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COVER: Old concrete pavement is broken, crushed, and recycled as aggregate into new concrete pavement to widen and improve I-90 and I-94 near Madison, WI.

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The Use of Recycled Portland Cement Concrete (PCC) as Aggregate in PCC Pavements

by
Stephen W. Forster

Introduction and Background

Economic considerations are the primary reasons for recycling portland cement concrete (PCC) as aggregate in PCC pavements, although environmental benefits often are derived as well. In some areas of the United States there is no supply of virgin aggregate and recycling is the *only* viable economical solution. In other areas, new aggregate is inaccessible, either because of the high value of land or because zoning constraints prevent the opening of pits or quarries. In some highly developed urban areas, it is less expensive and more environmentally acceptable to re-use the PCC than to dispose of it. Therefore, when a PCC pavement will be removed before a new pavement is placed, the project is a prime candidate for recycling. The old pavement serves as a source of aggregate in the new concrete, and the need and expense of disposing of the material removed are eliminated. Further, if the project is large enough for an onsite aggregate plant, the materials' transportation costs are reduced.

Results of a 1971 survey conducted by the Texas State Highway Department and the Texas Transportation Institute indicate that most States gave little consideration to recycling existing pavement material for any use other than unstabilized base courses. (*1*, pp. 128-133) [1] PCC removed from a roadway usually was disposed of in landfills or used as erosion control in drainage ditches. Because of the increasing cost of natural resources and energy, this attitude has changed.

Initial proposals to use recycled PCC as concrete aggregate material generated a number of questions. First, how does the quality of the new concrete containing the recycled material compare with the old concrete and with new concrete made with natural aggregate? Does the crushed concrete make good aggregate? How can the reinforcing be easily removed? Is recycling for aggregate an economically viable alternative? These questions and many others concerning PCC recycling have been answered by subsequent research. This article reviews research on the use and properties of the recycled material as aggregates in PCC.

[1]Italic numbers in parentheses identify references on page 42. Page numbers in parentheses refer to reference 1.

In June 1977, the Federal Highway Administration (FHWA) established project 22 on PCC and asphalt pavement recycling under its National Experimental and Evaluation Program (NEEP). Forty-two States participated in the project, which has now been integrated into Demonstration Project No. 47 (DP47), Recycling Portland Cement Concrete, and DP39, Asphalt Pavement Recycling. The initial DP47 project report was the reprinting of an Iowa Department of Transportation report on an early recycling project. (*2*) Since then, several States have conducted recycling projects under DP47, and States continue to show interest in participating in DP47.

In September 1981, a national seminar on PCC recycling and rehabilitation was sponsored by FHWA and conducted by the Transportation Research Board (TRB). (*1*, *3*)

Recycling Categories

PCC pavement recycling may be grouped into three categories. First, surface recycling involves milling or grinding the pavement surface (approximately the top 1 in [25.4 mm]) to remove surface deterioration, restore rideability, and improve surface friction. Because the removed material usually is quite fine and relatively small in quantity, it typically is not used as concrete aggregate. Second, inplace recycling involves crushing the old pavement and combining it with the existing base or subbase material to support a new pavement. Third, plant recycling involves breaking up the existing PCC pavement, taking it to a crushing plant where it is crushed and sized, and finally incorporating the resulting aggregate material into a new PCC mixture. This article focuses on this use of the old concrete as aggregate in new PCC.

Properties of Recycled PCC Aggregate

Aggregate tests

In an early laboratory study of recycled PCC, the properties of an aggregate made from crushed concrete containing chert gravel (coarse) and natural sand (fine) and a second aggregate made from crushed concrete containing limestone (coarse) and natural sand (fine) were compared with natural aggregate. The material then was incorporated into new concrete mixes for further comparisons. (*4*) Table 1 shows the results of absorption and specific gravity tests.

Visual inspection of the crushed concrete indicated a good particle shape. The fine aggregate produced did not meet the normal gradation requirements but was used in the concrete mixes discussed under the section, Concrete tests, below.

A synopsis of studies conducted by the U.S. Army Engineers Waterways Experiment Station, Iowa Department of Transportation, Massachusetts Institute of Technology, Minnesota Department of Transportation, Michigan Department of Transportation, and FHWA concludes that the aggregate particles produced by crushing concrete have good shape, high absorptions, and low specific gravity compared with natural mineral aggregates. (*1*, pp. 128-133)

Table 2 shows the results of a Michigan Department of Transportation laboratory investigation of a series of crushed concrete materials compared with natural aggregate. (*1*, pp. 144-160) A concrete material that had been recycled twice also was tested, and its specific gravity was still lower (2.11) and the absorption even higher (8.36 percent) than material recycled once. These results are predictable because the percentage of natural aggregate decreases and the percentage of lighter, more

Table 1.—Properties of crushed concrete and natural aggregate (*3*)

	Recycled material		Natural material	
	Chert concrete	Limestone concrete	Chert gravel	Crushed limestone
Coarse fraction:				
Absorption	4.0-4.3	3.9	2.6	0.8
Saturated surface dry specific gravity	2.43-2.44	2.52	2.52	2.67
Fine fraction:			Sand	
Absorption	7.6-9.0	—	0.4	
Saturated surface dry specific gravity	2.36	—	2.63	

Table 2.—Properties of crushed concrete and natural aggregate (*1*, pp. 144-160)

	Material recycled once	Material recycled twice	Natural material Gravel
Coarse fraction:			
Absorption	3.43-5.0	8.36	1.02
Bulk specific gravity	2.31-2.40	2.11	2.67
Fine fraction:			
Absorption	7.17-8.31	—	1.38
Bulk specific gravity	2.15-2.23	—	2.60

absorptive cement paste increases with each recycling. Interestingly, the soundness loss of the recycled material was less (0.9 to 2.0) than that of the natural aggregate (3.9).

Concrete tests

In the 1973 study, recycled concrete was mixed with a water/cement ratio of 0.49, had a target air content of 6 ± 1/2 percent, and a slump of 2 1/2 ± 1/2 in (64 ± 13 mm). (*4*) Concrete made with recycled concrete as both coarse and fine aggregate had lower slumps and higher cement contents than comparable mixes made with either all natural aggregate or recycled coarse aggregate and natural sand fine aggregate. The concrete with recycled aggregate had compressive strengths 300 to 1,300 psi (2.0 to 9.0 MPa) less than the control concrete with natural coarse aggregate throughout the period of testing (up to 180 days). Freeze-thaw test results differed depending on the original aggregate. Recycled concrete containing freeze-thaw susceptible coarse aggregate performed better as aggregate in a new concrete than concrete containing that stone as coarse aggregate (although whether the improvement is sufficient to bring performance to an acceptable level would have to be judged case-by-case). Conversely, new concrete made with recycled concrete containing an originally freeze-thaw resistant aggregate performed somewhat worse than the control mix with the natural coarse aggregate, although both mixes performed acceptably. Finally, volume change in response to temperature changes or increased moisture was similar for the recycled concrete mixes and the controls. (*4*)

The following conclusions were made about recycled concrete in the synopsis report (*1*, pp. 128–133):

- Using crushed concrete as coarse aggregate did not significantly affect mixture proportions or workability of the mixtures compared with the control mixtures containing natural aggregate.
- When crushed concrete was used as fine aggregate, the mixture was less workable and needed more water and therefore more cement. Substituting natural sand for up to 30 percent of the recycled fine aggregate improved workability to the approximate levels of a conventional mixture.
- The frost resistance of the concrete made from recycled aggregates usually was much higher than the frost resistance of the control concrete.
- Using recycled aggregate did not significantly affect the volume response of concrete specimens to temperature and moisture changes.
- Using low-strength, recycled concrete as aggregate is not detrimental to the concrete's compressive strength.
- Using water-reducing admixtures to lower the water content strengthens concrete mixtures that contain recycled concrete as aggregate.

The Michigan Department of Transportation varied the percentages of recycled PCC in the fine aggregate to determine the effect on the mixture. (*1*, pp. 144–160) The percentage of recycled bituminous concrete also was varied in the mixture to simulate contamination that would occur in practice. Mixtures had a water/cement ratio of 0.43, a cement factor of 6 sacks/yd ^{3} (7.8 sacks/m ^{3}), and an entrained air percentage of 5.5 ± 1.5. The results of this research agree with the findings previously discussed. (*1*, pp. 128–133; *4*) Because of the harshness of the recycled fine aggregate, the slump, and therefore workability, of the recycled concrete mixtures was less than that of the control mixture. Compressive and flexural strengths of the recycled concrete were slightly less than those of the control mixture made with a gravel aggregate but still exceeded the Michigan Department of Transportation minimum specifications for pavement concrete. Recycled mixtures containing small amounts of crushed bituminous concrete (such as patches and unremoved overlay spots) tested satisfactorily unless they included crushed bituminous fines. These fines are almost totally bitumen coated and, therefore, act as voids in any strength test of the new concrete. The recycled concretes had higher durability factors than the control concrete.

Special Concerns for Recycled PCC

Recycled "D" cracked pavement

The possibility of using crushed "D" cracked pavement as an aggregate material raises the question as to whether the recycled material will continue to promote "D" cracking or will the crushing that occurs during recycling alleviate the problem?

Before using a "D" cracked PCC pavement on a recycling project, the Minnesota Department of Transportation conducted a laboratory study to determine the behavior of recycled "D" cracked material when used as aggregate in new concrete. (*5*) A 3 ft (0.91 m) section, the full width of the candidate pavement, was removed and crushed for testing in the laboratory. A control was made with all natural aggregate and 20 percent fly ash substituted for 15 percent of the cement. The recycled material passing the No. 4 (4.75 mm) sieve was found to be very angular, which substantially increased the water demand to provide acceptable workability. Mix 1, 100 percent recycled aggregate, required 333 lb/yd ^{3} (197.6 kg/m ^{3}) of water compared with 250 to 260 lb/yd ^{3} (148.3 to 154.3 kg/m ^{3}) for the control. This higher water demand also increased the cement requirement. Compressive strengths were at or above conventional mixtures, and there was no problem entraining the necessary air. Based on these results, three additional trial mixes were made. One had no fly ash, one had 10 percent of the cement replaced by fly ash, and the third had 15 percent of the cement replaced by 20 percent fly ash. All the recycled aggregate used passed the 3/4 in (19 mm) sieve, and 0 to 5 percent passed the No. 4 (4.75 mm) sieve.

To evaluate the "D" cracking susceptibility, the mixes were freeze-thaw tested. Compared with concrete containing the "D" cracking natural aggregate, the concrete with the recycled concrete aggregate was more resistant to freeze-thaw action, and the mixtures with 10 to 20 percent fly ash had a greatly reduced "D" cracking potential. In addition, the fly ash acted as a plasticizer, lowering the amount of water necessary to make the mix workable.

Based on these laboratory results, U.S. Rte. 59 in Minnesota was reconstructed using recycled concrete as coarse aggregate in the new concrete. The specific gravity of the recycled coarse aggregate was 2.41, and its absorption was 4.4 percent. Natural sand was used as the fine aggregate, and 20 percent fly ash was substituted for 15 percent of the cement. Average core strength on the concrete was 4,590 psi (31.6 MPa) after 60 days. The minus No. 4 (4.75 mm) recycled material was used in the base course as a stabilizing material.

Salt content of recycled pavement

Because large amounts of rock salt are used as a deicer on Michigan highways, the sodium chloride (NaCl) content of recycled PCC aggregate material was examined. (*1*, pp. 144–160) The NaCl content of the recycled material was less than 2 lb/yd ^{3} (1.2 kg/m ^{3}) compared with Michigan's critical NaCl level of 4 lb/yd ^{3} (2.4 kg/m ^{3}) used for bridge decks. It was concluded that no restrictions were necessary on the use of the material based on its NaCl content. Further, because the recycled material is used only as the aggregate portion, the overall level of sodium chloride in the new concrete is even less; namely, the amount of NaCl in the recycled PCC times the fraction of the new concrete that is recycled material.

In preparation for a recycling project, the State of Connecticut examined the total chloride content of recycled PCC material and found NaCl contents of 12 lb/yd ^{3} (7.1 kg/m ^{3}) at the 1.5 in (38 mm) level, 0.96 lb/yd ^{3} (0.57 kg/m ^{3}) at the 4 in (102 mm) level, and 0.27 lb/yd ^{3} (0.16 kg/m ^{3}) at the 6.5 in (165 mm) level. (*6*) The new mixture with the recycled concrete aggregate contained 1.93 lb/yd ^{3} (1.15 kg/m ^{3}) total sodium chloride.

These findings suggest that checking the NaCl content of any recycled material that may have excessive salt and calculating the NaCl content for the new mix are advisable. Based on the results, any additional steps (such as reinforcement coating) necessary to avoid corrosion problems could be taken.

Alkali-aggregate reactivity

Three conditions are necessary to cause damaging alkali-aggregate reactivity: An aggregate with sufficient amounts of reactive constituents that are soluble in highly alkaline solutions; enough water-soluble alkali from some source (usually the cement) to increase the pH of the liquid in the concrete to 14–15 long enough to produce swelling alkali-silica gel; and sufficient water to maintain the solutions and provide moisture for the swelling of the gel.

The consequences of using recycled PCC material that has suffered from alkali-aggregate reaction as an aggregate in a new concrete have not been studied thoroughly. This special case of PCC recycling requires answers to several questions. How severe is the reaction and the resulting distress at the time of recycling? Has the reactive mineral matter been completely used? If petrographic or other examinations indicate this, it may be safe to use the material. On the other hand, using a low-alkali cement in the new concrete may not prevent further alkali-aggregate reaction with the recycled material because the reaction may continue within the recycled material between the old mortar and aggregate. Probably the only safe way to screen materials for this potential problem is to perform long-term, mortar-bar expansion tests (ASTM C-227) with the recycled material in cements with various alkali contents to determine the acceptable level of alkali. If a reaction occurs between the recycled materials, there may be no level of alkali in the cement low enough to prevent the reaction. The addition of limestone aggregate in the mix may reduce the probability of alkali-aggregate reactivity, but this is not yet proven. (*7*) Reducing recycled aggregate size also may be helpful in controlling the reaction problem. Recycling alkali-aggregate reactive materials needs additional investigation, and work currently is underway.

Field Projects With Recycled PCC

Results from field projects where recycled PCC was incorporated as aggregate in the mixture should aid the planning and conduct of future recycling projects. In a 1976 recycling project on U.S. Rte. 75 in Iowa, the entire crushed recycled PCC from a secondary crusher (1.5 in [38 mm] minus) was placed in a single stockpile. (*2*) Segregation problems resulted as well as inconsistent feed through the automatic bin gates of the batching plant. To alleviate the problem on subsequent projects, the material was split on the 3/8 in (9.5 mm) sieve. Using recycled material for both coarse and fine aggregate produced a harsh, nearly unworkable mix. Adding 15 percent concrete sand made the mixture much easier to work. Also, less air entraining agent was needed to reach the desired air content than for a conventional mix. Because contaminants often affect the air content of the new concrete, their amount in the recycled material must be controlled. Approximately 75 to 80 percent of the old pavement was recovered as crusher product.

Using the experience gained in the initial project, Iowa conducted two additional projects in 1977. As in the first project, the crusher product was low in fine material (22 to 24 percent passing the No. 4 [4.75 mm] sieve). A three-aggregate blend (coarse and fine recycled, plus concrete sand) controlled the segregation of the recycled material and made a workable mixture. Washing the recycled material was unnecessary if proper removal and processing practices were followed.

The 1980 recycling project using a "D" cracked pavement on U.S. Rte. 59 in southeastern Minnesota found that the crushed material passing the No. 4 (4.75 mm) sieve is very angular and increases water demand and cement content when used in the mix. (*5*) To avoid this situation, the minus No. 4 (4.75 mm) material was removed from the crushed concrete and used as a stabilizer in the base material. However, the material still needed constant watering to achieve target densities. A blend of 60 percent recycled coarse aggregate and 40 percent natural sand was expected to provide enough recycled material for coarse aggregate in the mix. The actual yield was very close to this estimate.

Specifications

Several States have developed specifications covering all phases of the construction for removing, crushing, storing, and incorporating recycled materials into new PCC. (*1*, pp. 140-143) The following discussion of specifications refers only to items directly affecting the recycled aggregate material.

Removal and contamination. Some limit should be set on the amount of allowable contamination from any asphalt overlay, patch, joint sealant, or subbase material in the material recycled. Some amount of adhering asphaltic concrete is allowable and not detrimental to the mixture.

Crushing and stockpiling. The maximum size of material should be specified and may vary depending on the use of the concrete. The top size typically specified is 100 percent less than 1 1/2 in (38 mm). The maximum size specified may have to be reduced (100 percent less than 3/4 in [19 mm]) if the material being recycled is a "D" cracked pavement. Standard, good stockpiling techniques should be followed, and the plus 3/8 in (9.5 mm) and minus 3/8 in (9.5 mm) material should be stored separately to avoid segregation. Usually, washing is not necessary; however, individual job conditions should dictate this. The amount of minus No. 200 (0.075 mm) material should be limited to a maximum percentage.

Mix proportions. Crushed, recycled material may be used for both the coarse and fine aggregate; however, specifying 15 to 30 percent natural sand in the fines will improve the workability and the finishability of the mix. Trial mixes made in the laboratory should determine mix proportions. The proportion of coarse to fine recycled material used in the concrete should be the same as the crusher produces, if possible.

The cement factor will be determined according to the strength desired, as with a conventional mix. The water content should provide acceptable workability and finishability without requiring excessive cement to maintain strength. As mentioned above, natural fine aggregate may be added to improve these characteristics while holding the water content at a reasonable level. Water-reducing admixtures also may be specified to maintain the water/cement ratio at an acceptable level. Air entrainment also will increase workability.

Durability. The durability of the concrete produced should be checked in the laboratory according to ASTM C-666 or some equivalent method. If recycled alkali-aggregate reactive material is used, the expansive characteristics of the new concrete also may be checked with ASTM C-227 or an equivalent method to determine if it will perform adequately.

Air entrainment. Air content may be specified and obtained by adding an approved air entraining agent, as with a conventional mix. If the recycled material is air entrained, the specified air for the new concrete may have to be set higher than usual because the measured air will include the newly entrained air plus the air content of the recycled material. When the air content of the recycled material is subtracted from the measurement obtained on the new plastic concrete, the residual then will provide a measure of the amount of air in the new mortar. The presence of organic contaminants may cause high air contents; therefore, de-air entraining agents may be needed.

Conclusions

In many instances, the recycling of PCC as aggregate in a new concrete is a viable alternative to the use of natural aggregate. Research has shown that with proper planning, testing, and construction techniques, high-quality concrete can be made using recycled PCC as aggregate.

Further work needs to be done on the use of recycled concrete that has undergone "D" cracking or alkali-aggregate reaction; the long-term behavior of this material when used as aggregate still is not known. Critical chloride contents for recycled concrete in various applications also are not yet well established.

Current knowledge and practices in the recycling of PCC pavement will be summarized in a National Cooperative Highway Research Program synthesis study. Recycling of PCC also will be one of the subjects addressed by the Strategic Highway Research Program.

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Research Needs in Asphalt Technology

by
E.T. Harrigan

Introduction

This article discusses from the perspective of the Federal Highway Administration (FHWA), research needs in asphalt technology—one of six topics selected by the American Association of State Highway and Transportation Officials (AASHTO) to receive special attention in the planned Strategic Highway Research Program (SHRP). FHWA supports this selection and, along with other interested public and private organizations, will provide specific recommendations on needs and methods in 1985 and beyond as AASHTO formally develops a scope and plan for each study area.

In 1983, before the SHRP was conceived, FHWA reviewed asphalt research needs as a preliminary step in developing an asphalt research program. Expert opinions were gathered on the desirability and practicality of changing current asphalt specifications, particularly by including measures of asphalt chemical composition, to improve asphalt pavement performance. Including asphalt chemistry in asphalt specifications has generated great interest in recent years as a possible solution to premature or catastrophic asphalt pavement failure. Indeed, there is a misconception that the main thrust of the SHRP asphalt technology program will be asphalt chemistry. However, AASHTO states that the following five needs will be equally important (*1*) [1]:

- Define properties of different asphalts.
- Improve testing and measuring systems.
- Determine relationships between asphalt cement and pavement performance.
- Develop improved asphalt binders.
- Validate performance in the field.

The importance of asphalt chemistry in influencing pavement performance, particularly pavement distress, must be evaluated to develop a sound research program. A brief historical review of asphalt chemistry research may help explain the present situation.

[1] Italic numbers in parentheses identify references on page 45

Developments in Asphalt Chemistry Research

FHWA and its predecessor, the Bureau of Public Roads, had a strong, productive program of asphalt research from the 1930's into the early 1970's. This program, which stressed the study of asphalt rheology and the development of tests and specifications, was instrumental in introducing the asphalt grading systems and standard test methods used today throughout the United States. FHWA also stressed the basic chemistry of asphalts, particularly how the chemical constituents of asphalt interact with aggregate, moisture, and oxygen, and how chemistry influences the aging of asphalt in a pavement. (*2*)

Reports of premature distress in asphalt pavements increased sharply in the past decade. A perception developed that pavement failures evidenced by rutting, stripping, and cracking were occurring at an unprecedented rate and that materials and designs that had always given satisfactory performance now were yielding pavements that failed unpredictably and prematurely. Combined with the 1973 oil embargo that disrupted traditional crude oil sources for U.S. asphalt production and the introduction of new refining technology on a massive scale, a consensus developed in the highway community that a primary cause of asphalt pavement distress and failure was a subtle, but significant, change in the quality of U.S. asphalt cements. Several studies sponsored by private organizations and by FHWA failed to detect major differences in physical properties between pre- and post-1973 asphalt cements. In fact, the data indicate that the physical properties of the asphalt cements in a given grade have changed very little in 35 years despite major changes in crude oil sources and refining technology over this same period.

Could two AC-20 asphalts, one produced in 1950 and the other in 1980, have the same physical properties (for example, viscosity and ductility) but still have chemical compositions so different that their individual performances in pavements vary significantly? The answer is a qualified "yes"—although two materials with the same chemical composition will have the same physical properties, the converse is not necessarily true. For example, the viscosities of chloroform and methanol are approximately the same at 20 °C (68 °F), and the densities of water and asphalt are approximately the same at 25 °C (77 °F); chemically, the members of each pair are very different. However, although the chemical composition of crude oils varies widely, limits of chemical composition can be defined within which all crude oils fall. Consequently, the chemical composition of asphalts will fall within natural limits. Therefore, a change in crude oil source should not radically alter asphalt physicochemical properties. Changes in asphalt composition can contribute to pavement performance problems, but these changes cannot account for all the poor performance noted in the last decade.

The chemical composition of an asphalt is directly involved in some important causes of pavement distress, such as stripping. The size and structure of the component molecules of asphalt are important in determining the physical properties of the asphalt. Also important are the associative forces between individual molecules and those forces that provide bonding between the asphalt and aggregate. These forces are highly dependent upon the heteroatom content of the asphalt (primarily nitrogen, oxygen, sulfur, and trace elements). Asphalt molecule functional groups containing heteroatoms are directly involved in the mechanism of stripping. (*2*)

Asphalt chemistry also is important in the aging of asphalt in a pavement. Aging predominantly involves reaction of oxygen with the asphalt, resulting in changes in molecular size, structure, and functional group content, and is reflected in changes in rheological properties. The passage of time structures the asphalt in a manner analogous to crystallization and without the need for external agents such as oxygen or moisture. Structuring on a molecular level is manifested as hardening of the pavement.

This discussion of asphalt chemistry suggests that, while important, it does not account entirely for premature and pervasive asphalt pavement distress. Also, asphalt chemistry research in the SHRP should be narrowly defined and goal oriented, confirming the view expressed by AASHTO. (*1*) An extensive asphalt chemistry research program is neither warranted nor possible with the resources available.

Considerations for an Asphalt Research Program

The expert panel convened by FHWA in 1983 made several significant remarks about the state of asphalt technology. To develop a research program to address the problems evident in asphalt pavement performance, the following should be considered:

- Asphalt is rarely the sole culprit in a pavement failure. Asphalt chemistry alone cannot account for the performance of pavements under traffic loading.

- Chemical specifications for asphalts would be unrealistic, but chemical factors can be used to evaluate the overall quality of an asphalt.

- Asphalt specifications overemphasize handling qualities. The gap between asphalt specifications and asphalt mixture properties should be bridged with performance-related specifications that address conditions such as rutting, cracking, stripping, and adhesion.

- The dominant chemical factors that influence asphalt performance and how these factors interact must be determined and quantified.

• Moisture is the worst enemy of an asphalt pavement, but many pavement failures can be traced to improper mix design or construction techniques. An asphalt can be too hard because asphalt films are too thin, air void contents are too high, or the choice of asphalt grade is poor.

• Materials and construction specifications are not enforced; the fundamentals of proper mixture and pavement design and construction are neglected.

• Highway agencies and contractors need a working knowledge of the physicochemical properties of each asphalt used, not just of the grade of the asphalt, so that production and construction procedures can compensate for any shortcomings and take advantage of the asphalt's strong points.

This strong emphasis on a balanced research program, examining both asphalt mixture behavior and asphalt physicochemical properties, combined with attention to proper construction techniques and the intelligent use of available materials can prevent many pavement failures.

When asked to recommend a list of topics that FHWA might include in an asphalt research program, the panel of asphalt technologists arrived at nine topics from a list of 39 different items discussed. In order of importance, the list includes the following:

1. *Moisture damage mechanisms.* Determine the adverse effect of moisture on pavements, the physicochemical interactions that produce these effects, and how these effects are reflected in changes in asphalt and aggregate properties. Explore the long-term results of moisture damage on pavement performance and methods to control the damage mechanisms.

2. *Training and technology transfer.* Identify and implement training activities and multimedia technology sharing to improve asphalt mix design, construction practices, and inspection and quality control in all phases of asphalt pavement construction.

3. *Improved asphalt specifications.* Synthesize existing information and field data to evaluate the possibility of simplifying asphalt specifications, particularly eliminating the asphalt residue and penetration grading systems.

4. *Low-temperature behavior.* Investigate how asphalt responds to various cooling rates and how it accommodates repeated strains in the cold weather service range. In addition, develop a measure of low- temperature stiffness in fundamental units.

5. *Asphalt additives to upgrade desirable asphalt characteristics.* Investigate additives to upgrade or control asphalt properties (such as oxidative and steric hardening and temperature and shear susceptibilities) and to counteract pavement distress mechanisms that lead to rutting, cracking, and stripping.

6. *External effects on asphalt performance in service.* Investigate on a controlled basis by locality and climate how asphalt specification grade, mix design, and construction practices determine or influence pavement performance.

7. *Establish relationships between asphalt rheology and mixture rheology.* Investigate techniques to measure the influence of asphalt rheology on mixture rheology, emphasizing the mixture stiffness at low temperature; the correlation of asphalt flow properties with field performance; the development of mix design methods to compensate for variations in asphalt rheology; and the measurement of properties such as viscosity, ductility, and direct tensile strength over the whole asphalt service temperature range.

8. *Asphalt chemical functionality.* Characterize the chemical functionality of asphalt, emphasizing the chemical groups that interact with moisture, oxygen, and aggregate and that influence the rheology of an asphalt over its service life.

9. *Effects of new production equipment and techniques.* Investigate how hot-mix production methods that allow moisture retention in aggregates and mineral fines in asphalt influence asphalt and aggregate mixture quality. Explore the need to change mix design methods to compensate for various mix production technologies.

A series of studies would be needed to accomplish the goals of each of these nine topics, but the total program would not be as large as that envisioned for asphalt technology in the SHRP. In its final form, the SHRP probably will encompass a much wider spectrum of research areas.

The SHRP has the resources to provide a unique opportunity toward solving several important problems. FHWA welcomes the opportunity to participate in the development and conduct of research in asphalt technology as well as in the other five topic areas.

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Limited Sight Distance Warning for Vertical Curves [1]

by

Mark Freedman, L.K. Staplin, and Lawrence E. Decina

This article summarizes the methodology and findings of a Federal Highway Administration (FHWA) contract study to evaluate highway signs designed to warn motorists of restricted sight distance because of crest vertical curves. Driver awareness, understanding, and response to a new warning sign (see display art) that was developed were better than for the existing LIMITED SIGHT DISTANCE warning sign. However, the new sign's effectiveness still was minimal. As a result of this evaluation and of a previous study conducted by the New York State Department of Transportation (*1*) [2], the National Committee on Uniform Traffic Control Devices voted to eliminate the LIMITED SIGHT DISTANCE sign (W14-4) from the *Manual on Uniform Traffic Control Devices* (MUTCD). FHWA plans to issue a Final Rule to delete this sign from the MUTCD.

Introduction

Contemporary roadway geometry and highway design features must satisfy safety and operational requirements of the vehicle and the driver. Prominent among these highway design features are vertical and horizontal alignment, superelevation, delineation, guardrails, signals, signs, and lighting. One of the most important aspects of highway design is to provide sufficient sight distance to enable the driver to respond properly to situations ahead. Modern highways, therefore, are designed and built with horizontal and vertical curvature appropriate for the planned speed and composition of traffic.

Many older highways, however, evolved from old pathways used by slow vehicles, and the highway design is not appropriate for modern traffic. Gradual improvements to the roadway, especially upgraded paving, allowed traffic to operate more smoothly at higher speeds. However, on many two-lane rural roads, horizontal and vertical alignments were not upgraded to match the level of service offered by the roadway surface.

[1]This article summarizes "Limited Sight Distance Warning for Vertical Curves," Report No. FHWA/RD-85/046, Federal Highway Administration, Washington, DC, November 1984. The report is available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161 (Stock No. PB 85 193399).

[2]Italic numbers in parentheses identify references on page 53.

On two-lane roads with poorly designed crest vertical curves, drivers cannot see far enough beyond the crest of the hill to determine whether a hazard, such as debris on the roadway, pedestrians, bicyclists, animals, or another vehicle, exists ahead. An intersection just beyond a hill crest, where neither the mainstream nor the crossing traffic can see each other's approach, is especially hazardous. Passing maneuvers at crest vertical curves are equally hazardous; motorists do not have sufficient time to avoid oncoming cars.

Such situations occur most often on low volume two-lane rural highways that once carried primarily local traffic. Local drivers who know of the danger at these vertical curves with restricted sight distance reduce their speed or are more attentive while approaching the curve. Unfamiliar drivers, however, who may represent a large portion of traffic on highways in recreational areas, are unaware of the danger and generally do not exercise such cautious behavior.

One solution to the crest vertical curve sight distance problem is to reconstruct the vertical curvature; however, this is very expensive and may not be cost-effective in most cases. Another solution is to limit traffic speed to ensure sufficient response time to hazards. However, the safety of frequent and abrupt speed-limit reductions on high-speed highways is questionable. A more cost-effective and rational approach is to warn the motorist of the potential hazard and to advise of a safe speed through the hazard area.

This warning approach was adopted with the incorporation of the LIMITED SIGHT DISTANCE verbal sign (W14-4), supplemented with a speed advisory panel, into the *Manual on Uniform Traffic Control Devices* in 1976. However, the effectiveness of this sign, either with or without a speed advisory panel, has been questioned. Although familiar to traffic engineers, the terminology of the sign legend is not familiar to motorists, so it was not known whether motorists adequately comprehend the sign to reduce speed and increase attentiveness.

In 1982, a Federal Highway Administration contract study was conducted to develop and test an improved limited sight distance warning sign for crest vertical curves. Study objectives included the following:

- Test the effectiveness of developed alternative warning signs as well as the LIMITED SIGHT DISTANCE sign with and without a speed advisory panel.
- Compare the effectiveness of vertical curve warning signs with other traffic control devices.
- Provide recommendations for proper use of the selected warning sign.

Work on these objectives was preceded by a literature review to determine performance objectives for vertical curve warning signs.

Highway Sign Performance Objectives

Although the literature on highway signs contains extensive information on legibility, noticeability, comprehension, and other sign/driver performance measures, little has been written about the performance of the LIMITED SIGHT DISTANCE sign in particular.

The effectiveness of the LIMITED SIGHT DISTANCE sign has not been proven. A study of vehicle speed, driver comprehension, and accidents at LIMITED SIGHT DISTANCE sign sites in New York showed that either the sign had no impact on drivers' speeds or that drivers reduced their speeds only after the sign was removed. Only about one out of every six motorists fully understood the sign's meaning, while half recognized the advisory speed but did not know that the warning referred to the hill. The sign's effect on accident reduction could not be concluded. (*1*) Also in New York it was found that the LIMITED SIGHT DISTANCE sign is used where resurfacing and/or other minor road improvements result in at least a 5-mph (8-km/h) increase in speed above the design value for the vertical alignment. (*1*)

The LIMITED SIGHT DISTANCE sign has become the second most frequently used sign (horizontal curve warning is first) at all recent highway rehabilitation projects where signing has been installed. The availability of the LIMITED SIGHT DISTANCE sign has allowed many substandard vertical curves to be treated with resurfacing and sign installation rather than reconstructing the vertical curvature, which is not always cost-effective.

The parameters that determine sight distance on crest vertical curves are the change of gradient (A), the length of the curve (L), the driver's eye height (h_e), and the height of the obstacle to be seen (h_o). The following equation is used to determine the length of the curve required to provide a given sight distance (S):

$$L = \frac{AS^2}{100\,(\sqrt{2h_e} + \sqrt{2h_o})^2}$$

Thus, the sight distance provided by a particular geometric layout is:

$$S = 10\sqrt{L/A}\,(\sqrt{2h_e} + \sqrt{2h_o})$$

Setting sight distance on vertical curves is determined by the distance required to stop for an obstacle on the road:

$$D = 1.467(RT)V + V^2/30(f \pm s)$$

Where,
D = Stopping distance (ft).
RT = Reaction time (s). (The American Association of State Highway and Transportation Officials currently uses 2.5 s).
V = Speed (mph).
f = Tire-pavement coefficient of friction. (The range for wet pavement is 0.36 at 30 mph [48 km/h] to 0.29 at 70 mph [113 km/h]).
s = Longitudinal slope of roadway.

The stopping distance for vertical curves is extremely sensitive to speed, friction, and reaction time. For speeds near 55 mph (89 km/h), for each 1 mph (1.6 km/h) that speed is reduced, stopping distance is reduced by about 9 ft (2.7 m) on dry pavements and by about 14 ft (4.3 m) on wet pavements. Similarly, stopping distance is reduced by about 8 ft (2.4 m) for every 1/10 s reduction in reaction time. Therefore, a warning device that causes a driver to reduce his/her speed and be more alert also reduces the time needed for detection, recognition, and control movement, and thus substantially reduces stopping distance. A warning device that reliably reduces traffic speed and minimizes reaction time by heightening driver attentiveness to the potential problem ahead would be a highly cost-effective treatment for the typical vertical curve with restricted sight distance.

Other research (*2-5*) on warning signs has shown that signs augmented by constantly flashing lights or vehicle-actuated flashers are more effective in reducing speeds than signs without flashers. Generally, flashing lights should be used only where a real hazard is likely to be present or is especially severe. Flashing lights are most effective in reducing drivers' speeds and increasing their attention when a hazard is obvious, such as a wet roadway or sharp horizontal curve, and therefore may not be appropriate for most vertical curves with restricted sight distance.

Development of Alternative Sign Candidates

The literature review pointed to the need for an understandable and effective alternative to the LIMITED SIGHT DISTANCE sign. In developing and evaluating alternative warning signs, numerous verbal and symbol candidate signs were prepared, and laboratory experiments were conducted to eliminate the least promising candidates and select the most promising candidates for field testing.

Preparation of sign candidates

Thirteen preliminary verbal messages were created using various combinations of key words selected to convey a preparatory element (the appropriate degree of attentiveness), an action element (what the motorist must or must not do), and an identification element (defining the hazard). In addition, 10 candidate symbols were prepared to depict the vertical curve sight distance situation from front, side, and perspective views as well as several more abstract representations. Each verbal and symbol candidate was prepared as a small, individual cardboard sign.

A sample of 41 respondents examined each of the verbal and symbol candidates and ranked them according to how well each candidate conveyed caution because of a hill crest restricting vision of possible traffic hazards.

The most highly ranked verbal candidate messages were CAUTION HILL BLOCKS VIEW, DANGER HILL BLOCKS VIEW, and SLOW HILL BLOCKS VIEW. The candidate message DANGER HILL BLOCKS VIEW was eliminated because DANGER was believed to be too strong for most situations where no danger is apparent, and overuse of the word might diminish its value.

The two most highly ranked symbols were both side views depicting one or two vehicles approaching the hill crest. A third candidate showing a single car, an obstruction, and an occluded line of sight also was recommended by FHWA for further testing.

The signs recommended for further laboratory testing are shown in figure 1.

Laboratory experiment

The laboratory experiment was conducted to determine how well and how quickly the LIMITED SIGHT DISTANCE sign and each of the other candidate warning signs were understood and assimilated by motorists. A total of 256 drivers, from 16 to 75 years old and equally comprised of men and women, were test subjects. Testing was performed in an urban and rural area in two State-operated motor vehicle inspection centers in New Jersey and two drivers license photograph centers in Pennsylvania.

The laboratory experiment consisted of three complementary tests—a comprehension test, an assimilation test (speed of recognition), and a ranking test—for each of the candidate signs shown in figure 1. The LIMITED SIGHT DISTANCE sign was tested with and without a 35 mph (56 km/h) advisory speed panel. The CAUTION HILL BLOCKS VIEW sign was tested with and without a supplementary panel with the legend INTERSECTION. Each subject was exposed to only one of the candidate signs and three similarly shaped, but otherwise unrelated, distractor signs to eliminate any learning effect from alternative candidates. Slides of the signs set in an identical, real-world background of a hilly, two-lane rural road were displayed on a screen to each subject.

For the comprehension test, slides of the selected candidate sign and its three distractor signs were projected, and each subject was asked to explain what the message or symbol meant and what the subject would do if he/she encountered the sign while driving. No time limit was imposed on this part of the experiment.

In the assimilation test, each subject examined and became familiar with one selected candidate sign and set of distractors, then identified each sign when exposed to a very brief (50 ms) projection.

For the ranking test, each subject was given a packet of three miniature verbal signs and asked to rank which sign was the best, next best, and worst at conveying the intended warning. The same procedure was used to rank the symbol signs.

Following are the principal findings of the laboratory experiment:

- Of the verbal messages, SLOW HILL BLOCKS VIEW scored highest in comprehensibility and recognizability and was ranked second best among verbal signs. This sign was selected for further field testing.

- Of the symbol messages, the sign depicting two vehicles approaching each other from opposite sides of a hill scored highest in comprehensibility and second highest in recognizability. It was overwhelmingly preferred among symbols in the ranking test. This sign also was selected for further field testing.

- The currently used LIMITED SIGHT DISTANCE verbal message was least comprehensible of the verbal signs, was least recognizable of all verbal and symbol signs, and was deemed worst by more test subjects than any other symbol or verbal sign. This sign was used as the basis for comparison in the field tests.

- In the assimilation test, symbol signs were correctly identified 50 percent more often than signs with verbal legends.

Figure 1. Candidate limited sight distance warning signs.

Field Tests of Candidate Signs

The candidate verbal sign SLOW HILL BLOCKS VIEW and the candidate symbol sign depicting two vehicles approaching each other from opposite sides of a hill (see display art) were field tested under fully operational conditions in a controlled field test and an observational field test. In the controlled field test, subjects accompanied by a test administrator drove a test vehicle along a 12.6-mile (20.3-km) route containing four vertical curves with restricted sight distance that were identified by a candidate warning sign. Drivers' abilities to notice and remember the signs, correctly interpret the signs, and respond appropriately were measured. In the observational field test, traffic sensing equipment was placed on a roadway at three vertical curves with restricted sight distance to measure the speed of passing motorists who were not aware that a study was being conducted.

The LIMITED SIGHT DISTANCE sign was studied both with and without a 30 mph (48 km/h) advisory speed panel at each of the study locations. In addition, at one site located near an intersection, a 12-in x 24-in (305-mm x 610-mm) panel bearing the legend INTERSECTION was placed on the sign post below the LIMITED SIGHT DISTANCE sign. At each site, the symbol sign also was accompanied by a 24-in x 18-in (610-mm x 457-mm) verbal panel bearing the legend SLOW HILL BLOCKS VIEW.

Controlled field test

Sixty-four drivers (28 men and 36 women) ranging in age from 18 to 69 years participated as test subjects. The three dependent measures in this study were observations of how drivers responded to candidate signs along the route, memory measures to reveal which signs were most often noticed and most correctly identified, and expressions of relative preference for each candidate limited sight distance warning sign.

Driver responses to the signs were measured as follows: As subjects drove the route and encountered each candidate warning sign, the administrator recorded what the driver did in response to the sign, using a checklist that included slowing or braking, any unusual or inappropriate response, any remarks concerning the sign, turning his/her head toward the sign, or other obvious responses.

Two different memory measures assessed how well each subject could remember the candidate signs distributed along the test route. In a free recall test, drivers named from memory as many signs seen along the route as possible. They also were asked to explain the meaning of each sign that they recalled. In a recognition memory test, drivers were asked to indicate whether or not they had encountered the signs shown in a series of photographs.

Both the SLOW HILL BLOCKS VIEW candidate sign and the symbol candidate sign were more frequently recalled than either the LIMITED SIGHT DISTANCE sign alone or with the 30 mph (48 km/h) speed advisory panel. SLOW HILL BLOCKS VIEW was correctly interpreted more often than any other sign.

Although the symbol candidate was the second most frequently recalled sign after SLOW HILL BLOCKS VIEW, it was incorrectly interpreted twice as often as it was correctly interpreted. This misinterpretation probably was because of the test subjects' lack of familiarity with the new symbol.

In the recognition memory test, SLOW HILL BLOCKS VIEW was correctly recognized more often than the other signs.

Both the SLOW HILL BLOCKS VIEW and the symbol sign were greatly preferred to the LIMITED SIGHT DISTANCE signs in the preference ranking test.

The study of behavioral responses demonstrated that drivers responded most often to the symbol sign, primarily by slowing or braking.

The LIMITED SIGHT DISTANCE sign, both with and without the 30 mph (48 km/h) advisory panel, was associated with poorer performance than either of the other candidate signs in the recall test and the preference ranking test.

Results of the controlled field test are shown in tables 1-4.

Table 1.—Recall memory performance for target stimuli in controlled field test

Candidate warning sign	Total number of times remembered	Correct interpretations	Incorrect interpretations
Symbol sign	21	7	14
SLOW HILL BLOCKS VIEW	26	23	3
LIMITED SIGHT DISTANCE	18	13	5
LIMITED SIGHT DISTANCE—30 mph advisory panel	4	3	1

1 mph = 1.6 km/h

Table 2.—Recognition memory performance for target stimuli in controlled field test

Candidate warning sign	Number of "yes" responses	Percent correct
Symbol sign	36	45
SLOW HILL BLOCKS VIEW	43	67
LIMITED SIGHT DISTANCE	37	58
LIMITED SIGHT DISTANCE—30 mph advisory panel	29	45

1 mph = 1.6 km/h

Table 3.—Preference ranking of candidate warning signs in controlled field test—frequency counts and weighted scores

	Symbol sign	SLOW HILL BLOCKS VIEW	LIMITED SIGHT DISTANCE	LIMITED SIGHT DISTANCE—30 mph advisory panel
Position 1 (best)	30	23	4	7
Position 2	13	24	10	17
Position 3	7	9	18	30
Position 4 (worst)	14	8	32	10
Weighted scores	187	190	114	149

1 mph = 1.6 km/h

Table 4.—Driver behavior response to candidate warning signs noted during controlled field test

	Symbol sign	SLOW HILL BLOCKS VIEW	LIMITED SIGHT DISTANCE	LIMITED SIGHT DISTANCE—30 mph advisory panel
Slowing or braking	25	22	13	21
Inappropriate response	0	0	0	0
Makes remark	6	5	3	6
Overt orienting response (eye fixation of over 2 s)	5	2	0	1
Other	0	1	0	0

Driver swerved across lane boundary while staring at sign.
1 mph = 1.6 km/h

Observational field test

This test, conducted concurrently with the controlled field test at three rural vertical curve sites with restricted sight distance, was intended to determine the extent to which each of the candidate warning signs tested influenced the driving behavior of motorists who were not aware that an experiment was being conducted. Vehicle velocity was measured for 5,338 vehicles at five locations within an area 1,250 ft (381 m) before each vertical curve to 200 ft (61 m) beyond the hill crest. In addition, vehicle lateral position and other indications of driver response to the warning signs were recorded.

The average daily traffic volume (both directions) at the sites ranged from 2,000 to 3,750 vehicles. Posted speed limits were 55 mph (89 km/h), 45 mph (72 km/h), and 40 mph (64 km/h). No traffic control devices warning of sight distance restrictions because of vertical curves existed at any of the three sites before the experiment.

Data were collected at each site for the following sign conditions:

- Baseline—no limited sight distance warning sign.
- SLOW HILL BLOCKS VIEW.
- Symbol sign with SLOW HILL BLOCKS VIEW panel.
- LIMITED SIGHT DISTANCE.
- LIMITED SIGHT DISTANCE with 30 mph (48 km/h) speed panel.

At one site, a vehicle was parked on the shoulder of the road beyond the crest of the hill, thus out of drivers' sight until they were within about 200 ft (61 m) of the hill crest. The sudden presence of what appeared to be a potential hazard was intended to force drivers to take some anticipatory or corrective action such as reducing speed or moving toward the center of the roadway.

Figure 2 shows a typical layout of the data collection equipment and sign placement for the observational field test.

Measures of vehicular velocity were not sensitive enough to identify any effects caused by differences among signs. In general, velocity and velocity difference measures for each sign condition were similar; thus neither statistically nor operationally significant differences were evident.

Although some marginally statistically significant differences between the behavioral measures (including braking, drifting left or right, crossing the centerline, and crossing onto the shoulder) associated with each sign were discovered, no consistent pattern could be defined, thus no sign emerged as the superior candidate.

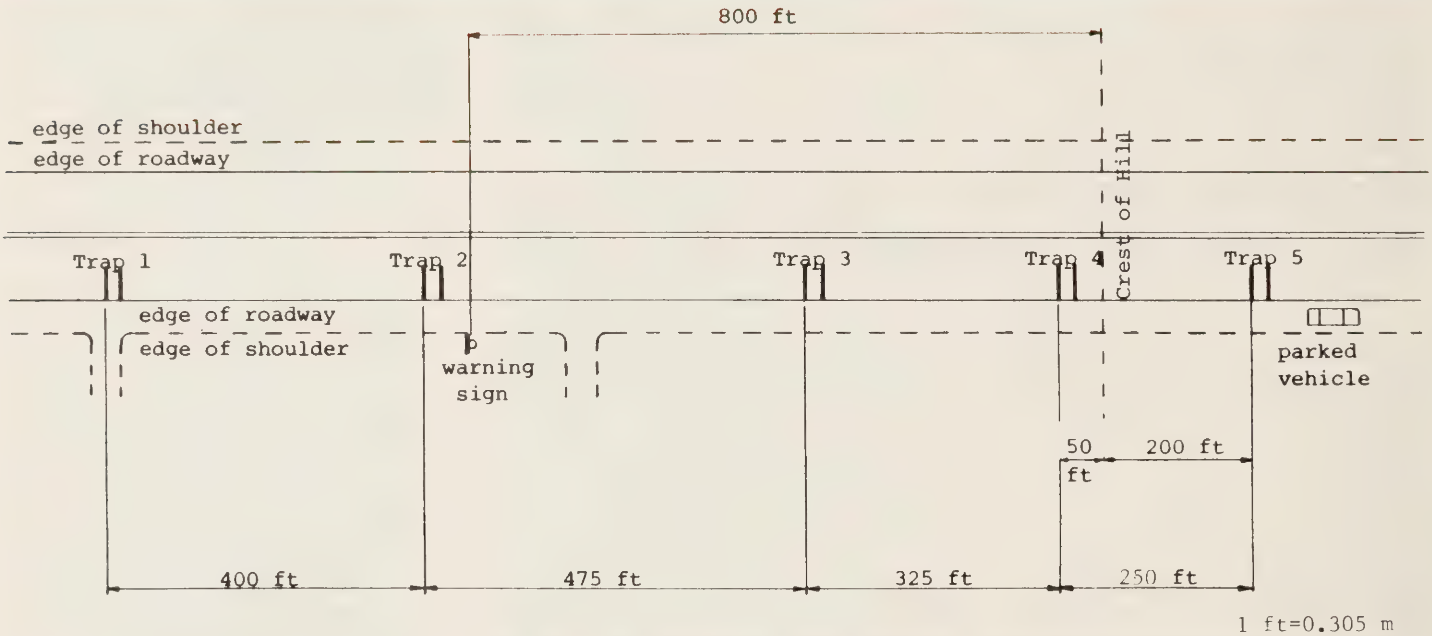

Figure 2.—Conditions and experimental layout for the observational field test.

Conclusions From the Field Tests

The effect that each sign had on driver behavior could not be measured by techniques used in the observational field test. In the controlled field test, however, driver behavior was measurably influenced by each of the candidate warning signs. That influence was measured by differences in the number of observations of certain driver responses, each driver's ability to freely recall, recognize, and comprehend each of the warning signs, and each driver's relative preference for each candidate limited sight distance warning sign. Clearly, the existing LIMITED SIGHT DISTANCE sign, with or without a supplementary advisory speed panel, did not produce desirable driver responses as frequently as the SLOW HILL BLOCKS VIEW sign or the symbol sign, nor was the LIMITED SIGHT DISTANCE sign recalled, comprehended, recognized, or preferred as often as the SLOW HILL BLOCKS VIEW sign or the symbol sign. These candidate signs are more likely to increase driver awareness that a hazard may exist downstream than is the existing LIMITED SIGHT DISTANCE sign.

However, although the SLOW HILL BLOCKS VIEW verbal sign candidate and the symbol sign candidate are the most desirable choices to replace the LIMITED SIGHT DISTANCE sign, neither candidate sign was very effective in influencing test subjects in the field test to reduce speed. Less than half of the drivers slowed or braked for any of the signs. Therefore, the importance of this study is that it provides additional evidence of the need to eliminate the use of the LIMITED SIGHT DISTANCE warning sign.

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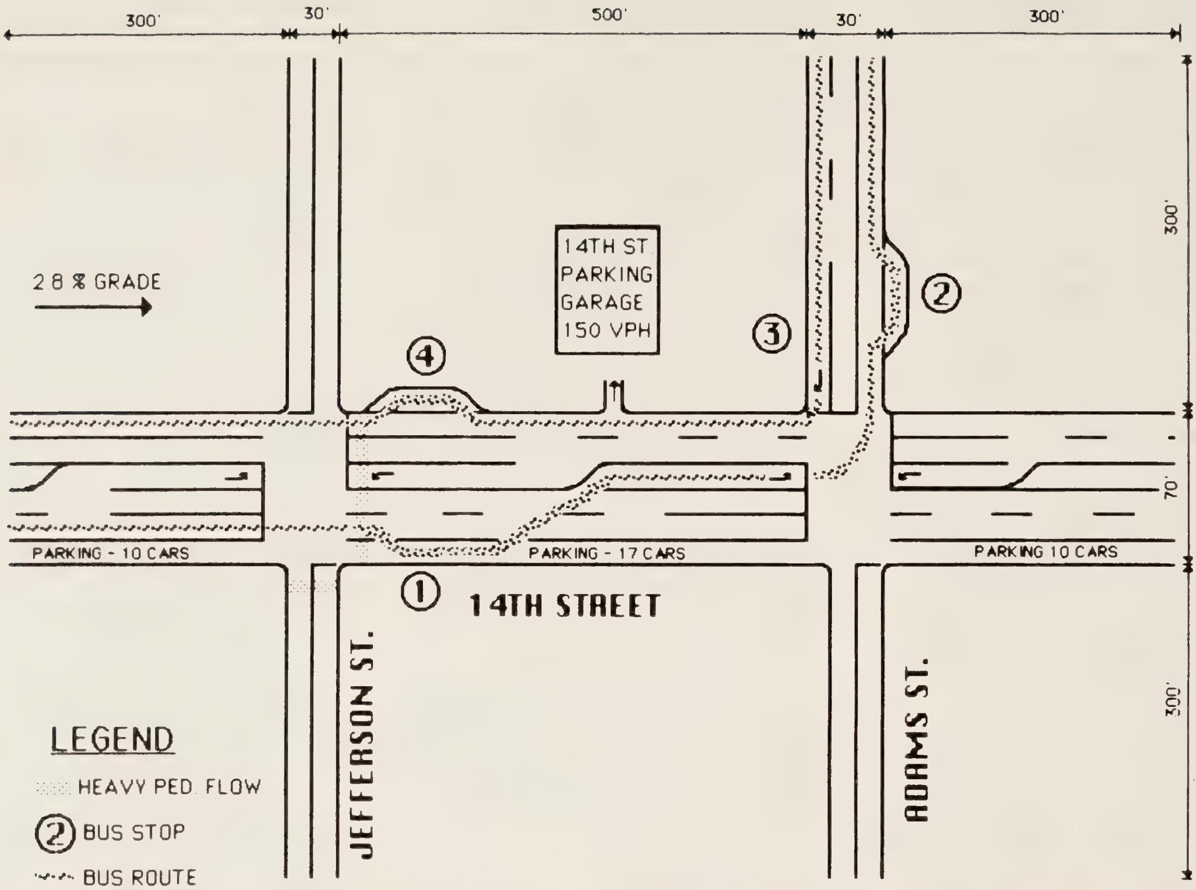


Netsim for Microcomputers

by
Scott W. Sibley

Introduction

Netsim, a computer model that simulates microscopic traffic flow on urban streets, is one of the most powerful traffic engineering and research tools available today. Netsim was developed in 1971 as UTCS-1 to evaluate the Urban Traffic Control System, a computer-based signal control system. Today, there are about 130 Netsim users in the United States and abroad. Over the years, the model has been enhanced to include fuel consumption and vehicle emissions data and other features requested by its users. The mainframe program was written in ANSI Fortran 66 and is portable to most mainframe computers. (*1*) [1]

The use of Netsim has been limited to users who have access to a mainframe computer. Often, the lack of opportunity or cost of using a large computer has made the use of Netsim impractical. Because of the growing number of microcomputers in use, a version of Netsim that runs on a microcomputer would make the program available to a larger number of users. I have developed such a version under a research fellowship with the Federal Highway Administration (FHWA), Office of Implementation. The microcomputer program is based on the current version of Netsim with actuated signal logic and is written in Fortran 77 for use on IBM-PC compatible microcomputers. This microcomputer version makes the use of Netsim feasible for an extended range of problems, including much smaller networks and situations in which a number of alternatives are to be examined.

[1]Italic numbers in parentheses identify references on page 59.

Background

Simulation, particularly useful when studying a complex situation that cannot be analyzed directly, allows experimentation with design alternatives without committing the resources necessary to implement the alternatives in the field. Simulation is quicker and more flexible than field evaluation and avoids the risk of creating hazardous or undesirable operating conditions. The user has complete control over the experimental conditions, which allows one aspect of a problem to be modified without changing other aspects. (*2*) However, because a simulation is a simplification of the real world, it has its limits. The quality of the results depends on the time and care used in collecting data and preparing inputs.

Netsim simulates urban traffic operations by modeling the movement of individual vehicles through a network of streets and intersections. Each vehicle responds to local conditions such as signal control and neighboring vehicles. (*3*) Netsim was developed to evaluate, not optimize, a range of relatively complex traffic control strategies. The model is especially useful for predicting fuel consumption and vehicle emissions; however, it does not generate or select alternatives. Netsim simulates a range of network configurations and traffic control schemes and analyzes bus stop placement, bus routing, turn restrictions, turning pockets, parking control, and the placement of traffic detectors.

The Netsim model is stochastic—traffic modeling is based on probabilities of random events, and outputs have random variability. Vehicles do not move according to origin-destination travel paths because their routes depend on fixed turning probabilities at intersections; therefore, vehicles are not diverted from routes or intersections that become congested.

The Microcomputer Version

The microcomputer version of Netsim is essentially the same as the mainframe computer version. The Netsim User Guide (*2*) is applicable to this version, and most data sets from the mainframe version can be used with the microcomputer version with little or no modification.

The program has been modified to fit the limits and capabilities of a microcomputer. The file-handling features have been removed, and the user is given direct control over the input and output files (fig. 1). The mainframe version allows the user to specify several time intervals with different traffic characteristics in each; the microcomputer version is limited to simulation of one time interval.

The microcomputer version of Netsim has the same size limitations as the mainframe version. The program can handle a network up to 160 links and 99 nodes and a maximum of 20 actuated traffic signals. Up to 30 bus routes can be included. The program handles a maximum of 1,600 vehicles in the network at one time. Most situations can be handled within these flexible limits.

The computation time of the microcomputer version depends on the size of the network and number of vehicles. This becomes a major factor for very large networks. The simulator may run 10 hours or more for a 15-minute simulation on the largest possible network. A more typical 30-intersection network will take approximately 1 1/2 hours. The user only needs to be present during the first 5 minutes of this time for the input processing.

```
B>PREPRO<cr>
NETSIM: Preprocessor                      Version  1.1    1/85
Translated By S.Sibley        Federal Highway Administration


Input  File [NETSIM.DAT]:A:SAMPLE<cr>
Output File [SAMPLE.PRE]:A:<cr>

Ready To Write NET.FIL
Change Diskette If Necessary And Enter Drive Specifier[A]:<cr>
Writing File A:NET.FIL. . .DONE

Ready To Run SIMUL
```

Figure 1. —Execution of preprocessor.

Performing the Simulation

The microcomputer version of Netsim is simple to use, consisting of three separate programs that combine to provide the complete Netsim package. To obtain useful results, the user should have some knowledge of the fundamentals of traffic engineering and an understanding of the situation being modeled. Some user interaction is required, but primarily the program runs itself using the input files provided by the user.

The first step, which is the same for the mainframe version, is to gather the required input information. The user must collect the information for the network, including the geometrics of the network; the signalization and other traffic controls; traffic volumes, composition, and turning percentages; bus routes, stops, and schedules; and vehicle and driver operational characteristics. Default values are built into the program or can be assumed by the user where appropriate.

Next, the network must be reduced to a link-node diagram (fig. 2). This could take several hours or several days, depending on the size of the network, the availability of the information, the need for data collection, and the experience of the user. The representation of the network by a link-node diagram and the assumptions made about the data to be used are critical in obtaining useful and significant results. Much of the information required is available for the study of the problem; little additional data collection is needed.

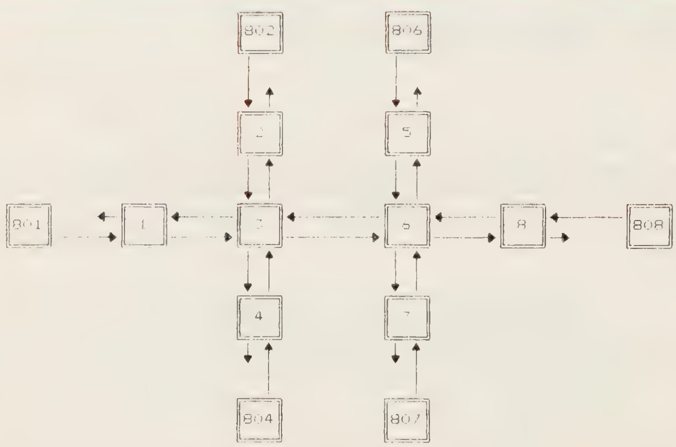


Figure 2.—Link-node diagram.

The second step, as with the mainframe version, is to prepare the input data set by using the Netsim coding sheets and the Users Guide. (*2*) A card image file then must be created using a text editor such as MS-DOS or Wordstar. As for any program, the data set then should be verified for accuracy, which could take from several hours to several days, depending on the size and complexity of the problem being modeled. A data set for a single time interval from the mainframe can be used without modification by transferring the file from the mainframe to the microcomputer.

The third step is to run the preprocessor to check the input data set for completeness and, to an extent, consistency. A portion of the output from the preprocessor is shown in figure 3. The user then must correct the data set and rerun the preprocessor. Even for a large data set, each run takes less than 10 minutes.

The fourth step is to run the simulator, which performs the simulation and accumulates the measures of effectiveness. This step involves the major portion of computer time, but the computer runs without assistance from the user. The speed of the simulator depends on the options selected and the reports requested, as well as on the size of the network and the number of vehicles. A typical simulation takes from 5 to 10 seconds of real time for every second of simulation time. Sample run times are shown in figure 4.

During the simulator run, the optional fuel consumption and emissions program can be run for any additional analyses that may be desired, such as using different vehicle performance values. This program uses the vehicle trajectory data generated by the simulator, so the analysis is based on the same simulation. The user can alter the vehicle fuel consumption and emissions tables to see the effect of different vehicle characteristics on the network's performance. Again, the speed of this program depends on the number of vehicles in the network and the time period simulated. However, the program runs quickly, completing most problems in less than 1 hour.

SIMULATION OF TRAFFIC
THE NETSIM MODEL

14TH ST PARKING GAR., NICETOWN , PENNSYLVANIA 0 01/30/85

LINK	LANE	SPAN	POCK L	POCK R	MEAN U-F	H	TURNING MOVEMENTS LEFT	THRU	RT	DIAG	DESTINATION NODES LEFT	THRU	RT	DIAG	LOST	PED DEN	LANE CHAN 1	2	3	4	5	TYPE	G	L	IDENTIFICATION
(801, 1)	2	500	0	0	ENTRY	22	0	100	0	0	0	3	0	0	0		0	0	0	0	0	1	2	1	
(1, 3)	2	300	10	0	30	22	20	70	10	0	2	6	4	0	26	0	0	0	0	0	0	1	5	2	14TH ST EB
(3, 6)	2	530	11	0	30	22	45	30	25	0	5	8	7	0	26	2	0	0	0	0	0	1	2	3	14TH ST EB
(6, 8)	2	330	0	0	30	22	0	100	0	0	0	808	0	0	26	0	0	0	0	0	0	1	2	4	14TH ST EB
(808, 8)	2	500	0	0	ENTRY	22	0	100	0	0	0	6	0	0	0		0	0	0	0	0	1	2	5	

TRAFFIC SIGNAL DATA
* INDICATES RTOR IN EFFECT FOR THIS APPROACH

NODE	INTVL	DURATION	OFFSET	SIGNAL CODES FACING INDICATED APPROACHES (1, 3)*	(6, 3)*	(2, 3)	(4, 3)*	(
3	1	18 (30P)	0 (0P)	2	2	1	1	
3	2	3 (5P)	18 (30P)	2	2	0	0	
3	3	10 (17P)	21 (35P)	4	4	2	2	
3	4	3 (5P)	31 (52P)	0	0	2	2	
3	5	23 (38P)	34 (57P)	9	9	2	2	
3	6	3 (5P)	57 (95P)	0	0	2	2	

Figure 3. — Sample of input summary report from preprocessor.

Network				Time Period		Running Time		
Name	Links	Nodes	Avg.# Vehs.	Fill	Simul	Without FC&E	With FC&E	With O-D Tables
STAR	12	5	27	10:00	5:00	8:40	9:30	
			27	10:00	15:00	12:40	14:40	14:30
			50	7:30	5:00	10:00	11:20	
			93	6:00	15:00	23:10	30:50	25:30
			130	6:00	15:00	43:10		
MADISON,WI	69	30	37	7:00	5:00	14:00	25:20	
			37	7:00	15:00	25:40		
			73	8:45	15:00	36:00		
			159	8:45	15:00	56:10		
WASHINGTON,DC	101	40	181	5:20	2:00	14:50		
			181	5:20	4:00	25:40	29:10	
			252	5:20	4:00	31:50	36:40	

Notes:

All times are given in minutes:seconds
Fill = Period before network reaches a state of equilibrium
Simul = Period when simulation is performed to gather statistical data
FC&E = Fuel Consumption and Emissions
O-D = Origin-Destination

Figure 4. — Sample run times for typical networks.

As the fifth and final step, the user must analyze the output to determine if additional simulations are required. The user can examine the output with a text editor or print it as a permanent record. Several measures of effectiveness, such as average delay and cycle failure, are provided to indicate how the network operated (fig. 5). Based on this information, the user can make appropriate changes to the network and compare the results. This step could take several hours to several days, depending on the level of detail required.

Advantages of the Microcomputer Version

The microcomputer version of Netsim can be used for problems that would be too expensive or too time consuming on a mainframe computer, making the program ideal for analyzing several alternative solutions to a problem. Apart from the cost of the time required to gather data and prepare the input data set, there is virtually no cost for using the microcomputer version.

LINK STATISTICS AT TIME 8 21 0

LINK	OCC.	VEH DIS	TURN MOVEMENT LEFT	THRU	RT.	QUEUE LENGTH BY LANE 1	2	3	4	5	DELAY/ VEH.	STOP DLY(P)	CYC FLR	EVNT	CURRENT CHANNELIZATION					AVG. SPEED	NO. STOP	SIG CODE
(801, 1)	0	65	0	64	0	0	0	0	0	0	.0	0	0	0	0	0	0	0	0	.0	0	1
(1, 3)	1	66	11	49	5	0	0	0	0	0	20.3	73	0	0	0	0	0	0	0	7.6	50	2
(3, 6)	11	66	39	21	12	0	0	0	0	1	35.3	80	3	0	0	0	0	0	0	7.6	57	4

CUMULATIVE STATISTICS SINCE BEGINNING OF SIMULATION
PRESENT TIME IS 8 30 0, ELAPSED SIMULATED TIME IS 15 MINUTES, 0 SECONDS
LINK STATISTICS

LINK	VEH-MILES	VEH TRP	MOV. TIME V-MIN	DELAY TIME V-MIN	M/T	TOTAL TIME V-MIN	T-TIME / VEH. SEC	T-TIME/ VEH-MILE SEC/MILE	D-TIME / VEH SEC	D-TIME/ VEH-MILE SEC/MILE	PCT STOP DELAY	AVG. SPEED MPH	AVG. OCC.	STOPS /VEH	AVG SAT PCT	CYCL FAIL
(1, 3)	9.1	161	18.6	47.2	.28	65.8	24.5	431.6	17.6	309.9	70	8.3	4.3	.71	11	0
(3, 6)	14.6	146	28.9	58.5	.33	87.4	35.8	358.4	24.0	239.9	70	10.0	5.9	.90	10	4
(6, 8)	3.8	62	7.7	4.3	.64	12.0	11.6	188.0	4.1	67.2	5	19.1	.8	.08	3	0

NETWORK STATISTICS

VEHICLE-MILES= 91.86   VEHICLE-MINUTES= 565.2   VEHICLE-TRIPS (EST.)= 531   STOPS/VEHICLE= 1.35
MOVING/TOTAL TRIP TIME= .361   AVG. SPEED (MPH)= 9.75   MEAN OCCUPANCY= 37.4 VEH.   AVG DELAY/VEHICLE= 40.80 SEC
TOTAL DELAY= 361.1 MIN.   DELAY/VEH-MILE= 3.93 MIN/V-MILE   TRAVEL TIME/VEH-MILE= 6.15 MIN/V-MILE
STOPPED DELAY AS A PERCENTAGE OF TOTAL DELAY=70.7

Figure 5. — Sample of output reports from simulator.

With the microcomputer version of Netsim, the program can be run whenever a microcomputer is available; there is no need to wait for access to a mainframe computer. This can mean substantial savings over renting time on a mainframe computer and makes it feasible to use Netsim with smaller simulation problems and with a larger number of alternative solutions. Also, the output is immediately available; it does not have to be returned from a remote computer center. In addition, the program can be easily modified and rerun.

Computer Requirements

The microcomputer version of Netsim, designed to run on IBM-PC compatible machines, runs under either PC-DOS or MS-DOS, version 2.0 or higher. It requires at least 335 K of memory, exclusive of memory needed for the operating system. Two floppy disk drives are recommended, although one will suffice for most problems. A hard disk drive provides additional flexibility and increases the speed slightly, particularly with certain options such as printing the origin-destination table or saving vehicle trajectory data.

Availability

The microcomputer version will be available later this year after final testing is completed and a user guide is prepared.[2] Availability will be announced in the UPBeat newsletter of the STEAM user group. Information concerning this microcomputer conversion can be obtained from Mr. James Clark, HTO-23, Office of Traffic Operations, Federal Highway Administration, Washington, DC 20590; telephone (202) 426-0411.

[2]S. Sibley, "Use of Netsim for Microcomputers," Office of Implementation, Federal Highway Administration, Washington, DC, January 1985. Not yet printed.

REFERENCES

(*1*) Charles R. Stockfisch, "The UTCS Experience," *Public Roads*, vol. 48, No. 1, June 1984, pp. 25-29.

(*2*) E. Lieberman and N. Rosenfield, "Traffic Network Analysis With Netsim—A User Guide," Report No. FHWA-IP-80-3, *Federal Highway Administration*, Washington, DC, January 1980.

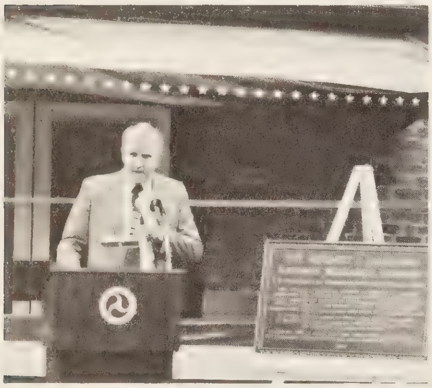
(*3*) E. Lieberman and N. Rosenfield, "Network Flow Simulation for Urban Traffic Control System—Phase II, Vol. 5, Field and Emissions Extension," Report No. FHWA-RD-77-45, *Federal Highway Administration*, Washington, DC, October 1977.

Scott W. Sibley is a highway engineer with Gannett Fleming Transportation Engineers in King of Prussia, PA, and a Master's Degree candidate at Villanova University. He performed the work described in this article under a Research Fellowship Grant from the Federal Highway Administration at the Turner-Fairbank Highway Research Center in McLean, VA.

The Herbert S. Fairbank building is part of the Turner-Fairbank Highway Research Center in McLean, VA.

Reopening of the Herbert S. Fairbank Building

On May 24, 1985, the Federal Highway Administration (FHWA) held an open house to mark the reopening of the Herbert S. Fairbank building at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, VA. The reopening followed 6 months of renovations to the Fairbank building, which is one of the two original buildings constructed at the highway research center in the 1940's.

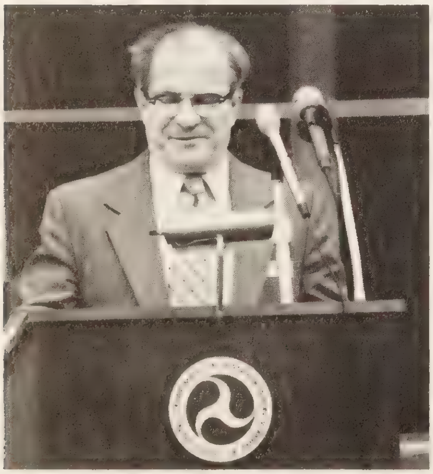


David K. Phillips, Associate Administrator for Research, Development, and Technology, welcomed guests to the ceremony.

David K. Phillips, Associate Administrator for Research, Development, and Technology (RD&T), welcomed the approximately 350 FHWA employees, retirees, and friends and representatives from highway associations and other Federal agencies.

Charles F. Scheffey, RD&T Science Advisor, discussed the history of the TFHRC and introduced Federal Highway Administrator R.A. Barnhart.

After brief remarks, Mr. Barnhart, with the aid of representatives from the Offices of RD&T, cut the ribbon at the entrance of the Fairbank building to officially commemorate the renovation.

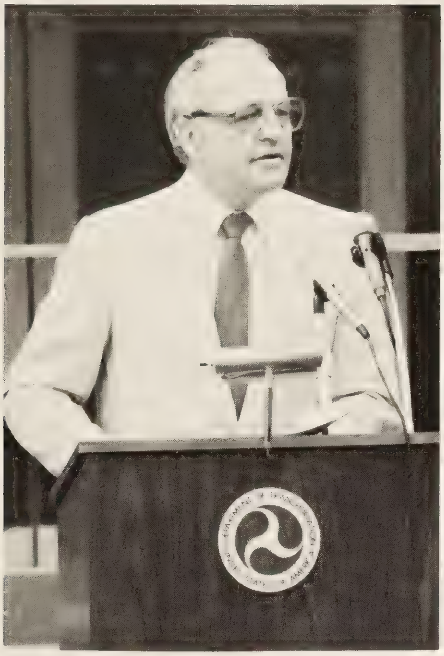


Charles F. Scheffey, RD&T Science Advisor, discussed the history of the Fairbank building.

As part of the day's festivities, Mr. Barnhart, Deputy Federal Highway Administrator L.P. Lamm, and FHWA Executive Director R.D. Morgan joined in a ceremonial groundbreaking for the Pavement Testing Facility to be constructed at TFHRC. The facility will include an accelerated load test facility and two test pavement sections.

Visitors viewed improvements to the Fairbank building and toured the laboratories, wind tunnel, highway driving simulator, demonstration projects exhibits, and U.S. Highway Technology Exhibit. Outdoor demonstrations by the Demonstration Projects Division included pavement striping, epoxy injections in concrete slabs, a portable flume, and a borehole camera. Also demonstrated was an impact test at the Federal Outdoor Impact Laboratory.

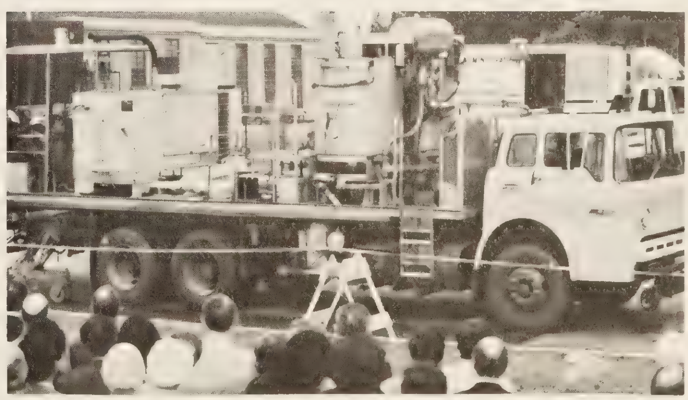
A ribbon-cutting ceremony marked the reopening of the Fairbank building.



Federal Highway Administrator R.A. Barnhart officiated at the reopening ceremony.

Mr. Barnhart, FHWA Executive Director R.D. Morgan, and Deputy Federal Highway Administrator L.P. Lamm participated in the groundbreaking for the Pavement Testing Facility to be constructed at the Turner-Fairbank Highway Research Center.

The U.S. Highway Technology Exhibit, on display at the Fairbank building, illustrates highway technology in colorful photographs, by microcomputer, and in a videotape.



Pavement striping was demonstrated at the highway research site.

Recent Research Reports You Should Know About

The following are brief descriptions of selected reports recently published by the Federal Highway Administration, Offices of Research, Development, and Technology (RD&T). The Office of Engineering and Highway Operations Research and Development (R&D) includes the Structures Division, Pavements Division, and Materials Division. The Office of Safety and Traffic Operations R&D includes the Traffic Systems Division, Safety Design Division, and Traffic Safety Research Division. The reports are available from the source noted at the end of each description.

Requests for items available from the RD&T Report Center should be addressed to:

Federal Highway Administration
RD&T Report Center, HRD-11
6300 Georgetown Pike
McLean, VA 22101-2296
Telephone: 703-285-2144

When ordering from the National Technical Information Service (NTIS), use PB number and/or the report number with the report title and address requests to:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

Pedestrian Signalization Alternatives, Final Report, Report No. FHWA/RD-83/102

by Safety Design Division

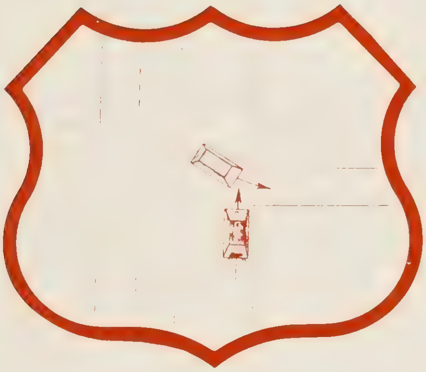
Pedestrian accidents, traffic and pedestrian volumes, geometrics, and signal data for approximately 1,300 signalized intersections in 15 U.S. cities were analyzed to determine the safety and operational effects of various pedestrian signals and signal timing. The presence of standard-timed pedestrian WALK/DON'T WALK signals did not significantly affect pedestrian accidents. However, scramble (or exclusive) pedestrian timing was associated with significantly lower pedestrian accidents. Current warrants for traffic signals based on pedestrian volumes were evaluated, and an improved warrant was developed and is recommended for adoption.

Several new sign and signal alternatives were developed and field tested to indicate the clearance interval and to warn of pedestrian-vehicle conflicts. Alternatives recommended for inclusion in the Manual on Uniform Traffic Control Devices for use at high-hazard pedestrian intersections include the WALK WITH CARE signal, a YIELD TO PEDESTRIANS WHEN TURNING regulatory sign, a PEDESTRIANS WATCH FOR TURNING VEHICLES warning sign, and a verbal and symbol pedestrian signal explanation sign. A three-phase pedestrian signal using DON'T START to indicate the clearance interval was recommended for additional testing.

Limited copies of the report are available from the RD&T Report Center.

Relationships Between Traffic Conflicts and Accidents, Vols. 1-3, Report Nos. FHWA/RD-84/041-043

by Safety Design Division



These reports analyze the relationships between traffic conflicts and accidents as well as expected and abnormal conflict rates for various intersection situations. Accidents/conflict ratios were statistically determined for several kinds of collisions for each of four kinds of intersections—signalized high volume, signalized medium volume, unsignalized medium volume, and unsignalized low volume. These ratios can be applied to comparable intersections to obtain an expected accident rate of a specific type after the appropriate conflict data are collected. Also, statistical procedures were developed to determine conflict rate values that could be considered abnormally high.

Volume 1, **Executive Summary**, highlights the research results and conclusions. Volume 2, **Final Technical Report,** provides research details, data, and an analysis of results. Volume 3, **Appendixes**, contains raw data summaries.

Limited copies of the reports are available from the RD&T Report Center.

Fingerprinting Versus Field Performance of Paving Grade Asphalts, Report No. FHWA/RD-84/095

by Materials Division

This report discusses a study to determine whether there have been significant changes in the properties of asphalt cement in recent years, especially since the 1973 oil embargo. Nearly 300 asphalt samples were tested and compared with the FHWA fingerprint file and other recently published data. Results indicate that the temperature susceptibility of asphalt cements has increased in recent years. Also, mixtures identified as tender could not be related to any single asphalt cement property.

Although heat of immersion tests may identify asphalts that do not set properly and therefore are susceptible to tenderness, more research is needed to verify this. Finally, current specification test methods cannot adequately predict the field performance of asphalt cement. Because mixture design and construction quality control play a major role in determining the performance of asphalt cement, the performance of the asphalt should be evaluated as part of the overall performance of the mixture.

Limited copies of the report are available from the RD&T Report Center.

The Behavior of Piles and Pile Groups in Cohesionless Soils, Report No. FHWA/RD-83/038

by Materials Division

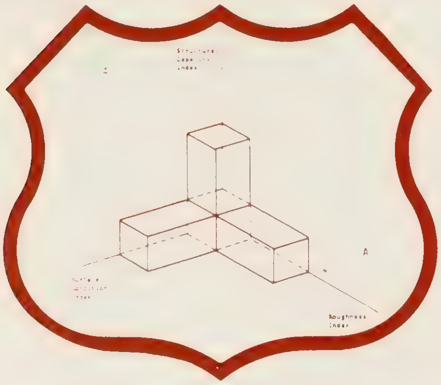
This report describes the results of an indepth literature review to collect data on instrumented piles driven in sand and tested under vertical loads. The load transfer characteristics of the piles were analyzed without considering residual stresses. The results of this analysis then were correlated with available soil data to obtain a predictive pile capacity method that considers residual driving stresses. Results of this method as well as conventional and new in situ test methods then were compared to actual load test results. Field load tests on piles in cohesionless soils will be conducted in a follow-on study to investigate the new design method and residual stress theory.

The report should be of interest to geotechnical and foundation engineers concerned with load transfer characteristics of pile foundations for highway structures in cohesionless soils.

Limited copies of the report are available from the RD&T Report Center.

Pavement Performance Model Development, Vols. I-IV, Report Nos. FHWA/RD-84/103-106

by Pavements Division



A computer program was developed to compute indices of pavement performance for pavement management systems. Inputs to the computer program include deflection, distress, roughness, and pavement description data. Indices computed for surface condition, structural capacity, and serviceability may be combined into a pavement condition statistic with probability and matrix evaluation. Traffic volumes, highway class, and the statistic define an overall highway condition rating function.

The **Executive Summary**, Report No. FHWA/RD-84/103, briefly reviews the research. The **Final Model Development**, Report No. FHWA/RD-84/104, and the **Program Documentation Manual**, Report No. FHWA/RD-84/105, provide detailed information on the computer program. The **Roughness Measurement and Calibration Guidelines**, Report No. FHWA/RD-84/106, selects a statistic for generalized roughness index and presents a procedure that can be used to calibrate roughness measurements in the long-term monitoring program.

The reports may be purchased from NTIS.

Corrosion Susceptibility of Internally Reinforced Soil Retaining Structures, Report No. FHWA/RD-83/105

by Structures Division

This report assesses the state-of-knowledge of metal corrosion in reinforced soil retaining walls. Four Reinforced Earth Walls with concrete facings were studied to determine

corrosion susceptibility. These four structures were between 6 and 11 years old and were exposed to severe environments such as high chloride and pH. It was found that two of the four structures may have corrosion problems that could reduce their design life. One of these structures is in a marine environment and uses aluminum alloy strips. The other structure has backfill material with low resistivity and high pH value that surrounds the galvanized steel strips.

Additional field studies are needed to assess the magnitude of the problems, and further research is needed to determine the safe limits of the reinforced earth concept.

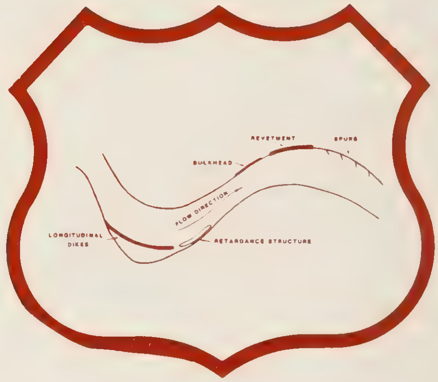
The report may be purchased from NTIS.

Streambank Stabilization Measures for Highway Stream Crossings, Executive Summary, Report No. FHWA/RD-84/099; Streambank Stabilization Measures for Highway Engineers, Report No. FHWA/RD-84/100; and Design of Spur-Type Streambank Stabilization Structures, Report No. FHWA/RD-84/101

by Structures Division

These reports discuss the findings of a research study on the application and usefulness of spurs, groins, and other countermeasures for streambank stabilization in the vicinity of highway stream crossings. Report No. FHWA/RD-84/099 summarizes the findings discussed in the other two reports.

Report No. FHWA/RD-84/100 discusses erosion processes in channel bends and methods of controlling this erosion, identifies useful flow control and streambank stabilization structures, and provides guidelines for selecting an appropriate flow control or streambank stabilization countermeasure for a particular field design condition. Some design information for specific countermeasures also is included.



Report No. FHWA/RD-84/101 details the applicability and design of spur-type flow control and streambank stabilization structures. Design guidelines for establishing spur permeability; the required extent of protection; spur length, spacing, orientation, height, and crest profile; and the shape of the spur tip or head are presented. An example is given for a recommended procedure for establishing the geometric layout of spurs within a spur scheme.

Limited copies of the reports are available from the RD&T Report Center.

New Research in Progress

The following new research studies reported by FHWA's Offices of Research, Development, and Technology are sponsored in whole or in part with Federal highway funds. For further details on a particular study, please note the kind of study at the end of each description and contact the following: Staff and administrative contract research—*Public Roads* magazine; Highway Planning and Research (HP&R)—performing State highway or transportation department; National Cooperative Highway Research Program (NCHRP)—Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, NW., Washington, DC 20418.

FCP Category 1—Highway Design and Operation for Safety

FCP Project 1P: Night Visibility

Title: Develop and Evaluate Traveling Photometer. (FCP No. 41P3193)

Objective: Design and build a photometer that can be used at highway speeds to measure the reflectivity of raised reflective pavement markers and reflective lane lines. Develop an algorithm for translating photometer data into an evaluation of the adequacy of lane line delineation. Construct and program an onboard data acquisition system for evaluating and recording lane line adequacy and location information for input to a pavement marking management system.
Performing Organization: California Department of Transportation, Sacramento, CA 95807
Expected Completion Date: June 1986
Estimated Cost: $60,000 (HP&R)

FCP Project 1T: Roadside Safety Hardware

Title: Vehicle Downsizing and Roadside Safety Hardware. (FCP No. 51T2982)

Objective: Assess the performance of selected existing highway safety appurtenances and roadside features with passenger vehicles below 1,800 lb (0.82 Mg). Project the limits of vehicle characteristics that can be accommodated safely through improvements in current hardware and roadside features.
Performing Organization: Texas A&M Research Foundation, College Station, TX 77842
Expected Completion Date: October 1987
Estimated Cost: $150,000 (NCHRP)

FCP Category 2—Traffic Control and Management

FCP Project 2L: Electronic Devices for Traffic Control

Title: Lightning-Protection Hardware and Techniques for Electronic Traffic Control Equipment. (FCP No. 32L1232)
Objective: Evaluate existing standards and guidelines for lightning and electrical transient protection of electronic devices, including grounding and bonding of power systems and appurtenant structures (lightning rods, ground rods, and shielding) and transient and surge protection of power and signal system lines (fuses, filters, varistors, and gas discharge devices). Identify the standard practice for applying each protective device, balancing initial hardware and installation costs against the probability of equipment damage, malfunction, and repair cost.
Performing Organization: Peer Consultants, Inc., Rockville, MD 20852
Expected Completion Date: February 1986
Estimated Cost: $48,470 (FHWA Administrative Contract)

FCP Project 2Q: Urban Network Control

Title: Enhancement of the Value Iteration Program for Actuated Signals. (FCP No. 42Q1222)
Objective: Extend the VIPAS program to include additional left turn geometrics. Collect field data to calibrate, validate, and test VIPAS. Reprogram to increase the modularization of some current subroutines.
Performing Organization: University of Pittsburgh, Pittsburgh, PA 15260
Funding Agency: Pennsylvania Department of Transportation
Expected Completion Date: August 1986
Estimated Cost: $174,985 (HP&R)

Title: Graphic Displays for the Integrated Traffic Data System (ITDS). (FCP No. 32Q2322)
Objective: Develop and integrate graphics software to the data base portion of ITDS to ease the task of loading and maintaining the data base. Develop query software to allow for the generation of reports based on the information stored on the data base.
Performing Organization: Oak Ridge National Laboratory, Oak Ridge, TN 37831
Expected Completion Date: April 1987
Estimated Cost: $94,000 (FHWA Administrative Contract)

FCP Project 2Z: Implementation of Traffic Control R&D

Title: Integrated Traffic Data System (ITDS) Maintenance and Support. (FCP No. 32ZQ108)
Objective: Develop a microcomputer data base system for traffic engineering data. Use data to execute mainframe programs such as SIGOP-III, TRANSYT-7F, and NETSIM without coding input data for each program. Make the ITDS more user friendly and provide assistance to users on all aspects of the software.
Performing Organization: Oak Ridge National Laboratory, Oak Ridge, TN 37831
Expected Completion Date: April 1987
Estimated Cost: $50,000 (FHWA Administrative Contract)

FCP Category 4—Pavement Design, Construction, and Management

FCP Project 4A: Pavement Management Strategies

Title: Improved Prediction of Equivalent Axle Loads. (FCP No. 34A1022)
Objective: Develop procedures to forecast the total number of equivalent axle loads over the design period in various load groups. Investigate how truck volumes and vehicle miles (kilometers) of travel have varied with economic output and how axle load distribution has changed with legislative changes.
Performing Organization: Texas A&M Research Foundation, College Station, TX 77843
Expected Completion Date: December 1986
Estimated Cost: $121,320 (FHWA Administrative Contract)

FCP Project 4C: Design and Rehabilitation of Flexible Pavements

Title: Layer Coefficients in Terms of Performance and Mixture Characteristics. (FCP No. 44C2074)
Objective: Conduct a literature review and determine data requirements. Collect and analyze both field and laboratory data. Determine layer equivalencies for different asphalt concrete mixtures, and model pavement performance to evaluate the effects of seasonal and climatic factors.
Performing Organization: Purdue University, West Lafayette, IN 47907
Funding Agency: Indiana Department of Highways
Expected Completion Date: April 1988
Estimated Cost: $7,540 (HP&R)

FCP Project 4E: Construction Control and Management

Title: Methodology for Cost Comparison Between Department and Contractor Performance for Various Department Operations. (FCP No. 44E3096)
Objective: Develop methodology and a model for comparing costs of contracting for services with costs for using Pennsylvania Department of Transportation staff. Examine maintenance, bridge and highway design, and inspection of bridge and highway construction services.
Performing Organization: Deloitte Haskins and Sells, Philadelphia, PA 19102
Funding Agency: Pennsylvania Department of Transportation
Expected Completion Date: April 1986
Estimated Cost: $25,000 (HP&R)

FCP Category 5—Structural Design and Hydraulics

FCP Project 5A: Bridge Loading and Design Criteria

Title: Prestressed Concrete Intermixed With Steel Beams for Bridge Widening. (FCP No. 45A3242)
Objective: Determine if practical problems related to behavior and long-term performance are caused by the combinations and intermixture of prestressed concrete beams and steel beams in the same span. Identify these problems and recommend concrete slab design and live load distribution to longitudinal beams with respect to mixed girder support systems.
Performing Organization: Tulane University, New Orleans, LA 70118
Funding Agency: Louisiana Department of Transportation and Development
Expected Completion Date: February 1986
Estimated Cost: $74,060 (HP&R)

Title: Redundancy of Welded Steel I-Girder Bridges. (FCP No. 45A4052)
Objective: Develop and implement a framework to facilitate decisions regarding the realistic adequacy of welded steel I-girder bridges to resist catastrophic failure from the fracture of a critical member. Use computer modeling to develop meaningful quantitative comparisons of potential collapse mechanisms.
Performing Organization: Lehigh University, Bethlehem, PA 18015
Funding Agency: Pennsylvania Department of Transportation
Expected Completion Date: December 1986
Estimated Cost: $149,930 (HP&R)

FCP Project 5H: Highway Drainage and Flood Protection

Title: Channel Widening Process and Long-Term Channel Geometry in Adjusting Streams in West Tennessee. (FCP No. 45H1392)
Objective: Perform extensive channel modifications, and collect information along newly dredged reaches to establish the magnitude and extent of the modifications, test the ability of a quantitative model, and predict resultant channel responses and instability. Obtain bed and bank material samples and data on channel geometry and vegetation at all sites.
Performing Organization: U.S. Geological Survey, Nashville, TN 37203
Funding Agency: Tennessee Department of Transportation
Expected Completion Date: September 1987
Estimated Cost: $100,000 (HP&R)

Title: Design of Depressed Invert Culverts. (FCP No. 45H3182)
Objective: Review current guidelines for designing a culvert with a depressed inlet to enhance fish passage.
Performing Organization: University of Alaska, Fairbanks, AK 99701
Funding Agency: Alaska Department of Transportation and Public Facilities
Expected Completion Date: September 1986
Estimated Cost: $8,770 (HP&R)

Title: Hydrologic Criteria for Fish Passage With Regard to Southeast Alaska. (FCP No. 45H3802)
Objective: Develop small streamflow relationships between frequency, magnitude (high or low), duration, and season. Include orographic, maritime, and elevation influences from analysis of existing data from certain watersheds in southeast Alaska.
Performing Organization: University of Alaska, Fairbanks, AK 99701
Funding Agency: Alaska Department of Transportation and Public Facilities
Expected Completion Date: September 1986
Estimated Cost: $10,180 (HP&R)

FCP Project 5Q: Bridge Maintenance and Corrosion Protection

Title: Effectiveness of Concrete Bridge Deck Asphalt Membrane Protection. (FCP No. 45Q2612)
Objective: Evaluate further through field testing the performance of waterproofing membrane systems in service in the State of Washington. Select sites that had satisfied existing criteria regarding the application of membrane systems at the time of waterproofing.
Performing Organization: Washington State Transportation Center, Seattle, WA 98195
Expected Completion Date: February 1986
Estimated Cost: $37,000 (HP&R)

FCP Category 9—R&D Management and Coordination

FCP Project 9C: Highway Safety Programs Support

Title: Highway Simulator (HYSIM) Maintenance and Support. (FCP No. 39C3122)
Objective: Maintain HYSIM hardware and software, and modify hardware and/or software to meet requirements of specific experiments. Assist in testing subjects in HYSIM studies, calibrate and operate simulator during experimentation, and assist in data reduction. Incorporate general-purpose hardware/software into HYSIM to enhance research capability.
Performing Organization: ENSCO, Inc., Springfield, VA 22151
Expected Completion Date: April 1986
Estimated Cost: $159,800 (FHWA Administrative Contract)

U.S. Government Printing Office: 1985—461-830/10005

RD&T Outstanding Technical Accomplishment Award Presented

Dr. Samuel C. Tignor was the recipient of the 1985 award in the annual outstanding technical achievement competition held among the employees of the Federal Highway Administration's (FHWA) Offices of Research, Development, and Technology. The award covers the documentation of any technical accomplishment, which may be a publication, technical paper, report, film, or package; an innovative engineering concept; an instrumentation system; test procedure; new specification; mathematical model; or unique computer program. Each eligible candidate is judged on excellence, creativity, and contribution to the highway community, general public, and FHWA.

Dr. Tignor, Chief of the Traffic Safety Research Division, Office of Safety and Traffic Operations Research and Development, received the award for his film "Traffic Management for Freeway Incidents." This 17-minute film promotes the rapid removal of freeway incidents (for example, spilled loads or disabled vehicles) and describes low-cost solutions that highway, police, fire, and other local agencies can use to improve traffic management, safety, and control at incident sites. Traffic management approaches for both simple and complex incidents are illustrated in the 16 mm film. Footage is incorporated from several major metropolitan areas in the United States. Currently, the film is being used in a National Highway Institute training course.

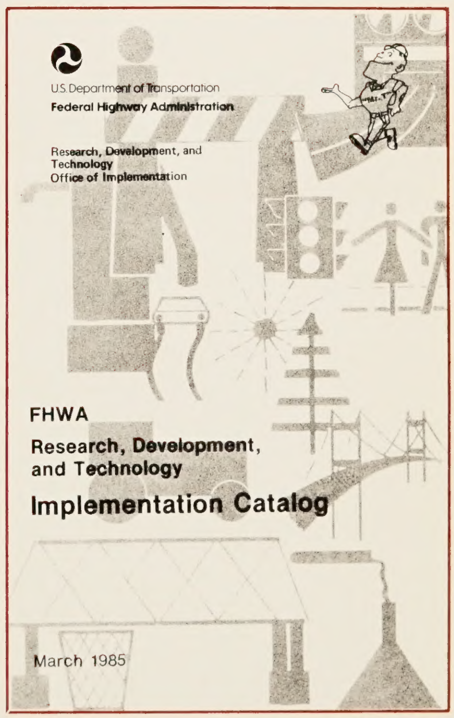
FHWA Research, Development, and Technology Implementation Catalog

by Office of Implementation

This catalog, which is revised periodically, lists selected publications, visual aids, computer programs, and training materials that are available as part of the FHWA Implementation Program. Items are listed alphabetically under program areas. Subtitles and series are shown separately under the main item heading. Indexes at the back of the catalog are arranged alphabetically, by program area, and by report number.

Items in the catalog are available directly from the source indicated under the "Availability" heading in each listing. Some items are available without charge to qualified individuals and agencies; others are available on a loan basis only.

Copies of the catalog are available from the Federal Highway Administration, RD&T Report Center, HRD-11, 6300 Georgetown Pike, McLean, VA 22101-2296; telephone (703) 285-2144.



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