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COVER: An ongoing project at West Virginia University is evaluating a major natural brine deicing program. The Connecticut high-pressure sprayer was used in Phase I of the research, which is discussed in the first article.

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The Use of Oil and Gas Field Brines as Highway Deicing Agents[1]

by

Ronald W. Eck and William A. Sack

Introduction

Because of environmental problems and tight operating budgets, highway agencies are seeking ways to minimize the use of the traditional deicing chemicals—sodium and calcium chlorides. A variety of approaches has been proposed (*1-3*)[2], including using naturally occurring salt brines—a waste product of oil and gas production. As a liquid, brine has the advantages of being fast-acting, and it does not blow or bounce off of the roadway.

Using natural brine for deicing could solve several problems simultaneously. The oil and gas industry could dispose of an unwanted byproduct, and highway agencies could acquire a deicing material at minimal cost. Furthermore, the natural brine would be applied at controlled rates rather than be unlawfully discharged directly into the ground or into surface waters (resulting in contamination) as is frequently done now in some areas. Using the brine for deicing would eliminate the need to import thousands of tons of rock salt into a State or region each year and would reduce the amount of salt in the environment.

[1]This article is adapted from "Determining the Feasibility of West Virginia Oil and Gas Field Brines as Highway Deicing Agents," Phase I, final report, West Virginia Department of Highways, Research Project 68, *Department of Civil Engineering, West Virginia University*, Morgantown, WV, January 1984.

[2]Italic numbers in parentheses identify references on page 81.

An ongoing project at West Virginia University is evaluating a major natural brine deicing program by researching the following issues:

- Brine quality from the major producing formations (including both the major salts and the minor and trace constituents).
- Comparison of brines with commercial deicing agents relative to melting, skid resistance, and refreezing of roadway surfaces.
- Corrosion of metals and concrete and bituminous pavement deterioration characteristics.
- Quantity of brine available for highway deicing in a given geographical area.
- Estimates of transportation and storage costs.

This article discusses laboratory and field studies addressing the first three issues listed above; the remaining issues are beyond the scope of this article.

Laboratory Evaluation

Brine characteristics

Forty-nine samples of natural brine were collected over a 17-month period in Phase I of the project. The oil and gas industry was extremely supportive of the work—five companies provided brine samples and/or quantities of brine. Samples were obtained from 13 different counties and 12 separate West Virginia oil and gas fields. Brines were collected from 8 different geological formations, which included more than 12 different oil and gas zones. The depths of wells from which samples were taken ranged from 1,980 to 11,380 ft (603 to 3 469 m). In all cases, the brines were collected from above-ground steel storage tanks located at the wellhead. Some of the wells were sampled repeatedly during the project to observe possible changes in brine quality with time.

To analyze the composition of the 49 brines collected, 20 different kinds of tests were performed, although not all of the tests were carried out for each sample because of time and resource constraints. The constituents determined were divided into four main groups: General parameters—total dissolved solids (TDS's), conductivity, density, pH, and acidity; major constituents—chloride, sodium, calcium, magnesium, and potassium; minor constituents—iron, sulfate, barium, ammonia, and total organic carbon (TOC); and trace constituents—cadmium, chromium, arsenic, lead, and zinc.

The range and mean value for each test parameter are given in table 1. Although mean values are presented in each case, the mean concentration is not very meaningful for parameters such as barium where variations in barium levels between brines from different formations are very large. Table 1 also presents a range of values reported for brines in West Virginia, Pennsylvania, and Ohio. *(4-6)* The range given is not meant to be comprehensive, but represents a sampling of brines with TDS's greater than 80 000 mg/L (0.66 lb/gal) that were judged to be typical of brines produced in the three States.

General parameters and major constituents—The TDS's of the samples collected range from 90 420 to 323 700 mg/L (0.75 to 2.70 lb/gal), with a mean value of 218 600 mg/L (1.82 lb/gal). Brine strength generally increased with depth. The mean calcium concentration was over 31 000 mg/L (0.26 lb/gal). This is significant because the presence of calcium salts allows the use of deicing agents at lower temperatures than is feasible with sodium salts alone.

Minor and trace constituents—Iron ranged from 28 to 750 mg/L (0.00023 to 0.0062 lb/gal), with a mean value of 276 mg/L (0.0023 lb/gal). Sulfate levels, which varied from less than 5 to 547 mg/L (mean of 163 mg/L) (0.000041 to 0.0045 lb/gal [mean of 0.0014 lb/gal]), are of interest with respect to attack of concrete. Sulfate levels of 150 mg/L (0.0012 lb/gal) or less would result in negligible attack on concrete, levels of 150 to 1 500 mg/L (0.0012 to 0.012 lb/gal) would result in a positive degree of attack, and levels above 1 500 mg/L (0.012 lb/gal) would result in a severe degree of attack. *(7)* Also to be considered is that brine applied to the roadway would be diluted by snow or ice almost immediately and would run off as melting occurred. It is conceivable that a heavy application rate of brine containing high sulfate levels could result in sulfate attack if there was limited snow and ice meltwater for dilution. However, under most field situations, the sulfate levels in West Virginia brines would not be expected to contribute significantly to concrete deterioration. The materials testing work, reported later in this article, supports this conclusion.

Barium levels varied widely among the brine samples, ranging from 1.3 to 2 500 mg/L (0.000011 to 0.021 lb/gal). Barium levels greater than 100 mg/L (0.00083 lb/gal) occurred in 22 of the 48 samples analyzed for barium. However, almost all of the high barium samples were taken from two particular geological formations in one field.

Ammonia and TOC levels also were examined for a limited number of samples. The level of ammonia ranged from 11 to 386 mg/L (0.000091 to 0.0032 lb/gal), while TOC varied from 6 to 45 mg/L (0.000050 to 0.00037 lb/gal). These levels are not likely to pose environmental problems when using brine for deicing because of the relatively small quantities of brine used in comparison with the quantity of meltwater runoff.

Table 1.—Project brine concentration compared with reported values

Constituent	Range—Project Brines	Mean—Project Brines	Reported Range (4-6) WV, OH, PA
TDS (mg/L)	90,420-323,700	218,600	80,000-373,000
Conductivity (micromhos/cm)	200,000-605,000	413,800	140,000-598,000
Density (lb/gal)	9.191-10.129	9.774	8.985-10.235
pH	2.72-6.14	NA	4.4-6.5
Acidity (mg/L)	80-227	144	2-560
Cl (mg/L)	57,510-192,420	128,600	52,500-190,840
Na (mg/L)	29,130-82,240	52,740	37,150-75,000
Ca (mg/L)	5,470-57,900	31,310	8,790-49,000
Mg (mg/L)	645-4,950	3,200	1,900-10,000
K (mg/L)	30-3,310	590	122-8,200
Fe (mg/L)	28-750	276	2-560
SO_4 (mg/L)	<5-547	163	0-1,100
Ba (mg/L)	1.3-2,500	545	0-1,150
NH_3-N (mg/L)	11-386	51	7-450
TOC (mg/L)	6-45	29	NA
Cd (mg/L)	<.01-1.627	.365	<.1-6.0
Cr (mg/L)	<.06	<.06	<.1-.7
As (mg/L)	.138-.457	.263	NA
Pb (mg/L)	1.583-6.100	3.360	<.1-6.0
Zn (mg/L)	.212-1.739	.619	0-13

1 mg/L = 8.345×10^{-6} lb/gal
1 micromhos/cm = 0.398 micromhos/in
1 lb/gal = 119 826 mg/L

The values for the five trace constituents analyzed—cadmium, chromium, arsenic, lead, and zinc—are generally in the ranges reported for the three States. Each of these trace constituents, except zinc, has a maximum limit based on toxicity under the Resource Conservation and Recovery Act (RCRA) of 1976. Barium also is limited by RCRA. It is important to note that production brines are excluded from regulation under RCRA and are compared with RCRA-regulated wastes simply to gain a perspective on the trace constituent levels. RCRA limits are as follows: arsenic-5 mg/L (0.000041 lb/gal); barium-100 mg/L (0.00083 lb/gal); cadmium-1 mg/L (0.0000083 lb/gal); chromium-5 mg/L (0.000041 lb/gal); and lead-5 mg/L (0.000041 lb/gal). Comparing RCRA limits with values obtained for the 49 project brines in table 1 suggests that barium is the only constituent of concern. The elevated cadmium and lead values were found in only 2 of the 49 brines and were only slightly higher than the RCRA allowable levels. As noted earlier, most of the samples with high barium levels originated from one oil and gas field. Brines from formations with unacceptably high trace element levels must either be pretreated to reduce the element before highway application or be rejected.

All brine sources most likely would be analyzed for a variety of major and trace elements before being approved for application. The frequency of subsequent testing of a given source would depend on the requirements of the particular State or agencies involved. In this project, the brines sampled from a given source were relatively constant in quality over the 17-month period. Hence, re-testing certain key parameters from the source every 2 years would be adequate. Costs of brine analysis would have to be included as part of the cost of the brine application program. However, the oil and gas companies would likely bear a substantial portion of the brine analysis costs.

Brine variability

One of the objectives of the brine sampling program was to evaluate variability in quality from different formations and zones as well as changes in brine quality over the 17-month sampling period for a given formation. The change in brine quality between locations for a given formation or zone also was evaluated.

Nine different sample groups, based on the number of formations, zones, counties, or wells from which the samples were taken, were made to evaluate variability. For each group, an average percent coefficient of variation (standard deviation divided by the mean) was determined for eight sample parameters—TDS, chloride, sodium, calcium, magnesium, arsenic, lead, and zinc. As would be expected, the lowest variation was observed for samples taken from single wells. The single-well samples had an average percent coefficient of variation of 6.6 for the eight sample parameters. Samples taken from single wells over a 13-month period showed no trend in increasing or decreasing concentration with time. Brine variability increased (for the same formations) as samples were taken from greater distances and from a greater number of zones. For example, the largest formation group variability (24.8 percent coefficient of variation) occurred for a group that contained samples from six counties and three zones.

As would be expected, the largest variation in brine quality was between different formations. For example, brines sampled from a deep lying formation were almost twice as strong as those from more shallow formations.

Comparison of constituents in dry deicing agents and brines

It would be expected that the dry agents—sodium and calcium chlorides—used for deicing or road stabilization also would contain a variety of minor and trace constituents. Seven dry agents were analyzed for six minor and trace substances as shown in table 2. The sodium and calcium chloride samples randomly were collected over a 2-year period from the West Virginia Department of Highways, the West Virginia University physical plant, and the City of Morgantown. Also shown in table 2 are results adapted from an analysis of dry sodium chloride used in Pennsylvania. (*4*) The brine group values presented are average values for each constituent.

Examination of the data shows that the dry agents as well as the brines contain a variety of trace constituents. The brines are generally higher in iron, zinc, and barium, while the dry agents are higher in chromium and cadmium. The dry calcium chloride samples also had elevated lead levels when compared with the brines.

Table 2.—Comparison of constituents in dry deicing agents and brines (mg/kg TDS)

Agent	Constituent					
	Chromium	Lead	Iron	Cadmium	Zinc	Barium
			Dry Salts			
NaCl-WVDOH[1]-1982	2.4	5.8	9.1	8.3	.7	–
NaCl-Mgtn[2]-1982	1.9	5.4	10.6	8.9	.6	–
NaCl-Mgtn-1983	–	–	–	10.4	–	132
NaCl-WVDOH-1983	–	–	–	9.1	–	96
NaCl-WVU-PP[3]-1982	2.7	6.2	17.3	6.1	.3	–
$CaCl_2$-WVDOH-1982	6.2	53.9	24.4	16.6	2.0	–
$CaCl_2$-WVU-PP-1982	8.5	46.0	27.6	18.4	2.3	–
NaCl-Penn	.7	8.8	12.3	1.7	.8	.1
			Brines			
Group 1A	<.2	14.6	1350	1.1	3.4	4838
Group 2A	<.3	17.3	1122	2.5	3.0	454
Group 2C	<.2	18.7	783	4.8	3.2	21.7
Group 2D	<.3	12.2	315	<.05	2.9	50.8
Group 3B	<.3	14.4	631	2.5	2.0	65.5

[1]West Virginia Department of Highways.
[2]Morgantown.
[3]West Virginia University physical plant.
1 mg/kg = 8.345×10^{-6} lb/gal

Surface degradation

Because brines contain a larger number of constituents than do traditional deicing agents, the well-known detrimental effects of sodium and calcium chlorides on highway materials cannot be assumed to apply to natural brines. The effects of brines on two paving materials—bituminous concrete and portland cement concrete—were assessed in the laboratory. These materials were subjected to distilled water, a 100 000-mg/L (0.83-lb/gal) TDS solution of sodium and calcium chloride (50:1 ratio of sodium to calcium), and a 100 000-mg/L (0.83-lb/gal) TDS solution of natural brine diluted with distilled water.

A bituminous concrete mixture representative of those used in pavement surfaces in West Virginia was used to prepare 50 standard Marshall specimens. Specimens were divided into the three treatment groups noted above, with each group having three subgroups (exposure to 10, 50, and 100 freeze-thaw cycles), plus a control group for a total of 10 groups. Each group consisted of five replicate specimens to provide statistical reproducibility.

Figure 1 shows that the specimens exposed to distilled water experienced a reduction in Marshall stability, while all but one of the salt solutions showed higher stabilities than the control value. Results of t-tests performed on the data indicated that there were no statistically significant changes in Marshall stability between specimens subjected to rock salt and those subjected to natural brine. In addition, results suggested that saline solutions will not significantly change the Marshall stability of bituminous concrete. These results are consistent with previous research. (*8*)

A surface degradation test to evaluate concrete performance was conducted on specimens prepared from a portland cement mix typical of that used for highway pavements in West Virginia. The surface degradation test specimens were divided into five groups. For each group, five specimens were fabricated. Two different procedures (freeze-thaw and wet-dry) were selected to simulate the field conditions existing when deicing chemicals are applied. The wet-dry test was conducted at constant rather than varying temperatures. ASTM Method C 672, "Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Salts," was followed. (*9*)

Figure 2 shows the mean effect of each of the three solutions on the scaling resistance of portland cement concrete subjected to freezing and thawing. Specimens covered with distilled water showed no change in surface condition; the 0- to 5-scale visual rating of the surface remained at 0 (no scaling) for all five specimens during the entire 100-cycle study period.

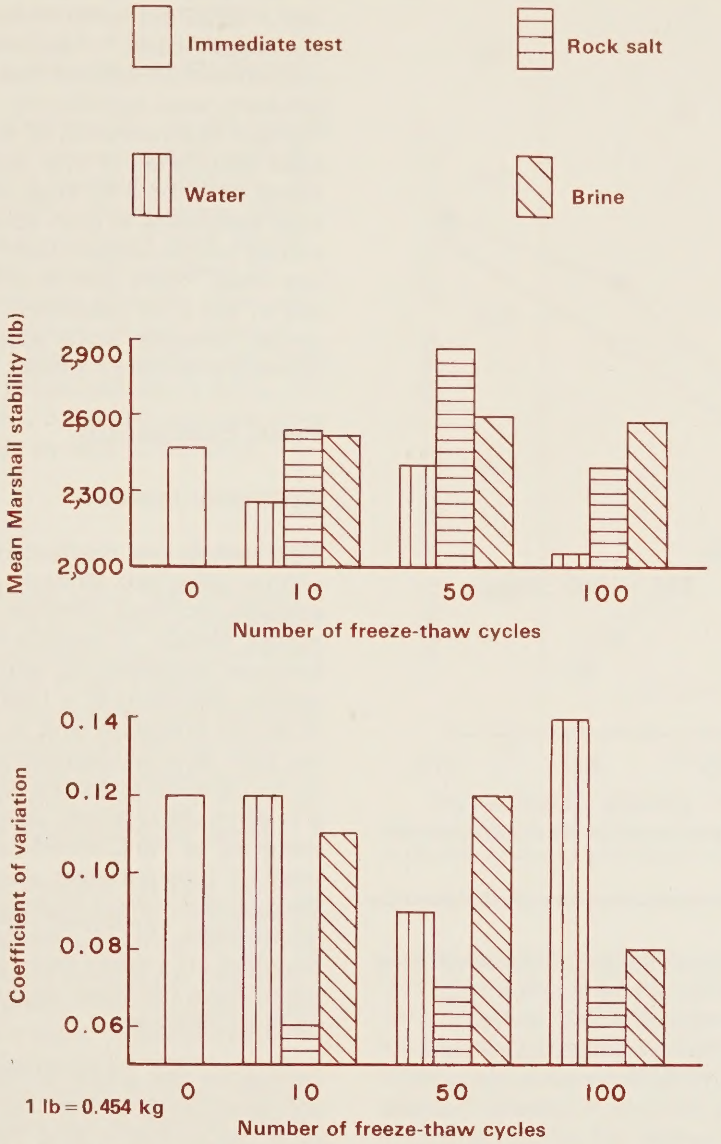

Figure 1.—Marshall stability test results for bituminous concrete specimens subjected to freeze-thaw cycles of water, rock salt solution, and natural brine.

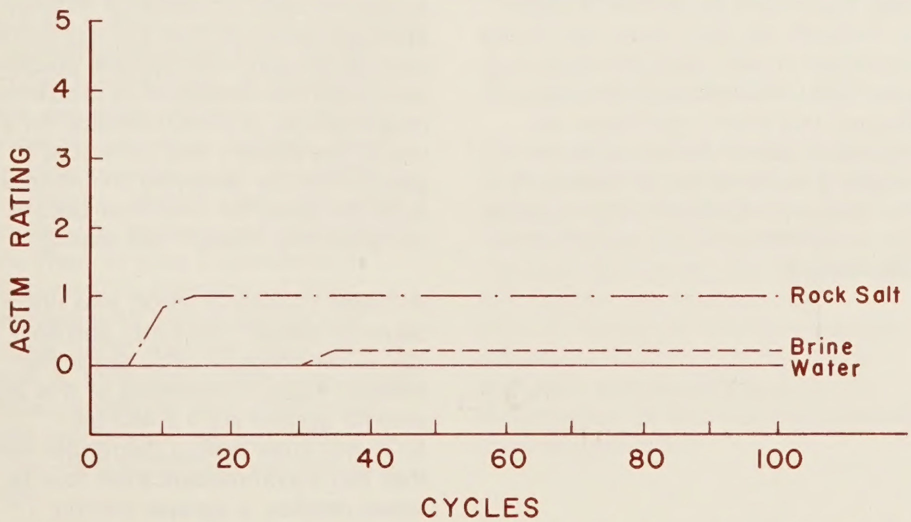

Figure 2.—Effect of deicer solutions on surface scaling of concrete specimens subjected to freeze-thaw cycles. Values shown are means of five specimens.

Concrete specimens subjected to the sodium and calcium chloride solution showed the earliest scaling. Specimens subjected to natural brine solution scaled later and showed less scaling than did those subjected to the sodium and calcium chloride solution. Thus, natural brine appears to be no more detrimental to portland cement concrete pavement surfaces than are traditional deicing agents.

Specimen groups that underwent wet-dry cycles were rated using the same scheme as for the freeze-thaw tests. Neither the specimens subjected to brine nor those exposed to the sodium and calcium chloride solution showed any scaling through the 100 cycles.

Steel corrosion

A wet-dry immersion test in which metal specimens were alternately immersed and removed from salt solutions was used as an accelerated corrosion test. Corrosion was measured by weight loss. Two kinds of steel were tested—A-36 steel was chosen to represent the steel used in highway construction and SAE-1010 steel was selected to represent that used in automobile bodies. The experimental procedure essentially followed ASTM Method G 31, "Laboratory Immersion Corrosion Testing of Metals." (*10*) Each group of specimens was photographed as it was removed from the test solution, and the surface condition of each specimen was visually evaluated. Each specimen then was cleaned and weighed.

Weight loss data for the automobile body steel specimens are shown in figure 3. As expected, the curves become asymptotic. Specimens immersed in the sodium and calcium chloride solution lost slightly more weight than those immersed in natural brine (4 percent difference after 100 cycles).

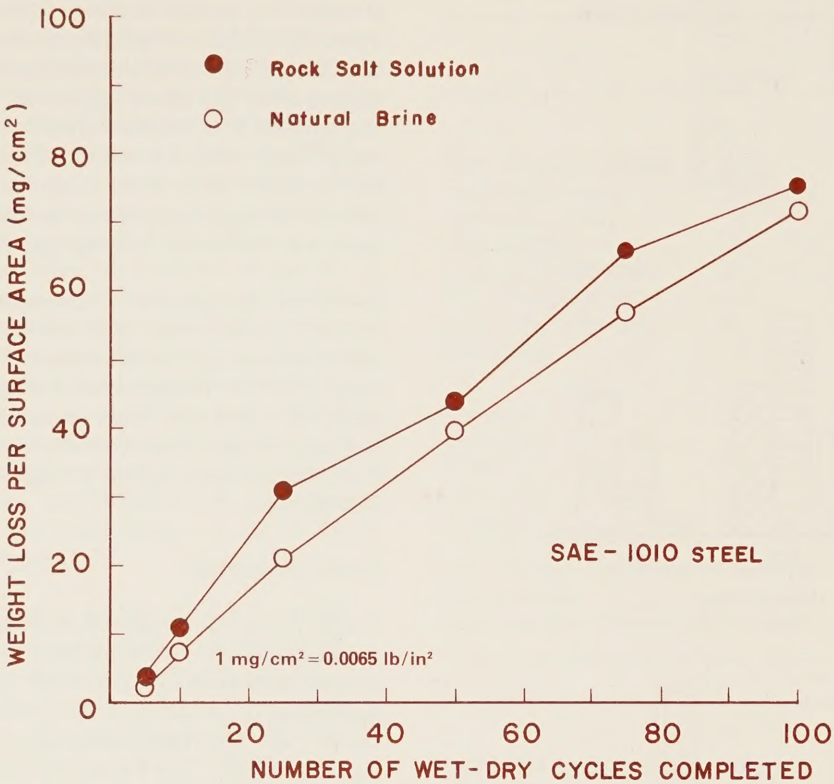

Figure 3.—Relationship between weight loss per surface area and number of cycles completed for SAE-1010 steel specimens submerged in deicing solutions.

A least-squares regression analysis indicated that there were no differences in corrosion between rock salt and natural brine; however, some qualitative differences were observed. The surfaces of the specimens immersed in brine remained relatively smooth, whereas the surfaces of the specimens immersed in the sodium and calcium chloride solution were noticeably rougher with high and low anode areas. After 100 cycles, the bottom edges of the specimens immersed in the sodium and calcium chloride solution were severely corroded and had lost about 2 mm (0.08 in) from their original length. Similarly, the other three edges had lost their original shape, indicating that the weight loss was more rapid around the edges. Weight loss was uniformly distributed over specimens immersed in natural brine.

Careful examination of the specimens revealed no pitting in any of the groups, even after 100 wet-dry cycles. Pitting would be even less with liquid deicing agents because there are no large crystals to become trapped against the surface of the metal.

Weight loss results for the structural steel specimens are shown in figure 4. Through the 25th cycle, specimens immersed in both solutions had essentially identical weight losses. Beyond this point, specimens immersed in natural brine lost more weight than did those immersed in the sodium and calcium chloride solution (a difference of 22 percent after 100 cycles).

A least-squares regression analysis and a visual evaluation indicated that the weight losses for specimens immersed in rock salt and natural brine solutions were significantly different. Surface characteristics of the A-36 steel were different from those obtained with the SAE steel. Structural steel specimens in both solutions exhibited rough surfaces with high and low areas. There was no pitting in any of the A-36 specimens after 100 cycles; however, some specimens showed a tendency toward cratering.

Field Evaluation

Applicator systems

Field testing was conducted for four winters using two different applicator systems and three different spray modes. Initially, a portable high-pressure hydrodynamic applicator system consisting of a 1,500-gal (5.68-m^3) fiberglass tank, a distributor bar with 28 small diameter nozzles, a 25-hp (18.6-kW) gasoline engine, and a positive displacement pump and designed by the Connecticut Department of Transportation was acquired through the Federal Highway Administration. (*11-13*) The system was mounted on a dump-body truck obtained from the West Virginia Department of Highways.

During the first winter of Phase I, corrosion products from the steel spray bar tended to plug the 0.08-in (2.03-mm) diameter nozzle openings, reducing sprayer effectiveness. In addition, discussions with maintenance personnel from a number of highway agencies indicated that the high initial cost of the spray-bar system, coupled with potential maintenance problems, might reduce its attractiveness. As a result, the system was converted to gravity flow by removing the nozzles from the spray bar and then used to complete the Phase I field testing.

A Phase II research effort was undertaken to design, fabricate, and field test a low-pressure brine applicator system. Main components of this applicator system are a 2,450-gal (9.27-m^3) steel tank, a distributor bar that can accommodate from four to seven nozzles, a sprayer control system, and a centrifugal pump. The system is mounted on a tandem dump-body truck. The truck's hydraulic system powers the pump.

For each spraying run, careful records were kept of the amount of brine applied and the weather conditions. To monitor melting effectiveness, roadway surface conditions were photographed and visually assessed at periodic intervals after the brine was applied. A limited amount of pavement skid resistance testing was done using the British pendulum tester. On several runs, brine and rock salt were applied side-by-side to compare results.

Results

Eight field runs using high-pressure application were made on the West Virginia University campus during the first winter of Phase I testing. Four runs with gravity flow were made on a 2.8-mi (4.5-km) section of State highway during the following winter. To date, 17 runs have been made using the low-pressure spray system.

Table 3 summarizes the field runs for the first three winters in which testing took place. In general, 500 lb (227 kg) of TDS's were applied per two-lane mile of highway—the application rate used by the West Virginia Department of Highways on Interstate and other limited-access facilities. The application rates during the first winter (1981-1982), indicated in table 3, were higher than desired for several reasons: The researchers' inexperience in operating snow removal and ice control equipment, restrictive roadway geometrics that seriously limited truck speeds, and unplowed test roadways requiring repeat applications to induce melting. These drawbacks were overcome during succeeding winters when brine was applied (by experienced personnel in the West Virginia Department of Highways) to a section of State highway with higher speeds and higher traffic volumes. As shown in table 3, brine application rates under these conditions were comparable with typical rock salt application rates—500 lb (227 kg) per two-lane mile.

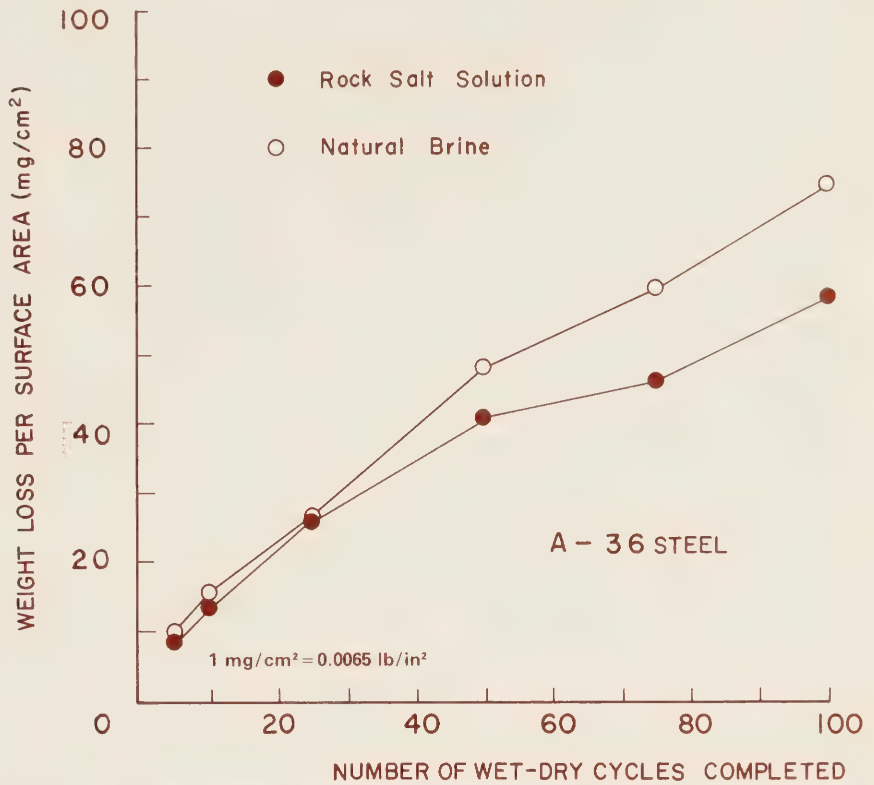

Figure 4.—Relationship between weight loss per surface area and number of cycles completed for A-36 steel specimens submerged in deicing solutions.

Overall, brine performance was similar to that of rock salt. Brines were effective in melting snow and ice and achieving bare pavement within a relatively short time. In cases where heavy snowfall continued after brine application, the roads again would become covered with snow, requiring a second brine application. However, this also was true for roads treated with rock salt.

Summary and Recommendations

Many natural brines from the Central Appalachian Region (including West Virginia, Ohio, Pennsylvania, and New York) are suitable for use as highway deicing agents. Brines from this region have relatively high calcium concentrations—an asset in deicing applications. Of the minor and trace constituents analyzed in these brines, barium was the only element of concern.

Major variations in brine quality result from differences in formation and zone. Brines from different formations have significantly different concentrations of major and trace constituents. Also, brine strength tends to increase with depth. Over a period of 13 months, there was no change in brine concentration from a given formation. It is recommended that brines continue to be monitored to determine any long-term changes in composition.

The constituents of the natural brines examined were compared with those of conventional chloride chemicals. The brines generally were higher in iron, zinc, and barium, while the conventional chemicals were higher in chromium and cadmium. Dry calcium chloride samples had elevated lead levels when compared with the brines.

Table 3.—Summary of field test results for three winters

Date	Temp. (°F)	Roadway conditions	Mode of delivery	Speed (mi/h)	Lb TDS / Two-lane mile	Comments
1981–1982						
12/17/81	28–30	Loose snow	Hi-pressure	–	697	Produced bare pavement
1/9/82	14–17	Loose snow	Hi-pressure	4–10	1,480	Better melting than NaCl[1]
1/16/82	28–31	Loose snow	Hi-pressure	6	1,693	Bare pavement quickly
1/25/82	16–22	Packed snow	Hi-pressure	12–15	355	Bare pavement achieved
2/11/82	17–19	Packed snow	Hi-pressure	11	1,422	Slow melting due to cold
2/13/82	21–25	Loose snow	Hi-pressure	4–10	1,750	Excellent meltoff
3/3/82	25	Packed snow	Gravity flow	12	534	Produced bare pavement
4/6/82	26–30	Packed snow	Gravity flow	7	506	Good meltoff
1982–1983						
1/12/83	21	Packed snow	Gravity flow	26	534	Same results as NaCl
1/15/83	17	Packed snow	Gravity flow	25	506	Melted ice pack
2/6/83	26	Packed snow	Gravity flow	23	182	Slush after 15 min
2/11/83	17	Packed snow	Gravity flow	23	659	Results identical to NaCl
1984–1985						
1/10/85	26–28	Loose snow	Lo-pressure	18	441	Rapid meltoff
1/10/85	29–30	Packed snow	Lo-pressure	15	1,227	Immediate meltoff
1/11/85	25–27	–	Lo-pressure	–	–	–
1/17/85	24	Loose snow	Lo-pressure	17	623	Produced bare pavement
1/17/85	26	Packed snow	Lo-pressure	17	656	Same results as NaCl

[1]All comparisons to NaCl in this table refer to a sodium chloride application rate of approximately 500 lb (227 kg) per two-lane mile.

°F = 1.8°C + 32
1 mi/h = 1.6 km/h
1 lb = 0.454 kg

In general, the effects of natural brines on bituminous concrete pavements appear to be no different than the effects of traditional rock salt deicing agents. The use of natural brines resulted in less portland cement concrete surface deterioration than did the use of conventional chloride deicers during 100 freeze-thaw cycles. Although some discoloration of the concrete occurred because of iron in the brines, the problem is not expected to be significant under actual field conditions.

No general statement could be made about the relative effects of natural brine and rock salt on steel corrosion because the effects depend upon the chemical compositions of the steels and brine. In this study, specimens of automobile body steel demonstrated less corrosion in natural brine than in a sodium and calcium chloride solution. However, specimens of structural steel yielded opposite results.

Chloride deicers create serious problems on reinforced concrete bridges because the expansion behavior of the corrosion products disrupts the concrete cover. Reinforcing steels usually have a higher carbon content than do those tested in this study, thus the results are not directly transferable, and corrosion tests with a reinforcing-type steel in concrete should be conducted. A number of studies have been performed to evaluate methods for protecting reinforced concrete from the adverse effects of deicing salts. (*14-17*) Review of these studies provides insight about testing procedures that could be applied to evaluating the effects of natural brines on reinforced concrete.

Field testing conducted during three winters shows that West Virginia oil and gas field brines are effective deicing agents for a variety of weather and pavement conditions using either gravity or high-pressure application. Visible melting began to occur almost immediately after the brine was applied, and bare pavement was achieved rapidly on low-volume roadways, even at temperatures of 15 °F (−9.4 °C). The brines were effective at low temperatures probably because the brines used contained significant amounts of calcium as well as of sodium salts.

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Ronald W. Eck is a professor of civil engineering at West Virginia University. He has been principal investigator on several West Virginia Department of Highways/FHWA joint-sponsored research studies including winter maintenance, truck escape ramps, rail-highway grade crossings, and high-speed signalized intersections. Dr. Eck is active in the technical committees of the Transportation Research Board, Institute of Transportation Engineers, and American Society of Civil Engineers.

William A. Sack is a professor of civil engineering at West Virginia University and leader of the Civil Engineering Department's Environmental/Water Resources Group. For the past 22 years, Dr. Sack has been teaching and conducting research on industrial and municipal waste treatment and reuse.

Road Humps for the Control of Vehicular Speeds and Traffic Flow

by
Burton W. Stephens

Introduction

Road humps, sometimes referred to as undulations or speed humps, are protuberances constructed in the roadway to reduce vehicular speed. They have a unique set of design specifications that distinguish them from the more conventional road bump. Road humps, an arc approximately 12 ft (3.7 m) long and 3 to 4 in (76.2 to 101.6 mm) high, have been designed for use on residential streets that have speed limits of 25 mi/h (40 km/h) or less. In contrast, a road bump typically is an arc between 0.5 and 3.0 ft (0.15 and 0.9 m) long and 2 to 6 in (50.8 to 152.4 mm) high and is used in parking lots, on private roads, and on some residential streets. Figure 1 shows the contrast between the two road protuberances.

Another distinction between road humps and bumps is the difference in how vehicles respond to them. In general, for road humps, as speeds increase, the vertical forces to the vehicle and thus occupant discomfort increase. The opposite is true for road bumps; peak vertical accelerations and associated discomfort of vehicle occupants are great at relatively low vehicular speeds, but vertical forces and associated discomfort diminish with increasing speeds.

This article discusses the purpose and development of road humps, the effectiveness of road humps relevant to safety issues, signing and marking requirements, the benefits and problems of road humps, and other considerations. The article concludes with an assessment by city engineers, planners, and local highway administrators of the feasibility of establishing regulations and legislation on the road hump as a traffic control device.

Development of Design Specifications for Road Humps

To accomplish the three major purposes of road humps—increase the safety of residential streets, improve the environmental quality of residential neighborhoods, and improve traffic flow throughout residential areas—humps must be designed carefully because there are many possible variations in their construction that can influence vehicles traversing them. Thus, functional design requirements must be specified.

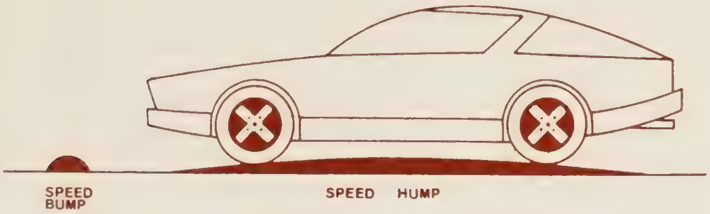

Figure 1.—Schematic representation of road hump and speed bump.

The four basic requirements of a road hump configuration are as follows:

- Increasing vehicular speed in the vicinity of road humps should be countered progressively by increasing occupant discomfort.
- Speed reductions should be maintained *throughout* the roadway section bounded by humps, not only in the vicinity of the humps.
- Speed reductions in the vicinity of humps should be gradual, facilitated by the use of road signs and markings.
- Speed reductions in the vicinity of humps should be long lasting and not merely the result of novelty or driver uncertainty.

Initial evaluations of the feasibility and effectiveness of using road humps for speed control involved test track studies that measured peak vertical vehicle acceleration and associated occupant discomfort. An important assumption underlying such data is that when discomfort reaches a threshold value, a driver will slow the vehicle. Several reseachers have used a 7-point discomfort scale to predict hump crossing speed. For a 12-ft (3.7-m) long and 4-in (101.6-mm) high hump, test track discomfort data predicted on-road vehicle speeds over the hump in the range of 14 to 21 mi/h (22.5 to 33.8 km/h). (*1*)[1] In subsequent on-road tests at nine British locations, the overall average speed at the road hump was slightly lower (11.1 mi/h [17.8 km/h]). The 85th percentile speed was 14.2 mi/h (22.9 km/h), while the overall average speed on the road segment bounded by humps was 22.2 mi/h (35.7 km/h).

Similar results were obtained in Australia (*2*) and Sweden. (*3*) Finnish research (*4*) indicates vehicle occupant discomfort levels far less than those reported by other researchers. Moderate levels of occupant discomfort were reported for only one of the five vehicles used in the Finnish tests, although operators of heavy-duty vehicles reported intolerable levels of discomfort.

Disparate results of this kind suggest that different vehicles react differently to humps, perceptions of discomfort vary among cultures, and/or the underlying attitude scales were being used differently by different researchers.

Best-fit analyses of discomfort and the peak vertical acceleration of vehicles passing over humps yield good-fit linear relationships. (*1*, *4*) Assuming that a midpoint discomfort value is a threshold for speed control at the road hump, peak vertical accelerations of about 0.69 g (22 ft/s² [6.8 m/s²]) will induce the typical driver to reduce speed. For passenger vehicles with soft suspension systems, motorists will drive over the road hump at approximately 25 mi/h (40 km/h); for passenger vehicles with harder suspension systems or over-inflated tires, speeds are expected to be somewhat less. For heavy vehicles without cargo, peak vertical accelerations would be quite high, thereby inducing even slower speeds.

Physical Characteristics of Road Humps

Road hump parameters that have been varied empirically in test programs are hump length, height, and shape and the distance between humps. Ideally these parameters could be varied to design hump configurations for a prescribed traffic speed and to minimize speed variations.

Road hump length

A hump that is longer than the wheelbase of a vehicle transfers an upward force to the vehicle at low speeds, imparting a low amplitude and a simple vertical acceleration waveform to the vehicle, its occupants, and its cargo. As speed and the wheelbase-hump length difference increase, the amplitude and waveform complexity also increase, increasing occupant discomfort and the potential for damaged cargo.

Figure 2 illustrates the amplitudes and waveform complexities of vertical accelerations transferred to vehicle occupants. (*4*) The figure shows three vehicle conditions—an empty passenger vehicle, with acceleration measurements taken at the driver's seat; an empty air suspension bus, with measurements taken at the driver's seat; and the same bus with measurements taken at the back seat. As shown, the amplitude of the acceleration measures increases with increases in speed over a road hump 4 in (101.6 mm) high and 12 ft (3.7 m) long. For the passenger vehicle, the vertical acceleration is in a comfortable-to-tolerable range for all speeds. For the air suspension bus, only speeds below 20 mi/h (32 km/h) are tolerable.

Figure 3 plots the relationship between road hump length and peak vertical acceleration for a Mini Clubman Estate passenger vehicle traversing experimental 4-in (101.6-mm) high road humps at 15 to 24 mi/h (24 to 39 km/h). Although data for vertical accelerations at higher speeds are not available for all conditions and extrapolation is risky, it is clear that hump lengths of less than 12 ft (3.7 m) will cause many operators (because the Mini Clubman Estate car is representative of the class of lightweight, soft-suspension vehicles) to drive at less than 20 mi/h (32 km/h). On the other hand, humps much longer than 12 ft (3.7 m) will not cause occupants of many vehicles great discomfort but would lead to increased road hump crossing speeds for large vehicles and those with stiff suspensions.

[1]Italic numbers in parentheses identify references on page 90.

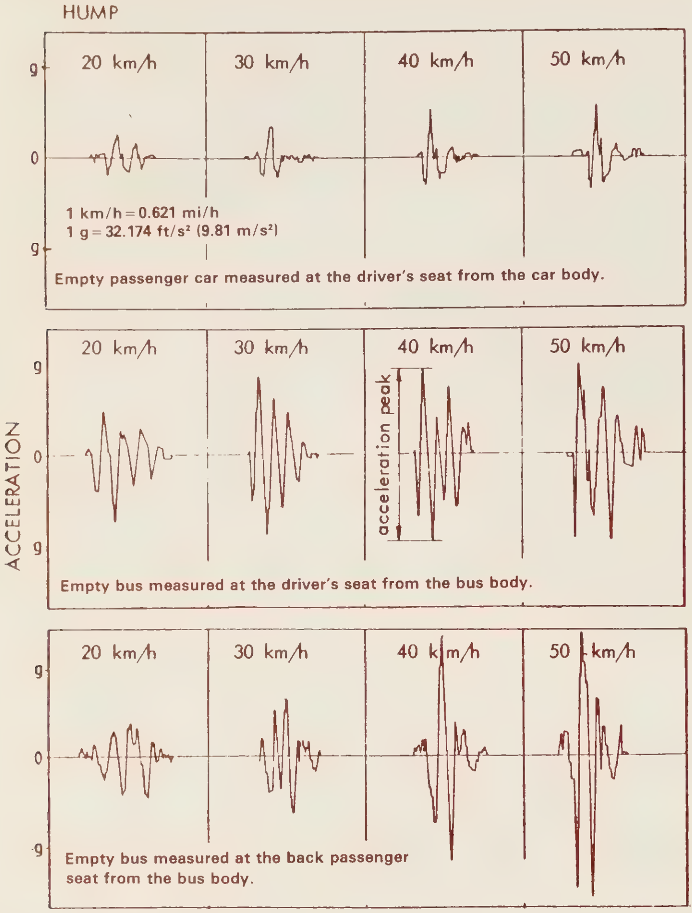

Figure 2.—Examples of peak vertical acceleration recordings as vehicles traverse a 12-ft (3.7-m) long and 4-in (101.6-mm) high road hump. (4)

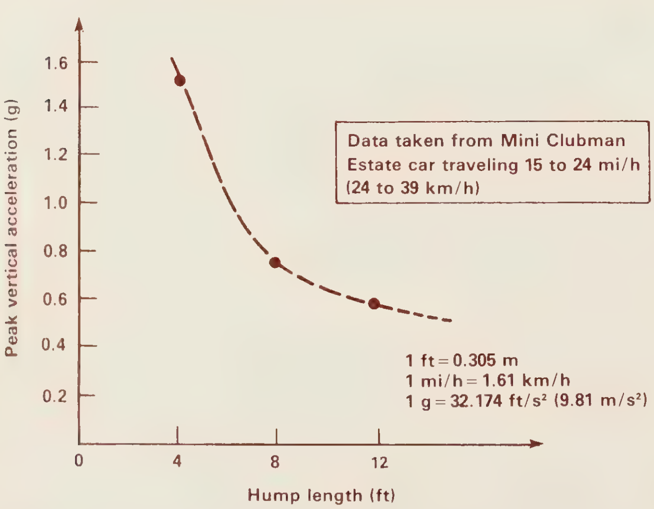

Figure 3.—Average peak vertical acceleration recorded for three hump lengths.

Road hump height

The optimal height of road humps has been investigated less thoroughly than hump length. Although the height of the hump also contributes to the peak vertical acceleration value, it is more important to the ground clearance of the vehicle. High humps can damage vehicle undercarriages and promote roadway scarring by vehicles, especially as vehicles emerge from the hump. A 3-in (76.2-mm) high hump may be optimal for lightweight, soft-suspension vehicles operating at 25 mi/h (40 km/h). Furthermore, the lower hump will scrape fewer low-riding vehicles.

In one experiment with a 12-ft (3.7-m) long hump that was 3 in (76.2 mm) high, passenger vehicle on-hump speeds were 4 mi/h (6.4 km/h) higher than speeds on 4-in (101.6-mm) high humps. (*1*) Higher on-hump speeds also lead to higher speeds between humps.

Road hump shape

As with the height of the road hump, the optimal shape has not been evaluated thoroughly. Although hump shape can modify the complexity of the vertical acceleration waveform, it probably has little impact on occupant discomfort because most of the higher frequency waveform components are negated by the vehicle characteristics or physical makeup of the occupants. Two designs used are humps with a single circular section and those with a parabolic section with a flared ramp at the entry side of the hump. (*5*) Other variations have been proposed to make the transition onto the hump smoother—for example, reversing parabolic curves at the ends of the hump. As discussed earlier, it is likely that complex waveforms are not resolved by the driver in selecting a desired speed over the road hump. The analyses of such complex shapes likely would require computer simulation tests to determine whether the peak amplitudes of the vertical acceleration patterns are modified significantly. On-road driver discomfort measurements also would be necessary. Finally, the cost-effectiveness of strict construction standards would have to be addressed.

Road hump spacing

The distance between road humps—the linear separation of individual humps—also can influence the vertical acceleration waveform. For separations of more than a few feet, there is no interaction between the vertical acceleration waveforms of the individual road humps. However, large separations lead to increased speeds between the humps. As previously mentioned, a basic requirement of road hump configurations is that constant vehicular speeds be maintained *throughout* the entire roadway section bounded by humps, including on-hump speeds.

All on-road tests show speed variations at and between road humps, the extent of which is affected by both the hump geometry and the spacing between humps. If road humps are constructed to ensure a spot speed reduction, a single hump may suffice. However, because humps generally are used to reduce speed on an entire block or series of blocks within a residential or business district, hump spacing is a critical design parameter.

Field data from the United Kingdom and Corio, Australia, show an empirical relationship between road hump spacing and speeds midway between humps. (*6*) The equation that approximately fits these data is as follows:

$$H_S = 0.50\ (2.59\ (V_{85})^2 - 656).$$

Where,

H_S = the optimal spacing of road humps (ft).
V_{85} = the desired 85th percentile speed between road humps for $V_{85} > 22.5$ mi/h.

Effectiveness of Road Humps

Overall speed effectiveness of road humps

Table 1 summarizes the effectiveness in terms of speed reduction of various road hump configurations without regard to specific configuration characteristics. As can be seen, speeds are reduced significantly at the road humps and between road humps at most studied locations. The speeds shown in table 1 are 85th percentile speeds, which ideally should converge with the speed limit on the streets where road humps have been placed.

Stability of road hump effectiveness

Figure 4 illustrates the effects over time of road humps. Although nearly all drivers are expected to be affected immediately by the humps, bringing the 85th percentile speeds to the speed limit, the faster drivers will be affected more gradually. Unlike most traffic control signs, the road hump is continuously reinforcing; that is, there is a penalty every time the driver traverses the hump at an excessive speed. Signs, however, merely inform drivers or provide the legal basis for a penalty and provide reinforcement only when an enforcement authority is present.

Two studies on road hump installations indicate that there is no regression of speeds to the pre-hump speed conditions. The effectiveness of road humps in Brea, California, was tested using speed data collected before hump construction, immediately after construction, and 3 months and 7 months after construction. (*7*) Consistency of overall speeds at reduced levels was found for all three "after" data collection periods. The fastest vehicle speed also was recorded for each of the four periods; the fastest speed occurred toward the middle of the block immediately after the road humps were installed. However, in subsequent testing periods, the overall speeds of the fastest vehicles were reduced by approximately 5 mi/h (8 km/h) compared with the "before" testing period. This is either due to a moderating influence of the humps on the fastest vehicle speeds or else operators of these vehicles chose other routes.

Table 1.—Comparison of before and after speeds at 18 locations—85th percentile speeds

	At-hump speed			Between-hump speed		
Location	Before	After	Difference	Before	After	Difference
	Miles per hour			*Miles per hour*		
Light Street (AUS)	40.4	13.0	27.4	43.5	28.0	15.5
Peacock Avenue (AUS)	32.9	18.0	14.9	33.6	25.5	8.1
Armytage Street (AUS)	30.4	16.2	14.2	32.9	26.1	6.8
Cuddesdon Way (UK)	39.0	13.5	25.5	39.0	23.0	16.0
Motum Road (UK)	30.1	12.9	17.2	30.1	25.0	5.1
Palace Road (UK)	32.1	16.3	15.8	32.1	21.9	10.2
Abbotsbury Road (UK)	39.8	14.2	25.6	39.8	27.2	12.6
Barlanark Road (UK)	35.7	15.4	20.3	35.7	21.9	13.8
College Walk (UK)	31.1	14.0	17.1	31.1	21.1	10.0
Esplande (UK)	19.0	13.0	6.0	19.0	16.3	2.7
Albron Street (UK)	30.3	14.0	16.3	30.3	20.9	9.4
Kelly Road (USA)	43.0	19.0	24.0	43.0	32.0	11.0
Silas Avenue (USA)	38.0	24.0	14.0	38.0	34.0	4.0
Silas Avenue (USA)	38.0	23.0	15.0	38.0	27.0	11.0
Cindy Avenue (USA)	27.0	21.0	6.0	27.0	23.0	4.0
46th Street (USA)	–	–	–	36.0	26.0	10.0
Lockstead Avenue (USA)	37.0	26.0	11.0	–	–	–
La Canada Drive (USA)	36.0	21.6	14.4	32.0	23.4	8.6

1 mi/h = 1.61 km/h

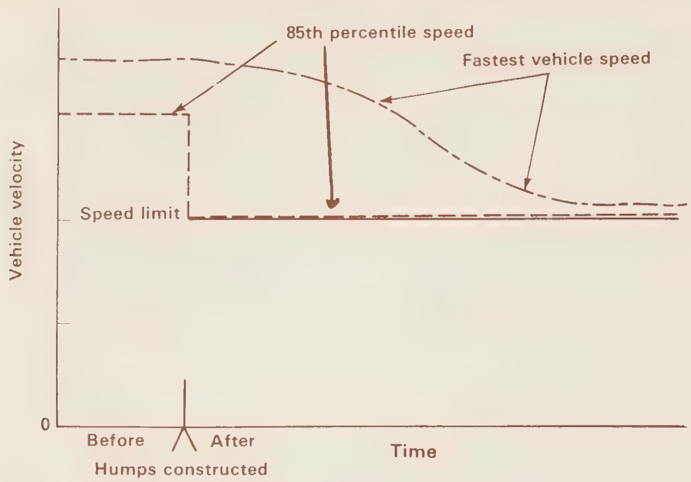

Figure 4.—Ideal temporal profile of 85th percentile and fastest vehicle speeds at site of speed zone controlled by road humps.

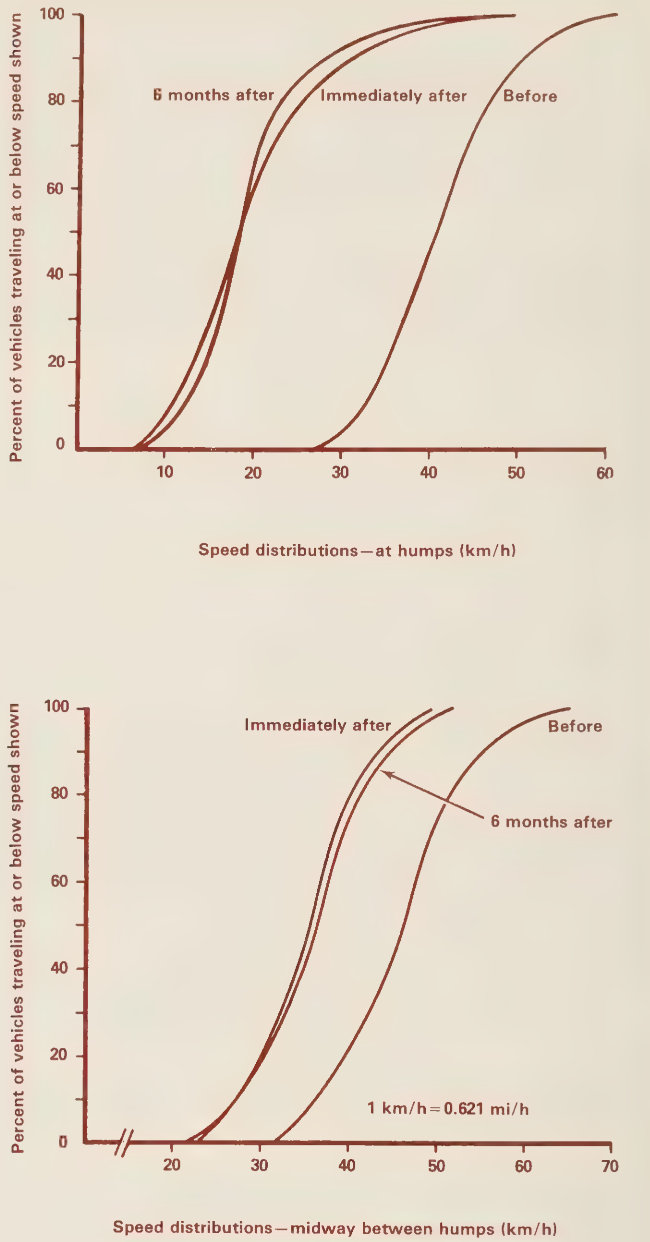

Figure 5.—Cumulative speed distributions before, immediately after, and 6 months after road hump construction. (6)

A study of residential streets in Corio, Australia, also provides information on effectiveness stability. (*6*) Figure 5 shows the speed distributions at humps and midway between humps. The data collected immediately after hump installation and 6 months after virtually are indistinguishable.

Traffic flow and diversion

Traffic volumes generally decrease on streets where road humps have been constructed. For some streets, this was the reason the road hump was built. On other streets, the construction can have an unplanned and possibly undesirable impact. If speeders and heavy volumes of traffic are diverted to parallel streets, traffic operations may not be improved. Table 2 shows the magnitude of diversion from streets with road humps. As can be seen, there is a large range in the percent change in traffic volumes from pre-hump levels.

Diversion from streets with road humps appears to be uniform throughout the day and not merely during peak hours; although, 10-hour and 24-hour traffic volume counts for 46th Street in Washington, DC, showed a slight increase in diversion during nonrush hours. (*8*) On the surrounding streets, traffic volumes did in fact increase—in some cases between 3 and 4 percent—but the overall distribution of traffic appeared to improve. After road humps were constructed on 46th Street, traffic volume decreased 31 percent.

Speed changes on surrounding streets also are of interest. In one study, small changes were found in the 85th percentile speeds on two adjacent streets, with an overall net reduction suggested. However, the differences were not statistically significant. (*7*)

Safety of road humps

Road hump safety has been assessed by comparing accident data on the street before humps were constructed with accident data after construction. Some studies have included subjective assessments of the potential safety of humps, but the reliability of such assessments is questionable.

A study that used surrogate measures of safety showed significant decreases in conflicts between vehicles, pedestrians, and bicyclists after construction of road humps in Lund, Sweden.[2] In other studies, accident data taken at a number of locations indicate that accidents have not increased after installation of road humps; however, in general, the number of accidents at such locations is too small to perform statistical analysis.

Two studies in the United Kingdom, which has the most experience with road humps, have evaluated the surrounding streets as well as the streets with road humps to evaluate accident experience. An overall 14 percent net improvement in accident experience may be attributed to the construction of road humps. (*9*, *10*)

One study (*11*) indicates that road humps can increase pedestrian safety gaps; yet another study (*12*) indicates that drivers spend less time looking for pedestrians and other vehicles and concentrate instead on the road humps themselves. The overall impact of these findings on safety is unknown.

Signing and marking requirements

Signs and markings are used with road humps to warn drivers so they will approach a single road hump or the first hump in a series at a smooth speed. Signs and markings also provide legal protection to the construction authority.

If signs and markings are poorly visible or located too far from the road hump, it is likely that a driver will not respond appropriately when traversing the hump. Oversigning or using markings that are too conspicuous also can have a detrimental effect by distracting and confusing the driver. In addition to safety considerations, excessive signs or high-reflectance signs and markings can pose esthetic problems for many residential neighborhoods.

No specific research has been reported that discriminates one set of markings and signs from others, nor has there been any universal acceptance of particular marking and signing configurations. Symbolic signs with verbal messages are used at most European road hump constructions (fig. 6). (*9*) Markings generally consist of solid white paint covering the entire hump. In areas without overhead lighting, reflective beads are embedded in the paint.

Australia and England use the word "hump" on signs; the United States uses the standard "Manual on Uniform Traffic Control Devices" (MUTCD) "BUMP" warning sign, W8-1. (*13*) Markings usually include a number of parallel longitudinal stripes on the road hump, characteristic of "zebra" crosswalks (fig. 7). (*5*)

[2]C. Hyden and P. Garder, "Further Development of a Traffic-Conflicts Technique and Research on Speed-Reducing Measures," paper presented at the 61st annual meeting of the Transportation Research Board, Washington, DC, January 1982.

Table 2.—Magnitude of traffic volume changes on streets with road humps

Location	"Before" volume	"After" volume	Percent change
10-hour count			
Barlanark Road (UK)	387	141	−64
16-hour count			
Cuddesdon Way (UK)	4,560	2,066	−55
Motum Road (UK)	713	472	−34
Palace Road (UK)	3,457	2,818	−18
Abbotsbury Road (UK)	6,050	4,172	−31
South Park/Moorfield Drive (UK)	4,288	1,977	−54
College Walk (UK)	2,594	2,436	−6
Esplande (UK)	1,978	1,955	−1
Albron Street (UK)	1,553	1,326	−15
24-hour count			
Rosewall (AUS)	1,038	786	−24
Norlane (AUS)	558	431	−23
Hawthorn (AUS)	2,468	1,254	−49
Dianella (AUS)	4,085	2,077	−49
Washington, DC (USA)	8,174	5,450	−33

Figure 6.—Symbolic sign and supplementary plate in conjunction with road humps in the United Kingdom. (10)

Other sign variations include the internally illuminated signs used in the United Kingdom; marking variations include using a series of longitudinal or transverse markings before the individual road humps or placing on-road messages such as "BUMP" adjacent to the road hump (fig. 7).

The degree to which markings and signing contribute to the overall effectiveness of road humps is unknown. However, researchers do seem to agree that road humps cannot be used safely without signs and markings.

Other considerations

Other relevant issues that should be considered in a thorough study of the operational effects of road humps include the following:

- Lateral placement of vehicles.
- Gutter running of vehicles.
- Hump damage.
- Major design variations such as raised pedestrian crossings.
- The comparative advantages of other traffic control devices for controlling speed (for example, chokers).
- The design of road humps for vehicles with long wheelbases such as firetrucks, buses, and trucks.
- Environmental issues such as noise levels and fuel emissions.

Viewpoints of Users and Potential Users

Early in 1983, the Traffic Division of the City of Thousand Oaks, California, surveyed U.S. cities and counties to determine the prominence of road hump usage in the United States, the perceptions of local officials and the engineering community on the benefits and problems of road humps, opinions on standardizing and codifying road humps, and whether additional research and development on road humps is merited.

Questionnaire and sample

The questionnaire used consisted of four parts: Information on the respondent's profession and jurisdiction, general information on usage and direct experience of the respondent with road humps, attitudes regarding the benefits of including road hump specifications into State or national manuals on traffic control devices (including the need for more research and development), and detailed information on existing road hump installations including evaluative data.

The sample was drawn from all jurisdictions that had requested a copy of a 1981 report on residential street improvements (7), participants in two University of California conferences on road humps, and all city traffic engineers in the State of California. From approximately 600 solicitations sent nationwide, 286 responses were received.

Figure 7.—Variation of road hump markings.

Direct experience and perceptions of road hump functions

Overall, 37 percent of the 286 respondents had driven over road humps. Respondents were asked whether road humps differed in any respect from speed bumps: Two percent indicated that there was no difference, 6 percent indicated that the humps differ only in size, and 10 percent noted other differences. However, 82 percent of the respondents indicated that humps and bumps have different functions.

Most appropriate uses of road humps

Seventy-five percent of the respondents indicated that humps should be used on two-lane residential streets with traffic volumes less than 10,000 vehicles per day, 66 percent indicated that humps should be used in parking lots, and 59 percent indicated that humps could be appropriately used on private roads.

Perceived benefits and problems with road humps

Benefits and problems were ascertained using responses to the question, "What do you perceive as the greatest benefits (or problems) with speed humps?" Respondents could indicate a "major benefit (problem)," "some benefit (problem)," or "unknown benefit (problem)" for several identified issues or specify additional issues.

Out of 12 potential benefits, 3 potential benefits—speed reduction in the vicinity of humps, speed reductions overall, and more effective than stop signs—emerged as being a "major benefit." Three potential benefits—increased property values, reduced noise, and improved air quality—were judged to be unachievable with road humps.

Out of 16 potential problems, 4 were found to be a "major problem," including increased liability and legal problems, the fact that humps are not an official traffic control device, the concern that if used on one street, other residents would want them, and the potential loss of vehicle control.

Comparisons were made to determine whether respondents without road humps in their jurisdictions differed in their ratings from those respondents with road humps. For respondents with road humps constructed in their jurisdictions, only the question of increased liability and legal problems remains a concern, although to date no legal history has developed for road hump usage. The "with road humps" group also indicated only one significantly different benefit: Speeds decreased between humps as well as in the vicinity of humps, an attitude not shared by the "without road humps" group. Nearly all of the "with road humps" respondents also cited reduced traffic volumes, greater diversion of nonlocal traffic, fewer complaints from citizens, reduced demands for enforcement, and accident reductions. Only one respondent in a jurisdiction with road humps felt that humps could present "a dangerous condition to a reasonable driver." In this respondent's jurisdiction, however, the road humps were atypical (10 ft [3.0 m] long and 6 in [152 mm] high).

Safety is the prominent issue seen by different respondents as being both a potential benefit and a potential problem. Speed-related issues, which can be associated with safety and changes in environmental quality, and property values and public acceptance issues also were perceived by some respondents as positive and by others as negative. The issues related to traffic planning and operations were more diverse. No respondent suggested a reduction in maintenance activities following construction of road humps, although a number of potential problems were cited. Nearly 90 percent of the respondents cited liability as a major constraint in constructing road humps; this concern is closely linked to the absence of authoritative standards or warrants for the construction and placement of road humps. Reduced police monitoring and enforcement of speed limits were cited as benefits to local government.

Are warrants and specifications needed?

Because of the concern voiced by various traffic engineers that warrants and specifications are needed to prevent a snowballing of requests for road humps (*14*), the questionnaire asked whether warrants and specifications are needed and whether additional research and development is needed before warrants and specifications can be developed.

The majority of respondents indicated that uniform sign specifications should be developed; approximately one-third of the respondents felt that no additional research and development was needed for signing, although virtually no hump signing research has been performed. Less than 50 percent of the respondents indicated a need for specifications/warrants dealing with design, placement, and markings for road hump use.

Review of responses from jurisdictions with road hump installations

Approximately 80 percent of hump installations are 12 ft (3.7 m) long by 4 in (101.6 mm) high. Six of the jurisdictions have lowered hump heights to 3 to 3.5 in (76.2 to 89 mm).

Costs vary from $200 per hump to more than $1,800 per hump, with an average of $866.

The signs used in conjuction with humps vary greatly, ranging from symbolic signs with one or two humps to word messages such as "Undulations Ahead." The most common signed message is the MUTCD standard bump warning sign. (*13*) Also, advance warning signs vary in distance from the hump; some jurisdictions locate warning signs at intersections of streets with humps installed.

Road markings used also vary. Some humps have no markings; others have longitudinal, lateral, or diagonal markings or combinations of markings.

Conclusion

Road humps are a viable means of controlling speeds of passenger vehicles on residential streets. The preponderance of evidence indicates that judicious placement of these devices can enhance safety and improve traffic distribution.

If hump use becomes more widespread, signs, markings, and construction practices will have to be standardized. Widescale adoption of optimal designs for road humps will require additional research and incorporation into State and, possibly, national authoritative documents on uniform traffic control devices.

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(*9*) R. Sumner and C. Baguley, "Speed Control Humps in Kensington and Glasgow," TRRL Report No. SR456, *Transport and Road Research Laboratory*, Crowthorne, Berkshire, England, 1979.

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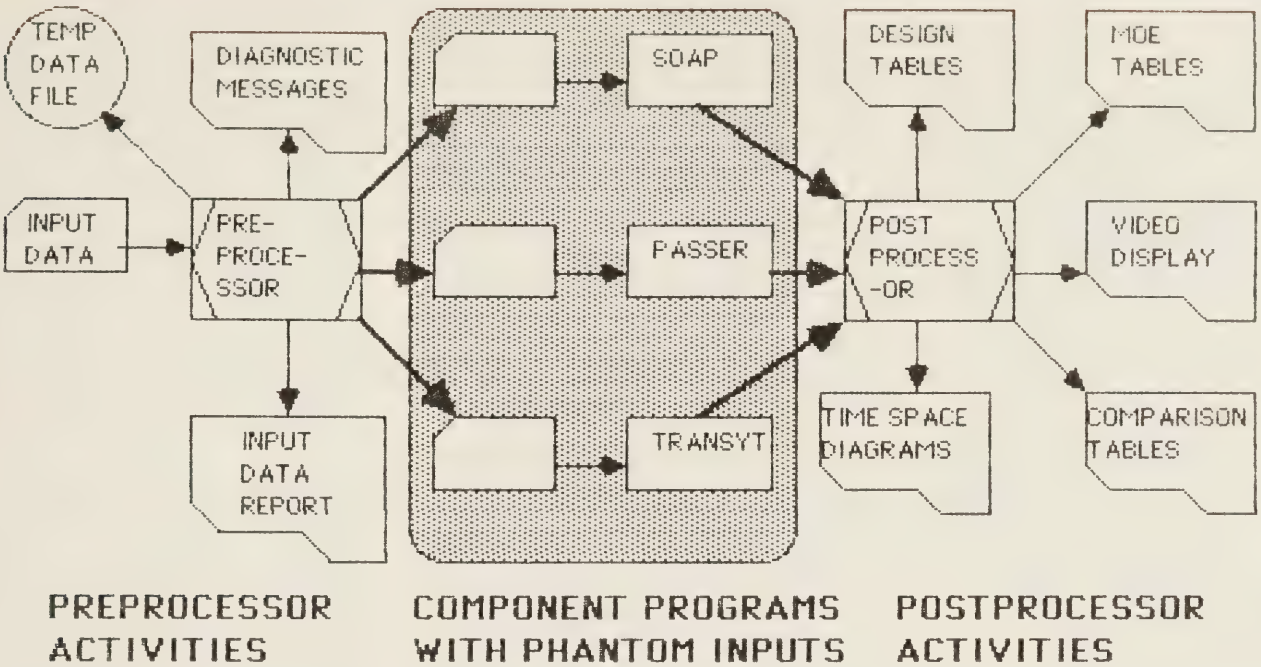
(*12*) B. Erikson and U. Horberg, "The Influence of Speed Reducing Bumps on Search Behavior of Road Users," Uppsala Psychological Report No. 284, *University of Uppsala, Department of Psychology,* Sweden, 1980.

(*13*) "Manual on Uniform Traffic Control Devices for Streets and Highways," Part II-C, "Warning Signs," *U.S. Department of Transportation*, *Federal Highway Administration*, Washington, DC, 1978.

(*14*) ITE Journal, "To the Editor," vol. 53, No. 5, June 1983, pp. 7-8.

Burton W. Stephens is a research psychologist in the Traffic Systems Division, Office of Safety and Traffic Operations R&D, Federal Highway Administration. He has extensive experience in human factors research and has been active in research involving the highway/motorist interface. Mr. Stephens, who serves as Deputy Division Chief, was on a professional exchange assignment with the Australian Road Research Board during 1986.



The Arterial Analysis Package

by

David R.P. Gibson and Llewellyn Williams

Introduction

The Arterial Analysis Package (AAP), conceived as a tool for timing traffic signals on arterial streets, gathers the most widely used design and analysis programs to provide a framework for solving signal timing problems using commonly available traffic engineering data.

Many traffic engineers already are using the AAP signal timing methods—the Signal Operations Analysis Package (SOAP), Progression Analysis and Signal System Evaluation Routine (PASSER), or Traffic Network Study Tool (TRANSYT) are all AAP component programs. They all, however, are used as independent programs with their own particular strengths and weaknesses. The AAP provides a common coding structure for arterial systems so that the component programs can be used from a common data file. In addition to the three component programs that form the engineering analysis core of the AAP a group of interactive and batch support programs is provided.[1]

This article discusses the three component traffic signal timing programs, the overall operation of the AAP, how to define a problem for analysis, how to prepare the input deck using the support programs, how to interpret results, and how the AAP was tested.

[1]C.E. Wallace, K.C. Courage, and D. Reaves, "Arterial Analysis Package," Report No. FHWA-IP-86-1, Federal Highway Administration, Washington, DC. Not yet printed.

Component Programs

SOAP 84

SOAP was developed for the Federal Highway Administration (FHWA) by the State of Florida and the University of Florida to provide a convenient yet powerful signal timing tool for analyzing individual intersections. (*1*)[2] The original SOAP (SOAP 79) was written in Fortran for mainframe computers, in BASIC for Apple II microcomputers, and in calculator notation for the Texas Instruments and Hewlett Packard hand-held programmable calculators. However, because of the wide differences in computational power between the versions, they differed somewhat in their methodologies and the degree of human intervention required. A second program, SOAP 84, developed a unified version for both mainframe and microcomputers (MS-DOS, IBM, and Apple Macintosh) using ANSI standard Fortran 77.

SOAP has three computational functions: Design, analysis, and evaluation. SOAP can assign and time up to six dials for various time periods. If actuated control is specified, no dial assignments are made. SOAP 84 does not select an "optimum" cycle length or phasing; the user must use the design and analysis capabilities to set up and evaluate designs to determine the best mix of measures of effectiveness (MOE's). SOAP provides four kinds of reports: Input data, signal design recommendations, MOE reports, and plots and diagrams.

[2]Italic numbers in parentheses identify references on page 96.

PASSER II-84

PASSER II, which evolved from SIGART, SIGPROG, and mathematical programming techniques, is an arterial signal progression optimization program based on the concept of maximizing the green bandwidth available to traffic. PASSER II-84 release 3.0 is the current version of PASSER available from the Texas State Department of Highways and Public Transportation. Texas cooperates with FHWA to ensure that the version of PASSER II in the AAP is the current release version. PASSER II, written in Fortran 77, works with multiphase signals and calculates phase lengths, offsets, and demand/capacity ratios at intersections to evaluate their levels of service. (*2*) PASSER provides three kinds of reports: Input data, signal design recommendations, and time-space diagrams.

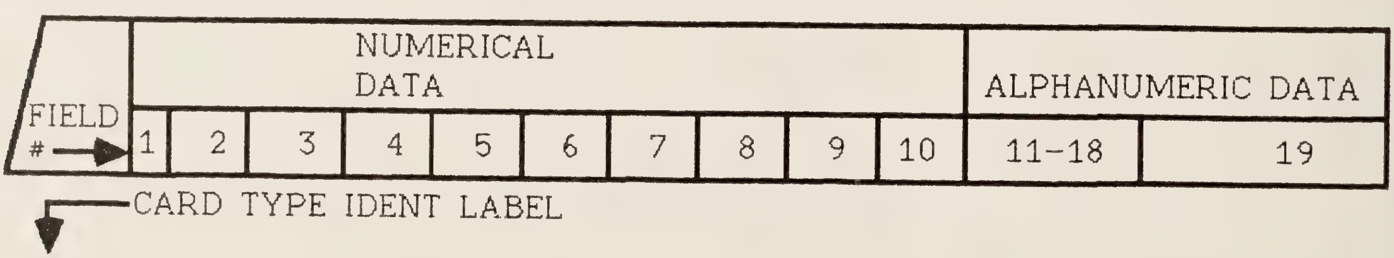
TRANSYT-7F

TRANSYT-7F is a signal progression optimization program for networks based on the concept of minimizing traffic delays and stops. TRANSYT-7F release 4 is the current version of TRANSYT available from FHWA. (*3*) TRANSYT-1 was written in assembly language in 1967. Since then, the program has been improved by recoding into Fortran, adding multiphase analysis, enhancing input error checking, adding automatic calculation of initial signal timing, providing multiple links at single stop lines, adding bus analysis and fuel consumption, and, in version 7F, "Americanizing" the input. TRANSYT-7F varies offsets and splits in user-specified time increments, analyzes the results with a deterministic platoon dispersion model, and keeps iterating with a "hill climb" optimization algorithm until the "optimum" solution is obtained. TRANSYT-7F provides five kinds of reports: Input data, signal design recommendations, time-space diagrams, a performance table, and flow profiles. TRANSYT-7F analyzes only arterials when used within the AAP.

Description of the AAP

Inputs

The AAP input coding scheme is based on that of SOAP 84. Each card begins with an "identification" field that tells the AAP what kind of data to expect on the remainder of the card. A two-column numerical field (to identify time period or duration), a five-column numerical field (to identify begin time or intersection number), and eight five-column fields for variables (usually data by movement) follow. The last 25 columns are for alphanumeric variables—usually one-column directional indicators such as N, S, E, W, T(hru), and L(eft) and labels for use in headings. By using the same structure for all kinds of cards, it is easier to learn the coding scheme and to spot errors. Typical cards—the SETUP card and the VOLUME card—are shown in figure 1. The coding format allows the same "card deck" to be used for both PASSER and TRANSYT with minimal changes.




```
SETUP              1      12     60                   1.6                         N       EXAMPLE ROAD
C NAME BEGIN  TIME     NBT    NBL    SBT    SBL    EBT     EBL    WBT    WBL        LABEL-IF DESIRED
VOLUME        0700    1500    100   1500    100   1500     100   1500    100        EXAMPLE DATA
VOLUME        0800    1500    100   1500    100   1500     100   1500    100
CAPACITY      0700     1.8    0.5    2.0    1.5    2.0     1.0    2.0    1.0
```

Figure 1.—AAP input card format.

Outputs

A major problem with using SOAP, PASSER, and TRANSYT before the AAP was developed was in mentally converting from one set of outputs to another while evaluating the results. A consistent set of 80-column output formats was developed for each of the three component programs, which allows the outputs to be spread side by side so that the results can be compared easily (figs. 2-4). Although the MOE's generated by the programs are not identical, they are now comparable, facilitating translation of the program outputs to traffic signal controller settings.

AAP structure

The AAP structure (fig. 5) consists of data input managers (DIM's) to create the input data card deck; the card deck; the preprocessor, which maps the card deck to the temporary data file, performs diagnostic checking, and then creates input card decks for one or more component programs; the three component programs; the postprocessor, which creates the information for creating graphic displays on microcomputers and transmits information between PASSER and TRANSYT; and the microcomputer-based graphic display programs.

Defining a Problem for Analysis

The AAP can define two kinds of problems: A single-intersection, multiperiod analysis with SOAP and a multiple-intersection, single-period analysis using PASSER and TRANSYT to optimize signal progression. The same general file structure (a three-dimensional array) is used for both problems.

For multiple-intersection, single-period analysis, a SETUP card is defined (fig. 6) with the file definition as multiple intersection, the number of intersections, the period length, the progression speed, if signal-timing information is to be entered in seconds or percent of cycle, the orientation of the artery (N, S, E, or W), and the arterial name. Next, the ARTERIAL card tells the AAP whether to run PASSER or TRANSYT. The MAP cards establish

SYSTEM TOTAL MEASURES OF EFFECTIVENESS

ARTERIAL: SKILLMAN AVENUE BY: TRANSYT

PERFORMANCE MEASURES	TOTAL TRAVEL (V-MI)	TOTAL TIME (V-HR)	TOTAL DELAY (V-HR)	AVG. DELAY (SEC/V)	UNIFORM STOPS NO. (%)	FUEL CONS. (GA)	SYSTEM SPEED (MI/H)	PERFORMANCE INDEX
<TOTALS>	3009.88	183.14	97.07	27.5	9298.(73)	244.86	27.82	129.98

Figure 2. — TRANSYT system MOE's.

SYSTEM TOTAL MEASURES OF EFFECTIVENESS

ARTERIAL: SKILLMAN AVENUE BY: PASSER II

BANDWIDTH RESULTS	CYCLE LENGTH (SEC)	BANDWIDTH EFFICIENCY (%)	ATTAINABILITY (%)	THRU BANDWIDTHS (SEC)	PROGRESSION SPEEDS (MPH)
SYSTEM :	95	38	100	71	
NORTH BOUND :		35	-	33	31
SOUTH BOUND :		40	-	38	35

PERFORMANCE MEASURES	TOTAL VEHICLES (VEH/HR)	TOTAL DELAY (VEH-HR)	AVERAGE DELAY (SEC/VEH)	TOTAL STOPS (VEH/HR)(%)	FUEL CONSUMPTION (GAL/HR)	MAX MIN CYCLE (SEC)
TOTALS :	12717.	97.7	27.7	8724. (69)	398.3	94

Figure 3. — PASSER system total MOE's.

ARTERIAL SUMMARY

ARTERIAL: SKILLMAN AVENUE BY: PASSER II

INTERSECTION NO. NAME	MAX V/C (%)	TOTAL DELAY (V-HR)	AVG. DELAY (SEC/V)	TOTAL STOPS (VEH/H)(%)
1 MOCKINGBIRD :	88	38.55	35.1	3287.(83)
2 UNIVERSITY :	71	7.86	12.0	773.(33)
3 LOVERS LANE :	82	27.67	26.2	2625.(69)
4 SOUTHWESTERN :	89	23.63	32.7	2038.(78)
TOTAL SKILLMAN AVENUE :	89	97.71	27.7	8723.(69)

Figure 4. — PASSER arterial summary.

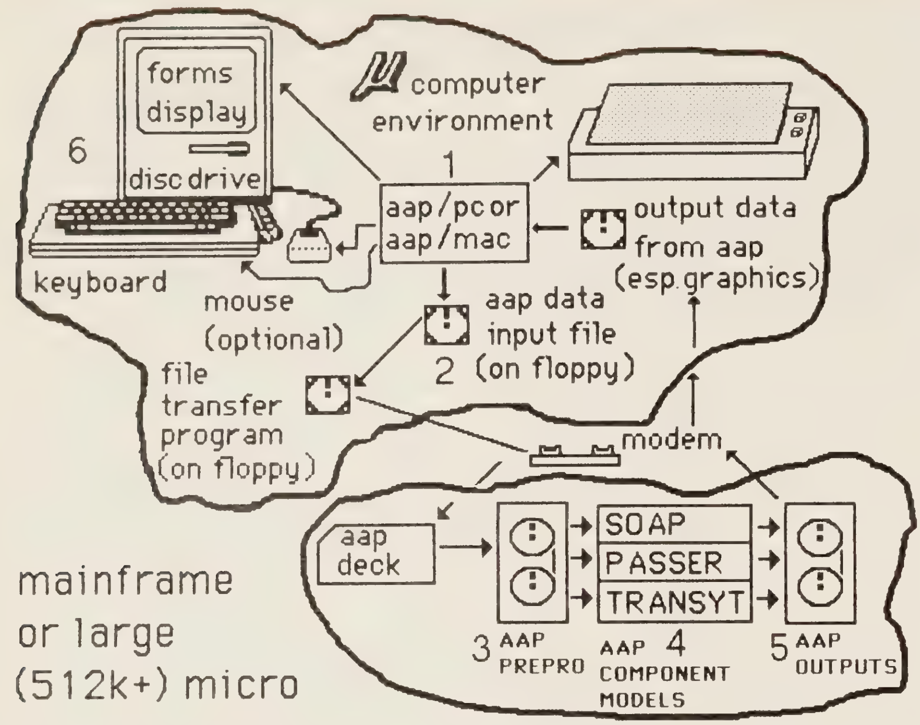


Figure 5.—AAP data flow and structure.

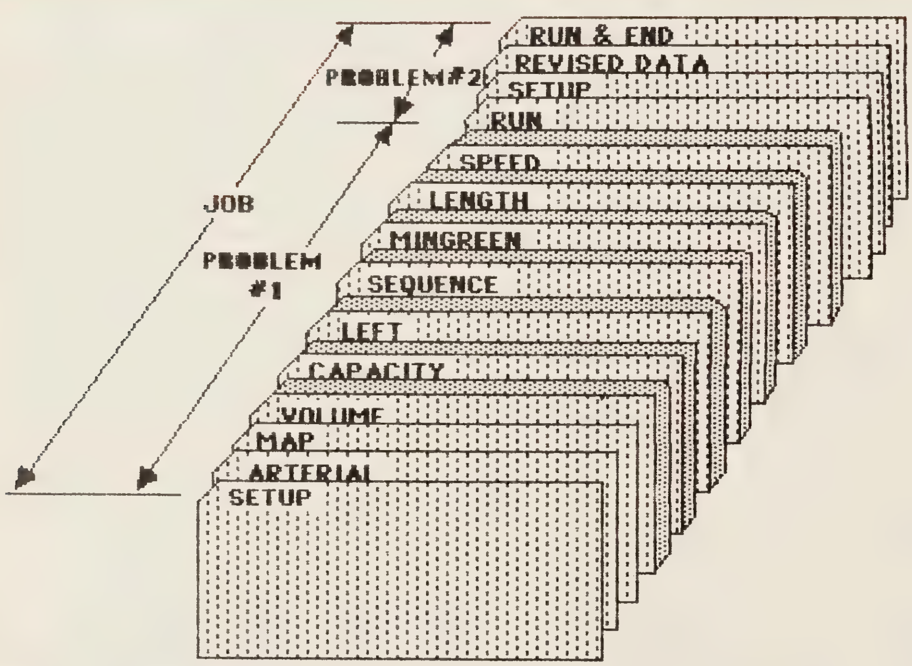


Figure 6.—AAP data deck structure.

the sequence number, the intersection reference number, and the name of each intersection. The VOLUME cards follow and provide the intersection reference number and traffic volumes for each of the intersection's movements. The CAPACITY cards then define the capacity for each movement either as a number of lanes (for example, 1, 2.0, or 3.4) or as saturation flow rates. LEFT cards are entered to describe permissive and restrictive left-turn movements or the lack of these movements. MINGREEN cards are needed if minimums for any movements differ from the default values—15 seconds for through movements and 10 seconds for left-turn movements. Because pedestrian volumes, intersection geometry, and local policies strongly affect these values, this optional card usually will be present. The LENGTH cards are used to give the distance from the stopline to the upstream stopline for the arterial approaches. The SPEED card gives the approach speed in miles per hour for each approach. The RUN card tells the computer that all the data have been entered, and the run should be made. The RUN card also specifies a case number and whether an optimization, evaluation run, actual run, or just an input data check is desired. The card also provides for an optional title for the run. The END card signals the computer that no more data for additional runs are in the data deck and that the AAP should terminate execution.

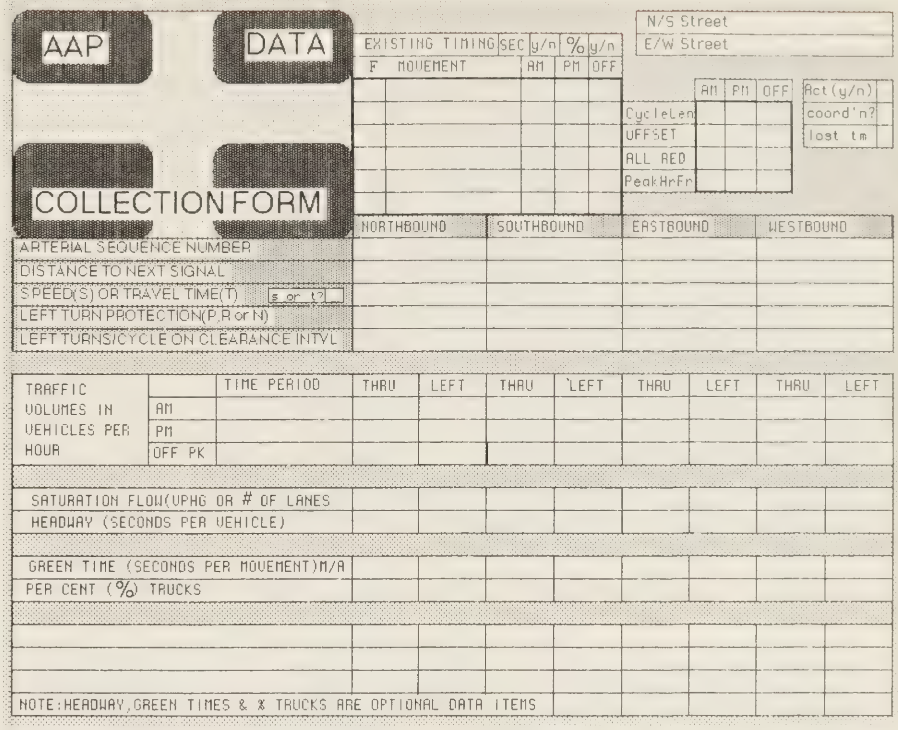
Preparing the Input Deck

The AAP input deck can be prepared in two ways. Traditionally, data are written on coding forms and then IBM cards are keypunched on a machine. This method, however, is being superseded by the use of DIM's, interactive data input programs written in BASIC or Fortran 77 on MS-DOS, Apple II, or Apple Macintosh microcomputers. The data coding form is replaced with a data collection form (fig. 7) organized to collect most of the data relevant to an individual intersection on one page for easy reference and entry into the DIM.

An AAP forms program hastens the creation of the initial AAP deck for single-period arterial analysis. The first menu in AAP forms allows the user to begin a new problem, enter input data, prepare an AAP input file, select an AAP input file, or exit. If "enter input data" is selected, the user has the option of dealing with the problem-description data, the intersection-oriented data, or the approach data; specifying tables or plots to be printed; or providing run data. Sub-menus then allow the data to be entered in a tabular format similar to a spreadsheet.

The AAP DIM edits individual data cards, enters multiple-run or multiple-period data, and enters special cards not provided for in the AAP forms program (figs. 8 and 9).

After the AAP input deck has been prepared, it is transmitted to a mainframe computer for execution by the AAP using a modem program. A larger microcomputer (IBM PC or XT with 256k bytes of memory or an Apple Macintosh 512k or plus) can execute the AAP directly.


AAP DATA COLLECTION FORM

N/S Street
E/W Street

EXISTING TIMING	SEC	y/n	%	y/n
F MOVEMENT		AM	PM	OFF

	AM	PM	OFF
CycleLen			
OFFSET			
ALL RED			
PeakHrFr			

Act (y/n)
coord'n?
lost tm

	NORTHBOUND	SOUTHBOUND	EASTBOUND	WESTBOUND
ARTERIAL SEQUENCE NUMBER				
DISTANCE TO NEXT SIGNAL				
SPEED(S) OR TRAVEL TIME(T) [s or t?]				
LEFT TURN PROTECTION(P,R or N)				
LEFT TURNS/CYCLE ON CLEARANCE INTVL				

TRAFFIC VOLUMES IN VEHICLES PER HOUR	TIME PERIOD	THRU	LEFT	THRU	LEFT	THRU	LEFT	THRU	LEFT
	AM								
	PM								
	OFF PK								
SATURATION FLOW(VPHG OR # OF LANES									
HEADWAY (SECONDS PER VEHICLE)									
GREEN TIME (SECONDS PER MOVEMENT)M/A									
PER CENT (%) TRUCKS									

NOTE: HEADWAY, GREEN TIMES & % TRUCKS ARE OPTIONAL DATA ITEMS

Figure 7.—Data collection form.

Interpretation of Results

The AAP outputs were designed to be listed on an 80-column CRT screen or printed on 80-column paper. This allows tables to be inserted conveniently into standard-sized 8½- × 11-in reports. The major sets of results are: Input data reports, performance evaluations, signal timing, time-space diagrams, platoon dispersion diagrams (under development),[3] and error/warning messages.

There are three input data reports. The input data echo, an echo of the input cards exactly as they were read into the program without any preprocessing, allows the user to see where any errors occur in the input deck. The global parameters allow the user to review the data set up for the entire system in a structured and commented fashion. The approach-specific parameters provide the same function for the data for each individual intersection. Because not all input data are relevant to all AAP component programs, some parameters may not be relevant for particular runs. Default values for nonspecified parameters will be provided.

Performance evaluation of a design is critical to determine what will happen if the design is implemented. Intersection MOE reports are available from SOAP, PASSER, and TRANSYT; system total and arterial summary MOE reports are available from TRANSYT and PASSER (figs. 2-4).

If the MOE results are satisfactory, then the signal timing can be implemented. The single-intersection signal timing tables from SOAP and the system signal timing plans and intersection timing plans from PASSER and TRANSYT provide detailed information on phase lengths, percent of cycle, and (for electromechanical controllers) pin settings. Engineers can adjust the offsets to increase the "perceived" progression with minimal damage to the MOE's.

Validation and Availability

The AAP component programs have been in widespread use since 1979 when SOAP was introduced as a signal timing tool for isolated intersections. The GASCAP program in the State of Florida demonstrated the use of SOAP for practical applications. The State of Texas has used the PASSER program as a maximal bandwidth coordination tool since the early 1970's. As a mathematical algorithm, PASSER has been shown to produce very usable results. The TRANSYT model was used by the State of Kentucky in a signal timing study and produced reasonable results, with MOE's comparable to those of Netsim, SIGOP III, and field data. A similar study in Overland Park, Kansas, also found TRANSYT-7F to give good MOE data comparable to field data and other optimization models evaluated. As a result, it was decided that TRANSYT-7F would be the "evaluation" tool in the AAP.

[3] Courage et al., "Platoon Progression Diagram User's Manual," prepared for the Federal Highway Administration course on the AAP, Washington, DC, 1984.

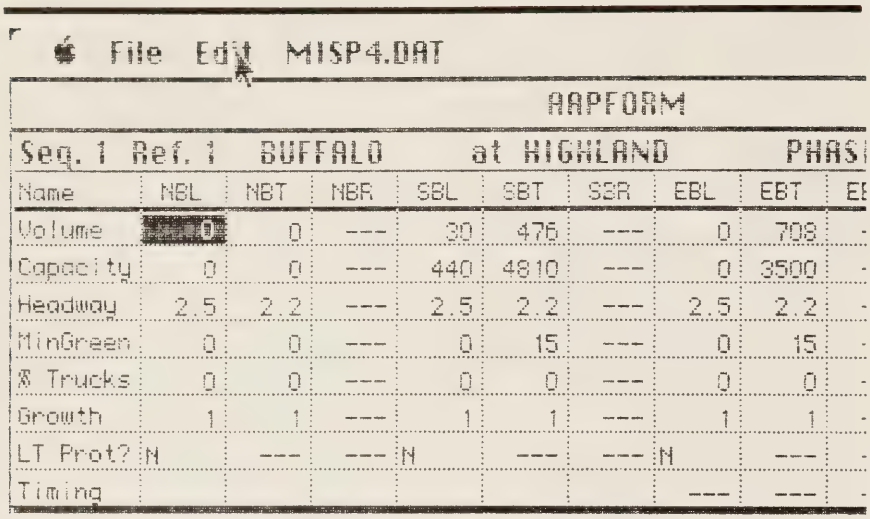


Figure 8.—AAP forms—intersection data screen.

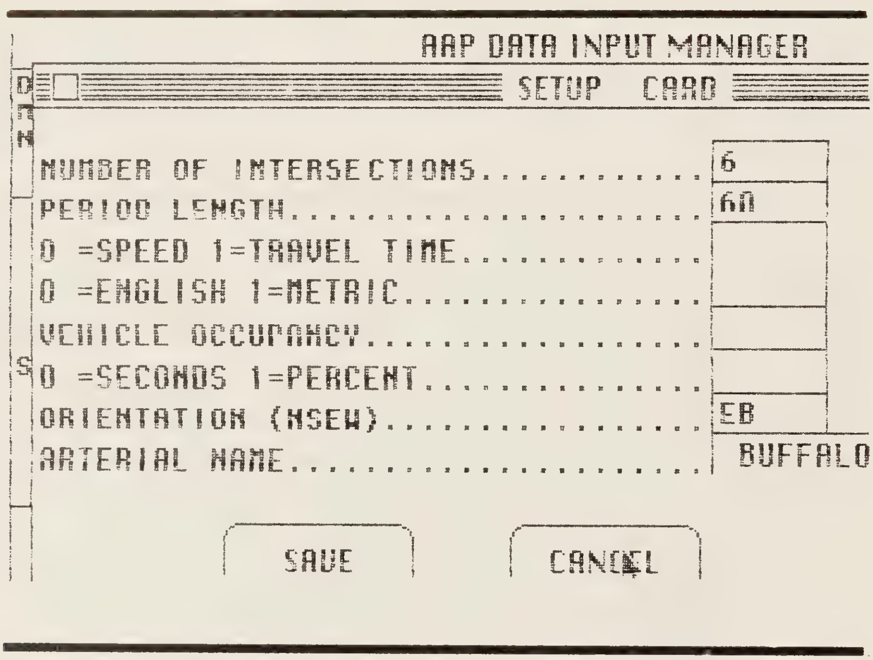


Figure 9.—AAP DIM edit card screen.

The mainframe version of the AAP (version 2.0) is available on a trial basis from the Federal Highway Administration, Office of Implementation, HRT-20, 6300 Georgetown Pike, McLean, Virginia 22101-2296. The microcomputer versions are available on floppy disk from the McTrans Support Center, University of Florida, 346 Weil Hall, Gainesville, Florida 32611, for IBM PC's and Apple Macintosh microcomputers. DIM's for the AAP are available for the IBM, Apple Macintosh, and Apple II microcomputers.

A 3-day training course on the AAP is available for a fee of $4,000 from FHWA's National Highway Institute. Please contact Mr. Ron Giguere, Federal Highway Administration, Office of Traffic Operations, HTO-23, 400 7th Street, SW., Washington, DC 20590; telephone: (202) 366-2203. The course may be taught in any of three ways depending on the availability of microcomputers. If a microcomputer laboratory with 12 or more IBM and/or Apple microcomputers is available, then a microcomputer-based "hands on" course can be presented. If only a few microcomputers are available and a laboratory setting is not available, then a mainframe-based course with microcomputer demonstrations can be presented. If no microcomputers are available, then a mainframe-based course will be given.

REFERENCES

(*1*) K.C. Courage and D. Reaves, "Signal Operations Analysis Package," Report No. FHWA-IP-85-7, *Federal Highway Administration*, Washington, DC, January 1985.

(*2*) "PASSER II-84 Users Manual," Report No. FHWA/TX-84/50+375-1F, *Texas State Department of Highways and Public Transportation*, Austin, TX, 1984.

(*3*) Wallace et al., "TRANSYT-7F User Manual," *Federal Highway Administration, Office of Traffic Operations*, Washington, DC, June 1984.

David R.P. Gibson is a traffic engineer with the Safety and Traffic Implementation Division, Office of Implementation, Federal Highway Administration. He is project manager of the Arterial Analysis Package project and is responsible for technology transfer activities on traffic signal controller hardware and timing. Before joining the Office of Implementation, Mr. Gibson was a traffic engineer for the District of Columbia.

Llewellyn Williams is a traffic engineer with the Safety and Traffic Implementation Division, Office of Implementation, FHWA, where he is responsible for technology transfer activities in traffic and safety. Before joining the Office of Implementation, Mr. Williams was head of traffic operations for the State of West Virginia.

Technology Transfer Laboratory

Traffic control systems equipment, displayed in the Technology Transfer Laboratory at the May 1985 Open House at the Turner-Fairbank Highway Research Center.

The Federal Highway Administration (FHWA) Offices of Research, Development, and Technology (RD&T) have established a **Technology Transfer Laboratory** at the Turner-Fairbank Highway Research Center in McLean, Virginia. Operated by the Office of Implementation, the purpose of the Laboratory is to investigate and facilitate new methods for technology transfer (T^2), including more effective and efficient promotion of new technology, better communication to the highway community, and faster response to FHWA and State requests for assistance. The Technology Transfer Laboratory currently includes office space, a computer-user area, a photologging work station, a slide preparation area, and classroom space.

During the developmental stage of the Laboratory, microcomputer assistance services were provided—testing and evaluating applications software; testing new microcomputers and related hardware; investigating new uses for microcomputers to support T^2; and providing consultation and support for microcomputer users throughout FHWA. In the future, this assistance function will focus primarily on investigating new microcomputer hardware and software and new ways to support T^2 effectively as the use of microcomputers by the FHWA staff increases.

When fully operational, the Laboratory will be staffed by FHWA personnel and a support services contractor. Electronic devices and concepts, such as computer-generated graphics systems, microcomputer/laser disk interfacing, and microcomputer display systems, will be evaluated and adapted in the Laboratory to reduce the cost of T^2. The support services contractor will help develop the electronic devices and concepts selected and prepare the operation and maintenance procedures to ensure continued use of the systems. The contractor also will assist with onsite operational support for these devices and concepts.

Expert systems represent a promising technology that is expanding rapidly in many industries but has not reached widespread use in the highway engineering field. FHWA's Technology Transfer Executive Committee has recommended that the Technology Transfer Laboratory be the focal point for expert systems development in FHWA, serve as a clearinghouse for information on expert systems, and assist with systems developed by the Offices of RD&T and the FHWA T^2 offices. The Technology Transfer Laboratory is providing training for FHWA personnel and is developing the capabilities—hardware, software, and expertise—for evaluation and development of expert systems.

Expert systems will provide effective support for diagnosis, design, decisionmaking, and training. Currently, three expert systems are being developed under the sponsorship of FHWA: "An Expert System for Asphalt Concrete Construction," a joint venture between FHWA and the Corps of Engineers' Construction Engineering Research Laboratory to support asphalt construction inspection, including asphalt mixes, plant operation, weighing, laydown, and compaction; "Application of Artificial Intelligence to Urban Congestion Problems," to assess the feasibility of and recommend an approach for developing artificial intelligence tools for reducing congestion and improving throughput in major highway corridors; and "EXPAVE: A System to Assist the Design Engineer in Concrete Pavement Evaluation and Rehabilitation."

The Technology Transfer Laboratory is developing a slide library to store slides and associated text for the FHWA T^2 Program. This library will be maintained by the support services contractor and will be available to FHWA personnel. An optical disk system will be used for storage and rapid access to the slides and text.

Long-range communications plans include developing full teleconferencing facilities to improve methods of T^2 to remote locations, which could augment T^2, training, and general information exchange with the field.

Further information on the Technology Transfer Laboratory can be obtained by contacting:

Messrs. Jim Wentworth or Bob Ellington
FHWA, Office of Implementation
Safety and Traffic Implementation Division, HRT-20
6300 Georgetown Pike
McLean, Virginia 22101-2296
Telephone: (703) 285-2511 or 285-2512

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, Virginia 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, Virginia 22161

Cost-Effectiveness of Sampling and Testing Programs, Executive Summary, Report No. FHWA/RD-85/029, and Final Report, Report No. FHWA/RD-85/030

by Materials Division

These reports present the results of a study to develop a new model and computer program for improving the cost-effectiveness of sampling and testing programs. The new program, COSTOP1, is used to establish priorities among quality control tests and to optimize sampling frequencies for each test. The model considers the cost of testing, the impact of testing changes on construction practice, the effect of a material property (test result) on pavement performance, and maintenance strategy and cost in determining the cost-effectiveness. The program is modular, allowing users to substitute their own cost data, maintenance strategies, and performance models.

The reports may be purchased from NTIS (PB Nos. 86 243995 and 86 155199).

Behavior of Piles and Pile Groups Under Lateral Load, Report No. FHWA/RD-85/106

by Materials Division

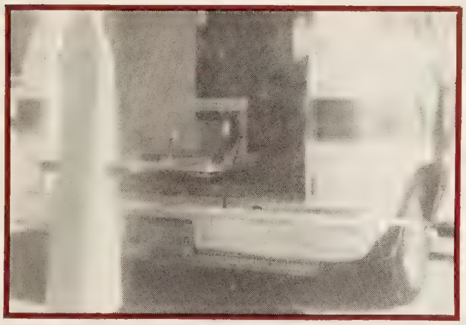
Several methods of analysis and design of piles under lateral loading are in use. Presumptive values that suggest allowable, but conservative, loads are included in some manuals of practice. For example, batter piles may be used with an assumption, not entirely correct, that no lateral load is taken by vertical piles. Several rational methods in which the equations of mechanics are satisfied have been proposed and are reviewed in this report.

The rational method uses different equations to solve the governing differential equation along with the use of nonlinear curves to describe the soil response. Curves showing soil resistance "p" as a function of pile deflection "y" have been recommended for several kinds of soil and pile loading.

Case studies are presented in which results from analysis are compared with results from experiment. Design recommendations are made, and needed research is outlined.

The report may be purchased from NTIS (PB No. 86 238466).

Rapid Nondestructive Delamination Detection, Report No. FHWA/RD-85/051

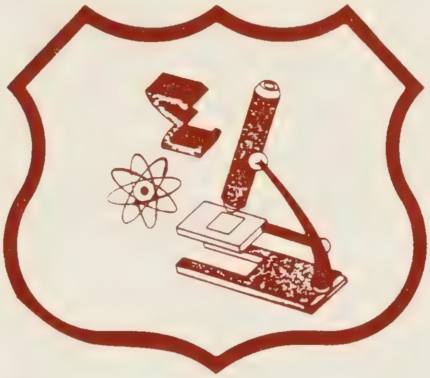


by Materials Division

Corrosion-induced delamination of bridge decks is a major problem in the United States. Early detection of delaminations can optimize the scheduling of maintenance and prevent costly repairs at a later date. This report discusses a study on assessing the delamination condition of inservice bridge decks without disrupting traffic. The radar field instrumentation system developed in the study was successful in detecting delaminations at a speed of 40 mi/h (64 km/h). The radar system also can be used at low speeds or in an essentially static mode to define the exact areas of concrete removal at the time of bridge deck rehabilitation. The system is suitable for decks overlaid with asphalt as well as bare concrete decks and is substantially independent of weather. Standing water has a disabling effect on the inspection signal, and it is doubtful that an inspection could be performed with puddles on the surface. However, damp pavement has virtually no adverse effect on the inspection signal.

The report may be purchased from NTIS (PB No. 86 177516).

Engineering Characterization of SULPHLEX Binders, Report No. FHWA/RD-85/032, and Chemical Characterization of SULPHLEX Binders, Report No. FHWA/RD-85/033



by Materials Division

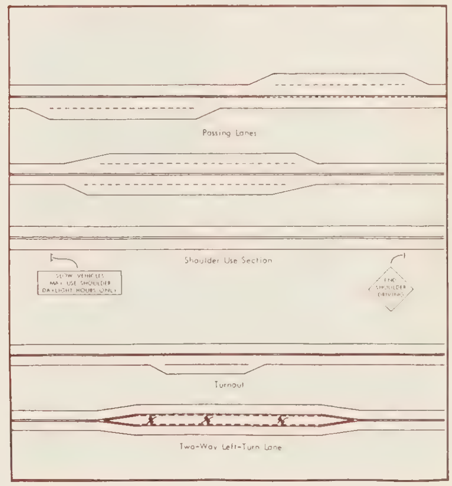
A chemically-modified sulfur called SULPHLEX (a trademark of Southwest Research Institute) consists of 70 percent elemental sulfur and 30 percent of a combination of hydrocarbons, which chemically react with molten sulfur. This chemical reaction allows the polymeric, molten sulfur to retain, at least to some extent, certain favorable engineering properties after cooling.

Report No. FHWA/RD-85/032 presents the results of an extensive engineering characterization including mixture design considerations; flexural fatigue; fracture potential; deformation potential; creep compliance and stiffness response; aging characteristics; and resilient and dynamic moduli properties. In addition, a pavement performance prediction of SULPHLEX as a paving material under various climates and traffic conditions was made using a systems pavement analysis approach.

Report No. FHWA/RD-85/033 discusses the chemical stability and characteristics of SULPHLEX.

The reports may be purchased from NTIS (PB Nos. 86 186483 and 86 182219).

Passing Lanes and Other Operational Improvements on Two-Lane Highways, Report No. FHWA/RD-85/028

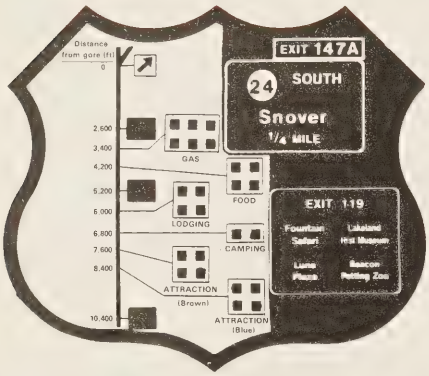


by Traffic Safety Research Division

Many rural two-lane highways experience operational problems related to high traffic volumes; lack of adequate passing opportunities; recreational and other slow-moving vehicles, such as schoolbuses and farm equipment; roadside development that generates turning maneuvers at driveways; and turning movements at intersections. This report evaluates five operational treatments to alleviate these problems: Passing lanes; short, four-lane sections; shoulder-use sections; turnouts; and two-way, left-turn lanes. Current signing, marking, and design practices used for these operational treatments in 13 States that participated in the study are reviewed. An operational evaluation of the treatments was based on field data collected at 35 treated sites, and a safety evaluation of these treatments was based on accident data collected at 138 treated sites. The study concluded that all five operational treatments evaluated can improve traffic operations on two-lane highways at relatively low cost. Passing lanes; short, four-lane sections; and two-way, left-turn lanes also improved safety. Turnouts and shoulder-use sections had no effect on safety.

The report may be purchased from NTIS (PB No. 86 214293).

Effects of Supplemental Interchange Signing on Driver Control Behavior, Report No. FHWA/RD-86/077

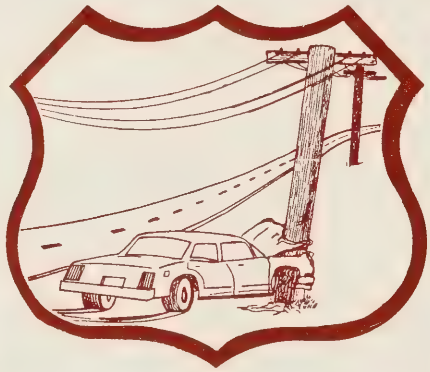


by Traffic Safety Research Division

Research was conducted to determine the effect on driver behavior of supplemental interchange signing, including various combinations and numbers of tourist-oriented attraction and service signs. Thirty-six test subjects "drove" the Federal Highway Administration driving simulator on a simulated 40 mi (64 km) freeway with 14 interchanges with supplemental signing for attractions and services. Test subjects were asked to identify specific attraction and/or service signs when approaching interchanges. Data were collected for computer analysis regarding speed differential, erratic maneuver, acceleration noise, and recognition distance. The addition of the supplemental attraction signs generally was detrimental to driver control behavior. Field tests should be conducted to confirm the behavior effects. Driver age, sign spacing, and total number of supplemental signs per interchange should be examined during the field study. The sign designs also require refinement and further study.

The report may be purchased from NTIS (PB No. 86 199353).

Cost-Effectiveness of Countermeasures for Utility Pole Accidents, Report No. FHWA/RD-83/063



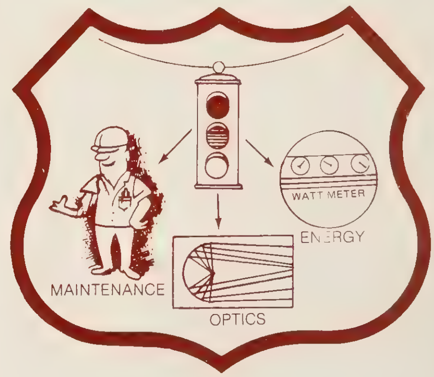
by Safety Design Division

The study described in this report was conducted to develop a cost-effectiveness analysis procedure for the optimal selection of countermeasures for utility pole accidents. Accident, traffic, and roadway data were collected and analyzed for over 2,500 mi (4 000 km) of urban and rural roads in four States. The results of the data analysis showed that lateral pole offset, traffic volume, and pole density were most highly related to utility pole accidents. A utility pole accident predictive model was developed.

Based on a cost-effectiveness analysis, undergrounding, pole relocation, and breakaway pole hardware were found to be cost-effective for telephone and electric distribution lines for various traffic and roadway conditions. Reducing pole density through multiple use also was cost-effective in some instances, but increasing pole spacing generally was not cost-effective. No countermeasures involving large transmission poles and lines were cost-effective within the limits of the analysis. General guidelines were developed for selecting cost-effective countermeasures. A computer program was developed for selecting optimal countermeasures for specific roadway sections.

The report may be purchased from NTIS (PB No. 86 181245).

Alternative Incandescent Traffic Signal Lamps and Systems for Improved Optical and Energy Efficiency, Report No. FHWA/RD-85/089



by Traffic Systems Division

This report discusses a study to determine methods of improving the optical efficiency of traffic signals to reduce power usage while maintaining high safety standards. Indepth investigations on the use of quartz-halogen lamps, low-voltage lamps, redesigned lenses, and nighttime signal dimming showed that all methods decreased power usage, although in some cases the increased initial cost did not justify their application. Very large efficiency gains were obtained using redesigned lenses, and these principles are described in the report.

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

Implementation/User Items "how-to-do-it"

The following are brief descriptions of selected items that have been completed recently by State and Federal highway units in cooperation with the Office of Implementation, Offices of Research, Development, and Technology (RD&T), Federal Highway Administration. Some items by others are included when the items are of special interest to highway agencies.

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, Virginia 22161

Cost-Effective Inventory Procedures for Highway Data: Users Manual, Report No. FHWA-IP-85-14

by Office of Implementation

This users manual was developed to aid in selecting cost-effective inventory procedures for highway data. The experiences of highway agencies and other users were analyzed to determine advantages and disadvantages of alternative inventory procedures. A cost analysis was performed for these procedures under various roadway, population density, and other system characteristics conditions, and a procedure for selecting the most cost-effective inventory method was developed.

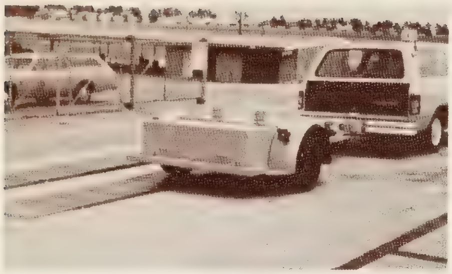
The manual may be purchased from NTIS (PB No. 86 196953).

Model Procedure for Inservice Evaluation of Roadside Safety Hardware Devices, Report No. FHWA-IP-86-8

by Office of Implementation

This report presents procedures for conducting inservice evaluations of roadside safety hardware devices. Part I of the report reviews the planning process, identifies key elements required in an evaluation work plan, and outlines the responsibilities of various State agencies. It also describes the process for selecting sites, installing hardware devices, analyzing evaluation data, and reporting the findings. Part II of the report consists of sample work plans for the following roadside safety appurtenances: Eccentric loader breakaway cable terminal, IBC barrier system, controlled release terminal, and the self-restoring traffic barrier (SERB) median barrier.

The report may be purchased from NTIS (PB No. 86 195906).



Calibration Procedures for Roadmeters, Report No. FHWA-TS-86-201

by Office of Implementation

This report discusses a research project conducted to evaluate the performance of an inexpensive, noncontact roughness measuring device—the Roughness Surveyor—as well as the potential use of this device as a calibration reference for response-type road roughness measuring (RTRRM) systems. RTRRM systems from Georgia, Florida, and Minnesota were correlated against the Roughness Surveyor, the inertial profilometer owned by the Ohio Department of Transportation, and the profilometer designed and operated by the South Dakota Department of Transportation.

Sixteen test sites were selected for the correlation and calibration study, with 52 individual test sections encompassing a variety of roughness levels and pavement surfaces. The results of the roughness testing showed an excellent correlation between all of the devices. The standard error of estimate, however, was rather large for some of the linear regression equations. An analysis of serviceability of index ratings from the Florida, Ohio, and South Dakota units indicated that different values were obtained between the units on the same test sections.

The evaluation of the Roughness Surveyor indicated that the roughness results obtained were insensitive to speed variations. Problems were encountered with obtaining valid roughness readings on extremely rough textured surfaces, such as surface treatment. The testing repeatability of the Roughness Surveyor was not as good as that obtained with the Ohio profilometer and slightly better than two of the three RTRRM systems. The day-to-day variability was much higher for the Roughness Surveyor than for the Ohio profilometer and the RTRRM systems.

The report may be purchased from NTIS (PB No. 86 246642).

Mobile Reflectance Checker for Snowplowable, Raised Pavement Markers

by the Ohio Department of Transportation

The Ohio Department of Transportation (ODOT) has built a device—LIFE-LITE—that can check for the presence of adequately-performing reflectors in snowplowable, raised pavement markers (SRPM's) at highway speeds.

The LIFE-LITE checker is a combination of two sensing systems. To detect the passage of the metal SRPM casting, ODOT adapted the antenna and associated circuitry from their Paint-Skip machine, an attachment for traffic paint stripers that interrupts paint flow across each SRPM in its path.

The optical system, which responds to the SRPM's retroreflector, consists of a row of six infrared scanners, off-the-shelf components that are common in the industrial control field. The scanners emit a pulsed, infrared light beam, and sense, with synchronous detection circuitry, a returned portion of that beam from a retroreflector—in this case, the one in the SRPM. The scanners respond within a millisecond by producing a voltage level change (essentially a switch closure) when their detection threshold is exceeded. They can operate as well in daylight as they can at night.

The sensors are mounted on a simple rectangular aluminum frame attached to the driver's side of the car. The metal-sensing antenna, which must have a small road clearance, is on a pivot so that it can deflect upward in case of contact with obstacles.

For more information on the LIFE-LITE, contact Mr. Wallace Richardson at the Ohio Department of Transportation, Bureau of Traffic, Research and Development Section, 25 S. Front Street, Columbus, OH 43215. Telephone: (614) 462-8175.

Guidelines for Slope Maintenance and Slide Restoration, Report No. FHWA-TS-85-231

by Office of Implementation

As part of a continuing project to evaluate and improve maintenance activities, a study on slope maintenance and slide restoration was undertaken. Slope maintenance and slide restoration was identified by a number of States as a major problem involving considerable maintenance funds.

This report discusses guidelines on slide identification and definition of terms, investigation and inspection of critical slopes and drainage, maintenance activities that will aid in the prevention and minimization of slides, maintenance activities that are related to particular distress items, and repair and restoration techniques including relative cost information.

The guidelines reflect the collective experience of the six participating States and are designed for use by the first level maintenance supervisor—the person responsible for scheduling day-to-day maintenance work.

The report may be purchased from NTIS (PB No. 86 245578).

Design and Construction of the Linn Cove Viaduct, Report No. FHWA-TS-84-214

by Office of Implementation

The Linn Cove Viaduct is located on the eastern slope of Grandfather Mountain in Avery County, North Carolina, in the last section of roadway to be completed along the Blue Ridge Parkway. This report documents the design and construction of the structure with indepth discussions on the major innovations in precast concrete segmental design, materials requirements, precasting, and erection procedures that were used in the project. The investigation, design, and construction of the structure's complex foundation requirements also are documented.

The progressive placement technique was used to construct the Linn Cove Viaduct to minimize the environmental impact on the site. Construction of the 1,243-ft (379-m) long structure with its S-and-one-half curvature proceeded overhead without the need for ground access except at the piers.

The report may be purchased from NTIS (PB No. 86 181682).

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 1A: Traffic and Safety Control Devices

Title: Construction Costs and Safety Impacts of Work Zone Traffic Control Strategies. (FCP No. 31A5754)
Objective: Determine the costs and safety impacts associated with traffic control through work zones on four-lane divided highways using single-lane closure or two-lane, two-way traffic operations. Prepare an informational guide to assist highway engineers in selecting the most cost-effective traffic control strategy in rebuilding an existing rural, four-lane divided highway.
Performing Organization: E.N. Burns and Associates, Columbus, OH 43229
Expected Completion Date: September 1988
Estimated Cost: $248,660 (FHWA Administrative Contract)

FCP Project 1K: Accident and Countermeasure Analysis

Title: Trends in Highway Information. (FCP No. 31K1012)
Objective: Assess the impact of trends related to highway information on the ability of FHWA, States, and local jurisdictions to perform the highway safety mission successfully. Make recommendations concerning the appropriate means for dealing with reduced reporting of property-damage-only accidents and the process for identifying high-hazard locations and evaluating accident countermeasures.
Performing Organization: Daniel Consultants, Inc., Columbia, MD 21045
Expected Completion Date: June 1987
Estimated Cost: $105,725 (FHWA Administrative Contract)

FCP Project 1Z: Implementation of Safety R&D

Title: Accessible Networks for Elderly and Handicapped Pedestrians—Manual Revisions. (FCP No. 31ZN038)
Objective: Develop an updated manual to summarize current problems, opportunities for improvement, and beneficial changes to the existing priority accessible network procedure.
Performing Organization: KRW, Inc., Burke, VA 22015
Expected Completion Date: August 1987
Estimated Cost: $72,000 (FHWA Administrative Contract)

FCP Category 2—Traffic Control and Management

FCP Project 2P: Urban Freeway Management

Title: Investigation of Successful Communications and Traffic Control System Design, Installation, and Operations Practices. (FCP No. 32P2182)
Objective: Visit nine existing traffic control systems (including both freeway surveillance and control and signal systems) and perform indepth case studies of practices that resulted in successful design, installation, and operation of such systems. Develop guidelines for successful traffic control system implementation. Assess existing and new communications technologies used, or with potential for use, in traffic control systems including cable television, fiber optics, low-cost satellite communications, FM side-band communications, low-cost/low power UHF radio communications, and cellular telephone communications.
Performing Organization: JHK and Associates, Alexandria, VA 22304
Expected Completion Date: June 1988
Estimated Cost: $220,825 (FHWA Administrative Contract)

FCP Category 3—Highway Operations

FCP Project 3B: Environmental Management

Title: Determination of Noise Source Height of Vehicles on Florida Roads and Highways. (FCP No. 43B2026)
Objective: Apply source localization techniques used in Europe to identify noise sources to highway vehicle source heights to improve criteria for highway noise barriers. Use a seven-element microphone array and seven-channel tape recorders to measure noise of passing vehicles. Analyze noise signals. Measure source heights of individual vehicles on isolated roads, three roads with various kinds of truck traffic, and typical highways with heavy traffic. Develop source heights for vehicle type, speed, and sound frequency.
Performing Organization: Florida Atlantic University, Boca Raton, FL 33431
Funding Agency: Florida Department of Transportation
Expected Completion Date: June 1988
Estimated Cost: $132,110 (HP&R)

Title: Slope Erosion Control Study. (FCP No. 43B3232)
Objective: Characterize soil, granite, and other rocks for erosion resistance, weathering, and slope protection. Develop temporary and permanent slope protection systems. Evaluate literature and observations of roadside erosion control measures. Analyze the causes of and damage from erosion on road slopes and costs to drainage systems and traffic flows. Analyze in the laboratory soils and rocks representing those found on road slopes to determine the erosion indices with simulated weathering, soils tests, and artificial rainfall. Make field observations at 50 sites with various materials and treatments to determine soil erosion, plant behavior, and other conditions. Develop a manual for recommended practices to control roadside slope erosion.
Performing Organization: Arizona State University, Temple, AZ 85281
Funding Agency: Arizona Department of Transportation
Expected Completion Date: September 1987
Estimated Cost: $104,555 (HP&R)

Title: Construction Erosion Control. (FCP No. 43B3252)
Objective: Evaluate the effectiveness and costs of alternative means for erosion/pollution control at highway construction sites. Determine the most cost-effective measures and marginal costs for selection of more effective measures. Develop a highway construction site erosion/pollution control manual that presents decision criteria for strategy planning and guidelines and specifications for design and operation of control measures.
Performing Organization: University of Washington, Seattle, WA 98501
Funding Agency: Washington State Department of Transportation
Expected Completion Date: July 1987
Estimated Cost: $41,605 (HP&R)

FCP Category 4—Pavement Design, Construction, and Management

FCP Project 4C: Design and Rehabilitation of Flexible Pavements

Title: Development of an Improved Overlay Design Method. (FCP No. 44C1323)
Objective: Evaluate existing methods of overlay designs, both empirical and mechanistic, as well as the method used by Alaska. Develop an improved framework for overlay design. Collect data on selected projects including modulus and deflection, and test the developed system. Computerize the procedure.
Performing Organization: Oregon State University, Corvallis, OR 97331
Funding Agency: Oregon Department of Transportation
Expected Completion Date: April 1988
Estimated Cost: $27,750 (HP&R)

Title: Evaluation of Antistripping Additives. (FCP No. 44C4394)
Objective: Study in the field and laboratory five antistripping additives, including hydrated lime and four liquid chemical additives. Evaluate the additives with both a tensile strength test and a boiling water test.
Performing Organization: Virginia Highway Research Council, Charlottesville, VA 22903
Funding Agency: Virginia Department of Highways and Transportation
Expected Completion Date: June 1989
Estimated Cost: $28,000 (HP&R)

Title: Polymer Modified Asphalt Guidelines—Phase 1. (FCP No. 44C5114)
Objective: Develop guidelines for evaluating the performance of polymer modified aphalts in the laboratory. Use the guidelines to prepare preliminary specifications for purchasing such materials.
Performing Organization: New Mexico Engineering Research Institute, Albuquerque, NM 87131
Funding Agency: New Mexico State Highway Department
Expected Completion Date: October 1987
Estimated Cost: $82,000 (HP&R)

Title: Evaluation of Asphaltic Concrete Modifiers to Reduce Rutting. (FCP No. 44C5125)
Objective: Evaluate the effectiveness of asphalt additives to decrease rutting using three experimental pavement test sections—a control, a section containing the modified binder, and sections containing both modified and unmodified binders where a greater proportion of local, lower quality aggregate is used.
Performing Organization: Georgia Department of Transportation, Atlanta, GA 30334
Expected Completion Date: June 1989
Estimated Cost: $40,000 (HP&R)

Title: A Comparative Study of Performance of Different Designs for Flexible Pavements. (FCP No. 44C6344)
Objective: Collect data on material properties (moduli, permanent deformation parameters, etc.) for use in mechanistic design methods. Develop a mechanistic pavement performance predictive model. Compare the field performance of a pavement with the predicted performance. Evaluate the effect of different kinds and thicknesses of pavement layers on pavement distress and performance. Evaluate the effect of subgrade strength on the relative strength of each base course type.
Performing Organization: North Carolina State University, Raleigh, NC 27695
Funding Agency: North Carolina Department of Transportation
Expected Completion Date: December 1996
Estimated Cost: $50,000 (HP&R)

FCP Category 5—Structural Design and Hydraulics

FCP Project 5A: Bridge Loading and Design Criteria

Title: Computer-Aided Bridge Design/Drafting Integration—Phase I. (FCP No. 45A4142)
Objective: Integrate bridge design capabilities into the existing New Mexico State Highway Department computer-aided design/drafting (CADD) system. Develop the software necessary to interface the CADD system with the proposed AASHTO bridge design system as well as other design processes.
Performing Organization: New Mexico State University, Las Cruces, NM 88003
Funding Agency: New Mexico State Highway Department
Expected Completion Date: July 1987
Estimated Cost: $98,000 (HP&R)

FCP Project 5H: Highway Drainage and Flood Protection

Title: Estimating Flood Hydrographs and Volumes for Alabama Streams. (FCP No. 45H2622)
Objective: Develop a technique to estimate the shape of the average flood hydrograph and the flood volume from a given flood peak of a specific recurrence interval on ungauged basins with drainage areas of specified square miles with minimum in-channel storage.
Performing Organization: United States Geological Survey, Alabama District Office, Tuscaloosa, AL 35401
Funding Agency: Alabama Highway Department
Expected Completion Date: May 1988
Estimated Cost: $35,000 (HP&R)

Title: Development of a Risk-Cost Methodology to Size Detour Drainage Structures. (FCP No. 45H4952)
Objective: Establish a logic methodology capable of determining the design flood for a detour drainage on the basis of risk-cost relative to the permanent structure.
Performing Organization: University of Colorado, Boulder, CO 80309
Funding Agency: Colorado Department of Highways
Expected Completion Date: June 1987
Estimated Cost: $5,000 (HP&R)

FCP Project 5K: Bridge Rehabilitation Technology

Title: Long-Term Weathered Steel Beams. (FCP No. 45K2382)
Objective: Determine the loss in fatigue life of weathered steel beams after an equivalent of 25 years of exposure. Compare the results with existing data on nonweathered specimens tested under constant and variable amplitude fatigue, 2-year and 3-year weathered specimens, and the AASHTO fatigue specification requirements to determine the safe life expectancy of long-term weathered steel beams. Extrapolate the results to estimate expected loss in life at 50 years of service.
Performing Organization: University of Maryland, College Park, MD 20742
Funding Agency: Maryland State Highway Administration
Expected Completion Date: June 1987
Estimated Cost: $67,175 (HP&R)

Title: Field Monitoring of the Cable-Stayed, Segmental James River Bridge During Construction. (FCP No. 45K2402)
Objective: Instrument the I-295 James River cable-stayed bridge to determine live load stress range in the stay cables and the torsional and thermal stresses in the box girders. Evaluate the structural behavior of the delta frame assemblies, and evaluate the influence of concrete creep and shrinkage on the behavior of the bridge.
Performing Organization: Virginia Highway Research Council, Charlottesville, VA 22903
Funding Agency: Virginia Department of Highways and Transportation
Expected Completion Date: June 1989
Estimated Cost: $87,000 (HP&R)

FCP Project 5Q: Bridge Maintenance and Corrosion Protection

Title: Conductive Polymer Concrete Overlays. (FCP No. 35Q2642)
Objective: Install overlays having adequate conductance and good riding characteristics on deteriorated bridge decks. Evaluate the performance of these overlays for cathodic protection application to stop corrosion.
Performing Organization: Brookhaven National Laboratory, Upton, NY 11973
Expected Completion Date: September 1989
Estimated Cost: $244,960 (FHWA Administrative Contract)

FCP Category 9—R&D Management and Coordination

FCP Project 9D: Feasibility of New Technology for Highway Safety

Title: Basic Study to Improve Speed and Efficiency of Vehicle/Barrier Simulation. (FCP No. 39D6461)
Objective: Review available numerical analysis and nonlinear finite element methods to identify those methods that can improve the speed and efficiency of digital simulation of vehicle/barrier collisions. Study the technical and economic feasibility of incorporating these methods into FHWA's existing simulation programs. Study the feasibility of acquiring other appropriate simulation programs and installing them in FHWA's roadside safety library. Modify and improve these programs as necessary, and validate them against full-scale test data.
Performing Organization: Chiapetta, Welch and Associates, Inc., Paltos Hills, IL 60465
Expected Completion Date: December 1988
Estimated Cost: $152,325 (FHWA Administrative Contract)

☆U.S. Government Printing Office: 1986—181-780/60001

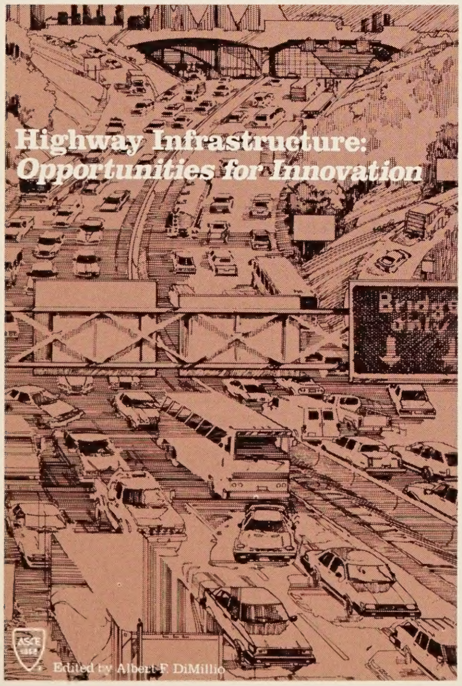
RD&T Outstanding Paper Awards Presented

Mr. Thomas J. Pasko, Jr., Dr. Yash Paul Virmani, Mr. Walter R. Jones, and Dr. Truman M. Mast were the recipients of the awards 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.

Mr. Pasko, Chief of the Pavements Division, Office of Engineering and Highway Operations Research and Development, Dr. Virmani, a research chemist in the Structures Division in the Office of Engineering and Highway Operations R&D, and Mr. Jones, a senior technician in the Structures Division, received awards for their research report "Polymer Concrete Used in Redecking a Major Bridge." This report, FHWA/RD-85/079, describes the successful use of polymer concrete for supporting the precast deck elements on the existing girders and stringers on the Woodrow Wilson Bridge, which crosses the Potomac River between Virginia and Maryland. The report may be purchased from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22161 (PB No. 85 249290).

Dr. Mast, a research psychologist in the Traffic Systems Division, Office of Safety and Traffic Operations Research and Development, received an award for the research report "Motorist Direction-Finding Aids: Recovery From Freeway Exiting Errors," which he coauthored with Mr. William Lareau, Jr., who was on assignment with FHWA. The report, FHWA/RD-82/098, describes the results of a study that examined driver performance in a route-following situation using different kinds of direction-finding aids. The findings indicate that a significant motorist direction-finding problem exists and that different kinds of direction-finding aids can significantly increase motorist route-following efficiency. The report may be purchased from NTIS (PB No. 86 226206).

New Publication



The proceedings of a July 1985 conference held in Leesburg, Virginia, and sponsored by the Highway Division of the American Society of Civil Engineers and the Federal Highway Administration are contained in the report **Highway Infrastructure: Opportunities for Innovation.**

The 2-day conference focused on opportunities for highway innovation through research to develop methods to design, construct, and maintain the highway infrastructure in the most economical manner. The conference hoped to focus national attention on research as an effective and economical tool to help solve the Nation's highway infrastructure problems.

After opening remarks, a welcome, and the keynote address, the proceedings contain papers on the elements of innovation, the elements of a successful research and development program, and research success stories. The challenge facing the highway research community is addressed as well as the resources available to meet this challenge.

The report may be purchased for $15 (ASCE member, $11.25) from the American Society of Civil Engineers, 345 East 47th Street, New York, New York 10017-2398. (Book code #540.)

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Road Humps for the Control of Vehicular Speeds and Traffic Flow

The Arterial Analysis Package