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Public Roads

A JOURNAL OF HIGHWAY RESEARCH

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FEDERAL HIGHWAY ADMINISTRATION

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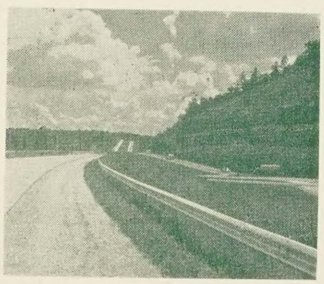

COVER

I–65 between Cullman and Decatur, Ala. (Photo courtesy of State of Alabama Highway Department.)

NOTICE —The title sheet for vol. 36 is now available. (See page 32)

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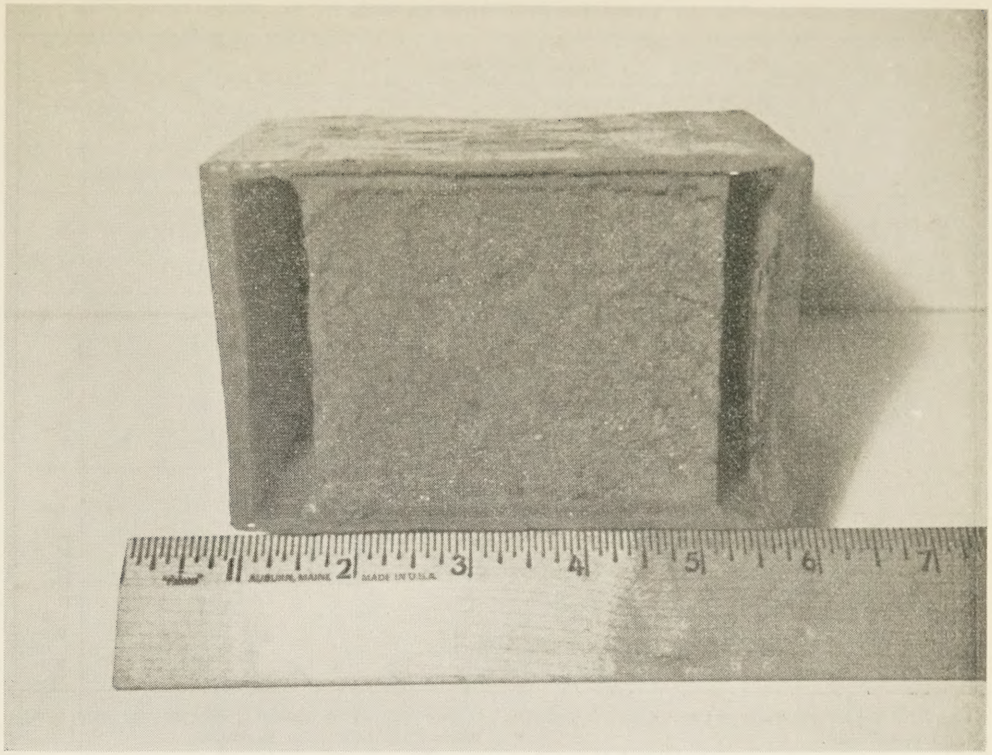

Figure 1.—Wax encased soil specimen.

Migration of Lime in Compacted Soil

Reported by **DONALD G. FOHS**
and **EARL B. KINTER**
Highway Research Engineers,
Materials Division

This study concerns the horizontal migration of lime in compacted block specimens of two plastic soils. Lime slurry was placed at one end of each specimen, and lime migration was permitted for periods up to 180 days. Specimens were then analyzed to determine the amount and distance of lime migration. It appears from this study that applying lime by drilled-hole methods is not useful because the amount and distance of migration is so limited that the bulk of the soil does not benefit from the action of the lime.

Introduction

IN highway construction, stabilizing a soil material with lime usually involves preparing a compacted soil-lime layer in the top portion of the subgrade. Lime, applied to the subgrade surface in a dry form or as a slurry, is mechanically mixed with the soil. The required amount of water is added and the mixture compacted. In very wet soils, or in stiff clayey soils where mixing is difficult, part of the lime may first be lightly mixed with the soil. The partly treated soil is allowed to mellow for a day or two before the remaining lime is added and the mixing and compaction process is completed.

Success of the conventional treatment of subgrade soils with lime has encouraged engineers to consider using lime for treating large earth masses in problem situations where mechanical mixing is not practicable—in deep existing embankments, soft foundations, and landslides. Efforts to place and distribute lime in such soil masses have led to the development of *drill-hole* and *pressure-injection* methods.

The drill-hole method has been used mainly as a maintenance tool in distressed flexible pavement sections. Holes having a diameter of 6 to 9 inches and spaced 5 to 10 feet apart in an arbitrary pattern are drilled through the pavement structure, or through the shoulder near the edge of the pavement, to depths penetrating the unstable soil layer. Lime slurry or dry lime is placed in the bottom of the hole. The hole is then filled with the excavated soil or granular material and capped with base course and surfacing material. The pressure-injection process, an adaptation of techniques associated with oil well drilling, involves jacking a tapered injector through the unstable soil and forcing lime slurry into the soil mass at pressures as high as 600 p.s.i. Slurry is injected at about 1-foot vertical intervals. Injector penetration points are distributed horizontally at spacings assumed to provide good distribution of the lime slurry.

Aside from rapid ameliorative effects, such as reduced plasticity and increased granularity, the principal engineering requirement of a compacted soil-lime mixture is strength development. Although the chemistry of soil-lime interactions is not completely understood, it is agreed that soil and lime react chemically, and that cementitious reaction products such as hydrated calcium silicates and aluminates

Table 1.—Properties of soils [1]

Sieve analysis		
Sieve No.	Keyport clay loam	Cecil clay
	Percent passing	
10	100	100
40	93	92
60	81	88
200	59	78
Hydrometer analysis		
Percentage finer than		
0.050 mm	57	74
.020 mm	52	61
.005 mm	40	47
.002 mm	34	41
.001 mm	30	39
Engineering and chemical analysis		
Liquid limit ... percent	46	56
Plastic limit ... do	22	30
Plasticity index ... do	24	26
Maximum dry density (AASHO T99) ... p.c.f.	110	99
Optimum moisture content ... percent	16	24
Cation exchange capacity ... m.e./100 g.	21.5	6.0
Calcium content [2] ... do	4.0	0.3
... percent	.15	.01
pH	3.9	3.9

[1] AASHO classification: Keyport clay loam, A–7–6(11): Cecil clay, A–7–5(18).
[2] Blank determination by titration as described in text.

Note.—Major clay mineral in Keyport clay loam, montmorillonite; in Cecil clay, kaolinite.

are formed, bonding the soil particles together and thereby promoting strength development in the soil-lime mixture. Because of the considerable amount of particle surface area involved in clayey soils, the small percentages of lime used, and the normal slowness of strength development, it has been recognized that thorough and intimate mixing of the soil and the lime is desired not only to facilitate speed of reaction but to prevent the occurrence of large zones of untreated soil. Most specifications concerning conventional soil-lime stabilization require 80 percent or more of the soil-lime mixture to pass a No. 4 (4.75 mm. opening) sieve.

In both the drill-hole and the injection techniques, lime is placed in rather than mixed with the soil. Especially in the drill-hole method, masses of introduced lime are separated by several feet of untreated soil. It is doubtful that lime so placed in a relatively compact soil mass will be able to migrate in adequate quantity and to a sufficient distance to bring about any meaningful degree of soil alteration. Dry lime, or even a slurry, can hardly be expected to permeate the fine pores of the soil; saturated lime solution from the slurry is limited in quantity and has only a very small lime content; simple diffusion of dissolved lime through the soil water would be expected to be so slow as to be of little value. Despite these apparent drawbacks, engineers having difficult problems with large soil masses have begun to use the drill-lime technique and have expressed considerable interest in pressure injection.

This study was undertaken to obtain further information on the movement (migration) of lime in compacted soil, and thus provide a better assessment of the potential value and effectiveness of these two methods than is now available.

Previous Work

The drill-hole treatment was first used in 1961 in Oklahoma (*1*)[1] where it was applied to a section of flexible pavement which, after a number of years of satisfactory service, had become seriously distressed during an unusually wet season. About 6 months after treatment, the soil had gained sufficient strength to permit repaving. As a result of this apparent success, other sections of distressed pavement in Oklahoma have been similarly treated, and the method has also been tried in various other States.

In 1965 the first application of the pressure-injection method in highway work was attempted in Louisiana (*2*), where a low embankment for a relocated section of U.S. Highway 51 was treated experimentally to prevent settlement. The experiment demonstrated that lime could be forced into the subsoil by this method. The resulting lime distribution was stratified, generally horizontal. Little penetration of the slurry into the heavy clays occurred. The results of this project led Louisiana researchers to conclude that improvements such as closer or continuous vertical injection spacing would be required to make the injection process a workable tool; and that a considerable reduction in cost would be required to make the injection process economically feasible for construction.

[1] References identified by numbers in parentheses are listed on page 6.

The pressure-injection technique was also used in Pennsylvania (*3*) for stabilizing the foundation of a 40-foot embankment being placed over glacial lake sediments. The Pennsylvania experiment demonstrated that the lime slurry flowed through planes of weakness or fissures in the soil mass, resulting in irregularly distributed veinlets and pockets of lime with much of the soil mass remaining, in effect, untreated. With this distribution pattern effective treatment of the entire soil mass would require further lime movement by migration or diffusion subsequent to injection. Observations of the walls of trenches dug a month and a year after injection demonstrated movement of only about 1 inch.

Davidson et al. (*4*) reported the results of a laboratory study in which lime slurry was placed on top of cylindrical specimens of compacted soil. Little movement of lime into the soil was detected. Noble (*5*) indicated that, although calcium does migrate away from a lime source, the rate of movement is very slow. Traskis (*6*) after sampling three Australian field projects that had been lime-treated by the drill-hole method 1 or 2 years earlier, reported that calcium hydroxide did not migrate to an extent which could be considered of any practical importance. Lamb (*7*) tested three methods for inducing lime migration in the laboratory: hydrostatic head, air pressure, and electrochemical. His results suggested that none of the methods would be successful in the field situation.

The Davidson et al. study (*4*) involved vertical movement of lime in a column of soil. The present study was designed to measure the horizontal movement of lime, as this was thought to more closely represent field conditions where lime is injected or placed in drilled holes.

Experimental Materials and Procedures

Soils

Two soils were used: Keyport, a clay loam from Fairfax County, Va.; and Cecil, a clay from Fluvanna County, Va. Data on physical, chemical, and mineralogical properties of these soils are given in table 1.

Table 2.—Properties of hydrated lime[1]

Chemical analysis [2]	
Properties	Percent of total
Silica as SiO_2	0.20
Iron as Fe_2O_3	.06
Aluminum as Al_2O_3	.34
Calcium as $Ca(OH)_2$	97.93
Magnesium as $Mg(OH)_2$	1.10
Sulfur as SO_3	(nil)
Loss on ignition	23.40
Carbon Dioxide (CO_2)	.20
Available calcium oxide (CaO)	75.11
Sieve analysis	
Sieve No.	Percent passing
100	100.00
200	99.70
325	99.50

[1] Chemical and sieve analysis results provided by M. J. Grove Lime Company, Lime Kiln, Md.
[2] Impurities: free of core, ash and dirt.

Lime

The lime used was a commercially available, high-calcium, hydrated lime produced near Stephens City, Va. Sieve and chemical analysis data are given in table 2. The lime was applied to the soil specimens in the form of lime-water slurries having 1:2, 1:3, and 1:6 ratios of lime to tap water.

Specimen preparation

Statically compacted blocks (3 by 3 by 11¼ inch) of each soil were prepared at optimum moisture content and AASHO T 99 maximum dry density. For preparation of the blocks, ASTM Designation: D 1632–59 T, "Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory," was followed, except that the cement indicated in the procedure was omitted. Three small blocks (3 by 3 by 3½ inch) were cut from each large block, and the remaining portion of the large block was dried and saved for blank determinations of lime content.

Each small block was made into a *migration* specimen (fig. 1) by coating all but the two 3 by 3 inch faces (ends) with paraffin wax. As illustrated in figure 1, a wax-walled chamber was formed at each end. One chamber was filled with lime slurry and the other with dry sand. A coating of wax was then placed over the entire top of the specimen to form a seal over the slurry, soil, and sand chambers. Several pinholes were made in the wax over the sand chamber to maintain atmospheric pressure within the wax-enclosed block. Prepared specimens were stored in a high-humidity cabinet at 73°F. and 95 percent relative humidity for periods of 14, 28, 60, 90, and 180 days.

Migration measurements

After completion of its scheduled migration period, each specimen was removed from the cabinet, and the end chambers containing the remaining slurry and the sand were removed. The slurry and the sand portions were sampled for determination of moisture content and discarded. In a few cases, to determine the extent of carbonation during the migration period, an X-ray diffraction pattern of a sample of the slurry was obtained immediately after the specimen was dismantled.

The soil block was then cut into slices by a power band saw (3 by 3 by ⅛ inch, dry weight about 20 grams, representing successive ⅛-inch increments from the lime source) each successive slice being immediately sampled for moisture content and sealed in a separate air-tight, screwtop jar until all required slices had been obtained. To effect drying, the jars (with lids removed) were placed in a vacuum desiccator containing silica gel and Ascarite, a CO_2 absorbent. After vacuum drying, the jars were removed from the desiccator and capped immediately.

As required for determining the lime content, each slice was removed from its jar and quickly ground with a mortar and pestle. The ground material was then returned to the jars and recapped to prevent carbonation. For each slice, a 3-gram portion of the ground material was weighed into a 100 ml. centrifuge tube, about 70 ml. of 0.1*N* HCl was added, and the tube was stoppered and mechanically agitated for 10 minutes. The suspended residue was settled by centrifuging, and the supernatant solution was decanted into a flask and tightly stoppered. The residue was given another HCl treatment and then washed twice with distilled water by the same procedure, each supernatant being in turn decanted into the flask. The accumulated solution was adjusted to a pH of 13+ with potassium hydroxide solution, and made up to a volume of 500 ml. Three 50 ml. aliquots were used for the determination of calcium by titration with a standardized solution of the disodium salt of EDTA, using hydroxy naphthol blue as indicator. The normality of the titrant ranged from 0.005 to 0.01, depending on the anticipated calcium content of the aliquot. The calcium contribution of the original soil to the titration was corrected by subtracting the amount of

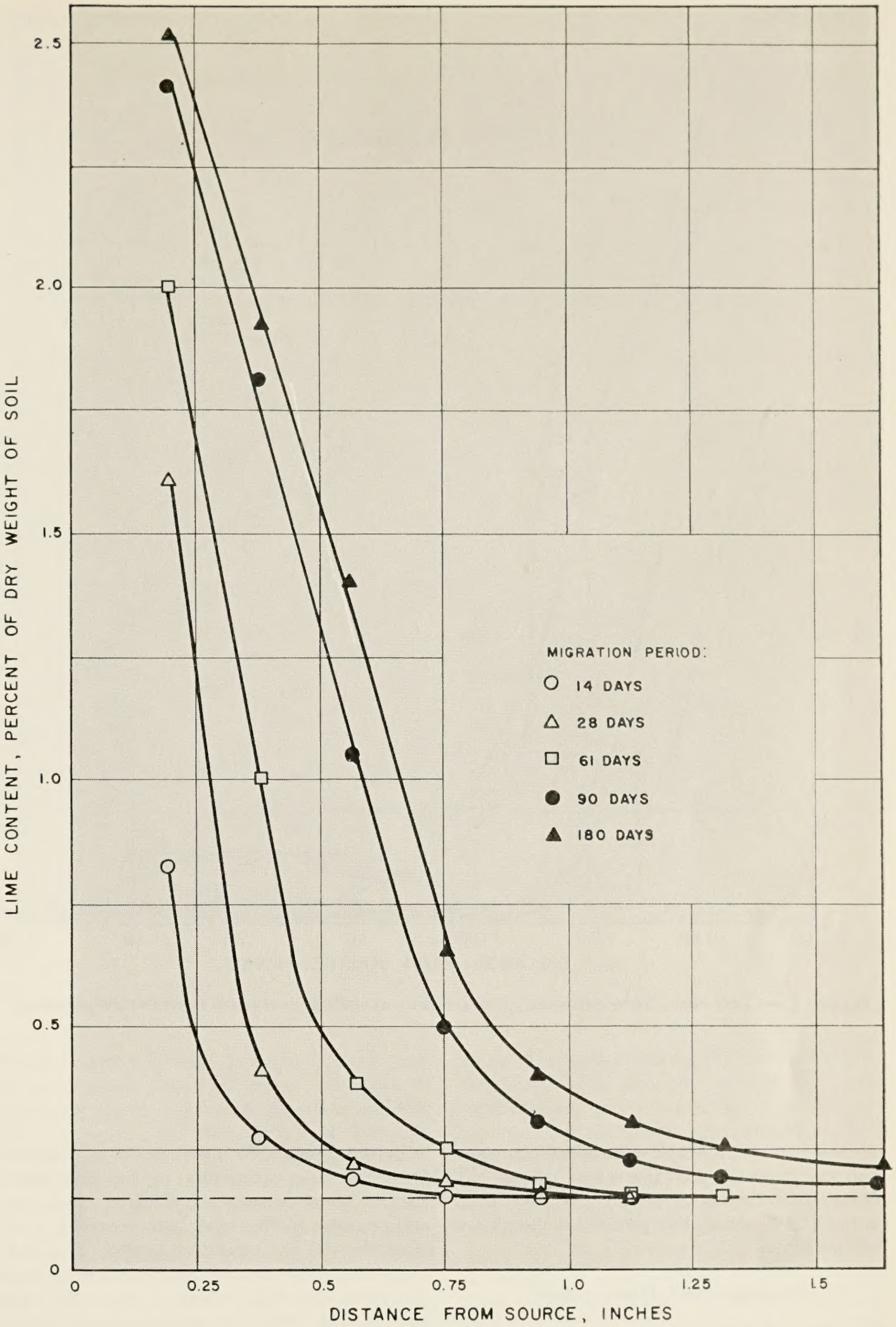

Figure 2.—Keyport loam, lime content vs. distance; molding moisture content 16 percent.

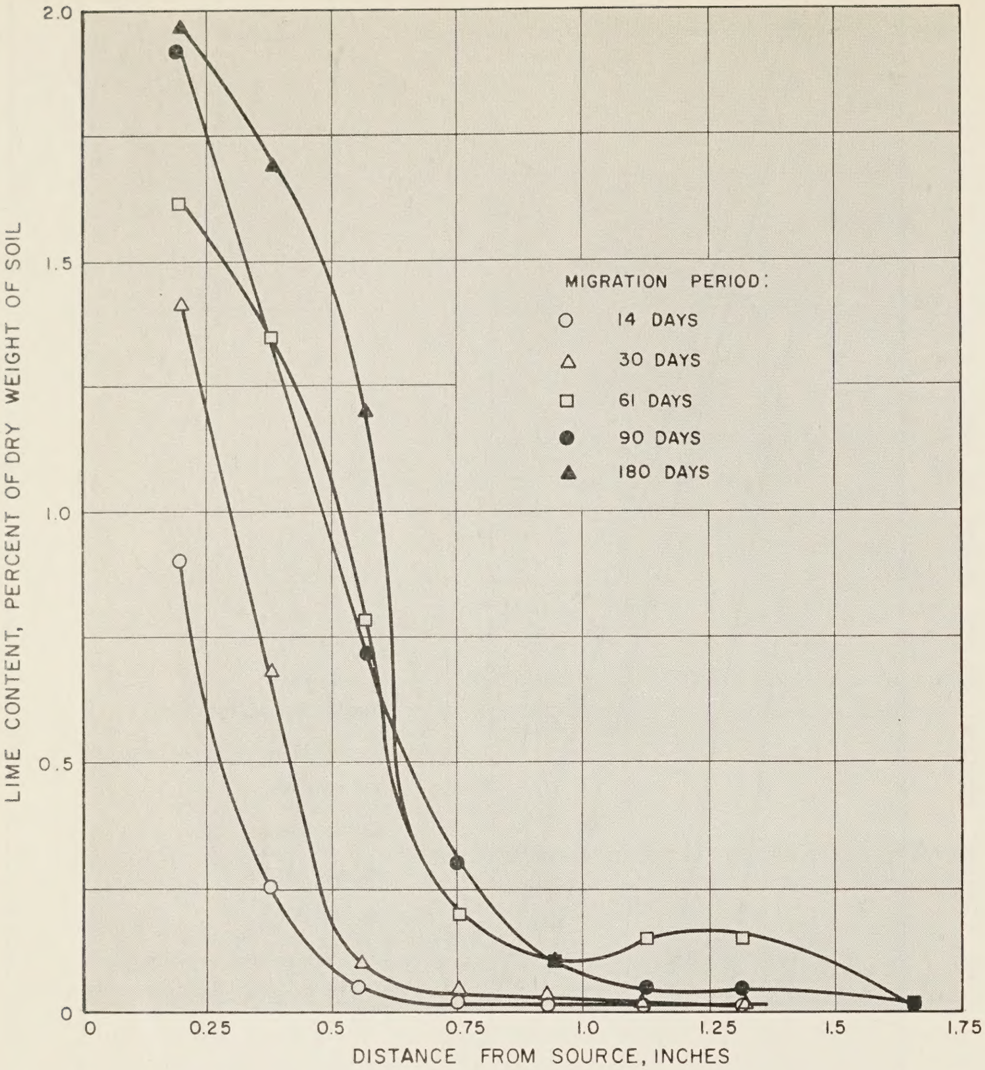

Figure 3.—Cecil clay, lime content vs. distance; molding moisture content 24 percent.

calcium found in a blank determination made with saved portions of the original large soil blocks. The minimum amount of lime that could be detected by this procedure was about 0.01 percent.

Results and Discussion

Condition of slurry at the end of the migration period

When the lime slurry was removed from the specimens at the end of the migration period, the slurry in all cases had the consistency of a soft paste. This paste was always found to be in close contact with the face of the soil specimen. Moisture determinations showed that in the slurries which originally had a lime-water ratio of 1:2 (200 percent water, based on dry weight of lime) the final moisture content of the lime paste averaged about 100 percent, indicating that each such slurry had lost about half of its original moisture. The average final moisture content of the 1:6 slurries was about 150 percent; that of the 1:3 slurries was intermediate.

In the X-ray diffraction patterns obtained from the lime remaining in the lime-water pastes, there was no indication that any carbonation of the lime had occurred, even after the 180-day migration period. This finding attests that the specimen-sealing method employed was fully effective, and thus that any possible effect of carbonation on movement of lime into the soil had been averted.

Lime content vs. distance from the lime source

Data for the calcium contents found at increasing distances from the lime source are presented in figures 2 and 3 for curing times ranging from 14 to 180 days. The dashed horizontal lines on the figures represent the amounts of calcium found in the raw soils by the blank determinations. For the Keyport soil (fig. 2), at the sampling point nearest to the lime source (0.19-inch distance), the greatest content of migrated lime found was about 2.5 percent for the 180-day migration period. At this same distance, migrated lime contents for shorter migration periods ranged down to about 0.8 percent for a period of 14 days. Corresponding percentages for Cecil clay in figure 3 were about 2.0 and 0.9, respectively. From the higher contents near the source, the migrated lime (for both soils) decreased rapidly with increasing distance from the source, approaching the *blank* lime content at about ¾ to 1½ inches, depending on the length of the migration period.

The potential value of the detected percentages of migrated lime in producing strength in the experimental soils may be placed in perspective by the results of earlier (unreported) laboratory tests, in which, with an admixture of 5 percent lime, specimens of Keyport and Cecil soils (compacted to AASHO T 99 maximum density and moist cured 7 days) developed immersed unconfined compressive strength values of about 60 and 30 p.s.i., respectively. Further, with respect to reduction of plasticity, general experience in soil-lime stabilization has indicated that a minimum of about 2 percent lime is required to produce a practical level of improvement. Lime migration characteristics of the experimental soils are very similar, despite important differences in gradation and predominating clay mineral. The experimental work was not designed to provide explanations for this observation.

Migration vs. time

The migration of lime as a function of time is illustrated graphically in figures 4 and 5. Each figure contains four curves, representing the relation between lime content and time at four specific distances from the lime source, ranging from 0.19 to 0.75 inch. Curves for greater distances are not included because little migration occurred beyond about 0.75 inch. The curves show that at all four distances the migration is essentially complete after about 100 days. Judging from the slopes of the curves, the rate of migration is greatest at points nearest the lime source. For a given elapsed time, the decreasing rate of migration at increasing distances from the lime source indicates that as the lime solution passed through the soil, lime was removed and the solution became progressively depleted of lime.

Moisture movement

As previously indicated, the moisture content of each slice was determined at the end of the migration period. The data for migration periods of 14, 90, and 180 days for each soil are presented in figures 6 and 7. They show for all specimens that there was a gain in moisture through most of the specimen and that moisture movement occurred relatively quickly, as evidenced by the fact that curves for 14 days and 180 days are almost collinear. The average moisture content of the soil was slightly higher than the as-molded moisture content of the specimen, and was essentially uniform over the 2 inches of the specimen furthest from the lime source. In nearly all cases, with the Keyport soil, the slice nearest the lime source, and sometimes the second slice as well, was slightly drier than the remainder of the specimen. This effect was more

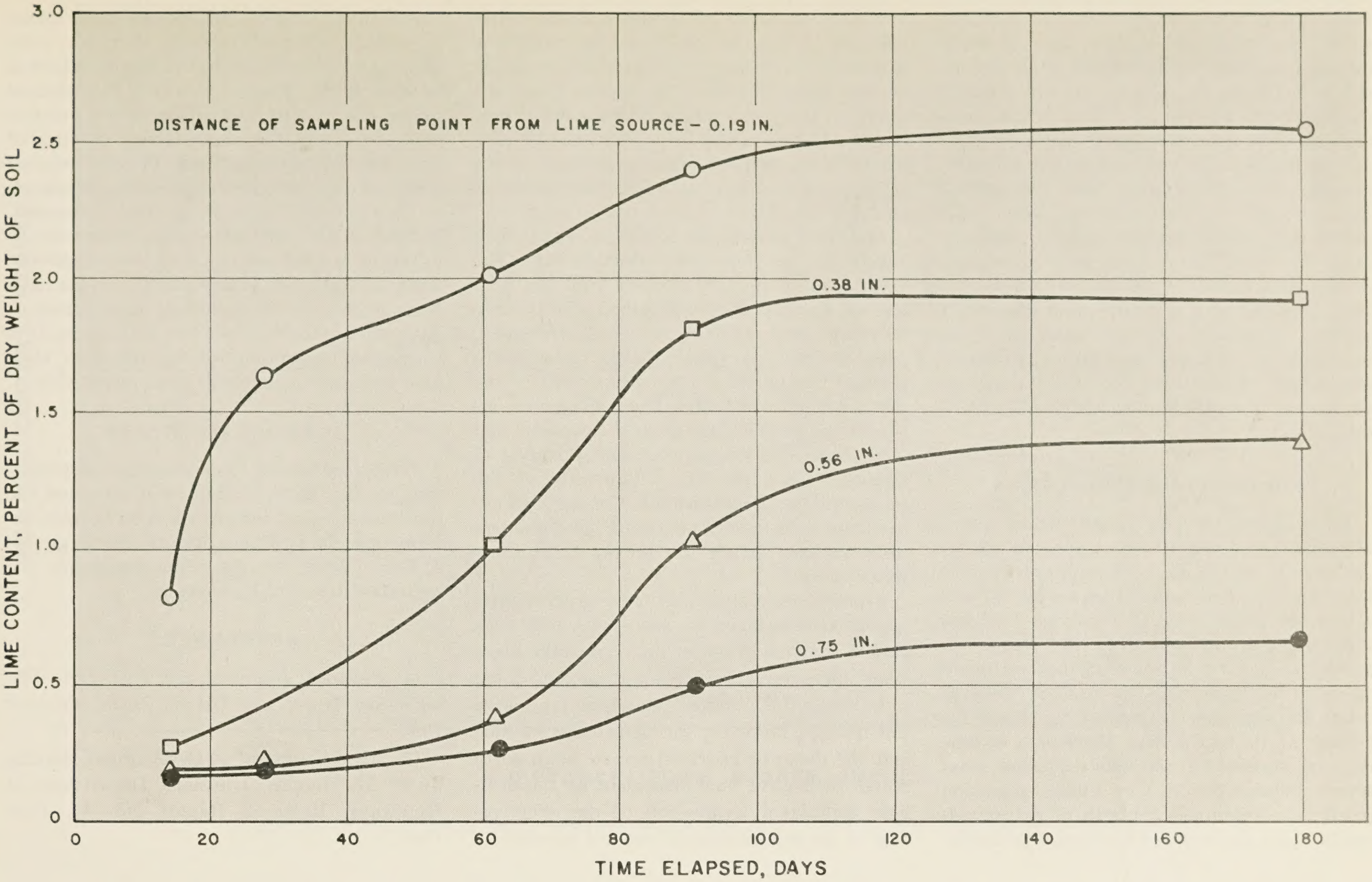

Figure 4.—Keyport loam, lime content vs. time at specific distances from lime source.

noticeable in the physical appearance (dry, crumbly, with hair-cracks) of the slice than in the modest differences in the moisture content data. The reasons for this drying effect immediately adjacent to the lime source is not fully understood. One possible reason, however, might be a lowering in moisture-holding capacity due to a change in soil structure. Another might be the utilization of free water in the formation of hydrated soil-lime reaction products.

Effect of molding moisture content

Some data were obtained concerning the effect of molding moisture content (three levels: AASHO T 99 optimum, optimum +2 percent, optimum +4 percent) on the amount and distance of lime migration in Keyport soil, over periods of 14, 60, and 90 days. The results were inconclusive, primarily because of the small amount of lime that actually migrated and the short distances involved. As indicated, a relatively rapid transfer of moisture takes place along the full length of the specimen, but this is not accompanied for the whole distance by a corresponding movement of lime. Apparently liquid movement is essentially complete in less than 14 days. It was shown, however, that lime movement continued over a period of about 100 days. It therefore seems reasonable to conclude that for the most part lime moves by diffusion rather than by movement of a lime solution.

Such diffusion would require a liquid medium, that is, liquid-filled pores. Normally, when a soil is compacted to maximum density at optimum moisture content, about 75 percent of the void space is occupied by water, only a small fraction being filled with air. Compaction at 4 percent above the optimum moisture content increased the proportion of liquid-filled pores to about 95 percent (about 99 percent saturation) and yet had little effect on lime diffusion.

In retrospect, further clarification of the effect of molding moisture content on the lime movement might have been obtained if an additional set of specimens had been fully saturated with water after compaction, and then placed in contact with lime slurry.

Migration vs. lime-water ratio of slurry

In the experimental procedure, the volume of slurry was the same for all soil specimens. With a fixed volume of slurry, the lime-water ratio governs the amount of lime available for migration and also the amount of water available for transmitting the lime through the soil. It was accordingly assumed that the use of slurries of different lime-water ratios would affect the nature and extent of migration. In figure 8, curves that show the relation of lime content to distance from the lime source as affected by the lime-water ratio of the slurry are presented for Keyport soil. The curves are for three different lime-water ratios—1:2, 1:3 and 1:6—and they represent a 90-day migration period and an 18-percent molding moisture content.

The curves show that at the sampling point nearest the lime source (0.19 inch), the lime content ranges from 2.5 to 1.3 percent, the higher content resulting from the 1:2 slurry and the lower from the 1:6 slurry. At increasing distances from the source, the differences in lime content for the three slurries decrease until, at about 0.75 inch, the lime contents are identical. The differences in lime content shown by the curves support the stated hypothesis that migration is affected by the lime-water ratio in the slurry.

It would seem reasonable to expect that, given slurries of the same volume and all containing an excess of lime at the beginning of the migration period, and approximately the same residual water content in all slurries at the end of the experiment—as was actually the case—the movement of lime would have been greatest from the slurry originally containing the greatest amount of water. Actually, however, the curves show that the reverse occurred; that is, the 1:6 slurry, which contained the greatest amount of water, contributed the least lime to the soil. As similar results were found for 14- and 60-day migration periods, and also 16- and 20-percent molding moisture contents, the effect is regarded as real and not an experimental aberration. Resolution of this apparent contradiction would require additional experimental data.

Summary and Conclusions

Lime slurries of various lime-water ratios, after being in contact with compacted soil for periods up to 180 days, were found to have lost much of their original water but to still retain the consistency of a soft paste. Lime migrated into the soil from the slurries in amounts ranging from about 2.5 percent (based on weight of dry soil) at a distance of 0.19 inch from the slurry-soil interface to about 0.8 percent at 1.5 to 2 inches. Movement of lime was not detected beyond about 2 inches, even after a 180-day period. Very similar migration results were obtained for both of the experimental soils, one of which has a predominantly montmorillonite clay fraction and the other kaolinite. Under the experimental conditions employed, migration was essentially complete in 100 days. Moisture movement from the slurry to the soil brought about a fairly uniform moisture content throughout the 3½-inch length of the soil specimens, averaging about 1 percent above that at which the soil specimen was molded.

Moisture movement seems to have been essentially complete after about 14 days. For a distance of about 0.25 inch from the lime source, the Keyport soil gained slightly less moisture than did the rest of the specimen, seeming dry and being friable rather than plastic. The molding moisture content of the soil specimens (AASHO T 99 optimum, optimum +2 percent, optimum +4 percent) had little effect on the amount and distance of migration, but the lime-water ratio of the slurry did have some effect. Contrary to expectations, however, migration was greatest from slurries having the lowest (1:2) lime-water ratio.

From the data obtained for the experimental conditions employed in this study, it is concluded that migration of lime does take place when lime slurry is applied to a compacted soil. From the practical standpoint of large soil masses, however, the percentage of lime and the distance migrated are so small as to render ineffective lime placement by the drill-hole technique. Evaluation of the effectiveness of pressure injection was not specifically a part of this study. Limited field observations by others, however, indicate that this technique provides a somewhat better distribution of lime slurry than is provided in drill-hole placement at such intervals as 5 feet, veinlets and pockets of the slurry being distributed near the points of injection. It was observed that the distribution was irregular and much of the soil mass remained, in effect, untreated, indicating that lime movement subsequent to injection would be required to completely treat the soil mass. If any actual benefits have been obtained from such field applications as have been made of these two techniques, it is concluded that unknown factors other than lime migration must have been responsible.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Mr. E. F. Bailey, who prepared the specimens and performed the lime content determinations. Additional thanks go to the M. J. Grove Lime Company for supplying the hydrated lime and its analysis.

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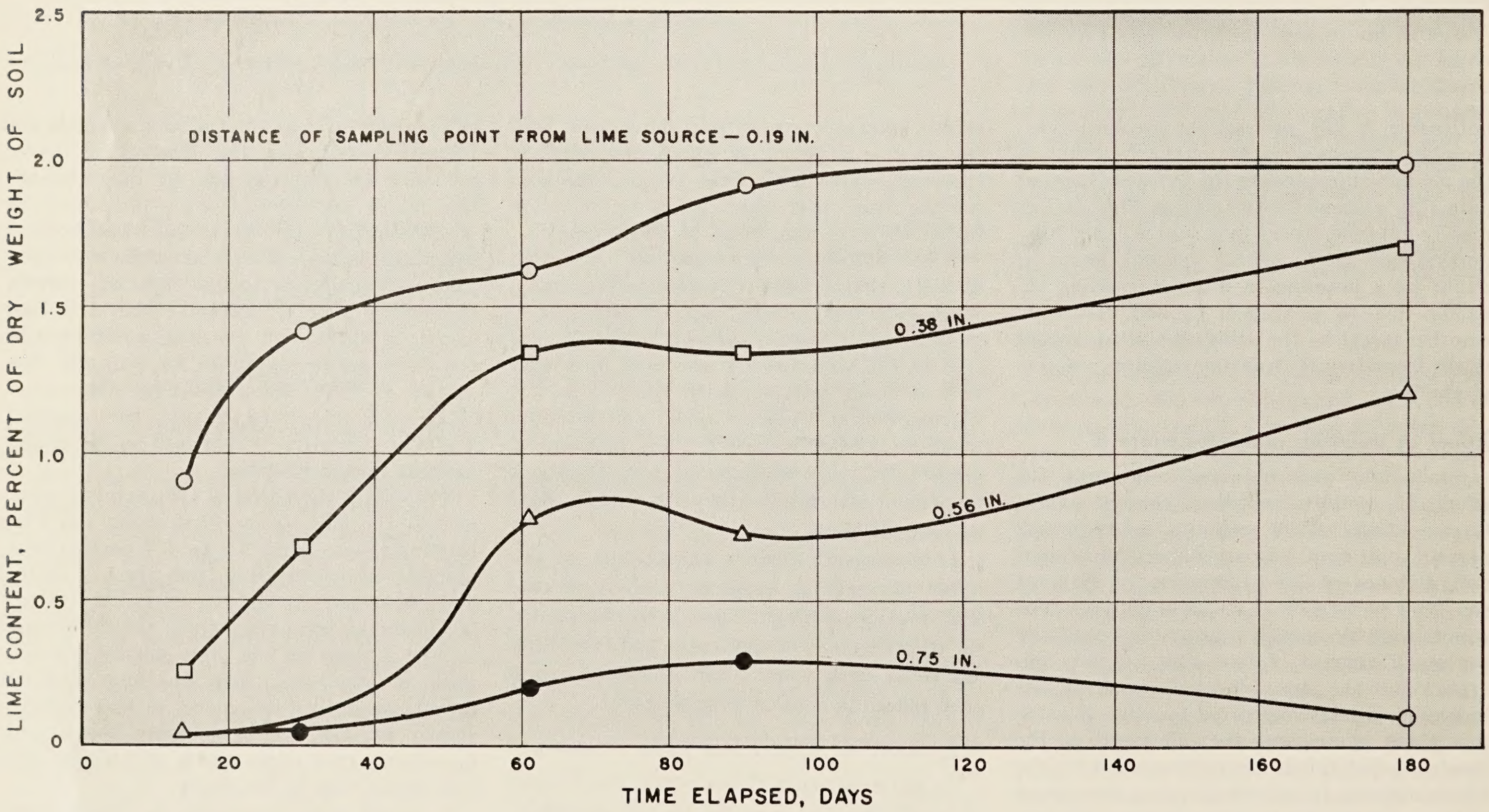

Figure 5.—Cecil clay, lime content vs. time at specific distances from lime source.

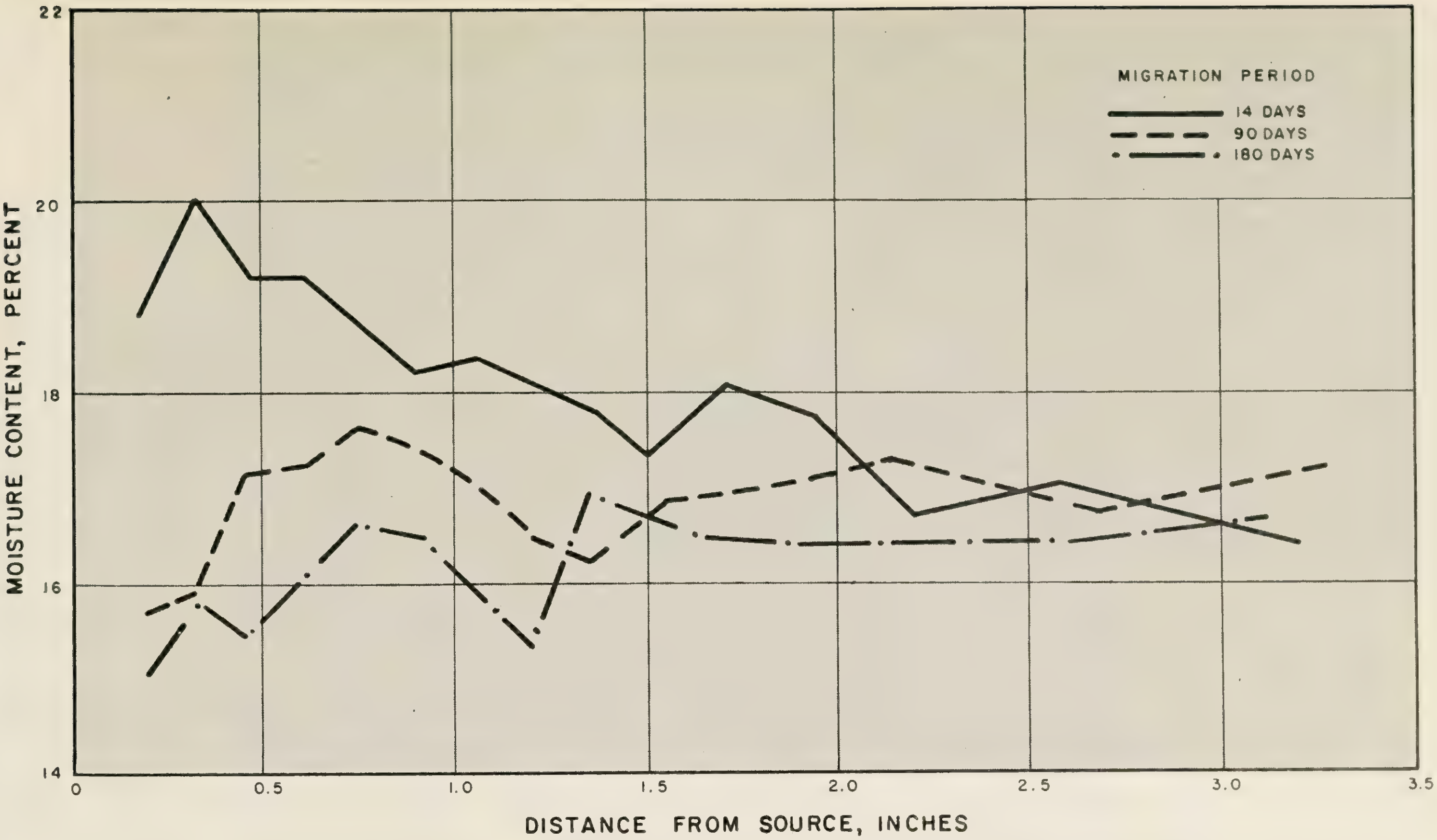

Figure 6.—Keyport loam, moisture content vs. distance; molding moisture content 16 percent.

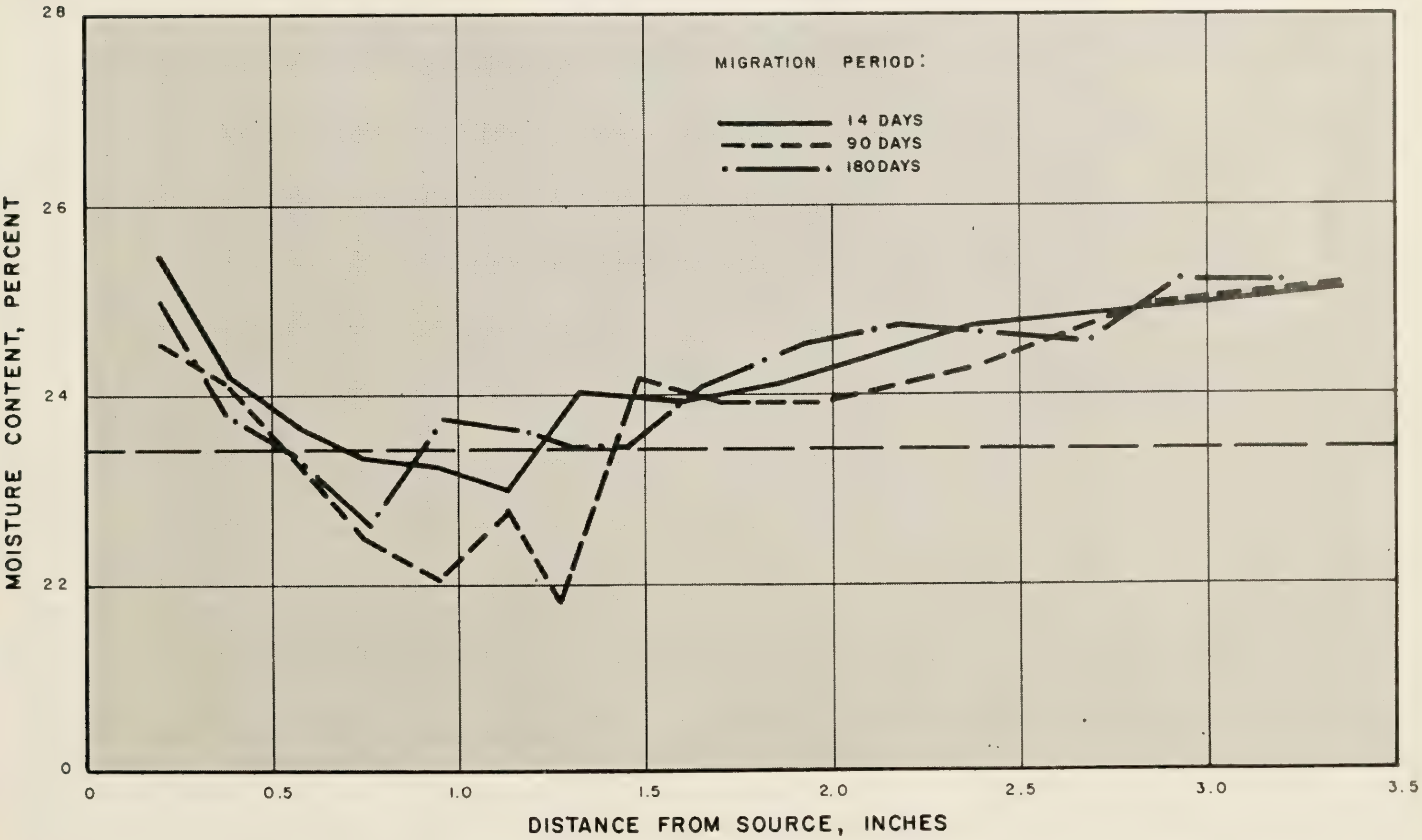

Figure 7.—Cecil clay, moisture content vs. distance; molding moisture content 23.4 percent.

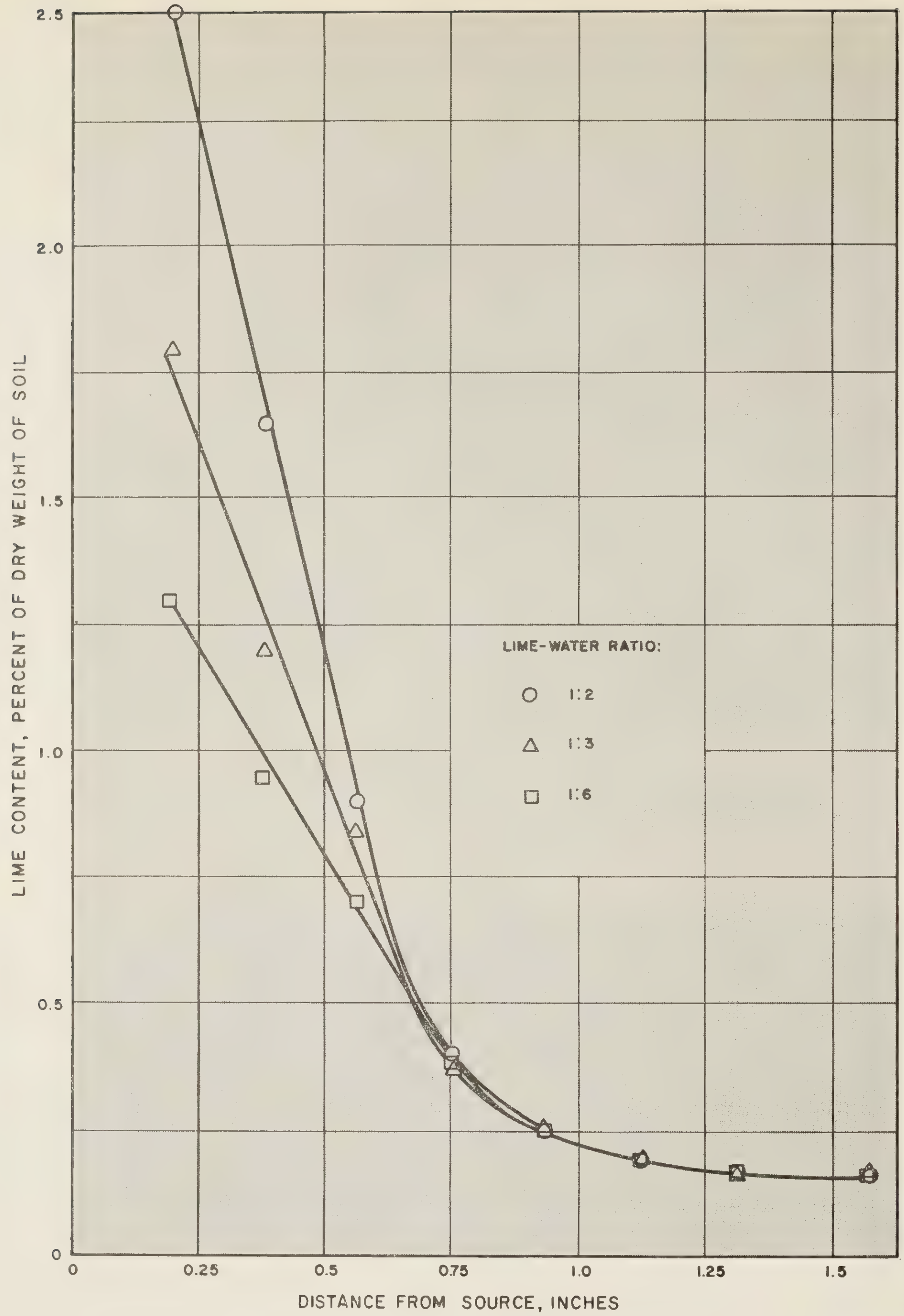

Figure 8.—Effect of lime-water ratio on lime migration in Keyport loam (curing time 90 days; molding moisture content 18 percent).

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Figure 1.—Interstate shield—an example of coding.

Some Factors Affecting Reception and Use of Information by Drivers

OFFICE OF
TRAFFIC OPERATIONS

Reported by GERSON J. ALEXANDER,
Chief, Human Factors Branch; and
HAROLD LUNENFELD, Consultant,
AIL Division of Cutler-Hammer

Introduction

HIGHWAY ENGINEERS are under an increasing amount of pressure to make the highway system more responsive to the needs of the motorist. One of many ways in which this can be accomplished is to transmit information to the motorist that will enable him to drive safely, efficiently, conveniently, and comfortably.

To determine what information the motorist needs to perform the driving task, the nature of the task must be understood. What does the driver do, and how does information he receives help or hinder?

Recent research has given highway engineers an insight into the nature of the driving task, and the interaction among the subtasks, as well as the way drivers receive and use information. This article discusses a concept of the task, some of the ways its subtasks are interconnected, and some engineering and psychological principles for transmitting information to motorists. From this research a plan for presenting information that will satisfy motorists' needs can now be developed and implemented.

Driving Task

The basic driving task consists of three activities—control, guidance, and navigation. These activities or subtasks are described according to an ascendant scale of task complexity.

Control

The control activity or subtask relates to the driver's interaction with his vehicle. The vehicle is controlled in two dimensions—speed and direction. The driver exercises control through three mechanisms—steering wheel, accelerator, and brake. Information that determines how well or how poorly he controls his vehicle comes primarily from the vehicle itself. He receives feedback from each control mechanism in the form of vehicle response to control activity. This information is critical to successful performance of the control subtask.

Guidance

Guidance refers to the driver's ability to maintain a safe path on the highway. While the *control* subtask requires overt action by the driver, the *guidance* subtask requires judgment. The highway driver must evaluate the immediate environment and translate it into control actions needed to survive in the traffic stream. Information pertaining to this subtask comes from the highway—alinement, configuration, striping, regulatory and warning signs, hazards, shoulders, etc., and from other traffic—speed, relative position, gaps and headways, lane changes, etc.

Navigation

Navigation refers to the driver's ability to plan and execute a trip from point of origin to destination. Information pertaining to navigation must be used effectively if this part of the task is to be performed successfully. Maps, verbal directions, guide signs, and landmarks are typical sources for this kind of information.

The total driving task does not consist of independent tasks independently performed. At any given point in time the driver is faced with a multitude of information transmitted from a variety of sources received through several sensory inputs. He is required to sift through this information, determine it relative importance, make proper interpretations, decide on a course of action and take that action in a limited time period. In computer parlance, man is not a parallel processor—he can do only one thing at a time. And, at freeway speeds that time is very limited.

The three subtasks—*control, guidance,* and *navigation*—form a hierarchy of task performance complexity. At the control level performance is relatively simple and so completely overlearned by most drivers that it is performed almost by rote. At the guidance and navigation levels performance is increasingly complex and drivers need more mental processing time in order to respond properly to information input.

If drivers are required to sift through the mass of information available to them to determine relative priority, there must be a criterion upon which decisions on importance are based. A concept of *primacy* has been developed to deal with this problem.

Primacy

The primacy concept accepts safety as its primary criterion and considers the results of the driver's failure to receive or to act on information as its basic determinant. Here, too, a hierarchy is developed from control through navigation. Primacy in information decreases from control through navigation and the scale is thus descendant as compared with the ascendant scale of task complexity. In other words, the easiest tasks are the most important and the most complex tasks are the least important. The following examples show how this operates.

- If a driver does not respond properly to a sudden change in vehicle handling such as a skid, the resultant failure will probably be catastrophic; i.e., resulting in property damage, injury or death. Failure to respond properly to control information nearly always results in a catastrophic system failure. Vehicle control then is considered the most important task a driver performs.
- In the guidance category results are similar. Failure to respond to a rapidly closing headway or a change in horizontal alinement usually results in a catastrophic failure.
- Failures in navigation are noncatastrophic. Drivers get lost or delayed or angry or all three when navigation information is improperly handled. This is not to say that navigation information is unimportant, but according to the safety criterion, failure in navigation has less impact on the system than failure in either control or guidance. One implication of this fact is that when the driver is in a situation where information at all three levels is present and time will not permit him to handle all of it, it is the navigation information he should give up. This is meaningful to highway engineers in deciding where certain information should be located. For example, navigation information should not be placed at a location where the guidance task is complex, such as on a tight horizontal curve, because low-primacy information would then compete with high-primacy information for the driver's attention.

Expectancy

Expectancy is another factor that affects the driver—how he perceives information and how he uses it. Drivers, and people in general, expect certain things to operate in certain ways. When entering a dark room, a person will expect to find an *on-off* toggle switch for the lights. He also expects the switch will operate up for *on* and down for *off*. When it works the other way around, or when there is a rheostat knob, it takes a bit longer to respond properly to what is actually there. The same situation occurs with drivers. When a driver's expectancy is incorrect, either it takes him longer to respond properly or, even worse, he responds poorly or wrongly. If, for example, he is expecting a right-hand off ramp and alines his car on the right side of the highway to exit, and he is faced with a left-hand exit, it takes him longer to respond to that situation. He may, in fact, respond poorly by turning at the last moment to drive across three lanes to avoid missing his exit. Expectancies, of course, occur in all three parts of the driving task.

Control

The driver wants and expects his vehicle to respond to control activity in a predictable way. When he depresses the brake with a certain force, he expects the car to slow at a certain rate; but if for some reason the brakes fail, or if his car is on a patch of ice, the car does not respond in the way he expects. In that situation, the driver is less likely to handle his vehicle properly. The same is true of steering, if he turns the wheel with a certain force and to a certain position, he expects the car to turn at a given rate in the desired direction. If it doesn't for one reason or another—sand on the road, bad alinement, or his misinterpretation—then it is unlikely that he will respond quickly or properly.

Guidance

In the guidance task, expectancies relate to highway design and traffic interaction. Highway designs that drivers do not expect include left-hand off ramps, tangential off ramps, left-hand on ramps, two-lane on ramps, two-lane off ramps, lane drops at exits, and lane drops between exits, to name but a few.

Navigation

In the navigation task, expectancies relate primarily to guide signing. In pre-trip preparation, many drivers will assume that their destination, no matter how obscure, will be signed for on the freeway. While this appears to engineers as unreasonable, it may be quite logical from the driver's viewpoint. Since the driver has no way of knowing what destination will appear on signs and he knows that many destinations are signed for, it is fair for him to assume that his destination will appear on highway guide signs.

Evidently then, what is needed is a means by which drivers can predict the content of guide signs at key decision points along their route.

A Priori Knowledge

The driver brings a body of knowledge, experience, and skills to the driving task. This *a priori* information is supplemented by the information acquired in preparation for a specific trip.

It can be assumed that he can add, subtract, deal in fractions, and read and comprehend simple English. It can further be assumed that the highway user has (1) the ability to operate a motor vehicle (2) the basic knowledge of laws and rules necessary to obtain a driver's license and (3) more or less specific information about his trip plan. Knowledge and ability in the following exist to some degree in all drivers:

- General knowledge of geography. Distance and direction relationship of destination to origin and of destination to nearest prominent landmark or town.
- Ability to read a map. Knowledge of where to obtain maps, and knowledge of which maps to obtain.
- Ability to understand compass direction. Ability to translate changes of course into driving maneuvers; for example, westbound to northbound usually requires a right turn.
- Ability to understand weather reports and translate them into roadway and visibility conditions.
- Ability to translate distance into driving time under prevailing conditions.
- Degree of familiarity with highway and interchange types and elements.

A priori knowledge relates to each of the three levels of task. In a specific trip plan, it affects the driver's ability to perform the navigation task. A knowledge of general highway configuration affects his ability to perform the control and guidance tasks, his ability to obtain information from the highway itself and how to handle it, and his ability to interact with other traffic. Here, as in expectancy, design engineers must understand much about the driver's knowledge and his ability to deal effectively with highway information. Although this may not have a direct bearing on design engineers, it does have a bearing on those who are responsible for educating the public in what is being designed. Unless motorists understand highway design, they cannot navigate safely through the system that has been designed for them.

So these three things—primacy, expectancy, and a priori knowledge—affect and are affected by the manner in which the task is performed.

Coding

Coding is a method of information presentation which organizes bits of information into a larger unit and uses a symbol to represent the unit. Coding recognizes man's limited ability to process information, and it presents much information on a single, simple source. An example is the Interstate route shield (fig. 1) where the colors red, white, and blue, the shape, and the number inside convey much more information than is evident just by looking at the shield and the number. The shield and the colors designate the route as a high-type facility, with no at-grade intersections, and no railroad grade crossings.

The numbering system is part of the code—routes ending in an even number are basically east-west routes and those ending in an odd number are north-south routes. The Interstate numbering system works from west to east and south to north. Motorists can expect the low odd numbers along the Pacific Coast—routes like I–5 linking San Diego and Seattle. On the other hand, high two-digit odd numbers, like I–95, place the highway on the East Coast. Even numbered routes are I–10 from Southern California to Florida and I–90 from Seattle to Boston. Additionally, routes ending in 0 are coast to coast, those ending in 5 are from border to border.

The shield and the numeral are attempts to code all that information into a simple information-giving source. It represents an excellent idea in terms of informing the driver, allowing him to read and scan the information quickly. However, engineers have certain responsibilities with regard to the use of coding. First, the drivers must know the code. The problem is, and it is a serious one, that drivers do not know the code. There is little or no communication between the people who devise the coding systems and the people for whom the systems are devised. Consequently, instead of facilitating the task, it makes the task harder because the driver has to guess what the traffic or highway engineer had in mind when he put up a sign.

Moreover, a code cannot be allowed to obscure the primary information on the source. For example, in the Interstate shield the primary information is the route number. That it is an Interstate route is good information and is important, but that it is Interstate Route 495 is the information the driver really needs. When any coding system is designed, it is essential that the primary information can be easily seen and quickly understood.

In one State, the State route shield contains an 8-inch numeral inside a figure head silhouette. An 8-inch numeral is difficult to read from any appreciable distance, but inside the silhouette it becomes virtually impossible to read. Another State is using a State route shield designed with a simple square, black-on-white sign; and by using the top third of the sign for the State flag, the size of the numeral was reduced. That is a violation of the primary information-giving intent of the sign.

Also, it is imperative that the use of the code be consistent. If the Interstate shield is a code that promises no at-grade intersections or railroad grade crossings, it must always deliver on the promise. Non-Interstate characteristics are unexpected events on an Interstate route. As noted above, drivers are more prone to error under such conditions.

Coding affects primacy as well as expectancy because it allows the driver more time to look at important information, whether the information is signing, marking, or traffic and geometry which is the predominant source of guidance information. Coding thus represents an understanding of primacy and, if used properly, affects expectancy and a priori knowledge as well.

Redundancy

Redundancy refers to giving the same kind of information in more than one way on a given source. An example is the standard STOP sign (fig. 2) where the color red, the octagonal shape, and the word STOP, all convey the same information to the driver. Drivers respond to the color, the shape, and the word. So if just one of the three is changed, many drivers will not recognize the difference. Also redundancy responds to the expectancy of a wider population of drivers. In the Washington area, I–495, also known as the Capital Beltway, is a circumferential route around the metropolitan area. Some drivers in the Washington area are unfamiliar with the route number, to them it is the Capital Beltway. Other drivers who visit Washington are unfamiliar with the name Capital Beltway. It is the responsibility of design engineers to help all drivers. If some of them expect I–495, and others expect the Capital Beltway, then the highway should be signed for both I–495 and Capital Beltway. In the design of new freeways, freeway names are superfluous and unnecessary. Route numbers clearly identify routes, but if for some reason routes are named, then perhaps it is the engineers' responsibility to the public to use both number and name when signing any given route.

Figure 2.—STOP sign—an example of redundancy.

Spreading

Spreading recognizes that there are some places on the highway where drivers are overloaded; even when coding and redundancy are used, there is still too much information for drivers to handle. It further recognizes that some information is more important than other information. The concept of spreading says, "Let us take the least important information from an area where drivers are potentially overloaded, and move it either upstream or downstream—give the driver more time to handle the information that we're giving him." Figure 3 shows a simple diamond interchange ramp. Shown here is a single-lane off-ramp and two lanes going through. Let's say the mainline is an Interstate, with the crossroad overpassing the freeway. In the past, we have mounted signs A and B on a butterfly support or overhead truss at the physical gore ①. When a truss was used, a *Thru-Traffic* sign was installed over the left-hand lane. An analysis of the driving task indicates that this is an area where drivers are potentially overloaded. Signs located at the physical gore become readable at the beginning of the deceleration lane. According to the primacy concept this is the wrong place to give navigation information to the driver. Irrespective of the sign content, the driver has complex evaluations and decisions to make. Much control and guidance information is to be gathered when he is in this situation.

He must gage the path and speed of other vehicles weaving into or out of the right lane. He must determine his proper path and speed based on highway alinement and traffic. And, he must take the appropriate control action. Superimposed on this task is the requirement to decide whether he should exit or continue through. The latter decision affects each of the previously mentioned decisions. If all this is attempted at one point in time or space, probability for error is increased.

Information contained on sign B (fig. 3) is important to a driver in making navigational decisions. Moving this information upstream—to the theoretical gore—will give the driver more time to plan his moves and more time to handle control and guidance information at the critical area.

Information on sign A is not as important in navigation as the information on sign B, as it relates to an exit well beyond the interchange. That information should be moved downstream and either mounted on the overpass or, if the freeway overpasses the crossroad, mounted on a cantilever at about the location of the overpass ②.

This example of spreading is not applicable to the signing requirements of the standard

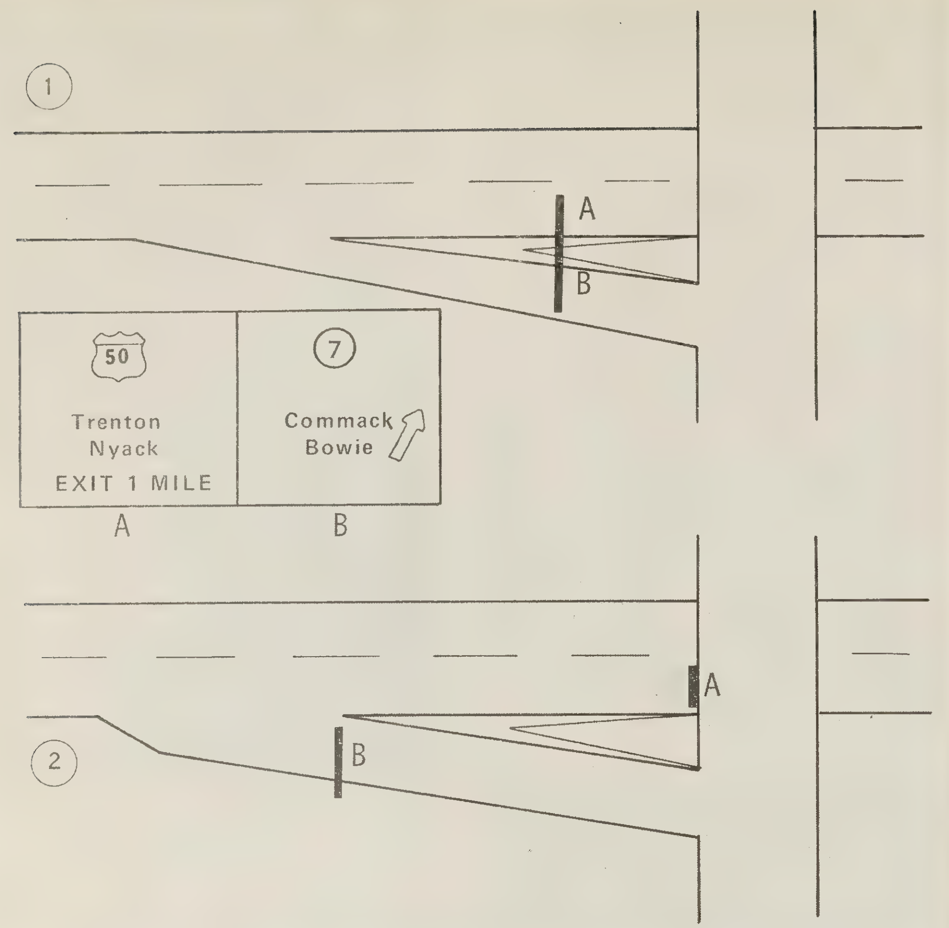

Figure 3.—Spreading of navigation information.

cloverleaf design. Since the two off ramps are very close to each other and they both lead to the same route, different directions, the driver needs to have that information at the same place in order to make a direct comparison of the choices. However, as in sign B, that information needs to be at the theoretical not physical gore.

On most interchange designs, a *Thru-Traffic* sign (with or without a down arrow) is rather unnecessary. When the interchange design is such that the through movement is not clear to the driver by visual inspection, then a pull-through sign of some kind may be necessary. However, it is not necessary in the gore area. This information can be given at the overpass. What should the information be? Should it be *Thru-Traffic*? Should it have a down arrow on it? The down arrow is a coded message which implies a specific lane assignment. Unnecessary lane changes usually result when the down arrow is used in this situation. Further, the credibility of the down arrow is affected. If the use of the code is inconsistent, the risk of misinterpretation when it does denote a specific lane assignment is significantly increased.

The *Thru-Traffic* message is somewhat ambiguous. The intent of the message is that these lanes will pull traffic through the interchange on the main facility. A clear, unequivocal message would contain the route shield, the cardinal direction, and the name of the control city. This configuration would pull traffic through the interchange and provide route confirmation at little additional cost to the driver.

The concept of spreading is affected by many of the factors mentioned previously. The levels of task performance, primacy, and coding are the major considerations in the utility of this technique. While the example was taken from a freeway interchange problem, it has direct application at any location where the driver is faced with a complex task performance requirement.

If the goal of the highway system is defined as the safe, efficient, convenient, and comfortable movement of man, machine, and material, it can be seen that failure in any one element constitutes a failure of the system.

A system can fail catastrophically, as in accidents, or it can fail noncatastrophically. There are many kinds of noncatastrophic system failure, which, when considered in their entirety, are quite costly to the economy in dollars and time. A nonmoving lineup of traffic two lanes wide and several miles long, for example, indicates that a system has failed. Another example is a driver who becomes lost because directions on a sign are inadequate.

A driver who stops on the freeway and backs up because he passed his exit indicates that the system has failed noncatastrophically. But obvious here is that the system is vulnerable to a greater catastrophic failure.

The point to stress here is that highway safety cannot be fully achieved until attention is given to *all* factors that affect system operation. When the system is understood as a system in research, design, and operations, greater strides in making highways safer for motorists can be made.

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Demonstration Projects: Bridging the Gap Between Research and Operations

REGION 15,
ARLINGTON, VA.

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The first of a series of articles on research and implementation begins in this issue of **Public Roads**. *Two articles are featured here—one giving background material and one covering the prestressed concrete demonstration project. The background article concerns the organization and development of demonstration projects, a most successful avenue for implementing research. The article on prestressed concrete gives an overall report on the demonstration project at Dulles International Airport, as well as the construction details used in developing the access road.*

Currently, 29 demonstration projects have been approved for implementation. Work has progressed and accomplishments have been recorded on all but five projects. Articles on most of these projects will be featured in future issues of **Public Roads**. *Obviously one article on an in-progress demonstration, which generally takes several years to complete, may not tell the whole story from beginning to end. Therefore, follow-up articles will be published from time to time to keep interested readers abreast of progress and accomplishments.*

OFTEN the most promising highway research efforts never become operational, not from any inherent deficiency, but from the sheer inability of engineers to find the time and manpower to analyze useful research and translate it into operation. Thus a gap exists, and has existed for some time, between research results and their implementation. But through the Research and Development Demonstration Projects Program, a bridge is being built between research and operation, so research results can be readily applied to the operational highway program.

From its inception in January 1969, Federal Highway Administration (FHWA) engineers have been working through the Demonstration Projects Program to demonstrate the practical use of research and development results. These results are presented in a way to show their effectiveness and benefits for general use. Additionally, the program provides special training for State and Federal highway engineers. Figures 1 and 2 show the overall operational structure of the program.

Although the program is operated as a service to the States, no pressure is applied to the States to adopt a particular research result. All the States have to do is take time to observe the demonstration.

Because of its field capabilities through the design and construction of direct Federal projects in the eastern half of the United States, Region 15, Arlington, Va., is the principal field office implementing the demonstration projects effort. Generally, all manpower, planning, final development work, equipment, and funds for on-site demonstrations are provided by Region 15.

Since the beginning of the program, three distinct demonstration methods have emerged: (1) Field demonstration of advanced location, design, and construction engineering procedures; (2) physical construction of demonstration installations with the Region 15 direct Federal capabilities; and (3) physical construction of demonstration installations as experimental features by State highway departments, with Region 15 and Technical Advisory Committee (TAC) assistance and support in monitoring and reporting the results.

Just as there are several methods of demonstrating research results, there are also several media through which the projects work, such as on-site demonstrations, demonstration installations, workshops, seminars, and conferences.

Each research development or practice scheduled for demonstration demands a unique demonstration method and media to get it into practice—media meaning on-site demonstration versus conference. Some require several methods, especially media. A very flexible demonstration program structure has therefore been built through which all demonstration methods and media are analyzed to find one or possibly several effective combinations to implement the item.

Quality, a fundamental requisite for demonstration activities, is achieved through trial runs, critiques, and reworking individual demonstrations within FHWA before contacting the States. From several months to a year is generally spent mobilizing, equipping, training, and preparing for field demonstrations. Although the demonstration projects effort is primarily a show-and-tell rather than a report program, reporting the results of demonstration activities and accomplishments is most important. Timely reporting and follow up often determine whether the demonstration is just an activity or a documentable adoption of the concept being demonstrated.

Project reports are purposely different from the classical monumental research report. Reports are a summary of the demonstration results, and have appendices listing the demonstrated procedures and equipment used. They are designed primarily for the State highway departments to operate with rather than try to determine how to translate them into operation. If requested, FHWA personnel visit interested

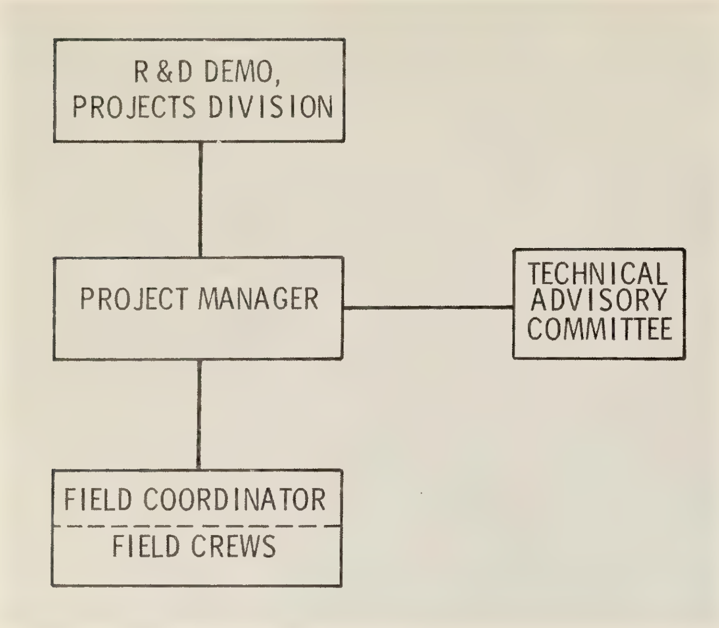

Figure 1.—Project organization.

States to discuss the demonstration results and clarify any questions concerning a State's adoption of the demonstrated concepts. Additional training sessions are offered, if necessary, during the follow-up sessions to insure complete understanding of the demonstrated techniques.

Program Accomplishments

By using movies, slide presentations, conferences, and workshops, as well as personal on-the-job demonstrations, approximately 250 separate demonstrations were conducted during FY 1971 for more than 1,500 engineers from State highway departments, the U.S. Forest Service, and the National Park Service. About 500 FHWA engineers received training at the same demonstrations. Included in these demonstrations were such diverse items as aerial photogrammetry, statistical quality control, skid resistance measurement of pavements, steel corrosion detection, and erosion control procedures. Several conferences and workshops were also conducted.

The Bituminous Concrete Phase of the Quality Assurance Demonstration Project is an example of the demonstration, reporting, and follow-up approach resulting in substantial accomplishments. For this project on-site simulated demonstrations of the FHWA Bituminous Pavement Guide Specification were conducted, followed by a report on the results of the simulation, including an operations manual chapter on the use of the guide specification, the computerized analysis of the test data, and equipment used. Then a personal visit was made to each participating State to discuss the report and simulation results, and answer questions. Next, training sessions were held at the States' central laboratories.

This total approach resulted in the documented adoption of at least one and often several of the demonstrated concepts by 15 of the 19 States receiving the full treatment in 1971. This year demonstrations have been performed in 11 States. Reports and follow-up visits are presently being conducted.

California engineers, under a Highway Planning and Research (HPR) project, developed a nondestructive steel corrosion detection device. Through the demonstration program, 472 demonstrations of the device were conducted in 45 States. Today approximately half the States are using this equipment in their bridge condition inventory programs.

Other specific project accomplishments include the Nebraska and South Dakota Highway Departments preparation of budget requests for demonstrated aerial analytical triangulation equipment. The savings the use of aerial analytics ranges from 500 to 1,000 dollars per mile surveyed. Using this equipment in the up-coming 2,000-mile primary program survey could save Nebraska from one to two million dollars.

Demonstrations of serrated soft-rock cut slopes have been described to State highway department personnel through a field conference, formal presentations at regional AASHO design meetings, a slide presentation, the production and regional distribution of a 15-minute color movie, and the nationwide distribution of an interim report. Fifteen of 37 States having suitable material conditions have built, are building, or will be building these slopes within the next year.

Three conferences on improved skid-resistant pavement have been sponsored. More than 250 engineers from 45 States attended these conferences and learned the latest information and technology for designing and constructing improved skid-resistant pavements. An additional conference is planned for fiscal year 1973.

Advantages of improved inlet design procedures, to select the most economical highway culvert for a given location, are being demonstrated to the States through design workshops. Detailed design procedures, developed from previous research by the demonstration project team, and a portable hydraulic flume with models of improved inlets are used in the workshop sessions. Six workshops have been conducted, reaching about 600 engineers, who studied the procedures and received training in their use. Applying these procedures should significantly reduce the $600 million spent annually on drainage facilities.

These program accomplishments are of several demonstration projects that have progressed to the documented accomplishments stage. Work is steadily progressing on other projects to bring them to the same level of completion. The potential value of these projects, as well as those planned during fiscal year 1973, are equal to those already recorded.

Program Control and Coordination

Coordinating Committee

Although Region 15 serves as the principal field office responsible for managing the program, the Demonstration Projects Program is actually a totally coordinated FHWA effort. Coordination is accomplished at the top level through the Demonstration Projects Coordinating Committee, which is composed of representatives of 10 headquarters offices of FHWA: Office of the Chief Counsel, Office of Highway Planning, Office of Research, Office of Development, Office of Environmental Policy, Office of Highway Operations, Office of Engineering, Office of Traffic Operations, Bureau of Motor Carrier Safety, and Office of Highway Safety. The Coordinating Committee meets monthly to give overall policy direction and provide coordination and communication with each of the represented offices, thereby insuring that the demonstration project program is consistent with other FHWA programs.

The committee also reviews and approves proposed projects for submission to the Administrator's Office, approves project work plans, approves project managers, reviews progress, and approves final reports.

Coordination and communication with the field is also accomplished through the cooperation and assistance of the Office of Highway Operations. They handle contacts with field offices through their Construction and Maintenance Division, Construction Methods and Practices Branch, which is also responsible for the administration of the experimental projects program.

Also involved in this effort are the regional and division experimental coordinators who give considerable time and effort in scheduling and following the demonstration activities as an adjunct to their normal duties.

Region 15 Demonstration Projects Division

The Region 15 Demonstration Projects Division manages the execution of the program. Suggestions for proposed projects are analyzed; project prospectuses are developed for review by the Coordinating Committee; overall administrative, financial, and technical control of the projects is administered; and liaison is maintained with trade associations, the Highway Research Board, State highway departments, and other FHWA offices to assure recognition of worthy projects and effective prosecution of on-going projects.

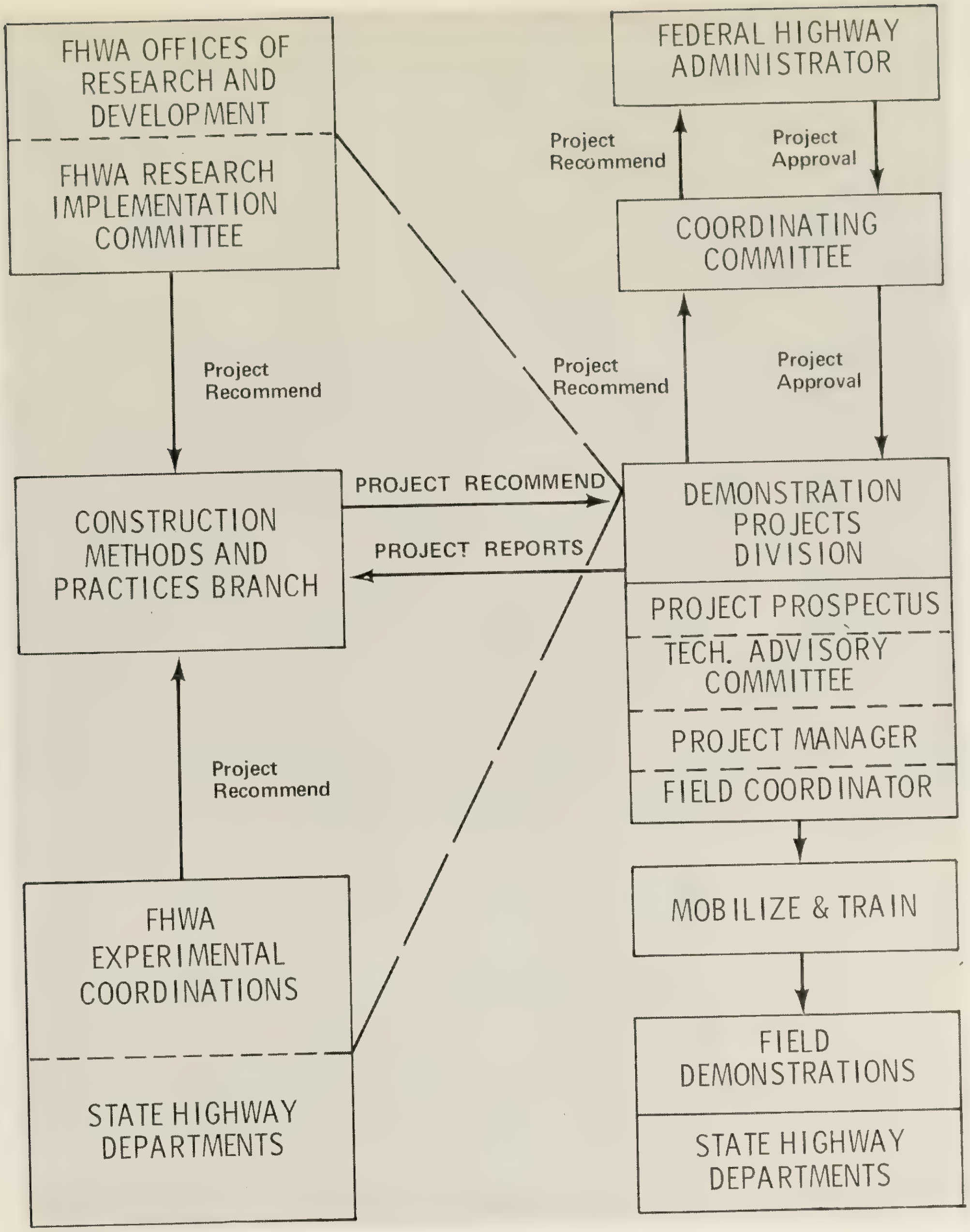

Figure 2.—Program operation.

Project manager

Each project manager, appointed with the approval of the coordinating committee, is responsible for the technical conduct of the project. He insures that all technical features are properly incorporated into the design and prosecution of the project. Additionally, he is responsible for the technical surveillance, evaluation, and reporting of the project.

Technical Advisory Committee

Each demonstration project has a Technical Advisory Committee representing interested FHWA research and operating offices and other interested organizations outside FHWA. This committee is responsible for assuring that expert technical advice on project details is available. TAC advisors assist the project manager in developing the project work plan, monitoring the project, and reporting results.

Field coordinator

The Demonstration Projects Division field coordinator is located in the Gatlinburg Tenn. Field Office. Working closely with the project managers, the field coordinator selects and trains field crews, makes necessary schedule arrangements, and directs field operations.

A Promising Future

The Demonstration Projects Program is a challenging and responsive program—responsive to the States and challenging to the people working in it. As a challenge it gives one an opportunity to really dig into something and make it work to his own satisfaction. Responsive, too, because the end result can meet the needs of State and Federal agencies.

Today the interaction between research and operations is growing, and new bridges are being built by the Demonstration Projects Program. With this program the span between research and implementation has a strong foundation, and it is becoming stronger with more frequent passage of research results from the drawing boards to the operational highway program.

Aerial view, looking east, of the prestressed pavement.

Prestressed Concrete Pavement Demonstration at Dulles International Airport

Reported by Region 15, Research and Development Demonstration Project Technical Advisory Committee for Project 17 [1]

Introduction

THE Federal Highway Administration (FHWA), through the joint efforts of the Office of Research and Region 15, has placed 3,200 feet of 24-foot-wide, 6-inch-thick, prestressed concrete pavement at Dulles International Airport as part of the permanent airport road network (figs. 1, 2, and 3). This pavement will serve as an access road to the 1972 International Transportation Exposition (TRANSPO 72) scheduled for May 27 through June 4. The pavement construction was done as part of the FHWA Region 15 Research and Development Demonstration Projects Program, which was established to accelerate the implementation of research and development results.

Selection of outstanding research developments, translating them into operating procedures, and demonstrating their advantages to State and Federal agencies is the mission of the Demonstration Projects Program. The potential advantages of prestressed concrete pavement resulted in its early incorporation into this program.

Demonstration Project No. 17—Demonstration of Prestressed Concrete Pavement Construction—was therefore established to demonstrate that prestressed portland cement concrete pavement construction is practical and economically competitive with other types of pavements. A two-phase demonstration approach was established.

The first phase was to build a significant length of pavement, determine if it would hold up under normal and specially instru-

[1] This article was developed by the following Committee members: F. J. Tamanini, T. J. Pasko, B. F. Friberg, and R. A. McComb, Office of Research; W. H. Carter, Office of Engineering; L. M. Darby, L. Dreihaup, and J. W. Thwing, Region 15; and W. N. Woods, Office of Highway Operations.

mented traffic loads, and establish if substantial additional pavement construction would be economically competitive with conventional concrete pavements.

The Dulles demonstration pavement was therefore constructed to show the practicality of design and construction techniques, determine maintenance requirements, improve design criteria, determine construction cost data, create interest by the States, and provide information for contractors. In addition the project has the two-fold objective of: (1) Exploring and demonstrating existing prestressing techniques that may be practically and economically applied to large-scale highway paving operations; and (2) investigating the behavior of relatively long monolithic concrete pavement slabs with regard to movements and length changes, warping and curling behavior at ends, and frictional and flexural restraint stresses away from the slab ends.

A limited production time study was conducted on the pavement construction operations, and the contractor is making available his detailed construction and material costs.

Substantial cost analysis and projection work remain to determine if additional pavement construction would be economically competitive with conventional concrete pavements. Caution will be used in analyzing and projecting the cost information due to the construction techniques dictated by the short length of the project. A good indication of the pavement's serviceability, however, should be available by June 1972, since heavy construction material loads for TRANSPO 72 will be hauled over the pavement until that time.

If Phase I is successful, a second experimental phase will be initiated to encourage construction of prestressed pavements on major State highway networks. Construction of additional substantial lengths of prestressed concrete pavement will be within the experimental project framework and in cooperation with the FHWA Offices of Engineering and Highway Operations. FHWA, through the demonstration project manager and technical advisory committee, will provide technical advice and assistance to agencies desiring to build experimental installations.

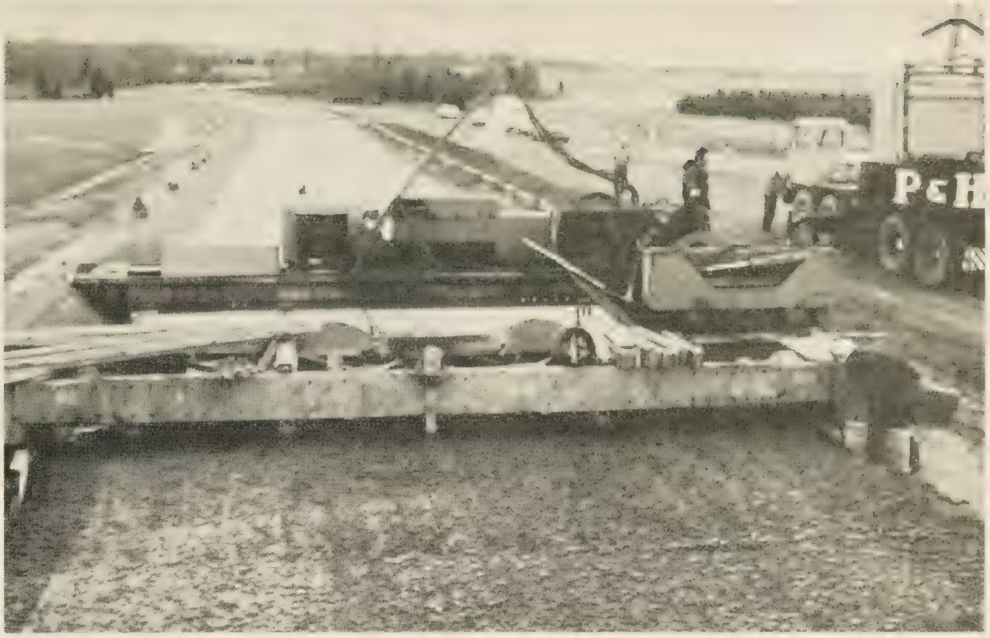

Figure 1.—Slipform paver placing the concrete.

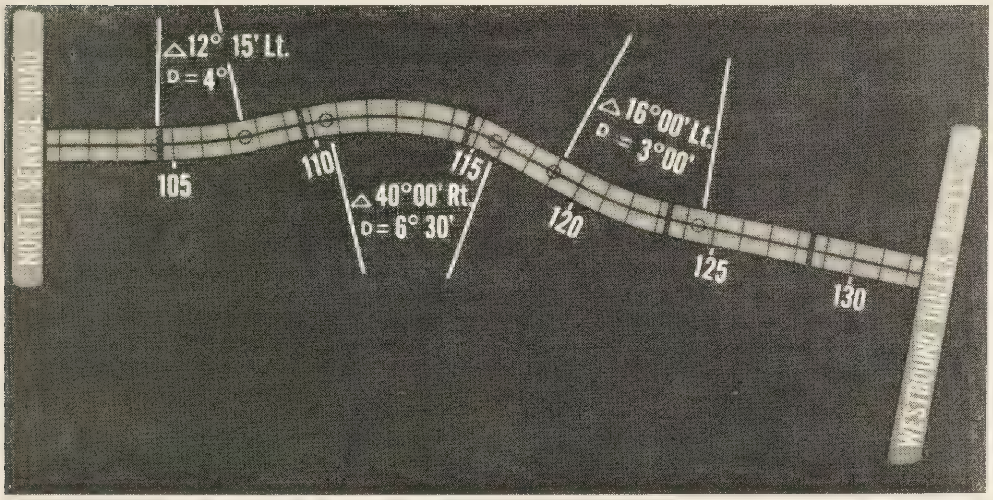

Figure 2.—Pavement alinement showing degree of curvature.

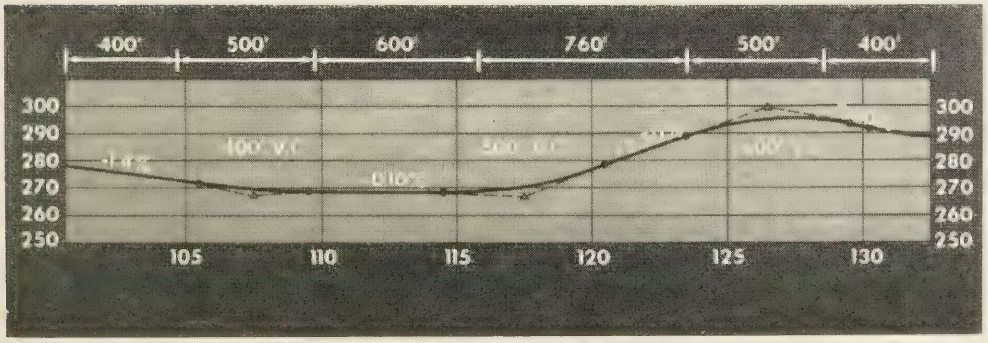

Figure 3.—Pavement construction profile.

Conventional Concrete Pavements

Prestressed pavement can be contrasted with the two main types of concrete pavements presently constructed for highways. The first type, jointed pavements, can be subdivided into: (1) short reinforced pavement slabs separated by doweled or undoweled transverse joints spaced 15 to 25 feet on centers, and (2) reinforced pavement slabs from 25 to 100 feet separated by doweled transverse contraction joints. The short, unreinforced slabs generally do not crack transversely; however, the longer reinforced slabs usually crack transversely into 15- to 30-foot segments. The reinforcement is distributed within the longer slab to tie the cracked pavement segments together so that slab contraction and expansion take place at the transverse joints, which are doweled to give adequate alinement and structural support across the joints. The amount of distributed steel in conventionally reinforced jointed pavements ranges from about 5 pounds per square yard for short joint spacing to 10 pounds per square yard for 100-foot joint spacings.

The second type, continuously reinforced concrete pavement, evolved from experiences with pavements over the past 50 years, experiences which show that structural distress is usually concentrated at transverse joints. To alleviate the difficulties at the joints, continuously reinforced concrete pavement is being used. Transverse cracks, spaced 2 to 10 feet apart, appear in the long unjointed pavements, but are held tightly closed by the reinforcement. Still, comparatively large amounts of longitudinal reinforcement steel are needed in this construction—about 20 pounds per square yard.

Prestressed Concrete Pavement Advantages

Prestressed concrete highway pavements offer many potential advantages in performance and economy. For example, transverse joints that accommodate contraction and expansion movements could be spaced several hundred feet apart, largely alleviating the joint problem. In addition, thinner pavements are capable of supporting traffic loads where the pavement behaves as a continuous slab. Adequate structural joint and drainage design becomes more economically feasible with a reduced joint pattern. Moreover, the amount of steel necessary for adequate prestress design is about 5 pounds per square yard. This is less than that used in all but the lightest conventional pavement.

Prestressed pavements, therefore, are a promising solution to the problems of joint failure, blowups, and crack maintenance. If successful, they could save millions of dollars each year in maintenance costs, while reducing hazards to maintenance personnel on high-speed highways. In addition, they offer a way to stop the trend of building thicker and thicker pavements.

Before the advantages of prestressed concrete pavement can be realized, valid design criteria and construction methods must be developed and more information obtained on pavement performance characteristics. Among the most important data needed are the following:

- Determine an optimum slab length and amount of prestress steel.
- Expansion and contraction characteristics of the slab.
- Design of joints and joint drainage systems.
- Warping characteristics of the slab.
- Load carrying characteristics of the slab.
- Develop construction procedures whereby the friction-reducing medium and tendons can be placed as part of the conventional paving train.
- Effect of pavement-base friction characteristics.

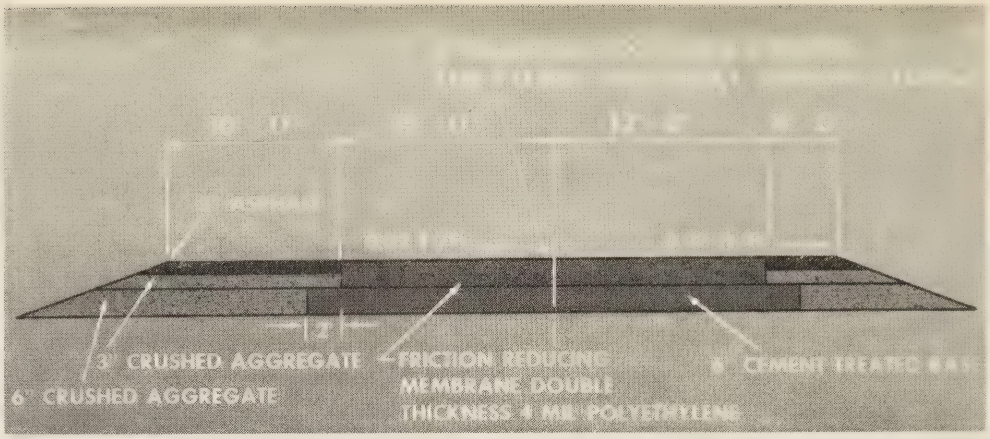

Figure 4.—Tangent roadway—typical section.

Earlier research efforts established preferred solutions for some of these items. These solutions were incorporated into the Dulles demonstration pavement along with additional research on the remaining items. This research will be evaluated over the next several years.

Dulles Demonstration Pavement

The demonstration prestressed pavement built at Dulles International Airport contains 6-inch-thick, slip-formed portland cement concrete (PCC) placed over a 6-inch-thick cement treated base (CTB). Two-inch slump, air entrained, class A concrete (Federal Highway Projects Specifications FP–69) containing 7¼ sacks per cubic yard of Type II cement with a minimum 28-day strength of 4,000 p.s.i. was placed (fig. 4). The diabase traprock aggregate all passed a 1-inch sieve, and concrete ingredients were heated to produce placement temperatures above 55° F. while the air temperatures hovered near freezing. The longitudinal steel consists of ½-inch diameter, 7-wire strand prestressing tendons spaced on 2-foot centers at ½-inch below slab mid-depth (figs. 5 and 6). These strands have an ultimate strength of 270 k.s.i. Full prestress load on each strand is 29 kips or 0.7 of its ultimate breaking load. The post-tensioning resulted in approximately 200 p.s.i. compression in the concrete at the anchors. Transverse reinforcing steel consisted of either No. 3 or No. 4 bars spaced on 30-inch centers, depending on the slab section.

Six prestressed slabs of various lengths between 400 and 760 feet were built, using two different types of prestress strand enclosures (table 1). Slab sections—400, 500, and 600 feet—were constructed by placing the 7-wire strand in ¾-inch O.D. steel 20-gage tubing. After post-tensioning the strand, and about a week after the concrete was placed, cement grout was injected through fittings spaced every 100 feet to lock the strand into the slab and protect it from corrosion (fig. 7). The other three slab sections—760, 500, and 400 feet—were constructed with polypropylene sheathed strand that remained ungrouted but which derives its protection from a corrosion-inhibiting grease.

Eight-foot long gaps were left to separate the prestressed slabs (fig. 8). The gaps provided a work area for the jacking and were subsequently filled with 6-inch-thick concrete. Special prefabricated terminals at the prestressed slab ends consist of 6-inch 17.25 lb./ft. I-beams against which the strand anchors bear (fig. 9). The joint, or gap, slabs were reinforced with two layers of 4 x 4 No. 4 gage wire fabric located 2 inches and 4½ inches from the surface. To facilitate joint construction and provide edge reinforcements, a 6-inch 12.5 lb./ft. I-beam forms the transverse edges of the joint slab. Dowel bars 1¼ inch in diameter, 15 inches long, and on 12-inch centers provide the load transfer from the prestressed slabs to the gap slabs (fig. 10).

The constructed opening between joint beam edges is approximately 1½ inches, although it varies depending on the length of the prestressed slab and the concrete temperature. The space between joint beams is filled with a foamed-in-place polyurethane material, which forms an expansion joint at each end of the joint slab (fig. 10). Movements

Table 1.—Slab data

Station	Prestressed slab length	Type prestress tendon	Joint slab length
	(feet)		*(feet)*
100+50			
	400	Grouted	
104+50			
104+58			8
	500	Grouted	
109+58			
109+66			8
	600	Grouted	
115+66			
115+74			8
	760	Plastic encased	
123+34			
123+42			8
	500	Plastic encased	
128+42			
128+50			8
	400	Plastic encased	
132+50			

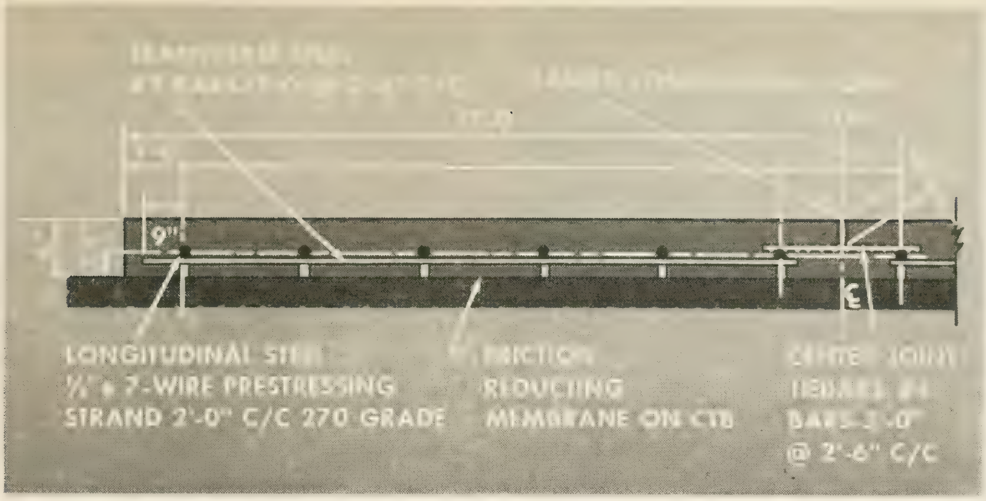

Figure 5.—Transverse prestressed pavement section.

at the joint adjacent to the longest slab should be about 1½ inches annually.

A conventional centerline longitudinal joint on the 24-foot-wide pavement was sawed to a depth of 2 inches. No. 4 tiebars, 36 inches long, were placed on 30-inch centers along the centerline. The concrete was cured with wet burlap covered with polyethylene sheathing. Straw was also used to protect the concrete from temperatures that fell well below freezing at night. The centerline joint was subsequently filled with rubberized asphalt.

The prestressed pavement foundation consists of 28-foot-wide, 6-inch-deep cement treated base (CTB) supported by compacted native soil. The CTB contained 4 percent cement and was cured with an asphalt membrane. A thin layer of sand was broomed over rough surface areas to fill surface irregularities. The base was then covered with double layers of 4-mil polyethylene to reduce friction under the slabs. Subgrade soil consisted of AASHO Soil Classification A-6(12) material, and aggregate gradations for the cement-treated subbase were in accordance with the July 1, 1970, edition of the Road and Bridge Specifications of the Virginia Department of Highways for gradation 21-A.

Prestressing operations followed a very detailed procedure. Briefly, as the slabs were placed, many concrete test cylinders, 6-inch by 12-inch, were made. These cylinders were broken to determine the concrete strength, which controlled the time prestress was to be applied. In theory the earlier the prestress is applied, during periods of falling temperature, the less the chance of shrinkage cracks occurring. Because of the prevailing cold weather during construction, the chances for early cracking were extremely high, but the cracks were not expected to create any difficulties.

Post-tensioning was applied in three stages of approximately 10 kips each until the final load of 29 kips was reached for each tendon. The first third of the stress was applied when the concrete reached a compressive strength of 1,000 p.s.i.; the second third at 2,000 p.s.i.; and the final load at 3,000 p.s.i. The strength gain was such that the stressing was applied in thirds at 1, 2, and 3 days' age. Starting in the mid-portion, alternate tendons were stressed, the outside tendons being jacked last. Prestressing was done by hydraulic jacks, using the terminal I-beams to jack against. Theoretically, the prestress operation should stretch the tendons about 8 inches for every 100 feet at slab length. Hence, the 400-foot slab had its tendons stretched 32 inches. Because of friction a slightly lower amount was achieved for full load. The jacks had a throw of about 8 inches, a condition which required multiple grippings to effect the full stretch at each prestressing level. Tendons were anchored by conventional prestress tapered strand anchor chucks against the 6-inch steel I-beams, which remain in place.

A portable testing laboratory trailer located on the project site was used to conduct conventional and rapid tests for concrete control and acceptance. The concrete was extensively tested to evaluate new tests, such as using a void space indicator, determining early strength by hot water and autogenous curing, determining gross quantity of water content of fresh concrete by using a microwave oven, determining the specific gravity using a vacuum pycnometer, using a continuous reading thermometer to record the temperatures of the autogenous aging molds, and using a programable calculator to calculate and change the mix design within seconds. The equipment and test procedures are part of another FHWA demonstration project entitled "Improved Quality Assurance Programs."

Continuing Research Aspects

In addition to the demonstration project objectives, the construction of the Dulles prestress pavement provides the opportunity for a valuable research study. To observe the behavior of the experimental pavement, the slabs have been extensively instrumented by the FHWA Office of Research. Thermal gradients through the depth of the slab are being continuously recorded while curvature, length changes, and movements at the joints are being periodically measured. Strain gages are embedded in the concrete and are also recorded periodically. It is anticipated that these measurements will continue for several years.

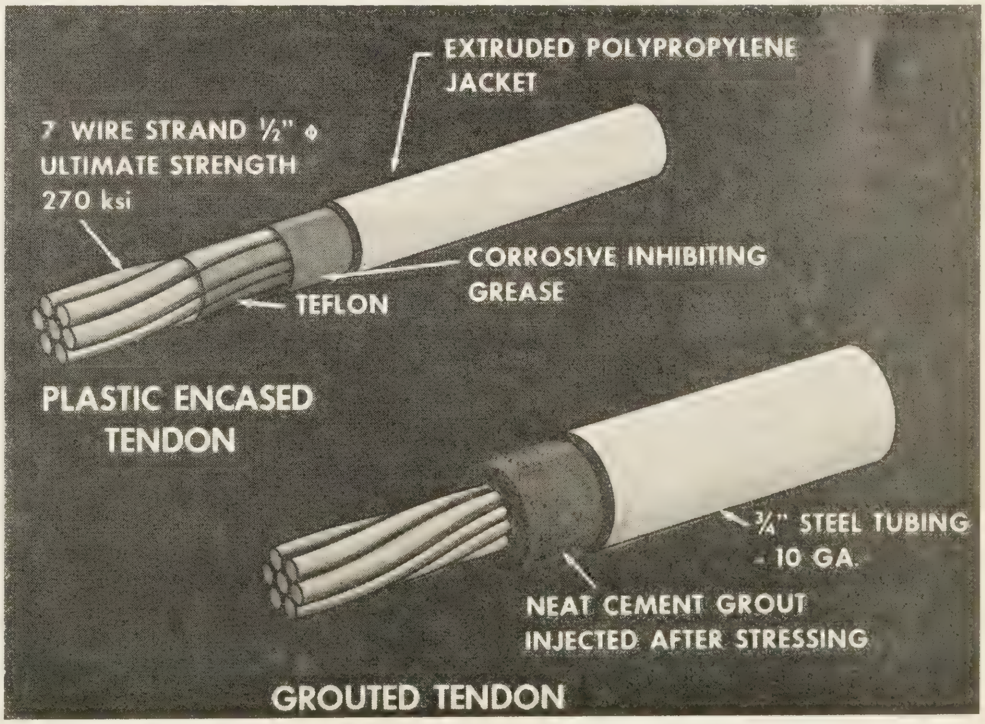

Figure 6.—Prestress tendons.

Figure 7.—Closeup of a grout fitting with locating wires projecting from the cap. Grout inlet is ½ inch.

The U.S. Army Corps of Engineers research group from Waterways Experiment Station is assisting in a FHWA-FAA funded project to evaluate the pavement under wheel loads. Special strain gages were installed in the two 500-foot slabs at the midlengths and at selected ends. In addition, surface strain gages are applied to the concrete and the end beams. In early February, 18-kip and 32-kip single-axle loadings were statically placed to determine deflections (using Benkelman beams) and strains in the materials under load. Selected readings were also made with the axles moving at creep speeds. The results of those heavy loads on a thin pavement supported by an unfrozen base were extremely favorable. After TRANSPO 72, additional deflection studies will be made with the 32-kip single-axle load and a simulated twin-wheel 100-kip aircraft gear load to measure the effects of such loads.

The smoothness of the pavement will be periodically measured with the BPR-type roughometer and the CHLOE profilometer in order to estimate the Pavement Serviceability Index (PSI). Typical weights and vehicle counts of the heavy construction traffic using the pavement are being obtained to try and establish a performance curve for the pavement.

Construction and Pavement Observations

Overall, the construction techniques are not unlike those used on continuously reinforced concrete pavement projects where the steel is preplaced on chairs. The exceptional work is the stressing, grouting, and joint construction.

As expected, several unique construction difficulties were encountered; most were resolved at the site. First, low slump concrete (½-inch slump) and the slow rate of paving pushed the grouted strands forward, producing lateral displacement and some buckling. The concrete slump was subsequently increased to 2 inches, expansion was provided for the strand sections, and the difficulty disappeared. No edge problems were observed using 2-inch slump concrete on the 6-inch slab.

Second, the methods used to protect the grout fittings during concrete placement were less than desirable and resulted in considerable hand labor to open the fittings for grout injection. Likewise the equipment used for grout injection was not dependable. Third, the foamed-in-place polyurethane joint filler did not adequately fill and protect the joint. Solutions to these difficulties are being developed.

As was also expected, one crack developed in the 760-foot slab. However, the prestressing tendons pulled the slab sections together and the crack is barely noticeable. The movement of the slab sections and the action of the crack are being closely monitored.

Future Prestressed Concrete Pavement Construction

Although the results of the Dulles demonstration pavement will permit developing better prestressed concrete pavement design criteria and construction procedures to be used in projects several miles long, the following is a projection of how construction operations might be organized to reduce costs, delays, and manpower requirements:

- It should be possible to use pavement thicknesses of 5 to 6 inches, permitting increased paving speeds or placing additional width for a given quantity of concrete.
- It may be possible to eliminate all transverse steel, except tiebars.
- It should be possible to use only four strands of tendon per lane width; 0.6-inch diameter 7-wire strands each with an ultimate strength of 58,000 pounds would be spaced on 3-foot centers. Thus, the amount of steel is only 2¼ pounds per square yard as compared to 15 to 20 pounds per square yard for continuously reinforced concrete pavements.

Paving would probably proceed as follows:

- A strong cement-treated base would be constructed for the length of the project.
- A bituminous curing membrane would be sprayed on.
- A full-width double layer of 4-mil polyethelene sheeting would be rolled out with a specially built piece of equipment. Both layers must be held down at the edges to prevent wind damage.
- A specially designed trailer carrying reels of encased 0.6-inch diameter 7-wire strand could play out all the necessary strand on rough 3-foot centers across the roadway. A reel contains about a mile of strand.
- About every 500 feet (length depends on findings from Dulles) the strand would be cut and moved aside slightly.
- A preassembled structural steel blockout would be staked in place. The strand ends would be threaded through holes in the steel forms and temporary strand anchors installed.

A typical blockout for a 6-inch-thick, 24-inch-wide roadway would consist of one side being an I-beam, which becomes a permanent end of the slab. The other side would be a temporary steel angle that would be removed after the concrete had hardened and had been stressed. The beam and angle would be about 3 feet apart and would be temporarily connected by bracing to provide rigidity for handling. The beam and angle would be 5 inches high and 23 feet 8 inches long to provide clearance for the paving equipment to pass easily.

- The concrete would then be slipformed into place. Special holding devices into which the strands can be inserted and removed would be used to *position* the steel strands into the extruded concrete. The machine would be unlocked from the strand at a joint and *locked on* to strands at the beginning of the next slab.
- Tiebars would be depressed into the concrete with a wheel-type device and a plastic parting strip installed to form a longitudinal

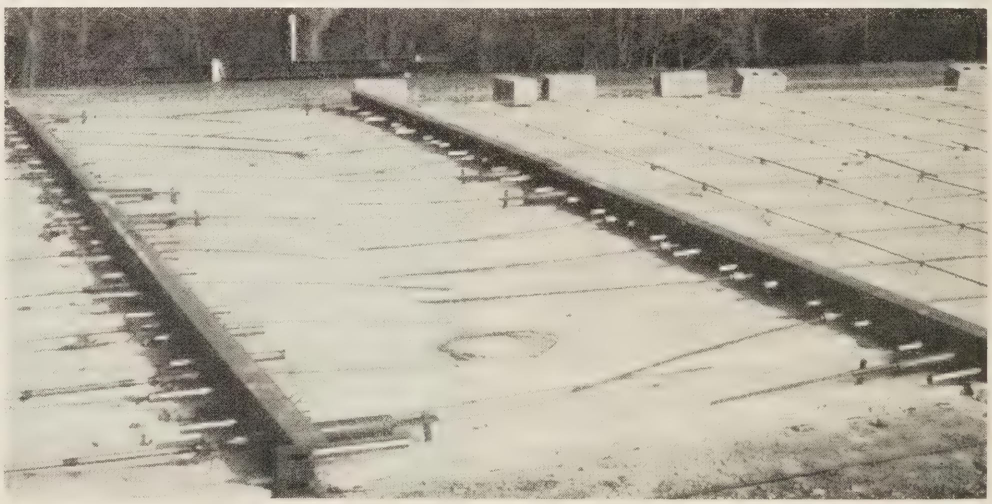

Figure 8.—Joint area between prestressed slabs. An 8-foot-long wire fabric reinforced slab will be placed. I-beams will form the reinforced edges of the 8-foot slab.

joint. After the finishing machine passed, metal caps would be placed on the top of the I-beam and the angle to build them up from 5- to 6-inch pavement thickness. The adjacent concrete would be handfinished and curing applied.

• The concrete would then be allowed to gain strength. If the pavement is expected to shrink or contract, it may be necessary to apply more than one step of post-tensioning to prevent tensile cracks from occurring. If the concrete remains close to its placement temperature for several days, it is possible to apply full post-tensioning when the concrete reaches 3,000 p.s.i. compressive strength (2-3 days).

• A gang of four jacks with 10-inch throws on a mobile cart would be lowered into the blockouts at the end of a slab and a jack positioned on the end of each strand in one lane. The jacks would be loaded to pull each strand to 40,000 pounds. Since this load will elongate the strand approximately 40 inches in a 500-foot slab, the jacks would have to be regripped several times. The gang would then be moved to the adjacent lane and that completed. Next the jacks would be moved to the other end of the slab and the strands pulled just a few inches to bring that end to full force, because about 20 percent of the force from the other end was lost to friction. The adjacent lane would then be done and the jacks moved to start on a new slab.

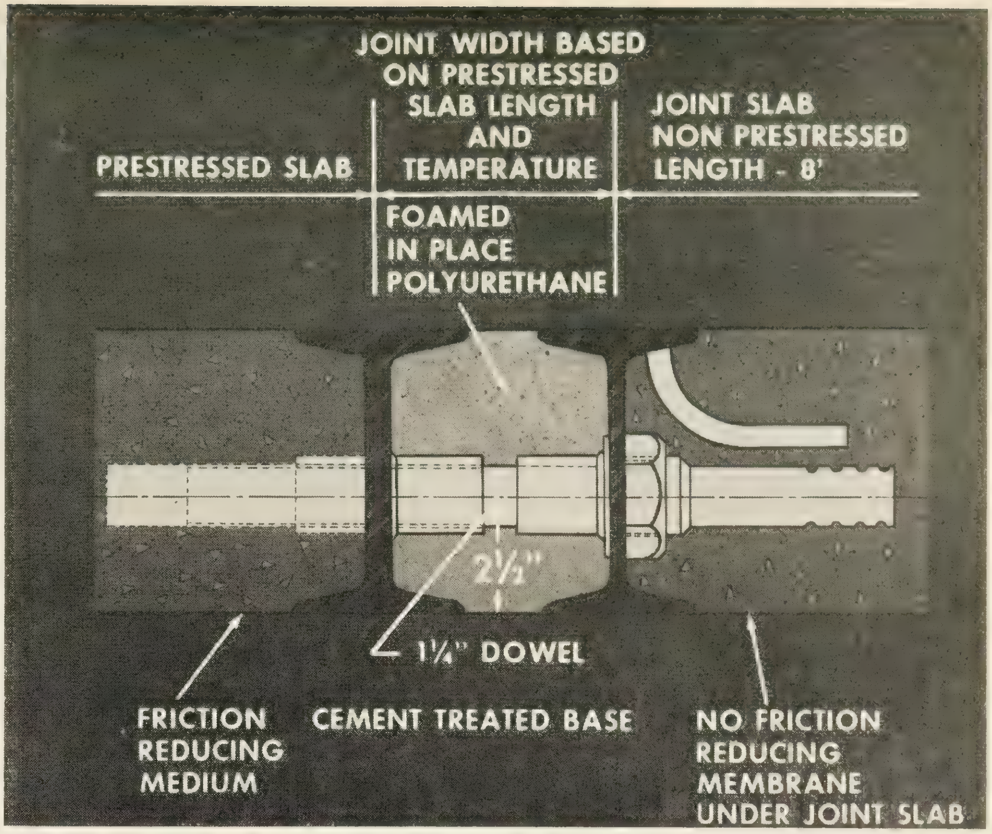

Figure 10.—Detail of joint longitudinal section showing joint beam fastened to dowel units.

Figure 9.—Closeup of the I-beam which serves as a bearing plate and as support for the dowels. The polypropylene strands pass through metal sleeves.

• With the stressing completed the 23-foot 8-inch angle would be removed. A second I-beam, 6 inches high, would then be fitted into place adjacent to the one already there and connected by dowels. Extension rods would be connected to the strand chucks, which are exposed on the side where the angle was removed. The 3-foot length of blockout is then concreted, and after it gains adequate strength is post-tensioned against the main slab with torque nuts on the ends of the extension rods.

• After the blockouts are filled and post-tensioned, only one small opening between two I-beams would remain to accommodate length changes of the slabs. Foamed-in-place polyurethane could be used to fill the opening so that debris is rejected, or a special bridge-type seal could be installed.

Overall, a very efficient operation could be effected. The two major areas of concern are getting well consolidated concrete at the joints and in determining the time for tensioning. The tensioning operation itself is relatively simple and possesses no problems. Filling the gaps with concrete requires some care, but it should be fairly simple because each requires only 1⅓ cubic yards of concrete.

The procedure could be modified slightly to construct prestressed concrete pavement with strands that are grouted in place. Tubing could be in continuous lengths and be unrolled in the field. Intermediate grouting connections could probably be eliminated with good grouting techniques.

Future Reports

It is planned to tie the results of Phase I of the demonstration project activities into a summary report about mid-1972. It will include construction details, cost information, and preliminary analysis of the pavement behavior at an early age. A sound movie will also be available through FHWA covering most aspects of pavement construction and testing. Additional reports will be available in the future as significant information becomes available.

The plans and specifications will be updated and altered to include the information obtained through the demonstration pavement installation. Additional research and development activities are planned to obviate the difficulties which were observed. All this material will be made available to the highway industry upon request.

Characteristics of Rural and Urban Fatal Accidents on the Interstate Highway System, 1969-70

OFFICE OF
TRAFFIC OPERATIONS

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Introduction

THE continuing study of fatal accidents on completed sections of the Interstate System conducted by the Office of Traffic Operations, Federal Highway Administration, has been the subject of several reports in *Public Roads;* a bibliography appears in vol. 36, No. 10, October 1971. The police investigation reports on which these reports were based contain no uniform information as to whether the accidents occurred on rural or urban sections of the System. Recently, however, through the use of material submitted by the State highway departments in support of estimated costs of completing the Interstate System, this information has been developed for a sample of about 75 percent of the police investigation reports furnished by the several State highway departments during 1969 and 1970. The distribution of the accidents by type for the 2 years indicates that the average number of fatalities and other important variables are essentially the same for the 75 percent sample as for the entire set of police reports. The sample represents 66.3 percent of the total number of fatal accidents on the Interstate System during the 2-year period. The accidents omitted consist, in substantial numbers, of those which occurred on frontage or service roads.

The statistical tables included in this article conform generally to those printed in the report for the year 1968 and made available on request for 1969 and 1970. The principal difference, of course, is that the present report provides separate data for rural and urban accidents. Consequently, the principal emphasis in the text is upon the rural-urban differences revealed; repetition of detailed comments on the total accident picture con tained in previous reports is purposely avoided

Accident Patterns

Approximately two-thirds of the 4,644 fatal accidents involved but one moving vehicle; the proportion for rural sections was slightly above that for the urban sections. Disproportionately high numbers of accidents in which a single vehicle ran off the road occurred in rural areas, as did rear-end collisions and head-on collisions caused by wrong-way drivers (table 1). Relatively larger numbers of pedestrian fatalities and sideswipe collisions occurred on urban sections.

In order to examine more precisely some of the factors which may underlie the differences between rural and urban accident patterns, the accident data have been converted to rates

Table 1.—Rural-urban distribution of fatal accidents by type on completed sections of the Interstate Highway System, 1969–70

Types of accident	Total accidents		Rural accidents		Urban accidents		Percent rural
	Number [1]	Percent	Number	Percent	Number	Percent	
All accidents	4,644	100.0	2,782	100.0	1,862	100.0	59.9
Single vehicle	3,061	65.9	1,880	67.6	1,181	63.4	61.4
Multiple vehicle	1,583	34.1	902	32.4	681	36.6	57.0
Single vehicle	3,061	100.0	1,880	100.0	1,181	100.0	61.4
Ran-off-road		78.8		83.0		72.3	64.6
Overturned on the road		1.7		1.5		1.9	56.9
Collision with parked vehicle		5.2		5.5		4.6	65.4
Pedestrian		12.0		8.0		18.5	40.8
Other [2]		2.3		2.0		2.7	53.6
Pedestrian	368	100.0	150	100.0	218	100.0	40.8
Ex-occupants		32.9		33.3		32.6	41.3
Trespassers		67.1		66.7		67.4	40.5
Multiple-vehicle	1,583	100.0	902	100.0	681	100.0	57.0
Rear-end collisions		45.2		48.4		41.2	60.9
Head-on collisions		35.7		35.8		35.5	57.2
Broadside collisions [3]		6.8		6.4		7.3	53.7
Sideswipes		12.3		9.4		16.0	43.8
Head-on collisions	565	100.0	323	100.0	242	100.0	57.2
Wrong-way drivers		41.2		44.3		37.2	61.4
Out-of-control vehicles		55.8		52.9		59.5	54.3
Other		3.0		2.8		3.3	52.9

[1] Approximately 66 percent of all reported fatal accidents as noted in the text.
[2] Principally collisions with objects or animals on the road and occupants falling from vehicles.
[3] Includes collisions with out-of-control vehicles (without cross-median movement) and collisions at intersections of ramps and connecting roads.

per 100 million vehicle-miles as shown in table 2. The fatal accident rate on urban sections is about a third below that for rural sections. These are national rates, however, and should be used with caution. It has been shown that fatality rates on the Interstate tend to be lower where travel densities are high and that in a State where the rural density is high or where the difference between urban and rural densities is moderate, the urban fatality rate is likely to be higher than the rural rate (*1*).[1] A summary of data submitted by State highway departments indicates that in about one-third of the States, fatal accident rates for the Interstate System are higher in urban than in rural areas (*2*).

The largest rural-urban variation appears in accidents of single vehicles which run off the road; the rural rate is nearly double that for urban sections. One of the factors contributing to this difference is speed. Data for 1970 show that the average vehicle speed on rural sections of the Interstate System was 63.8 m.p.h. as compared with 55.6 m.p.h. on urban sections. On rural sections, 22 percent of the vehicles exceeded 70 m.p.h.; on urban sections, only 3 percent exceeded 70 m.p.h. (*3*).

These differences affect not only the frequency of such accidents but also their comparative severity in terms of fatalities, personal injuries, and property damage (table 3). Accident severity may also reflect rural-urban differences in vehicle occupancy. While conclusive data are not available, preliminary results of a 1969–1970 Federal Highway Administration study (*4*) indicate that the number of occupants per vehicle is larger for types of travel more likely to be found in rural areas. For example, vehicles used for vacation travel had an average of 3.3 occupants, while vehicles used for transportation to and from work averaged only 1.4.

The rural rate for fatal rear-end collisions was markedly above that for urban sections.

[1] Italic numbers in parentheses identify the references listed on p. 28.

This appears to reflect more severe rather than more frequent rear-end collisions in rural areas. In addition to the contributing factors already noted, disproportionately high numbers of sleepy or fatigued drivers were involved in rear-end collisions on rural sections.

Rates for both principal types of head-on collisions—wrong-way operation and out-of-control vehicles—were also higher on rural sections. There are several possible reasons for the difference with respect to the collisions caused by wrong-way drivers. Generally denser traffic on urban sections probably lessens the tendency for drivers to enter freeways by exit ramps or to make U-turns on the through lanes. Wrong-way movements are also less likely at illuminated interchanges which are more common in urban areas. The rural rate for fatal accidents caused by out-of-control vehicles that collide after crossing medians was slightly above that for urban areas, probably reflecting, at least in part, speed differences.

The rates for fatal vehicle sideswipes were higher in urban sections. This type of accident occurs predominantly on multilane highways with frequent interchanges, acceleration and deceleration lanes, and where comparatively dense traffic is typical. Passing and merging maneuvers form the basis for many same-direction sideswipes.

The urban rates for pedestrian accidents were also above those for rural sections. Despite the fact that pedestrians (other than persons who find it necessary to leave their vehicles) are generally excluded from the Interstate System, *trespassers* still constitute about two-thirds of the pedestrian fatalities. It may be that hitchhikers seeking rides are usually near urban interchanges although the data available do not include pertinent information on the point. Police reports did, however, frequently refer to fatalities which occur when pedestrians attempt to cross multilane freeways during periods of heavy traffic and darkness.

Average fatalities and personal injuries per fatal accident were higher in rural areas as already noted (table 3). The only exception to this pattern involved rear-end and head-on collisions but the differences were insignificant. The highest fatality averages were those for head-on collisions which occurred more frequently on rural sections where speeds and numbers of occupants tend to be greater. Fatalities and injuries were naturally higher in accidents involving two or more vehicles, but numbers of vehicles per accident did not appear to be a significant factor in rural-urban differentials. Multivehicle fatal accidents on rural sections averaged 2.23 vehicles per accident; the corresponding figure for urban sections was 2.39. Many of the chain-reaction accidents which involve large numbers of injuries and heavy property damage may not result in substantial numbers of fatalities, at least on the Interstate System.

Average property damage figures indicated a similar pattern except for rear-end collisions. These collisions resulted in property damage averaging $5,069 for all such crashes and almost $6,000 for collisions on rural sections, well above the property damage for other types of accidents. An important element in this situation is the disproportionate number of tractor-trailer combinations involved in rear-end collisions (both as striking and struck vehicles) as noted in a subsequent section. Particularly where two or more such vehicles were involved, the damage to vehicles and cargo was extensive, often running well into five figures. As indicated in table 3, estimated damages to vehicles are limited to the current retail values of the models involved as published by the National Automobile Dealers Association. Property damages also include officers' estimates of damage to cargoes, roadside appurtenances, and animals.

Table 2.—Fatal accident rates [1] on completed sections of the Interstate Highway System by type of accident, 1969–70

Accident type	Total accidents	Rural accidents	Urban accidents
All accidents:			
Total	2.286	2.767	1.814
Single vehicle	1.507	1.870	1.150
Multiple vehicle	.779	.897	.664
Single vehicle	1.507	1.870	1.150
Ran-off-road	1.190	1.554	.833
Overturned on road	.025	.028	.021
Collision with parked vehicle	.078	.103	.053
Pedestrian	.181	.149	.212
Other	.033	.036	.031
Pedestrian	.181	.149	.212
Ex-occupants	.059	.049	.069
Trespassers	.122	.100	.143
Multiple vehicle	.779	.897	.664
Rear-end collisions	.353	.435	.274
Head-on collisions	.278	.321	.236
Broadside collisions	.053	.057	.048
Sideswipes	.095	.084	.106
Head-on collisions	.278	.321	.236
Wrong-way drivers	.114	.143	.088
Out-of-control vehicles	.156	.170	.141
Other	.008	.008	.007

[1] Per 100 million vehicle-miles. Total reported vehicle-miles have been reduced to conform to the size of the sample of police reports.

Table 3.—Fatalities, injuries, and property damage per fatal accident on completed sections of the Interstate System, 1969–70

	All accidents	Single vehicle accidents	Ran off road	Multiple-vehicle accidents	Rear-end collisions	Head-on collisions		
						Total	Wrong-way drivers	Out of control vehicles
Fatalities per accident:								
Total	1.218	1.143	1.157	1.362	1.237	1.592	1.575	1.641
Rural	1.251	1.173	1.179	1.411	1.255	1.656	1.629	1.713
Urban	1.169	1.095	1.117	1.297	1.211	1.508	1.489	1.556
Injuries per accident, all injuries:								
Total	1.146	.779	.856	1.856	1.721	2.120	1.687	2.438
Rural	1.257	.948	1.007	1.902	1.711	2.176	1.790	2.474
Urban	.980	.511	.581	1.794	1.736	2.046	1.522	2.396
Class A injuries:[1]								
Total	.759	.531	.592	1.200	.986	1.545	1.206	1.797
Rural	.823	.634	.676	1.217	.984	1.560	1.294	1.766
Urban	.662	.366	.438	1.176	.989	1.525	1.067	1.833
Class B injuries:[1]								
Total	.270	.181	.196	.442	.468	.414	.348	.463
Rural	.307	.236	.251	.456	.479	.424	.322	.515
Urban	.214	.093	.096	.423	.450	.401	.389	.403
Class C injuries:[1]								
Total	.118	.068	.068	.215	.267	.161	.133	.178
Rural	.127	.078	.080	.229	.248	.192	.175	.193
Urban	.104	.052	.047	.195	.296	.120	.067	.160
Property damage per accident:[2]								
Total	$3,150	$2,429	$2,680	$4,544	$5,069	$4,352	$4,064	$4,539
Rural	3,614	2,846	3,001	5,216	5,984	4,749	3,774	5,479
Urban	2,456	1,765	2,093	3,653	3,643	3,823	4,524	3,422

[1] Classified as defined by National Safety Council.
[2] Includes estimated damage to vehicles (not in excess of current retail values), cargoes, and roadside appurtenances.

Day and Time of Occurrence

Slightly more than half the Interstate fatal accidents occurred on weekends—12:01 a.m. Friday to 11:59 p.m. Sunday. There were relatively minor differences among the various types of accidents except in collisions caused by wrong-way drivers. On rural sections, two-thirds of these crashes occurred on weekends. Single-vehicle accidents on urban sections were concentrated more on weekends than were those for rural sections. The smallest daily percentage of accidents occurred on Tuesdays and the largest on Saturdays in both urban and rural areas (table 4).[2]

The data on accidents on lighted highways are influenced by the fact that the majority of lighted areas are on urban sections (table 5). There were three principal exceptions to the general pattern with respect to specific types of accidents. Roughly three-fourths of the pedestrian accidents occurred at night. In addition to the visibility factor, numerous references to intoxicated victims and possible suicides appeared in the police reports on nighttime pedestrian fatalities. In head-on collisions caused by wrong-way drivers—nearly four-fifths of which occurred during hours of darkness—visibility was probably a factor, particularly in view of the high average age of such drivers. Possibly even more important was the very high proportion of drinking drivers responsible for such crashes, if it is assumed that drinking is more common at night. Head-on collisions caused by out-of-control vehicles was the other notable exception to the general pattern. The initial circumstances of such accidents are essentially similar to those in which a single vehicle runs off the road. But more than half of these single-vehicle accidents occurred at night as compared with about a third of the related head-on collisions. In the absence of any factual explanation, it might be speculated that out-of-control vehicles collide with others more frequently during daylight hours merely because more vehicles, as targets, are present.

[2] Separate data for the several types of accidents are not shown in the tables where examinations of the basic data reveal no significant relationships.

An examination of the data on time of accident revealed that the largest proportion (6.2 percent) of the total accidents occurring during any 1 hour occurred between 1 and 2 a.m. The highest hourly frequency for urban accidents (7.8 percent) was also the hour beginning at 1 a.m. The maximum for rural accidents, however, occurred between 4 and 5 p.m. A similar pattern was found for most individual types of single-vehicle accidents. The principal exception was pedestrian fatalities, 10 percent of which occurred during the hour following midnight on both rural and urban sections. Accidents involving two or more vehicles occurred most frequently (6.3 percent) between 4 and 5 p.m. in rural areas, and between 1 and 2 a.m. in urban areas. In rear-end collisions, the largest proportion for any 1 hour (7.1 percent) occurred between 1 and 2 a.m.

Pavement Conditions

Approximately four-fifths of all the accidents occurred on dry pavements. The principal exception was head-on collisions caused by out-of-control vehicles; 36 percent of these occurred on wet pavements and another 8 percent on snow or ice. On the other hand, only 20 percent of the accidents involving single vehicles which ran off the road occurred on wet or icy pavements. This substantial difference is somewhat surprising since the initial circumstances of these two types of accidents are similar as noted previously. Also noteworthy is the fact that pavement conditions were apparently not a significant factor in rear-end collisions. Crashes that occurred on dry pavements on rural and urban sections were 86 and 81 percent, respectively, as compared with 80 and 78 percent for all accidents. The reductions in speeds frequently made on slippery pavements may be sufficient to reduce fatalities in such collisions without necessarily producing any decline in overall accident frequency.

Weather Conditions

The relationships between accidents and weather conditions were essentially the same as those for pavement conditions. While detailed analyses were not available, it was

Table 4.—Fatal accidents on completed sections of the Interstate System by day of occurrence and type of accident, 1969–70

	All accidents			Single-vehicle accidents			Multiple-vehicle accidents			Wrong-way driver: head-on collisions		
	Total	Rural	Urban	Total	Rural	Urban	Total	Rural	Urban	Total	Rural	Urban
Number[1]	4,635	2,779	1,856	3,053	1,877	1.176	1,582	902	680	233	143	90
Percent distribution:												
Sunday	16.7	16.4	17.2	18.2	17.6	19.3	14.3	14.3	14.4	16.3	15.4	17.8
Monday	12.0	12.3	11.5	12.4	12.5	12.2	11.4	12.2	10.4	9.0	8.4	10.0
Tuesday	10.3	10.6	9.8	10.4	11.1	9.3	10.3	9.5	11.2	6.4	7.0	5.6
Wednesday	11.7	11.7	11.8	11.3	11.5	11.0	12.2	11.8	12.8	9.4	7.7	12.2
Thursday	13.5	13.8	13.1	13.2	13.6	12.4	14.0	14.0	14.1	13.3	10.5	17.8
Friday	15.7	16.3	14.7	14.5	14.9	13.8	16.9	18.7	14.4	18.5	19.6	16.6
Saturday	20.1	18.9	21.9	20.0	18.8	22.0	20.9	19.5	22.7	27.1	31.4	20.0
Friday Sunday[2]	52.5	51.6	53.8	52.7	51.3	55.1	52.1	52.5	51.5	61.9	66.4	54.4

[1] Excludes accidents for which day not reported-
[2] 12:01 a.m. Friday to 11:59 p.m. Sunday.

Table 5.—Fatal accidents on completed sections of the Interstate System by light condition and type of accident, 1969–70

Accident type	Number	Darkness: Unlighted	Darkness: Lighted	Darkness: Total	Dawn or dusk	Daylight
		Percent distribution				
All accidents:						
Total [1]	4,627	41.6	10.0	51.6	4.5	43.9
Rural	2,770	46.0	1.8	47.8	5.1	47.1
Urban	1,857	34.9	22.3	57.2	3.7	39.1
Single-vehicle:						
Total	3,049	42.1	10.5	52.6	4.8	42.6
Rural	1,872	45.5	1.9	47.4	5.4	47.2
Urban	1,177	36.8	24.1	60.9	3.9	35.2
Ran-off-road:						
Total	2,407	38.9	10.0	48.9	5.1	46.0
Rural	1,555	42.3	1.8	44.1	5.5	50.4
Urban	852	32.6	25.0	57.6	4.3	38.1
Pedestrian:						
Total	364	59.3	16.7	76.0	3.4	20.6
Rural	147	70.0	3.4	73.4	4.7	21.9
Urban	217	52.0	25.8	77.8	2.3	19.9
Multiple-vehicle:						
Total	1,578	40.5	9.2	49.7	3.9	46.4
Rural	898	47.1	1.8	48.9	4.3	46.8
Urban	680	31.8	19.1	50.9	3.2	45.9
Rear-end collisions:						
Total	711	43.0	10.2	53.2	4.5	42.3
Rural	432	49.3	1.9	51.2	5.1	43.7
Urban	279	33.3	23.0	56.3	3.6	40.1
Head-on collisions:						
Total	565	41.9	9.3	51.2	2.3	46.5
Rural	323	47.4	1.8	49.2	3.1	47.7
Urban	242	34.7	19.0	53.7	1.2	45.1
Wrong-way driver:						
Total	233	67.8	9.9	77.7	1.7	20.6
Rural	143	75.5	1.4	76.9	2.1	21.0
Urban	90	55.6	23.3	78.9	1.1	20.0
Out-of-control vehicle:						
Total	315	23.8	9.2	33.0	1.6	65.4
Rural	171	25.8	2.3	28.1	2.3	69.6
Urban	144	21.5	17.4	38.9	0.7	60.4

[1] Cases for which data are not available (principally hit-run accidents) are excluded.

noted that numerous rear-end collisions involving several vehicles occurred during periods of heavy fog or smoke. There were also reports of light foreign passenger vehicles and a few campers upset by high winds.

Vehicles

Data on the relative importance of each of the more common types of vehicles appear in tables 6 and 7. Table 6 permits an analysis of the relative importance of each type of vehicle within the several categories of accidents. Conversely, table 7 employs the vehicle types as starting points and provides an analysis of the relative importance of the individual accident categories to each type of vehicle. It also permits comparison of the accident pattern for each type of vehicle with the overall or total accident pattern.

As noted in table 6, drivers of passenger vehicles were principally responsible for 76.9 percent of the accidents on rural sections and 84.4 percent on urban sections. No distinctions are made for types of passenger vehicles because the numbers of motorcycles, campers, and buses were too small to have a significant influence on the conclusions.

The comparatively low percentage shown in table 6 for property-carrying vehicles involved in accidents on urban sections is primarily a reflection of the data on tractor-trailer combinations. Such combinations, as noted earlier, were involved in disproportionately large numbers of rear-end collisions, particularly on rural sections. The difference is more readily apparent from table 7. While rear-end collisions constituted 15.7 percent of all rural fatal accidents, they amounted to 35.3 percent of those for which drivers of combination vehicles were primarily responsible. Involvement of these vehicles in head-on collisions, on the contrary, was relatively small. The accident patterns for pickup and panel trucks were essentially the same as those for passenger cars. The data for single-unit trucks refer to vehicles generally in excess of 1-ton capacity. Separate data for the small numbers of farm, highway maintenance, and other special-purpose vehicles are not included in the tables.

Age and Sex of Drivers

Male drivers were primarily responsible for 83.6 percent of all accidents; their representation was slightly lower on rural than on urban sections (table 8). The disproportionately large representation of males in rear-end collisions was partly the result of the relatively important role of property-carrying vehicles in such crashes as noted in the preceding paragraph. Other than light pickup trucks, relatively few property-carrying vehicles were operated by females. Female drivers were, however, responsible for disproportionately high numbers of head-on collisions caused by out-of-control vehicles.

Table 6.—Vehicle types involved in each type of fatal accident on completed sections of the Interstate System, 1969–70.[1]

Accident type	Total accidents	Vehicle type [2]: Passenger vehicles [3]	Property-carrying vehicles: Total	Property-carrying vehicles: Combinations	Property-carrying vehicles: Pickups and panels	Property-carrying vehicles: Single-unit trucks
		Percent distribution				
All accidents						
Total	4,644	79.9	20.1	9.4	7.1	2.5
Rural	2,782	76.9	23.1	12.0	7.2	2.7
Urban	1,862	84.4	15.6	5.4	6.7	2.0
Single-vehicle						
Total	3,061	81.2	18.8	8.0	7.4	2.1
Rural	1,880	79.0	21.0	9.7	7.8	2.5
Urban	1,181	84.8	15.2	5.3	6.8	1.4
Ran-off-road						
Total	2,414	84.3	15.7	7.2	6.5	1.6
Rural	1,560	81.5	18.5	8.8	7.4	1.7
Urban	854	89.3	10.7	4.4	4.8	1.1
Pedestrian						
Total	368	73.6	26.4	8.2	9.2	4.1
Rural	150	71.3	28.7	10.0	8.0	8.7
Urban	218	75.2	24.8	6.9	10.1	1.0
Multiple-vehicle						
Total	1,583	77.3	22.7	12.0	6.7	3.2
Rural	902	72.5	27.5	16.9	6.9	3.2
Urban	681	83.7	16.3	5.6	6.5	3.2
Rear-end collisions						
Total	716	68.2	31.8	20.0	6.4	4.5
Rural	436	61.0	39.0	27.0	6.7	4.6
Urban	280	79.3	20.7	8.9	6.1	4.3
Head-on collisions						
Total	565	88.0	12.0	3.2	6.5	1.9
Rural	323	86.1	13.9	5.0	7.1	1.5
Urban	242	90.5	9.5	.9	5.8	2.5
Wrong-way drivers						
Total	233	88.4	11.6	----------	10.3	1.3
Rural	143	87.4	12.6	----------	11.9	.7
Urban	90	90.0	10.0	----------	7.8	2.2
Out-of-control vehicles						
Total	315	87.9	12.1	5.4	4.1	1.9
Rural	171	86.0	14.0	8.8	3.5	1.2
Urban	144	90.3	9.7	1.4	4.9	2.8

[1] This table is the converse of table 7.
[2] Type of vehicle primarily responsible for each accident as indicated by police reports. Types of vehicles involved less frequently not shown separately.
[3] Includes insignificant numbers of motorcycles, campers, and buses.

The median age for female drivers responsible for fatal accidents was about 2.5 years above that for males—the difference being appreciably greater for accidents on rural sections. The differentials were about the same for the various accident types except where relatively small numbers of accidents were involved. While the sex-age pattern was reversed in certain head-on collisions, the numbers for that type of accident were comparatively small.

Drivers under age 25 constituted nearly a third of those primarily responsible for the accidents on rural sections and slightly more than a fourth on urban sections. The proportions of female drivers under 25 (28 percent for all accidents) were well below those for males except in rural rear-end collisions and head-on crashes, where the differences were small. In any event, drivers under 25 were substantially over-represented compared with their proportions in the licensed population, particularly with respect to off-the-road accidents and head-on collisions caused by out-of-control vehicles. These comparisons are subject to important limitations because no account could be taken of probable significant differences in exposure.

Almost 8 percent of the female drivers were 65 years old or older as compared with 4.7 percent for males. Only minor variations from this relationship were apparent. Significantly, 9.2 percent of the drivers responsible for collisions caused by driving in the wrong direction were 65 years old or older—80 percent above the corresponding proportion for all accidents. On the contrary, older drivers

Table 7.—Accident type in which each vehicle type was involved in fatal accidents on completed sections of the Interstate System, 1969–70.[1]

Accident type	All vehicles	Vehicle type [2]				
		Passenger vehicles	Property-carrying vehicles			
			Total	Combinations	Pickup and panel	Single-unit trucks
Number of accidents						
Total	4,644	3,710	934	435	332	114
Rural	2,782	2,139	643	334	208	76
Urban	1,862	1,571	291	101	124	38
	Percent distribution					
Single-vehicle						
Total	65.9	67.0	61.6	56.3	68.1	55.3
Rural	67.6	69.4	61.4	54.5	70.2	61.8
Urban	63.4	63.7	61.9	62.4	64.5	42.1
Ran-off-road						
Total	52.0	54.8	40.7	40.2	47.3	30.7
Rural	56.1	59.4	45.0	41.0	55.8	34.2
Urban	45.9	48.6	31.3	37.6	33.1	23.7
Pedestrian						
Total	7.9	7.3	1.0	6.9	10.2	13.2
Rural	5.4	5.0	.7	4.5	5.8	17.1
Urban	11.7	10.4	18.6	14.4	17.7	5.3
Multiple-vehicle						
Total	34.1	33.0	38.4	43.7	31.9	44.7
Rural	32.4	30.6	38.6	45.5	29.8	38.2
Urban	36.6	36.3	38.1	37.6	35.5	57.9
Rear-end collisions						
Total	15.4	13.2	24.4	32.9	13.9	28.1
Rural	15.7	12.4	26.4	35.3	13.9	26.3
Urban	15.0	14.1	19.9	24.8	13.7	31.6
Head-on collisions						
Total	12.2	13.4	7.3	4.1	11.1	9.6
Rural	11.6	13.0	7.0	4.8	11.1	6.6
Urban	13.0	13.9	7.9	2.0	11.3	15.8
Wrong-way drivers						
Total	5.0	5.6	2.3	----------	7.2	2.6
Rural	5.1	5.8	2.8	----------	8.2	11.3
Urban	4.8	5.2	1.4	----------	5.6	5.3
Out-of-control vehicles						
Total	6.8	7.5	4.1	3.9	3.9	5.3
Rural	6.1	6.9	3.8	4.5	2.9	2.6
Urban	7.7	8.3	4.8	2.0	5.6	10.5

[1] This table is the converse of table 6.
[2] Refers to the one vehicle primarily responsible for each accident—as indicated by police reports.

Table 8.—Age and sex of drivers in fatal accidents on completed sections of the Interstate System, 1969–70

Accident type	All drivers [1]			Males as percent of total	Percent under 25			Percent 65 and over			Median age		
	Total	Male	Female		Total	Male	Female	Total	Male	Female	Total	Male	Female
All accidents:													
Total	4,559	3,812	747	83.6	31.7	32.4	28.0	5.2	4.7	7.9	32.7	32.4	35.0
Rural	2,753	2,276	477	82.7	32.3	33.0	29.1	5.9	5.4	8.4	32.6	32.2	37.5
Urban	1,806	1,536	270	85.0	26.8	31.5	25.9	4.2	3.7	7.0	32.8	32.6	34.2
Single-vehicle:													
Total	3,007	2,495	512	83.0	34.2	35.0	30.5	5.2	4.5	8.6	31.7	31.4	33.2
Rural	1,860	1,506	354	81.0	34.9	35.9	30.8	6.1	5.5	8.5	31.8	31.4	33.9
Urban	1,147	989	158	86.2	33.0	33.6	29.7	3.8	3.0	8.9	31.6	31.5	32.9
Ran-off-road:													
Total	2,396	1,953	443	81.5	36.2	37.7	29.8	5.4	5.0	7.4	31.1	30.5	33.5
Rural	1,550	1,228	322	79.2	36.8	38.6	30.1	6.5	5.9	8.7	31.1	30.3	34.9
Urban	846	725	121	85.7	35.1	36.1	28.9	3.5	3.4	4.1	31.0	30.9	31.9
Multiple-vehicle:													
Total	1,552	1,317	235	84.9	26.7	27.5	22.6	5.7	5.1	9.4	34.6	34.1	37.6
Rural	893	770	123	86.2	26.9	27.3	24.4	5.6	5.2	8.1	34.1	33.6	38.5
Urban	659	547	112	83.0	26.6	27.8	20.5	5.8	4.9	9.8	35.4	34.8	38.1
Rear-end collisions:													
Total	694	628	66	90.5	29.8	30.7	21.2	3.7	3.5	6.1	32.5	32.3	36.9
Rural	430	398	32	92.6	33.3	33.2	34.4	2.8	3.0	----------	31.2	31.0	33.3
Urban	264	230	34	87.1	24.2	26.5	8.8	5.3	4.3	11.8	35.6	34.8	38.0
Head-on collisions:													
Total	560	454	106	81.1	23.8	23.8	23.6	5.2	5.1	5.7	36.8	36.8	37.2
Rural	321	260	61	81.0	20.9	21.2	19.7	5.6	5.8	4.9	38.5	37.9	41.7
Urban	239	194	45	81.2	27.6	27.3	28.9	4.6	4.1	6.7	35.1	35.4	34.9
Wrong-way drivers:													
Total	229	201	28	87.8	10.9	11.8	3.6	9.2	6.9	25.0	41.3	40.6	46.4
Rural	142	124	18	87.3	10.6	12.1	----------	9.9	8.9	16.7	42.4	41.0	47.5
Urban	87	77	10	88.5	11.5	11.3	10.0	8.0	3.8	40.0	39.8	40.2	37.5
Out-of-control vehicles:													
Total	314	238	76	75.8	33.4	34.5	30.3	2.5	2.9	1.3	33.0	32.7	32.5
Rural	170	127	43	74.7	30.6	31.5	27.9	1.8	2.4	----------	34.2	33.8	33.2
Urban	144	111	33	77.1	36.8	37.8	33.3	3.5	3.6	3.0	30.9	30.7	30.6

[1] Includes the driver responsible for each accident as indicated by police reports. Drivers whose ages were not reported are excluded.

were somewhat under-represented in rear-end collisions.

Driver Physical Condition

Data on the physical condition of drivers were available for about 70 percent of the total (table 9). Of this group, 70 percent were reported as normal, about a fourth as asleep or fatigued, 2.5 percent ill or handicapped and 1.7 percent as distracted. Drivers reported as distracted were those engaged in picking up dropped objects, attending to children, adjusting vehicle controls or similar activities. Sleep or fatigue continues to be the principal problem in this area, particularly on rural sections where it was reported in over two-fifths of the single-vehicle, off-the-road accidents; it was also a significant factor in rear-end collisions. Sleeping or fatigued drivers were reported less frequently in urban areas. This may be a result of the larger proportions of short trips performed on urban sections of the System where the environmental conditions are less likely to induce drowsiness. The difference, however, may be partly the result of variations in reporting. The proportions of drivers whose physical conditions were reported were considerably higher in the case of accidents on rural sections. This is partly because these accidents are, in general, investigated by State police officers and reported on detailed forms. Substantial proportions of the accidents that occurred on urban sections were covered by local police officers or sheriffs who usually report in considerably less detail.

Table 9.—Physical condition [1] of drivers involved in fatal accidents on completed sections of the Interstate System, 1969–70

Accident type	Total number of drivers [2]	Condition not reported		Condition reported					
		Number	Percent of total	Number	Normal	Asleep or fatigued	Ill or handicapped	Distracted	Other [3]
					Percent distribution				
All accidents:									
Total	4,644	1,306	28.1	3,338	71.0	24.4	2.5	1.7	0.4
Rural	2,782	706	25.4	2,076	63.8	31.6	2.3	1.9	.4
Urban	1,862	600	32.2	1,262	82.9	12.6	2.8	1.4	.3
Single-vehicle:									
Total	3,061	846	27.6	2,215	64.7	30.2	2.8	1.9	.4
Rural	1,880	454	24.1	1,426	57.7	37.4	2.5	2.0	.4
Urban	1,181	392	33.2	789	77.5	17.2	3.3	1.6	.4
Ran-off-road:									
Total	2,414	740	30.7	1,674	57.0	36.6	3.6	2.3	.5
Rural	1,560	398	25.5	1,162	51.8	42.5	3.0	2.2	.5
Urban	854	342	40.0	512	68.8	23.2	5.1	2.5	.4
Multiple-vehicle:									
Total	1,583	460	29.1	1,123	83.4	12.9	1.9	1.4	.4
Rural	902	252	27.9	650	77.2	18.8	1.8	1.7	.5
Urban	681	208	30.5	473	91.9	4.9	1.9	1.1	.2
Rear-end collisions:									
Total	716	184	25.7	532	77.6	19.4	1.3	1.7	------
Rural	436	110	25.2	326	69.1	27.3	1.5	2.1	------
Urban	280	74	26.4	206	91.2	6.8	1.0	1.0	------
Head-on collisions:									
Total	565	194	34.3	371	87.1	8.6	2.7	.8	.8
Rural	323	107	33.1	216	84.2	11.1	3.2	.5	1.0
Urban	242	87	36.0	155	91.0	5.2	1.9	1.3	.6

[1] As reported in police investigations.
[2] Includes the one driver responsible for each accident.
[3] Principally defective eyesight.

These differences in reporting exist in varying degrees with respect to other categories of information.

Driver Sobriety

Information on the sobriety of about 70 percent of the drivers primarily responsible for accidents was reported (table 10). Slightly less than a third of the drivers reported were described as having been drinking and 10 percent were characterized as obviously intoxicated. The substantial proportion (17 percent) described as impaired to an unknown degree represents primarily those to whom laboratory tests were not administered or

Table 10.—Sobriety of drivers, as reported by investigators, in fatal accidents on completed sections of the Interstate System, 1969–70

	Total number of drivers [1]	Sobriety not reported		Sobriety reported							
		Number	Percent of total	Number	Not drinking	Drinking	Intoxicated	Impaired	Not impaired	Degree of impairment not reported	Influence of drugs
					Percent distribution						
All accidents:											
Total	4,644	1,369	29.5	3,275	67.1	32.9	10.0	4.0	1.3	17.0	0.6
Rural	2,782	766	27.5	2,016	69.5	30.5	9.6	4.0	1.2	15.0	.7
Urban	1,862	603	32.4	1,259	63.2	36.8	10.8	4.1	1.5	19.8	.6
Single-vehicle:											
Total	3,061	929	30.3	2,132	69.1	30.9	9.1	3.4	1.5	16.2	.7
Rural	1,880	530	28.2	1,350	71.9	28.1	8.9	3.4	1.3	13.9	.6
Urban	1,181	399	33.8	782	64.2	35.8	9.5	3.4	1.9	20.2	.8
Ran-off-road:											
Total	2,414	813	33.7	1,601	64.4	35.6	10.8	3.5	1.5	19.0	.8
Rural	1,560	470	30.1	1,090	68.7	31.3	9.8	3.9	1.4	15.5	.7
Urban	854	343	40.2	511	55.2	44.8	12.9	2.5	1.8	26.6	1.0
Collision with parked vehicle:											
Total	159	49	30.8	110	63.6	36.4	9.1	5.5	.9	20.0	.9
Rural	104	30	28.8	74	71.6	28.4	8.1	2.7	--------	17.6	--------
Urban	55	19	34.5	36	47.2	52.8	11.1	11.1	2.8	25.0	2.8
Multiple-vehicle:											
Total	1,583	440	27.8	1,143	63.4	36.6	11.8	5.2	1.0	18.0	.6
Rural	902	236	26.2	666	64.7	35.3	11.0	5.3	1.0	17.1	.9
Urban	681	204	30.0	477	61.6	38.4	13.0	5.0	.8	19.4	.2
Rear-end collisions:											
Total	716	186	26.0	530	67.9	32.1	9.8	5.7	1.3	14.5	.8
Rural	436	110	25.2	326	68.7	31.3	8.3	5.2	1.8	11.8	1.2
Urban	280	76	27.1	204	66.7	33.3	12.3	6.4	.5	14.1	--------
Head-on collisions:											
Total	565	176	31.2	389	51.2	48.8	16.7	6.2	.8	24.6	.5
Rural	323	93	28.8	230	53.5	46.5	16.1	7.0	.4	22.1	.9
Urban	242	83	34.3	159	47.8	52.2	17.6	5.0	1.3	28.3	--------
Wrong-way drivers:											
Total	233	75	32.2	158	19.0	81.0	34.2	9.5	--------	36.7	.6
Rural	143	48	33.6	95	21.1	78.9	30.6	12.6	--------	34.7	1.0
Urban	90	27	30.0	63	15.9	84.1	39.6	4.8	--------	39.7	--------

[1] Includes the driver primarily responsible for each accident as indicated by police reports.

Table 11.—Characteristics of single-vehicle, off-the-road fatal accidents on completed sections of the Interstate System, 1969–70

Type of accident	Accidents					
	Total		Rural		Urban	
	Number	Percent	Number	Percent	Number	Percent
Total accidents, all types	2,414	100.0	1,560	100.0	854	100.0
Struck fixed object	1,969	81.6	1,202	77.1	767	89.8
Overturned	995	41.2	664	42.6	331	38.8
Overturned only	437	18.1	351	22.5	86	10.1
Total overturns	1,432	59.3	1,015	65.1	417	48.9
Off the road only	8	.3	7	.4	1	.1

investigations in which the test results were not entered on the accident reports. Table 10 shows that drivers who had been drinking constitute larger proportions of the total in urban areas. This may be an understatement of the actual differences in view of the typically less complete reporting of accidents on urban sections.

The reported proportion (32 percent) of drinking drivers involved in fatal accidents on the Interstate System was substantially below the 50-percent figure widely cited for highways generally. A previous study[3] has provided substantial evidence indicating that the fatal accident involvement of drinking drivers on the Interstate System is significantly below that for other highways, particularly on rural sections.

Since the data on drivers reported as being under the influence of drugs (table 10) amount to less than 1 percent of the total, the data relative to individual types of accidents are insignificant. Contrary to what might be expected, there is almost no reference in the investigation reports to drivers suspected of using *bennies* or other sleep preventives.

[3] Fatal Highway Accidents in Federal Highway Administration Region 8, April 1969-March 1970, Office of Traffic Operations, Federal Highway Administration, June 1971 (unpublished).

Single-Vehicle, Off-the-Road Accidents

The most common type of fatal accident on the Interstate System involves the single vehicle which runs off the road; this type makes up more than half the total. Of the 2,414 accidents of this type, more than four-fifths struck at least one fixed object and two-fifths of these subsequently overturned. Nearly another fifth of the total overturned without striking a fixed object with the result that only eight of these 2,414 vehicles ran off the road without striking a fixed object, overturning, or both (table 11).

With respect to this type of accident on urban as compared to rural sections, the proportion of vehicles impacting fixed objects was greater and the proportion of overturns was smaller on urban sections—presumably reflecting the relatively larger numbers of roadside appurtenances and the generally lower speeds in urban areas. On both rural and urban sections, guardrails were the first objects struck most frequently. In about 28 percent of the fatal accidents involving fixed objects, guardrails were struck first. Next in importance were bridge and overpass structures, which were struck first in 18 percent of the accidents.

The third highest category in urban areas, accounting for 10 percent of the total, consisted of impacts with curbs. Third in rural areas were embankments, which were struck first in 15 percent of fixed-object fatal accidents.

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(*3*) U.S. Department of Transportation, Federal Highway Administration, "Traffic Speed Trends," November 1971.

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Pedestrian Needs—Insights from a Pilot Survey of Blind and Deaf Individuals

OFFICE OF PLANNING

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Introduction

IN city and transportation planning, interest is now being directed to the needs of pedestrians. Unfortunately, little attention has been paid to deaf and blind pedestrians. For these people mobility in a city depends on their ability to move about unrestrained by inadequate pedestrian facilities. If walkways can be improved, walking will be safer and more attractive, and individual mobility for the deaf and blind will be substantially increased.

This exploratory study focuses on deaf and blind pedestrian needs within the total transportation system. It is assumed that these people would be more sensitive to general pedestrian needs because of their particular disability and associated mobility problems.

Blindness in this study denotes a range from complete absence of sight to legally blind and severe vision impairment—the inability to read ordinary newspaper print with corrective lenses. Deafness refers to a range from complete absence of sound to severe hearing impairment, causing great difficulty in normal activity due to lack of hearing cues. Both blind and hearing definitions are adapted from the U.S. Department of Health, Education and Welfare, National Center for Health Statistics. A control group, individuals with no discernible disability, was also included in the study to insure a balanced perspective on the total pedestrian role.

This investigation is based on 94 interviews and self-administered questionnaires given to deaf and blind individuals and others from the Washington, D.C., metropolitan area, as well as observations and secondary sources. It is primarily a case study rather than a statistical analysis of pedestrian needs. Although figures summarizing the information are quoted periodically, they may not be totally demonstrative, but at times heuristic, in character. The following are specific objectives of this study.

- Identify the respondent's attitude to pedestrianism.
- Relate the respondent's pedestrian patterns to his attitude to pedestrianism.
- Examine the disability variables and gain clues to other criteria regarding pedestrian activity.
- Derive pedestrian needs from the combination of the respondent's objective activities—as walking—and subjective attitudes.

Pedestrian considerations include safety, purposes, benefits and disadvantages of walking, and improving walking attractiveness. Because approximately 400,000 pedestrians annually are struck by vehicles, resulting in about 10,000 fatalities, pedestrian safety is a top priority consideration. Urban areas, posing special difficulties, sustain 88 percent of the pedestrian accidents. Accident rates show a heavy involvement of children and a high fatality rate for older pedestrians. About half the pedestrian fatalities were over 45 years old and 26 percent over 65. The 5- to 14-year age group had the highest injury rate (number of injuries/number of persons in that age group)—much higher than for older age groups (*1*).[1] Although pedestrian statistics, arranged by age and sex, are readily accessible, with the exception of a pedestrian study by Snyder and Knoblauch (*2*) figures for disabled persons are unavailable.

Of the approximately 200,000,000 persons in the United States, about 20 million (10 percent) have substantial hearing difficulties and about 8.5 million (4 percent) have serious visual impairments. In Snyder and Knoblauch's study (*2*) of a sample of 2,157 pedestrian accidents, the representation from the deaf and visually impaired groups showed no greater proportion of accidents than a sample from a population without these disabilities. Nevertheless, no information was available on the number of deaf and blind individuals who curtailed their walking activities because of poor pedestrian facilities.

When pedestrian needs are better understood and plans for coordinating these needs with other transportation modes are realized, pedestrian accident rates should decrease significantly. If pedestrianism should attain the status of a transportation mode, pertinent data would be collected and analyzed for inclusion in design studies for urban transportation improvements. Transportation planners would therefore be better equipped to offer optimal solutions for pedestrian-vehicle accommodation.

Methodology

Subjects

Deaf and blind persons were approached after consultations with officers and staff of the National Association of the Deaf, the Alexander Graham Bell Association for the Deaf, Gallaudet College, Office of Demographic Studies at Gallaudet College, the American Foundation for the Blind, the National Federation of the Blind, Columbia Lighthouse for the Blind, and the U.S. Department of Health, Education and Welfare—National Center for Health Statistics.

At first, data were gathered only from deaf and blind groups. As the study progressed, however, a control group—persons with no discernible disability—was included to maintain a balanced perspective on the entire pedestrian role. An attempt was made to match the control group's background factors (such as age, education, residence, race) with those of the deaf and the blind.

The participants (66 males, 28 females) consisted of: blind, 10 subjects (6 males, 4 females); deaf, 60 subjects (45 males, 15 females); and control group, 24 subjects (15 males, 9 females). Ages ranged from 18 to 62 years. Among the deaf and blind, males were proportionately greater in number than females (deaf, 75 percent male; blind, 60 percent). This conforms to the national deaf and blind population statistics.

Method and procedure

After reviewing the literature, it was evident that little information existed on the pedestrian characteristics of the blind and deaf, with the exception of the previously cited study by Snyder and Knoblauch.

Blind subjects were interviewed by two or three persons, who went on each personal contact to reduce the possibility of the respondent forming a bias against a single interviewer, and thus not answering the questions objectively. Questionnaires for the deaf group were primarily self-administered, with the exception of a few personal contacts that were sporadically mediated by a sign interpreter. The questionnaires for the control group were also self-administered. It was also kept in mind that, although a self-administered questionnaire eliminates bias between the interview and interviewer, the respondent's self-selection may be biased from an apathetic attitude toward the questionnaire.

Data Analysis

Walking was described as a pleasant activity by 70 percent of the sample (table 1). Although

[1] Italic numbers in parentheses identify the references listed on page 31.

Table 1.—Attitude versus walking trip length

Attitude toward walking	Percent of responses by attitude	Length in blocks
Favorable	70	13.5
Neutral	19	10.0
Unfavorable	11	13.5
Total	100	------------

the remaining 30 percent were indifferent or negative to pedestrianism, they still walked an average of 12 blocks daily. Most of the respondents indicated that they would prefer expanded opportunities for walking trips.

Tables 2 and 3 may indicate some overlap between walking purposes and benefits. Certain respondents specified health and recreation as both trip purposes and benefits; others chose between them. The categories in tables 2 and 3 as well as tables 4 and 5 are not mutually exclusive. For example, flexibility may be viewed as a component of health; social advantages and visits to family, friends, and other business may be seen as a form of recreation.

Table 5 presents a general picture of the more detailed vehicle-oriented and design recommendations. "Better pedestrian facilities" refers to concrete suggestions, such as construction of more sidewalks. "Strict enforcement of pedestrian laws" refers to better control of existing regulations of automobile infringements on pedestrians, such as vehicles turning into crosswalks while people are walking. "Enactment of better pedestrian laws" concerns suggestions for new and more effective pedestrian laws, such as restrictions on blowing horns within a certain distance of pedestrians.

Blind group

The blind group was especially vocal and enthusiastic in offering their responses. These individuals seemed particularly pleased to find concern being directed to their unique mobility problems; nevertheless, they indicated they wanted to be part of the mainstream of society rather than a segregated group. This sample consists of two segments, cane users and dog users.

The majority of the blind group used canes. Individuals using guide dogs, however, require substantial strength, must be able to walk about 5 miles per hour (normal walking speed for the dog), and usually range in age from 18 to 55. Under these constraints, less than 2 percent of the blind population use guide dogs.

An important distinction exists between these segments. Cane users, essentially self-reliant, are especially susceptible to all architectural barriers. Dog users, dependent on the dog for total mobility guidance, are basically unaware of any pedestrian difficulties for the animal detours his master from any problem-creating situation. The fact remains, however, that if the dog user is without his animal, walking outside his home environment would be almost impossible.

Table 2 shows work rated as the most important trip purpose. This result appears feasible, for all blind persons interviewed were professionally employed. Visits to family, friends, and other business were mentioned as the second most important trip purpose. Walking trip benefits (table 3) in descending order were flexibility, health, and economy. (It is cheaper to walk than ride as many informants added.) Throughout the interviewing process, utility—walking accessibility to places otherwise difficult to reach by vehicle, such as downtown shopping—emerged as a significant pedestrian factor. Despite a broader range of factors suggested by trip benefits, utility was still a source of pedestrian activity. This was particularly evident in the personal interviews. Blind individuals rely crucially, it seems, on walking to reach destinations, whether these be total pedestrian trips or pedestrian-vehicle combinations.

Table 2.—Walking trip purposes

Walking trip purposes	Percent of walking trips by purpose		
	Blind n=10	Deaf n=60	Control n=24
Visits	24	26	27
Recreation	24	15	20
Shopping	14	23	21
Work	33	14	20
School-church	--------	10	9
Medical-dental	5	8	3
Health	--------	4	------
Total	100	100	100

Car-related problems and inadequate pedestrian facilities were cited unanimously as the most hazardous pedestrian conditions (table 4). Unanimous support (table 5) was given also to providing better pedestrian facilities and strict enforcement of pedestrian laws.

Blind respondents gave specific insights into pedestrian problems, and offered the following recommendations for better enforcement of vehicle restrictions: (1) Do not allow vehicles to park in crosswalks, or turn into crosswalks where pedestrians are walking; (2) vehicles must yield to pedestrians; and (3) prevent unnecessary tooting at pedestrians. Noise diffusion from cars, trucks, buses, and aircraft causes great difficulty for the blind in deciphering appropriate mobility cues.

Blind individuals also offered a number of suggestions for improving pedestrianism. They expressed a need for more and wider sidewalks and crosswalks, especially in rural and suburban areas. Additional over- and underpasses would be an improvement, as would textured pavements. A colored line along specific pedestrian routes would help, for many visually impaired people can see vivid colors. And angular instead of rounded corners should be implemented for orientation.

Braille maps placed at strategic points (for example, near or on traffic circles) and audible pedestrain signals placed at both rural and urban streets offer another means for the blind to be sure of their direction. Additionally, more defined indications for transit stops by slightly depressed pavement, textured pavements, or braille maps improve directional cues.

Safety is obviously important, and much can be achieved in this area by eliminating sidewalk impediments where possible. For example, remove snow, ice, and construction items remaining on sidewalks, and provide better temporary pedestrian walks in construction areas.

In another area, strong opinions, basically among the blind, surround the white cane law issue. White cane laws, enacted in 49 States, require motorists to stop a specified distance from a pedestrian holding an extended white cane before him. It appears that many blind people view these laws as possibly injurious rather than advantageous. Although these regulations are on the books, they are little publicized and hardly known. In addition, many canes are no longer white and are hardly discernible at any distance, especially in a vehicle. Also, extended canes may easily cause difficulties for other pedestrians. Most of the blind informants, versed in these laws, expressed urgent concern for their reformulation or abolition, if no better solution is proposed.

Deaf group

Although they represented the largest group sample, deaf individuals offered the least information. Many stated that no mobility problem existed. This idea is also expressed in various publications, particularly those of the National Center for Health Statistics.

In each of the other two groups studied, noise always proved to be significantly deleterious to pedestrianism. The deaf have the advantage of noise absence; however, little information exists on the function of background noise and its effects on the human organism. As more knowledge on this subject becomes available, analysis of the deaf situation will be more complete and reliable.

The deaf sample indicated that visits to friends, family, and other business (table 2) were the most important trip purposes. They also specified health and then recreation (table 3) most frequently as trip benefits. Through the survey responses and personal interviews, a casual attitude toward walking was detected. This attitude was in direct contrast to the blind sample.

Table 3.—Walking trip benefits

Walking trip benefits	Percent of walking trips by benefit		
	Blind n=10	Deaf n=60	Control n=24
Health	29	27	29
Flexibility	36	17	33
Economy	21	17	27
Social advantages	7	19	11
Recreation	7	20	------
Total	100	100	100

Several of the deaf respondents also suffered from a lack of balance. This condition is not uncommon among the deaf, but rarely evident unless there has been infection in the inner ear. Tables 4 and 5 show the tendency of these individuals to emphasize pedestrian laws and also be aware of danger. Danger in the sense of fear from falling, being hit by a vehicle, being unable to walk a very straight path at night, and fear of personal harm were expressed. The deaf also offered suggestions to improve pedestrianism.

Table 4.—Walking trip disadvantages

Walking trip disadvantages	Percent of walking trips by disadvantage		
	Blind n=10	Deaf n=60	Control n=24
Car-related	32	30	20
Weather	12	17	16
Inadequate pedestrian facilities	32	12	17
Time	....	13	15
Danger	....	13	6
Fumes	4	8	14
Noise	20	7	12
Total	100	100	100

Their recommendations are offered on the basis of design problems as expressed in the survey data rather than directly specified by the respondents.

More and better simplified signs with perhaps visual-symbolic illustrations would better orient the deaf pedestrian; also optimal location of these signs should be stressed. (The uniform sign system now being nationally implemented is a step in the right direction.)

Audible crossing signals at various frequencies should be installed. Individuals whose hearing is severely impaired are still able to discern certain sounds at various frequencies, and they are able to associate certain sounds with their related connotation.

Better and more lighting facilities on pedestrian routes would aid those who have a balance problem.

More handrails, with greater elevation, also should be installed to help with the balance difficulty. These facilities could be located on a median strip separating vehicular traffic on a collector or arterial, or within a transit stop for aid in queuing for and boarding a bus, or on traffic circles.

Control group

The control group, a combination of professionals and graduate students, was extremely interested in participating in the study. This group appeared anxious to express their ideas, with the hope that their views would have an impact.

Although they walked primarily to visit family, friends, and stores (table 2) and saw flexibility (table 3) as the most important trip benefit, these individuals appeared particularly concerned about the pedestrian plight in a vehicle-dominated society. This pattern was indicated in tables 4 and 5, which show lengthy elaboration on problems caused by vehicles.

More detailed recommendations included placing restrictions on vehicles in congested urban areas (for example, no tooting of horns, parking tax on suburban vehicles in city); and constructing more pedestrian malls, especially in highly congested areas. *Walk* and *Do Not Walk* signals should be placed at each intersection, allowing sufficient time for handicapped pedestrians to cross. Vehicles should be permitted to turn only after pedestrians are clear of the crosswalk. Sidewalks should be repaired at regular intervals.

Table 5.—General recommendations

Recommendations	Percent of responses by recommendation		
	Blind n=10	Deaf n=60	Control n=24
Better pedestrian facilities	44	44	62
Strict enforcement of pedestrian laws	44	31	22
Enactment of better pedestrian laws	12	25	16
Total	100	100	100

Conclusions

Deaf and blind groups proved more sensitive to those aspects of the pedestrian role of which normally sighted and hearing individuals would be unaware or take for granted. This pattern emerged most emphatically when comparing the blind and deaf groups to the control sample. Blind and deaf individuals offered specific suggestions for walking improvements; the control group appeared interested in expressing negative generalizations about the vehicle orientation of urban life.

The blind group generally showed concern for expanding physical design features on streets and pavements. The noise dimension was also stressed. Because of high degree of noise diffusion, the blind find difficulty in deciphering appropriate mobility cues. Basically, the deaf sample specified the visual dimension -better, clearer signs with more appropriate location. Additionally, physical design considerations were also emphasized in the form of support structures.

Again, the control group assailed the motorized vehicle and its concomitant implications and suggested extension of walking facilities such as pedestrian malls. Although each of the groups implied dissatisfaction with the discourtesy or unconcern of the vehicle operator, the blind and deaf were more interested in providing suggestions for design improvements. The control group was more concerned with the urban technological environment.

Although the sample represents a limited number of individuals, definite patterns emerged. Blind and deaf individuals showed sensitivity to pedestrian needs that might never have been identified. This further reinforces the need for collecting adequate pedestrian data, which has been previously discounted or neglected entirely. The pedestrian mode needs to be included with the other transportation system modes in the design studies of urban transportation improvements. In this manner, optimal solutions for pedestrian difficulties would be more readily forthcoming.

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(*3*) Carp, F., "Pedestrian Transportation for Retired People," *Highway Research Record* No. 356, HRB, Washington, D.C., 1971.

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New Publications

The Federal Highway Administration has published four new documents. These publications may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, prepaid. The following paragraphs give a brief description of each publication and its purchase price.

Highway Statistics, 1970

Highway Statistics, 1970 ($1.75 a copy), a 199-page bulletin, is the 26th in the annual series, presenting 1970 statistical and analytical tables of general interest on motor fuel, motor vehicles, driver licensing, highway-user taxation, State highway finance, highway mileage, and Federal aid for highways; and 1969 highway finance data for municipalities, counties, townships, and other units of local government.

The *Highway Statistics* series has been published annually beginning with the year 1945, but most of the earlier editions (except for 1967, 1968, and 1969) are now out of print. However, much of the information presented in earlier editions is summarized in *Highway Statistics, Summary to 1965*, which may be purchased from the Superintendent of Documents for $1.25.

Fatal and Injury Accident Rates on Federal-Aid and Other Highway Systems, 1970

Fatal and Injury Accident Rates on Federal-Aid and Other Highway Systems, 1970 (45 cents a copy), is a 36-page publication and is the fourth in an annual series presenting accident, fatality, and injury rates per 100 vehicle-miles by State and administrative highway system. Included also are similar rates based on numbers of registered vehicles, licensed drivers, and population. In addition to the rates, the actual numbers of highway miles in service, vehicle miles, accidents, fatalities, and injuries are shown in supporting tables. This compilation is based on reports submitted by the State highway departments.

Debris-Control Structures

Debris-Control Structures, published in March 1971 (50 cents a copy), is No. 9 in the Federal Highway Administration series of hydraulic engineering circulars. It provides guidance for determining the need for a debris-control structure and for selecting the most suitable type based on debris classification. It also presents design information for six types of debris-control devices. The Circular is principally based on practice and experience in California, Washington, and Hawaii.

TITLE SHEET, VOLUME 36

The title sheet for vol. 36, April 1970–February 1972, of PUBLIC ROADS, *A Journal of Highway Research*, is now available. This sheet contains a chronological list of article titles and an alphabetical list of authors' names. Copies of this title sheet can be obtained by sending a request to the editor of the magazine, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. 20590.

Digest of Recent Research and Development Results

Reported by the Implementation Division, Office of Development

The items reported here have been condensed from highway research and development reports, predominantly of Federally aided studies. Not necessarily endorsed or approved by the Federal Highway Administration, the items have been selected both for their relevancy to highway problems and for their potential for early effective application.

Each item is followed by source or reference information. Reports with an "NTIS" reference number are available in microfiche (microfilm) at 95 cents each or in paper facsimile at $3 each from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Va. 22151.

FREEWAY EFFICIENCIES OF RESERVED TRAFFIC LANES

The efficiency of reserved traffic lanes on freeways during rush hours for specified priority vehicles, such as buses and other high-occupancy vehicles, can now be computer-evaluated for optimum use of freeways on the basis of total passenger time for various lane operating patterns. The computer program model will handle a variety of conditions applicable to a problem situation, including presence or absence of queuing, number of reserved lanes, occupants per vehicle using reserved lanes, vehicle occupancy distributions, etc.

A Mathematical Model for Evaluating Priority Lane Operations on Freeways—June 1970, The Institute of Transportation and Traffic Engineering, University of California, NTIS No. PB 195177.

VEHICLE-CLASSIFYING PORTABLE COUNTER

A portable, battery-operated, solid-state traffic counter which can detect and classify vehicles in one lane of a roadway according to wheelbase and the number of axles has been developed and field tested. The counter utilizes a vehicle presence loop detector imbedded in the pavement, and two road tube detectors. By using loop detectors now serving permanent traffic recorders, classification data coverage can be made more comprehensive than is now possible with manual counting and classification methods. Although differentiation among 2-axle cars, 2-axle cars with trailer, and 2-axle trucks is not consistent, this inconsistency seems to be outweighed by the ability to classify traffic for little more than the cost of obtaining normal permanent recorder data.

Vehicle Classifying Counter, California Division of Highways Research Project C–1–2, November 1969, NTIS No. PB 199421.

A LOW-COST QUALITY RETARDER FOR CEMENT-TREATED SOILS

Results of recent field trials and laboratory tests indicate that an admixture of sugar and lime in soil-cement mixtures effectively minimizes the detrimental effects of low density and low strength resulting from delayed compaction. Results also indicate that the sugar-lime admixture is:

1. easily processed with normal construction equipment.
2. inexpensive.
3. more satisfactory than two other types of retarders commonly used in concrete.

For periods in the field up to 6 hours after mixing, no detrimental effects on ultimate strength development occurred with the sugar-lime admixture. In another State, investigators also found in a separate study of shrinkage problems that a remarkable reduction in crack intensity results when a sugar-lime admixture is used in soil-cement stabilization.

Use of Retarders with Cement-Treated Soils, (final report) Report No. VHRC 70–R17, by the Virginia Highway Research Council, NTIS No. PB 182115.

Crack Control in Cement Treated Bases, University of Mississippi, NTIS No. PB 199500.

IMPROVED ACCEPTANCE PLAN FOR COMPACTION

More consistently competent results with less effort in the use of nuclear gages are cited as the benefits of research recently reported. The benefits are made possible by improved test procedures plus improved reliability in determining moisture content and percentage of relative compaction of materials. The improved reliability permitted revisions in California's statistically based acceptance plan, resulting in more rapid and efficient determination of compliance with specified target values. Nearly $150,000 savings per year in acceptance testing costs are expected. Some of the contributing revisions were:

- Standard Block Calibrations for nuclear gages will be used exclusively instead of field calibrations.
- The 8-inch direct transmission mode is used for testing all material 8 inches or greater in thickness (generally embankment material).
- The backscatter mode is used for testing all material less than 8 inches thick (generally structural section material).
- A guide plate 12 by 18 by ¼ inches is now specified instead of the 6 by 10 inch size.
- Density measurements in the backscatter and moisture modes are made by taking one 1-minute count, instead of 2.

The total number of gages in use by California was about 50 in 1967 and 140 at the end of 1970.

Relative Compaction Study (final report), California Division of Highways Study No. F–4–17. Available from Department of Public Works, Division of Highways, P.O. Box 1499, Sacramento, Calif. 95807.

USING EPOXIES FOR PATCHING CONCRETE

Full-scale field test evaluations were recently conducted on seven commercially available epoxy resin compounds used as thin bond overlays for patching and protecting concrete. These tests point up the importance of surface preparation of the concrete for applying the epoxy membrane, as well as adequate protection of the membrane from wear, if it is expected to seal out water or salt solutions.

All concrete of poor quality should be removed in preparing the surface. The remainder should be cleaned, preferably by sandblasting until the coarse aggregate in the concrete is visible. The debris from the sandblasting should be broomed away and the deck blown clean with compressed air. A wearing course of dense plant mix asphaltic surfacing is considered essential to protect the epoxy sealcoat for continued effectiveness.

Evaluation of Epoxy Compounds as a Material for Patching and Protecting Concrete (final report), Virginia Highway Research Council. NTIS No. PB 199792.

FULL-SCALE TEST URGED FOR RESERVED TRAFFIC LANES ON URBAN FREEWAY

Reserving traffic lanes for high-occupancy vehicles (buses and car pools) on freeways during rush hours is a basically sound concept that has good potential where the right conditions exist, but offers limited or no potential if the characteristics of the freeway are not suitable. The concept has definite potential for success—up to 13 percent increase in passenger-mile capacity—on Cleveland's Memorial Shoreway, according to the study analysis and conclusions developed in a contract report for the U.S. Department of Transportation. Approximately $750,000 in estimated annual user benefits could be realized there if the anticipated potential were developed. The report recommends a full-scale demonstration as the only means of providing definite answers to the pros and cons regarding workability of the concept on the Memorial Shoreway.

Feasibility and Evaluation Study of Reserved Freeway Lanes for Buses and Car Pools, January 1971, NTIS No. PB 198648.

New Research in Progress

Title. Unit Costs for Modes of Transportation Including Externalities Such as Air Pollution.

Objective. Relate unit costs per mile for automobiles (including carpools), buses, and rapid rail transit, on a vehicle and per passenger mile basis, to the related quantities and constituent amounts of air pollution produced.

Performing Organization. Federal Highway Administration, Washington, D.C.

Expected Completion Date. May 1972.

Title. Bridge Deck Rehabilitation—Methods and Materials.

Objective. To develop and evaluate methods to detect bridge deck deterioration and to construct economical and durable repairs.

Performing Organization. Oklahoma Department of Highways, Oklahoma City, Okla.

Expected Completion Date. January 1975.

Title. Surface Texture Measurement Evaluation.

Objective. To develop a pavement texture evaluation system, determine the relationship between skid resistance and texture, and implement the findings.

Performing Organization. Maryland State Highway Administration, Baltimore, Md.

Expected Completion Date. January 1975.

Title. Longitudinal Cracking in Flexible Pavement Wheel Paths.

Objective. To determine the cause of longitudinal cracking in the wheel paths of a high-type flexible pavement.

Performing Organization. Department of Highways and Traffic, Washington, D.C.

Expected Completion Date. February 1973.

Title. Requirements for Wear-Resistant and Skid-Resistant Highway Pavement Surfaces.

Objective. Identify, evaluate and develop recommendations for the implementation of any procedures, including new and innovative, intended to result in the construction of improved wear-resistant and skid-resistant pavement surfaces and the correction of worn or polished surfaces; conduct an experimental program to evaluate procedure considered promising for practical application.

Performing Organization. Materials Research and Development Inc., Oakland, Calif.

Expected Completion Date. April 1975.

Title. Proof Testing of a Structural Plate Pipe.

Objective. Obtain field data on the performance of a structural plate pipe under a deep fill for a range of backfill, bedding and bolt connection conditions.

Performing Organization. California Division of Highways.

Expected Completion Date. June 1976.

Title. Polymer Concrete Tunnel Support and Lining Test Program.

Objective. Develop and test low cost, high strength precast polymer impregnated concrete for tunnel support and lining systems that utilize the unique characteristics of polymer concrete materials.

Performing Organization. Colorado Bureau of Reclamation.

Expected Completion Date. June 1972.

Title. Development of a Procedure to Simulate Motor Vehicle Pollution Levels.

Objective. (1) Adapt a current atmospheric dispersion model considering emission factors. (2) Measure air pollutant concentrations and local and area meteorological information to confirm or rationally modify models. (3) Use model to establish conformity to federal ambient air quality standards about proposed highways. (4) Publish procedures and instruct highway department in application.

Performing Organization. Department of Highways and Traffic, Washington, D.C.

Expected Completion Date. December 1972.

Title. Nonmetallic Coatings for Concrete Reinforcing Bars.

Objective. To develop a nonmetallic coating for concrete reinforcing steel that will protect the reinforcing bars from chloride induced corrosion.

Performing Organization. National Bureau of Standards, Washington, D.C.

Expected Completion Date. September 1974.

Title. Binder Modifier Agents for Construction and Maintenance Seals.

Objective. Determine through field tests the relative merits of the different groups of products and the individual products as to their use as construction seals and preventive maintenance treatment in the preservation of the asphalt concrete surface and body. Determine the possible detrimental effects of these products such as lower skid resistance, excessive hardening or softening of the pavement.

Performing Organization. California Division of Highways, Sacramento, Calif.

Expected Completion Date. June 1977.

Title. The Determination of the Physical, Chemical, and Metallurgical Characteristics of Steels Furnished from Typical Highway Bridges.

Objective. To determine the physical, chemical, and metallurgical characteristics of three structural steel specimens furnished by the Government.

Performing Organization. Massachusetts Materials Research, Worcester, Mass.

Expected Completion Date. January 1973.

Title. Surface Impregnation and Polymerization of Concrete Bridge Decks.

Objective. To design, build and test scale size equipment for the in-place surface polymer impregnation of hardened portland cement concrete.

Performing Organization. Bureau of Reclamation, Denver, Colo.

Expected Completion Date. December 1972.

Title. Slope Stability of Certain Selected Colluvial Soils.

Objective. Develop a method to evaluate slope stability of certain selected colluvial soils so that problem areas can be detected early in the design of future projects.

Performing Organization. Oklahoma Department of Highways.

Expected Completion Date. June 1974.

Title. Water Drainage from in Place Fills to Prevent or Halt Fill Slides.

Objective. To determine the conditions within fills that contribute to the accumulation of water; to determine methods for preventing this accumulation and for draining excess water.

Performing Organization. Kansas State Highway Commission.

Expected Completion Date. June 1977.

Title. A Field Evaluation of Driver Information Systems for Highway-Railway Grade Crossings.

Objective. The study will field evaluate an electronic advance warning variable message sign for rail-highway grade crossings. It will display the standard advance warning symbol and warn of one of three conditions: tracks (or crossing) ahead; stalled (or stopped or slow) vehicle; and tracks (or crossing blocked).

Performing Organization. Purdue University, Lafayette, Ind.

Expected Completion Date. June 1973.

Title. Fill Stabilization Using Non-Biodegradable Waste Products.

Objective. To determine the stabilizing effect of selected waste materials on typical embankment soils.

Performing Organization. California Division of Highways.

Expected Completion Date. August 1973.

Title. Accident Potential at Rail-Highway Grade Crossings.

Objective. To develop reliable techniques for assessing the accident potential and severity at rail-highway grade crossings as a function of relevant influencing parameters such as railway and highway traffic volumes and level of crossing protection. These techniques may constitute refinements of existing and/or totally new techniques.

Performing Organization. Alan M. Voorhees Associates, McLean, Va.

Expected Completion Date. May 1972.

Title. Experimental Treatment of Fresh Concrete by High-Frequency-Excited Screw-Type Auger.

Objective. The study will evaluate the effects on specific engineering properties of concrete produced by treatment of fresh concrete with high-frequency energy in sonically-excited screw-type auger.

Performing Organization. Ohio State University, Columbus, Ohio.

Expected Completion Date. October 1972.

Title. Roadside Development.

Objective. To improve erosion control, enhance esthetics and reduce maintenance costs by refining roadside vegetation establishment techniques.

Performing Organization. University of Massachusetts, Amherst, Mass.

Expected Completion Date. December 1972.

Title. Study the Significance of Pavement Texture.

Objective. Review of literature, investigation of texture requirements, measurement systems, and texture standards.

Performing Organization. Federal Highway Administration, Washington, D.C.

Expected Completion Date. November 1973.

Title. Laboratory Evaluation of Pavement Surface Characteristics in Relation to Skid Resistance.

Objective. To provide an analysis, evaluation, and interpretation of data acquired under FHWA Staff Study No. 21H1014 during the period 4/1/70 to 9/30/71. Prepare a report suitable for publication, including a referenced summary of pertinent literature.

Performing Organization. S. H. Dahir, Consultant, Middletown, Pa.

Expected Completion Date. June 1972.

Title. Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Development).

Objective. To design and produce prototype sensors capable of measuring moisture in granular and soil materials. Two sensors will be employed. In the range of 0-100% moisture content the approach is to use Nuclear Magnetic Resonance (NMR) absorption of radio frequency energy and in the range of 100–200% moisture content the approach is to use resonant dielectric absorption of microwaves.

Performing Organization. Southwest Research Inst., San Antonio, Tex.

Expected Completion Date. January 1974.

Title. Study of the Toxicity of MSMA.

Objective. Investigation of the likelihood of contaminating the highway environment and immediate environs with arsenical residues.

Performing Organization. Tulane University, New Orleans, La.

Expected Completion Date. March 1974.

Title. Support of University of Michigan Remote Sensing Symposia.

Objective. Support the activities of the center for remote sensing information and analysis including presentation of international remote sensing symposia, and depository for remote sensing reports and data.

Performing Organization. University of Michigan, Ann Arbor, Mich.

Expected Completion Date. April 1973.

Title. Effects of Road Geometrics and Warning and Advisory Signs on Vehicular Control Proficiency (Phase I).

Objective. The interactive effects of road geometrics, warning and advisory signs and unexpected roadside activity on vehicular control is to be evaluated in a laboratory setting. The potential of warning and advisory information for improving vehicle handling is to be investigated so that more selective testing may be conducted in a field setting.

Performing Organization. Federal Highway Administration, Washington, D.C.

Expected Completion Date. May 1972.

Title. Determination of Earth Movements and Stresses in Connection with Tunneling.

Objective. To develop a finite element computer program which uses stress dependent elastic parameters. To perform four borings and to take undisturbed soil samples for laboratory testing. To determine the parameters of the stress-strain relationship. To analyze conditions of tunneling at the Lincoln Memorial.

Performing Organization. Federal Highway Administration, Washington, D.C.

Expected Completion Date. May 1972.

Title. Dragdown of Piles by Negative Skin Friction.

Objective. To develop guidelines for investigation and design of pile foundations subjected to dragdown.

Performing Organization. Massachussetts Institute of Technology, Cambridge, Mass.

Expected Completion Date. June 1977.

Title. Surface Icing of Insulated Pavements.

Objective. Determine the significance of the insulated pavement icing problem.

Performing Organization. New York Department of Transportation, Albany, N.Y.

Expected Completion Date. March 1973.

Title. Skid Resistance and Wear Properties of Aggregates for Asphalt Paving Mixtures.

Objective. Develop standard test procedures by which the wear and skid characteristics of different asphalt surface mixtures may be predetermined. The study will investigate wear and polish properties of aggregates for asphalt concrete available in Mississippi; and will include development of procedures and equipment for laboratory mixture design, and correlation with field performance.

Performing Organization. Mississippi State Highway Department, Jackson, Miss.

Expected Completion Date. October 1976.

Title. Curved Box Girder Model.

Objective. To test a curved box girder model to obtain model strains, determine load distribution, and to compare with theoretical behavior obtained by computer programs.

Performing Organization. University of California, Berkeley, Calif.

Expected Completion Date. June 1974.

Title. Tensile Characterization of Highway Pavement Materials.

Objective. Characterize the fatigue behavior of pavement materials and assist the Texas Highway Department in implementing the indirect tensile test for use in rational pavement design procedures.

Performing Organization. University of Texas, Austin, Tex.

Expected Completion Date. October 1975.

Title. Ground Vibration Investigation at Highway Construction Sites.

Objective. Measure vibration magnitudes on construction projects in terms of particle velocity.

Performing Organization. Louisiana Department of Highways, Baton Rouge, La.

Expected Completion Date. December 1975.

Title. PCC (Portland Cement Concrete) Pavement Performance.

Objective. A performance rating system will be developed utilizing detailed observations and photo logging techniques on approximately 100 existing projects and applying it to 20 new projects. Good and bad performing projects will be located and investigated to relate design, construction, materials, environment, support, and traffic to performance.

Performing Organization. California Division of Highways, Sacramento, Calif.

Expected Completion Date. June 1976.

Title. Studded Tire Pavement Wear Reduction and Repair.

Objective. To quantify pavement wear caused by use of studded tires on various pavement types constructed with local materials and to evaluate methods and materials for pavement repair. (This study provides for Idaho Department of Highways participation in Washington State University Study, FCP 40M1044).

Performing Organization. Washington State University, Pullman, Wash.

Expected Completion Date. October 1972.

Title. Measurement and Control of Air Pollution Produced by Highway Construction Operations and Related Industries.

Objective. To develop test methods to provide quantitative measurements, test various practical methods, and develop specifications for dust and smoke control from highway operations.

Performing Organization. California Division of Highways, Sacramento, Calif.

Expected Completion Date. December 1977.

Title. Feasibility Study and Preliminary Design of a System for Rapid Evaluation of Pavement Designs.

Objective. This study will critically evaluate the various methods of accelerated life testing of pavements, model testing and other methods, used or proposed for evaluating full scale pavement designs where testing and evaluation is not to exceed three months duration. Preliminary design concepts and rough plans will be prepared for the most feasible alternate.

Performing Organization. Ohio State University, Columbus, Ohio.

Expected Completion Date. May 1973.

Title. Stress Corrosion Susceptibility of Highway Bridge Construction Steels.

Objective. To identify those structural steels which are susceptible to stress corrosion cracking in the extreme conditions of the highway environment and to determine the extent and severity of the potential danger to highway structures.

Performing Organization. The Boeing Company, Seattle, Wash.

Expected Completion Date. May 1972.

Title. Effectiveness of Absorptive Form Liner for Horizontal Surfaces.

Objective. The objective of this study is to determine the effect on concrete density, absorption, resistance to abrasion, air-void system, and permeability of horizontal concrete surfaces when the fresh concrete has had a portion of the mixing water removed by absorptive form liner.

Performing Organization. Colorado Department of Highways, Denver, Colo.

Expected Completion Date. June 1972.

Title. A Proposal for Implementation of Sign Research for the Development of Computer Based Operational Tool for Highway Signing System Design.

Objective. Develop a computer model to provide (1) sign design, (2) measures of effectiveness of the design, and (3) costs of building, installing and maintaining the sign.

Performing Organization. Ohio State University, Columbus, Ohio.

Expected Completion Date. November 1972.

Title. "B-Safe" Bridge Safe-Load Analysis for Engineers.

Objective. To develop a computer software system for calculating the safe load capacity of existing highway bridges as a function of the legal load and to provide an inventory rating according to AASHO standard loads. This first phase of the project will concern itself with non-composite continuous girder bridges.

Performing Organization. CHI Corporation, Cleveland, Ohio.

Expected Completion Date. October 1972.

Title. Determination of Properties of Granular Pavement Components Under States of Stress Simulating Service Conditions.

Objective. Characterizing equations will be developed for predicting the in-service behavior of soil-aggregate materials. Dual cyclic tri-axial test equipment will be utilized as one method of characterization. Creep test data will also be obtained and analyzed as input toward visco-elastic characterization.

Performing Organization. Federal Highway Administration, Washington, D.C.

Expected Completion Date. July 1974.

Title. The Ultimate Load Capacity of Highway Bridges.

Objective. To develop an analytical technique incorporating the interaction of all elements for the prediction of the inelastic behavior of simple-span beam slab bridges.

Performing Organization. University of Maryland, College Park, Md.

Expected Completion Date. June 1976.

Title. The Development of Charts for Determining Load Carrying Capacity of Highway Bridges.

Objective. Collect truck loading permit data and establish typical truck characteristics. Establish the range in span lengths and span length ratios of existing two and three span continuous composite girder slab bridges. Develop moment influence line equations for these bridges. Develop continuous span moment Analysis Computer Program.

Performing Organization. University of Maryland, College Park, Md.

Expected Completion Date. June 1974.

Title. Loads on Box Culverts under High Embankments.

Objective. To evaluate factors affecting load configurations under high fills and devise a method of predicting these loads. Recommend revisions to box culvert design procedures.

Performing Organization. Kentucky Department of Highways, Frankfort, Ky.

Expected Completion Date. December 1976.

Title. Analysis of Asphalt Performance Data—Part I.

Objective. To analyze test data of asphaltic concrete pavement samples from 53 paving projects: Analyses to include the variability in bulk specific gravity of the various sampling units and the variability in mixture composition within and between projects: prepare an interpretive report suitable for publication.

Performing Organization. J.Y. Welborn, Consultant, Arlington, Va.

Expected Completion Date. April 1972.

Title. Minimizing Premature Cracking of Asphaltic Concrete Pavements.

Objective. To determine suitable materials specifications, paving mix design criteria, and construction requirements that will result in the ability to design and construct asphaltic concrete pavements to carry design traffic with a minimum of premature cracking.

Performing Organization. Materials Research and Development Inc., Oakland, Calif.

Expected Completion Date. January 1973.

Title. Development of New Passing Zone Criteria.

Objective. This staff study relates to current operational problems on two-lane rural highways concurrently with the research at the Maine facility. A large amount of research has been performed on passing zone criteria. This effort will put this work into an implementable form through the medium of proposing new criteria and thus improve operations and safety.

Performing Organization. Federal Highway Administration, Washington, D.C.

Expected Completion Date. October 1974.

Title. Information Content and Presentation to Induce Route Diversion.

Objective. This is a study of driver route selection criteria and is specifically designed to determine the information to be displayed at a freeway diversion point near Baltimore.

Performing Organization. Federal Highway Administration, Washington, D.C.

Expected Completion Date. June 1973.

Title. Field-made Joint in Prestressed Reinforced Concrete Bridge Girders.

Objective. The objectives of the study are to determine the most advantageous method of constructing field-made joints for prestressed concrete bridges and to establish design criteria for the joint. A two-span continuous bridge with three precast elements will be studied analytically and experimentally.

Performing Organization. University of Illinois, Urbana, Ill.

Expected Completion Date. June 1974.

Title. Strip Footing Analysis.

Objective. A finite element program will be developed for prediction of pore pressures and settlement under rigid and flexible strip footings as well as under embankment loading.

Performing Organization. Ohio State University, Columbus, Ohio.

Expected Completion Date. May 1972.

Title. Tire-Pavement Friction as a Function of Vehicle Maneuvers.

Objective. To relate pavement conditions and tire-pavement friction to the response of passenger vehicles as their drivers attempt various normal and emergency maneuvers. The definition of "Limit of Response," the break point between a controllable and uncontrollable vehicle, will be the end result of fulfilling this objective.

Performing Organization. Texas A&M Research Foundation, College Station, Tex.

Expected Completion Date. August 1972.

Highway Research and Development Reports Available from the National Technical Information Service

The following highway research and development reports are available from the National Technical Information Service (formerly the Clearinghouse for Federal Scientific and Technical Information), Sills Building, 5285 Port Royal Road, Springfield, Va. 22151. Paper copies are priced at $3 each and microfiche copies at 95 cents each. To order, send the stock number of each report desired and a check or money order to the National Technical Information Service. Prepayment is required.

Other highway research and development reports available from the National Technical Information Service will be announced in future issues.

STRUCTURES

Stock No.	
PB 205027	Determination of Motion and Deflection of Retaining Walls—Part II, Technical Application.
PB 206314	Pavement Deflection Measurement—Dynamic—Phase II.
PB 206482	Durability of Bridge Deck Concrete—Part 1: Effect of Construction Practices on Durability.
PB 206519	The Behavior and Design of Bolted Shingle Splices.
PB 206520	Field Testing of Horizontally Curved Steel Girder Bridges (Second Interim Report).
PB 206521	The Ultimate Strength of Curved I-Girder Bridges. (Progress Report No. 42—The Design of Curved Viaducts).
PB 206537	Expansion Bearings for Highway Bridges (Interim Report).
PB 206631	Experimental and Analytical Studies of Behavior of Single Piles in Sand Under Lateral and Axial Loading.
PB 206634	Evaluation of Colorado's Flexible Pavement Base Design Methods (Final Report).
PB 206654	Lithfield Shale Project—Report of Investigation.
PB 206659	Thickness Design Procedure for Bituminous Resurfacing of Portland Cement Concrete Pavements.
PB 206660	Strength Formular for Design of Steel Plate Girders.
PB 206662	Bridge Deck Deterioration Study—Part I: A Comparison of 777 Uncovered Decks.
PB 206749	Load-Carrying Characteristics of Drilled Shafts Constructed With the Aid of Drilling Fluids.
PB 207172	Lateral Resistance and Deflection of Vertical Piles (Interim Report No. 1).
PB 207216	Preliminary Evaluation of Test Pile Records for Highway Structures in Louisiana.
PB 207217	An Evaluation of the Relative Strength of Flexible Pavement Components.
PB 207222	An Evaluation of Bridge Vibration as Related to Bridge Deck Performance (Final Report).
PB 207228	Dynamic Studies on the Bearing Capacity of Piles, Phase III, vol. I.
PB 207229	Phase III, vol. II.
PB 207278	Field Study of a Predeflected Steel Concrete Composite Bridge: Research Report 3 (Interim Report).
PB 207284	The Catskill-Cairo Experimental Rigid Pavement: Construction and Materials Testing.
PB 207287	Analysis of Continuous Composite Beams.
PB 207289	Highway Friction Measurements With MU-meter and Locked Wheel Trailer.
PB 207333	Macro-texture, Friction, Cross Slope and Wheel Track Depression Measurements on 41 Typical Texas Highway Pavements.
PB 207344	Design Charts for Minor Service Structure Foundations.

MATERIALS

Stock No.	
PB 204701	The Economic Feasibility of the Application of Statistical Concepts and Methods to the Control and Acceptance of Highway Materials and Construction.
PB 206494	A Preliminary Investigation of Terrestrial and Low Altitude Aerial Infrared Photography as an Aid in Determining Water Table Depths and Buried Geological Structures in the Pierre Shale in Western South Dakota.
PB 206495	Factors Influencing the Durability of Aggregates (Interim Report).
PB 206630	Considerations in Adopting a Viscosity Specification for Asphalt Cement in New York State (Special Report 4).
PB 206632	Study of Longitudinal Joint Construction in Bituminous Concrete Pavements.
PB 206656	A Synthetic Coarse Aggregate Classification System (Final Report).
PB 206657	Glass Beads for Traffic Marking Paint.
PB 206661	The Effect of Surface Coatings and Bonded Overlays on Moisture Migration.
PB 206663	An Evaluation of Road Marking Materials (Study No. 52).
PB 206664	Investigation of Laser Beam Technique for Determination of Slope Stability (Final Report).
PB 206850	Shale Suitability—Phase II (Interim Report No. 1).
PB 206965	An Annotated Bibliography on Use of Rubber in Asphalt Pavements.
PB 207173	Patching and Grouting Materials for Portland Cement Concrete (Final Report).
PB 207219	Correlation of Seismic Velocities with Earthwork Factors (Interim Report No. 2).
PB 207221	Mortar Strength of Portland Cement Concrete Sands (Final Report).
PB 207224	Evaluation of Floating Glass Beads for Traffic Stripes.
PB 207277	Field Friction Performance of Several Experimental Test Sections.
PB 207306	Drainage Pipe Study.
PB 207316	Pore Size Distribution and its Effect on the Behavior of a Compacted Clay.
PB 207334	Evaluation of Asphalt Structural Performance.
PB 207338	Creep of Compacted Clay.
PB 207342	Loss of Durability in Bituminous Pavement Surfaces—Importance of Chemically Active Solar Radiation.
PB 207343	Evaluation of Pressure Cells used for Field Measurements of Lateral Earth Pressures on Retaining Walls.

TRAFFIC

Stock No.	
PB 204742	Development of an Electronic Means of Weighing Vehicles in Motion (Final Report)
PB 204822	Use of Traffic data for Calculating Equivalent 18,000-lb. Single-Axle Loads.
PB 204823	State-of-the-art of Wrong-way Driving on Freeways and Expressways.
PB 205430	Traffic Systems Reviews and Abstracts.
PB 205753	An Experimental and Analytical Investigation of the Effect of Truck-Induced Aerodynamic Disturbances on Passenger Car Control and Performance (Executive Summary Report).
PB 206658	Semi-actuated Signal Study.
PB 206728	Research and Development on Roads and Road Transport (1971 World Survey).
PB 207268	Network Flow Simulation for Urban Traffic Control System.
PB 207269	Network Flow Simulation for Urban Traffic Control System—Program Manual, Appendix I.
PB 207270	Network Flow Simulation for Urban Traffic Control System—Sub-Routine Documentation and Storage Arrays, Appendix 2.
PB 207279	Highway Signing for Safety.
PB 207305	A Probabilistic Approach to Traffic Problems: Phase III (Non-technical Summary Report).
PB 207335	A Determination Framework for Wet Weather Speed Limits.
PB 207336	Friction Requirements for High-Speed Passing Maneuvers (An Examination of the Basic Design Criteria as They Relate to Safe Operations of Modern High-Speed Highways).
PB 207337	Young Driver Follow-up Study: An Evaluation of the Role of Human Factors in the First Four Years of Driving.
PB 207341	A Systems Analysis for a Real-Time Freeway Traffic Information System for the Inbound Gulf Freeway Corridor.

ENVIRONMENT

Stock No.	
PB 206655	Bridge Deck Deicing Study (Summary of Phase A Activities).
PB 206879	Pavement Heating.
PB 207218	Lighted Deer Crossing Signs and Vehicular Speed.
PB 207220	An Ice and Snow Detection and Warning System Feasibility Study (Final Report).
PB 207223	Feasibility of Utility Tunnels in Urban Areas.
PB 207275	Storm Water Runoff from an Urban Highway Drainage System (Final Report).
PB 207276	Development of Plans for Public Evaluation of Polarized Headlights.

FIELD TESTING

Stock No.	
PB 206497	The Effects of Rainfall Intensity, Pavement Cross Slope Surface Texture, and Drainage Length on Pavement Water Depths. (Vehicle Pavement Interaction).
PB 207290	An Investigation of Bituminous Highway Materials and Methods of Production and Construction Control Based on Statistical Procedures—Phase IV: Quality Control Research Project (Final Report).

RESEARCH IMPLEMENTATION

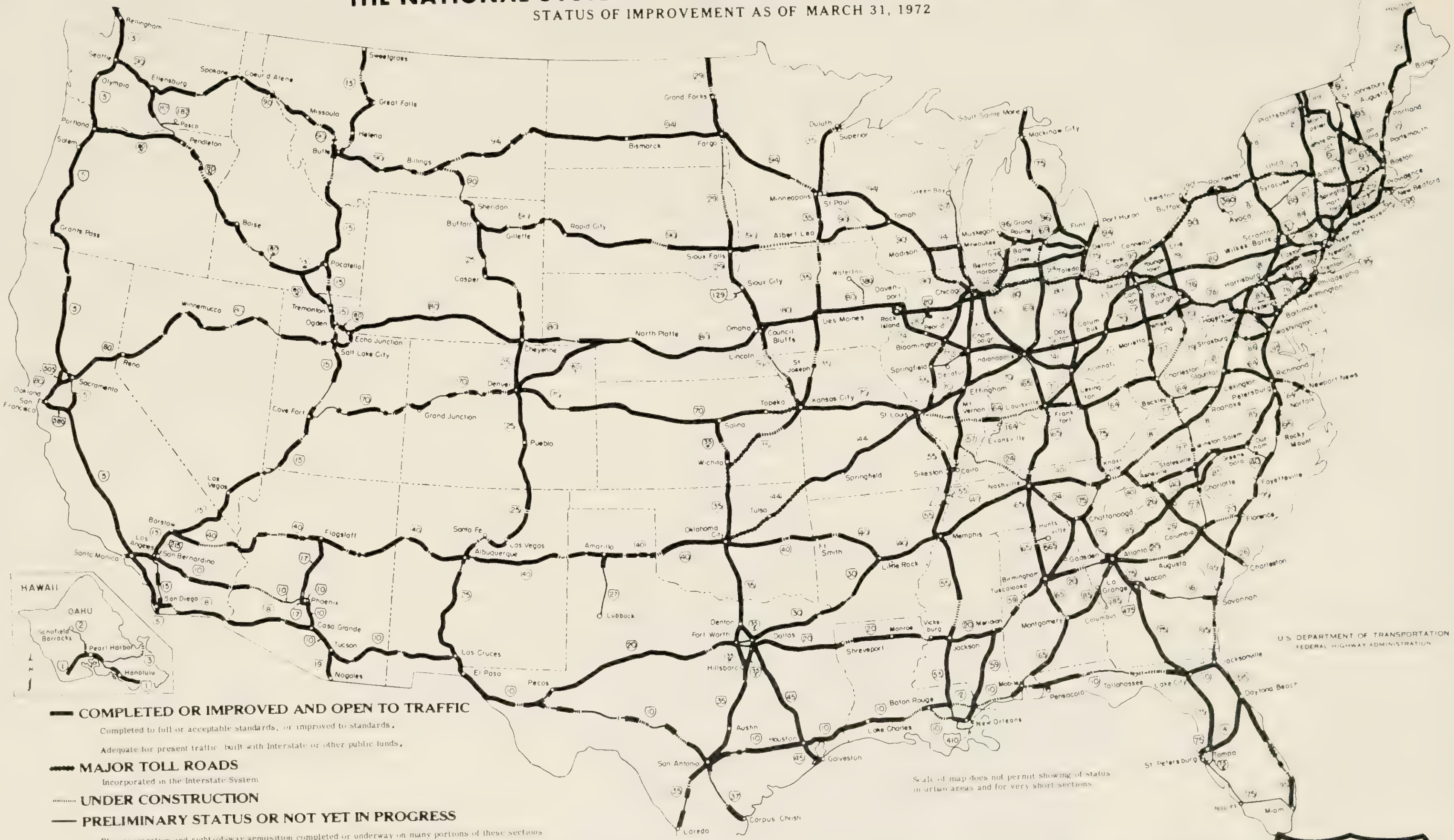
Stock No.	
PB 204888	Investigation of the Capability of the Analytical Stereoplotted AP/C in Application to Highway Engineering Projects.
PB 205738	Distribution of Truck Traffic (Bibliography).
PB 205754	Speed Control Designs by Physical Means (Bibliography).
PB 205755	Control of Sand Drifts on Highways (Bibliography).
PB 205756	Head-in, Angle, and Parallel Parking.
PB 205757	Maintenance Procedures (Bibliography).
PB 205758	Major Interchange Design and Operations.
PB 205759	Lane Control Studies (Bibliography).
PB 205760	Automobile Exhaust Emissions (Bibliography).
PB 206496	Skid Research Program—Phase I, Specifications and Acquisition of Equipment.
PB 206878	An Experimental and Analytical Investigation of the Effect of Truck-Induced Aerodynamic Disturbances on Passenger Car Control and Performance.
PB 206928	B.E.S.T.—Bridge Engineering System for TIES (Final Report).

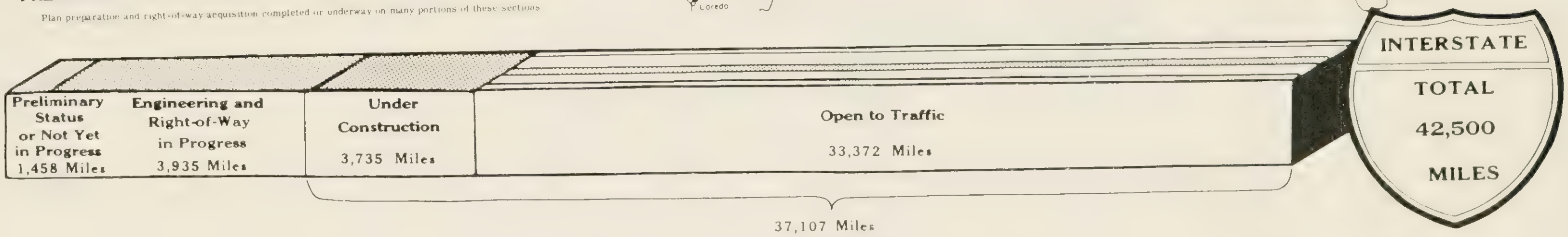
PLANNING

Stock No.	
PB 204534	The Effect of Right-of-Way Acquisition on Farm and Ranch Operation Units.
PB 205762	A Feasibility Study of a System for Monitoring the Road-User Cost of Urban Traffic Congestion.

THE NATIONAL SYSTEM OF INTERSTATE AND DEFENSE HIGHWAYS

STATUS OF IMPROVEMENT AS OF MARCH 31, 1972





Beginning with this issue, "PUBLIC ROADS, A Journal of Highway Research," will be published quarterly instead of bimonthly. This means that you will receive four issues per year--Summer (June), Autumn (September), Winter (December), and Spring (March).

The same amount of material will be published, but the average size of each issue will be larger than the previous bimonthly issues. Larger quarterly issues will provide additional space to include more diverse material on such subjects as Developments in Research Implementation, the Federal Highway Administration's Research Demonstration Projects, and New Research in Progress. Further into the future we also plan to include news on noteworthy research and development activities in the different States.

PUBLICATIONS of the Federal Highway Administration

A list of articles in past issues of PUBLIC ROADS *and title sheets for volumes 24–36 are available upon request from the Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. 20590.*

The following publications are sold by the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402. Orders should be sent direct to the Superintendent of Documents. Prepayment is required.

Aggregate Gradation for Highways: Simplification, Standardization, and Uniform Application, and a new Graphical Evaluation Chart (1962). 25 cents.

America's Lifelines—Federal Aid for Highways (1969). 35 cents.

Analysis and Modeling of Relationships between Accidents and the Geometric and Traffic Characteristics of the Interstate System (1969). $1.00.

A Book About Space (1970). 70 cents.

Bridge Inspector's Manual (1970). $2.50.

Calibrating & Testing a Gravity Model for Any Size Urban Area (1968), $1.00.

Capacity Analysis Techniques for Design of Signalized Intersections (1967). 45 cents.

Construction Safety Requirements, Federal Highway Projects (1967). 50 cents.

Corrugated Metal Pipe (1970). 35 cents.

Emergency Application Systems for Power Brake Mechanisms of Highway Trailer Combinations (1970). $1.00.

Fatal and Injury Accident Rates on Federal-Aid and Other Highway Systems (1970). 45 cents.

Federal-Aid Highway Map (42x65 inches) (1970). $1.50.

Federal Assistance Available (1971). 10 cents.

Federal Laws, Regulations, and Other Material Relating to Highways (1970). $2.50.

The Freeway in the City (1968). $3.00.

Freeways to Urban Development (1966). 15 cents.

Guidelines for Trip Generation Analysis (1967). 65 cents.

Handbook on Highway Safety Design and Operating Practices (1968). 40 cents.
- Supplement No. 1 (Nov. 1968). 35 cents.
- Supplement No. 2 (Nov. 1969). 40 cents.

The Highway and its Environment, 3d Annual Awards Competition (1970). 60 cents.

Highway Condemnation Law and Litigation in the United States (1968):
- Vol. 1—A Survey and Critique. 70 cents.
- Vol. 2—State by State Statistical Summary of Reported Highway Condemnation Cases from 1946 through 1961. $1.75.

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- 1967, $1.75; 1968, $1.75; 1969, $1.75; 1970, $1.75. (Other years out of print.)

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Highways to Beauty (1966). 20 cents.

Hydraulic Engineering Circulars:
- No. 5—Hydraulic Charts for the Selection of Highway Culverts (1965). 55 cents.
- No. 9—Debris Control Structures (1971). 50 cents.
- No. 10—Capacity Charts for the Hydraulic Design of Highway Culverts (1965). $1.00.
- No. 11—Use of Riprap for Bank Protection (1967). 50 cents.
- No. 12—Drainage of Highway Pavements (1969). $1.00.

Hydraulic Design Series:
- No. 1—Hydraulics of Bridge Waterways, 2d ed. (1970). $1.25.
- No. 3—Design Charts for Open-Channel Flow (1961). $1.50.
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Identification of Rock Types (1960). 20 cents.

Interstate System Accident Research Study–1 (1970). $1.00.

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Joint Development Opportunities Outside the Highway Right-of-Way (1971). 20 cents.

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National Highway Needs Report, H. Comm. Print 91st Cong. 70 cents.

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R&D Highway and Safety Transportation Systems Studies (1971). $2.75.

Read Before Driving (1971). 15 cents.

Reinforced Concrete Bridge Members—Ultimate Design (1969). 45 cents.

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Safety Rest Area Development (1970). $1.00.

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Second Annual Highway Beauty Awards Competition (1969). 50 cents.

Specifications for Aerial Surveys and Mapping by Photogrammetrical Methods for Highways (1968). $1.25.

Standard Alphabets for Highway Signs (1966). 30 cents.

Standard Land Use Coding Manual (1965). 50 cents.

Standard Plans for Highway Bridges:

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- Vol. II—Structural Steel Superstructures (1968). $1.00.
- Vol. III—Timber Bridges (1969). 75 cents.
- Vol. IV—Typical Continuous Bridges (1969). $1.50.
- Vol. V—Typical Pedestrian Bridges (1962). $1.75.

Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (1969). $3.50.

Standard Traffic Control Signs Chart (as defined in the Manual on Uniform Traffic Control Devices for Streets and Highways). 22 x 34, 20 cents—100 for $15.00. 11 x 17, 10 cents—100 for $5.00.

Study of Airspace Utilization (1968). 75 cents.

Transition Curves for Highways (1940). $2.50.

Transportation Planning Data for Urbanized Areas based on 1960 census (1970). $9.25.

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