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Annual road costs are computed from Texas highway control section records

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BUREAU OF PUBLIC ROAD

U. S. DEPARTMENT OF COMMERC

E. A. STROMBERG, Edito

IN THIS ISSUE

A Procedure for Determining the Annual Cost of a Section of Rural Highway

BY THE FINANCIAL AND ADMINISTRATIVE RESEARCH BRANCH BUREAU OF PUBLIC ROADS

eported by HAROLD W. HANSEN, ighway Engineer

Following its initial construction, every highway generates a demand upon current revenue for maintenance and operation and upon future revenue for rebuilding and modernization. In order that this demand may be met in a plan that will provide maximum service at minimum cost, it is essential to have knowledge of annual road costs. Such cost information is invaluable for planning and programing and, when correlated with traffic volumes, weights, surface types, and similar factors, is useful in a variety of economic analyses.

'N RECENT YEARS a number of State .highway departments have established ighway control sections [1] as a means of co-rdinating records of the work performed n highways. Among the objectives in-olved in such undertakings is the bringing gether of construction expenditures and aintenance and operation expenditures in fashion that will establish a current and ontinuing record of the annual cost of each ection of highway.

Such cost information, when available or the entire highway system, will pro-ide a wealth of facts concerning the costs f providing road transportation service.)ata pertaining to the annual cost of each ype of surface, each type of structure, and ther elements of the highway can be made vailable as a routine, continuing process n those States operating on a control-sec-ion basis. From such information on the ost of highways under a variety of condi-ions can be obtained the facts useful in hort- and long-range planning and pro-raming, and in numerous types of eco-omic analyses and problems of economic ustification.

Annual Road Cost

The term "annual road cost" as used in he following discussion refers only to the ictual or estimated annual depreciation harge plus the annual expenditure for naintenance and operation. In accord vith present-day accounting practice these wo cost elements would be considered es-ential to any method of computing annual oad costs.

The depreciation charge is a measure of he annual capital (construction) cost. The xpenditure for maintenance and operation ndicates what has been spent to preserve he highway as nearly as possible in its riginal condition as constructed or as sub-equently improved, and for the operation f highway facilities and services to provide atisfactory and safe highway transporta-ion.

Other elements of highway cost, such as interest, taxes, and the like, may be included in the term annual road cost depending on the use to be made of the cost information.[2] These items have been omitted from this discussion but could, if needed, be added to the costs obtained as described here.

The procedures outlined in this report have been discussed with members of State highway planning surveys, engineers, accountants, and highway officials in more than 20 States. This material has also been discussed by members of the Highway Research Board Committee on Highway Costs [3] at the twenty-eighth and twenty-ninth annual meetings of the Highway Research Board (1948 and 1949). The suggestions and advice received as a result of these discussions are gratefully acknowledged. Special recognition is due the Texas Highway Planning Survey for its cooperation in furnishing the basic data which were used to prepare the road cost charts exhibited in this report.

Depreciation

There are many mathematical formulas which can be utilized in computing depreciation charges. Some of the better known include the straight-line, production, compound-interest, sinking-fund, annuity, and fixed-percentage-of-declining-balance methods. There are others which are not as well known. In spite of the diversity of formulas the straight-line method is in almost universal use throughout the United States.[4] The principles of this method have been adapted to the determination of annual road costs.

For such purposes the funds which have been expended (invested) for the construction of highways are subdivided into various fixed-asset accounts. There are eight such fixed-asset accounts recommended by the Subcommittee on Uniform Accounting of the American Association of State Highway Officials: (1) Right-of-way, (2) roadway and drainage grading and earthwork, (3) drainage structures and roadway earthwork protective structures, (4) roadway surface and base (by roadway surface type), (5) improved shoulders and approach surfacing, (6) bridges, viaducts, grade-separation structures, and tunnels (by individual structure), (7) traffic and pedestrian services, and (8) roadside development.

For purposes of an annual cost computation, the basic information required for each control section includes date of construction, cost of construction (by fixed-asset accounts), amount depleted (or, conversely, the amount salvaged) at the time of each subsequent reconstruction, age at the time of reconstruction, and other facts. As used here, depletion refers to that portion of the construction investment which is lost at the time of reconstruction, aban-

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[1] Report of the Highway Research Board Committee n Highway Costs, Memorandum No. 1. Highway Re-earch Correlation Service Circular No. 61, May 1949.

[2] For a discussion of this subject, see *Costs of highways to the public and uses of cost computations*, Report of the Highway Research Board Committee on Highway Costs: Proceedings of the 24th annual meeting of the Highway Research Board, 1944; page 1.

[3] The members of this committee are Fred B. Farrell, *chairman*, Chief, Highway Cost Section, Bureau of Public Roads; James A. Foster, Highways and Municipal Bureau, Portland Cement Association; Carl E. Fritts, Director, Highways Division, Automotive Safety Foundation; Raleigh W. Gamble, Superintendent, Bureau of Street Construction and Repairs, Milwaukee, Wisc.; O. L. Kipp, Chief Engineer, Minnesota Department of Highways; Bertram H. Lindman, Transportation Consultant, Washington, D. C.; H. R. Wilson, Fiscal Manager, Finance and Management Division, Bureau of Public Roads; and Robley Winfrey, Research Professor of Civil Engineering, Iowa State College.

[4] *Report of Committee on Depreciation*, National Association of Railroad and Utilities Commissioners, 1943, page 89. Published by the Association, Washington, D. C.

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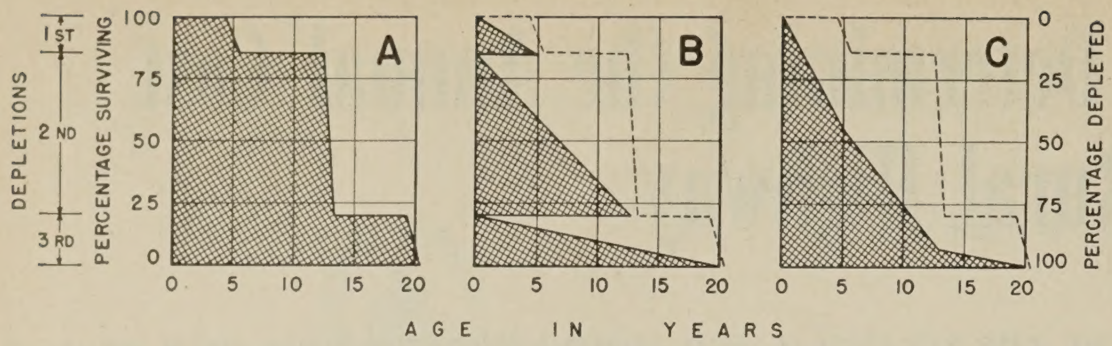


Figure 1.—A simple survivor curve, showing the age of the original investment at the time of each reconstruction and the amount of capital depleted, and the steps involved in deriving the combined straight-line depreciation curve.

donment, or transfer of the highway to another authority.[5]

This basic information can be used to construct for each fixed asset the type of graph shown in figure 1A, which was made by plotting the percentage of the original investment surviving at ½, 1½, 2½, etc., years of age and then connecting these points with straight lines, a standard practice in mortality studies of highways. The resulting curve shows the survivor history of the capital invested in a given year for the construction of one of the fixed assets (roadway and drainage grading and earthwork, drainage structures and roadway earthwork protective structures, each roadway surface and base type, etc.) comprising the highway. Such graphs can be prepared for the capital invested in each of the other fixed assets, and for additional capital invested when the highway is subsequently reconstructed. The total annual depreciation charge for the control section is built up from data computed from these individual investment survivor curves.

Depreciation Rate

To determine the rate of depreciation for a fixed asset having the survivor history indicated in figure 1A, each depletion is treated as a separate unit of property and the rate of depreciation for each depletion is found. Then the several rates of depreciation are added together to give the total rate of depreciation for that fixed asset. This is known as the unit summation method[6] for applying the principle of straight-line depreciation to a property group consisting of units having different service lives.

Figure 1B illustrates the first step in this procedure, that of determining the rate of depreciation for the individual depletions. The first reconstruction, 5 years after the initial construction, caused a depletion of 15 percent of the fixed asset. Accordingly, 15 percent of the fixed asset must be depreciated over a period of 5 years, which is the equivalent of an annual rate of 3 percent. Similarly, for the second depletion 65 percent is depreciated over a 13-year period, or an annual rate of 5 percent, and for the third depletion 20 percent is depreciated over 20 years, or 1 percent per year.

The manner by which the several rates of depreciation are combined to yield the resultant rate for the fixed asset is illustrated in figure 1C. During the period from age zero to age 5 years, the three separate rates of depreciation (3, 5, and 1 percent) are added together to obtain a total rate of depreciation of 9 percent per year. For this 5-year period, then, the total depreciation was $5 \times 9 = 45$ percent. From age 5 years to age 13 years two separate rates (5 and 1 percent) are added together to obtain the total rate of depreciation of 6 percent per year. For this 8-year period the total was $8 \times 6 = 48$ percent. In the final period, from age 13 years to age 20 years, the total rate of depreciation for the fixed asset was 1 percent per year. For this 7-year period, the total was $7 \times 1 = 7$ percent. The grand total depreciation for the three periods (45, 48, and 7 percent) is 100 percent of the original amount.

The unit summation method has the merit of relating depreciation charges to the service given by each of the units (depletions) comprising the group. It tends to reduce the underaccrual of depreciation charges on short-lived units and the overaccrual on long-lived units which is common to certain other methods for computing depreciation of group properties.

The example shown in figure 1 illustrates a situation in which all of the original fixed asset has been depleted. Comparable situations usually do not exist on highway control sections since much of the original investment (roadway and drainage grading and earthwork, for example) has not been depleted. For this undepleted capital it is necessary that the remaining life expectancy be estimated. Indications of service life may be obtained from the analysis of construction investment retirements, a phase of the road life studies being conducted by the State highway planning surveys in cooperation with the Bureau of Public Roads.

The share of construction costs which may properly be charged to a control section during a given year is found by adding together the depreciation charges which have been computed for that year for all improvements built within the control section. These figures in turn are made up of actual or estimated depreciation charges for the individual fixed-asset accounts comprising the improvement in accordance with the methods outlined above.

Forms for Computations

Depreciation computations can be greatly facilitated by the use of well-designed forms. A form which provides for all possible adjustments to depreciation rates and for all future additions of data may become unnecessarily complicated. A simple form will usually prove more desirable even though it may require the occasional preparation of a new depreciation sheet for the control section when an appreciable revision is caused by later reconstruction.

Forms 1 and 2, shown in figure 2, are examples of the type of form used for computing and summarizing depreciation data for control sections and are shown in this report for illustrative purposes only. To facilitate comparing the cost of one section of road with the cost of any other, these particular forms provide for showing depreciation as an annual charge on a per-mile basis for any selected segment within the control section and for the control section as a whole. It will be noted also that these forms provide for adjusting depreciation charges to a common price level in order that all costs may be expressed in terms of dollars having approximately the same purchasing power.

Correlating maintenance and operation expense with depreciation charges can be readily undertaken in those States that have established control sections since this is one of the basic functions of the control section procedure. In the same way that depreciation charges are adjusted to a common price level, maintenance and operation expense is adjusted by means of a maintenance price index to a common price level. The same base periods should be used for both the construction and maintenance price indexes.

Form 3 (fig. 2) is an example of a form for summarizing depreciation charges and maintenance and operation expense on a per-mile basis for a given control section. This particular form is for illustrative purposes only and should be designed in each instance to fit the needs in a given State. For example, bridge data are not recorded on form 3, but may readily be included if desired.

The annual road cost per mile for the control section is obtained by adding the total annual depreciation charge per mile for the control section and the corresponding maintenance and operation expense per mile.

[5] Methods of developing a progressive record of construction investment are outlined in the Bureau of Public Roads Planning Survey Memorandum No. 322, June 30, 1939: *Further suggestions on the summary and tabulation of the road life studies.*

[6] *Depreciation of Group Properties*, by Robley Winfrey, Iowa Engineering Experiment Station Bulletin 155, 1942; Iowa State College, Ames, Iowa.

FORM 1.—CAPITAL DEPRECIATION WORK SHEET

HIGHWAY SYSTEM ____________
CONTROL SECTION No. ____________
FIXED-ASSET ACCOUNT ____________

CONTROL SECTION LENGTH:
TOTAL....... ________
URBAN....... ________
RURAL:
ROADWAY... ________
BRIDGES... ________

TERMINI OF SEGMENTS WITHIN CONTROL SECTION	SEGMENT NUMBER							TOTAL
	1	2	3	4	5	6	7	
FROM								
TO								
NET LENGTH								

1	2	3	4	5	6	7	8	9	CAPITAL DEPRECIATION PER MILE FOR EACH CALENDAR YEAR: ADJUSTED COST DEPLETED PER MILE (COL. 7) DIVIDED BY SERVICE LIFE IN YEARS (COL. 9).						
IMPROVEMENT No.	SEGMENT No.	DEPLETION No.	ORIGINAL COST: AMOUNT AND YEAR CONSTRUCTED	TOTAL COST DEPLETED: AMOUNT AND YEAR DEPLETED	NET LENGTH IN MILES	COST DEPLETED PER MILE: ACTUAL AND ADJUSTED	PRICE INDEX FOR YEAR CONSTRUCTED	SERVICE LIFE: AVG. FOR YEAR CONSTRUCTED AND VALUE USED	19__	19__	19__	19__	19__	19__	19
			7/1/19__	7/1/19__											
			7/1/19__	7/1/19__											
			7/1/19__	7/											

FORM 2.—CAPITAL DEPRECIATION SUMMARY SHEET

HIGHWAY SYSTEM ____________
CONTROL SECTION No. ____________

CONTROL SECTION LENGTH:
TOTAL....... ________
URBAN....... ________
RURAL:
ROADWAY... ________
BRIDGES... ________

TERMINI OF SEGMENTS WITHIN CONTROL SECTION	SEGMENT NUMBER							TOTAL
	1	2	3	4	5	6	7	
FROM								
TO								
NET LENGTH								

1	2	3	4	5	CAPITAL DEPRECIATION PER MILE FOR EACH CALENDAR YEAR DATA SUMMARIZED FROM CAPITAL DEPRECIATION WORK SHEET					
SEGMENT No.	LENGTH IN MILES	FIXED ASSET	REMARKS	ITEM	19__	19__	19__	19__	19__	19__
				TOTAL DEPR.						
				WEIGHT ( )						
				TOTAL DEPR.						

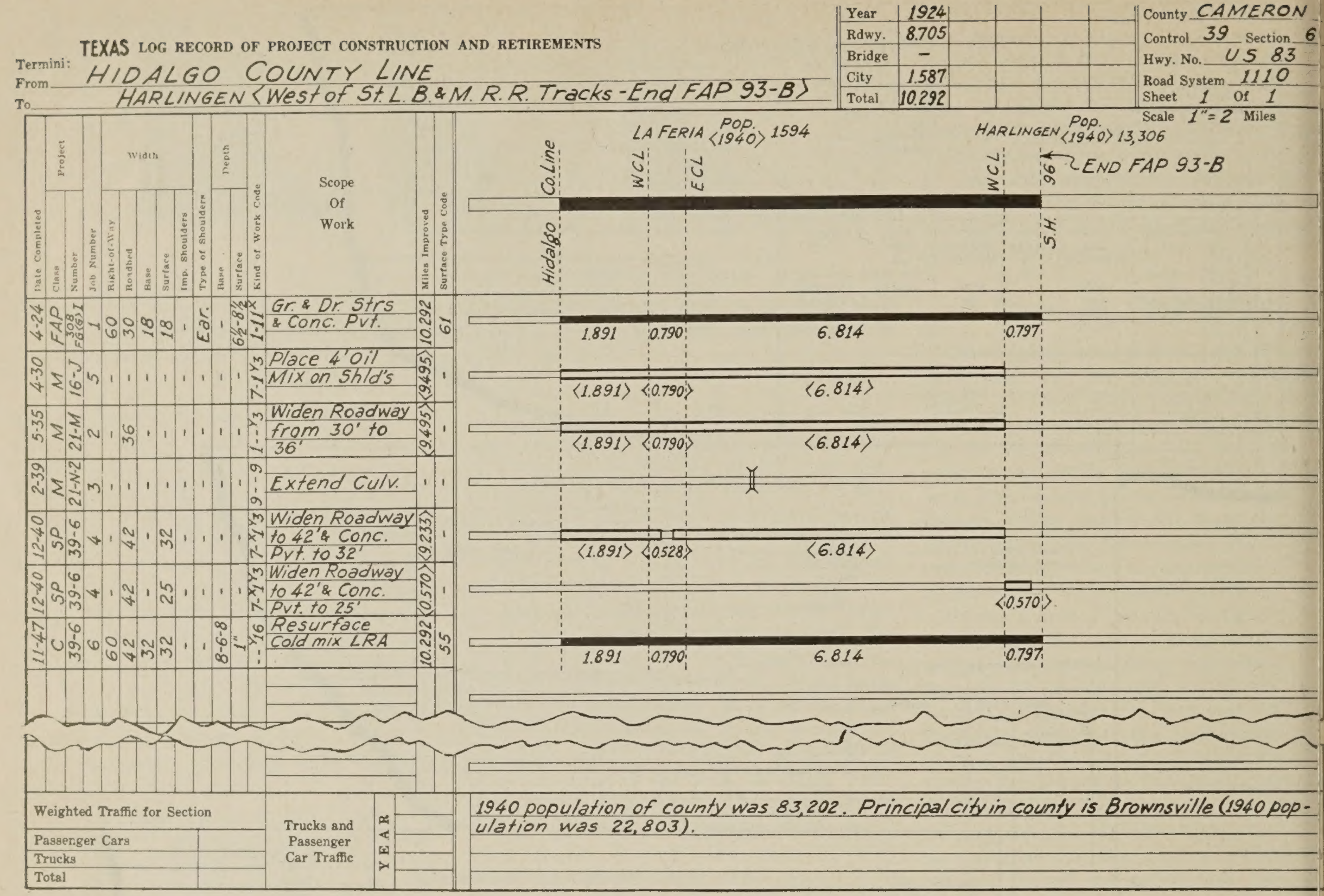
FORM 3.—ANNUAL ROAD COST WORK SHEET

HIGHWAY SYSTEM ____________
CONTROL SECTION No. ____________

LENGTH OF CONTROL SECTION:
TOTAL....... ________
URBAN....... ________
RURAL:
ROADWAY... ________
BRIDGES... ________

ITEM		DATA FOR EACH CALENDAR YEAR							
		19__	19__	19__	19__	19__	19__	19__	19__
ROADWAY AND DRAINAGE GRADING, AND EARTHWORK									
DRAINAGE STRUCTURES, ROADWAY EARTHWORK PROTECT. STR.									
SURFACE AND BASE	SOIL (D)								
	GRAVEL OR STONE (E)								
	BITUMINOUS TREATED (F)								
	MIXED BITUMINOUS (G-1)								
	MIXED BITUMINOUS (G-2)								
	BITUMINOUS PENETRATION (H-1)								
	BITUMINOUS PENETRATION (H-2)								
	BITUMINOUS CONCRETE (I)								
	PORTLAND CEMENT CONCRETE (J)								
	OTHER (INDICATE TYPE)								
	TOTAL SURFACE AND BASE								
ROADSIDE DEVELOPMENT									
TRAFFIC SERVICES									
OTHER ITEMS (INDICATE ITEM)									
TOTAL WEIGHTED AVERAGE DEPRECIATION PER MILE									
TOTAL MAINTENANCE AND OPERATION EXPENSE PER MILE									
WEIGHTED AVERAGE ANNUAL ROAD COST PER MILE (RURAL)									
ANNUAL AVERAGE DAILY TRAFFIC VOLUME									
TOTAL VEHICLES PER YEAR									
WEIGHTED AVERAGE ANNUAL COST PER VEHICLE-MILE (RURAL)									

Figure 2.—Forms for computing and summarizing depreciation charges and for summarizing annual road costs.



TEXAS LOG RECORD OF PROJECT CONSTRUCTION AND RETIREMENTS

Termini: From HIDALGO COUNTY LINE
To HARLINGEN <West of St. L. B. & M. R. R. Tracks - End FAP 93-B>

Year	1924
Rdwy.	8.705
Bridge	–
City	1.587
Total	10.292

County CAMERON; Control 39 Section 6; Hwy. No. US 83; Road System 1110; Sheet 1 Of 1; Scale 1"=2 Miles

Date Completed	Project Class	Project Number	Job Number	Width Right-of-Way	Width Roadbed	Width Base	Width Surface	Imp. Shoulders	Type of Shoulders	Depth Base	Depth Surface	Kind of Work Code	Scope Of Work	Miles Improved	Surface Type Code
4-24	FAP	308 FG(G)I	1	60	30	18	18	-	Ear.	-	6½-8½	1-11X	Gr. & Dr. Strs & Conc. Pvt.	10.292	61
4-30	M	16-J	5	-	-	-	-	-	-	-	-	7-1Y3	Place 4' Oil Mix on Shld's	‹9.495›	-
5-35	M	21-M	2	-	36	-	-	-	-	-	-	1--Y3	Widen Roadway from 30' to 36'	‹9.495›	-
2-39	M	21-N-2	3	-	-	-	-	-	-	-	-	9--9	Extend Culv.	-	-
12-40	SP	39-6	4	-	42	-	32	-	-	-	-	7-X1Y3	Widen Roadway to 42' & Conc. Pvt. to 32'	‹9.233›	-
12-40	SP	39-6	4	-	42	-	25	-	-	-	-	7-X1Y3	Widen Roadway to 42' & Conc. Pvt. to 25'	‹0.570›	-
11-47	C	39-6	6	60	42	32	32	-	-	8-6-8	1"	--Y16	Resurface Cold mix LRA	10.292	55

Weighted Traffic for Section		Trucks and Passenger Car Traffic	YEAR
Passenger Cars			
Trucks			
Total			

1940 population of county was 83,202. Principal city in county is Brownsville (1940 population was 22,803).

Figure 3.—Log record of project construction and retirements for Texas control section 39-6.

At the bottom of form 3, space should be provided for special computations. One such possible computation is the cost per vehicle-mile, as shown on the form. Others may be entered on the form at the discretion of the highway department to show trends in the annual costs of the control section in relation to other factors.

Annual Road Cost Data

As an example of annual cost determinations, a highway in Texas is here considered. Figure 3 shows one of the construction project log records prepared by the Texas State Highway Department for control section 39–6 on a portion of U S 83 in Cameron County, the southernmost county in the State. This control section begins at the west county line and extends eastward to the intersection with State Route 96 in the city of Harlingen. The total length of the control section is 10.292 miles, but only the rural portion of 8.705 miles is embraced in the following discussion.

A view of the roadway looking to the west from just inside the city limits of Harlingen is shown in figure 4, and another part of the control section is depicted on the cover. The existing three-lane surface is 32 feet wide and consists of a 1-inch limestone rock-asphalt mat on an old portland cement concrete base.

Although agriculture plays a dominant role in the economy of the county, one-half of the population lives in urban areas. Interurban bus service is scheduled at frequent intervals along this route. There are a number of manufacturing establishments in the county, some of which depend on local crops for raw materials. Many of these establishments rely upon motor carriers to support their operations. The area also has a modest tourist trade. Average traffic on control section 39–6 was 3,389 vehicles per day in 1936. Following a wartime decline

Figure 4.—View of the eastern end of Texas control section 39-6.

2,659 in 1943, the average traffic increased 5,542 vehicles per day in 1948.

Annual roadway costs for an average mile control section 39–6 are shown in the per left portion of figure 5. In this il- tration all costs have been adjusted to a 37–41 price level. Bridge costs were itted from the computations of costs, but ıld be included, if desired, with no change the general procedure.

The annual depreciation charges, as ob- ned from the investment study, extend ck to 1924. Data on maintenance and eration expense, however, date back only 1936. The State's control-section setup ıs not in full operation before that date, d maintenance and operation expense ıld not be correlated with construction sts for the years prior to 1936. Conse- ently, the data presented in figure 5 begin th the year 1936.

Only the total annual depreciation and total maintenance and operation expense are shown in figure 5. Similar charts could be prepared for each of the fixed-asset accounts, if desired, by selecting the appropriate data from the annual road cost work sheet for the control section.

For purposes of general illustration, annual average daily traffic information has been obtained for control section 39–6, and an annual cost per vehicle-mile computed. These data are also shown in the left side of figure 5. The true significance of such a trend for a particular control section can, of course, be properly appraised only after consideration and study of many factors, such as composition and type of traffic, frequency of heavy axle loads, subgrade conditions, degree of maintenance afforded, and type and width of surface and shoulders.

Cost Trends

In order to smooth out the somewhat erratic trends characteristic of these data when presented on an annual basis, averages for a group of years may prove more useful. The right side of figure 5 shows the annual cost data for control section 39–6 on the basis of 5-year averages. In this case the 5-year averages are plotted at the last year of each 5-year group. Thus, the average for 1936–40 is plotted at 1940, and so on. The trends are more apparent when the data are arranged this way, thus making them more acceptable for general administrative use. The average annual daily traffic and annual cost per vehicle-mile, on a 5-year average basis, are also shown in the right side of figure 5.

Computations similar to the foregoing have been made for other control sections in Texas and other States. The annual cost per mile, traffic volume, and annual cost per vehicle-mile for four additional control sections in Texas are shown in the upper

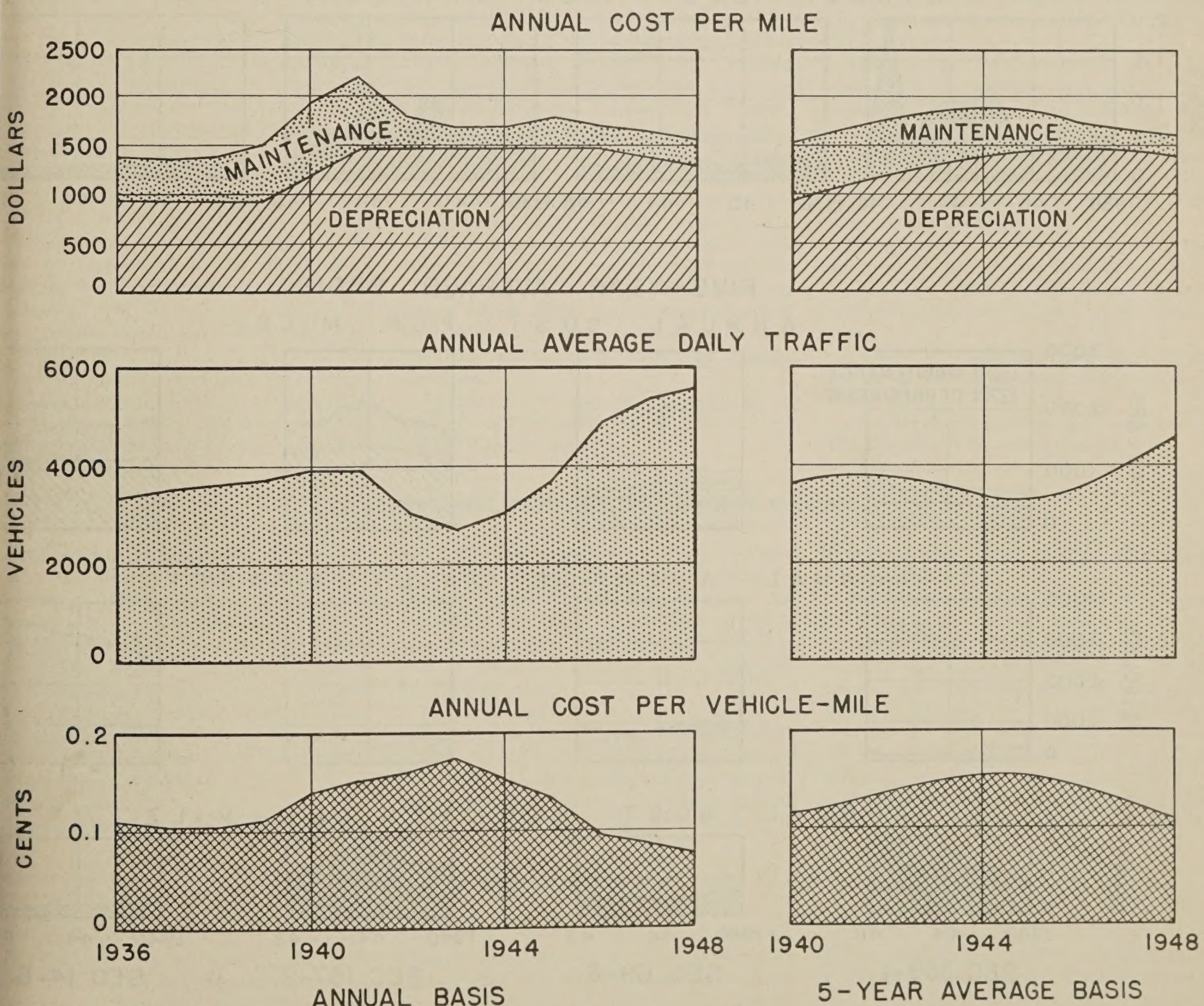


Figure 5.—Annual cost per mile, annual average daily traffic, and annual cost per vehicle-mile, on an annual basis and a 5-year average basis, for Texas control section 39-6 (data adjusted to 1937–41 prices).

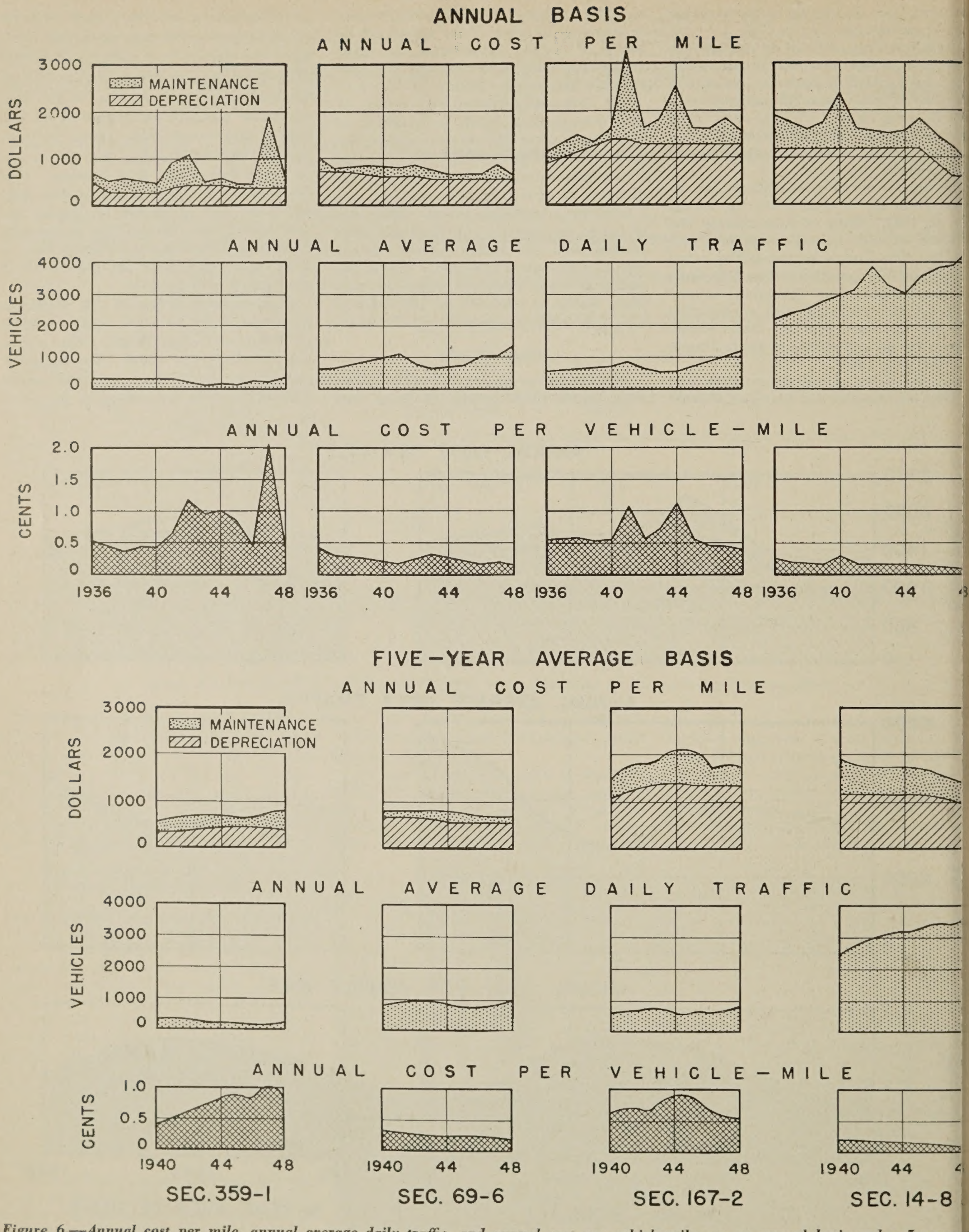


Figure 6.—Annual cost per mile, annual average daily traffic, and annual cost per vehicle-mile, on an annual basis and a 5-year-average basis, for four Texas control sections (data adjusted to 1937–41 prices).

t of figure 6. Similarly, the 5-year-rage annual cost per mile, 5-year-average ly traffic, and 5-year-average annual cost vehicle-mile for the same sections are wn in the lower part of figure 6. These trol sections, which were selected at ran-1, are briefly described in table 1. The t data shown here are not necessarily resentative of the average cost of these d types and consequently conclusions uld not be drawn from this small sample to relative cost.

Table 1.—*Length, type, and location of control sections*

Control section number	Length	Number of lanes	Surface type	Route	County	Location
	Miles					
359–1	7.102	2	Bituminous surface treated.	Texas 119	DeWitt	From Yorktown southeast toward Goliad.
69–6	9.768	2	Bituminous penetration.	U S 87	Tom Green	From Coke County line southeast toward San Angelo.
167–2	15.246	[1] 2	Bituminous concrete	U S 54	El Paso	From El Paso north to New Mexico State line.
14–8	10.062	[2] 2	Portland cement concrete.	U S 77 and 81	McLennan	From Hill County line south toward Waco.

[1] 4.776 miles adjacent to El Paso were widened to four lanes in 1941.
[2] 0.544 mile at the south end was built (1934) as three lanes.

New Publications

THE MATHEMATICAL THEORY OF VIBRATION IN SUSPENSION BRIDGES

The Bureau of Public Roads has recently blished *The Mathematical Theory of Vi-ation in Suspension Bridges*, a 450-page port of a study undertaken under the spices of the Advisory Board on the In-stigation of Suspension Bridges. The ok is for sale by the Superintendent of cuments, U. S. Government Printing Of-e, Washington 25, D. C., at $1.25 a copy.

The Advisory Board, established subse-ent to the collapse of the Tacoma Nar-ws Bridge in 1940, has sponsored a series investigations seeking to determine the uses of suspension bridge vibration, to velop a rational theory explanatory of the enomenon, and to work out methods of sign practice which will reduce these dan-rous motions.

The Mathematical Theory of Vibration in spension Bridges develops mathematical alyses of the dynamic problem and sug-sts experimental data needed to support them. Authors of this highly technical study are Dr. Friedrich Bleich, Consulting Engineer, American Institute of Steel Construction; Dr. C. B. McCullough, Assistant Chief Engineer, Oregon State Highway Commission; Richard Rosecrans, Structural Research Engineer, Oregon State Highway Commission; and George S. Vincent, Principal Highway Bridge Engineer, Bureau of Public Roads. Unfortunately, both Dr. Bleich and Dr. McCullough died before their work appeared in published form.

The content of the publication is indicated by the subjects of the major sections:

Chapter 1.—History of troublesome dynamic stress effects in suspension bridges; a general statement of the dynamic problems; the mathematical theory of vibration problems.

Chapter 2.—A general statement of the problem and determination of physical data needed for its solution.

Chapter 3.—Frequencies, modes of vibration, and energy storage in freely vibrating suspension bridges with hinged stiffening frames.

Chapter 4.—Application of the energy method to the analysis of the frequencies, modes of vibration, and energy storage capacity in freely vibrating suspension bridges with continuous stiffening frames.

Chapter 5.—Influence of various design factors on frequencies, modes of motion, and energy storage.

Chapter 6.—Consideration of structural damping in suspension bridges.

Chapter 7.—The flutter theory of truss-stiffened suspension bridges under wind action.

Chapter 8.—The linearized deflection theory developed for suspension bridges having tower stays.

Chapter 9.—Experimental verification of the linearized deflection theory.

SELECTED BIBLIOGRAPHY ON HIGHWAY FINANCE

The Bureau of Public Roads has recently blished a *Selected Bibliography on High-ay Finance* which provides nearly 1,400 notated references, for the years 1939–49, the field of highway taxation and finance the United States. Emphasis is placed iefly on theory, but basic sources of perti-nt statistics are included. The bibliog-phy may be purchased from the Super-tendent of Documents, U. S. Government inting Office, Washington 25, D. C., at cents a copy.

The search for solutions to the problems currently encountered by all levels of government in obtaining adequate revenues for highway operation and capital outlay has intensified the value of all types of information on finance. The *Selected Bibliography on Highway Finance* is the complete key to this need.

The references in the bibliography are arranged according to a useful classification scheme under seven major topics—general discussions, taxation, expenditures, borrowing, financial programs and plans, miscellaneous topics, and statistics. Both geographical and author indexes are included in the publication.

Brief annotations accompany most entries to indicate the general nature of content, but evaluation of importance, accuracy, or validity has not been attempted. The references were carefully selected, however, so that all included are of some significance.

While the bibliography covers intensively the years 1939–49, a limited number of significant references from earlier years are also included, as are available items published in the first four months of 1950.

HIGHWAY STATISTICS, 1949

Now available is the Bureau of Public ads' *Highway Statistics, 1949*, the fifth the bulletin series presenting annual atistical and analytical tables of general terest on the subjects of motor fuel, otor vehicles, highway-user taxation, financing of State highways, and highway mileage. Included for the first time in the annual publication is information concerning the financing of highways by county and local rural governments.

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Methods for the Determination of Soft Pieces in Aggregate

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The classification of materials in aggregates as "soft pieces" is subject to wide variation and loose definition. Materials classed as soft pieces in various State specifications also include those which more properly should be defined as unsound, light-weight, brittle, friable, highly absorbent, or combinations of these. As pointed out in this article, specifications for aggregates should define and limit soft pieces as such, and the presence of other deleterious substances should be separately restricted.

The study reported here included an examination of existing methods, and an attempt to develop new ones, for the determination of the presence and proportion of soft pieces in aggregate. All commonly known test methods, and many specially devised ones, were studied. It was concluded that the only method suitable for both field and laboratory use is the scratch hardness test using a hard, yellow brass scribe. For convenience, a wooden pencil with a brass core is suggested.

IN 1941 the Bureau of Public Roads undertook an investigation of methods of testing coarse aggregates to determine the content of soft pieces, at the request of Subcommittee IX of Committee C–9 of the American Society for Testing Materials. It was hoped that the results of this investigation would direct attention toward the development of a new method of testing aggregates for soft pieces, or identify existing methods which would be suitable for this purpose.

This paper describes the test methods employed and gives typical test values which were obtained. With each description of a method of test are presented the conclusions obtained from the test data: Whether the method appears to be useful, and the difficulties encountered in its performance. Throughout the investigation, efforts were made to develop a method which would be suitable for use in the field. It is thought that this determination—the detection of the amount of soft pieces in aggregates—is properly a duty of the inspector in the field. Any method which the inspector can use can also be performed in the laboratory; consequently, the program of the investigation was planned with consideration of field use as a primary requisite. In some of the methods employed, apparatus suitable only for use in the laboratory was used. In most of these cases, however, plans were prepared for the construction of equipment sufficiently portable to permit its installation at aggregate plants.

Conclusions

The tests reported were made in an attempt to develop a rational method of testing aggregates for soft-piece content. Although most tests used standard or readily procurable apparatus, some rather fanciful or weird contraptions were designed or actually constructed for this purpose. On the whole, a thorough study has been made of all different methods of test which could be expected to give information of value.

Of all methods tried, the only one considered suitable for both laboratory and field use is the scratch hardness test using a hard, yellow brass scribe. For convenience, a pencil with a brass core is suggested.

Attention is called to the rather frequent practice, in writing specifications for aggregates, of using the soft-piece classification as a catch-all for many different types of deleterious substances. If it is desired to limit types of deleterious substances other than soft pieces, these other types should be mentioned specifically and separately, in the specifications, from pieces which are merely soft.

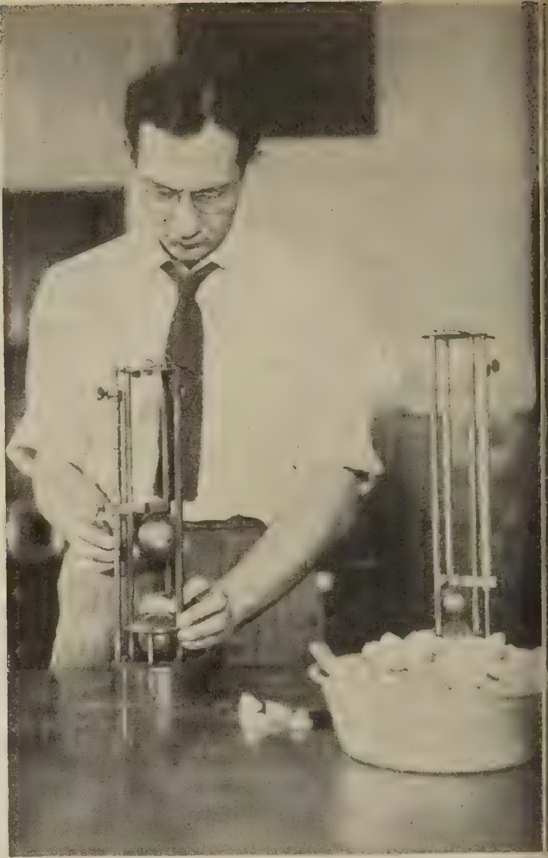

Figure 1.—Toughness test for gravel, using the 2½-inch ball.

Classification of Materials

Prior to starting this investigation of methods of test, an attempt was made to determine the character of the materials which the various highway authorities classify as soft pieces. The State highway departments were requested to submit samples of such soft pieces as are encountered in each State, and to furnish information relating to their particular conditions insofar as this problem is concerned. The information requested was as follows:

1. Names of the different materials which may be classified as soft pieces.
2. Names of such materials found generally throughout the State or in large areas of the State.
3. Amount of soft pieces permitted in specifications for pavement surface courses.
4. Method of test or identification used by laboratory operators or field inspectors.
5. Names of the materials occurring naturally which are considered to be objectionable for surface courses but which are not included in the class of soft pieces.

Replies were received from practically all of the State highway departments. Many were in sufficient detail, but a few were expressed in generalities, or in terms which appear to be of local usage only. From the information received, table 1 reports a list of materials which are classed as "soft pieces," the number of States which classify these materials as soft, and the number of States which report the materials to be widely distributed.

At first glance, many of the materials listed in table 1 appear to be included in the designation of soft pieces by mistake example, granite is placed in the classi- ion of soft pieces by two States, al- gh the word "granite" usually conveys impression of a hard and enduring e. A number of other apparent incon- encies exists. However, some interpre- on of these classifications is probably nissible.

here is little doubt that the inclusion of nite in a classification of soft pieces is nt to refer to material of a granitic ire which has weathered to such an ex- that the component crystals are soft oorly bonded to each other. Similar in- retations can be made of a number of materials included in table 1 and, in eral, most of the materials mentioned be placed in one or more of the follow- types:

1. Soft.
2. Unsound.
3. Light weight.
4. Brittle.
5. Friable.
6. Highly absorbent.

ome materials may be both soft and ble, or soft and brittle, or different sam- of the same material may be placed perly in separate groups. Consequently, hout reference to actual samples, a per grouping of materials by name alone s robably not feasible. Certain materials ntioned in table 1, such as brownstone, naceous granite, and limonite, are not ntified definitely by the names given, al- ugh use of such terms may be justified a limited area where the persons con- ned would have an understanding of their lication. However, as these terms may be widely used to describe materials of nite physical characteristics, some ught could be given toward the use of e descriptive names, or to the establish- nt and use of a systematized glossary of ns relating to the materials under sideration.

laterials classed as deleterious but not sidered as soft pieces by the reporting hority are listed below:

lkaline reactive	Mica
mphibolite	Mud balls
hert	Obsidian
hert, opaline	Ochre
hert, unsound	Pyrite in rock
lay lumps	Quartzite
oal	Sandstone, hard absorbent
oated material	Sandstone, soft
olomite, some	Shale
lint	Shale, hard
lassy rock	Shale, opaline cherty
neiss, soft	Shale, soft
ranite	Shale, some
ranite, soft	Shell
ranite, some	Slate
ravel, a quartz	Sulphates–sulphides, iron, in rock
ydrophilic rock	Thin or elongated pieces
imestone, argillaceous	Unsound pieces
imestone, siliceous	

Table 1.—*List of materials classed as soft pieces and number of States giving this classification or having material widely distributed*

Material	Number of States— Classifying as soft	Number of States— Reporting wide distribution	Material	Number of States— Classifying as soft	Number of States— Reporting wide distribution
Basalt, disintegrated	1	1	Limestone, soft	3	1
Brownstone	1	1	Limestone, some varieties	1	1
Caliche, hard	1	0	Limestone, weathered	4	3
Chert	2	1	Limonite	3	2
Chert, chalky	1	0	Marble	1	1
Clay balls	2	1	Ochre	3	2
Clay, iron bearing	1	0	Quartz, sugar	1	1
Coal	2	1	Quartz, weathered	2	2
Concretion, calcareous	1	1	Rock, disintegrated	2	1
Conglomerate	1	0	Rock, weathered	2	2
Dolomite, weathered and porous	1	1	Rottenstone	1	1
Earth, diatomaceous	1	1	Sandstone	9	9
Feldspar	1	1	Sandstone, argillaceous	1	1
Felsite	1	0	Sandstone, friable	1	1
Floaters	1	1	Sandstone, friable arkosic	1	0
Gneiss	1	0	Sandstone, soft	5	4
Gneiss, micaceous	1	1	Schist	5	3
Gneiss, weathered	1	1	Schist, some	1	1
Granite	2	1	Schist, micaceous	1	0
Granite, decomposed	1	1	Schist, talc	1	0
Granite, disintegrated	4	3	Schist, weathered	2	2
Granite, micaceous	1	1	Scoria	1	1
Granite, weathered	3	3	Scoria, certain grades of	1	1
Gravel, cemented	2	1	Shale	11	7
Gravel, magnesia	1	1	Shale, clay	1	1
Iron clay balls	1	1	Shale, diatomaceous	1	1
Iron oxide	2	1	Shale, disintegrated	1	1
Limestone, argillaceous	2	1	Shell	2	1
Limestone, porous	1	1	Soapstone	1	0
Limestone, shelly	1	0	Volcanic rock, coarse	1	1

It is interesting to note, in this list of 37 items, that 17 are placed in the category of soft pieces by other States. This illustrates one of the difficulties encountered in attempting to coordinate requirements or tests for soft pieces in aggregate. Unless there can be some agreement as to what constitutes a soft piece, work along the proposed line may not be of suitable value.

Table 2 presents a compilation of the various State specifications for limitation of soft pieces. Most specifications limit the content of soft pieces of aggregate to 5 percent or less. In a few cases, limits for specific types of soft particles are given, but usually the specifications fail to identify the materials covered by the requirement.

Test Methods Reported by States

The following methods of test to determine the content of soft pieces of aggregate were reported by the States:

	Number of States
Los Angeles abrasion test	10
Breakage test under roller	1
Visual inspection	14
Scratch test	4
Hand hammer or compression test	4
Douglass stone meter	2
Specific gravity	2
Solubility in acid	1
Sulfate soundness test	2
Absorption test	1
Flotation by heavy liquid	1
Gravel impact test	1
Deval abrasion test	1

The methods most commonly used are visual inspection, the Los Angeles abrasion test, the scratch test, and a test by use of a hand hammer or compression machine. These and the other tests listed are of two types—a test in which the individual particles are examined separately, and a test in which the effect of soft pieces on a characteristic of the entire material is determined. It should be noted that, with the exception of the requirement involving the use of the sodium-sulfate test, all of the specification requirements shown in table 2 necessitate the use of the first type of test and, in the one exception, this type of test is used in part. Consequently, there appears to be a strong opinion to the effect that determinations of the content of soft pieces should be based on actual count or weight of particles rather than through the use of an indirect method involving some characteristic pertaining to the whole sample.

A number of the States report the use of certain methods of test—the Los Angeles abrasion test for example—for determining

Table 2.—*State specification limitations for soft pieces*

Item	Specification limit	Number of State specifications
	Percent	
Soft pieces	2	2
Do	3	3
Do	5	4
Do	10	1
Do	Free from excess.	1
Soft pieces, bituminous aggregate	1	2
Soft pieces, concrete aggregate	2	2
Do	3	1
Soft pieces: Concrete aggregate	6	1
Soft pieces: Cover material	7	
Soft pieces: Oil mix material	12	
Soft pieces: Stabilized material	20	
Clay lumps	0.5	1
Shale	2.0	
Sp. gr. less than 1.95	2.0	
Total shale, coal, clay lumps, and soft fragments	5	1
If loss in Na_2SO_4 test is less than 2 percent, soft shale may not exceed	10	1
If loss is 2.0 percent or greater, soft shale is limited to	6	

the presence of soft pieces in aggregate, but fail to include numerical values in their reported limitation requirements for soft pieces which are applicable to these methods. Although the reporting authorities may consider the methods mentioned to be suitable for use, it is probable that lack of sufficient test data has so far prevented the establishment of specification requirements.

Eighty-four samples of aggregates were submitted by the States in response to the request for typical samples of material composed of soft pieces. In a number of cases the samples were confined, as requested, to a given type of material. However, many samples were found to be composed of a number of kinds of material differing as greatly as limestone and gneiss. It is possible that the request for samples composed wholly of soft pieces was misunderstood, and that some samples were submitted which contained a small amount of soft pieces as it naturally occurred in these materials.

From the number of varieties of materials submitted as representing soft pieces, it is apparent that there is no concordance of opinion as to the kind of material which should be thus described. It is further apparent that the term "soft pieces" is used as a catch-all description of a number of different types of possibly undesirable material in aggregates. Prior to spending much time in testing materials, it was realized that some rational conception must be formed of the type of material to be identified by the test procedure. Choice must be made between the application of the term "soft pieces" to pieces of aggregate which are actually soft, or the application of the same term to pieces of a wide variety of characteristics. Although the latter may be undesirable for use in construction, this is their only common feature. As shown in the samples submitted, these pieces may be hard or soft, tough or brittle, sound or unsound; in fact, they include the whole gamut of physical properties of aggregates. To this question of choice, there can be but one answer: If these tests are to identify soft pieces, the only problem to be considered is whether the piece under test is hard or soft. During the course of this investigation, tests foreign to a strict hard-or-soft determination were made. In these tests it was hoped that some correlation between the hardness of the particle and some other characteristic of interest could be established. As a general rule, the results were rather disappointing. Although in some cases, with selected samples, definite correlations were found between the hardness and some other characteristic of a material, when a wider variety of samples was considered the agreement between the two characteristics appeared to be largely a matter of chance.

Classification of Test Methods

The tests made in this investigation may be grouped in the following classifications:

1. Visual inspection.
2. Scratch hardness.
3. Specific gravity and absorption.
4. Resistance to impact.
5. Resistance to abrasion.
6. Resistance to static loads.
7. Soundness.

In some cases, the tests were made on the material as received; that is, without preliminary separation into individual sizes. In most tests, however, the size of the piece affected the test result to a marked extent, and it was necessary to sieve the test sample into separate sizes. The sizes generally used were 2- to 1½-inch, 1½- to 1-inch, 1- to ¾-inch, and ¾- to ½-inch. Pieces smaller than ½-inch were found to be difficult to test by some methods, and it was thought that it would be sufficient, for the present at least, to study methods of testing the larger pieces only.

In the first series of tests made on the 84 samples submitted by the State highway departments, the samples were separated into three groups with respect to hardness of the material: Soft, hard, and borderline. This was done by a combination of visual inspection and the use of a scratch test employing a steel knife. It was realized that these methods are not dependable for separating any and all materials into hard and soft classifications. However, they can be used to separate unquestionably soft material from unquestionably hard material. The materials that were found to be neither hard nor soft were classified as borderline materials and excluded from further tests.

Visual inspection of aggregates for the presence of soft pieces is associated with what might be called the luster or appearance by reflected light, and the degree of bonding. Pieces of aggregate with a gl
or stony luster are usually classed as ha
those with a dull or earthy appearance
classed as soft. Compact materials
usually placed in the hard classifica
while those which have a loose or fri
texture are considered as soft.

Specific Gravity and Absorptio

Tests for bulk specific gravity were m
on saturated and surface-dry samples u
the mason jar pycnometer.[1] This de
mination does not appear to have any
nificance in differentiating between
and soft pieces. Seven samples of hard
terials had bulk specific gravities var
from 1.62 to 2.55; five samples of soft
terials varied from 1.48 to 2.57; eight
ples classed as borderline materials va
from 2.11 to 2.59. Since there is so m
overlapping, use of the test for spe
gravity to identify hard and soft pieces
not appear feasible.

The absorption test was made by
mersing oven-dried samples in water f
period of 24 hours. The samples were
surface-dried with a towel and weighed
the absorption expressed as a percen
of the dry weight. A summary of th
sults obtained is given in table 3. In
table, as in others to follow, each si
each material tested is treated as an
vidual sample. This permits compar
between the two types of material,
and soft, for each size of piece. Alth
the average values for the two types o
terial differ markedly, there is some
lapping in the test values. In the 1- t
inch size, for example, one sample of
material had an absorption of only 3.2
cent, whereas a sample of hard mat
had a quite high absorption of 11.3 per
Because of this overlapping, it is not
sible to set a value separating hard
soft material and this method is of
use for the identification of soft part

Impact Tests

A number of different types of im
tests were used in this investigation.
one which is believed to have the
promise is the test for the toughne
gravel.[2] As shown in figure 1, the a
ratus used in this test consists essen
of a 2½-inch steel ball mounted on a
block to serve as an anvil, and another
ball of the same size which can be lift
a maximum height of 7 inches and all
to fall on the specimen under test. Du
the course of this investigation, certai
provements in the original apparatus
made so that the ball could be droppe
exact distance desired with but one r
urement of the thickness of the spec
under test.

Table 3.—*Use of the absorption test for the identification of hard and soft materials*

Item		Size of pieces			
		2- to 1½-inch	1½- to 1-inch	1- to ¾-inch	¾- to ½-inch
Soft Material:					
Number of samples		4	30	31	20
Absorption:					
Minimum	percent	2.6	2.6	3.2	4.3
Maximum	do	23.4	30.1	29.0	30.9
Average	do	11.5	12.8	14.4	18.2
Hard Material:					
Number of samples		6	22	22	10
Absorption:					
Minimum	percent	1.4	0.5	0.6	1.0
Maximum	do	11.1	11.3	11.3	11.0
Average	do	4.7	2.7	3.0	3.3

[1] Described in *Principles of Highway Constr*
as Applied to Airports, Flight Strips, and other
ing Areas for Aircraft, Bureau of Public Roads
1943. p. 297.

[2] Method T-6-27, *Standard Specifications for*
way Materials and Methods of Sampling and T
1938; American Association of State Highway O
p. 152. This method has been withdrawn by the
ciation.

making this test, the specimen was on the anvil in its most stable position, ally with the least dimension vertical, the movable ball dropped on the speci- from a height of 1 inch. The height all was increased 1 inch after each blow l the specimen failed or until it with- d a drop of 7 inches. Under normal con- ons, a test sample containing 50 to 100 es of the same sieve size was used. An irical value for each sample was ob- ed by multiplying the number of pieces h failed by the square of the drop, in es, at which they failed, and dividing sum of these values by the total number pieces tested. For the purpose of this putation, pieces which did not fail at a of 7 inches were assumed to fail at a of 10 inches. This value, called the ghness factor, can vary from a minimum to a maximum of 100.

he results of these tests are shown in e 4. Although higher toughness factors e found for the hard materials than the , there is a considerable amount of over- ping of the two sets of values. It is arent that the toughness test for gravel s not separate hard from soft material. er a review of the detailed records of test, it appears that the falling ball is h too heavy to separate soft pieces from d but brittle pieces. Furthermore, when brittle piece fails, the fracture is ap- ent, but many pieces of soft material fail without the break being seen from ve as the operator would normally view specimen. This results in the soft piece ng given a higher rating than it should e, thereby decreasing the value of the .

n an attempt to correct these difficulties, ther toughness apparatus was made ng a steel ball of 1⅞-inch diameter. For tain sizes of particles, the 1⅞-inch ball s found to furnish more indicative test results than the 2½-inch ball, but the conclusion was reached that to test aggregate of a complete range in size from 2- or 2½-inch to ⅜-inch, at least three toughness testers of different sizes should be used, and each size used to test material of a definite and narrow range in sieve sizes. As time to develop these testers and correlate the test results of each was not available, further consideration of the use of this type of apparatus was deferred.

gure 2.—*The rotary soft-stone machine.*

Table 4.—*Use of the toughness test (2½-inch ball) for the identification of hard and soft materials*

Item	Size of pieces			
	2- to 1½-inch	1½- to 1-inch	1- to ¾-inch	¾- to ½-inch
SOFT MATERIAL				
Number of samples	3	28	29	20
Toughness factor:				
Minimum	18.0	2.7	2.0	1.0
Maximum	59.0	46.2	16.9	5.7
Average	41.6	20.5	7.9	2.5
HARD MATERIAL				
Number of samples	7	23	23	10
Toughness factor:				
Minimum	5.0	4.5	2.9	1.1
Maximum	79.0	67.2	32.3	10.3
Average	42.3	29.8	11.4	3.8

Rotary Soft Stone Machine

Another type of impact test tried involves the use of the rotary soft stone machine shown in figure 2. This machine consists essentially of a cast-iron disk revolving in a horizontal plane inside a vertical steel drum made of ⅜-inch steel plate. The disk is 29 inches in diameter and the drum has an inside diameter of 33¼ inches. Ribs on the upper surface of the disk form pockets to catch the material fed on the disk through a sheet-metal cone, and to throw these pieces against the steel drum. Another cone below the disk serves to collect the sample and lead it to a pan in which the tested material can be inspected. The disk is powered by a variable-speed motor and can be operated at speeds from 110 to 200 r.p.m. In these tests, the fastest speed was used. The test was conducted on individual sizes of aggregate. The weight of the test sample was determined, and the pieces passed singly through the machine. After all pieces had been tested, the sample was sieved on the original retaining sieve, and the weight of material passing this sieve expressed as a percentage of the original weight of the sample.

The results obtained with the rotary machine are given in table 5. These results indicate the same conditions as were found for the falling-ball apparatus. Hard but brittle material as well as soft material is readily broken in the rotary machine, and it does not appear possible to separate truly soft pieces from others with this type of test.

Hand-Hammer Tests

Several other types of impact tests were tried. In former years, a hammer test was occasionally used to identify soft pieces. Although the application of a hand hammer involves a number of intangible conditions, it was believed desirable to include this test in the investigation. The hammers used varied from a 2-ounce tile-setter's hammer to a stone-mason's hammer with a 2-pound head, as shown in figure 3. Several different types of technique were used. In one, the hammer was allowed to drop without bending of the wrist; in another, the hammer was swung by movement of the wrist only; in a third, the end of the hammer handle was placed on the table and the hammer head allowed to fall through an arc of about 8 inches. The tile-setter's hammer has one flat and one sharply beveled end. With this hammer, one method included a free swing of the arm, with the flat face striking the piece under test. In another application of the same small hammer, the beveled end was used to peck at the test specimen to determine whether or not the material could be flecked away or cut by

Table 5.—*Use of the rotary soft-stone machine for the identification of hard and soft materials*

Item	Size of pieces			
	2- to 1½-inch	1½- to 1-inch	1- to ¾-inch	¾- to ½-inch
SOFT MATERIAL				
Number of samples	3	25	28	18
Loss:				
Minimum ... percent	13.5	2.5	2.5	1.4
Maximum ... do	22.0	29.9	21.4	20.8
Average ... do	19.0	11.2	10.4	9.6
HARD MATERIAL				
Number of samples	5	19	21	9
Loss:				
Minimum ... percent	1.0	2.0	2.5	1.4
Maximum ... do	24.0	19.5	32.0	34.2
Average ... do	15.9	10.3	9.9	11.6

Figure 3.—Hammers and scribes used in soft piece test. Left to right: 2-pound stone-mason's hammer, 1-pound tinner's hammer, 8-ounce tinner's hammer, 2-ounce tile-setter's hammer, brass scratch pencil, knife, and rubber mallet.

light taps. Consideration was also given to the type of failure of a specimen under blows of a reasonably heavy hammer. It was thought that if the material were soft it would crush under the hammer, producing a large amount of powder with relatively few large fragments; hard material, on the other hand, would break to sharp-edged fragments with relatively little powdering. Of all these hand-hammer tests, none gave satisfactory results, and this type of test was discontinued.

Consideration was then given to an impact test using as the striker an article which would deform around the piece under test but still transmit stress to it. The articles considered for this application were a device known in some circles as a blackjack, and a mallet with a rubber head such as is used in removing dents from automobile bodies. A blackjack having a leather case filled with lead shot was tried, but after a few tests the leather broke and further consideration of this was discontinued. For a few very soft materials, the rubber mallet gave satisfactory results, but moderately soft materials of 1-inch size or larger could not be crushed with the mallet. This test was also discontinued.

Compression Tests

The suitability of a compression test to identify soft pieces was tried. A small apparatus known as the Douglass stone meter [3] has been used for such a test, but the maximum load specified is only 75 pounds and this load will crush only the weakest specimens. This apparatus is shown in figure 4. The use of a hydraulic compression testing machine was then proposed. In the method considered, an attempt was made to apply load to the particle through ½-inch steel balls. For pieces of irregular shape, this was very difficult to perform, and flat-faced steel cylinders of ½-inch diameter were substituted for the balls. The pieces under test were ground on a lap to secure bearing faces, and were tested with the least dimension in a vertical position. Load was applied at a slow but predetermined rate and failure determined to the nearest 10 pounds. Each sample tested contained from 20 to 100 pieces.

The results obtained are given in table 6. It will be observed that no well-defined separation between hard and soft materials is obtained. Study of the pieces under load revealed one interesting feature. In testing one material—a shale which occurs in rather thin pieces—it was noticed that the portion of the piece not in contact with the loading cylinders fell away at a relatively low load, but the material between the loading cylinders became more compact as the loading continued. In one case, this material was loaded to 35,000 pounds or almost 180,000 pounds per square inch. It is apparent that this type of loading is unsuitable for thin specimens of soft material and that the test does not separate hard from soft material.

Freezing and Thawing Test

The freezing and thawing test was used to determine whether any relationship could be established between the results of this test and the hardness of the materials considered. The samples were immersed in water for 24 hours prior to freezing, frozen at about 15° F. in water, and thawed at about 80° F. A 24-hour cycle was used. After 10 cycles of the test, the samples were examined. With only a few exceptions, this short test failed to differentiate between hard and soft materials. The test was then resumed for another 10 cycles. After the twentieth cycle, the samples were dried, sieved on a sieve with openings ha[illegible] linear dimensions one-half the size of [illegible] in the original retaining sieve, and t[illegible] material passing the sieve expressed [illegible] percentage of the weight of the ori[illegible] sample. The half-size sieves were [illegible] rather than the original sieves to pr[illegible] the inclusion, in the loss, of those p[illegible] which might pass the original reta[illegible] sieve due only to minor flaking or chip[illegible] Results of these tests are given in ta[illegible]

Figure 4.—Douglass stone meter in use. T[illegible] the right are the toughness mac[illegible] with the 1⅞-inch and 2½-inch ba[illegible]

Table 6.—*Use of the compression machine for identification of hard and soft materia[illegible] (load applied through flat faces of ½-inch diameter)*

Item	Size of pieces			
	2- to 1½-inch	1½- to 1-inch	1- to ¾-inch	¾- to ½-[illegible]
SOFT MATERIAL				
Number of samples	4	9	20	[illegible]
Compressive strength:				
Minimum ... lb	1,130	540	120	12[illegible]
Maximum ... do	2,910	2,970	2,770	3,53[illegible]
Average ... do	1,840	1,270	860	1,01[illegible]
HARD MATERIAL				
Number of samples	5	10	13	[illegible]
Compressive strength:				
Minimum ... lb	500	860	690	48[illegible]
Maximum ... do	3,460	2,950	3,250	1,29[illegible]
Average ... do	1,890	1,830	1,750	86[illegible]

Table 7.—*Use of freezing and thawing (20 cycles) for identification of hard and soft material*

Item	Size of pieces			
	2- to 1½-inch	1½- to 1-inch	1- to ¾-inch	¾- to ½-[illegible]
SOFT MATERIAL				
Number of samples	1	12	21	11
Loss passing ½-size sieve:				
Minimum ... percent	...	3.1	5.0	9.4
Maximum ... do	...	92.8	93.0	92.2
Average ... do	9.2	26.1	42.5	51.5
HARD MATERIAL				
Number of samples	4	11	14	3
Loss passing ½-size sieve:				
Minimum ... percent	2.7	0.6	0.4	5.4
Maximum ... do	31.6	18.2	51.4	25.3
Average ... do	11.8	5.0	11.4	13.1

[3] Douglass stone meter described in Method T-8-24, *Standard Specifications for Highway Materials and Methods of Sampling and Testing, 1938;* American Association of State Highway Officials, p. 154. This method has been withdrawn by the Association.

onsiderable overlapping of test results ound, but the average values are sep- :ed so widely that they indicate some ibilities in the use of this method for identification of hard and soft aggre- s. The main objections to this test are length of time required and the expense nonportability of the apparatus. The appears to be of some value for use in arch investigations, but it hardly seems able for a routine testing procedure.

evision of the Compression Test

hortly after this investigation had been ted, the entry of the United States into ld War II required that the work be ontinued. Due to lack of storage space, a few of the samples originally re- ed were kept intact and, consequently, itable correlation between the two por- s of the investigation cannot be estab- ed without repeating a large amount of k.

hen the investigation was resumed in 5, a study of the then existing data indi- d that possibly a fair trial had not been n to the compression test. In the pre- is work, plane and approximately paral- faces had been ground on each piece ed, and the pieces loaded between flat- d cylinders of ½-inch diameter. The r of grinding faces on 50 to 100 pieces ach size in each sample tested was con- red objectionable, and some means of ing pieces of any shape without prelim- y grinding was sought. Trials were le of a number of different types of load- devices. After considerable work, a ling device consisting of a single-point er contact and a three-point lower sup- t was adopted. As shown in figure 5, upper contact consists of a short steel of ½-inch diameter, with a hemispheri- end, which is fastened to the spherical ring block of a hydraulic cube-testing hine. The lower bearing consists of three ½-inch diameter steel balls grouped together so that their surfaces are in contact, and welded to a small steel base. With this loading and support arrangement, most pieces of both regular and irregular shape can be placed in a stable position for the test.

To obtain values for use in identifying pieces of hard, sound aggregate, several hundred pieces of each size of three different materials were tested and the breaking load of each piece determined. From the data obtained, the following loads were selected as indicating hard materials:

Size of piece, inches	*Load, pounds*
⅜ to ½	200
½ to ¾	350
¾ to 1	500
1 to 1½	750
1½ to 2	1,100
2 to 2½	1,500

Tests of Commercial Gravels

With the establishment of these tentative acceptance values for hard material, it was believed desirable to conduct tests on a number of different materials to determine whether the test would be found satisfactory. Only a few of the materials obtained in 1941 were still available, and these had been sampled so extensively that complete ranges in size of particle could not be obtained. To obtain samples for further tests, the National Sand and Gravel Association was requested to furnish samples of commercially produced gravels which would contain some soft material. To the samples received from the Association were added a number of gravels which had been submitted to the laboratory for routine tests. These samples were tested for soft-piece content using the compression test described above, the 20-cycle freezing and thawing test, and the Los Angeles abrasion test. In the last test, determinations of the percentage of wear were made at 100 and 500 revolutions and a ratio of the losses used as an expression of the amount of soft material in the sample.

Figure 5.—Compression test for soft pieces, using a three-point support and a single-point load-bearing contact.

The results of these tests are given in table 8. Inspection of the results discloses immediately that there is little agreement among the indications of the three methods of test. For some few samples, all three methods show the presence of appreciable amounts of soft material. In most cases, however, the three methods give different results. One reason for nonuniformity among the three methods is the variance of the unit of failure on which the test result depends. In the compression test, the pieces of the sample are tested separately, and the whole piece is discarded if it fails to meet the conditions of the test. In the Los Angeles abrasion test and in the freezing and thawing test, it is entirely possible that only a portion of a given particle may be included in the loss. Consequently, it is doubtful that any satisfactory agreement among different methods of test can be established unless the unit of failure is the same in each case.

Consideration of the values obtained in the compression test shown in table 8 indicates that the limits set for the identification of hard pieces are probably too severe. A review of the individual test results for each sample shows a very high percentage of failures in the smaller sizes of piece, and also an excessive percentage of failures for pieces which tend toward a flat shape. In this test, the point of application of the load is normally above a point equidistant from the point of support of each of the three balls in the lower bearing. With thin or flat pieces, this could result in flexure of the piece under test, and the failure would be by bending instead of by compression.

Table 8.—*Soft-piece tests on commercially produced gravels*

Sample No.	Los Angeles abrasion test			Compression test: Percentage of soft material, by weight	Freezing and thawing test: Loss after 20 cycles
	Loss at 100 revolutions	Loss at 500 revolutions	Ratio of losses [1]		
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
67464	6.0	28.1	21.4		27.4
67621	4.9	24.2	20.2		10.4
67622	4.4	22.7	19.4		10.3
67628	8.1	32.6	24.8		9.1
67629	5.4	27.3	19.8		9.3
67680	4.2	23.4	17.9		6.8
67696	4.6	23.8	19.3		7.5
67757	5.6	23.6	23.7	12.1	4.2
67858	7.3	26.4	27.7		11.0
67909	5.6	23.3	24.0		17.0
67910	4.2	25.0	16.8		17.2
67954	6.1	27.8	21.9		20.4
68516	5.6	26.5	21.1	15.6	11.2
68768	7.6	30.7	24.8	24.5	19.7
68769	5.4	26.3	20.5	19.5	6.5
68770	5.7	27.1	21.0	21.3	5.7
68771	4.1	21.3	19.2	14.4	7.6
68772	6.5	29.0	22.4	26.2	8.4
68773	5.3	26.6	19.9	23.7	3.8
68774	8.5	32.9	25.8	33.1	12.7
68775	6.8	30.8	22.1	18.8	8.9
68776	6.4	31.8	20.1	38.9	21.3
68777	7.4	32.4	22.8	29.8	29.2
68778	6.8	29.6	23.0	14.0	4.1
68779	5.8	25.5	22.8	23.7	2.4
68780	6.6	30.3	21.8	17.6	9.5

[1] Ratio of loss at 100 revolutions to loss at 500 revolutions.

Review of Methods of Test

Late in 1946, several new methods of testing aggregates for content of soft pieces were suggested. These new methods included a scratch test using a scribe of yellow brass, and two abrasion tests. In one of the latter, the sample was placed in a canvas bag with a charge of steel balls and the bag dropped on or swung against an anvil a given number of times. In the other abrasion test, the sample alone was placed in a bag and subjected to blows delivered by a rubber-headed mallet, freely swung as shown in figure 6. In trying these methods, it was considered desirable to include in the program of tests some of the methods which had previously been used.

Figure 6.—Bag and mallet test for soft pieces.

The material used in these tests consisted of quartz gravel of a reasonably uniform hardness to which was added definite quantities of soft stone or gravel obtained from the remnants of the samples received in 1941. It seemed possible that the test operators might be influenced by the color of the different pieces and would unconsciously classify them on this basis, and suggestions were made that all the material be dyed to a uniform color, or the operators fitted with colored glasses. Both suggestions, after some consideration, were rejected and the difficulty overcome in part by the use of some soft material of nearly the same color as the base gravel. Furthermore, most of the tests made have definite end points, and the operator is not required to decide whether the material does or does not meet the conditions of the test.

Several changes in the test procedure as previously used were thought to be desirable. A brief description of each method follows.

Method 1: Steel scratch test.—Each piece was scratched with a sharp knife blade. The weight of the pieces identified as soft was reported as a percentage of the original weight of the sample.

Method 2: Brass scratch test.—Each piece was scratched with a pointed scribe prepared from ¼-inch diameter yellow brass rod. The results were reported as in method 1.

Method 3: Light hammer test.—The test piece was placed on an anvil in its most natural position of repose, held firmly with the fingers, and struck at the center of the upper face with the flat end of the tile-setter's hammer. The hammer was swung through an arc of about 6 inches using only a natural movement of the wrist. Softness was recognized by crushing or crumbling of the piece under test. A clean fracturing or splintering of the piece—that is, breaking into smaller but solid fragments without considerable powdering—was not considered indicative of softness. More than one blow was permitted if necessary to classify the piece properly. The results were reported as in method 1.

Method 4: Rubber mallet test. — This method followed the procedure given in method 3, but using a rubber mallet instead of the tile-setter's hammer.

Method 5: Toughness test for gravel.—The falling-ball apparatus previously described, and illustrated in figure 1, was used. The 2½-inch ball was dropped as follows:

Size of piece, inches	*Height of fall, inches*
1½ to 1	3
1 to ¾	2
¾ to ½	1

The test piece was held on the anvil and adjusted under light tapping of the free ball to a secure bearing. The free ball was then raised to the height indicated for the size of aggregate under test and allowed to fall on the piece. Softness of the piece was shown by crushing, powdering, or crumbling. The test result for each piece was reported as in method 1.

Method 6: Toughness test for gravel.—The procedure given in method 5 was repeated, using the apparatus containing the 1⅞-inch ball, and with heights of fall as follows:

Size of piece, inches	*Height of fall, inches*
1½ to 1	5
1 to ¾	3
¾ to ½	1

Method 7: Rotary soft-piece test.—The rotary machine previously described, and illustrated in figure 2, was operated at its slowest speed (about 110 r.p.m.). The pieces of the test sample were fed separately into the machine and all debris caught. The material passing the original retaining sieve was determined, and expressed as a percentage, by weight, of the original sample.

Method 8: Douglass stone meter tes
The stone meter was used with the foll
ing loads:

Size of piece, inches	*Applied poun*
1½ to 1	125 (Maximum loa of spring)
1 to ¾	75
¾ to ½	60

The results were reported as in metho

Method 9: Compression test.—The t
were made in the hydraulic testing
chine with the one-point upper and th
point lower bearing surfaces, using the
lowing loads:

Size of piece, inches	*Applied poun*
1½ to 1	500
1 to ¾	350
¾ to ½	200

The piece tested was placed in its
stable position on the three-point sup
and load applied without shock through
single-point contact on the upper su
of the specimen. Breakage of the speci
at a load below those indicated constit
failure. The results were reported a
method 1.

Method 10: Bag abrasion method
1,000-gram sample was placed in a 10
14-inch canvas bag with an abrasive ch
of five 1⅞-inch diameter cast-iron or
balls. The neck of the bag was fast
securely to prevent loss of the sample.
bag was swung 100 times through a
tance of 12 inches against an anvil.
sample was then removed from the bag
sieved on a No. 4 sieve. The material p
ing this sieve was expressed as a percen
of the original weight of the sample.

Method 11: Bag and mallet method
1,000-gram sample was placed in a 6-
inch canvas bag and the neck fastene
curely to confine the sample in the
possible space. The bag was then p
on an anvil and struck 100 times wi
rubber-headed mallet. The blows were
tributed over the side of the bag, and
each tenth blow the bag was turned ov
expose the lower side. The results
determined as in method 10.

Method 12: Los Angeles abrasion te
Samples weighing 5,000 grams of each
of material were tested in the Los An
machine, with an abrasive charge
steel balls weighing 5,000 grams. The
centage of wear was determined at 10
500 revolutions.

The results obtained in these test
given in table 9. The values shown i
first line of the table are the percent
by weight, of soft material which
added to the quartz gravel. The v
given in the rest of the table, excep
those of the Los Angeles abrasion test
the percentages by weight of soft ma
found by the test method indicated.
values given for the Los Angeles test
the losses in percentages by weight obt
in the tests. The ratio of the losses a

Table 9.—*Results of tests for soft pieces using prepared samples*

Method	Percentage of soft pieces			
	Size of pieces			Average
	1½- to 1-inch	1- to ¾-inch	¾- to ½-inch	
Soft pieces placed in material	4.8	16.2	10.4	10.5
Scratch hardness methods:				
Steel scribe	17.6	18.2	14.9	16.9
Brass scribe	4.8	16.3	10.6	10.5
Impact methods:				
2-ounce hammer	11.3	18.8	17.9	16.0
Rubber mallet	1.4	10.1	12.6	8.0
Rotary machine	14.6	10.6	10.9	12.0
Toughness, 2½-inch ball	10.2	34.1	21.1	21.8
Toughness, 1⅞-inch ball	20.1	22.0	10.2	17.4
Compression method:				
Douglass machine	8.5	4.8	0.6	4.6
3-point support	4.2	16.9	21.0	14.0
Abrasion method:				
Bag abrasion	6.7	18.0	14.0	12.9
Bag and mallet	6.4	11.7	11.7	9.9
Los Angeles machine:				
Loss at 100 revolutions	5.1	11.9	14.8	—
Loss at 500 revolutions	22.5	40.3	45.3	—
Ratio, 100/500	22.7	29.5	32.7	—

500 revolutions has been thought to [h]e some relation with the amount of soft [ma]terial in the sample. A comparison be[twe]en these values and the amounts of soft [ma]terial actually added to the base gravel [ind]icates that this test, as made on indi[vid]ual sizes of aggregate, does not furnish [th]e results which are indicative of the [am]ount of soft material in the sample.

The most favorable results obtained in [thi]s series of tests are those furnished by [the] brass scribe, the rotary soft-piece ma[chi]ne, and the bag and mallet test. In pre[vio]us work, when the rotary machine was [op]erated at a speed of 200 r.p.m., it had not [be]en very significant results. Although [mu]ch better results are obtained when the [ma]chine is operated at a slower speed, fur[the]r consideration of this type of testing [equ]ipment was discontinued as the machine [was] not suitable for field use.

Bag and Mallet Test

Some questions developed regarding the [siz]e of sample which would be most desir[ab]le in the bag and mallet method, and also [ho]w many tests should be made to obtain a [tes]t value representative of a given mate[ria]l. From a practical consideration, a [sa]mple of the size used appears to be about [as] large as is desired for readiness of handling. Should the material to be tested have a maximum size greater than 1½ inches, the size of the test sample must be increased and a larger bag be used. Considerable development work along this and other lines remains to be done before this method can be adopted for use. To determine the other feature of particular interest here—that is, the number of 1,000-gram samples which should be tested for a material with a maximum size of 1½ inches—another series of tests was made.

In these tests, a soft sandstone was added in definite quantities to a quartz gravel to prepare four aggregates containing 0, 4, 8, and 12 percent soft material. Each material, both the hard and soft, was graded uniformly from 1½- to ⅜-inch. After each aggregate had been prepared, it was mixed thoroughly and ten 1,000-gram samples taken for test. The attempt made here was to duplicate conditions which would exist if a sample of graded aggregate were tested by the bag and mallet method. Each sample was placed in a double canvas bag, one bag inside of the other, and struck 100 times with a rubber-headed mallet. The sample was then sieved on a No. 4 sieve, and the amount passing the sieve determined as well as the amount of soft material retained on the sieve.

Table 10.—*Bag and mallet tests on prepared samples of quartz gravel containing soft sandstone*

Sample No.	Amount of soft stone added to gravel							
	None		4 percent		8 percent		12 percent	
	Loss	Cumulative average loss	Loss	Cumulative average loss	Loss	Cumulative average loss	Loss	Cumulative average loss
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	4.4	4.4	6.2	6.2	12.5	12.5	9.7	9.7
2	3.7	4.0	6.2	6.2	9.9	11.2	11.2	10.4
3	5.9	4.7	6.3	6.2	8.7	10.4	12.3	11.1
4	4.3	4.6	7.4	6.5	10.6	10.4	10.7	11.0
5	3.7	4.4	5.8	6.4	8.2	10.0	13.1	11.4
6	3.9	4.3	7.0	6.5	9.0	9.8	12.4	11.6
7	4.8	4.4	6.0	6.4	10.0	9.8	13.4	11.9
8	4.7	4.4	6.3	6.4	6.9	9.5	9.8	11.6
9	5.0	4.5	6.5	6.4	6.9	9.2	10.9	11.5
10	3.7	4.4	5.0	6.3	9.5	9.2	9.1	11.3

A summary of the results obtained is given in tables 10 and 11. In table 10, the percentage of loss for each sample tested is given, together with a cumulative average. For most aggregates, an average value obtained from tests of three samples is very nearly the same as the average for all ten samples of a kind tested. Of more importance, however, is the comparison of the amount of soft stone placed in the aggregate, the test result obtained, and the amount of soft stone remaining in the sample after the test, as shown in table 11. Tests of the base gravel show a loss of 4.4 percent. The results obtained in tests of the gravel containing 4 percent of soft stone show 6.3 percent loss but 2.0 percent of soft stone is left in the sample. This 6.3 percent loss then includes 2.0 percent of soft stone and 4.3 percent from the quartz gravel.

Table 11.—*Percentage of soft stone remaining in sample after test,[1] and loss from gravel*

Soft stone added to gravel	Cumulative average loss	Soft stone remaining	Loss from gravel
Percent	*Percent*	*Percent*	*Percent*
0	4.4	...	4.4
4	6.3	2.0	4.3
8	9.2	3.3	4.5
12	11.3	4.5	3.8

[1] Averages for 10 samples.

By a similar method of figuring, the test results for the aggregates containing 8 and 12 percent of soft stone include 4.5 and 3.8 percent, respectively, of the quartz gravel in the loss. Although it is granted that the quartz gravel may contain material of a friable nature, a comparison of the gravel and the sandstone used in these tests indicates that a satisfactory method of test should show a greater recovery of the soft material in the test results. The fact that from 38 to 50 percent of the soft sandstone placed in the sample remains there after the test shows definitely that the test as made is not satisfactory.

Brass Scratch Test

In this investigation, considerable difficulty was encountered in trying to unify the conceptions offered by different authorities regarding a proper description of a soft piece, and much time and effort were spent to develop a satisfactory method of test for soft pieces. In addition to the various tests described here, many more fanciful tests were considered and, in some cases, plans for quite elaborate pieces of testing equipment were prepared. A few of these fanciful tests were tried but did not prove even remotely satisfactory. Possibly we have been trying to make something difficult of a really simple problem: The testing of aggregates to determine the presence and quantity of soft pieces—those which yield easily to physical pressure or are not resistant to cutting or wear.

Among all of the test methods considered, the most simple and direct is a scratch hardness test. This would not indicate the pieces which are unsound, or light-weight, or highly absorptive; or the pieces of chert which appear to be included by some authorities in the general classification of soft pieces. It would, however, show which pieces of the sample are actually soft, including those formed of a soft material and those which are so poorly bonded that the separate particles in the piece are easily detached from the mass.

A satisfactory test for scratch hardness was used in this investigation. It consists merely of scratching the material under test with a piece of yellow brass, as shown in figure 7. This brass will not scratch limestone of good quality, but it is hard enough to scratch badly weathered materials which may be objectionable for use in concrete. The brass used first in these tests consisted of a ¼-inch rod which has a Rockwell hardness of about B70. Later in this work, the thought of preparing a pencil with a brass rod replacing the lead was developed. For this purpose, drill-rod brass [4] of about 1/16-inch diameter was used. Efforts were made to obtain a Rockwell hardness value for this material, but the rod was too small to secure a satisfactory reading. For the purpose of this test, it is probable that minute distinctions in the hardness of the brass used is of little moment. Possibly it is sufficient to describe the material as hard, yellow brass.

Figure 7.—The scratch test, using a hard, yellow brass scribe "pencil" made with a drill-rod brass core encased in wood. This is the only test for soft aggregates suitable to both field and laboratory use.

The test consists of separating the aggregate into different sizes, down to ⅜-inch, and determining the scratch hardness of a representative number of pieces of each size. With material of fairly uniform quality, 10 pieces of a size may be sufficient, but 50 or 100 pieces of a size may be required for heterogeneous materials. The weight of the pieces identified as soft is determined for each size, and a weighted average based on the grading of the sample is computed.

This test is for soft pieces only. If it is desired to limit the amount of other types of deleterious materials in aggregates, separate mention of these should be made in specifications.

[4] So called as it is obtainable in the same sizes as steel twist drills.

The courtesy of the State highway departments and the National Sand and Gravel Association in furnishing samples for use in these tests is appreciated, as are the many valuable suggestions offered by Mr. T. E. Smith, and the assistance furnished by him and the other employees of the laboratories of the Bureau of Public Roads.

Errata

In order to rectify a printer's error, page 121 of the February 1951 issue of PUBLIC ROADS (Vol. 26, No. 6) was reprinted with a heading "Errata Sheet" and distributed to all subscribers. A number of inquiries since received indicate that the purpose of this was in some cases misunderstood. The error involved a mix-up of text on page 121, under the caption "Part IV—Over-All Intersection Capacity." As originally printed, the first and third columns were inadvertently interchanged, so that the lower portion of the page must be read (by columns) from right to left.

The printer also unfortunately turned chart 4, on page 128, to read from the left edge of the page instead of the right edge, thus considerably impairing the facility of use of the chart series.

While these errors occurred after final proofing and were beyond the control of the editorial staff of PUBLIC ROADS, they nevertheless greatly regret the inconvenience caused thereby.

A complete list of the publications of the ureau of Public Roads, classified according to ıbject and including the more important rticles in PUBLIC ROADS, may be obtained upon quest addressed to Bureau of Public Roads, 'ashington 25, D. C.

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Road Work on Farm Outlets Needs Skill and Right Equipment.

STATUS OF FEDERAL-AID HIGHWAY PROGRAM

AS OF FEBRUARY 28, 1951

(Thousand Dollars)

STATE	UNPROGRAMMED BALANCES	ACTIVE PROGRAM											
		PROGRAMMED ONLY			PLANS APPROVED, CONSTRUCTION NOT STARTED			CONSTRUCTION UNDER WAY			TOTAL		
		Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles
Alabama	$18,088	$10,575	$5,344	214.9	$6,542	$3,327	129.5	$14,783	$7,107	352.5	$31,900	$15,778	696.9
Arizona	274	7,709	5,445	186.0	353	243	2.0	6,610	4,734	120.1	14,672	10,422	308.1
Arkansas	6,990	8,515	4,709	238.2	3,073	1,703	97.0	15,321	7,582	404.8	26,909	13,994	740.0
California	6,040	57,266	17,167	273.3	9,774	4,948	44.2	52,113	24,768	262.2	119,153	46,883	579.7
Colorado	3,957	6,231	3,527	223.6	2,921	1,522	64.0	11,152	6,193	241.3	20,304	11,242	528.9
Connecticut	3,668	7,664	3,888	21.3	3,659	2,025	1.7	6,353	3,485	10.6	17,676	9,398	33.6
Delaware	2,185	1,014	608	22.5	19	8		6,449	3,153	38.4	7,482	3,769	60.9
Florida	7,862	8,222	4,339	153.4	9,242	4,496	176.6	17,707	8,755	392.1	35,171	17,590	722.1
Georgia	8,160	12,985	6,668	243.0	11,898	5,071	91.9	28,555	14,135	694.4	53,438	25,874	1,029.3
Idaho	5,583	8,839	5,579	271.6	2,530	1,754	121.1	6,116	3,260	122.1	17,485	10,593	514.8
Illinois	21,364	53,518	28,307	506.5	24,055	12,443	220.8	47,441	22,880	277.5	125,014	63,630	1,004.8
Indiana	13,154	37,044	18,421	183.7	4,648	2,329	28.6	18,424	9,353	96.2	60,116	30,103	308.5
Iowa	3,388	14,498	6,810	750.9	10,284	5,090	301.7	11,310	5,731	291.7	36,092	17,631	1,344.3
Kansas	7,721	11,011	5,262	1,044.8	5,601	2,801	376.9	8,376	4,187	493.8	24,988	12,250	1,915.5
Kentucky	3,005	21,989	10,846	264.3	3,364	1,686	57.1	17,456	8,616	302.0	42,809	21,148	623.4
Louisiana	7,656	14,456	6,870	111.4	8,463	3,984	55.5	21,533	11,363	242.4	44,452	22,217	409.3
Maine	4,280	5,216	2,764	65.6	1,697	889	7.2	6,659	3,538	68.7	13,572	7,191	141.5
Maryland	5,296	4,576	2,265	23.2	3,822	1,481	14.1	11,138	5,099	39.7	19,536	8,845	77.0
Massachusetts	3,677	14,879	6,640	7.3	1,458	529		65,113	32,328	61.9	81,450	39,497	69.2
Michigan	11,003	18,424	9,121	524.4	11,780	6,377	207.9	39,759	16,197	275.2	69,963	31,695	1,007.5
Minnesota	6,034	15,689	8,219	1,382.4	3,075	1,963	114.9	16,791	8,845	276.8	35,555	19,027	1,774.1
Mississippi	9,373	9,109	4,747	345.7	8,161	4,290	229.9	5,871	2,870	178.3	23,141	11,907	753.9
Missouri	12,956	23,668	12,429	690.2	14,338	7,752	351.6	27,541	13,985	369.5	65,547	34,166	1,411.3
Montana	10,106	13,472	6,887	443.4	3,721	2,197	80.5	9,501	5,703	202.5	26,694	14,787	726.4
Nebraska	8,635	16,585	8,628	571.4	7,033	3,479	217.8	9,298	4,947	253.8	32,916	17,054	1,043.0
Nevada	5,738	2,271	1,873	33.0	928	775	65.3	3,496	2,883	113.8	6,695	5,531	212.1
New Hampshire	3,145	2,591	1,472	18.9	443	210	3.7	4,555	2,263	39.4	7,589	3,945	62.0
New Jersey	6,793	5,892	2,946	7.4	3,048	1,522	4.2	18,862	8,702	21.6	27,802	13,170	33.2
New Mexico	4,513	4,376	2,800	88.8	857	552	18.7	9,416	6,008	262.8	14,649	9,360	370.3
New York	47,223	56,400	28,998	153.5	17,012	7,798	42.9	106,555	49,795	200.3	179,967	86,591	396.7
North Carolina	8,692	11,096	5,439	278.0	8,626	3,932	147.2	22,995	11,087	529.9	42,717	20,458	955.1
North Dakota	5,020	8,465	4,371	1,254.2	5,216	2,616	405.0	4,849	2,403	408.1	18,530	9,390	2,067.3
Ohio	15,836	20,415	9,561	222.9	18,376	10,175	203.9	71,424	35,484	267.3	110,215	55,220	694.1
Oklahoma	2,077	21,834	10,268	384.4	6,808	3,575	83.7	24,068	11,815	440.2	52,710	25,658	908.3
Oregon	2,302	3,823	2,238	56.2	7,653	3,922	78.2	10,555	6,094	158.4	22,031	12,254	292.8
Pennsylvania	21,010	7,825	3,823	15.8	11,314	5,510	15.7	80,533	39,803	227.7	99,672	49,136	259.2
Rhode Island	1,769	6,340	3,170	45.0	1,090	544	7.1	13,175	6,691	10.0	20,605	10,405	62.1
South Carolina	5,396	8,462	4,370	227.5	2,877	1,440	58.2	7,663	4,032	216.5	19,002	9,842	502.2
South Dakota	1,154	13,829	7,952	1,126.8	3,240	1,862	231.1	8,378	5,177	610.1	25,447	14,991	1,968.0
Tennessee	7,883	12,273	5,824	271.4	5,393	2,772	101.7	18,975	8,743	323.9	36,641	17,339	697.0
Texas	13,858	8,409	4,292	196.3	15,256	7,717	167.4	46,889	22,196	895.8	70,554	34,205	1,259.5
Utah	4,903	3,089	2,259	71.0	1,488	1,102	36.9	4,484	3,250	140.4	9,061	6,611	248.3
Vermont	1,006	4,577	2,410	63.2	891	449	8.1	4,236	2,077	28.7	9,704	4,936	100.0
Virginia	10,160	19,631	9,727	396.6	5,910	2,945	197.1	14,249	6,943	238.6	39,790	19,615	832.3
Washington	6,520	6,893	2,446	71.5	1,602	836	19.0	21,113	10,112	127.3	29,608	13,394	217.8
West Virginia	5,316	13,211	5,242	92.1	4,512	2,257	50.1	9,212	4,659	96.7	26,935	12,158	238.9
Wisconsin	9,295	28,031	14,698	762.6	3,907	1,889	94.5	13,113	6,498	313.4	45,051	23,085	1,170.5
Wyoming	1,530	1,772	1,151	28.7	4,141	2,694	109.4	6,082	3,745	163.0	11,995	7,590	301.1
Hawaii	2,296	7,716	3,336	14.3	2,193	781	10.6	6,138	2,498	18.5	16,047	6,615	43.4
District of Columbia	3,951	3,960	1,980	4.1	166	83	.9	1,557	971	.9	5,683	3,034	5.9
Puerto Rico	3,635	13,161	6,027	66.0	855	377	3.5	8,128	3,778	33.7	22,144	10,182	103.2
TOTAL	391,476	699,496	344,163	14,713.2	295,313	150,722	5,156.6	1,022,070	506,521	11,955.5	2,016,879	1,001,406	31,825.3