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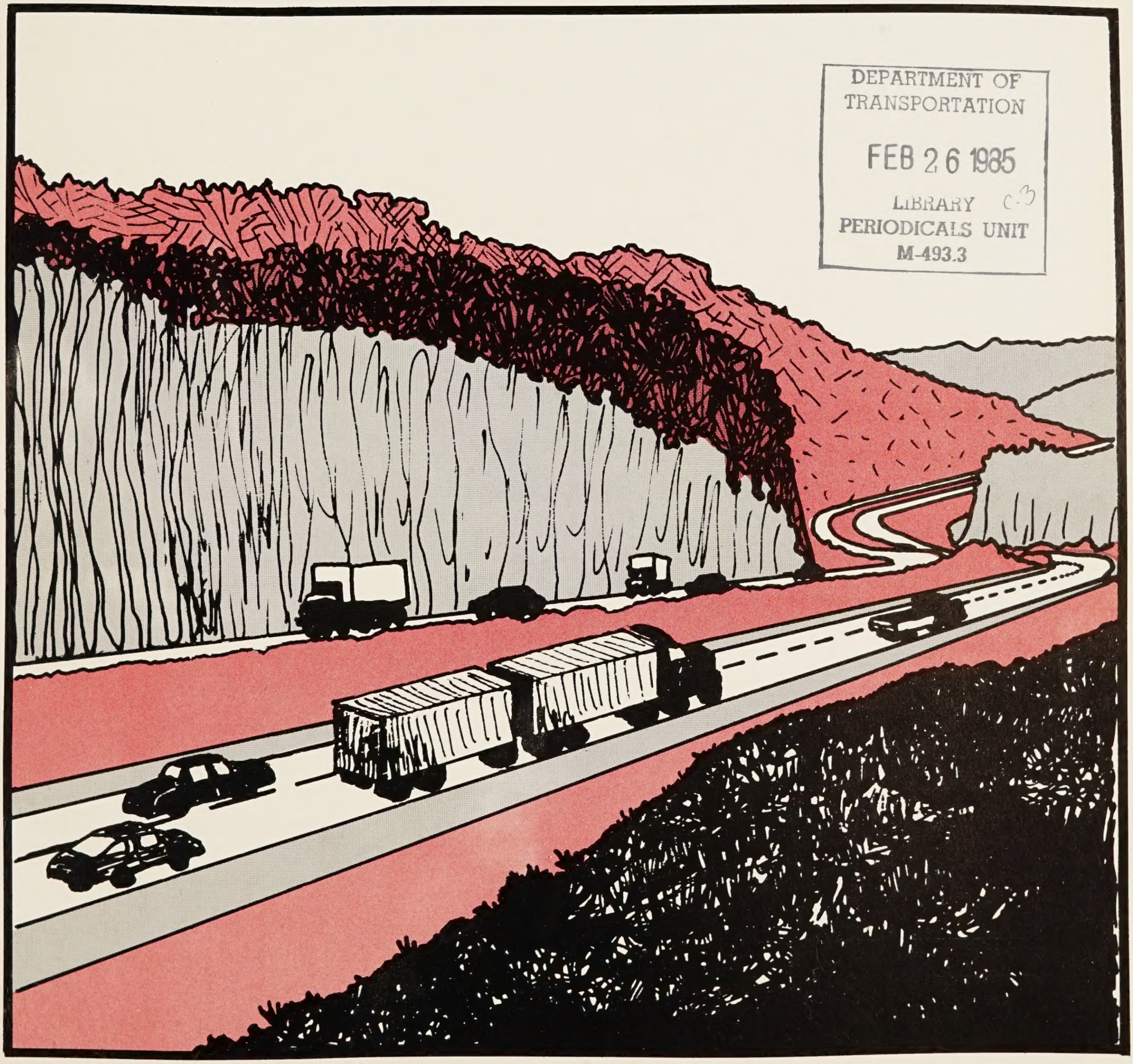

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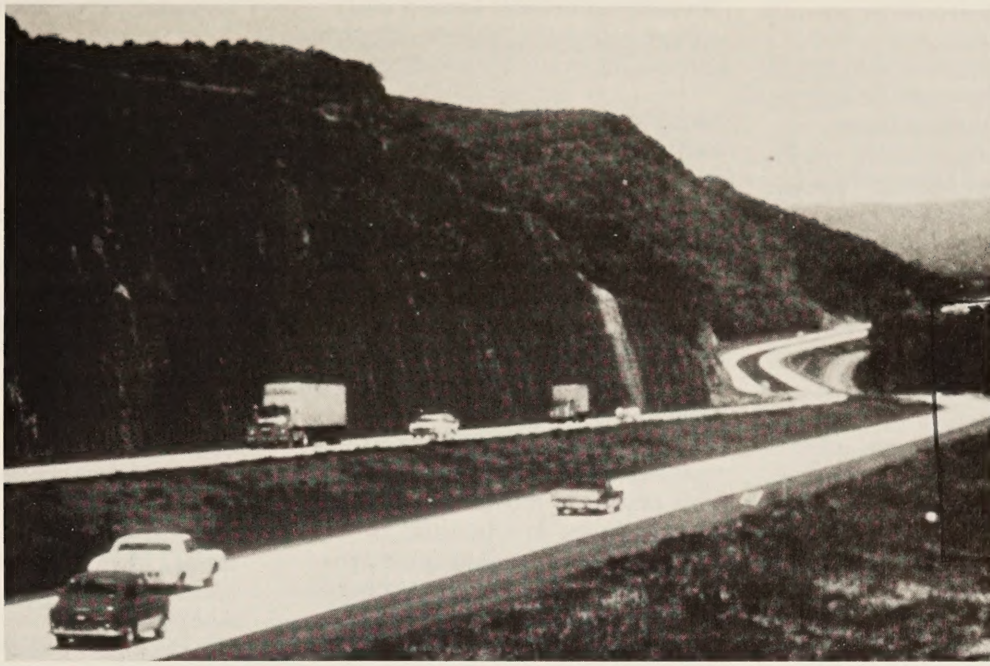

Safety of Twin-Trailer Operations

by
Michael D. Freitas

Introduction

The Surface Transportation Assistance Act of 1982 (1982 STAA) mandated the nationwide use of *doubles* [1] on the Interstate system and other designated highways. Although these trucks had been allowed on some highways in over 30 States prior to this legislation, the provisions of this act caused considerable concern in Eastern States, where such trucks previously had been prohibited. Protests from these States primarily involved public safety issues.

Specific concerns regarding doubles have included braking ability, maneuverability, handling, overall length, and, ultimately, accident experience. The following questions need to be answered: What is known about these vehicles? How does their performance compare to other trucks? Are they less safe than the vehicles they replace? This article discusses some of the issues concerning doubles, what they are, and what is known about them.

[1] Double is defined as a tractor with twin 28-ft (8.5-m) trailers, commonly referred to as a western double.

The Vehicle

The generic term double refers to a specific type of combination truck. This vehicle is also known as a twin-trailer combination. In all cases, a double consists of a tractor coupled to a semitrailer, which in turn is coupled to another semitrailer by means of a converter dolly. There are three general types of doubles—the western double, the Rocky Mountain double, and the turnpike double (fig. 1). The most common is the western double, so named because it originated and is most used in the Western States. The western double generally consists of a tractor coupled with two 27- to 28-ft (8.2- to 8.5-m) long semitrailers. Although until recently the western double had been prohibited in Eastern States, some eastern toll roads have allowed a very long combination, the turnpike double, to operate. This vehicle consists of a tractor coupled with two 40- to 48-ft (12.2- to 14.6-m) long semitrailers, and its operation has been limited to a few toll facilities. The third type of double, the Rocky Mountain double, is a hybrid that is now being used in several Western States. This truck consists of a tractor coupled with a long (40- to 48-ft [12.2- to 14.6-m]) and a short (27- to 28-ft [8.2- to 8.5-m]) semitrailer.

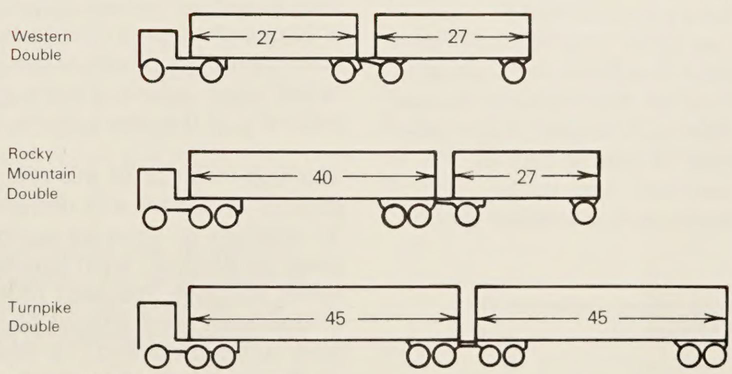

Figure 1.—Types of doubles.

Only the western double was mandated by Congress, and it is this vehicle that will be addressed in this paper. The Rocky Mountain and turnpike doubles are special vehicles allowed to operate under strict controls in only a few States. The Federal Highway Administration (FHWA) currently is conducting a comprehensive study on these two trucks as required by Section 138 of the 1982 STAA.

Use of Doubles

For the most part, doubles are used for long haul operations between terminals. They are operated primarily by common carriers for shipping packages and small loads. Generally, their cargo is a light density commodity and they usually weigh considerably less than the maximum allowable weight of 80,000 lb (36,000 kg). Doubles are not used by other carriers for the following reasons: Doubles are not practical for local pickup and delivery because they are difficult to back up, and the first trailer is inaccessible for loading or unloading while the trailers are coupled together; and most carriers can reach the maximum allowable truck weight with a tractor semitrailer and do not need the extra capacity of a double (the only incentive for using doubles is their extra cubic capacity). Therefore, the use of doubles has been somewhat limited even in those States where they have been allowed.

Accident Experience

The ultimate measure of safety is accident experience. If one situation is less safe than another, then it will probably result in more accidents. Several studies have addressed the relative accident experience of doubles. (*1-8*) [2] Unfortunately, these studies have confused rather than clarified the issue. The literature on the accident experience of doubles includes studies that indicate doubles are less safe than singles, more safe than singles, or just as safe as singles, and each position is supported by various interest groups. The only agreement among these groups is that the issue is complex and the literature is confusing.

These studies were reviewed in an earlier *Public Roads* article. (*9*) That article discussed the conclusions and specific shortcomings of 10 studies that examined the impact of truck size and weight on accident experience. A brief examination of the reports reviewed in the article and the problems associated with them provides some insight into the difficulties of doing truck accident research and the complexity of the trucking industry. Several studies have examined the safety of doubles using turnpike data because detailed travel data for turnpikes are often collected as part of the toll collection process. Unfortunately, the doubles used on turnpikes are primarily turnpike doubles which are much larger than western doubles, and the operation of turnpike doubles is very closely controlled.

A number of studies compared singles and doubles operating in different regions, States, or roadways. A study that compares singles operating in Eastern States to doubles operating in Western States could be as much a comparison of traffic and roadway conditions in different States as a comparison of truck types. In fact, one of the most common and serious errors in accident studies is the lack of control of other variables influencing accidents, such as roadway type. Another group of studies suffered from methodological problems during data collection or procedural problems during data analysis. One study was, at the time, considered to have resolved many of the problems associated with the other research in this area. (*8*) Since that time, this study has been critically reviewed by several parties and significant errors in data collection and analysis have been identified. These errors have raised some serious doubts about the accuracy of the conclusions.

The end result of all this effort is general confusion and disagreement. To conduct an accurate accident study of doubles, such variables as traffic volumes, roadway type, type of operation, and time of day would have to be controlled. To date, no study has accomplished this.

Maneuverability

Maneuverability is one of the issues often raised concerning the performance of doubles or other large trucks. Highway designers have long considered the turning ability of trucks in the design of ramps, intersections, and other restrictive geometries. This is commonly done by overlaying turning templates on design plans to insure that standard-size trucks are able to negotiate the geometry in question. These templates display the *off-tracking* or *swept path width* of standard trucks on curves of various radii. The low-speed off-tracking of a truck or truck combination is the distance that the rear tire deviates inward from the path of the corresponding tire on the front axle. Another commonly used measure of vehicle tracking is the swept path width, which is the width of the path swept by a vehicle as it negotiates a turn (fig. 2).

Unfortunately, until recently these templates had to be hand drawn using scale models of trucks. This was time consuming and costly and, as a result, the present templates are limited to a few standard trucks. To accommodate the wide range of truck configurations presently allowed to operate in various States or proposed for future use, a computer-based off-tracking model has been developed by the FHWA. This model includes a number of standard vehicles, and allows for new vehicle configurations to be entered into the program. Any roadway curve can be described and the model will determine the paths of selected wheels.

The computer model was used to calculate the swept path width of various common trucks negotiating a 35-ft (10.7-m) radius curve. This maneuver simulates a right turn at an intersection. Table 1 contains the results of that calculation and clearly shows that the typical western double has a maneuvering advantage over the typical tractor semitrailer. It should be noted that the 48-ft (14.6-m) semitrailer experiences a significant increase in off-tracking compared to the 45-ft (13.7-m) semitrailer and, therefore, should be considered as a future design vehicle for highway design purposes.

[2] Italic numbers in parentheses identify references on page 120.

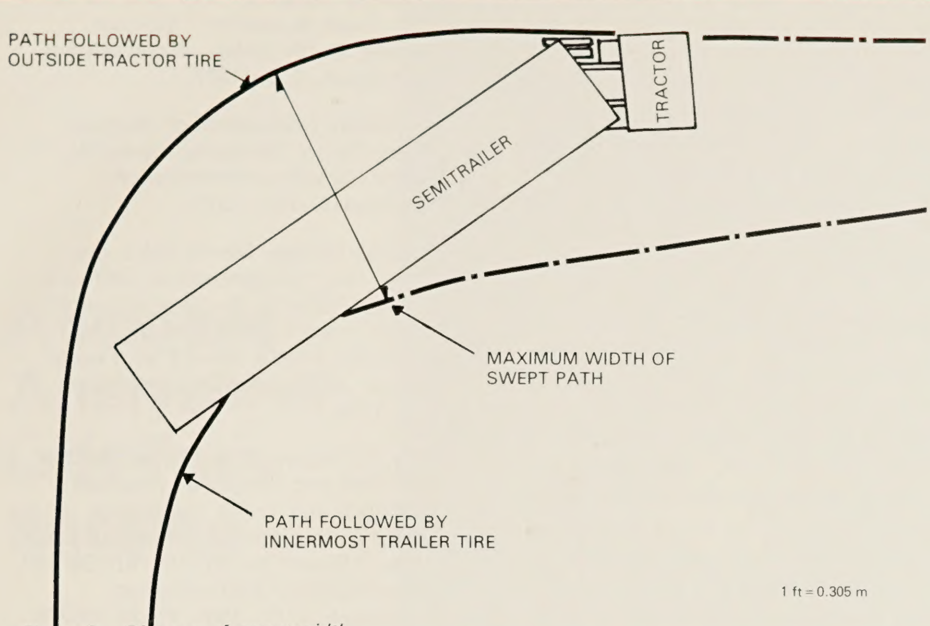

Figure 2.—Diagram of swept width.

Table 1.—Swept path width of common single and double trucks negotiating a 35-ft (10.7-m) radius curve

Configuration	Case	Tractor length	Trailer lengths	Swept path width
		Ft	*Ft*	*Ft*
Single	1	12	45	25.1
	2	12	48	26.9
	3	18	45	26.6
	4	18	48	28.3
Double	5	11	27 27	21.8
	6	11	28 28	22.6

1 ft = 0.305 m

Hill-Climbing Ability

In general, truck performance deteriorates significantly on steep upgrades. Operating speeds are reduced until a *crawl speed* is attained. Beyond this point, a truck's speed will remain constant until the grade ends. The crawl speed can be as low as 5 to 10 mph (8 to 16 km/h) for some trucks on very steep grades, although speeds this low are rare.

Where truck speeds and the volume of truck traffic warrant, truck climbing lanes have been built on steep upgrades. These lanes are provided for slow-moving trucks, but also benefit other vehicles because slow-moving vehicles are removed from the traffic stream.

One concern about doubles is that they will adversely impact traffic operations on grades. One study examined the performance of large numbers of trucks on grades and concluded that heavier trucks are associated with lower truck speed, poor acceleration performance, and both delay and high closure rates relative to other vehicles. (*10*) Doubles were also associated with these effects, although this appears to be due to the higher average weight of doubles used in the sample. Although the average double weighed more than the single it replaced, the weight differences observed in this study were primarily due to the fact that doubles rarely travel empty. On the other hand, singles often carry cargo in one direction and travel empty on the return trip.

The actual effect of one double on traffic is minimal, but large numbers of doubles could cause significant operational problems on grades.

Control Properties

The ability to control the vehicle is another concern in the use of larger or heavier trucks, especially doubles. FHWA sponsored a major study to quantify the braking and handling capability of various trucks. (*11*) This study used both vehicle simulation and full-scale testing to examine the influence of several vehicle characteristics on vehicle braking and handling (fig. 3). These characteristics included axle weights, gross vehicle weights, length of individual units or overall vehicles, types of multitrailer combinations, vehicle width, and bridge formula constraints. The following is a summary of the study's findings on doubles.

Figure 3.—Truck handling test.

- Braking—Although doubles are larger and sometimes heavier than singles, there is no perceptible difference in their braking ability, because their brake systems are designed to provide the required torque for the loads carried. (Similarly, a Cadillac should be able to stop in the same distance as a Toyota because the Cadillac brakes are designed for the heavier weight.) All truck combinations should have similar braking ability if they are operated within their designed weight range. However, there can be large variances in braking ability among trucks because of brake condition, weather, and other variables. Also, vehicles with more articulations are more likely to become unstable if their wheels lock up, although this has never been quantified.

• Yaw Stability—Under certain circumstances, this characteristic of tractors can cause them to become unstable in a turn and jackknife. Although yaw stability is a matter of concern for all combination trucks, the number of trailers has no effect on this characteristic; it is a function of the tractor only.

• High-Speed Off-Tracking—As discussed earlier, low-speed off-tracking involves the tendency of the rear trailer wheels to track inward of the path of the corresponding wheels on the front axle in low-speed turns. At high speeds, the rear wheels of combinations can track outward on curves. This maneuver is very much influenced by vehicle configuration. In one specific test at 55 mph (89 km/h), a typical double exhibited nearly twice the off-tracking of a tractor semitrailer (1.1 ft [0.3 m] versus 0.6 ft [0.18 m]). This phenomenon may contribute to the large number of truck rollover accidents on tight loop ramps where high-speed off-tracking can cause the trailer tires to hit a curb, thus precipitating a rollover.

• Rearward Amplification—Rearward amplification is a characteristic of multiunit trucks where the lateral acceleration of the tractor is amplified rearward to the point where the rear trailer could possibly roll over. Tests were conducted using various truck combinations to determine their amplification ratios (the ratio of the lateral acceleration of the rear trailer to the lateral acceleration of the tractor in an emergency lane change maneuver).

The tractor semitrailer exhibits an amplification ratio of 1.0, which means there is no amplification—the driver feels what the trailer feels. The double, on the other hand, has an amplification ratio of approximately 2.0, which means the trailer experiences twice the lateral acceleration of the tractor. This can result in the driver making an evasive maneuver that feels safe, but that can cause the rear trailer to roll over.

A new kind of converter dolly has been developed that significantly reduces rearward amplification. This dolly, known as the double drawbar dolly or "B" dolly, is used in Canada and is scheduled for extensive testing in the United States this year.

In addition, 102-in (2.6 m) wide trucks offer greater roll stability than the common 96-in (2.4 m) wide trucks. The extra width improves roll stability for doubles by about 16 percent. Such an increase in width (assuming the axle and spring spacing is also widened) could result in a significant reduction in rollover accidents.

Summary

The western double is a high volume capacity truck of limited use. It compares favorably to singles in some respects and unfavorably in others. Although the relative safety of doubles has never been quantified, it appears that if there is a difference in the accident experience of singles and doubles, the difference is not great. Because of the limited usefulness of doubles and the relatively few real differences between singles and doubles, it is unlikely that allowing doubles to operate nationwide will result in any observable differences in highway safety over the long term.

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(*10*) Fred R. Hanscom, "The Effect of Truck Size and Weight on Accident Experience and Traffic Operations, Volume 2: Traffic Operations," Report No. FHWA/RD-80/136, *Federal Highway Administration*, Washington, D.C., 1981. PB 82 139718.

(*11*) R. D. Ervin et al., "Influence of Size and Weight Variables on the Stability and Control Properties of Heavy Trucks," Report No. FHWA/RD-84/049, *Federal Highway Administration*, Washington, D.C., 1983.

[3]Reports with PB numbers are available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

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Accident Analysis of Left Turn Phasing

by
Davey L. Warren

Introduction

Until recently, protected left turn phasing was the most common method used in the United States to control left turns at signalized intersections. A major complaint about this type of phasing is that motorists turning left must wait for a green turn arrow (protected turn) even when there are gaps in the opposing traffic stream. For example, at three sites in Kentucky there was a 31 percent increase in total intersection delay after left turn signals were installed. (*1*) [1] In addition, although the left turn accident rate at 24 sites decreased a dramatic 77 percent after left turn signals were installed, this safety gain was offset by an increase in rear end accidents for a net effect of no change in intersection safety.

One type of left turn phasing gaining in popularity is protected/permitted left turns. Protected/permitted phasing still provides motorists with a protected turn, but also permits left turns on the green light after yielding to opposing traffic. A few recent studies show that protected/permitted left turn phasing reduces intersection delay from 25 to 46 percent, compared to protected-only phasing. (*2–5*)

Information on the effect of protected/permitted phasing on accidents is limited. Data from previous studies are not definitive but consistently indicate that when protected-only phasing is changed to protected/permitted, the number of left turn accidents increases sharply, while all other accidents generally increase slightly or not at all. (*2–6*) However, the number of left turn accidents tends to decrease over time, particularly after the first 6 months as motorists become acclimated to the protected/permitted phasing.

The study described in this article was conducted to further examine the effect of protected/permitted left turn phasing on accidents. The investigation was limited to high-speed signalized intersections with separate left turn lanes on the treated approaches.

Method

Two types of left turn control changes were evaluated in this study: (1) The change from protected-only to protected/permitted, and (2) the introduction of protected/permitted phasing at signalized intersections that previously had no left turn signals. Only signalized intersections were included.

The number of accidents before and after the change to protected/permitted phasing was analyzed and compared to the number of accidents at similar intersections that were not changed. Because the number of accidents can vary from year to year, even without any change in phasing, accident data were compiled and examined for the 2 years before and after the change to provide a more stable measure.

Intersection selection

Nine sites were selected from protected/permitted intersections in Prince Georges and Howard Counties, Maryland. These counties are located in the Washington, D.C., metropolitan area. The list of candidate sites was provided by the Maryland State Highway Administration.

[1] Italic numbers in parentheses identify references on page 127.

Only intersections that were signalized by the end of 1976 and where protected/permitted left turn phasing had been introduced between 1978 and 1979 were studied. This was done to allow at least 2 years of after data and to eliminate the need to reconcile discrepancies in accident records and signalization dates associated with pre-1976 data. Nearby signalized intersections that were not changed during the 4-year study period or similar intersections on other roadways were used for comparison.

Each intersection was inspected and information on number of lanes, median width, signal placement, left turn signal display, supplementary signing, posted speeds, and sight time was recorded. Sight time was measured as the time it took an opposing free flow vehicle to travel from the first sight point to the intersection.

Figure 1 shows a typical protected/permitted phasing installation in Maryland. It consists of a five-lens cluster mounted over the through lane adjacent to the left turn lane. A list of the sites used and their geometric characteristics are summarized in table 1. All the study sites had traffic actuated leading left turn phasing and supplementary signs.

Accident data base

The data on accidents at these intersections between 1976 and 1981 were retrieved from accident records on file in Maryland's Accident Studies Bureau. Accidents that occurred on the approach to the intersection (0.2-mile [0.32-km] main road, 0.1-mile [0.16-km] side road) and that were associated with the intersection were classified as "intersection accidents."

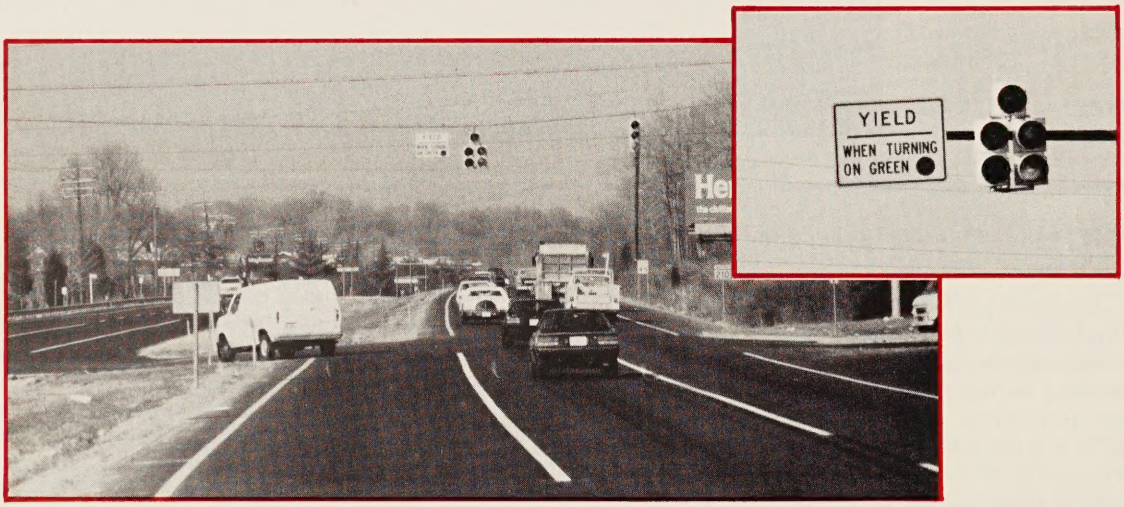

Figure 1.—Protected/permitted left turn signal.

Table 1.—Characteristics of intersections used in the analysis

	Intersection	Left turn phasing [1] before P/P	Date P/P	Geometrics: Number P/P approaches	Number through lanes	Median width	Sight time	Speed limit
						Ft	*Sec*	*mph*
1.	MD 175 and Thunderhill Rd.	P	3-5 1978	2	2 2	0	13 15	45 25
2.	MD 175 and Tamar Drive	P	3-5 1978	2	2 2	0	13 15	45 30
3.	MD 210 and Old Washington	PO	4-26 1979	2	4 2	45	10 10	55 25
4.	MD 210 and Livingston	PO	4-26 1979	2	4 2	45	20+ 20+	55 35
5.	MD 210 and Ft. Washington	PO	4-26 1979	2	4 2	45	10 10	55 35
6.	MD 210 and Old Fort	PO	4-26 1979	2	4 2	45	13 20	55 40
7.	MD 210 and Palmer	PO	4-26 1979	2	4 2	40	20 20	55 35
8.	MD 210 and Kirby Hill	PO	4-26 1979	2	4 2	30	20 20	45 30
9.	MD 210 and MD 214	PO	4-26 1979	2	4 4	30	20 13	45 35

[1]P = Permitted left turn; PO = Protected-only left turn; P/P = Protected/permitted.

1 ft = 0.305 m   1 mph = 1.6 km/h

Similar periods before and after signalization were compared to avoid seasonal bias. That is, if a full 2 years before and after data were not available, only the same months in the before and after periods were used in the analysis. Factors related to accident type, severity, and intersection geometrics were examined.

Results

Table 2 shows the number of accidents at the nine intersections before and after the change in left turn phasing. The total number of accidents increased at only three of the nine intersections but left turn accidents increased at five intersections. The left turn accidents included only those accidents involving left-turning vehicles on the approaches where protected/permitted phasing was installed.

Table 2.—Average accidents per year at intersections changed to protected/permitted left turn

Sites	All accidents		Approach left turn		Rear end	
	Before	After	Before	After	Before	After
Permitted left turn [1]						
1	20	11	3	3	8	3.5
2	9	14	3	6	2	1.5
Protected-only left turn [1]						
3	23.5	15.5	1.5	6.5	6.5	1.5
4	21	13	2	4.5	6	4.5
5	7.5	10.5	0	1.5	4	4
6	20	22	1	13	5	2.5
7	29	18.5	8	5.5	12	4.5
8	22	14	1.5	2	9	8
9	63	37	14.5	8	21.5	19.5

[1]Type of before phasing.

Rear end accidents were included to determine if protected/permitted left turns merely changed the type of accident that occurred. While protected-only phasing is known to reduce the number of left turn accidents, it may increase the number of rear end accidents. (*1*) The converse could be expected when changing to protected/permitted phasing. With protected/permitted left turns, motorists are given more freedom, which results in more left turn accidents. However, because the delay is dramatically reduced, there are fewer rear end crashes. Rear end accidents did not increase at any of the nine intersections observed; in fact, the overall decrease in rear end accidents more than offset the increase in left turn accidents.

For control purposes, intersections changed to protected/permitted phasing were compared to similar intersections that were not changed. Figure 2 shows the number of accidents per year in the before and after periods at each intersection, both at sites where protected/permitted phasing was installed and at sites that were not changed. In both cases, the number of accidents decreased in the after period. The total number of accidents per year tended to be higher at intersections changed to protected/permitted left turn phasings. One of the major causes of this was the high crash rate at one intersection of two major arterial streets located in the vicinity of a freeway interchange. Another cause was the low accident rate at control sites that did not have left turn phasing.

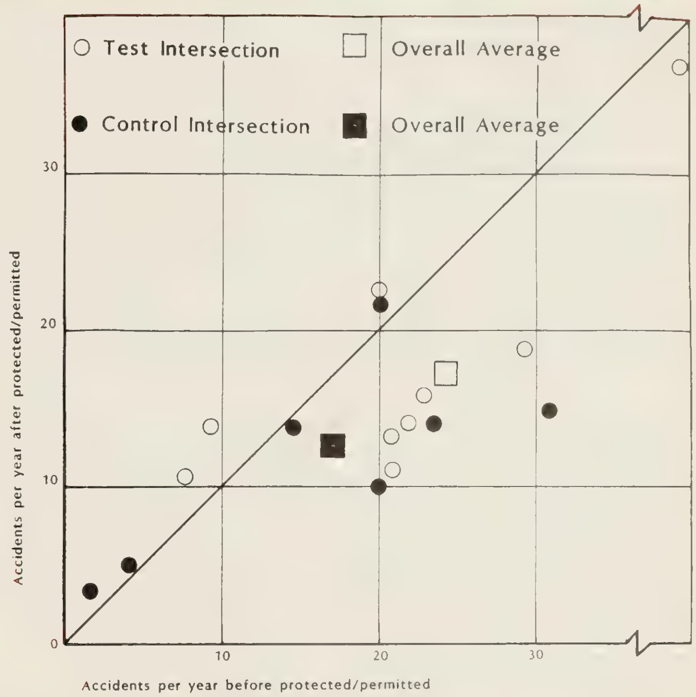

Figure 2.—Comparison of intersections converted to protected/permitted (test) and intersections not changed (control).

Permitted to protected/permitted

The effects of protected/permitted phasing depend on the phasing used in the before period. For this reason, the data were separated into two groups—those locations where protected/permitted phasing was installed that previously had no left turn phasing (permitted left turns), and those locations where protected-only phasing was changed to protected/permitted.

Table 3.—Comparison of accidents before and after installing protected/permitted left turn phasing at sites previously without left turn phasing

Accident category		Test intersections changed to protected/permitted [1]		Control intersections not changed [2]	
		All intersections	Per intersection	All intersections	Per intersection
Total accidents per year	Before	29	14.5	20	6.7
	After	25	12.5	24	8.0
	Change	− 14%		+ 20%	
Approach left turn accidents per year	Before	6	3.0	1	0.3
	After	9	4.5	3.5	1.1
	Change	+ 50%		+ 250%	
Rear end accidents per year	Before	10	5.0	8	2.7
	After	5	2.5	10.5	3.5
	Change	− 50%		+ 32%	
Injury accidents per year	Before	9	4.5	7	2.3
	After	13.5	6.7	9.5	3.2
	Change	+ 50%		+ 36%	

[1]Two sites.
[2]Three sites.

Table 3 presents the accident results before and after protected/permitted phasing was introduced at two intersections with no previous left turn phasing. The total number of accidents decreased slightly because of a large drop in rear end accidents. Left turn and injury accidents increased at both the test and control intersections. The percentage increase in injury accidents at the test sites was greater than at the control sites. This suggests that accident severity increased with protected/permitted phasing even though total accidents decreased.

The Chi-square statistic was used to determine if the change in accidents at the sites where protected/permitted phasing was installed differed significantly from the change at the control sites. Table 4 shows the results of this analysis along with the relative change in accidents due to protected/permitted left turns. The relative change in accidents was determined by subtracting the change in the average annual number of accidents per intersection at the control sites from the average number at sites converted to protected/permitted phasing.

Left turn accidents increased by less than one accident per year per intersection relative to the control sites while total accidents and rear end accidents decreased. Although the decreases in both total and rear end accident decreases were large, the accidents tended to be more severe.

Protected-only to protected/permitted

More intersections were available for this part of the analysis (protected-only to protected/permitted phasing) than were available for the analysis discussed above (permitted to protected/permitted). Table 5 is a $2 \times 2 \times 3$ contingency table showing the total number of accidents sampled, stratified by test and control intersections for both before and after conditions. Accident levels are shown for left turn, rear end, and other accidents.

Table 4.—Overall effect of protected/permitted left turns on the average annual number of accidents per intersection (two sites changed from permitted to protected/permitted)

Accident category	Relative change [1]	Chi square	p [2]
All accidents	− 3.3	0.98	> 0.10
Approach left turn	+ 0.7	0.31	> 0.20
Rear end	− 3.3	2.56	> 0.10

[1]Change in accidents at test sites minus change at control sites.
[2]Probability change is due to chance.

Table 5.—Accidents at intersections with protected phasing and intersections changed to protected/permitted phasing

Intersection type	Period	Accident type: Approach left turn	Rear end	Other	Total
Test intersections changed to protected/permitted	Before	57 (15.3%)	128 (34.4%)	187 (50.3%)	372
	After	82 (31.4%)	89 (34.1%)	90 (34.5%)	261
Control intersections not changed	Before	8 (4.5%)	67 (37.6%)	103 (57.9%)	178
	After	6 (5.8%)	47 (45.6%)	50 (48.6%)	103

A convenient method of statistical analysis for contingency tables was employed, using an information statistic, that is especially useful when the possible statistical significance of main effects and interactions within contingency tables must be accounted for. (7) For this problem there are three main effects and three two-way interactions to be interpreted (table 6). The actual number of test and control intersections (7 and 4 respectively) was solely dependent on the number of intersections available; thus no real importance should be associated with the significant main effects of before or after period, intersection type, and accident type. Instead, emphasis should be placed on interpreting the two-way interactions. As seen in table 6, the analysis shows, by the 29.36 information statistic, that the distribution of accident types between the before and after periods were not independent. Furthermore, the distribution of accident types between the type of intersection control were not independent, as demonstrated by the 48.2 information statistic. The small 1.7 information statistic shows that the before and after distribution of the total number of accidents for the protected-only and protected/permitted controlled intersections was not significantly different. These findings strongly suggest that the conversion of intersections from protected-only to protected/permitted phasing altered the distribution of accident type (left turn, rear end, other).

Table 6.—Analysis of accident frequencies for intersections converted from protected-only to protected/permitted (test) and intersections not changed (control)

Component	Information statistic [1]	Degrees of freedom	p [2]
Main effects:			
Period (before/after)	38.11	1	< 0.01
Intersection (test/control)	140.44	2	< 0.01
Type (left turn, rear end, other)	139.13	1	< 0.01
Interactions:			
Type × period	29.36	2	< 0.01
Intersection × period	1.70	1	< 0.20
Type × intersection	48.20	2	< 0.01
Type × intersection × period	0.35	2	> 0.20
Total	396.59	11	< 0.01

[1]Analogous to X^2 test statistic. (7)
[2]Probability of exceeding the observed value due to chance.

A homogeneity test was also conducted to determine whether the significant accident type by intersection control could be further explained. The test statistically analyzed the distribution of accident types before and after the conversion from protected-only to protected/permitted phasing, both at intersections that were and were not changed. The results of the statistical analysis are given in table 7. The accident types differed in the before and after periods for the protected/permitted sites, did not differ in the two periods for the control sites, and differed between the test and control sites. The differences were largely due to a doubling in the proportion of left turn accidents at sites that had been converted from protected-only to protected/permitted phasing and the fact that the proportion of left turn accidents at these sites was more than 4 times greater than at intersections that were not changed. Thus, some of the changes shown in table 5 could be attributed to the bias introduced by differences in the accident types prior to any change in left turning phasing. Nevertheless, the evidence of an increase in the left turn accidents is clear.

Table 7.—Test of homogeneity of distribution of accident types

Component	Information statistic [1]	d.f.	p [2]
Test sites between before and after	26.701	2	< 0.001
Control sites between before and after	2.297	2	> 0.20
Between test and control sites	48.197	2	< 0.001

[1]Analogous to X^2 test statistic. (7)
[2]Probability that distribution of accident types are the same (that is, no shift in accident type).

Table 8.—Comparison of accidents before and after conversion from protected-only to protected/permitted left turns

Accident category		Test intersections changed to protected/permitted [1] All intersections	Per intersection	Control intersections not changed [2] All intersections	Per intersection
Total accidents	Before	185	26.5	89	22.3
per year	After	130.5	18.6	52.5	13.1
	Change	−30%		−40%	
Approach left	Before	28.5	4.1	4	1
turn accidents	After	41	5.9	3	0.8
per year	Change	+44%		−25%	
Rear end	Before	64	9.2	33.5	8.4
accidents	After	44.5	6.4	23.5	5.9
per year	Change	−30%		−30%	
Injury	Before	74.5	10.6	26.5	6.6
accidents	After	81.5	11.6	25.5	6.4
per year	Change	+9%		−4%	

[1]Seven sites.
[2]Four sites.

The accident distribution by type of phasing and time period was examined further by studying the average number of accidents per year per intersection. Table 8 shows the total number of accidents and rear end accidents decreased at intersections converted from protected-only to protected/permitted phasing. However, during the same periods, a similar decrease occurred at protected-only control intersections. Left turn accidents increased dramatically at sites with protected/permitted phasing, but decreased at sites with protected-only phasing. Injury accidents increased at protected/permitted sites but not at control locations, indicating that accident severity had increased.

The statistical significance of the above comparison of annual accidents per intersection was tested and the results are shown in table 9. The number of accidents at locations changed from protected-only to protected/permitted phasing was higher than expected when the control sites are taken into account. This was mainly a result of the large increase in left turn accidents; the reduction in rear end accidents does not sufficiently offset the increase. Even though there is little confidence from a statistical standpoint that total accidents increased, with left turn accidents increasing almost 50 percent, the changes shown in tables 8 and 9 are somewhat consistent with the findings of other studies. For example, left turn accidents increased nearly 50 percent, but the total number of accidents decreased 17 percent at four sites in Virginia after conversion to protected/permitted left turn phasing. (*3*) At 17 converted sites in Florida, the number of left turn accidents was 7 times higher, even though the number of total accidents was 4 percent lower with protected/permitted phasing than with protected-only. (*6*)

Table 9.—Overall effect of protected/permitted left turns on the annual number of accidents per intersection (seven sites changed from from protected-only to protected/permitted)

Accident category	Relative change [1]	Chi square	p [2]
All accidents	+1.4	1.70	=0.20
Approach left turn	+2.0	1.35	>0.20
Rear end	−0.3	0.01	>0.20

[1]Change in accidents at test sites minus change at control sites.
[2]Probability change is due to chance.

Conclusions

The effect of converting to protected/permitted left turn phasing was found to affect the type of accidents that occurred. The magnitude and direction of the change depended on whether protected/permitted phasing was installed at sites that previously had no left turn signals or whether the sites had been converted from protected-only phasing.

At intersections that previously had no left turn signals, rear end and total accidents generally decreased, with left turn accidents showing an increase of less than one per year. At intersections that were converted from protected-only to protected/permitted phasing, rear end and total accidents decreased, while left turn accidents increased dramatically. The number of left turn accidents increased 50 percent and four-fold increases can be expected at some sites.

When compared to sites that were not changed, the apparent effect of converting from protected-only to protected/permitted left turn phasing was an increase of slightly more than one intersection accident per year, usually an injury accident.

The slight rise, if any, in the number of overall accidents must be weighed against the dramatic savings in delay time of up to 50 percent reported in other studies. Other studies report that motorists overwhelmingly favor protected/permitted left turn phasing and want additional protected-only signals converted to protected/permitted phasing. (*2*, *3*) This suggests that motorists are willing to accept the additional risk of protected/permitted left turns in exchange for increased driving freedom, dramatic delay savings, and reduced driver frustration from not having to wait at traffic lights for no apparent reason.

The conclusions of this study are not totally definitive because of the small number of intersections for which data were available. However, the study results agree reasonably well with other documented studies. A large-scale study should be carried out to provide more precise estimates of the safety effect of protected/permitted left turn phasing. The effects of site and traffic factors, as well as signal placement and display, on the safety of protected/permitted left turn phasing should be determined. Such a study is currently planned by the Federal Highway Administration.

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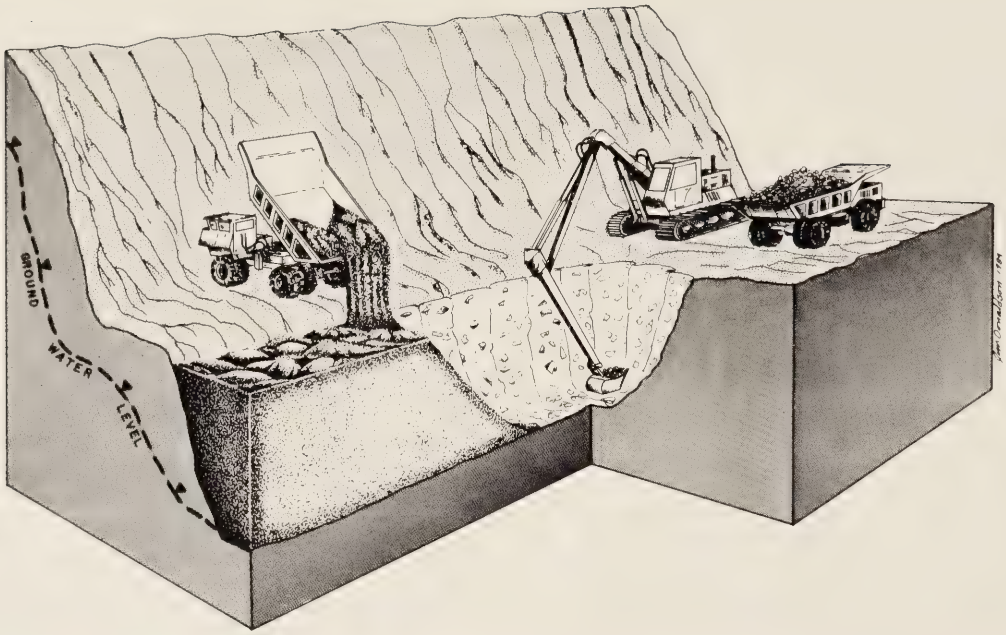

Slide Corrections Using Deep Interceptor Trenches

by
Raymond A. Forsyth and Gordon K. Wells

Introduction

The California Department of Transportation's (Caltrans) methods for dewatering large soil masses to reduce or eliminate hydrostatic pressure have included installing horizontal drains, vertical wells, or constructing stabilization trenches.

Horizontal drains are relatively easy and economical to install before, during, or after construction. Specialized drilling equipment, using 3- to 4-in (76- to 102-mm) roller rock or drag bits and water circulation, can drill to over 300 ft (91.4 m) on 5 to 10 percent grades. After drilling the required length, 2-in (51-mm) slotted PVC pipe, which has largely replaced 2-in (51-mm) perforated steel pipe, is pushed into the boring. Generally, several drains are plumbed together to provide efficient drainage away from the unstable area.

Caltrans' 46 years of experience with horizontal drainage indicate a variable success rate in removing subsurface water and stabilizing soil masses. Horizontal drains do not provide positive drainage but can intercept and remove large amounts of water at relatively low cost. They appear most effective where water is moving in well-defined aquifers or fissures. Horizontal drains are least effective in relatively homogeneous fine-grained soil masses and can be sheared by relatively little movement.

Interconnected drainage galleries (vertical wells) can be installed conveniently before, during, or after construction. Vertical borings 30 to 36 in (762 to 914 mm) in diameter are drilled on closely spaced centers. Bucket auger type drill rigs can drill to 100 ft (30.5 m) with little effect on existing stability during drilling. After drilling to the planned depth, a device on the auger bucket is used to bell the bottom of the boring so adjacent bells are interconnected. In some instances, casing is installed in the boring and a worker is lowered for mining to insure the interconnection. The borings are backfilled with permeable material and the well system typically is drained by a series of horizontal drains drilled into the bells.

Although a drainage gallery system is relatively costly, it does provide deep positive drainage with no risk of inducing or accelerating slide movement. A gallery can tolerate some mass movement and still remain operable if the horizontal drain outlets are located outside the movement zone.

Generally, stabilization trenches are installed during initial construction of sidehill embankments when large excavation equipment can be used efficiently and there is only slight risk to adjacent facilities in the event of slope failure. Trenches may be constructed to fit terrain and geometric requirements and with a bottom width of 12 ft (3.7 m) to accommodate construction equipment. Side slopes are excavated as steep as conditions will tolerate because the trench is open for only a short time before backfilling. The bottom of the trench must be "keyed" into competent material to provide stability. The trench is backfilled with a 3-ft (0.91-m) permeable layer on the bottom and back slope to intercept seepage zones. A PMP collector system is placed in the bottom of the trench to provide a drainage outlet. This technique is extremely costly although it provides both stability and positive drainage.

The concept of deep interceptor trenches evolved as an economical and practical technique that combines the positive drainage of stabilization trenches and the minimal stability risk of drainage galleries.

Cut Slide Repair on I-80 in Solano County, Calif.

An example of the successful use of deep interceptor trenches is a section of I-80 in Solano County, Calif.

During the 1963 construction of I-80 near Vallejo, a 500-ft (152.5-m) long cut slide occurred in weak, saturated sedimentary material. The cut slope through the slide area was flattened to 3:1 and a series of horizontal drains were installed at roadway level. Flows from the drains were small; however, continuing slide movement sheared the drains and flows ceased. For several years, this area was a maintenance problem and required frequent removal of slide debris.

In 1972, before major reconstruction, the failed 3:1 slope was resloped to 3 3/4:1 and additional horizontal drains were installed. However, following slope reconstruction, the 1972-73 winter rains caused renewed movement, shearing the newly installed drains.

In 1973, Route 80 through this area required widening for two additional truck climbing lanes and a shoulder that encroached well into the unstable slide mass. Boring and test result data indicated that stability could be achieved by positive drainage and a 3:1 slope. To effect drainage, a drainage gallery would be constructed by augering 30-in (762-mm) diameter holes to competent material, belling the bottoms so that they were interconnected, and backfilling with permeable material.

Horizontal drains would be drilled into the flanks near the bottom of the gallery for drainage outlets. This scheme would provide positive drainage and allow some slide movement to occur without disrupting drainage, as had occurred with previous horizontal drain installations.

Instead of constructing the drainage gallery and dewatering to gain in situ strength before excavation started, excavation was started near the head of the slide and proceeded down to roadway level. Unfortunately, instead of removing material as it was excavated near the slide scarp, material was dozed onto a flat area within the slide mass. Movement occurred rapidly onto the existing I-80 traveled way. Movement stopped when the stockpiled material was removed from the slide mass. However, when excavation through the slide area was completed, movement continued to occur in the unstable material.

Vertical borings and slope indicators were installed and short-term monitoring (before they were sheared) indicated movement approximately 35 ft (10.7 m) below the wide bench on the slide. The water table was located 3 ft (0.91 m) below bench surface (fig. 1).

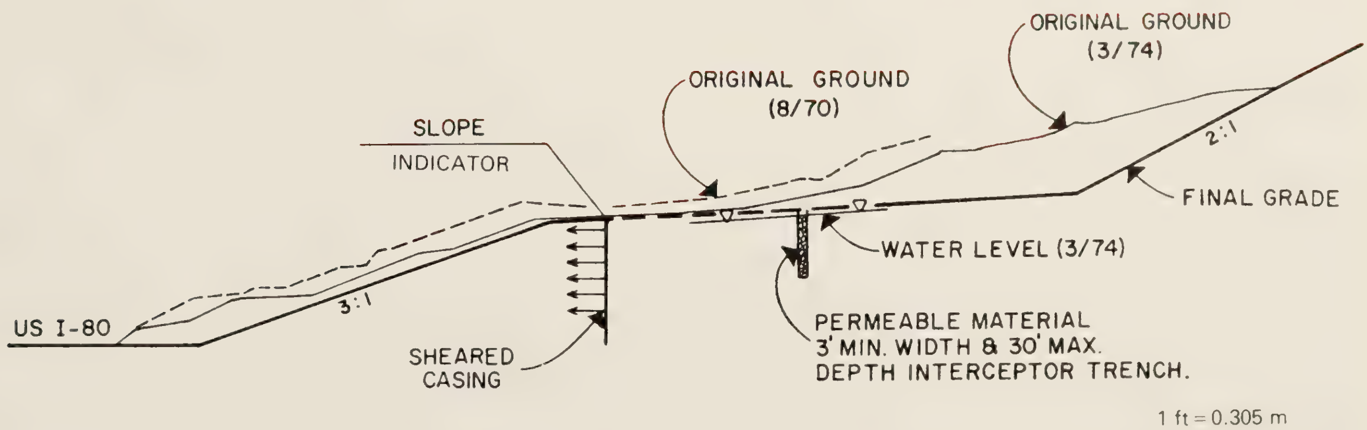

Figure 1.—Cross section of slide repair on I-80 near Vallejo, Calif.

Examination of data led to the rental of a backhoe capable of digging to a depth of 42 ft (12.8 m). A deep interceptor trench was excavated parallel to the roadway along the flat bench on the slide (fig. 2). Because of the unstable nature of the sedimentary material, the width of the 30-ft (9.1-m) deep trench would slough up to 30 ft (9.1 m) wide at the top, tapering to a bottom width of 30 in (762 mm). As excavation progressed, permeable material was placed in the trench to within 3 ft (0.91 m) of the trench top.

By immediately filling the excavation with permeable material so a minimal length of the trench was open at any time, the risk of sliding was reduced greatly. A drainage outlet was excavated perpendicular to the interceptor trench out through the slope to roadway grade using the same excavation and backfill method. To insure positive drainage of the permeable material, several horizontal drains at roadway level were installed to intercept the lower portion of permeable backfill in the longitudinal trench. To inhibit surface water infiltration, paved ditches and overside drains were installed and a vegetative treatment was used to establish plant growth on the relatively sterile soils. Since 1974, and through the wet winter of 1981-82, no further movement has occurred in this slide area.

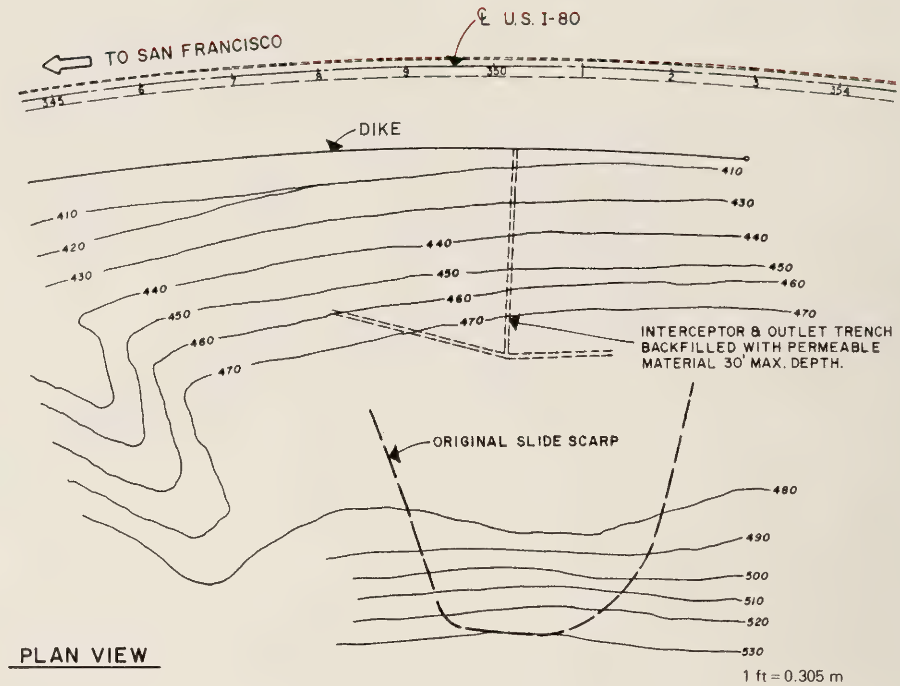

Figure 2.—Plan view, interceptor trench on I-80 near Vallejo, Calif.

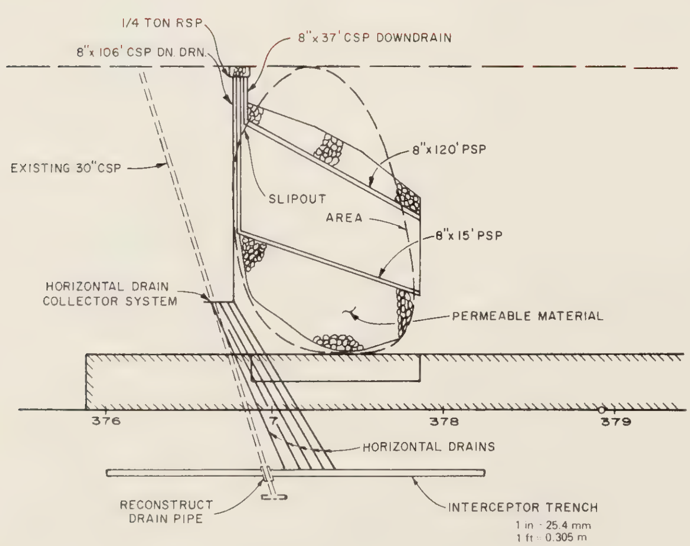

Figure 3.—Plan view, slide repair on U.S. 50 near Bridalveil Falls, Calif.

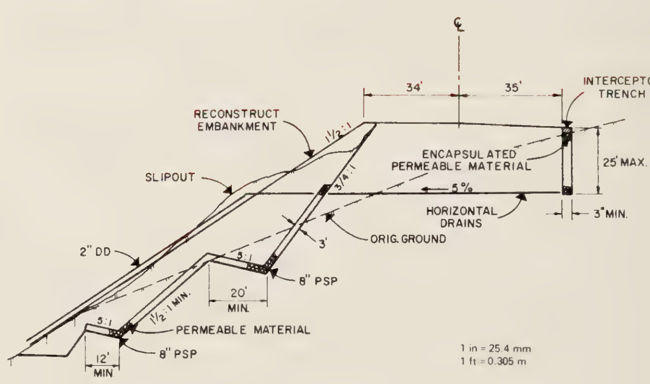

Figure 4.—Typical cross section, slide repair on U.S. 50 near Bridalveil Falls, Calif.

Embankment Slide Repair on U.S. 50 in El Dorado County, Calif.

In early 1978, an embankment failure occurred along 100 ft (30.5 m) of U.S. 50 near Bridalveil Falls. The head of the slide in the embankment dropped vertically about 20 ft (6.1 m) causing a loss of a portion of the westbound travel lanes. Investigation indicated failure was primarily from seepage along the original ground and embankment interface. Borings encountered a saturated zone of weathered granitic soils with decomposed vegetation and rocks, varying in depth from 7 to 17 ft (2.1 to 5.2 m) below the roadway surface.

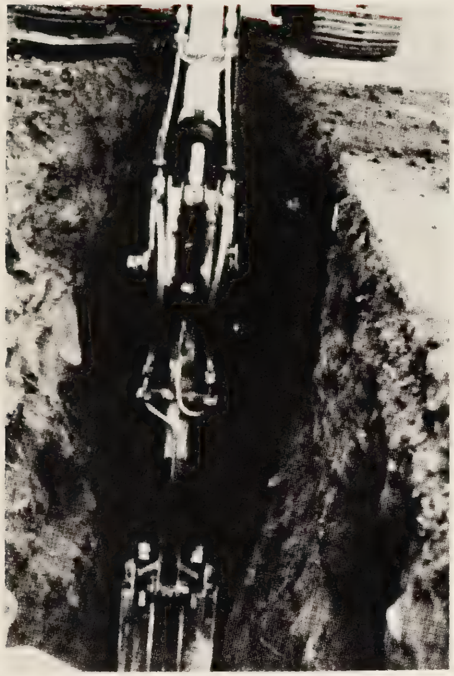

Figure 5.—Deep interceptor trench under construction on U.S. 50 using a track-mounted backhoe.

The recommended repair consisted of excavating an interceptor trench through the shallow embankment (uphill side) and backfilling with permeable material enclosed in a filter cloth. Trench drainage was to be accomplished by drilling horizontal drains into the lower portion of the trench (figs. 3 and 4).

The trench, excavated by a track-mounted backhoe (fig. 5), was 3 ft (0.91 m) wide, varied in depth from 3 to 25 ft (0.91 to 7.6 m) and was 225 ft (68.6 m) long. Five horizontal drains, 116 ft (35.4 m) long, were installed into the trench for drainage from a pad on the opposite (downhill) stable side of the embankment. The failed portion of the embankment was removed and reconstructed with a permeable blanket placed along the bottom and up the backslope to provide positive drainage along the downhill toe of the embankment.

No further movement has occurred since corrective repairs were made.

Conclusions

Caltrans' experience indicates that the use of backhoes capable of excavating to 40 ft (12.2 m) presents an innovative, safe, and cost-effective method to construct deep interceptor trenches to control ground water seepage. This technique has several advantages:

1. Backfilling with permeable material can proceed along with excavation through unstable areas to minimize the risk of slope failure.

2. Considerably less excavation is required than is needed for stabilization trench excavation.

3. Soil structure can be observed in situ, resulting in accurate bottoming in competent material.

4. Positive drainage of a seepage zone or zones can be achieved.

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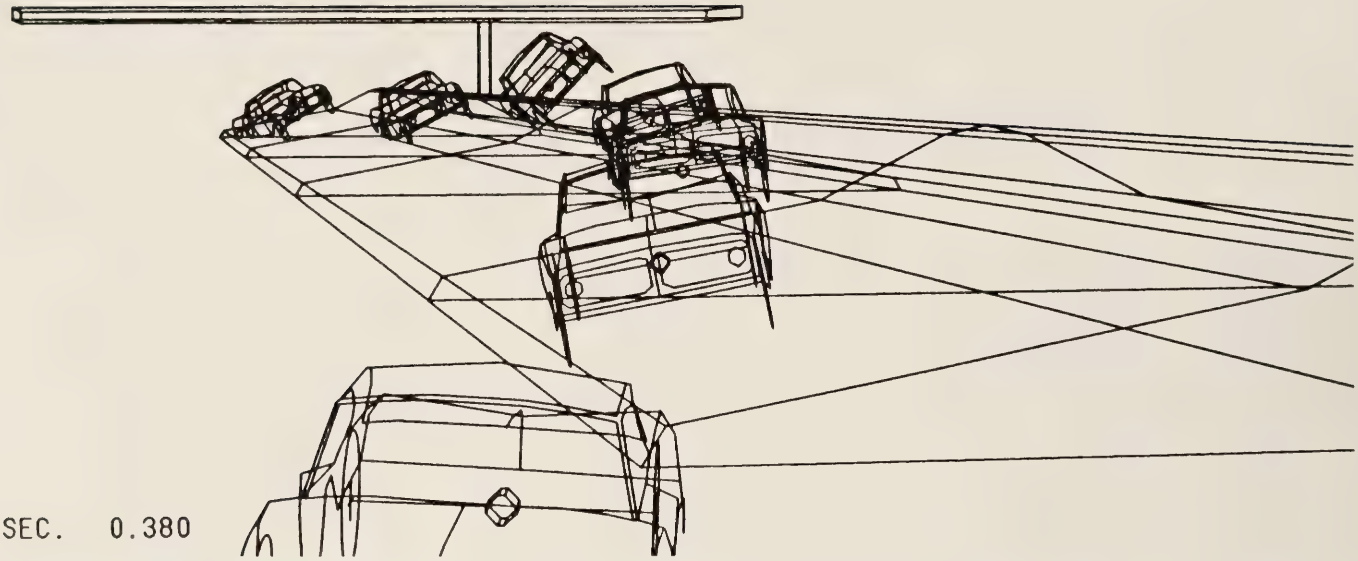


Roadside Safety Software and Data Library: Basic Concepts and Present Status

by
Morton S. Oskard

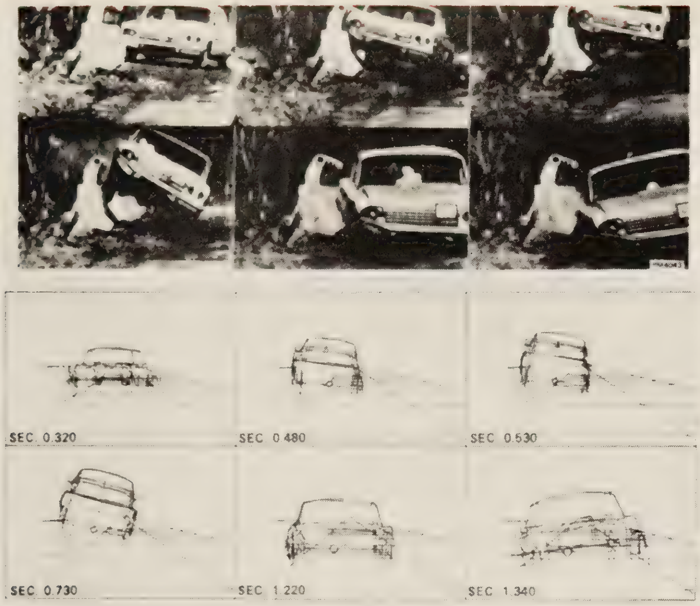
This article presents an overview of a planned Federal Highway Administration (FHWA) Roadside Safety Software and Data Library—its origins and purpose, its present form, and the status of its various elements. Many of the functions described in the article are under development and thus are nonoperational. This article serves as a preliminary announcement about these planned functions and the anticipated capability. It also serves as a means of soliciting ideas and recommendations from active safety researchers with sufficient time to incorporate them as the data library is being designed. Additional information is available from the FHWA, Safety and Design Division (HSR-20.)

Introduction

The Roadside Safety Software And Data Library (RSL) is an information repository established and managed by the FHWA. The information is not, however, the usual material found in a library. The RSL's files will consist of analytical tools and computer models specifically designed for the investigation of vehicles impacting roadside structures. The intended users of these materials are the safety researchers in the highway community whose general mission is to design safer roadside structures that cost less and are functionally acceptable under a broad range of conditions. This area of highway research has a long and impressive history as demonstrated by the evolution of roadside appurtenances. Each new safety device introduced during this evolutionary process was the result of research based on the best analysis tools of the period. Impressive examples of safety devices such as the following can be observed along the Nation's highways:

- The steel drum impact attenuator (1971, FHWA)—Computer simulations were used extensively to explore alternate configurations during the prototype design phase.
- The hi-dro cell impact attenuator (1970-71, FHWA)—Individual cells were designed by simulation and laboratory tests.
- Luminaire support trajectory studies (1967, National Cooperative Highway Research Program)—Early work on the breakaway concepts successfully used computer models of a pole impact.
- The Ohio weak post guardrail (1969, State funds)—Computer simulation detected poor impact behavior and facilitated the redesign process.
- The collapsing ring and collapsing tube rails (1976, FHWA)—Basic analytical research on plastically deforming rings led to a practical design method for energy-absorbing rail support elements. A new bridge rail and retrofit bridge rail for heavy vehicle impacts resulted from the application of this energy-absorbing element.

Many other examples are available. Any careful survey will clearly show the eventual benefits to safety of improved analytical methods in the hands of safety researchers. The RSL is an attempt to accelerate safety improvements by establishing a central source for these analytical tools as well as concentrated activity on improving the quality and accuracy of the technology. When completed the RSL will represent a means of maximizing researchers' productivity, efficiency, and accuracy.



Experimental and predicted vehicle responses for 50 mph (80 km/h), 12° collision with the General Motors bridge parapet. (1)[1]

Heavy vehicle barrier test. (2)

[1]Italic numbers in parentheses identify references on page 136.

Background

The literature shows an evolutionary trend from the rigid, high-resistance safety structures of the past to the current advanced roadside hardware. Today, roadside structures are designed with carefully controlled yielding features minimizing both passenger injury and vehicle damage. The yielding structures are a direct consequence of the higher vehicle speeds and heavier weights that exist today.

During the early period of motorized travel, both passenger vehicle speeds and weights were much lower, and the vehicle structure provided suitable crush characteristics to protect occupants during typical impacts with rigid roadside structures. One effect of these factors was that thus roadside features tended to be rather stiff structures. These structures had the attractive advantage of requiring minimal repair after impact. As passenger vehicles began to operate at higher speeds and to increase in weight, the amount of vehicle crush resistance needed to properly protect passengers began to exceed an economical level. This initiated the trend toward roadside structures that yield, as presently seen along the Nation's highways.

Collapsing ring, heavy bridge rail design. (3)

The recent energy shortages aggravated the trend, as the popularity of smaller-sized passenger vehicles made passengers more vulnerable to the impacted structures as well as to the rate at which the structures deformed during impact. Designing safety structures thus became more complicated and, in some ways, still presents a difficult challenge. The guiding criterion of the RSL is to reduce the level of complexity that the researcher faces by providing as much assistance and as many supportive research tools as are feasible. Eventual benefits will be improved safety hardware that is designed in a shorter time and will result in a lower level of accident severity.

The Mission of the RSL

The information now accumulating in the RSL represents the techniques and methods used by researchers for the analysis of impacted structures. The range of materials on file includes both older results as well as recent experimental methods. These analysis tools are being checked and validated and will eventually be released as operational tools. When formulating the structure of the RSL, it was noted that the evolution of both the analysis methods and the resulting hardware was not without problems. The newer analysis methods are more complex and require greater user input and skills, which fall into three categories:

- Problem definition skills—The user's ability to select meaningful input parameters pertaining to a problem.
- Analytical skills—The user's ability to correctly organize and input data required by the newer analytical methods.
- Interpretive skills—The user's ability to detect obviously erroneous answers, isolate the cause, and take corrective actions before proceeding with an in-depth evaluation.

This increased complexity tended to deter extensive application of the newer analytical methods during the search for innovative and improved concepts. In general, use of these new tools did not grow in proportion to the expanded range of modeling capability. One or more of the user requirements or skills outlined above acted as an obstacle to growth. The RSL was thus designed to minimize these types of user problems and expand usage of these analytical methods, as well as facilitate the rapid discovery, dissemination, and correction of errors.

There were other factors, however, that did make the use of analytical models attractive. Prior to the general availability of these analytical methods, hardware development had relied upon the experimental approach. Candidate structures were subjected to full-scale impacts; designs that proved successful were then installed along highways. As experimental methods improved, however, so did the complexity of basic roadside impact problems. Passenger vehicles became smaller, increased land and construction cost reduced roadside space, and heavier

Table 1.—Roadside Safety Software and Data Library (RSL) General Operational Elements: Crash Test Database

Element	Percent completed
User documentation	
Five volumes of draft reports on file.	80
Test query system	
Computer program to search test data files.	65
Test computer files	
Partially completed collection of test abstracts.	15
Test report files	
Collection of final reports from each abstract.	15
16mm test films	
Approximately 600 reels of high-speed movies, full scale tests.	25
Test video tapes	
Video tapes of abstracted full scale tests.	15
35mm slide file	
10-year collection of slide pictures-full scale test.	5
Loaner 16mm films	
Duplicate film copies when available.	20
Unprocessed test data	
Backlog of test data being processed.	35
Picture files	
10-year collection of pictures-full scale tests.	5
Workshops	
Training material to be maintained and developed.	(planned)
Video data	
Copies of all printed material on video tape.	(planned)

Table 2.—RSL General Operational Elements: Crash Analysis Database

Element	Percent completed
User documentation	
8 volumes of draft documents on file.	50
Analysis query system	
Computer program to search simulation program files.	60
Analysis data files	
Preliminary collection of simulation program abstracts.	60
Prestored job control language files	
Computer instructions to run various simulation programs.	60
Impact model files	
Program codes stored in accessible files.	80
Pre/post processor	
User assist program for preparation of input/output material.	30
Prestored input	
Prestored files of known input parameters.	0
Graphics program	
Graphics program available for actively used program.	70
Program documents	
Hard copy collection of program reports.	80
Closed form equations	
Collection of known closed form solutions.	(planned)
Approximate solutions	
Summary of available approximate methods.	(planned)
Test instruments	
Summary of test data collection and reduction methods.	(planned)
Validation activity	
Continuing assessment of crash analysis methods.	30
Workshops	
Technology transfer to researchers.	(planned)

Table 3.—RSL General Operational Elements: Support equipment

Elements	Percent completed
Computer terminals	
Three terminals with graphics.	50
Video editing equipment	
Two 3/4 in. video recorders.	100
Film projection equipment	
Five 16mm projectors with stop motion action.	100
35mm slide projector	
Three projectors plus slide preparation equipment.	100
Film motion analysis	
One VanGuard motion analyzer.	90
Minicomputer	
Dedicated minicomputer with analog/digital equipment.	70
Video to hard copy	
All hard copy material on tape for ease of distribution.	(planned)
Instrumentation equipment	0

Vehicle handling models

- HVOSM (single unit vehicle)
  Passenger vehicle handling simulation.
- PHASE 4 (Articulated Vehicle)
  Truck handling simulation.

Hardware crash models

- GUARD (single unit vehicle)
  Vehicle impact simulation. (under development)
- CRUNCH (articulated vehicle)
  Vehicle impact simulation. (under development)
- BARRIER VII (single unit vehicle)
  Vehicle impact simulation (2-D).
- WRECKER II * (structure impact)
  General structure impact simulation.
- RVA (vehicle vaulting model)
  Support program to Barrier VII.

*Note: The Wrecker II program is not maintained or supported by the RSL activity. It is only on file for reference.

Research support programs

- SMAC * (accident reconstruction)
  Program for approximation of initial accident conditions.
- CHISMAC* (accident reconstruction)
  Program for approximation of initial accident conditions.
- LIRS (retrieval-simulations)
  General simulation information storage/retrieval.
- GRAFIX (graphics program)
  General graphics program for simulation output.
- QUERY (retrieval-tests)
  General test information storage/retrieval.
- PREP (plot/report program)
  Simulation output processor.
- PSIP (input preprocessor)
  Simulation input processor.

*Note: The SMAC and CHISMAS programs are not maintained or supported by RSL activity. They are only on file for reference.

Occupant models

- CVS (instrumented dummy model)
  Advanced vehicle occupant simulation.
- UCIN (instrumented dummy model)
  Advanced vehicle occupant simulation.
- CHIKOR (injury model)
  Assessment of occupant injury from test or simulation.
- HIC/GSI (injury model)
  Assessment of occupant injury from test or simulation.

Note: The occupant models are not maintained or supported by RSL activities. They are only on file for reference.

Figure 1. — Simulation model files

articulated trucks with hazardous cargo began appearing more frequently. These factors and others strained the purely experimental approach that was initially popular. Thus newer analytical methods were gradually drawn into the design process, with rather impressive results. However, the number of applications still remains rather limited. To reverse this trend, the RSL is concentrating on reducing input requirements and skills, thus creating a "user-friendly" environment.

The Organization of the RSL

The RSL is designed to function as a focal point for users, where the exchange of information about analytical methods is encouraged. The material on file will be divided into three general categories: crash testing, crash analysis, and support tools and equipment. The crash-testing category will consist of a database that can be accessed by RSL users to quickly retrieve documentation of previously performed full-scale tests. A researcher confronted with a new roadside safety problem can search these files by using key words and problem parameters such as speed, vehicle weight, impact angle, and barrier type to locate data on tests performed under similar conditions. The user can thus review the material prior to initiating any new research. This future service to researchers will ensure that new studies are designed using data from all related past work resulting in only a minimum duplication of experiments. Table 1 presents a summary of the crash-testing database contents. The crash-testing database is approximately 40 percent operational.

Material in the crash-analysis database consists of information on methods and techniques used for analyzing vehicle impacts on roadside safety structures. This database allows a researcher to search the analytical methods on file, and review their strengths and weaknesses before selecting the appropriate analytical method. Most of the methods now on file are computer simulations of vehicle/barrier impacts. However, future plans include collecting simplified approximate solution methods. Table 2 contains a summary of the crash-analysis database. The crash-analysis database is approximately 40 percent operational.

The final category, support equipment, contains various instruments that are used in support of impact analysis (table 3). Ongoing activity in instrument research is expected to expand this category in the future.

Most full-scale experiments have had extensive instrumentation on the vehicle with very limited instrumentation on the impacted structure. Data on internal loads of the barrier are a direct link to all computer simulations. Once instrumentation research is completed and becomes fully used in experiments, a large improvement in simulation accuracy is expected because any weakness or limitation in the analytical structural model becomes obvious and changes can then be planned in a systematic manner.

The anticipated advance in instrumentation may possibly include the use of high-speed video equipment. Because each video frame is a digitized representation of an experiment at an instant of time, examination of each frame by computer is straightforward. What remains to be developed is an automated program that can reduce the data on each frame from targets placed on the structure. This possible application is planned for the distant future; however, presently available video equipment has provided potential benefits that will be in effect soon.

Specifically, all high-speed test films that are abstracted for the crash-test database are also being copied onto video tape. Under consideration are video displays with lightpen equipment as a means of extracting more detailed information from old test films. This data, supplemental to the original test documentation, can make these tests applicable as validation tests for new computer simulations. In the past, this type of data was derived manually with the VanGuard Motion Analyzer. Because the process was laborious, its use was usually limited. If this source of data becomes practical the availability of extensive check cases for checking new computer models will also insure more accurate analytical tools in the future. A secondary benefit of the video capability is the ease with which copies of older test films can be transmitted to researchers. Direct use of this application will expand as more films are processed and the RSL becomes operational.

The support equipment category is a critical part of the total RSL system. As noted earlier, one of the three problems that limited extensive use of analytical models, the researcher's inability to detect obvious erroneous answers, is partially solved by the instrumentation capability and visual comparison to related past experiments. This section of the RSL is approximately 20 percent operational.

The RSL will also function as a source of information on quality assurance activity. In-depth studies regarding the operational status, accuracy, and efficiency of the various methods on file are now in progress and eventually will be placed in RSL files. When completed, the existence of the information in the RSL for researchers will accelerate the application of existing technology to a particular problem, insure the accuracy of the predictions made (within the limitations of the models used), and permit more detailed studies of alternative designs before a final prototype is selected for testing. The long-term goal for the RSL is to provide significant improvement in safety hardware along the Nation's highways.

Summary

Most features of the RSL are partially completed, others are under development. The appoximate status of the system is presented in tables 1-3. Figure 1 is a list of the specific analytical methods now on file within the library. Readers wishing more details about the RSL may contact the FHWA Safety and Design Division (HSR-20). Presently, there are no formal reports published, and access to the computer files is restricted to FHWA research staff only.

As initially stated, this article serves as a preliminary announcement about ongoing work and the capability FHWA plans to have available for the highway research community in the future. It also serves as a means of soliciting ideas and recommendations from researchers with sufficient time to incorporate them as the RSL is being designed. Copies of older literature and photographs with historical value are also of interest to the RSL staff.

REFERENCES

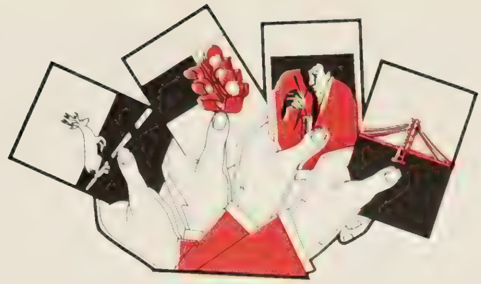
(*1*) D. J. Segal, "Highway-Vehicle-Object Simulation Model: Engineering Manual—Validation," Report No. FHWA-RD-76-165, *Federal Highway Administration*, Washington, D.C., 1976, p. 193.

(*2*) M. E. Bronstad, L. R. Calcote, and C. E. Kimball, Jr., "Concrete Median Barrier Research, Executive Summary," Report No. FHWA-RD-77-3, *Federal Highway Administration*, Washington, D.C., June 1976.

(*3*) "Development of a Collapsing Ring Bridge Railing System," Report No. FHWA-RD-76-39, *Federal Highway Administration,* Washington, D.C., January 1976.

Morton S. Oskard is a structural research engineer in the Safety and Design Division, Office of Safety and Traffic Operations Research and Development, FHWA. Dr. Oskard has been active in roadside safety research since 1971 with emphasis on vehicle crash simulations and its application to the roadside appurtenance design process. Present research activity is centered on scale model studies of roadside structures with eventual application to performance and cost optimization. Prior to his present position, Dr. Oskard worked on various aerospace and military structural research projects in the private sector.

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. The Office of Engineering and Highway Operations Research and Development (R&D) includes the Structures Division; Pavement Division; Construction, Maintenance, and Environmental Design Division; and the Materials Technology and Chemistry Division. The Office of Safety and Traffic Operations R&D includes the Systems Technology Division, Safety and Design Division, Traffic Control and Operations Division, and Urban Traffic Management Division. The reports are available from the source noted at the end of each description.

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

Requests for items available from NTIS should be addressed to:
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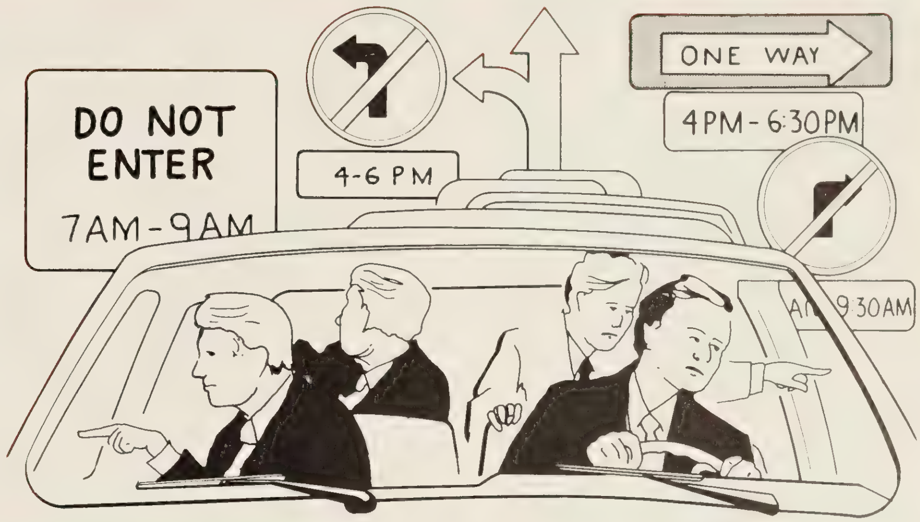


Motorist Direction-Finding Aids: Recovery From Freeway Exiting Errors, Final Report, Report No. FHWA/RD-82/098

by Systems Technology Division

Improvements in motorist direction-finding performance could reduce unnecessary travel, provide an important savings of fuel, increase highway safety, and decrease the physical deterioration of the system. There could also be benefits associated with reductions in traffic congestion, air pollution, and driver stress.

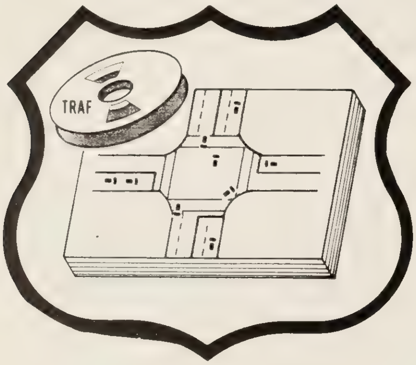
This study examined driver performance in a route-following situation using different types of direction-finding aids. The route-following situation involved recovery from a freeway exiting error. The aids were a road map, a telephone information system, and a computerized roadside information system. Generally, the additional mileage required to recover from the error was largest for the control groups (no aid) and fell in decreasing order for the groups receiving aid from a map, telephone system, or computer system.

The results of this study are consistent with prior research indicating a significant motorist direction-finding problem exists. The findings also suggest alternative types of direction-finding aids can significantly increase motorist route-following efficiency.

This report may be purchased from NTIS.

The TRAF System—Technical Summary, Report No. FHWA/RD-83/084

by Urban Traffic Management Division



This report presents an overview of the TRAF traffic simulation system. The models that have been integrated into the system are: (1) *Netsim*, which simulates urban traffic in a detailed or microscopic fashion; (2) *Netflo*, which performs a similar simulation at lower levels of detail; (3) *Freflo*, for a coarse or macroscopic representation of freeway traffic; and (4) *Roadsim*, a detailed two-lane traffic simulator.

The descriptions of each component model cover the input requirements and the output capabilities, which include measures of effectiveness of traffic performance, fuel consumption, and air polluting emissions.

The report is intended for individuals and agencies considering the use of computer simulation for evaluating the effect of changes in traffic systems, ranging from resetting a traffic signal to building a new freeway.

This report may be purchased from NTIS.

Centrifugal Testing of Model Piles and Pile Groups, Executive Summary and Final Reports, Report Nos. FHWA/RD-84/002, 84/003, and 84/004

by Construction, Maintenance, and Environmental Design Division

These reports discuss a research program conducted to evaluate the feasibility of testing model piles and pile groups in sand and clay using the geotechnical centrifuge. The reports describe the preparation of the sand and clay samples, details of the model piles, method of pile placement, test procedures, and description of the centrifuge and its operations. Results are presented and analyzed. Conclusions are presented on the verification of the similitude relations, sensitivity of capacity to angle of internal friction, influence of driving sequence, pile group efficiency, and load transfer relations.

These reports will be useful to investigators using the centrifuge as a research or engineering design tool. Results presented will be of interest to engineers designing pile foundations in sand and clay.

The reports may be purchased from NTIS.

Environmental and Safety Evaluation of Sulphlex Binders, Report No. FHWA/RD-84/005

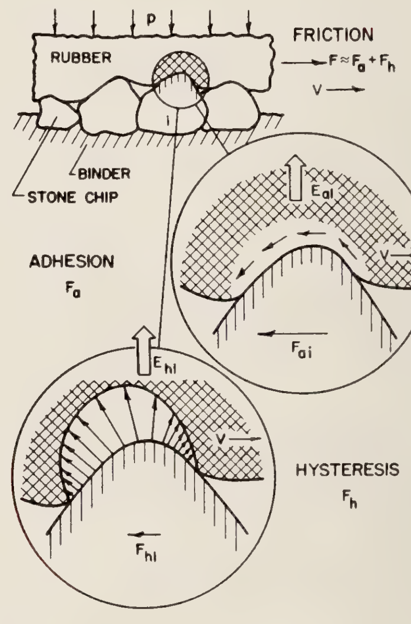
by Materials Technology and Chemistry Division

This report presents the results of a comprehensive environmental and safety assessment of Sulphlex (chemically-modified sulfur) paving binders. The study goal was to determine potential hazards associated with the use of these materials in field operations. Of particular concern was any evidence of carcinogenicity or mutagenicity; a wide spectrum of bioassay tests were conducted to measure these effects. In addition, detailed identification was made of the type and levels of emissions released during normal construction operations with Sulphlex binders, as well as during abnormal situations, such as pavement fires and severe overheating of the binder in bulk storage. The report will be of interest to research and operations personnel involved with pavement mixtures employing Sulphlex or similar binders.

The report may be purchased from NTIS.

Evaluation of Pavement Texture, Report No. FHWA/RD-84/016

by Pavement Division



It has been recognized for some time that tire-pavement friction on wet roads depends largely on the surface texture, both micro- and macrotexture. This report discusses two indirect methods of measuring texture, and the relationship between wet weather accidents and friction measurements for ribbed and bald test tires.

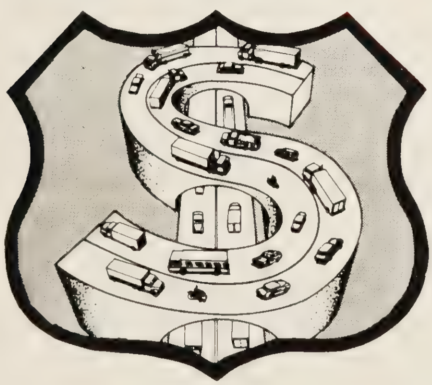
A prototype texture measuring system, using the depolarization effect of texture on polarized light, was previously developed by the Naval Surface Weapons Center. This is a simple, low cost system and can be operated from a vehicle moving at traffic speeds. The evaluation showed excellent repeatability, but correlation with pavement friction or pavement texture was inconsistent. No further work on this system is currently planned.

The opposite approach, deriving texture data from friction measurements, was more successful. A friction tester was modified for measuring friction alternately with the left and right trailer wheels, fitted with a ribbed and bald tire, respectively. Consistently high correlations with texture data were obtained; however, further validation on a larger spectrum of pavement surface is needed.

This report may be purchased from NTIS.

Pavement Damage Functions for Cost Allocation, Executive Summary and Final Reports, Report Nos. FHWA/RD-84/017, 84/018, 84/019, and 84/020

by Pavement Division



These reports discuss pavement damage functions which were developed for both flexible and rigid pavement distresses that were considered significant as generators of major repair or rehabilitation. These damage functions were then used to develop load equivalence factors for each of these significant distresses. The results of this is a family of damage functions or distress for broad application for pavement management and other uses as well as for cost allocations. Two classes of damage functions were produced: those that predict load-induced damage and those that predict damage caused by the environment with general independence of axle loads.

Flexible pavement damage functions for rutting and serviceability loss were also developed from a representative subset of AASHO Road Test data consisting of 76 test sections. The primary purpose of this limited project was to check and validate the use of a combined mechanistic and empirical modeling approach to develop damage functions that were used in the recent cost allocations studies.

Two related volumes were developed discussing computer programs: Flexible Pavement Model VESYS IV-B, FHWA/RD-84/021; and Program DAMAGE Users Manual, FHWA/RD-84/022.

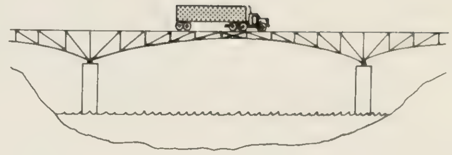
These reports may be purchased from NTIS.

Bridge Formula Application and Procedure Manual for Bridge Formula Application, Report Nos. FHWA/RD-84/029 and 84/030

by Structures Division

These reports describe a study conducted to review and evaluate the current practices and methods used at truck weigh stations in the United States with emphasis on identifying problems and proposing remedies in the application of the current Bridge Formula. The first volume details the methods and the equipment used at weigh stations in various States. It presents a systematic analysis of the Bridge Formula, containing the analytical basis for simplifications that are possible and the methods for implementing them.

The second volume provides an easy-to-follow procedure manual with illustrations for the application of the formula. Through the simplification explained in the manual, tedious and repeated numerical calculations and weighing procedures are either

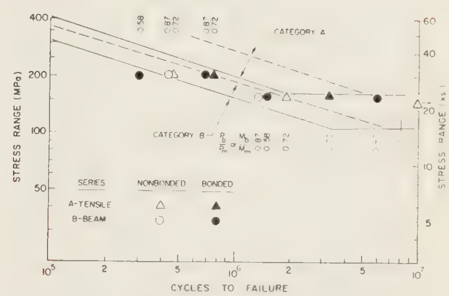


eliminated or significantly reduced. The use of a hand-held computer for the implementation of the Bridge Formula is also discussed and a program written for field application.

These reports are available from NTIS.

Application of Adhesives to Steel Bridges, Report No. FHWA/RD-84/037

by Structures Division



This report describes research conducted to study the feasibility of using adhesive bonds as replacements for welds on secondary structural members. The results of fatigue and static loading showed that bonding the contact surfaces significantly increased the fatigue life of high-strength bolted splices. Bonding of cover plates increased the fatigue life by a factor of 20 over that of conventionally welded cover plates. While bonding greatly increased the slip resistance of bolted joints, it did not affect the ultimate strength of the joint. In addition, it was found that the creep strength of the adhesive bond decreases with time, particularly in outdoor environments with high ambient temperatures. Successful application of this technology will require careful adhesive selection for the intended service environment. Further research is needed and is underway to better characterize the adhesive properties needed in bridge applications.

This report may be purchased from NTIS.

Brown Coal Fly Ash in Soil Stabilization, Report No. FHWA/RD-84/072

by Materials Technology and Chemistry Division

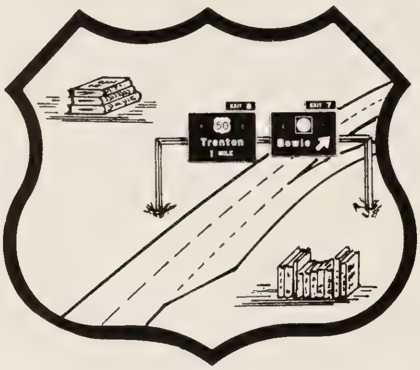
This report discusses research performed by a team from the Polish Ministry of Transport's Road and Bridge Research Institute for the U.S. Department of Transportation as part of Agreement No. P-9 with the Ministry. It deals with the findings of the researchers' investigation of the physical and mechanical characteristics of mixtures of cohesionless soils, sand or sand-gravel aggregate, and brown coal fly ash (with and without lime). The report includes: (1) a discussion of the characteristics of the materials; (2) test results of specimens cured at various temperatures; (3) observations on test sections of pavements; and (4) guidelines for the construction of road base courses using brown coal fly ash. The discussion is a continuation of related work previously reported in FHWA-RD-79-101, "The Application of Brown Coal Fly Ash to Road Base Courses."

The report may be purchased from NTIS.

Night Visibility of Overhead Guide Signs: A Review of the Literature, Report No. FHWA/RD-84/087

by Systems Technology Division

The report documents the results of a literature review on night visibility of highway signs. In conducting this review, over a hundred research studies were critically evaluated to determine the adequacy of prior research findings in addressing the question of whether any or all overhead guide signs should be

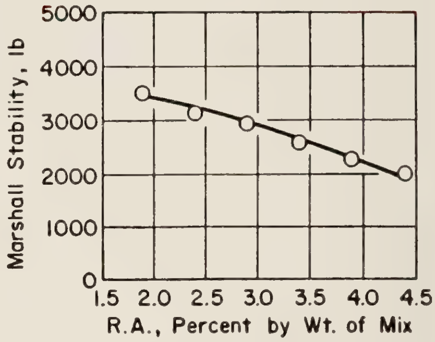


required to be illuminated or fully reflectorized. The report organizes this literature into chapters dealing with general factors affecting driver-sign communication, legibility, conspicuity, driver preference, error, color, adverse weather, and cost. The basic issues pertinent to sign material choice are identified and the findings of previous research summarized. Specific weaknesses in the scientific literature which were identified during the study are discussed.

This report may be purchased from NTIS.

Flexible Pavement Mixture Design Using Reclaimed Asphalt Concrete, Report No. FHWA/RD-84/088

by Pavement Division



This report covers the development and verification of the design method for hot mix recycled paving using both Marshall and Hveem test equipment. It includes tentative design criteria and statistically-based sampling plans for obtaining pavement cores prior to recycling, samples of stockpiled materials, and samples from trucks transporting processed reclaimed materials. The design procedures and sampling plans, which are listed step-by-step, were tested on five asphalt recycling projects.

The report may be purchased from NTIS.

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 they have a special interest to highway agencies. 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

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

Requests for items available from NTIS should be addressed to:
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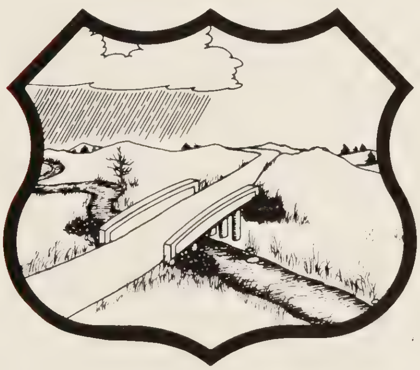
Hydrology, Report No. FHWA-IP-84-15

by Office of Implementation

An estimated one-fifth of every highway construction dollar is spent on drainage-related items. In a highway program which spends billions of dollars annually, any factor that appreciably affects drainage-related costs is critical.



This report provides practical hydrologic methods and techniques to assist bridge and highway engineers in determining discharges to be used in the design of bridge and drainage structures. The manual presents the procedures and techniques for estimating peak flows and hydrographs as used in traditional hydraulic design. It also provides the highway designer with the capabilities to develop the hydrologic inputs for modern design methods using risk analysis and least total expected cost techniques. Many examples and illustrations of hydrologic computational procedures are presented.

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

State Laws and Regulations Governing Settlement of Highway Construction Contracts Claims and Claim Disputes, Report No. FHWA-TS-84-209

by Office of Implementation

This report is a compilation of State constitutional, statutory,and administrative provisions governing the bases and procedures for bringing claims against State highway and transportation agencies arising out of and in the course of highway construction. Information for this report was obtained from State highway and transportation departments and Attorneys General and is presented in State-by-State narrative summaries.

Summaries for each State include (1) legal status of sovereign immunity rules regarding proceedings against State agencies for construction contract claims; (2) departmental administrative regulations governing review and determination of claims by the highway agency; (3) legislation or regulations governing proceedings on appeal from departmental decisions to special boards or commissions, or to arbitration; and (4) legislation prescribing procedure for litigation of construction contract claims in regular or special courts. Citations to legislative authority and pertinent court decisions are noted. Summaries cover all States and the District of Columbia.

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

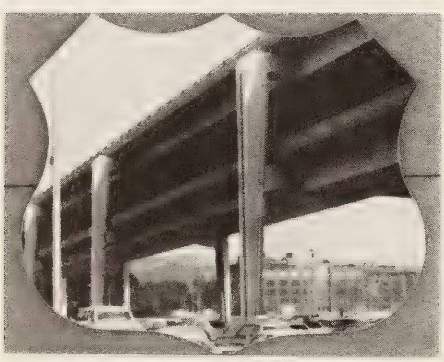
Fort Duquesne Bridge: Fracture Analysis of Flange Cores, Report No. FHWA-TS-84-210

by Office of Implementation

A materials testing program was conducted on A-517 steel cores to determine the cause of cracking of the Fort Duquesne Bridge bents. Tests performed were metallographic examination, Charpy V-notch impact tests, compact tension (fracture toughness) tests, and Z-direction tensile tests.

The results of the testing program showed that cracking was associated with repair welding and verified lamellar tearing characteristics of the flange plates. The test results also provided useful information on the fracture behavior of A-517 steel.

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



Value Engineering Contract Provisions on Federal-Aid Highway Construction Projects, Final Report and Executive Summary, Report Nos. FHWA-TS-84-216 and 84-217

by Office of Implementation

This report examines the use of Value Engineering Contract Provisions (VECP) on Federal-aid construction projects to determine if the maximum benefits are being obtained. The report makes several recommendations to State highway agencies, contractors, and the FHWA, which if implemented should increase the use of VECP's and improve the review and acceptance process of contractor proposals.

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

Value Engineering Study of Crack and Joint Sealing, Report No. FHWA-TS-84-221

by Office of Implementation

The sealing of cracks and joints in both asphalt and reinforced concrete pavements is often an overlooked preventive maintenance operation. The States of Delaware, Georgia, Montana, Tennessee, and Utah cooperated to complete a study of crack and joint sealing materials and placement techniques that used a "Value Engineering" approach. Optimizing the expenditure of maintenance funds for sealing materials and the manpower involved in sealing operations was a prime consideration of this study.

Recommendations for cost effective joint and crack sealing materials and methods are included in the study findings. Also, the best practical methods used for crack and joint sealing by the States which participated in the study are documented and discussed in the report.

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

New film available "Traffic Management for Freeway Incidents"

The Office of Safety and Traffic Operations Research and Development, Federal Highway Administration (FHWA), has completed a new freeway film entitled "Traffic Management for Freeway Incidents." This 17-minute, 16mm film promotes the rapid removal of freeway incidents and describes lower cost solutions that highway, police, fire, and other local agencies can use to improve traffic management, safety, and control at incident sites.

While freeways are only 2 percent of the total miles of highways, they carry about 26 percent of the total travel. In urban areas, freeway incidents are highly visible disruptions, and they typically account for one-half of all freeway congestion.

The film illustrates how a preplanned coordinated interagency approach among traffic engineers, police, fire, media, and other local agencies can be implemented quickly when the need arises. Traffic management approaches are illustrated for both simple and complex incidents. The film incorporates footage from Chicago, Los Angeles, San Antonio, and other locations. The film will be of interest to Federal, State, city, and local traffic engineers.

The FHWA's Demonstration Projects Division is planning a demonstration effort on how local agencies can develop incident response plans and teams. This film plus freeway management reports and other examples will also be displayed and demonstrated to traffic engineers and local highway administrators in numerous cities and counties in the United States during 1985.

FHWA Division Offices may borrow a copy of the film from their regional offices. Others may borrow a copy by writing to the FHWA, RD&T Report Center, 6300 Georgetown Pike, McLean, Virginia 22101 or by telephoning (703) 285-2144.

ASCE/FHWA Specialty Conference Highway Infrastructure: Opportunities for Innovation

The American Society of Civil Engineers (ASCE) and the Federal Highway Administration (FHWA), along with several other cooperating highway organizations, will be holding the conference "Highway Infrastructure: Opportunities for Innovation" on July 17 through 19, 1985, at the Xerox International Center for Training and Management Development in Leesburg, Virginia. The Research Committee of the ASCE Highway Division and the FHWA organized the conference to focus national attention on research as an effective and economical means for solving many highway infrastructure problems. The conference will benefit individuals and organizations that sponsor and/or use research results in the highway programs.

The initial session will emphasize the challenge facing the highway research community and the need to develop a national strategy for getting the innovation required to support our highway system. An overview will be given of where we have been in the highway research process, and the question of the value of research will be addressed. A look will be taken at the future of highway research with the answer hinging on whether or not there is innovation.

A second session will address the available research programs (the market) and the various procedures used to carry these programs out (the process). A comprehensive description of each program (market and process) will be provided as a handout to each conference participant. An overview of the various programs will be given by the session moderator followed by a panel discussion. Many of the panel members will come from the major organizations that sponsor highway research, most of which are cosponsors of this conference.

A series of workshops will be held to discuss available resources and response mechanisms to address the challenge issued in the initial session. The conference participants will be divided into small groups to work with a designated workshop leader to address topics such as: research areas of the future, people resources, funding resources, getting research into practice, and managing research programs.

Demonstrations and exhibits of successful and innovative research for highway applications will be showcased at the conference site. Hands-on/walk-around demonstrations and opportunities for audience participation will be available in the evenings and during the last session of the conference.

For further information, contact Mr. Edward Kippel (American Society of Civil Engineers, 345 East 47th Street, New York, New York 10017, telephone: 212-705-7495) or Mr. Albert F. DiMillio (Federal Highway Administration, Turner-Fairbank Highway Research Center, 6300 Georgetown Pike, McLean, Virginia 22101, telephone: 703-285-2436).

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, 2101 Constitution Avenue, NW., Washington, D.C. 20418.

FCP Category 1—Highway Design and Operation for Safety

FCP Project 1A: Traffic and Safety Control Devices

Title: Traffic Control for Stop-and-Go and Short-Term Maintenance/Construction Operations and Techniques for Installing Lane Closures. (FCP No. 41A5774)

Objective: Develop guidelines and typical work site layouts for stop-and-go and slow-moving maintenance operations.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1986
Estimated Cost: $105,000 (HP&R)

FCP Project 1K: Accident and Countermeasure Analysis

Title: Assessment of Existing Data Bases to Monitor RRR Activities. (FCP No. 31K1058)

Objective: Review existing large data bases (National Accident Sampling System [NASS], Fatal Accident Reporting System [FARS], and Highway Performance Monitoring System [HPMS]) to determine their adequacy for monitoring the safety implications of RRR activities. Investigate and analyze alternatives such as combining NASS and HPMS in selected States and collecting NASS data on HPMS. Develop a plan to more effectively use existing data resources.
Performing Organization: Texas A&M Research Foundation, College Station, Tex. 77843
Expected Completion Date: November 1985
Estimated Cost: $69,821 (FHWA Administrative Contract)

Title: Development of Exposure Measures for Highway Safety Analysis. (FCP No. 31K3072)

Objective: Refine and further develop exposure measures for signalized intersections and determine their most appropriate forms based on (1) reliability and accuracy, (2) sensitivity to input parameters, and (3) feasibility of large scale data usage (for example, city ordinances).
Performing Organization: University of North Carolina, Chapel Hill, N.C. 27514
Expected Completion Date: March 1987
Estimated Cost: $150,000 (FHWA Administrative Contract)

FCP Project 1M: Rural Two-Lane Highways

Title: Field Evaluation of Edgeline Widths. (FCP No. 31M2734)

Objective: Determine the cost effectiveness of the 8-in (203-mm) edgeline to reduce run-off-the-road accidents on rural two-lane roadways. Conduct a 2-year before/after study with a control group, which will consist of sections marked with 4-in (102-mm) edgelines, and treatment groups, which will consist of similar sections of two-lane roadways marked with 8-in (203-mm) edgelines. Collect and analyze accident, traffic operational, and edgeline service life data.
Performing Organization: Bellomo-McGee Incorporated, Vienna, Va. 22180
Expected Completion Date: April 1988
Estimated Cost: $162,630 (FHWA Administrative Contract)

FCP Project 1O: Railroad Crossing Safety

Title: Railroad-Highway Crossing Signal Visibility Improvement Field Demonstration. (FCP No. 31O1234)

Objective: Establish a visibility definition for the railroad-highway crossing signal and identify alternatives for improving signal performance (light intensity and dispersion level, uniformity, stability, and reliability). Prepare experimental prototypes and test under laboratory and simulated field conditions. Identify and evaluate photometric instrumentation to aid laboratory and field adjustment of the crossing signal and provide a means of performance verification.
Performing Organization: Oak Ridge National Laboratory, Oak Ridge, Tenn. 37831
Expected Completion Date: September 1986
Estimated Cost: $246,337 (FHWA Administrative Contract)

FCP Project 1P: Night Visibility

Title: Noticeability Requirements for Delineation on Non-Illuminated Highways. (FCP No. 31P1022)
Objective: Determine the needed conspicuity for adequate visual guidance. Study alternate methods of providing this guidance with and without glare from oncoming traffic and determine where standard delineation treatments need to be supplemented with more effective treatments, such as raised pavement markers. Consider both normal and adverse weather.
Performing Organization: Ketron, Inc., Wayne, Pa. 19087
Expected Completion Date: April 1987
Estimated Cost: $241,787 (FHWA Administrative Contract)

FCP Project 1S: Design and Corrective Geometrics

Title: Safe Geometric Design for Mini-Cars. (FCP No. 31S1032)
Objective: Measure the static and dynamic characteristics of mini-cars up to 2,000 lb (1 Hg) and use as input for the Highway-Vehicle-Object Simulation Model (HVOSM). Use this validated vehicle simulation model to identify the critical limits of various geometrics, such as vehicle redirection due to curbs, slopes, and slope breaks. Evaluate pavement characteristics necessary for safe vehicle acceleration and deceleration and recommend modifications for critical design features.
Performing Organization: University of North Carolina, Chapel Hill, N.C. 27514
Expected Completion Date: September 1986
Estimated Cost: $118,667 (FHWA Administrative Contract)

FCP Project 1T: Roadside Safety Hardware

Title: Guardrails on Low Fill Bridge Length Culverts. (FCP No. 41T2372)
Objective: Determine if the standard guardrail post embedment depth of 38 in (966 mm) can be reduced while also decreasing the post spacing, and still retain adequate guardrail strength for use on low fill depth bridge length culverts. Develop culvert deck mountable guardrail posts with the required strength and similar force versus deformation characteristics as soil mounted posts for even lower soil fill depths.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1986
Estimated Cost: $100,000 (HP&R)

FCP Project 1W: Vehicle/Surface Interaction Problems

Title: Pavement Friction Normalized for Operational, Seasonal, and Weather Effects. (FCP No. 31W1172)
Objective: Develop and validate procedures for normalizing pavement friction measurements to standard environmental and operational conditions. Consider how to simplify and improve friction testing.
Performing Organization: Pennsylvania State University, University Park, Pa. 16802
Expected Completion Date: August 1987
Estimated Cost: $466,464 (FHWA Administrative Contract)

Title: Wet Weather Exposure Measure. (FCP No. 31W2122)
Objective: Combine analytical and experimental investigations to establish the minimum level of wetness at which tire-pavement friction is significantly reduced. Develop a model for predicting the duration of wet pavement slipperiness as a function of regional conditions of rainfall and other factors causing a reduction in skid resistance.
Performing Organization: Midwest Research Institute, Kansas City, Mo. 64110
Expected Completion Date: December 1986
Estimated Cost: $150,000 (FHWA Administrative Contract)

FCP Project 1Z: Implementation of Safety R&D

Title: Automated Recordation and Analysis of Pavement Conditions. (FCP No. 31ZW028)
Objective: Survey all kinds of equipment being used to automatically record and analyze the surface condition of highway pavement. Select the most promising equipment/techniques and field test them to determine their adequacy for use by State highway agencies.
Performing Organization: Eikonix Corporation, Bedford, Mass. 01730
Expected Completion Date: January 1986
Estimated Cost: $86,860 (FHWA Administrative Contract)

FCP Category 2—Traffic Control and Management

FCP Project 2P: Urban Freeway Management

Title: Effect of Pavement Conditions on User Cost and Capacity. (FCP No. 32P1192)
Objective: Measure the effects of pavement conditions on the speed capacity and user costs for high volume, rural two-lane and multilane roadways, urban freeways, and selected limited access urban arterials.
Performing Organization: Sparta Systems, Inc., Laguna Hills, Calif. 92653
Expected Completion Date: November 1986
Estimated Cost: $75,000 (FHWA Administrative Contract)

Title: HOV-Related Parking Facilities. (FCP No. 32P3082)
Objective: Develop guidance to assist transportation engineers with the planning, design, and operation of corridor parking facilities associated with high occupancy vehicles (HOV), such as fringe lots, large suburban terminals, and downtown carpool parking facilities. Address procedures for locating the facilities and the special traffic circulation problems encountered with these facilities.
Performing Organization: Daniels Consultants, Inc., Columbia, Md. 21045
Expected Completion Date: April 1986
Estimated Cost: $122,899 (FHWA Administrative Contract)

Title: Integrated Motorist Information System (IMIS) Evaluation. (FCP No. 32P4032)
Objective: In cooperation with the New York State Department of Transportation, conduct a comprehensive evaluation of the costs and effectiveness of IMIS, which is now being constructed in the Northern Long Island Corridor.
Performing Organization: JHK and Associates, Alexandria, Va. 22304
Expected Completion Date: September 1987
Estimated Cost: $345,000 (FHWA Administrative Contract)

FCP Project 2Q: Urban Network Control

Title: Graphics Display Package for Netsim Output Analysis. (FCP No. 32Q2202)
Objective: Design and code programs for microcomputers to display output from the computer traffic simulation program, Netsim. Develop training courses and program maintenance.
Performing Organization: KLD Associates, Inc., Huntington Station, N.Y. 11746
Expected Completion Date: August 1986
Estimated Cost: $400,000 (FHWA Administrative Contract)

Title: Impact of Arterial Lane Obstructions. (FCP No. 32Q2232)
Objective: Determine the effect of arterial lane obstructions (such as illegally parked vehicles or pickup and delivery operations) on vehicle operating costs and quality of traffic service. Supplement existing data on arterial traffic with newly collected data. Use the data to calibrate a simulation model that will be used to simulate various lane obstructions and their impact.
Performing Organization: JFT and Associates, Culver City, Calif. 90230
Expected Completion Date: April 1986
Estimated Cost: $150,782 (FHWA Administrative Contract)

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

Title: Traffic Simulation Models—Maintenance and Support. (FCP No. 32ZQ328)
Objective: Provide support and maintenance of the TRAF family of traffic engineering simulation models. Assist users in installing and using the TRAF models on different computer systems, issue updates of program documentation and user manuals, make minor model enhancements, and issue a periodic newsletter to keep users current with changes in the program.
Performing Organization: KLD Associates, Inc., Huntington Station, N.Y. 11746
Expected Completion Date: November 1986
Estimated Cost: $240,000 (FHWA Administrative Contract)

FCP Category 3—Highway Operations

FCP Project 3B: Environmental Management

Title: Design Procedure to Estimate Pollutant Loading from Highway Stormwater Runoff. (FCP No. 33B1042)
Objective: Identify with the design procedure where significant potential exists to impact receiving waters and where there will not be an impact. Analyze highway runoff pollutant constituent data and information on sources and transport mechanisms with such parameters as traffic, design geometry, cross section, and operational parameters, to predict pollutant loadings to receiving waters.
Performing Organization: Woodward-Clyde Consultants, Walnut Creek, Calif. 94596
Expected Completion Date: May 1987
Estimated Cost: $325,000 (FHWA Administrative Contract)

Title: Modification of Highway Air Pollution Models for Complex Terrain and Site Geometry. (FCP No. 33B1832)
Objective: Evaluate limitations of highway air pollution models developed for open highways and confined locations. Evaluate highway air contaminant source changes for confined complex systems. Determine limited number of roadway sites and building geometry variations covering significant highway air pollution problems. Conduct wind tunnel dispersion patterns using varied scale models and wind flows and directions. Develop algorithms to evaluate air pollution impacts and relate such algorithms to current highway air pollution models.
Performing Organization: Technology Integration and Development, Billerica, Mass. 01821
Expected Completion Date: September 1986
Estimated Cost: $231,319 (FHWA Administrative Contract)

FCP Project 3Z: Implementation of Maintenance and Environment R&D

Title: Technology Transfer Training Course. (FCP No. 33ZA048)
Objective: Develop a training package for FHWA regional and division personnel and State technology transfer specialists. Identify ways to improve highway maintenance technology delivery. Base material on a new technology transfer program being developed under an FY 1982 contract.
Performing Organization: University of Wisconsin—Milwaukee, Milwaukee, Wis. 53201
Expected Completion Date: September 1986
Estimated Cost: $77,952 (FHWA Administrative Contract)

Title: Highway Runoff Water Quality Training Course. (FCP No. 33ZB058)
Objective: Develop a training course/technology transfer workshop on highway runoff and water quality. Emphasize the real problems that exist in the participants' States and provide workable alternatives and mitigative measures. Include characterization and estimation of pollutant loading, environmental impact of highway runoff, and mitigative measures, as well as the results of Highway Planning and Research Program, State, and FHWA funded research on highway runoff and water quality.
Performing Organization: Dalton, Dalton, Newport, Inc., Cleveland, Ohio 44122
Expected Completion Date: August 1987
Estimated Cost: $87,822 (FHWA Administrative Contract)

FCP Category 4—Pavement Design, Construction, and Management

FCP Project 4A: Pavement Management Strategies

Title: Life Cycle Cost Analysis for New Pavement Projects and for RRR Projects. (FCP No. 34A2011)
Objective: Establish and document the basic parameters that are included in life cycle cost analysis for pavement projects. Group parameters into two major categories—agency costs and user costs.
Performing Organization: Massachusetts Institute of Technology, Cambridge, Mass. 02139
Expected Completion Date: September 1986
Estimated Cost: $229,563 (FHWA Administrative Contract)

Title: Pavement Evaluation System Improvements. (FCP No. 44A3362)
Objective: Assist the Texas State Department of Highways and Public Transportation with the implementation of its system for managing the State's pavement network. Evaluate the currently available pavement rating equipment and apply the latest work in pavement management to pavement rehabilitation activities.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1987
Estimated Cost: $80,500 (HP&R)

FCP Project 4B: Design and Rehabilitation of Rigid Pavements

Title: Determination of Rehabilitation Method for Rigid Pavements. (FCP No. 34B2024)
Objective: Evaluate the performance of selected pavement rehabilitation techniques. Coordinate this study with the proposed FHWA initiative on pavement rehabilitation and design, and include field reviews of selected existing pavement rehabilitation techniques and evaluation of promising new rehabilitation techniques.
Performing Organization: University of Illinois, Champaign, Ill. 61820
Expected Completion Date: April 1987
Estimated Cost: $250,000 (FHWA Administrative Contract)

FCP Project 4C: Design and Rehabilitation of Flexible Pavements

Title: Develop Improved Asphalt Concrete Mixtures Design. (FCP No. 44C2064)
Objective: Define the extent and severity of mixture design problems and how these problems are manifested in pavement distress. Define the sensitivity of the response of the mixtures produced in the laboratory to fabrication process variables. Relate variation in the laboratory fabrication to material mixture variations due to plant and construction variables.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: September 1987
Estimated Cost: $188,000 (HP&R)

FCP Project 4D: Improved Flexible Binders

Title: Evaluation of Asphalt Additives. (FCP No. 44D1582)
Objective: Evaluate performance of asphalt pavements containing verglimit and carbon-black in conjunction with Special Experimental Features Project No. 3, Asphalt Additives.
Performing Organization: Connecticut Department of Transportation, Wethersfield, Conn. 06109
Funding Agency: Connecticut Department of Transportation
Expected Completion Date: September 1989
Estimated Cost: $75,800 (HP&R)

FCP Project 4E: Construction Control and Management

Title: Relation of Degree of Consolidation to PCC Performance. (FCP No. 34E2073)
Objective: Conduct laboratory investigations of the relationship between degree of consolidation and properties such as 28-day compressive strength, freeze-thaw resistance, and permeability. Analyze data obtained with a new instrument for continuous monitoring of density to determine consolidation variability in the field. Determine the costs, benefits, and effectiveness of using this new instrument of static nuclear gauges to monitor density.
Performing Organization: Construction Technology Laboratory, Skokie, Ill. 60077
Expected Completion Date: March 1986
Estimated Cost: $140,635 (FHWA Administrative Contract)

FCP Project 4Z: Implementation of New Pavement Technology

Title: Evaluation and Training Related to Drum Mix Plants. (FCP No. 44ZC098)
Objective: Collect and evaluate available information on drum mix plants produced by various manufacturers and used by the construction industry. Develop a training course on the theory, equipment, and procedures related to the use of drum mix plants and present four seminars in Texas.
Performing Organization: University of Texas, Austin, Tex. 78712
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1986
Estimated Cost: $55,000 (HP&R)

FCP Category 5—Structural Design and Hydraulics

FCP Project 5A: Bridge Loading and Design Criteria

Title: Evaluation of Strength and Ductility of Precast Segmental Box Girder Construction with External Tendons. (FCP No. 45A3222)
Objective: Determine the level of strength and ductility that may be expected for precast segmental bridges with external tendons, current tendon anchorage and joinery details, and alternate tendon anchorage and joinery details. Recommend changes in anchorage details, joinery details,

and tendon locations where changes will improve the behavior of the system without significantly reducing construction efficiency. Develop suitable analysis methods. Recommend methods for design and load rating criteria.
Performing Organization: University of Texas, Austin, Tex. 78712
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1987
Estimated Cost: $50,000 (HP&R)

FCP Project 5H: Highway Drainage and Flood Protection

Title: Cost Effective Roadway and Bridge Drainage and Storm Drain Design Using Economic Analysis. (FCP No. 35H4042)
Objective: Develop a rational procedure for roadway and bridge drainage and storm drain design considering economics, storm frequencies, hydraulics, traffic and time losses, accident costs, and highway losses. Assess the extent of bridge deck drainage that can be justified considering typical duration of peak flows versus practical speed during intense storm events, bridge lengths, grades, cross slopes, traffic safety (hydroplaning, etc.), and potential bridge damage. Assess current design procedures and standards that result in drainage appurtenances that create excessive maintenance and high first cost, and provide guidance on more efficient design practices.
Performing Organization: GKY and Associates, Inc., Springfield, Va. 22151
Expected Completion Date: March 1988
Estimated Cost: $102,000 (FHWA Administrative Contract)

FCP Project 5K: Bridge Rehabilitation Technology

Title: Implementation of a Continuous Fixed Site Bridge WIM Operation. (FCP No. 45K2282)
Objective: Implement a version of the bridge weigh-in-motion (WIM) instrumentation which will be capable of long-term, unattended operation. Develop and test the new system configuration on one bridge installation. Train the State Department of Transportation in its use.
Performing Organization: Bridge Weighing Systems, Inc., Warrensville Heights, Ohio 44128
Funding Agency: Ohio Department of Transportation
Expected Completion Date: March 1986
Estimated Cost: $77,000 (HP&R)

FCP Project 5P: Foundations and Earth Structures

Title: Use of FHWA Step Bladed Vane Probe for Foundation Design. (FCP No. 35P1212)
Objective: Use stepped blade to obtain in situ measurement of lateral total and effective stress, porewater pressure, and dissipation of excess pore pressures. Use these data to derive K_0, consolidation parameters, and K_1 values for use in design procedures for pile foundations, embankments, shallow foundations, retaining walls, and cut slopes. Obtain the data from recently completed and ongoing State projects. Where feasible, monitor structure performance for comparison with predictions.
Performing Organization: Iowa State University, Ames, Iowa 50011
Expected Completion Date: September 1986
Estimated Cost: $247,615 (FHWA Administrative Contract)

Title: Behavior of Reinforced Soil. (FCP No. 35P2052)
Objective: Develop design and construction guidelines for using reinforced soil to support bridge foundations and roadway embankments. Identify and/or develop design parameters such as type of soil suitable for reinforcement; type, size, and location of reinforcing elements; and design equations for checking bearing capacity, settlement, overturning, sliding, etc. Conduct laboratory tests to verify the choice of appropriate parameters for prediction and design. Perform field tests to verify laboratory results and to develop appropriate methods for measuring the degree of improvement attained by the reinforcement method.
Performing Organization: STS Consultants, Ltd., Northbrook, Ill. 60062
Expected Completion Date: August 1987
Estimated Cost: $400,000 (FHWA Administrative Contract)

FCP Project 5Q: Bridge Maintenance and Corrosion Protection

Title: Maintenance Coating of Weathering Steel. (FCP No. 35Q1123)
Objective: Develop techniques for maintenance painting of weathering steel (A-588). Evaluate field methods to determine the level of chloride contamination, develop optimum surface preparation techniques, and evaluate the performance of coatings for the protection of weathering steel.
Performing Organization: Steel Structures Painting Council, Pittsburgh, Pa. 15213
Expected Completion Date: October 1991
Estimated Cost: $200,000 (FHWA Administrative Contract)

Title: Installation and Evaluation of Protective Coatings for Structural Steel in Connecticut. (FCP No. 45Q1174)
Objective: Evaluate the performance of zinc metallizing versus zinc rich paint versus the State standard basic lead silicochromate system. Visually examine the corrosion protection systems on bridges and expose metal coupons and return them to the laboratory to examine the effect of the coating on the base metal. Evaluate the three coating systems on four bridges, representing different environments in the State.
Performing Organization: Connecticut Department of Transportation, Wethersfield, Conn. 06010
Funding Agency: Connecticut Department of Transportation
Expected Completion Date: September 1990
Estimated Cost: $150,825 (HP&R)

FCP Project 5Z: Implementation of Structural, Hydraulics R&D

Title: Seismic Design and Retrofit Structures Manual. (FCP No. 35ZA078)
Objective: Develop a state-of-the-art structures manual on seismic design and retrofit concepts for highway bridges. Incorporate provisions for the recently developed seismic design specifications in the manual. Update existing workshop manual on seismic design of highway bridges to include the newly developed guidelines for bridge design.
Performing Organization: Computech Engineering Services, Berkeley, Calif. 94705
Expected Completion Date: March 1986
Estimated Cost: $123,843 (FHWA Administrative Contract)

Title: Culvert Failure Analysis/Bridge Inspector's Training Manual Supplement. (FCP No. 35ZH058)
Objective: Prepare a supplement to the Bridge Inspector's Training Manual/70 to include information regarding the inspection of large metal and concrete culverts.
Performing Organization: Byrd, Tallamy, MacDonald, and Lewis, Falls Church, Va. 22042
Expected Completion Date: April 1986
Estimated Cost: $62,500 (FHWA Administrative Contract)

Title: Inspection of Fracture Critical Bridge Members. (FCP No. 35ZK048)
Objective: Organize the information available on common fatigue problems in steel highway bridges into a series of case histories or examples that will be the basis of a training course on fatigue related bridge failures. The course will teach bridge engineers to recognize fatigue-prone details, determine causes of fatigue cracking, and develop effective retrofit procedures.
Performing Organization: Byrd, Tallamy, MacDonald, and Lewis, Falls Church, Va. 22042
Expected Completion Date: September 1987
Estimated Cost: $84,600 (FHWA Administrative Contract)

Title: Bridge Paint Inspection Training Course. (FCP No. 35ZQ038)
Objective: Revise an existing FHWA training course on bridge paint inspection to simplify the treatment of the material and develop a format which can be taught, on a periodic basis, by State highway agency instructors.
Performing Organization: Stephen G. Pinney and Associates, Port St. Lucie, Fla. 33452
Expected Completion Date: September 1988
Estimated Cost: $105,000 (FHWA Administrative Contract)

FCP Category 9—R&D Management and Coordination

FCP Project 9B: New Concepts Development and Systems Characterization

Title: Optimization of Left Turn Phase Sequence in Signalized Networks. (FCP No. 39B2232)
Objective: Extend the current limited network capability of the MAXBAND program to more complex grid networks. This will lead to an improved version of the TRANSYT-7F program, which is used in the National Signal Timing Optimization Project.
Performing Organization: Texas A&M Research Foundation, College Station, Tex. 77843
Expected Completion Date: April 1986
Estimated Cost: $109,535 (FHWA Administrative Contract)

FCP Category 0—Other New Studies

Title: Project Completion Time and Project Overruns. (FCP No. 40M3444)
Objective: Develop a method for estimating completion times for various types of construction activities. Determine costs of project overruns and recommend liquidated damages for projects. Study the feasibility of paying bonuses for early completion.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1986
Estimated Cost: $82,000 (HP&R)

Title: Image Analysis of Highway Materials. (FCP No. 40M3931)
Objective: Develop sample preparation techniques and analysis programs for image analyses of highway and construction materials. Useful applications include measurements of total pore volume and porosity, average pore or particle size, particle or pore size distributions, particle or pore shape, and particle or pore orientation in construction materials such as fly ashes and air entrained cement paste.
Performing Organization: Purdue University, West Lafayette, Ind. 46204
Funding Agency: Indiana Department of Highways
Expected Completion Date: March 1988
Estimated Cost: $87,530 (HP&R)

ERRATA: In the December issue, New Research in Progress, page 115, the Funding Agency for the study "Noncontact, Nondestructive Determination of Pavement Deflection Under a Moving Load (FCP No. 41W3232)" was mistakenly identified as the Michigan Department of Transportation. The correct Funding Agency is the Ohio Department of Transportation.

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