would be more economically justified for long-term projects than for short-term ones, assuming that they are needed at all. Remember that the accident experience from the sites in this study failed to support the necessity of barrier installation for low-volume roadways.

In regard to approach speeds, it can be expected that, as speed to the transition increases, the chances of a head-on collision would also increase. This is because at higher speeds vehicles would have a greater tendency to stray out of their lanes, particularly at curves such as those present at transition zones. This is implied in recent roadway delineation research (7). By using this reasoning, concrete barriers appear to be justified at transition zones where approach speeds are high. It is difficult to see a need for barriers at zones that have low approach speeds since the head-on accident frequency is expected to be low under those circumstances.

CONCLUSIONS

This paper was prepared with the aim of collecting, tabulating, and analyzing accident data from construction and maintenance zones to determine the validity of the requirements for concrete barriers at transition zones as part of a FHWA emergency rule.

The results of this study and the findings based on past research indicate that concrete barriers do not appear to be justified at those transition zones located on relatively low-volume roadways. The accident data showed that the occurrence of head-on collisions at transition zones was nonexistent at the rural sites reviewed. When errant vehicles did stray into the opposing traffic lanes within these zones, oncoming vehicle volumes were low so that no collisions occurred.

Intuitively, it appears that concrete barriers may be needed at the transitions during the early days of the project, due to the relatively low driver expectancy of the new traffic patterns. However, attention must be given to costs, particularly on short-term projects. Barriers also appear justified at transition zones where approach speeds are high because of the increased probability of a vehicle straying out of its lane due to the geometrics of the transition.

REFERENCES

1. Manual on Uniform Traffic Control Devices for Streets and Highways. FHWA, 1978.
2. Safety in Construction and Maintenance Zones--Two-Way Traffic on Normally Divided Highways. FHWA, Bull., Dec. 20, 1978.
3. Traffic Safety in Highway and Street Work Zones; Separation of Opposing Traffic. Federal Register, Rules and Regulations, Vol. 44, No. 181, Sept. 17, 1979.
4. Summary of Comments and Suggestions of FHWA Docket No. 79-31. Office of Highway Operations, FHWA, 1980.
5. L.M. Pang. Evaluation of Centerline Treatment Used for Two-Way, Two-Lane, No-Passing Operations on Normally Divided Rural Freeways. Department of Civil Engineering, Univ. of Nebraska, Lincoln, M.S. thesis, Dec. 1979.
6. J.L. Graham. Accident and Speed Studies in Construction Zones. FHWA, FHWA-RD-77-80, June 1977.
7. W.A. Stimpson. Field Evaluation of Selected Delineation Treatments on Two-Lane Rural Highways. FHWA, FHWA-RD-77-118, Oct. 1977.

Publication of this paper sponsored by Committee on Traffic Safety in Maintenance and Construction Operations.

Abridgment

Alternative Sign Sequences for Work Zones on Rural Highways

RICHARD W. LYLES

Two experiments were done on a two-lane rural road (US-2) in central Maine to evaluate the effectiveness of alternate signing sequences for providing warning to motorists of construction and maintenance activities that require a lane closure on the road ahead. The signs tested included a standard Manual on Uniform Traffic Control Device (MUTCD) warning sequence, the same sequence on both sides of the road augmented with continuously flashing beacons, and a sequence of symbol signs. Data were collected covertly on random motorists by using a combination of inductance loops imbedded in the roadway and piezoelectric cable sensors on the road surface. Analysis of the data showed that (a) the most effective sign sequence was the MUTCD sequence augmented with flashing beacons, (b) the symbol sign sequence appeared to be at least as effective as the standard sequence, and (c) in no instance did the sign sequence appear to cause confusion or potentially dangerous abrupt motorist reaction.

Over the past several years interest has increased in the safety aspects of construction and maintenance activities undertaken when traffic is maintained. Specifically, How can the safety of both passing motorists and the workers be assured while traffic is maintained? Relative to the traffic, the key issues are to alert the approaching motorists to the activity to be encountered ahead and to reduce their speeds in advance so that they can stop safely if the need arises nearer, or in, the work area.

Previous research in this area has ranged from information needs (1), through evaluations of barriers and barricades (2,3), to questions of liability (4,5). Several state-of-the-art reviews are also available (e.g., King and others 6). The Federal Highway Administration's (FHWA) recent programs have been reviewed by Warren and Robertson (7). Within this context, two experiments were undertaken in 1977 to examine several alternative sign sequences for work areas in rural, two-lane situations.

EXPERIMENT IMPLEMENTATION

The original designs for the experiments, (6) were modified prior to implementation in Maine. Two sites were used on US-2 between Skowhegan and Newport, Maine:

1. The long zone was the reconstruction of a two-lane bridge deck where traffic was maintained on one lane at virtually all times during construction, and
2. The short zone was staged to resemble a maintenance operation (e.g., a culvert replacement) with one lane of traffic maintained during the daylight hours and removed at night.

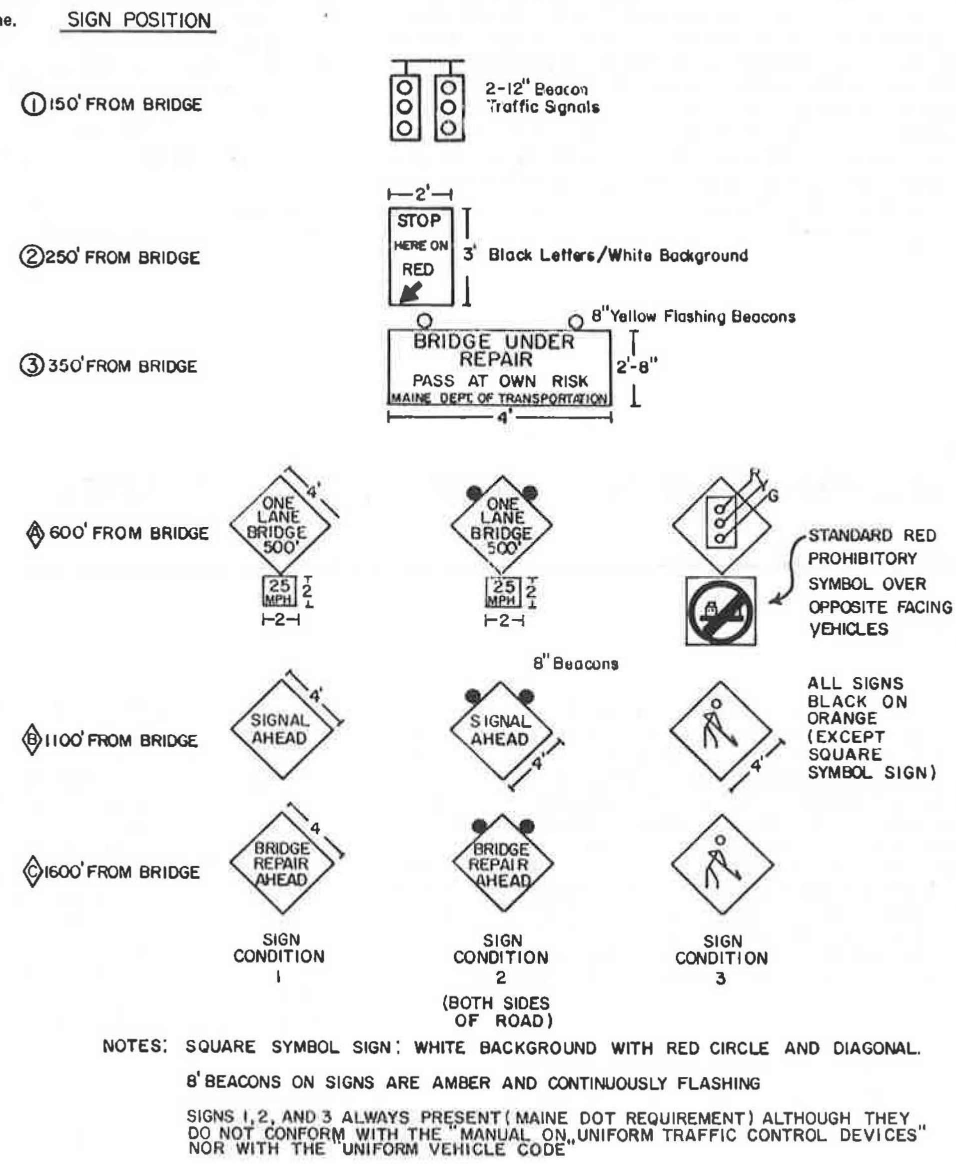
The basic experiment situation was to erect a specified sign sequence in advance of one of the work areas (both approaches to the sites were used) and collect data as motorists approached and passed the signs and eventually passed through the work area. Data were automatically collected (unbeknown to the motorists) from inductance loops embedded in the pavement and piezoelectric cable sensors taped to the road surface.

The sign sequences examined in each experiment are shown in Figures 1 and 2. Although the specific messages differ somewhat, the types of signs tested in each instance were similar. The short-zone experiment was run only during the day, and the long-zone experiment was run during both the day and the night.

The raw data obtained from the automatic collection system (8) were primarily converted to a series of speeds (typically a mean speed over a 200-ft link) for each vehicle and constituted the set of dependent variables in the ensuing analysis (e.g., Where did speed reductions occur?). Data were also available on vehicle type (i.e., two or two or more axles), direction of travel, day of week, time of day, weather conditions (i.e., dry or wet), whether vehicles were in queue or not (i.e., 6-s headway or not), presence of opposing traffic close to the work area (short zone only), and signal color (long zone only). Insofar as possible, the data analysis accounted for potential confounding effects due to the independent variables other than sign sequence displayed (e.g., the analysis was controlled for signal color for the long-zone experiment).

Traffic control at the short zone (short lane closure) was passive insofar as a truck and barricades were present but not workers or a flagger, whereas control at the long zone (long lane closure)

Figure 1. Sign sequences in long zone.



was accomplished with a standard traffic signal. Figure 3 shows the sensor array for data collection on the westbound approach to the short zone. The array for the long zone was similar although data collection for the westbound approach began before the first sign was in view (due to terrain).

SUMMARY OF RESULTS

The analysis of the data primarily consisted of a series of statistical comparisons of the mean vehicle speeds at various points on the approaches to activities in the work zone. Key elements in the analysis were the separating of differential sign effects from those of other confounding factors (e.g., signal color in the long zone).

Summary of Long Zone

As an example of some of the results, Figure 4 shows

Figure 2. Sign sequences in short zone.

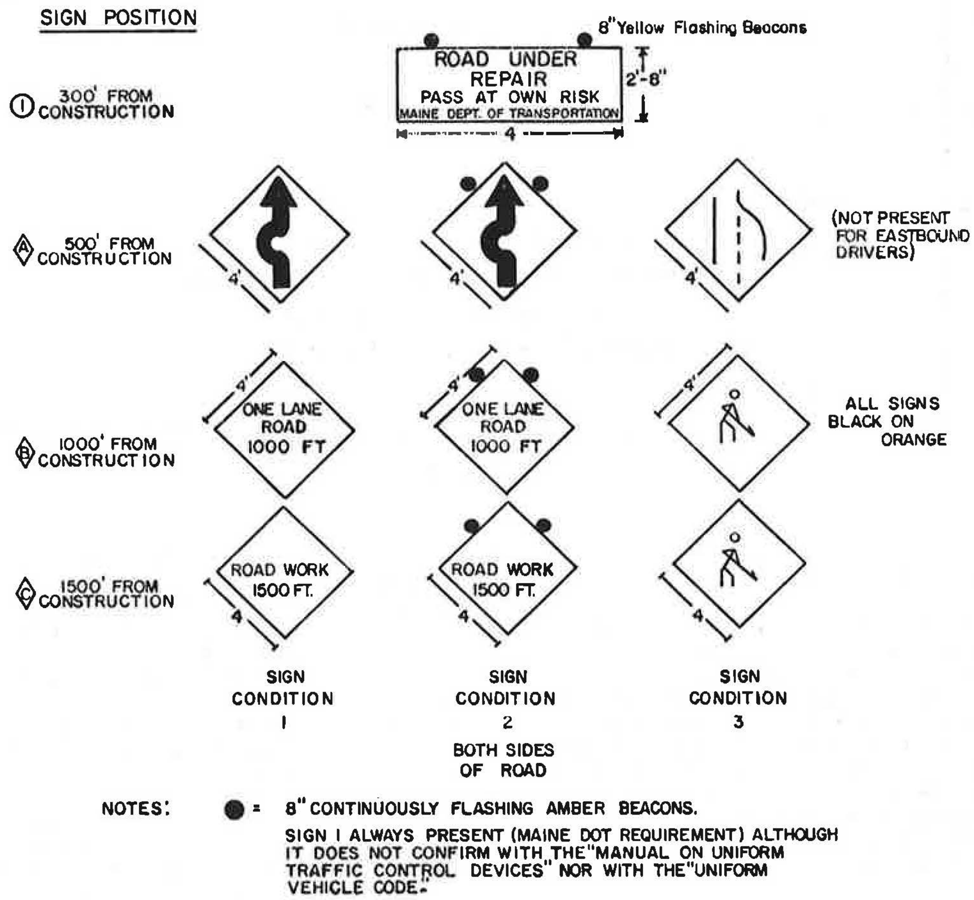


Figure 3. Typical sensor array.

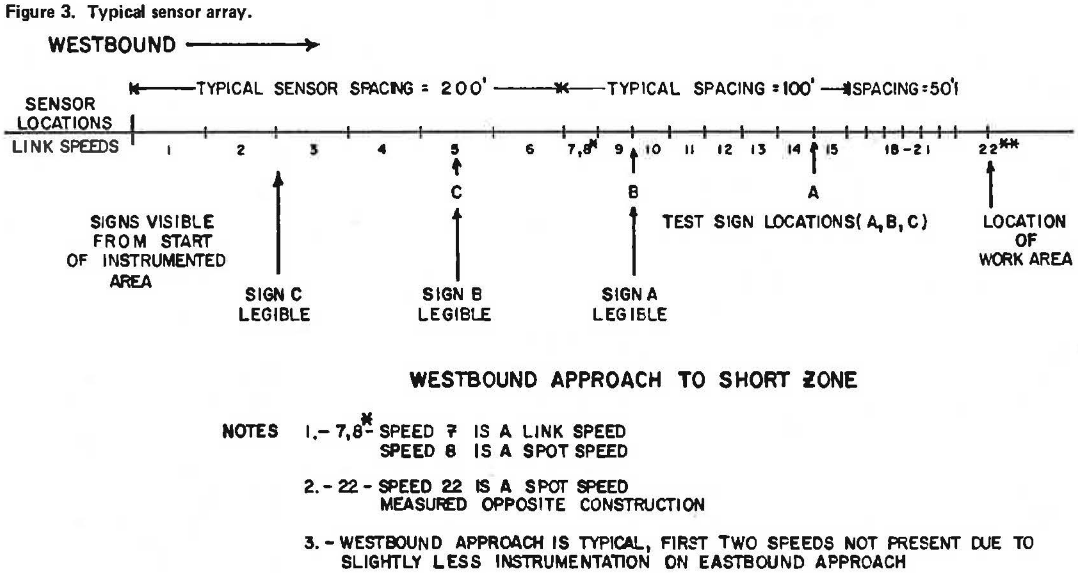
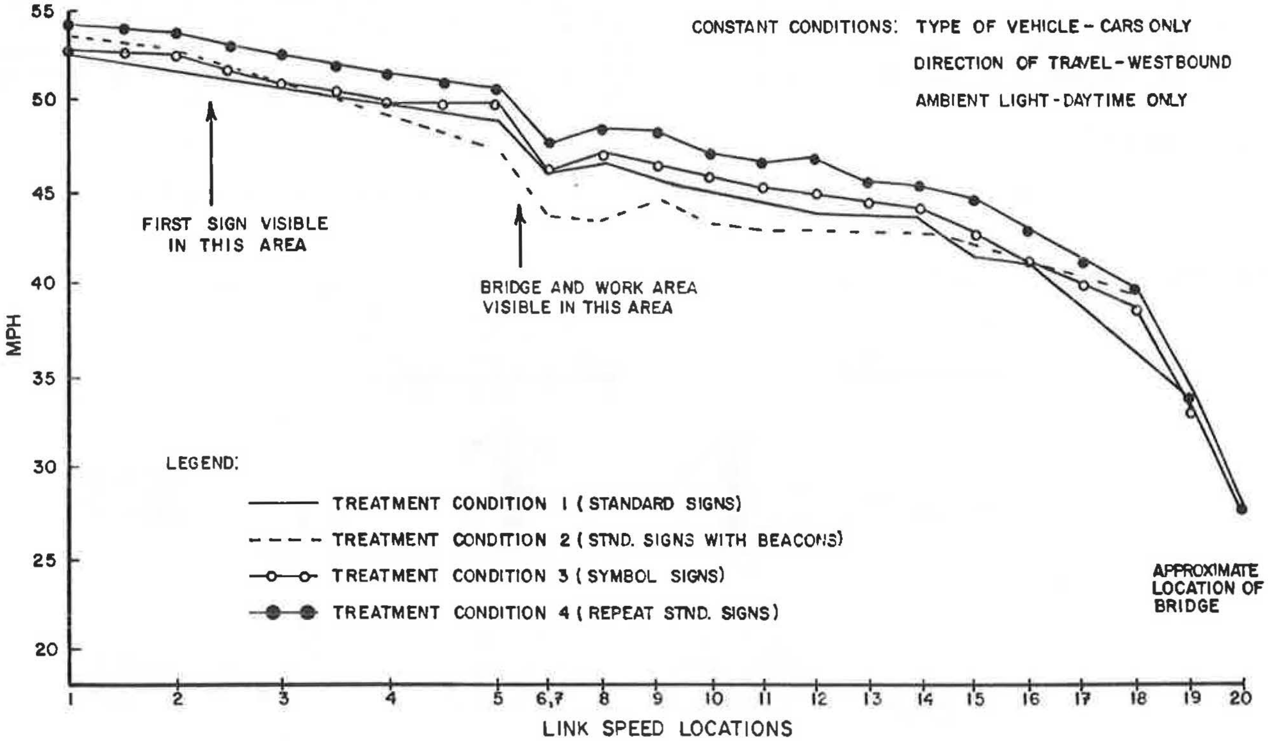


Figure 4. Mean speed profile in long zone.



the mean speed profile for the westbound approach for the motorists who were exposed to different sign sequences (note that the first sequence, standard signing, was repeated as a base). These results illustrate the basic superiority of the lighted signs (insofar as lower speeds are concerned) over part of the approach. Similar data (not shown) indicated that the lighted signs were even more effective at night and over a longer distance. By way of a brief summary, the experiment in the long zone dealt with an explicit situation where approaching motorists saw both warning signs and a traffic signal on a rural, two-lane road. Within that context, the following conclusions are offered:

1. Where first the signs, then the signal, and then the work area became visible, the effects of the sign were significant and gave way eventually to the signal effects.
2. Once the signal color was established, all motorists slowed to similar speeds within 600 ft of the work area.
3. Relative to the differential effects of the various sign sequences, (a) the difference between the effects of standard and symbol signs (treatments 1 and 3, respectively) was not significant; (b) differences between lighted and unlighted signs were significant; the former was more effective earlier on the approach; and (c) the maximum difference in effectiveness (in b) was about 3 mph during the day and 4 mph at night at a distance of 1400 ft at night and 1000 ft during the day.
4. Vehicles stopped at the signal stop line or the work area appeared to have no effect on approaching motorists until they were quite close.

Note that the analysis of the long zone excluded consideration of vehicles that had more than two axles because data were insufficient for the analysis to be conclusive.

Summary of Short Zone

The experiment in the short zone, although a somewhat different situation, yielded results similar to those just summarized--that is, the basic superiority of lighted signs over unlighted ones relative to slowing approaching vehicles. By way of a brief summary of the experiment situation, the short zone consisted of a common situation where routine maintenance activities require the temporary closure of one lane of a two-lane road and where traffic control at the site is basically passive (e.g., granting of the right-of-way is left to the motorists). In this experiment the three test sign sequences were compared to each other and to a base condition where no activities or signs were present. A summary of the conclusions for the short-zone experiment is as follows:

1. Detailed analysis showed that the effectiveness of one set of signs over another was not correlated with the type of vehicle, nor was it correlated with whether or not vehicles were approaching from the opposite direction (with one exception).
2. Relative to the base condition (no signs or activity), the analysis showed that all motorists slowed as they approached the work area. Overall decreases ranged from 12.4 to 20.9 mph over approximately 2400 ft on the westbound approach (where a lane change was necessary at the actual closure) and from 3.1 to 7.0 mph on the eastbound approach (no lane change was necessary).
3. In virtually all instances, the sequence that caused the most substantial speed reduction was the lighted signs. For example, the lighted standard signs were from 47.4 to 118.8 percent more effective than the unlighted signs. Actual magnitudes of the speed reductions ranged from 20.9 mph (slowing from an initial speed of 52.1 mph to 31.2 mph at the closure) for the lighted signs to 12.4 mph (slowing from 53.1 mph to 40.7 mph) for the unlighted stan-

dard signs. (Both examples were for motorists who were opposed in the vicinity of the lane closure traveling in the westbound direction.)

4. Although results were somewhat conflicting for the symbol signs, the effectiveness was never any less than that for the standard word message signs.

SUMMARY AND CONCLUSIONS

Two experiments were conducted to evaluate the effectiveness of three different types of signs for warning motorists on rural roads of a work area on the road ahead that requires a lane closure. Whereas one experiment was concerned with a closure that required supplementary traffic control (i.e., a traffic signal), the other depended on the signs and a passive control only. In both instances relatively similar results were found:

1. The most-effective sign sequence in virtually all instances was one that was flasher augmented; in one instance in the second experiment, the effectiveness was twice that of similar signs that had no lights for slowing vehicles in the vicinity of the lane closure.
2. Symbol signs were generally at least as effective as the standard sequence in slowing approaching motorists.
3. When another traffic control device was present (i.e., a traffic signal), the effects of that device dominated those of the signs as the motorists got closer.
4. In no instance did any of the signs appear to cause any abrupt motorist reactions that might be hazardous in and of themselves.

Based on these results, if maximum effectiveness is desired, signs augmented with flashing beacons should be considered as an effective device for advance warning. They should be given special consideration if approach speeds are likely to be high, advance visibility is poor, or the open lane is narrow or otherwise requires much lower than normal speeds adjacent to the construction site.

ACKNOWLEDGMENT

The experiments described herein were funded by FHWA and executed by the Maine Department of Transportation (MaineDOT) at the Maine Facility in Pittsfield, Maine, with assistance from the Social Science Research Institute of the University of Maine at Orono. John Wyman of MaineDOT was primarily responsible for the implementation of the experiments in the field. Data reduction and overall management of the experiments were provided by Maurice H. Lanman III, formerly the resident manager of the Maine facility for FHWA. These contributions notwithstanding, all conclusions (and any errors therein) and opinions are, however, my responsibility and not necessarily those of FHWA, MaineDOT, or the University of Maine at Orono. Additional detail on these experiments is contained in the final reports prepared by the Social Science Research Institute and MaineDOT for FHWA (9,10).

REFERENCES

1. R.F. Pain and B.G. Knapp. Motorist Information Needs in Work Zones. ITE Journal, Arlington, VA, April 1979.
2. M.E. Bronstad and C.E. Kimball. Crash Test Evaluation of Temporary Traffic Barriers. TRB, Transportation Research Record 693, 1978, pp. 13-18.
3. F.N. Lisles. Evaluation of Timber Barricades and Precast Concrete Traffic Barriers for Use in Highway Construction Areas. TRB, Transportation Research Record 693, 1978, pp. 18-25.
4. L.W. Thomas. Liability for Improper Traffic Signaling, Signing, and Pavement Marking. TRB, Transportation Research Record 693, 1978, pp. 4-6.
5. D.C. Oliver. Tort Liability: Special Problems Encountered by Highway Agencies and Contractors in Designing Work Zone Layouts. TRB, Transportation Research Record 693, 1978, pp. 47-51.
6. G.F. King, P. Abramson, J.W. Cohen, and M.R. Wilkinson; KLD Associates, Inc. Experimental Design to Evaluate MUTCD and Other Traffic Controls for Highway Construction and Maintenance Operations on Two-Lane Highways. Transportation Systems Center, U.S. Department of Transportation, Huntington Station, NY, 1977.
7. D.L. Warren and D. Robertson. Research in Work Zone Traffic Control: Status Report. ITE Journal, Arlington, VA, April 1979.
8. M.L. Lanman III. The Maine Facility: Capability for Rural Road Research. ITE Journal, Arlington, VA, Dec. 1978.
9. R. Lyles. Alternative Sign Sequences for Work Zones on Rural Highways. FHWA, Final Rept., FHWA/RD-80/162, 1980.
10. R. Lyles. Alternative Sign Sequences for Work Zones on Rural Highways. FHWA, Executive Summary, FHWA/RD-80/163, 1980.

Publication of this paper sponsored by Committee on Traffic Safety in Maintenance and Construction Operations.