dx$$

$$=\frac{W}{5760EI}\left[-9L^3b+15Lb^3-15b^4+\frac{6b^5}{L}-\frac{b^6}{L^2}\right] \tag{3}$$

$$e=\text{effective width}=\frac{A}{y_{\text{max.}}}=b-\frac{5b^3}{3L^2}+\frac{5b^4}{3L^3}-\frac{2b^5}{3L^4}+\frac{b^6}{9L^5} \tag{4}$$

when $b=L$, e will be a maximum, or the effective width of a slab of indefinite width,

$$e_{\text{max.}}=\frac{4}{9}L \tag{5}$$

*　　*　　*　　*　　*

No tests were made with two loads on the slab at the same time, but their effect may be studied by the use of the deformation curve given by equation 1.

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The curve for each load may be assumed to be independent of the other and the total deformation at any point may be taken as the sum of the two deformations at that point.

APPLICATION OF TEST RESULTS TO BRIDGE DESIGN

In the above series of tests certain limitations are noted which affect the application of the results to actual bridge design, as follows:

1. The influence of slab width for *single central* loads is quite definitely established by the tests of the Bureau of Public Roads and University of Illinois. The Ohio tests give results only for wide slabs.

2. For loads applied at two points on the same transverse element of the slab, the only data are those furnished by the Bureau of Public Roads tests. These tests were only for loads spaced 5 feet apart and therefore do not give results which are applicable to other spacings of loads.

The theoretical principles developed in Ohio Bulletin No. 28 were applied only to two loads on wide slabs.

We are therefore still in considerable doubt as to the effect of two wheels when both wheel spacing and width of slab are variables and, as yet, there are no data on the effect of four loads, such as would be occasioned by two trucks passing.

3. The effect of eccentric loads has been studied only by the Bureau of Public Roads and the results of the tests made are not entirely conclusive, as is evidenced from the following, quoted from the paper by Goldbeck and Fairbank.[4]

> Unfortunately, however, the results can not be regarded as entirely conclusive, owing to the fact that the recent test involved only one span length and yielded only two points on the critical part of the curve between the total widths of 18 and 22 feet. It is hoped that this point will be cleared up by further tests.

In view of the above it is highly desirable to investigate more fully the various conditions of loading which may arise and, in the absence of test data, it is believed that this may be done satisfactorily by developing further the theory proposed in Ohio Bulletin No. 28.

Referring, then, to this theory and substituting values of $\frac{b}{L}$ in equation 4, we obtain the values of $\frac{e}{L}$ given in the second column of Table 1.

[4] Tests of a Large-Sized Reinforced Concrete Slab Subjected to Eccentric Concentrated Loads. By A. T. Goldbeck and H. S. Fairbank. Jour. Agri. Research, Vol. XI, No. 10, Dec. 3, 1917

But from equation 5 we have $e_{\text{max.}}=\frac{4}{9}L$ and from the Bureau of Public Roads curve, which may be assumed to give conservative values, we have $e_{\text{max.}}=0.72S$

Equating these values of $e_{\text{max.}}$

$$L=1.62S \tag{6}$$

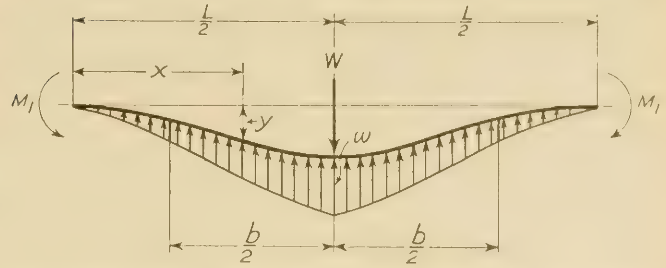


Fig. 4.—Elastic curve and loading diagram of beam with fixed ends used in development of theory based on the Ohio tests

By substituting this value of L in the values of $\frac{b}{L}$ and $\frac{e}{L}$ given in the first two columns of Table 1 we obtain the values of $\frac{b}{S}$ and $\frac{e}{S}$ given in the third and fourth columns of Table 1 and these have been plotted in Figure 1.

The close agreement of the theoretical curve with that proposed by the bureau is very striking and there is so little difference between the two that, for all practical purposes, they may be said to be the same. The values proposed by the bureau and those given by equation 4 are compared for identical values of $\frac{b}{S}$ in the last two columns of Table 1.

Table 1.—*Values of* $\frac{e}{L}$, $\frac{b}{L}$, $\frac{e}{S}$, *and* $\frac{b}{S}$, *derived from equation 4 and the Bureau of Public Roads curve*

Values of $\frac{e}{L}$ computed from equation 4 with assumed values of $\frac{b}{L}$		Values of $\frac{b}{S}$ and $\frac{e}{S}$ computed from equations 4 and 6		Comparison of values of $\frac{e}{S}$, corresponding to assumed values of $\frac{b}{S}$, as given by equation 4 and the Bureau of Public Roads curve		
					$\frac{e}{S}$	
$\frac{b}{L}$	$\frac{e}{L}$	$\frac{b}{S}$	$\frac{e}{S}$	$\frac{b}{S}$	Bureau of Public Roads curve	Equation 4, $e_{\text{max.}}=.72S$
0.05	0.0498	0.081	0.081	0.1	0.1	0.1
.10	.0985	.162	.160	0.2	0.2	0.2
.15	.1452	.243	.235	0.3	0.28	0.28
.20	.1891	.324	.306	0.4	0.37	0.37
.25	.2298	.405	.372	0.5	0.44	0.44
.30	.2670	.486	.433	0.6	0.50	0.51
.35	.3003	.567	.486	0.7	0.55	0.56
.40	.3296	.648	.534	0.8	0.58	0.61
.45	.3551	.729	.575	0.9	0.62	0.64
.50	.3767	.810	.610	1.0	0.65	0.67
.55	.3947	.891	.639	1.1	0.67	0.69
.60	.4093	.972	.663	1.2	0.68	0.70
.65	.4208	1.053	.682	1.3	0.70	0.71
.70	.4295	1.134	.696	1.4	0.71	0.72
.75	.4358	1.215	.706	[1]	0.72	0.72
.80	.4400	1.296	.713	----------	----------	----------
.85	.4426	1.377	.717	----------	----------	----------
.90	.4439	1.458	.719	----------	----------	----------
.95	.4444	1.539	.720	----------	----------	----------
1.00	.4444	1.620	.720	----------	----------	----------

[1] 1.5 and over.

This agreement between the test curve and the theoretical curve indicates that values of L may be taken as independent of the width of slab and dependent only on the span length. Accepting the maximum value for effective width as proposed by the Bureau of Public Roads, the relation between L and the span length is given by equation 6.

Having thus determined the value of L, the span of the transverse deformation curve, we may proceed to the consideration of multiple loads.

In Figure 5 is shown a slab of width, b, loaded with a single concentrated load. The curve ABC represents the transverse deformation curve of length, L, and maximum ordinate, y. The effective width equals the area under the curve for the length, b, divided by the maximum ordinate, y; that is, the area $DEFBG$ divided by y.

In Figure 6 the slab of width, b, is shown loaded with two equal concentrated loads P_1 and P_2 and with transverse deformation curves ABC and DEF, respectively. The curve AGF is the summation curve of the two curves ABC and DEF and therefore represents the deformation curve for the two loads. The effective width for the two loads is therefore the area $HJGKL$ divided by the maximum ordinate, y_m.

It will be noted that the maximum ordinates y_1 and y_2 of the two deformation curves are not equal. This is due to the fact that the corresponding effective widths for the two loads are not equal, as shown by the following:

Let A_1 = area $HJMBL$

A_2 = area $DENL$

e_1 = effective width for load P_1

e_2 = effective width for load P_2

Then $e_1=\frac{A_1}{y_1}$ and $e_2=\frac{A_2}{y_2}$.

As previously stated, the area under the deformation curve is a function of the total resisting moment of the

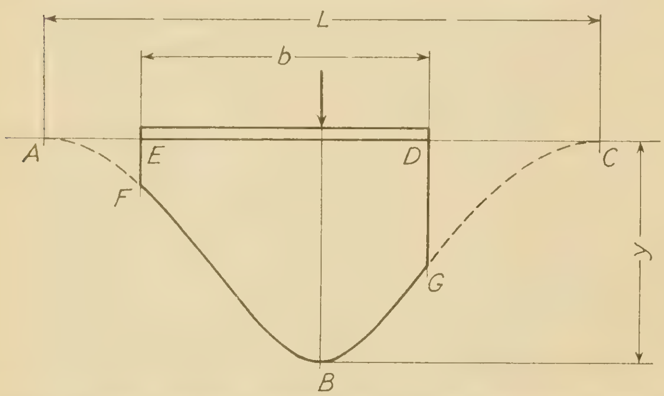


FIG. 5.—Transverse deformation curve of a slab with single concentrated eccentric load

slab. Since the loads P_1 and P_2 are equal, the respective resisting moments of the slab must also be equal and therefore the areas under the two deformation curves must be equal.

The $A_1=A_2$ and, from the above two equations,

$$\frac{y_2}{y_1}=\frac{e_1}{e_2}.$$

Thus it is clear that when the effective widths are unequal the corresponding maximum ordinates of the deformation curves are also unequal.

DETERMINATION OF THE EFFECTIVE WIDTH

Knowing the characteristics of the deformation curve, the principles outlined above may be applied to any combination of loads on slabs of varying spans and widths, and the resulting effective widths deter-

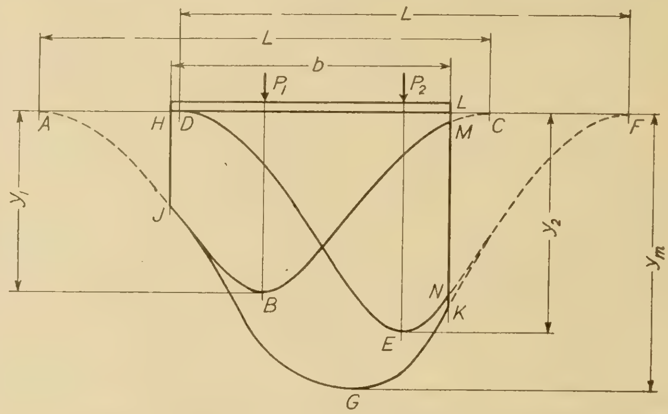


FIG. 6.—Transverse deformation curve of a slab with two equal concentrated loads unsymmetrically placed

mined. The method is illustrated by the two typical examples which follow:

EXAMPLE I

Assume a slab of 20-foot span and 20-foot width loaded at the center of the span with two equal loads P_1 and P_2 which are placed transversely in the positions shown in Figure 7 (a).

From equation 6,

$$L=1.62S=1.62\times 20=32.4 \text{ feet.}$$

Using the value of L thus determined and the known width of the slab, b, the effective width, e, may be obtained from equation 4, or from Figure 8, which presents the relation between $\frac{b}{L}$ and $\frac{e}{L}$ expressed by the equation. The value of e thus obtained, however, will be for a single load centrally placed. In order to determine the effective width for each load eccentrically placed as in Figure 7 (a) the following method may be used.

Figure 7 (b) shows the transverse deformation curve for a slab of width $(a+c)$ unsymmetrically loaded with a single concentrated load. Since the deformation curve is symmetrical about the load it is evident that the area $ABCDE$ equals twice the area $ABCK$, and the area $FGCHJ$ equals twice the area $KCHJ$.

Let A = area $ABCHJ$

A_a = area $ABCDE$

A_c = area $FGCHJ$

Then $A=\frac{1}{2}(A_a+A_c)$. (7)

But the effective width is equal to the area under the deformation curve divided by the maximum ordinate.

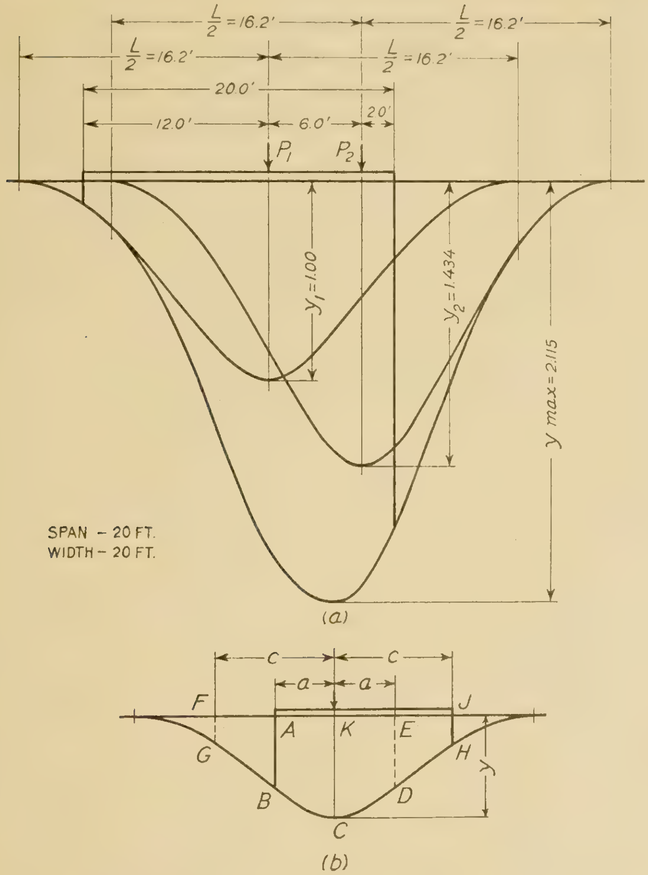


FIG. 7. (a) Diagram of loading of 20-foot slab, 20 feet wide and transverse deformation curves resulting from eccentric loads applied at center of span. (b) Diagram of slab of width $(a+c)$ loaded unsymmetrically with a single concentrated load, and deformation curve resulting from load

Therefore, $e=\frac{A}{y}=$ effective width for the slab as shown.

$e_a=\frac{A_a}{y}=$ effective width for a centrally loaded slab of width $2a$.

$e_c=\frac{A_c}{y}=$ effective width for a centrally loaded slab of width $2c$.

And substituting in equation 7, $e=\frac{1}{2}(e_a+e_c)$.

From Figure 8, e_a may be obtained by taking b as equal to $2a$ and e_c may be obtained by taking b as equal to $2c$.

For the load P_1, in the example under consideration the effective width, e_1, is equal to $\frac{1}{2}(e_a+e_c)$,

where $e_a=$ effective width for a centrally loaded slab of width $b_a=2\times12=24$ feet, and
$e_c=$ effective width for a centrally loaded slab of width $b_c=2\times8=16$ feet.

For this load then, the curve, Figure 8, gives the following values:

$$\text{For } \frac{b_a}{L}=\frac{24}{32.4}=0.7407;\ \frac{e_a}{L}=0.435$$

$$\text{For } \frac{b_c}{L}=\frac{16}{32.4}=0.4938;\ \frac{e_c}{L}=0.374$$

Then $e_1=\frac{1}{2}(0.435L+0.374L)=0.4045L$.

Similarly, for the load P_2 the effective width, e_2, is equal to $\frac{1}{2}(e_a+e_c)$
where $e_a=$ effective width for a centrally loaded slab of width
$b_a=2\times18=36$ feet and
$e_c=$ effective width for a centrally loaded slab of width
$b_c=2\times2=4$ feet
$e_a=0.444L$ and $e_c=0.120L$
and $e_2=\frac{1}{2}(0.444L+0.120L)=0.282L$.

Then, from the previous discussion $\frac{y_2}{y_1}=\frac{e_1}{e_2}$

$$\text{If } y_1=1.\ y_2=\frac{0.4045L}{0.282L}=1.434$$

Using these values of the maximum ordinates, the deformation curves for the loads P_1 and P_2 may now be drawn, as shown in Figure 7 (a), the lesser ordinates being determined from equation 1 or from Table 2 which has been constructed from this equation assuming the maximum ordinate to be unity. The curves for the two loads being constructed in this way, the summation curve may be drawn and its maximum ordinate is found to be 2.115.

The area of the summation curve equals the sum of the respective areas A_1 and A_2 of the curves for the loads P_1 and P_2. But as it has already been shown that A_1 equals A_2, the area, A, of the summation curve is equal to $2A_1$.

$$\text{Then since } e_1=0.4045L=\frac{A_1}{y_1}$$

and since $y_1=1.\ A_1=0.4045L$
and $A=2\times0.4045L$.

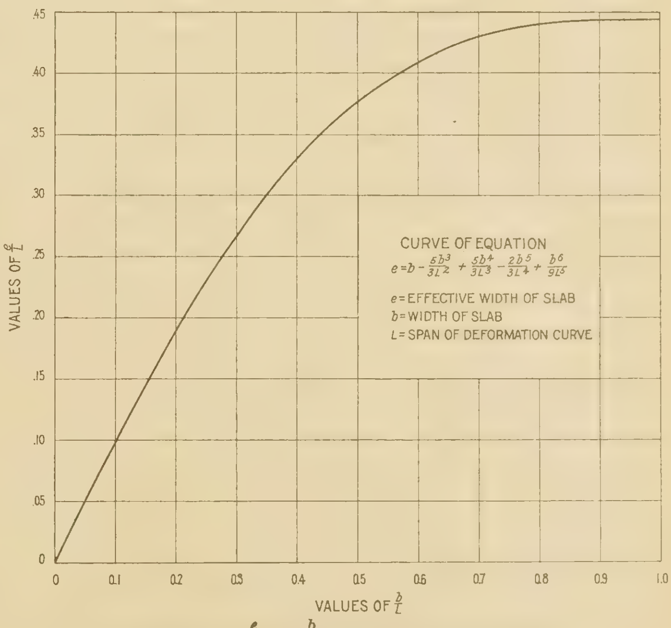


FIG. 8.—Relation of $\frac{e}{L}$ and $\frac{b}{L}$ as expressed by Ohio equation

And, finally, if we let $E=$ effective width for the two loads, and

$e=\frac{E}{2}=$ effective width for one of the loads

$$\text{Then } E=\frac{A}{y_{max.}}=\frac{2A_1}{y_{max.}},\ \text{and}$$

$$e=\frac{2\times0.4045L}{2\times2.115}=\frac{0.4045\times32.4}{2.115}=6.20 \text{ feet}$$

TABLE 2.—*Coordinates of deformation curve when* $y_{max}=1$ *derived from equation 1,* $y=\frac{W}{6EI}\left[\frac{x^5}{5L^2}-\frac{Lx^2}{16}\right]$

Values of x	Values of y	Values of x	Values of y
0.05L	0.017	0.35L	0.702
.10L	.066	.40L	.848
.15L	.149	.425L	.908
.20L	.260	.45L	.957
.25L	.396	.475L	.988
.30L	.548	.50L	1.000

EXAMPLE II

Assume a slab of 22-foot span and 24-foot width loaded at the center of the span with four equal loads P_1, P_2, P_3, and P_4 as shown in Figure 9.

$$L=1.62S=1.62 \times 22=35.64 \text{ feet}$$

By the method described in Example I the following values of effective widths for the various loads are found:

$$e_1=0.385L$$
$$e_2=0.424L$$
$$e_3=0.399L$$
$$e_4=0.277L$$

And if, as before, $y_2=1$

$$y_1=1.101$$
$$y_3=1.062$$
$$y_4=1.531$$

The deformation curves with the above maximum ordinates may then be drawn and from them the summation curve constructed; and, as from the previous discussion it is known that the areas under the various deformation curves must be equal, that is, $A_1=A_2=A_3=A_4$.

Therefore, A (area of summation curve) $=4A_2$.

But, since $y_2=1$, $A_2=e_2=.424L$ and from the summation curve, $y_{max}=3.42$.

If, again, we let

E = effective width for the four loads, and

$e=\frac{E}{4}$ = effective width for one of the loads.

Then $E=\frac{A}{y_{max}}=\frac{4A_2}{y_{max}}$, and

$$e=\frac{4\times 0.424L}{4\times 3.42}=\frac{0.424\times 35.64}{3.42}=4.42 \text{ feet.}$$

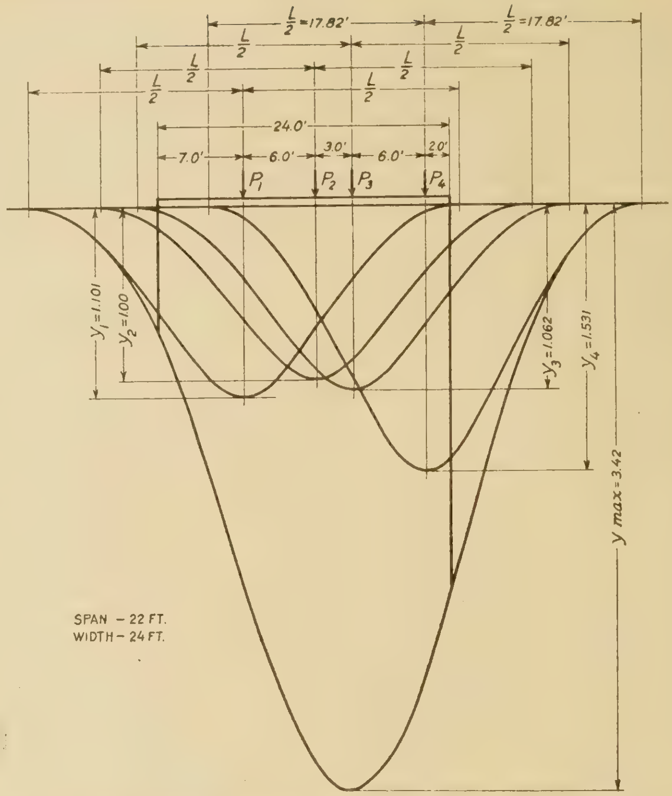


FIG. 9.—Diagram of loading of 22-foot span, 24 feet wide loaded at the center of the span with four equal loads, and transverse deformation curves resulting from loads

EFFECTIVE WIDTH OF SLABS WITH MAIN REINFORCING PARALLEL TO DIRECTION OF TRAFFIC

Following the method outlined above, effective widths have been determined for various conditions of truck loading on slabs from 12 to 36 feet in width and of spans from 2 to 24 feet; and the results are tabulated in Tables 3 and 4 for four conditions of loading designated as Cases I, II, III, and IV. In some cases an approximate method for the determination of the maximum ordinate of the summation curve has been used in order to eliminate a great amount of tedious curve construction, and this has caused slight errors in the results. However, these errors do not exceed 2 or 3 per cent and are on the side of safety.

The cases considered include slabs symmetrically and eccentrically loaded with one and two trucks. For eccentric loading the minimum distance from the center of the outer wheel to the edge of the slab has been taken as 2 feet, which is a fair minimum figure for any slab carrying a curb or rail.

It will be noted that the values of effective width for Case II are equal to or greater than the corresponding values for Case I, and that the values for Case IV, except for a few slight discrepancies probably due to unavoidable errors in computation, are equal to or greater than the values for Case III. Since a conservative specification must provide for the worst conditions—in this case, the minimum effective widths—we may eliminate Cases II and IV and consider only Cases I and III in deriving approximate values for distribution which may be used in slab design.

The curves in Figure 10 show the maximum and minimum values of effective width for Cases I and III, as given in Table 3. For a single concentrated load the effective width has been shown to be greatly influenced by the slab width, but these curves show clearly that, for the multiple loads here considered, the effective width, except for the slab of 12-foot width in Case I, is influenced very little by the slab width and depends almost entirely on the span of the slab.

The straight dotted lines on the diagrams represent approximate values of effective width which agree closely with the computed values and are convenient for design purposes.

The equations of the dotted lines are as follows:

For Case I (one truck):

$e=0.65S$, for spans of 7 feet or less;

$e=0.12S+3.71$, for spans of more than 7 feet.

For Case III (two trucks):

$e=0.65S$, for spans of 4 feet or less;

$e=0.25S+1.6$, with a maximum value of 4.4, for spans of more than 4 feet.

It should be noted that Cases I and III involve slabs in which the main reinforcement is in the direction of the traffic; also that, in computing the effective widths, no account has been taken of the width of wheel contact. Professor Young's equation, $E=kS+w$ takes into account the width of wheel contact when the main reinforcement is in the direction of the traffic and we may therefore substitute for kS in this equation the values of the effective widths as determined for Cases I and III above. Making these substitutions we obtain the following equations for the effective width of a single wheel of a group when the main reinforcement of the slab is parallel to the direction of the traffic.

For one truck:

For spans of 7 feet or less, $e=0.65S+w$.

For spans of more than 7 feet, $e=0.12S+w+3.71$.

For two trucks:

For spans of 4 feet or less, $e=0.65S+w$.

For spans of more than 4 feet, $e=0.25S+w+1.6$, with a maximum value of $4.4+w$.

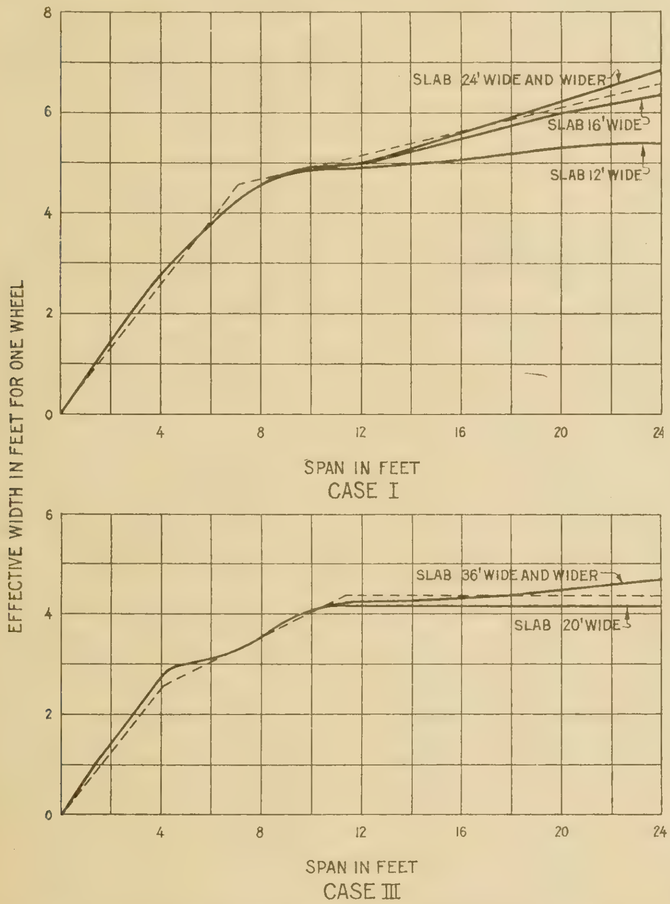


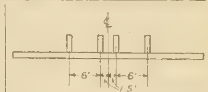
Fig. 10.—Maximum and minimum values of effective width for one wheel (eccentric loading), the main reinforcing at the slab being parallel to the direction of the traffic, and the effect of tire width neglected

Referring again to the curves of Case I, Figure 10, it may seem at a glance that the approximate equation represented by the dotted line is not in sufficiently close agreement with the values for the slab of 12-foot width. However, it can be shown that this is not the case when the width of wheel contact and the fact that the sum of the effective widths for all the loads on the slab can not exceed the width of the slab are taken into consideration. Since this slab of 12-foot width carries two wheel loads, the effective width for one of them can not exceed 6 feet, and it will be reasonable to

Table 3.—*Effective width for one wheel (eccentric loading). Main reinforcement parallel to direction of traffic; effect of tire width neglected*

Condition of loading	 Case I					 Case III			
	Width of slab					Width of slab			
Span (feet)	12	16	18	20	24 and wider	20	24	30	36 and wider
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
2	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
4	2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78
6	3.79	3.79	3.79	3.79	3.79	3.15	3.15	3.15	3.15
8	4.61	4.61	4.61	4.61	4.61	3.59	3.59	3.59	3.59
10	4.86	4.93	4.93	4.93	4.93	4.07	4.07	4.07	4.07
12	4.85	5.01	5.01	5.01	5.01	4.25	4.29	4.29	4.29
14	4.98	5.25	5.30	5.30	5.30	4.23	4.32	4.34	4.34
16	5.12	5.53	5.59	5.60	5.60	4.19	4.34	4.38	4.38
18	5.20	5.76	5.84	5.88	5.88	4.16	4.38	4.42	4.42
20	5.30	6.00	6.12	6.20	6.22	4.17	4.43	4.51	4.52
22	5.39	6.20	6.41	6.50	6.55	4.18	4.42	4.59	4.60
24	5.40	6.37	6.61	6.75	6.85	4.21	4.55	4.71	4.73

Table 4.—*Effective width for one wheel (symmetrical loading). Main reinforcement parallel to direction of traffic; effect of the tire width neglected*

Condition of loading	 Case II							 Case IV			
	Width of slab							Width of slab			
Span (feet)	12	16	18	20	24	30	36	20	24	30	36
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
2	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
4	2.88	2.88	2.88	2.88	2.88	2.88	2.88	2.88	2.88	2.88	2.88
6	4.17	4.32	4.32	4.32	4.32	4.32	4.32	3.15	3.15	3.15	3.15
8	5.16	5.66	5.70	5.70	5.70	5.70	5.70	3.59	3.59	3.59	3.59
10	5.15	5.84	5.98	6.04	6.05	6.05	6.05	4.07	4.09	4.09	4.09
12	5.07	5.84	6.06	6.20	6.28	6.28	6.28	4.25	4.32	4.36	4.36
14	5.11	5.97	6.24	6.44	6.64	6.67	6.67	4.21	4.40	4.49	4.51
16	5.21	6.17	6.50	6.75	7.04	7.17	7.17	4.20	4.46	4.64	4.68
18	5.27	6.35	6.76	7.04	7.43	7.68	7.71	4.19	4.53	4.78	4.87
20	5.34	6.52	6.96	7.32	7.83	8.18	8.27	4.19	4.60	4.93	5.05
22	5.40	6.67	7.18	7.62	8.21	8.71	8.87	4.19	4.64	5.05	5.22
24	5.49	6.83	7.38	7.85	8.58	9.21	9.47	4.25	4.73	5.21	5.45

assume the width of wheel as 1 foot. Substituting these values in the equation for effective width we find that, for a wheel 1 foot wide, the effective width is 6 feet when the span length is 10.75 feet. For spans less than 10.75 feet, the actual values for the 12-foot slab width are shown by Figure 10 to be in close agreement with those of the approximate equation while, for spans greater than 10.75 feet, the equation does not apply since the effective width is limited by the width of slab. Therefore, the actual values for the 12-foot slab width are in practically as close agreement with those of the approximate equation as are the actual values for the other widths of slab.

EFFECTIVE WIDTH OF SLABS WITH MAIN REINFORCEMENT PERPENDICULAR TO DIRECTION OF TRAFFIC

Concrete slabs in which the main reinforcement is perpendicular to the direction of traffic are used in through girder bridges, deck girder or T-beam bridges and in slab floors supported on longitudinal steel joists. For such designs the problem of load distribution is entirely different from that which has been outlined in the case of slabs which have their main reinforcement parallel to the direction of traffic.

The maximum bending moment in a slab, the span of which is at right angles to the direction of traffic, is determined by one of several different conditions of loading, depending upon the transverse spacing of the longitudinal beams or joists and the number of trucks for which the floor is to be designed.

In Figure 11 assumed transverse wheel spacings are shown for one and two trucks and five conditions of loading designated as Cases I to V inclusive, one of which will determine the maximum bending moment for any particular spacing of longitudinal beams; and Table 5 gives the bending moments due to unit loads for these five loading conditions.

For through girder bridges, the bending moment in the floor slab will be determined by either one or two axle loads, depending upon whether the floor is designed for one truck or two. In through girder construction the maximum range in span of the floor slabs may be taken as from 16 to 24 feet. Therefore, effective widths must be determined for one axle load (Case III) on spans from 16 to 24 feet and for two axle loads (Case V) on spans from 18 to 24 feet.

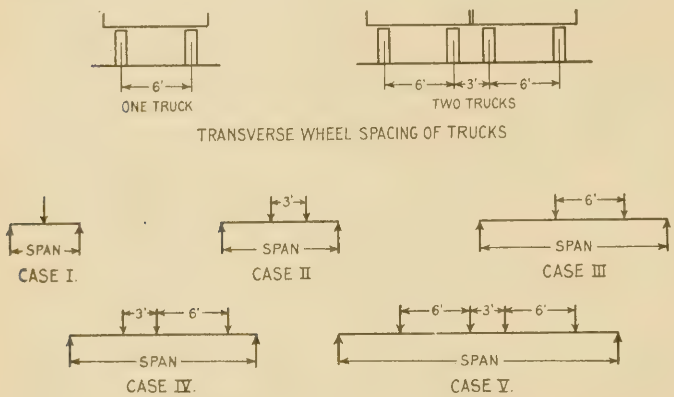


FIG. 11.—Assumed transverse wheel spacings and five conditions of loading

In a deck girder bridge designed for one truck, the bending in the floor slab will be determined by either Case I or Case III, and as shown by Table 5, Case I governs for span lengths up to 10 feet and Case III for greater span lengths. In a deck girder designed for two trucks, the bending in the slab will be determined by Case I, Case II, Case IV or Case V, depending upon the girder spacing. Case II governs for spans from 6 to 12 feet and Cases IV and V need not be considered since the girder spacing in this type of construction will seldom, if ever, exceed 12 feet.

To sum up, for both through and deck girder bridges, effective widths must be determined for various widths of wheels, as follows:

Case I, spans up to 10 feet.
Case II, spans from 6 to 12 feet.
Case III, spans from 10 to 24 feet.
Case V, spans from 18 to 24 feet.

The minimum effective width for a slab centrally loaded with a single load will occur when the slab width is a minimum and the span length a maximum; that is, when the ratio of width to span is a minimum. For the type of construction under consideration, when the spacing of longitudinal beams is such as to give maximum bending under one wheel load, an extreme assumption is that of a slab of equal span and width. For this case the value of $\frac{b}{S}$ equals 1.0 and the corresponding value of $\frac{e}{S}$, from Table I, is 0.67. Since this assumed condition is extreme and since axle spacings are so great that the preceding or following wheel loads will have no effect on the distribution, we will provide amply for all ordinary cases by assuming

$$\frac{e}{S}=k=0.70$$

TABLE 5.—*Maximum bending moments for various spans due to unit loads for five conditions of loading. Main reinforcement perpendicular to direction of traffic*

Span in feet	Bending moments in foot-pounds				
	Case I	Case II	Case III	Case IV	Case V
2	0.50				
3	.75				
4	1.00				
5	1.25	1.23			
6	1.50	1.69			
7	1.75	2.16			
8	2.00	2.64			
9	2.25	3.13	2.0		
10	2.50	3.61	2.45		
11		4.11	2.91	3.82	
12		4.59	3.38	4.56	
14			4.32	6.05	
16			5.28	7.55	
18			6.25	9.04	9.13
20			7.23		11.11
22			8.20		13.11
24			9.19		15.10

Professor Young's equation for the effective width of a centrally loaded slab in which the main reinforcement is perpendicular to the direction of traffic is $E=k(S+w)$.

Substituting the above value of k in this equation we obtain $E=0.7(S+w)$ which may be used for the determination of effective width for slabs in which the maximum bending is determined by one wheel load, as in Case I.

In Cases II, III, and V the maximum bending is determined by either two or four wheel loads and the above equation, which is for central loading, can not apply since, when the loads are placed in the position to produce maximum bending, none of them is at the center of the span of the slab. In dealing with these cases, therefore, it will be necessary to consider loads not centrally located on the span and in order to do this it will be convenient to make use of an equation proposed by Professor Young in a paper published in the Engineering News in 1914.[5] For the conditions shown in Figure 12 this equation is

$$E=2\left(x+\frac{w}{2}\right)\tan\theta+d$$

in which E = effective width
w and d = dimensions of bearing area of wheel
$\tan\theta=k$
x = distance from center of wheel to near support

When $\tan\theta=0.7$ and $d=0$ this reduces to

$$E=1.4x+0.7w \tag{8}$$

In the following discussion this equation will be used for the determination of effective width for single loads on slabs in which the main reinforcement is perpendicular to the direction of traffic.

[5] The effective width of Reinforced Concrete Slabs Supporting Concentrated Loads. By C. R. Young. Engineering News, July 30, 1914.

Figure 13 shows the case of two equal loads, P, in the position to produce maximum bending in the slab of span, S. From the above equation the effective width for the load at point 1 is $E_1 = 1.4b + 0.7w$, and for the load at point 2 it is $E_2 = 1.4c + 0.7w$. These effective widths are the widths of slab, transverse to the direction of the slab span, over which the respective loads may be assumed to be uniformly distributed.

Therefore, at point 1 the load on a strip of the slab 1 foot in width is $\frac{P}{E_1}$ and at point 2 the load carried by a 1 foot strip is $\frac{P}{E_2}$, E_1 and E_2 being expressed in feet.

Let M_1 = bending moment on a strip of slab 1 foot in width.

Then

$$M_1 = \left[\frac{\frac{Pb}{E_1} + \frac{P(a+b)}{E_2}}{S}\right] c.$$

Let M = total bending due to the two equal wheel loads.

Then

$$M = \frac{P(a+2b)c}{S}.$$

If M is the total bending in the slab and M_1 is the bending in a strip 1 foot wide, it follows that the width in feet over which the total bending is distributed; in other words, the effective width is equal to $\frac{M}{M_1}$.

A typical determination of effective width in accordance with the above assumptions will now be given in detail.

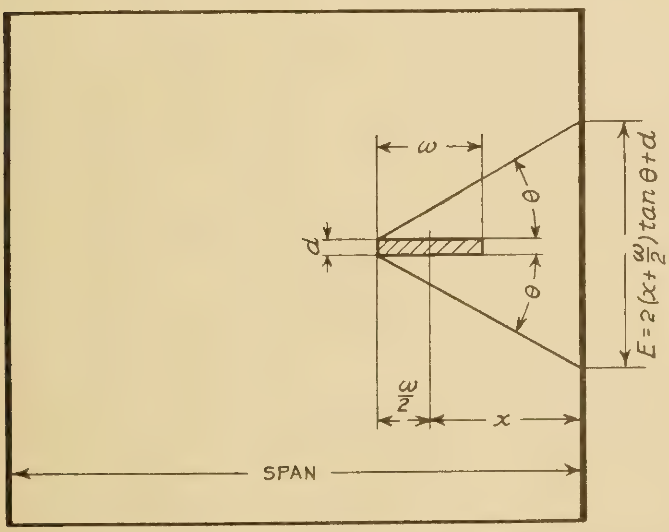


FIG. 12.—Diagram of effective width of slab with main reinforcement perpendicular to direction of traffic and load not at center of span

In Figure 13, assume

$$P = 1 \text{ and}$$

$$S = 24.0 \text{ feet}$$

$$a = 6.0 \text{ feet}$$

$$w = 1.0 \text{ foot}$$

Then

$$b = 7.5 \text{ feet}$$

and

$$c = 10.5 \text{ feet}$$

$$E_1 = (1.4 \times 7.5) + (0.7 \times 1.0) = 11.2 \text{ feet}$$

$$E_2 = (1.4 \times 10.5) + (0.7 \times 1.0) = 15.4 \text{ feet}$$

$$M = \frac{(6.0 + 15.0)10.5}{24} = 9.19$$

$$M_1 = \left[\frac{\frac{7.5}{11.2} + \frac{6.0 + 7.5}{15.4}}{24}\right] 10.5 = .676$$

$$E = \frac{M}{M_1} = \frac{9.19}{.676} = 13.60 \text{ feet}$$

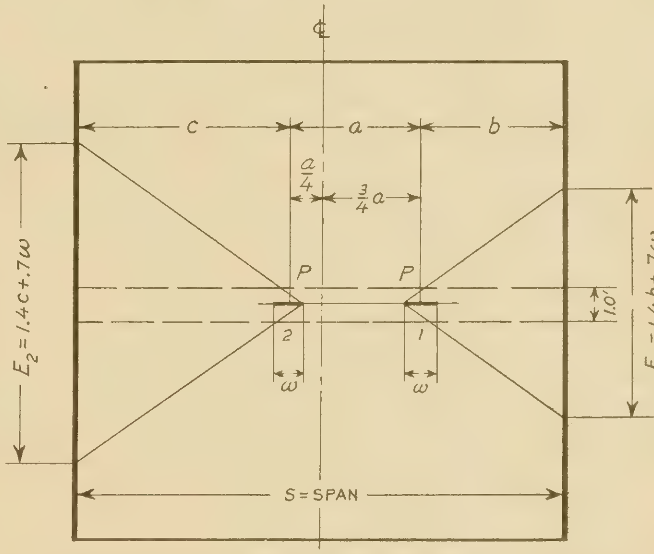


FIG. 13.—Diagram of effective widths for two loads in position to produce maximum bending on slab with main reinforcement perpendicular to direction of traffic

Following the method described above the effective widths have been computed for Cases II, III and V for various span lengths and wheel widths and the results are tabulated in Table 6. These results are also shown graphically in Figures 14 and 15, the full lines indicating calculated values of effective width and the dotted lines indicating approximate values given by straight line equations which are sufficiently accurate for purposes of design.

These approximate equations are as follows, all dimensions being in feet:

Case II, $E = 0.7(S + w) - 1.9$.
Case III, $E = 0.7(S + w) - 3.8$.
Case V, $E = 0.7(S + 1.4w) - 6.2$.

It will be noted that, for Case III, the values given by the equation are not in close agreement with the calculated values for wheels of 1 and 2 feet width on spans of less than 12 or 13 feet. The error is not important, since spans of these lengths will seldom, if ever, be encountered in practice.

SUGGESTED SPECIFICATIONS

In the foregoing discussion there have been developed equations for the determination of the distribution in concrete slabs of the bending moments due to concentrated loads. These equations are intended to provide for the range of conditions which may ordinarily be encountered in the design of highway bridges. The fundamental assumptions have been explained in sufficient detail so that, if desired, other equations to provide for other conditions may be derived.

TABLE 6.—*Effective width of slabs, with main reinforcement perpendicular to the direction of traffic for three conditions of loading and different tire widths*

Span (feet)	Effective width: Case II, $w=0$	Case II, $w=1.0$	Case II, $w=2.0$	Case III, $w=0$	Case III, $w=1.0$	Case III, $w=2.0$	Case V, $w=0$	Case V, $w=1.0$	Case V, $w=2.0$
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
6	2.36	3.21	3.98						
8	3.70	4.45	5.18						
10	5.05	5.78	6.51	3.43	4.61	5.51			
12	6.43	7.15	7.86	4.73	5.59	6.41			
14				6.05	6.84	7.61			
16				7.39	8.15	8.90			
18				8.75	9.49	10.23	6.40	7.72	8.8
20				10.12	10.84	11.57	7.79	8.81	9.74
22				11.48	12.20	12.92	9.16	10.07	10.92
24				12.87	13.60	14.30	10.56	11.39	12.23

w = width of tire in feet.

The following specifications may now be written:

SPECIFICATION No. 1

In calculating bending stresses due to wheel loads on concrete slabs, no distribution in the direction of the span of the slab shall be assumed. In the direction perpendicular to the span of the slab, the wheel load shall be considered as distributed uniformly over a width of slab which is known as the "effective width."

In the following equations let—

S = span of slab.
w = width of wheel or tire.
E_1 = effective width for one wheel of a group on the same transverse element of the slab.
E_2 = total effective width for the wheel or group of wheels determining maximum bending.

All dimensions to be in feet.

Case I.—Main reinforcement parallel to direction of traffic:

(*a*) Slabs designed for one truck.
For spans of 7 feet or less, $E_1 = 0.65S + w$.
For spans of more than 7 feet, $E_1 = 0.12S + w + 3.71$.

(*b*) Slabs designed for two trucks.
For spans of 4 feet or less, $E_1 = 0.65S + w$.
For spans of more than 4 feet, $E_1 = 0.25S + w + 1.6$, with a maximum value of $(4.4 + w)$.

The sum of the effective widths for all the wheels in the group shall not exceed the width of the slab. The entire width of slab, including that portion under the curbs or railings, shall be proportioned for live load stresses as determined by the above equations. In addition to the live load and the weight of the slab itself, the edges of the slab shall be designed to provide for the additional dead load of the curbs or railings.

Case II.—Main reinforcement perpendicular to direction of traffic:

(*a*) Maximum bending moment determined by one wheel load, $E_2 = 0.7(S + w)$.

(*b*) Maximum bending moment determined by two adjacent wheels of passing trucks (wheels 3 feet c. to c.), $E_2 = 0.7(S + w) - 1.9$.

(*c*) Maximum bending moment determined by one axle load (wheels 6 feet c. to c.); $E_2 = 0.7(S + w) - 3.8$.

(*d*) Maximum bending moment determined by two axle loads (wheel spacing 6 feet, 3 feet, and 6 feet c. to c.), $E_2 = 0.7(S + 1.4w) - 6.2$.

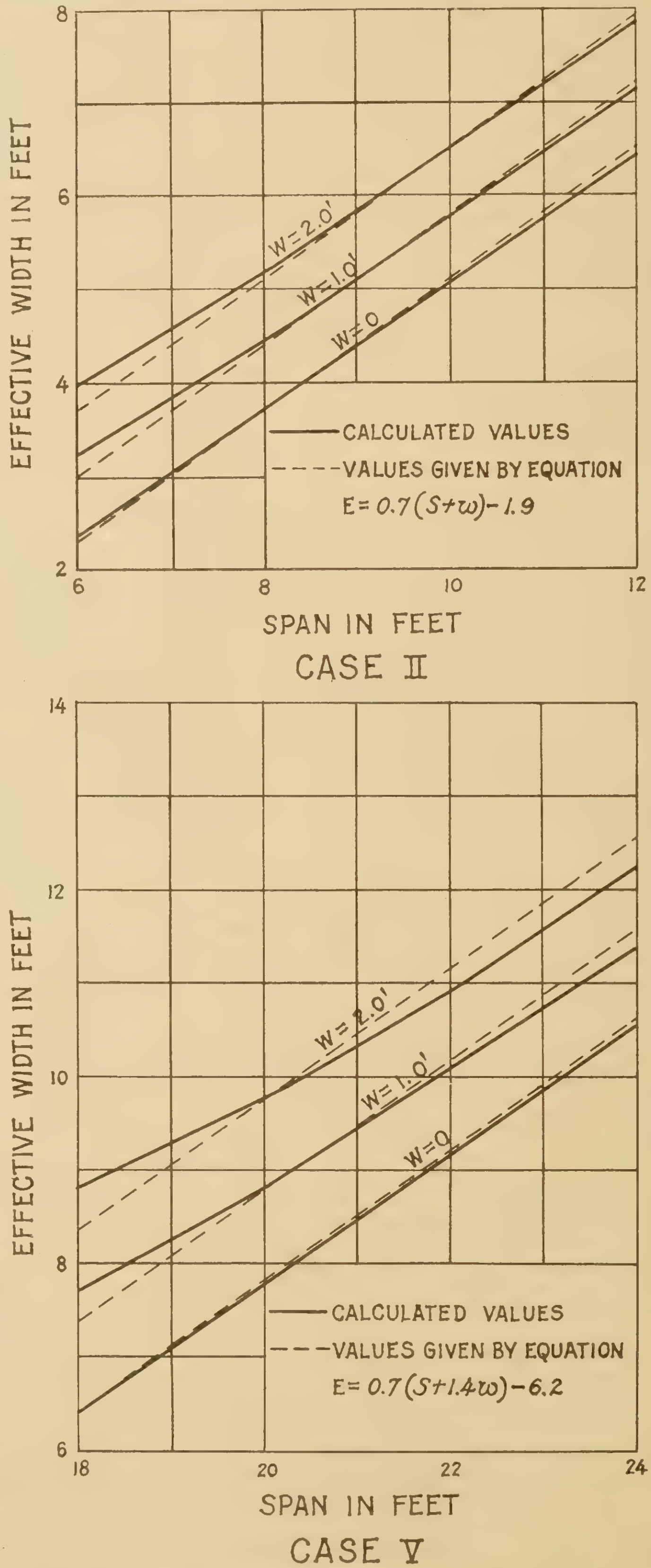


FIG. 14.—Values of effective width for Cases II and V

The equations of Case II apply to slabs supported by longitudinal beams or girders and do not provide for the effect of loads near unsupported edges. Therefore, at the ends of the bridge and at intermediate points where the continuity of the slab is broken, the edges of the slab shall be supported by diaphragms or other suitable means.

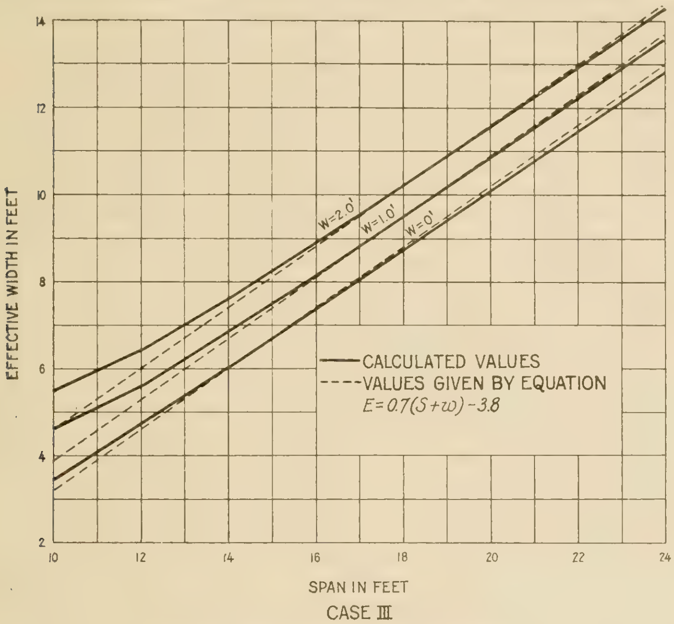


FIG. 15.—Values of effective width for Case III

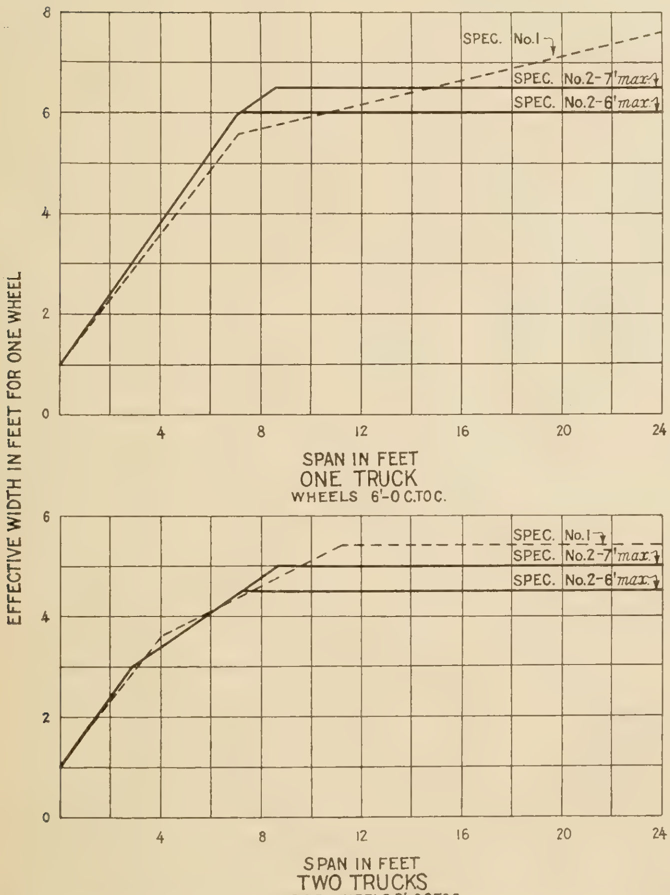


FIG. 16.—Comparison of specifications. Main reinforcement parallel to direction of traffic. Wheel width, 12 inches

The foregoing requirements are somewhat involved and cumbersome for the purpose of a design specification and, furthermore, are restricted in application to the particular conditions of loading which have been considered. The following specification is less cumbersome, more general in application, and gives results which are considered as being in sufficiently close agreement with those of Specification No. 1.

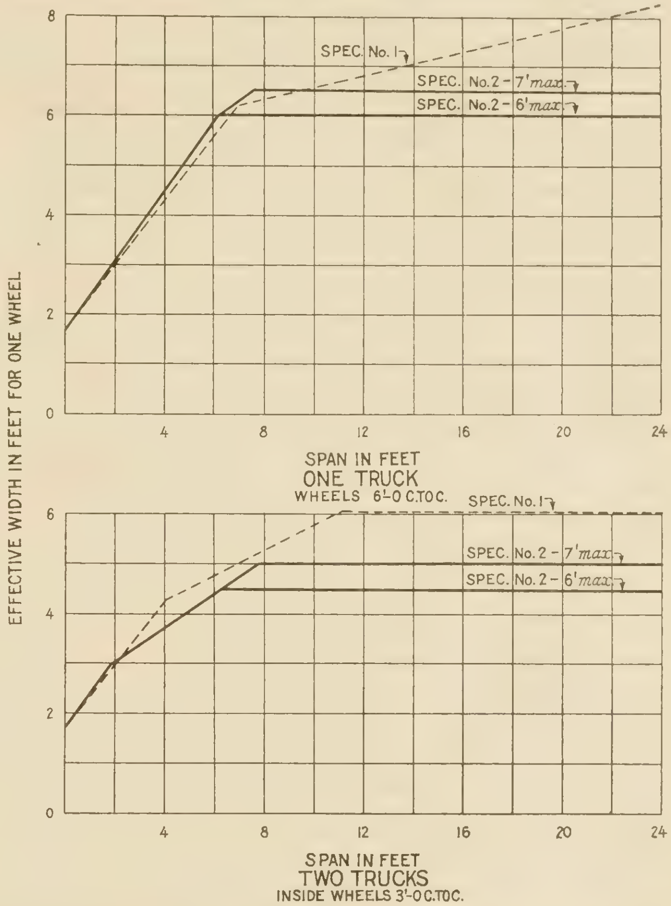


FIG. 17.—Comparison of specifications. Main reinforcement parallel to direction of traffic. Wheel widths, 20 inches

SPECIFICATION No. 2

In calculating bending stresses due to wheel loads on concrete slabs, no distribution in the direction of the span of the slab shall be assumed. In the direction perpendicular to the span of the slab the wheel load shall be considered as distributed uniformly over a width of slab which is known as the "effective width."

In the following equations let—

S = span of slab in feet.
w = width of wheel or tire in feet.
x = distance in feet from the center of the near support to the center of wheel.
E = effective width in feet for one wheel.

Case I.—Main reinforcement parallel to direction of traffic $E = 0.7S + w$.

For this case the value of E shall not exceed 7 feet.

(Continued on page 24)

EFFICIENCY IN CONCRETE ROAD CONSTRUCTION

A Report of Observations Made by the Division of Control, Bureau of Public Roads

Reported by J. L. HARRISON, Highway Engineer

PART V.—SPEEDING UP CONSTRUCTION WORK

The preceding articles in this series have dealt with losses of time while work is in progress. In addition to these losses, it has been found that on most jobs a surprising amount of time is lost through failure to work at all. Work is often begun a little late in the morning. Often it is stopped too early at night. Unpleasant weather is permitted to interrupt. Wet weather unduly delays operations; in many cases because there has been a failure to keep the roads in a condition which minimizes the effect of heavy rainfall. These and the lesser causes which have been found to influence the length of the working-day accumulate a total of time lost which becomes a material factor in determining the amount of work which can be done during a normal season.

The bureau's study of these losses has not been completed; therefore no final conclusions will be drawn. However, as illustrating how important they may be, two cases from the Middle West will be cited. In each case the records given below are for the month of July last; and, as on each job one Sunday was used for work, the maximum working time possible was 27 days.

Job A.—Working-day, 10 hours:

Time worked, hours	225
Time lost because of rain, hours	18
Other time lost, hours	27

Job B.—Working-day, 11 hours:

Time worked, hours	155
Time lost because of rain, hours	22
Other lost time, hours	120

To what extent the "other time losses"—in one case 27 hours and in the other 120 hours—are due to managerial laxity can not be definitely stated at this time but the data already in hand warrant the conclusion that a good deal of it can be properly placed under no other heading. It may, perhaps, be added that the general data bearing on this matter suggest that time lost because of managerial laxity, that is, time allowed to pass without even so much as an effort to produce, appears to amount to approximately two hours a day. Averages of this sort are of little value to the contractor who must, of course, deal with conditions as they are on his particular job rather than as they are found to prevail generally. The general figure is referred to here only because it points to a really serious condition that is affecting the production of paving plants more than most contractors suppose.

The facts given above and in the preceding articles deal with the losses of time which the bureau's studies in this field have developed. But, in the last analysis, it is of little value to know what losses of time are occurring on a construction job, unless this knowledge can be utilized for their elimination and through their elimination for the improvement of production. Moreover, until such use has been made of the data, there is ground for reasonable doubt as to whether an effort to so modify common practices as to eliminate or reduce these time losses will not at once develop new difficulties, as great as or greater than those which it is sought to correct. Thus, the writer has often been cautioned that the mixer time can not be saved by fully overlapping the discharge and the raising of the skip because the power plant is not adequate to start the skip and the discharge mechanism together while driving a full drum. Of course, there is no such inadequacy of power on any good mixer but more than once both the operator and the contractor have shown honest fear as to the safety of the mixer until the demonstration has progressed for some time. On other occasions a fear has been expressed that the puddlers or the finishers or other elements in the organization can not keep up if production is increased.

Such doubts are natural enough, and while the assurance that their lack of validity can be developed when the conclusions based on the time studies are put to a test increasingly dominates the viewpoint of the investigator as the mass of data at his disposal increases, it must nevertheless be true for him as for the contractor that his case is not fully established until the accuracy of his conclusions has been subjected to the test of application under ordinary working conditions. Indeed, it was this view of the matter that brought about the decision to attempt a field application of these studies. The data which had been collected showed a general condition of low efficiency in production. The causes were, in a general way, common to all projects and their rectification had every appearance of being simple enough. But, no matter what appearances may be, a decision that current conditions are properly to be laid to inefficiency can not reasonably be made until it has been shown that the unsatisfactory conditions which have been found to exist can readily be improved, eliminated or changed for the better.

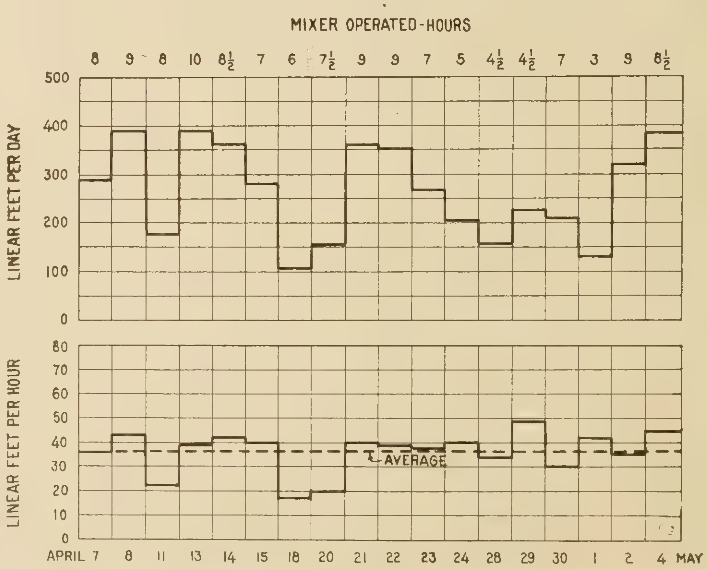


FIG. 1.—Daily and hourly production on project No. 1, under the supervision of the contractor

EFFICIENCY INCREASED ON SEVEN TEST PROJECTS

During the past year, work specifically looking toward improving the production of concrete paving plants has been done on seven projects or sections of projects in three States, under the immediate charge of four different engineers. About two months has been given to each project studied, except No. 7, as listed in the following brief summary of the results obtained:

Project	Engineer	Result
1	A	Output about doubled. Production limited by an inadequate truck supply. For greater detail see Figures 1, 2, 3, and 4, and Tables 1 and 2.
2	B	Output increased materially. Maximum run under contractor's management 683 feet. Maximum run under suggestions based on studies 944 feet. Work on this section was discontinued because truck supply was inadequate to serve both project 2 and project 3 (two sections of the same contract) and it was desired to have an adequate transportation supply on project 3.
3	A	Output about doubled. Maximum production 101 feet per hour for 12½ hours. Average production during last week of study 97 feet per hour for 61 hours. For greater detail see Figures 5, 6, and 7 and Tables 3 and 4.
4	C	Efficiency of truck operation increased from about 73 to about 95 per cent. Production correspondingly increased. Truck supply inadequate during whole of study. For additional data see Figure 8.
5 6	A D	Two sections of the same contract. Production on both sections was consistently increased in spite of inadequate transportation, which the contractor did not see fit to remedy, and exceptionally adverse weather conditions which prevented the development of really first-class working organizations and caused a direct loss of 69½ hours of working time during the month of September. Notwithstanding these difficulties, the output on the first section (5) was increased from 9,269 feet in 170¼ hours of mixer operation during the month of August to 12,796 feet in 160 hours of mixer operation during the month of September, an increase from 57 to 80 feet per hour. On the second section the maximum production was increased from 406 feet in 9 hours of mixer operation to 1,127 feet in 12½ hours of mixer operation.
7	A	Contractor's low production found to be almost entirely due to functional inadequacy of mixer and contractor so informed. No effort was made to speed up this project.

Two plans of operation have been tried on this work: (1) Assistance to the contractor, rendered through suggestions as to appropriate changes in methods and practices; and (2) placing at the contractor's disposal an engineer competent to act as superintendent who thereafter, during the test period, took over a considerable part of the work of the superintendent in directing operations on the project. It is hardly necessary to point out that there are vital differences between these plans. The first depends on the salesmanship of the engineer. His data may be perfectly correct and the conclusions which he draws from the data may be unassailable, but unless he can convince the contractor and his superintendent, little or nothing is done.

It has been the uniform experience of the bureau's representatives that contractors assume that the results which they are securing are the best that anyone can secure under existing conditions, and that uncontrollable adverse physical conditions or others differing from the conditions prevailing on some other job are responsible for the low production record. It may be admitted that in occasional

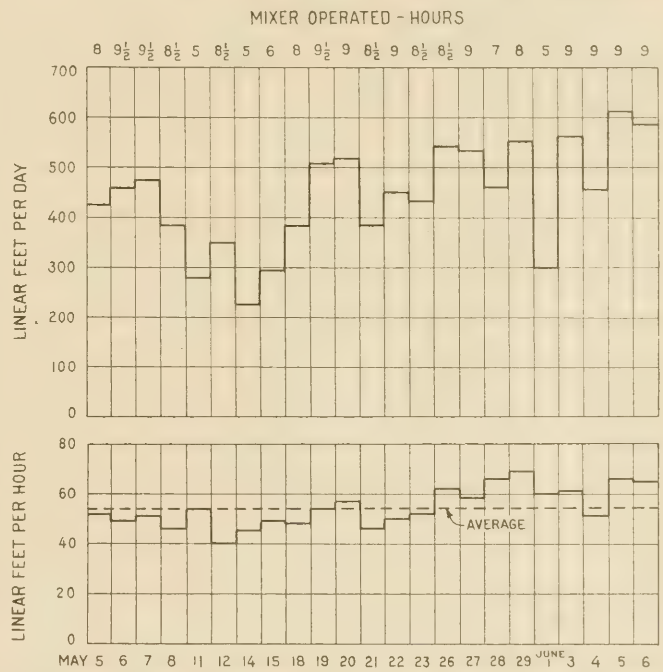


FIG. 2.—Daily and hourly production on project No. 1 under suggestions made by the bureau engineer

instances this is correct. Jobs 5 and 6 offer an illustration somewhat in point. These jobs were undertaken toward the end of the construction season and weather conditions became so adverse that, though improvement in output resulted, it was impossible to maintain a smooth-running organization, and so fully to develop this improvement. But even in this case, it would be improper to assume that the problem did not permit of solution by older or more experienced men. On the other hand, in the great majority of cases, it is apparent to the impartial and disinterested observer, that physical conditions are a small factor in determining the relative efficiency of production on different projects. Commonly the quality of the superintendence is the factor of first importance. The adequacy of the plant also is a factor but it would appear to be a fair presumption that if the superintendence is really first-class, inadequacies in plant and equipment will be corrected within a reasonable period.

But as the engineer, endeavoring to improve production by offering suggestions, must convince a man who is disposed to lay his troubles to almost anything other than their real cause, the problem of initiating improved methods on the basis of pure salesmanship will be understood to be a difficult one. Results have been secured on this basis but it is by no means as uniformly effective as placing on the job a man who, with the full consent of the contractor, will take over the direction of personnel and equipment so far as this is necessary in order to place the modified practices in operation.

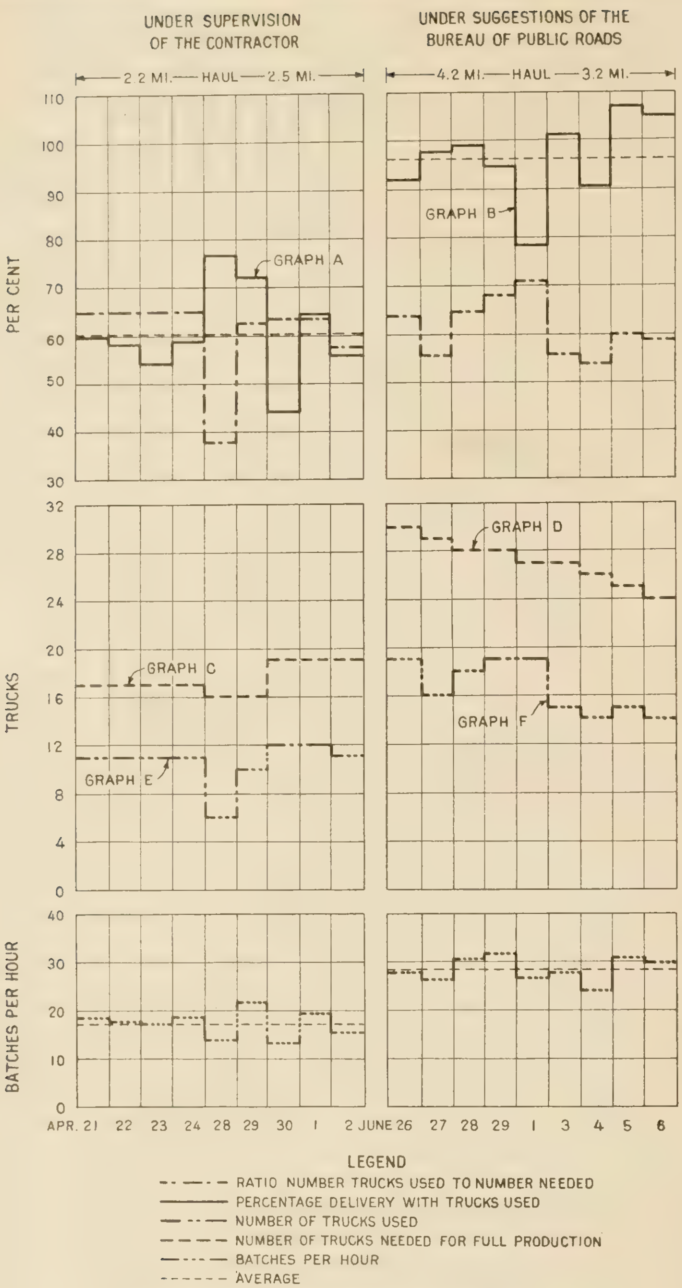


FIG. 3.—Study of truck operation on project No. 1

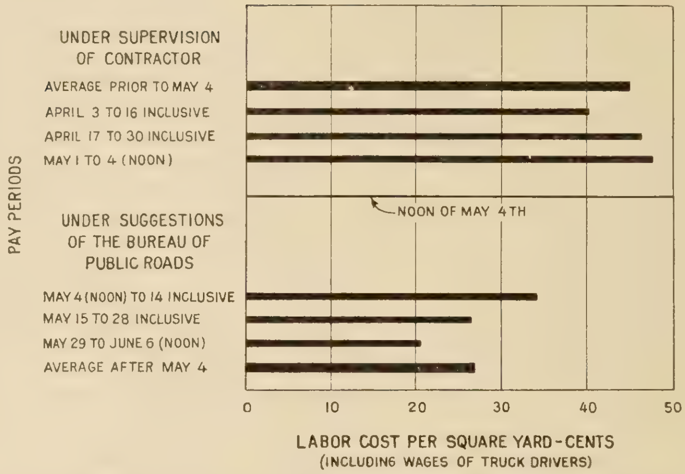


FIG. 4.—Effect of increase in production on labor cost (including wages of truck drivers) on project No. 1. The increase in production resulted from the suggestions of bureau engineer

When the latter method is used the new methods sell themselves as their application increasingly develops production and it has commonly been found that as production has increased, confidence in the merit of the new practices has encouraged the contractor to facilitate their perfection in every possible way.

GRADUAL SIMULTANEOUS IMPROVEMENT OF ALL OPERATIONS THE AIM OF TESTS

In the application of data obtained from time studies, the practice has been to make a gradual correction in operation affecting all related parts of the improvement program simultaneously. This has been found to be desirable, if not necessary. The major difficulties on most concrete jobs are at the mixer and in the material supply. To correct mixer operation without modifying the material supply ordinarily will have no effect on production. On the other hand, unless there is a shortage in the material supply, to improve practices in handling the trucks without improving the operation of the mixer will not improve production. But the objective is improved production—not a theoretical perfection in operating practices—so both operations must be improved together or the program tends to discredit itself for the simple reason that it becomes obvious to all that the objective is not being reached.

One other comment in regard to this work may be appropriate, namely, that when an effort is made to improve production the extent to which this can be accomplished will depend on the equipment at hand. There is a difference here between the work of the engineer whose problem it is to demonstrate efficient methods with the equipment available and that of the superintendent, one of whose normal functions it is to determine what equipment is required and to procure and maintain a full supply of such equipment.

The engineer who is endeavoring to increase production may, of course, make every effort to induce the contractor to obtain such equipment as may be needed in order to obtain full production. But often conditions are such that this equipment can not be obtained at once. The criterion of his success must, therefore, be the amount of correction that can be obtained in operating efficiency using the equipment with which prevailing conditions force him to work. As a result, it is not always possible to secure a full correction of the mixer output even though improvement in the operating efficiency of the available truck supply is quite satisfactory. The graphs in Figure 8, which are for project No. 4, bring out this point. Graph A shows the efficiency of truck operation under the contractor's management, which had been at least as good as the average. Graph B shows the efficiency of truck operation as effected by suggestions made by the bureau's representative. In this case, the truck supply was inadequate for the whole period during which suggestions were being made; but the production per hour of work increased, partly because of the shortening haul which naturally brought mixer output capacity and truck delivery capacity closer together and partly because of the greater efficiency of truck operation. Toward the end of the period production per hour rose high enough to force the mixer, and the improvement is clearly apparent from a study of graphs C and D of Figure 8, which show the number of batches placed per hour before the suggestions were made and toward the end of the bureau's connection with the job.

Another job, project No. 1, of similar characteristics as to truck supply but with a lower original efficiency in operation, is represented by the graphs of Figure 3. Initially the haul was about 1.5 miles. This increased during the next few days to a maximum of about 3.2 miles which completed that section. The mixer was then moved to a point to which the haul was 4.9 miles, from which it was reduced as the work progressed to 3.2 miles at the completion of paving. This job differed from project No. 4, referred to above, in that the bureau's engineer was able to persuade the contractor to rent a few extra trucks though not enough to enable him to make a delivery equal to the mixer's output capacity. However, the contractor let these trucks go too soon. Under the contractor's management operating efficiency at the mixer was low. This was complicated by an unfair setting of the mixing time as evidenced by the high mixing time shown in Table 1. In addition, however, the general efficiency prevailing on all parts of the job was considerably below normal. Increasing the efficiency with which the trucks operate (compare graphs A and B, fig. 3) improved the supply of material at the mixer, and cutting out the time losses at the mixer increased the mixer's capacity to handle the material delivered to it. As a result production rose steadily (time losses due primarily to weather conditions being allowed for). As in the first case cited, the material supply during the latter part of the work was also influenced by the decreasing haul, but as truck supply was never sufficient (compare graphs C and D with E and F in fig 3) the output of the mixer never reached its full capacity. The increased output was secured without material change in personnel employed. Figure 4 shows the effect of this increased production on the unit labor cost (including truck drivers) of this work

RECOMMENDATIONS OF THE BUREAU CONVINCINGLY DEMONSTRATED

On project No. 3, as listed above, transportation facilities were adequate and working conditions, weather, etc., normal. The contractor had maintained a rate of production which would be considered in most places, at least, as quite satisfactory. (See fig. 5.) In this respect this job differed widely from project No. 1, just noted. On that job it has been possible to raise production from subnormal to about normal, but because of the limited truck supply available it was impossible to get really first-class production from the mixer, though this job, as well as project No. 4, showed that the efficiency with which the transportation was operated could be maintained at an

TABLE 1.—*Results of stop-watch studies on job No. 1 under the contractor's management before suggestions were made by the bureau*

Study No.	Number of batches per hour	Mixer time				Lost time								
		Charge	Mix	Discharge	Percentage of total working time	Truck shortage	Slow truck operation	Mixer trouble	Slow mixer operation	Water supply	Setting dowel rods	Preparing subgrade	Lack of cement at mixer	Dumping cement into skip
		Seconds	*Seconds*	*Seconds*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
49	22	11	78	23	68		3		27					2
50	22	11	78	21	68			3	22				5	2
51	13	10½	79	21½	41		46		9					4
52	12	10½	76½	21	36		39	9	10	2				4
53	9	11	76½	21	27	15	44		8					6
54	20	11	76	21	60	13	10		14					3
55	16	10½	76	22	49				23		6	21		1
56	17	10½	71½	20	48				21			31		
57	14	10½	79½	21	43		41		10					6
58	15	10	78	20	45		45		2					8
59	20	10½	80½	20	62		19		14					5
60	20	10½	79½	20½	61				23	7			5	4
61	19	11	77	20	58		2	15	7		5	7	6	
Average	16.9	10.7	77.4	20.9										
Percentage					51.2	2.2	19.2	2.1	14.6	0.7	0.8	4.5	1.2	3.5

Total time per batch $=\frac{3,600}{16.9}=213$ seconds. Time per batch for maximum efficiency (48 batches per hour) $=75$ seconds. Actual operating efficiency $=\frac{75}{213}=35.2$ per cent.

TABLE 2.—*Results of stop-watch studies on job No. 1 operated in accordance with suggestions made by the bureau*

Study No.	Number of batches per hour	Mixer time				Lost time			
		Charge	Mix	Discharge	Percentage of total working time	Truck Shortage	Mechanical truck trouble	Slow mixer operation	Water supply
		Seconds	*Seconds*	*Seconds*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
60	28	10	72	8	70		17	3	10
61	26	10	71	8	64	11	16	3	6
62	25	10	68½	8	60	37	3		
63	31	10	68	8	75	23	1	1	
64	23	10	71	8	57	20	20	3	
65	31	10	51	8	60	37	1	2	
66	30	10	51	8	57	34	7	2	
67	28	10	59	8	60	35	4	1	
68	30	10	64	8	68	25	1		6
Average	28	10	63.9	8					
Percentage					63.3	24.7	7.8	1.8	2.4

Total time per batch $=\frac{3,600}{28}=129$ seconds. Time per batch for maximum efficiency (48 batches per hour) $=75$ seconds. Actual operating efficiency $=\frac{75}{129}=58.2$ per cent

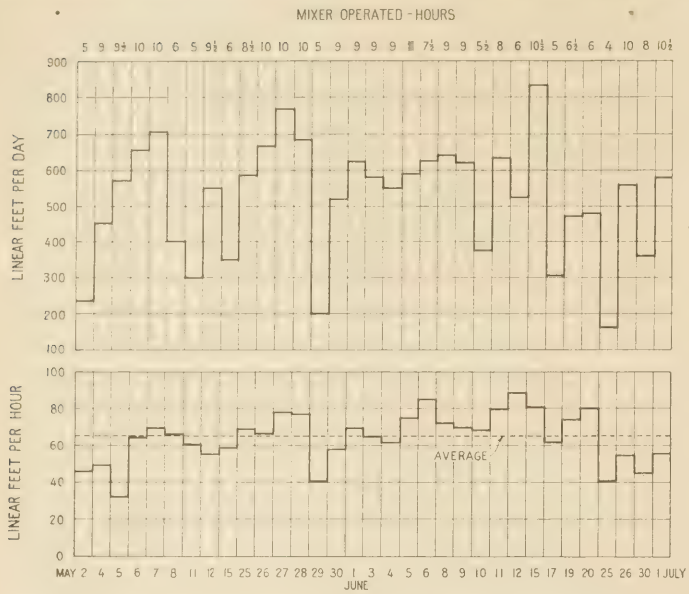


FIG. 5.—Daily and hourly production on project No. 3, under the supervision of the contractor

FIG. 6.—Daily and hourly production on project No. 3 under suggestions made by the bureau engineer

average above 90 per cent of theoretically perfect performance. As it was evident that project No. 3 could provide an adequate transportation supply it was apparent that it would be possible to use it to ascertain: (1) Whether efficiency at the mixer could be developed to, and consistently maintained at, over 90 per cent of theoretical efficiency; (2) whether the efficiency of material delivery could be maintained at a correspondingly high level while such a high rate of demand was being made on it; (3) whether in the face of such a rate of output any other unit of the equip-

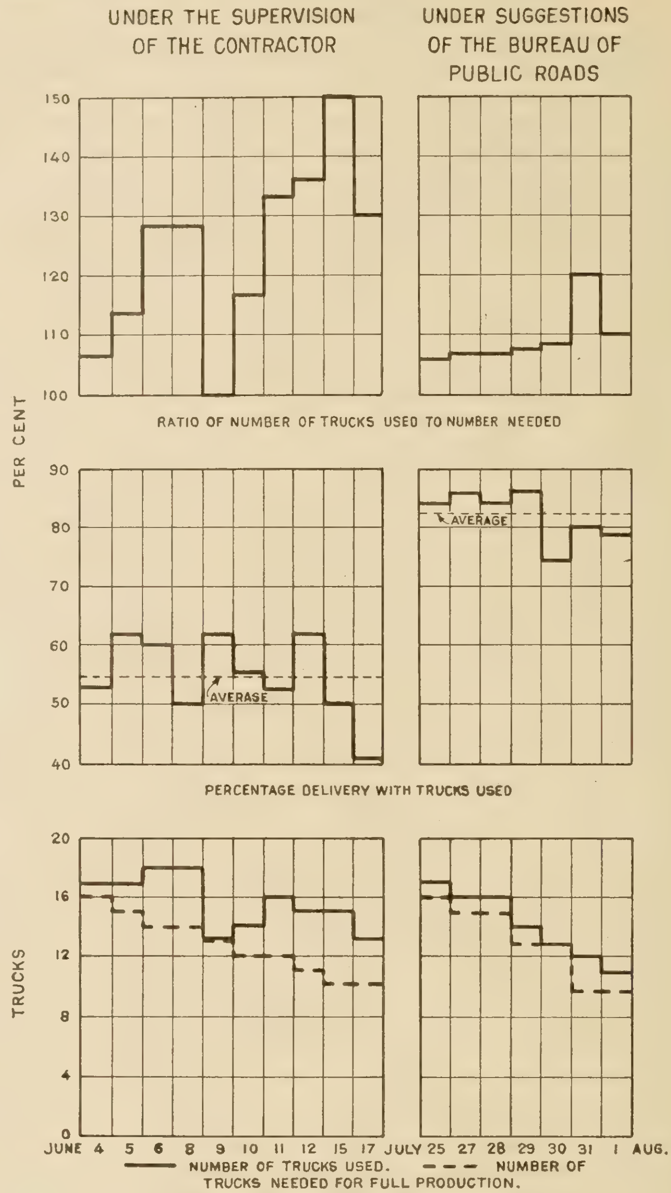


FIG. 7.—Study of truck operation on project No. 3

ment would prove inadequate; or (4) whether any part of the labor organization would have to be enlarged.

Operations were begun simultaneously at the mixer where the operator was carefully trained to avoid time losses, at the material yards where cement handling had been causing some delay in operating the trucks, and on the truck supply where miscellaneous losses had amounted to about six minutes per trip. On this particular job production developed rather slowly (fig. 6), the reason being that it took a good deal of time to train the truck drivers to operate on a schedule which would deliver enough material to force the mixer. At first there was some actual truck shortage, but this was soon corrected, and as the delivery increased the mixer operator made increasing efforts to master the problem of handling it.

The demonstration was a complete success. Figure 6 shows the increase in production; and Figure 7 shows the characteristic differences between the contractor's operation of trucks and the operation developed by the bureau's representative for the same length of haul. Tables 3 and 4 show the characteristics of operation under the contractor's management, and, during the last week of the test period, under the suggestions of the bureau. The maximum rate of production was attained on the last full day's operation when 101 feet per hour were laid for 12½ hours. During this period, which was long enough to test the effectiveness of operating practices, no time was lost on account of functional inadequacy in any unit of the mechanical equipment, thus demonstrating conclusively that the equipment correlated with the mixer had ample capacity. The truck supply was adequate and its performance demonstrated that trucks are capable of showing and of maintaining a high rate of efficiency if their operation is properly supervised.

ADVANTAGE OF HIGH-CLASS SUPERINTENDENCE EMPHASIZED

Possibly an even better demonstration of the real capacity of a paving outfit is offered by the performance during the last week (61 working hours) of the bureau's contact with this project. During this period production amounted to 5,925 feet, which is an average of 97.1 feet per hour worked. The lowest rate of production during this period was 92.4 feet per hour and the highest 101 feet per hour, an operation of notable uniformity at a high rate of efficiency which fully demonstrates that the well balanced paving outfit is capable of sustained high production if the various elements in the construction organization are correlated and synchronized to eliminate time losses.

The experience on this job points directly to the last conclusion it is desired to draw at this time, namely, that job management, or superintendence, is commonly the weakest point in the construction organization. Contractors are losing thousands of dollars every year because they employ as superintendents men who have proved to be good foremen or who have been found to be bright inspectors on their jobs. The point that is commonly overlooked is that the efficient field supervision of a large construction job requires a breadth of knowledge and an ability to analyze, arrange, and synchronize the elements of a construction opera-

TABLE 3.—*Results of stop-watch studies on job No. 3 under the contractor's management before suggestions were made by the bureau*

Date	Number of batches per hour	Mixer time				Lost time							
		Charge	Mix	Discharge	Percentage of total working time	Truck shortage	Mechanical truck trouble	Mixer trouble	Slow mixer operation	Water supply	Preparing subgrade	Delay due to concrete finishers	Miscelleanous delays
1925		*Seconds*	*Seconds*	*Seconds*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cen*
June 11	16	9½	59½	10	35				15			50	
12	36	9½	61	10	80½				10½		9		
12	31	9	60	12	69½		9		16½		5		
15	36	9½	61	10	81		9½		6	2	1½		
15	34	9½	61½	10	76		5		13	6			
19	31	9	58	12	67		3		17½		5½	7	
20	38	10	59	10	82	10	1		6	1			
20	38	10	59	10	82½	6			8	2	1½		
20	31	9½	59	10	67	14	1		9				9
25	10	10	61	10	23	13	21½	41½	1				
26	17	9½	61	10	38	28	1	27½	1½	4			
26	24	9	60	12	54	39½			4½	2			
30	20	9½	61	10	44	49	3		3	1			
30	23	9	61	12	51½	30½	2		6	10			
Average	27.4	9.5	60.1	10.6									
Percentage					60.9	13.6	4.0	4.9	8.4	2.0	1.6	4.0	0.6

Total time per batch$=\frac{3,600}{27.4}=131$ seconds. Time per batch for maximum efficiency (48 batches per hour)=75 seconds. Actual operating efficiency$=\frac{75}{131}=57.1$ per cent.

TABLE 4.—*Results of stop-watch studies on job No. 3 during the last week of the bureau's assistance to the contractor*

Date	Number of batches per hour	Mixer time				Lost time					
		Charge	Mix	Discharge	Percentage of total working time	Mechanical truck trouble	Mixer trouble	Water supply	Preparing subgrade	Lack of materials due to poor supervision	Miscellaneous delays
1925		*Seconds*	*Seconds*	*Seconds*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
July 27	45	10	64	3	95½	2½	1	1			
28	44	10	64	2½	94½	5		½			
28	43	10	63½	2½	91	8½					½
28	44	10	64	2½	93	½				6½	
29	45	10	63½	3	95½			4½			
29	46	10	64	2½	99½	½					
30	38	10	64	3	81			2	4	13	
30	38	10	64	3	81	3		[1] 16			
31	47	10	64	2½	100						
31	43	10	63½	3	91½	2		1	5½		
31	46	10	63½	2½	98			2			
Aug. 1	45	10	64	2½	95½			4½			
Average	43.7	10	64	2.7							
Percentage					97.0	2.0		2.6	0.8	1.6	

[1] Because of this time loss due to high pressure in the line, the water losses do not show the improvement that was actually made.

Total time per batch$=\frac{3,600}{43.7}=82.4$ seconds. Time per batch for maximum efficiency (48 batches per hour)$=75$ seconds. Actual operating efficiency$=\frac{75}{82.4}=91.0$ per cent.

tion which few men possess. So much is at stake in a large construction operation, and the difference between ordinary operation and really efficient operation is so great, that really first-class superintendents, i. e., men who can obtain a general efficiency of operation exceeding 90 per cent of theoretical perfection, are

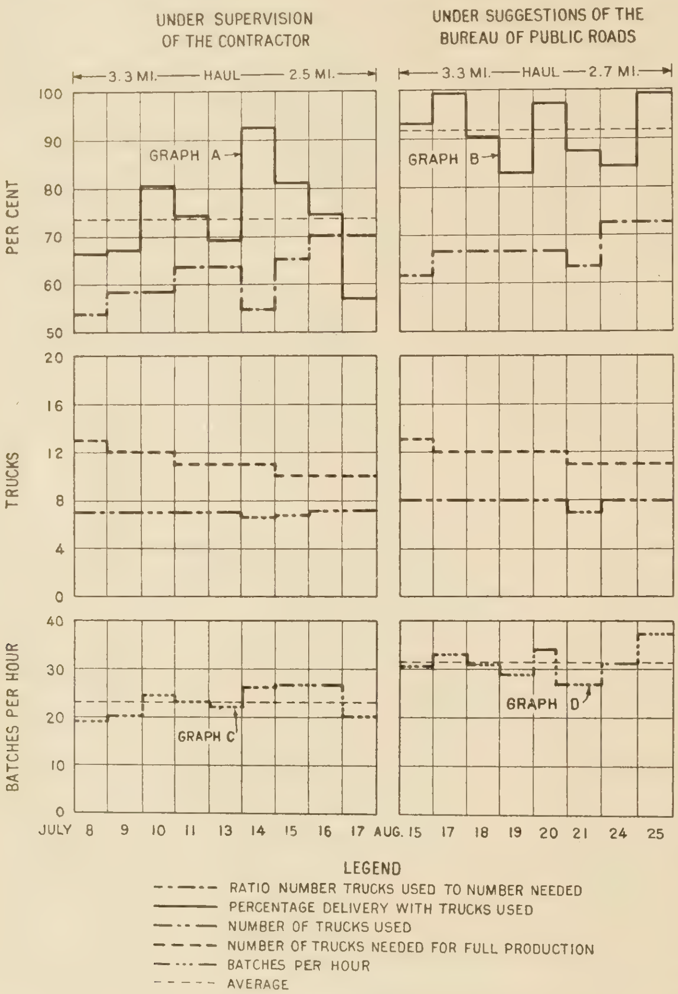


FIG. 8.—Study of truck operation on project No. 4

worth, to a large contractor, almost anything they care to ask, while men of ordinary ability are expensive at any price. Indeed it is no exaggeration to say that the first-class superintendent can secure at least twice the production which is now commonly obtained with little or no increase in labor or in equipment charges, which is equivalent to saying that he can reduce by half the ordinary unit labor and equipment charges that enter into the cost of a concrete pavement. Contractors would be well advised to give more thought to this phase of their work for, under conditions generating keen competition, weakness at this point in the construction organization is an invitation to financial ruin.

(Continued from page 17)

When two wheels are so located on a transverse element of the slab that their effective widths overlap, the effective width for each wheel shall be $\frac{1}{2}(E+a)$, where a is the distance between centers of wheels.

Case II.—Main reinforcement perpendicular to direction of traffic, $E=0.7(2x+w)$.

For this case the bending moment on a strip of slab 1 foot in width shall be determined by placing the wheel loads in the position to produce maximum bending; determining the effective width for each wheel; and assuming the load delivered by each wheel to the 1-foot strip to be the wheel load divided by its respective effective width.

This design assumption does not provide for the effect of loads near unsupported edges. Therefore, at the ends of the bridge and at intermediate points where the continuity of the slab is broken, the edges of the slab shall be supported by diaphragms or other suitable means.

It will be noted that specification No. 2 is somewhat similar to certain specifications now in general use, particularly as regards the requirements for Case I. However, the usual specification of this type limits the effective width to a maximum of 6 feet and it is felt that this requirement is more severe than is necessary. A maximum of 7 feet gives results which, for ordinary widths of wheel, are in closer agreement with those given by specification No. 1. Wheel widths of from 12 to 20 inches practically cover the range of widths which are usually assumed for design purposes. In Figures 16 and 17 comparisons are shown for Case I, between specification No. 1 and specification No. 2 for wheel widths of 12 and 20 inches and, in the case of specification No. 2, for both a 6-foot and a 7-foot maximum. For Case II the comparison of the two specifications is shown in Figures 14 and 15, the dotted lines representing specification No. 1 and the full lines specification No. 2.

It is realized that certain of the basic assumptions which have been made for the derivation of these specification requirements are open to serious criticism and that future research may discredit the conclusions which have been reached. One of the assumptions which might be questioned is Professor Young's basic equation which has been reduced to the form, $E=0.7(2x+w)$. The use of this equation results in a seeming discrepancy in that the live load bending moment on a 1-foot strip of slab loaded at the center is less than that due to the same load placed at the quarter point. In spite of this discrepancy the equation has been accepted for lack of data upon which to base one which might, perhaps, lead to more logical results.

The foregoing study is an attempt to apply the available test data in as logical a manner as possible to the variety of conditions encountered in the design of the floor slabs of highway bridges and the specifications are suggested for use only until such time as further research may increase our knowledge of the subject

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Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

ANNUAL REPORT

Report of the Chief of the Bureau of Public Roads, 1924.
Report of the Chief of the Bureau of Public Roads, 1925.

DEPARTMENT BULLETINS

No. 105. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.
*136. Highway Bonds. 20c.
220. Road Models.
257. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*314. Methods for the Examination of Bituminous Road Materials. 10c.
*347. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*370. The results of Physical Tests of Road-Building Rock. 15c.
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387. Public Road Mileage and Revenues in the Southern States, 1914.
388. Public Road Mileage and Revenues in the New England States, 1914.
390. Public Road Mileage and Revenues in the United States, 1914. A Summary.
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*1132. The results of Physical Tests of Road-Building Rock from 1916 to 1921, Inclusive. 10c.
1216. Tentative Standard Methods of Sampling and Testing Highway Materials, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.
No. 1259. Standard Specifications for Steel Highway Bridges; adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road work.
1279. Rural Highway Mileage, Income and Expenditures, 1921 and 1922.

DEPARTMENT CIRCULAR

No. 94. TNT as a Blasting Explosive.
331. Standard Specifications for Corrugated Metal Pipe Culverts.

MISCELLANEOUS CIRCULAR

No. 60. Federal Legislation Providing for Federal Aid in Highway Construction, the Construction of National Forest Roads and Trails, and the Distribution of Surplus War Materials.

FARMERS' BULLETINS

No. *338. Macadam Roads. 5c.
*505. Benefits of Improved Roads. 5c.

SEPARATE REPRINTS FROM THE YEARBOOK

No. *727. Design of Public Roads. 5c.
*739. Federal Aid to Highways, 1917. 5c.
*849. Roads. 5c.
914. Highways and Highway Transportation.

OFFICE OF PUBLIC ROADS BULLETIN

No. *45. Data for Use in Designing Culverts and Short-span Bridges. (1913.) 15c.

OFFICE OF THE SECRETARY CIRCULARS

No. 49. Motor Vehicle Registrations and Revenues, 1914.
59. Automobile Registrations, Licenses, and Revenues in the United States, 1915.
63. State Highway Mileage and Expenditures to January 1, 1916.
*72. Width of Wagon Tires Recommended for Loads of Varying Magnitude on Earth and Gravel Roads. 5c.
73. Automobile Registrations, Licenses, and Revenues in the United States, 1916.
161. Rules and Regulations of the Secretary of Agriculture for Carrying Out the Federal Highway Act and Amendments Thereto.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D- 2. Effect of Controllable Variables Upon the Penetration Test for Asphalts and Asphalt Cements.
Vol. 5, No. 20, D- 4. Apparatus for Measuring the Wear of Concrete Roads.
Vol. 5, No. 24, D- 6. A New Penetration Needle for Use in Testing Bituminous Materials.
Vol. 10, No. 5, D-12. Influence of Grading on the Value of Fine Aggregate Used in Portland Cement Concrete Road Construction.
Vol. 10, No. 7, D-13. Toughness of Bituminous Aggregates.
Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

* Department supply exhausted.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

STATUS OF FEDERAL AID HIGHWAY CONSTRUCTION

AS OF

FEBRUARY 28, 1926

STATES	FISCAL YEARS 1917-1925			FISCAL YEAR 1926									BALANCE OF FEDERAL AID FUND AVAILABLE FOR NEW PROJECTS	STATES
	PROJECTS COMPLETED PRIOR TO JULY 1, 1925			PROJECTS COMPLETED SINCE JUNE 30, 1925			*PROJECTS UNDER CONSTRUCTION			PROJECTS APPROVED FOR CONSTRUCTION				
	TOTAL COST	FEDERAL AID	MILES	TOTAL COST	FEDERAL AID	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES		
Alabama	$ 5,970,097.71	$ 2,863,197.86	611.8	$ 9,448,345.53	$ 4,513,891.57	522.6	$ 6,538,152.30	$ 3,164,382.03	318.3	$ 760,674.71	$ 335,512.73	16.6	$ 3,472,470.81	Alabama
Arizona	9,580,133.43	5,016,119.94	613.8	1,041,126.35	636,703.27	92.2	1,248,182.17	827,613.98	89.0	176,977.10	108,150.70	26.7	3,028,661.11	Arizona
Arkansas	13,310,190.08	5,380,181.73	1,048.9	3,827,872.61	1,684,144.69	200.9	5,760,682.93	2,766,042.82	367.7	545,641.81	240,645.74	37.4	1,534,789.02	Arkansas
California	22,346,175.99	10,719,249.61	894.8	2,893,278.94	1,327,019.89	83.8	11,688,518.61	5,777,134.17	345.9	298,080.20	107,351.38	6.0	4,149,059.95	California
Colorado	11,876,703.94	6,067,814.34	651.2	1,029,861.87	530,202.26	41.7	4,588,109.90	2,317,820.29	240.8	246,862.45	138,452.34	19.5	3,271,522.77	Colorado
Connecticut	4,558,639.29	1,819,368.66	101.6	750,965.91	250,212.14	13.4	1,901,818.16	590,259.68	29.1	238,929.61	62,777.95	3.8	1,611,062.57	Connecticut
Delaware	4,281,559.81	1,496,190.65	107.1	455,744.13	212,544.95	12.3	980,042.66	388,784.75	22.7	445,559.65	9,000.00	10.5	367,537.65	Delaware
Florida	2,959,273.72	1,405,487.97	96.3				10,346,486.92	4,918,554.60	295.5	130,171.16	65,085.58	13.7	1,695,825.85	Florida
Georgia	20,156,002.37	9,406,366.46	1,478.3	3,423,882.39	1,664,584.99	217.6	11,417,017.80	5,396,853.76	699.4	314,279.02	157,139.48	33.1	1,807,008.31	Georgia
Idaho	9,394,676.80	4,815,332.26	600.1	1,013,545.40	645,811.83	73.2	2,442,858.61	1,491,685.71	157.3	461,293.42	249,557.36	17.0	1,357,239.84	Idaho
Illinois	40,010,481.10	18,640,076.28	1,236.2	1,939,886.69	932,621.30	64.0	7,398,089.70	3,590,111.46	253.4				6,669,388.96	Illinois
Indiana	13,639,172.65	6,562,455.68	422.1	1,195,563.59	573,819.54	47.1	18,057,715.07	8,476,579.76	490.9	421,901.51	208,509.47	12.7	2,382,990.55	Indiana
Iowa	27,272,285.21	11,107,492.99	1,996.9	722,462.52	320,365.06	36.5	8,002,159.55	3,608,569.59	491.1	1,516,282.01	738,026.75	164.3	3,711,108.61	Iowa
Kansas	26,399,695.77	9,755,273.32	831.4	4,634,468.65	2,066,681.33	264.9	10,122,229.25	4,058,981.07	507.1	3,083,682.14	839,663.69	182.9	2,743,811.59	Kansas
Kentucky	14,832,324.28	6,205,994.59	584.9	3,359,707.53	1,300,700.93	92.3	7,350,016.07	3,357,893.11	312.9	193,076.46	79,641.23	2.0	2,268,579.14	Kentucky
Louisiana	11,939,424.97	5,279,870.86	927.6	1,079,810.60	503,534.86	68.9	3,901,298.42	1,900,233.11	186.0				1,588,769.17	Louisiana
Maine	8,174,281.31	3,907,870.33	281.4	516,374.59	257,101.90	19.3	1,864,565.87	734,349.40	60.4	92,205.65	46,102.82	4.7	1,519,403.55	Maine
Maryland	8,132,506.90	3,849,383.15	294.4	2,174,198.13	980,502.05	104.6	854,165.63	389,675.27	35.1				705,496.53	Maryland
Massachusetts	14,047,656.22	5,467,661.28	300.6	792,371.07	275,356.11	20.7	6,030,673.96	1,587,507.67	80.1	1,161,802.28	285,284.20	16.9	2,492,916.74	Massachusetts
Michigan	16,234,000.80	7,328,316.91	612.6	8,225,220.35	3,783,576.07	301.6	10,230,087.14	4,641,089.56	252.1	382,294.00	178,607.13	17.2	4,410,775.33	Michigan
Minnesota	30,415,685.89	12,738,642.04	2,721.2	5,271,152.99	2,284,974.52	397.0	7,612,864.46	2,445,300.00	522.3	644,913.81	111,000.00	37.9	2,011,863.44	Minnesota
Mississippi	10,292,285.79	4,988,702.73	803.4	2,299,446.54	1,148,761.55	188.6	8,338,802.44	4,163,145.56	402.2	868,082.97	425,577.19	79.6	1,401,830.97	Mississippi
Missouri	17,368,156.57	8,219,411.43	1,118.9	5,738,800.74	2,782,790.60	228.2	23,931,410.82	9,467,301.10	669.7	1,532,876.60	666,571.48	47.6	1,650,361.39	Missouri
Montana	10,156,600.41	5,317,523.15	921.6	1,137,349.69	918,104.73	116.0	1,466,040.38	1,016,032.35	124.6	967,051.02	525,862.82	110.3	5,647,361.95	Montana
Nebraska	9,306,374.36	4,389,523.50	1,570.6	1,521,442.87	736,793.25	120.3	11,056,199.98	5,476,968.51	1,079.6	974,531.55	485,668.58	94.2	3,546,281.16	Nebraska
Nevada	4,917,465.69	3,088,299.78	357.3	1,987,708.50	1,550,845.26	155.1	3,723,079.29	3,135,983.82	341.0				1,020,086.14	Nevada
New Hampshire	4,165,687.86	1,986,226.87	208.1	765,008.74	361,274.93	27.6	648,566.19	304,202.46	19.5	9,979.13	4,989.56	0.5	512,798.18	New Hampshire
New Jersey	11,961,357.45	3,820,679.99	219.1	2,112,044.24	581,403.46	35.1	8,463,105.76	3,104,060.72	56.4				961,275.83	New Jersey
New Mexico	8,717,999.18	4,914,070.61	1,081.3	3,545,064.81	2,313,941.49	329.6	1,476,466.48	972,341.77	116.3	74,555.37	46,757.90	5.4	2,725,274.23	New Mexico
New York	28,597,769.67	12,229,076.53	831.5	8,334,912.28	3,326,763.27	210.2	31,965,395.58	9,564,379.74	604.0	8,552,570.00	2,045,840.00	136.8	6,879,135.46	New York
North Carolina	21,014,450.41	8,746,454.59	1,119.8	3,279,250.74	1,394,509.94	89.7	8,435,413.26	3,535,746.63	192.1	1,367,383.75	429,981.85	31.5	1,610,512.99	North Carolina
North Dakota	10,829,263.82	5,268,930.47	1,917.5	1,250,083.84	645,843.12	248.8	3,676,089.74	1,817,763.04	452.2	956,712.98	478,356.38	131.0	2,537,765.99	North Dakota
Ohio	41,572,252.81	15,244,993.93	1,191.1	5,893,936.99	2,030,223.35	167.4	8,526,465.69	3,384,252.39	268.6	2,066,699.69	669,907.97	57.5	4,402,418.36	Ohio
Oklahoma	20,787,024.94	9,672,890.34	852.2	3,088,439.52	1,427,381.27	131.0	6,445,480.58	3,078,587.94	285.3	234,268.05	110,765.51	7.3	1,770,161.94	Oklahoma
Oregon	14,388,188.70	7,142,364.63	794.6	1,771,199.12	928,700.65	84.1	2,633,017.61	1,583,056.23	135.4	1,567,212.09	296,739.58	46.9	928,485.91	Oregon
Pennsylvania	43,054,835.19	16,222,023.97	850.3	5,458,460.58	1,569,298.46	97.1	34,841,333.23	9,494,460.47	647.5	3,509,702.73	1,217,369.99	92.1	2,835,628.11	Pennsylvania
Rhode Island	2,628,496.20	1,119,688.09	64.8	1,243,314.98	392,540.21	20.5	1,674,518.20	474,795.57	29.9				680,545.13	Rhode Island
South Carolina	11,163,347.84	5,121,267.54	1,235.9	1,272,156.96	467,770.95	70.1	7,545,645.36	3,366,982.77	378.6	451,844.92	171,520.84	33.2	673,981.90	South Carolina
South Dakota	12,091,434.67	5,989,879.00	1,447.9	3,986,687.00	1,922,620.92	527.9	4,064,234.51	1,952,081.51	624.1				1,302,208.57	South Dakota
Tennessee	13,789,140.98	6,732,079.77	497.9	5,756,394.04	2,538,531.89	179.3	8,331,631.24	3,873,883.85	306.2	811,106.50	376,579.31	12.6	1,759,516.18	Tennessee
Texas	54,120,970.83	21,057,940.12	3,907.1	11,299,011.91	4,758,399.05	675.1	19,175,115.50	8,418,424.91	1,156.8	3,094,582.99	1,385,862.84	126.8	4,985,804.08	Texas
Utah	6,259,159.41	3,818,836.91	423.1	498,544.09	331,506.86	13.3	3,145,195.83	2,185,526.13	264.4	44,350.46	29,939.55	0.1	1,452,969.55	Utah
Vermont	3,015,174.51	1,452,894.45	107.8	995,612.97	453,868.72	21.4	1,275,735.50	549,360.08	28.4				812,383.75	Vermont
Virginia	13,099,720.01	6,271,998.20	676.2	7,144,835.58	3,308,995.45	268.3	5,289,885.13	2,300,376.91	168.4	3,003,893.02	1,343,816.12	75.8	276,327.32	Virginia
Washington	13,352,504.18	6,117,211.87	526.7	3,591,201.52	1,607,897.59	137.2	2,525,208.65	1,232,400.00	27.6				1,188,266.54	Washington
West Virginia	7;343,200.86	3,230,293.33	326.7	843,405.01	404,579.97	37.5	6,394,817.82	2,493,134.92	160.9	327,937.93	133,956.79	11.3	1,090,545.99	West Virginia
Wisconsin	21,807,140.91	8,919,640.62	1,451.7	1,457,080.92	722,578.76	67.6	5,484,949.02	2,694,686.42	261.6	335,059.18	167,528.00	16.6	4,934,381.20	Wisconsin
Wyoming	8,809,819.33	4,739,096.67	982.0	1,774,399.61	1,080,637.38	145.4	2,714,091.05	1,705,666.53	166.2	28,580.20	18,348.00	0.1	1,022,525.42	Wyoming
Hawaii							342,277.22	97,440.00	6.5				1,002,713.00	Hawaii
TOTALS	740,140,790.82	325,654,346.00	41,898.3	141,841,633.63	64,450,912.34	7,067.0	361,925,907.24	153,872,464.12	14,731.1	41,893,608.12	14,992,448.81	1,740.1	112,404,828.73	TOTALS

* Includes projects reported completed (final vouchers not yet paid) totaling: Estimated cost $ 104,884,653.55 Federal aid $ 44,450,778.49 Miles 3,928.0