232

TRANSPORTATION RESEARCH CIRCULAR

Number 232, October 1981
ISSN 0097-8515

Transportation Research Board, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, DC 20418

VISIBILITY IN CONSTRUCTION AND MAINTENANCE WORK ZONES

mode
1 highway transportation

subject areas
40 maintenance
52 human factors
54 operations and traffic control

GROUP 3 - OPERATION AND MAINTENANCE OF TRANSPORTATION FACILITIES

Patricia F. Waller, University of North Carolina
Chapel Hill, North Carolina, Chairman

COMMITTEE ON VISIBILITY

Nathaniel H. Pulling, Liberty Mutual Insurance Company,
Hopkinton, Massachusetts, Chairman

Members as of October 1, 1981:

William S. Farrell
John C. Buckingham
Albert Burg
Gerald P. Burns
Thomas J. Carr
Charles W. Craig
Eugene Farber
Paul H. Greenlee
Ronald J. Hansen
Antanas Ketvirtis
L. Ellis King
Ken F. Kobetsky
Robert C. Oliver
Charles M. Overbey
Charles D. Pike
Richard Priddy
Richard Schwab
Richard Stark
Frederick Vanosdall
Ned E. Walton
Earl C. Williams, Jr.
Henry Woltman

David K. Witheford, Transportation Research Board Staff

Author of this Circular for the Committee was Ned E. Walton, Walton & Associates, Bryan, Texas

INTRODUCTION

One element deserving of detailed examination in construction and maintenance work zones is visibility. Visibility of workers is important for construction zone safety. Likewise, conspicuity which is needed to alert complacent, side-tracked or inattentive drivers to the presence of a person, object or condition on the roadway is important.

The visibility element appears to need special examination for night conditions. For construction activities causing the greatest interference with traffic, the trend is for them to be carried out at night (1). Present headlight systems, particularly with the high degree of low beam usage, tend to further confound the situation.

Systematic examination of the visibility element in work zones appears to bear positive results in accident experience (2). Thus, it behooves those in the visibility practicing profession to promulgate the best technologies available to deal with the visibility element.

Purpose of Research Circular

The purpose of this research circular is to promulgate the current state of the art in construction zone visibility. Extensive research and practice efforts have been devoted to the subject and the research circular is a means to relate positive experiences to the user.

Magnitude of the Problem

Traffic and safety problems caused by construction and maintenance activities can be considerable. In addition, temporarily obstructed road sections may cause substantial time losses for, and inconvenience to, road users. The number of obstructions occurring simultaneously on the street network of a larger city may run into several hundreds. The resolution of these problems may affect several administrative authorities, various modes of transport and several utility services. In order to maintain desired levels of service, it is important that uniform methods be available for guiding traffic through construction zones (3). Special attention should be devoted to the contributions of good visibility toward desired levels of service.

Accident Considerations

In a 1972 CALTRANS study (4), Juergens examined "before" and "during" construction accidents at ten selected work zones. He reported:

- Property-damage-only accident rate increased by approximately 18 percent "during" construction.
- Injury accident rate increased approximately 21 percent "during" construction.
- Fatal accident rate increased by approximately 132 percent "during" construction.
- Total accident rate increased by approximately 21 percent "during" construction.

By carefully changing practices in geometric treatments, delineation and signing at work zones the experience changes as follows:

- Property damage only accident rate in creased by approximately 6 percent.
- Injury accident rate increased approximately 9 percent.
- Fatal accident rate increased by approximately 2 percent.
- Total accident rate increased by approximately 7 percent.

Illinois (5) reported nearly 7,000 motorists and workers were involved in work zone accidents during 1969. Two years later, after installation of a flexible system of construction zones traffic control, the accident rate dropped by one-third. The Illinois approach in the flexible system of control included a review of accident types to ascertain hazardous or easily overlooked elements of traffic operations.

Graham, et al, conducted a multi-state study of accidents and speeds in construction zones (6). They reported on 79 construction projects in seven states. Results of a one year "before" and "during" study indicated

- An average increase of 7 percent in number of accidents during construction.
- 24 percent of the locations with greater than 50 percent increase in accident rates during construction.
- 31 percent of the locations with decreases in accident rates during construction.
- Short duration and short length projects had higher accident rates.
- Bridge work and roadway construction had the largest "during" increase in accident rate.

- o Little difference in experience at rural and urban sites.
- o The proportion of night accidents to total accidents remained about the same.
- o Construction zones are most likely to increase fixed object, rear-end and head-on accidents, while decreasing right angle, turning and run-off-road accidents.
- o Speed zones had little or no effect on accident rates in construction zones.
- o National standards for traffic control layouts in work areas were often violated.

The Virginia Highway and Transportation Research Council (7) in an evaluation of barricades and barriers reported a 119 percent increase in accidents during construction. The report noted

- o A shift from injury accidents "before" construction toward property damage accidents "during" construction.
- o A shift from rear-end "before" accidents to fixed object "during" accidents.
- o A shift from accidents in the peak period "before" construction to accidents after dark in the "during" construction.

Russell (8) reported at the 21st California Street and Highway Conference that there are engineered shortcomings in construction zones contributing to higher accident experience. These shortcomings are

- o Lack of planning
- o The detour syndrome
- o The high cost syndrome
- o Anticipated life of temporary roadways
- o Poor delineation
- o Excess and confusing delineation
- o Misuse of signing and delineation devices

Russell suggests that simple strategies often work best. In one freeway project where traffic was shifted from one freeway roadway to another eight times, the only devices used were combinations of rubber tubes and rubber cones. During the life of the projects, the roadway had a lower accident, injury and fatality rate than it did the year before construction started.

In October 1978, the Federal Highway Administration issued an emergency policy (9) dealing with traffic safety where traffice is maintained on one roadway of a normally divided highway. The policy recommends

- o Not permitting two-way traffic on one-way roadways of a normally divided highway unless other methods of traffic control are infeasible.
- o Where opposing traffic is necessary that positive traffic barriers or appropriate delineation and channelization devices be used.
- o At transition zones concrete barriers must be used to separate traffic.

It is evident that construction and maintenance work zones present special problems to the traffic engineer. It is equally evident that many researchers have demonstrated positive experience in dealing with the problems. It is hoped that some of the following reported approaches and visibility considerations will likewise yield positive accident treatments.

It is not possible to give details of approaches and treatments in this research circular. Rather, summaries are given and the reader is advised to consult the referenced publications for design and application.

Approaches to Safe Construction Zones

Seltzer (10) has indicated three phases in achieving safe construction zones for traffic: planning, design, and inspection. Ordinary tools of traffic operations are suggested to be used as much as possible so that each driver is led smoothly through construction areas with as little trauma as possible. Clark (11) points out seven basic elements in a safe construction zone:

- o advance warning
- o alignment
- o segregated work area
- o adequate capacity
- o maintenance to locate warning devices properly
- o maintenance to check the condition of warning devices
- o maintenance of the detour roadway, which must be kept clean and free from mud, dust, and debris.

Brevoord (12) proposes four main aspects: safety of traffic, safety of road workers, the traffic flow, and the efficiency of the road work. He points out the good cooperation needed between the road authorities, police, and contractors.

Seltzer's three phases, Clark's seven elements, and Brevoord's four aspects of construction zone safety are all visibility related.

Visibility Considerations

It appears that in most construction zone accidents, the driver received neither visual stimulation nor sufficient warning to avoid the accident (13). Construction work zones can be made safer through improvements in visibility conditions. Methods of improving visibility may include special construction warning devices (11, 14), such as signs, markings, and delineation, barrier lighting, fixed overhead lighting, floodlighting, overhead and roadside sign lighting and signalization (15). Barriers may also be used (16). These methods may be combined with considerations of traffic flow, traffic volumes, pedestrian requirements, worker requirements, prevailing speeds, safe speeds and duration of construction (14), to provide proper construction zone designs.

To foster close attention to detail, according to one source (17), traffic control for work areas should be individual pay items in contracts. By making these considerations pay items, better planning and execution of safer construction zones should result. Plans can indicate where highly visible devices are to be located during each job phase in accordance with the Manual on Uniform Traffic Control Devices (14).

McGee and Knapp (18) recommend that construction work areas be divided into the following information-handling zones:

- o Advance Zone - where hazards of inefficiencies do not yet affect the drivers task.
- o Approach Zone - corresponding to decision sight distance less stopping sight distance where the driver must detect and recognize hazard ahead.
- o Non-Recovery Zone - point beyond which there is insufficient space to avoid a system failure.
- o Hazard Zone - distance corresponding to the length of the hazard.
- o Downstream Zone - area beyond the hazard where the driver can safely return to normal operating conditions.

McGee and Knapp provide visibility information requirements for reflective devices in each of these zones. Table 1, taken from FHWA Report FHWA-RD-79-143, summarizes the McGee and Knapp recommendations.

Humphreys, et al (19), recommend consideration of the following visibility findings at 103 work zones in eleven states:

- o Inadequate or misleading marking of work vehicles.
- o Failure to remove old markings and improper use or failure to use temporary markings.
- o Inconsistent placement of traffic control devices.
- o Inadequate, improper, or inconsistent use of advance warning signs.
- o Inadequate delineation.
- o Improper placement of flagman.

Humphreys reports that over two-thirds of the deficiencies identified are covered in the Manual on Uniform Traffic Control Devices (14). Nonstandard and inappropriate use of standard devices were found at 63 percent of visited work zones.

Road signs are probably the major source of visual presentation to the driver (20). Analysis and evaluation of sign size, height, and legend effects on driver responses as measured by speed change, conflict and queuing reveal:

- o Speed decreases on two-lane roadways are greater for 30-inch (0.76m) signs than for 36-inch (0.914m) or 48-inch (1.22m) signs.
- o At Interstate locations, 36-inch (0.914m) signs yield better overall responses than 30-inch (0.762m) signs.
- o The height of sign installation and sign legend do not indicate any statistical difference in the measured responses.
- o Sequencing accumulative bi-directional chevrons greatly enhance the obedience of drivers to warning signs.

McAllister and Kramer (21), reporting on advance warning arrows, recommend minimum, 4-foot by 8-foot sign boards with variable lighting control features for freeway application. Graham, et al (22), recommend the following for arrow boards:

- o Arrow boards should be capable of left, right, and double flashing arrows or,
- o Left and right sequential chevrons and double flashing arrows,
- o Appropriate use, size, and placement.

General specifications from this report are shown in Table 2.

Roadway delineation treatments and systems can provide guidance, regulatory, or warning visual information to drivers under various highway situations. Both negative (they tell the driver where not to drive) and positive (they tell the driver where he may safely drive) delineation have application. Non-guidance devices usually mark obstacles, obstructions and hazards. Positive delineation includes center and lane lines, edge lines and the like. Raised retroreflective delineation devices are superior to paint lines or non-reflective devices (23, 24). Taylor's report (23) is an excellent reference document for delineation treatment. FHWA has also published an extension of this work (25).

Channelization devices also play an important role in visual presentations to the driver. In a recent NCHRP report (26), the effectiveness of alternative channelization devices were examined. A survey of the usage of various MUTCD devices by states and utilities was summarized with research literature commentary. The NCHRP report gives valuable information that the reader should consult. Visibility requirements for each type of device are listed, as well as application guidelines.

Design parameters contributing to the visibility effectiveness of alternative channelization devices were also studied in the NCHRP report (26). Included were:

- o Device stripe width
- o Stripe configuration
- o Color ratio (trade-off between better contrast during the day with orange and during the night with white)
- o Size and height-to-width ratios
- o Reflectance
- o Spacing of the devices

The application of these design parameters in use and design of channelization devices for freeway operations is contained in the report.

Portable precast concrete barriers and timber barriers have been studied for their application in construction zones (27,28, 29). They are used either to protect vehicles and their occupants or to protect workers. Precast concrete barrier placement and removal is relatively rapid and simple, reducing traffic delays and tie-ups. Their freedom from maintenance means not only cost savings but also safety. They can be made esthetically attractive and highly visible and fewer construction workers are exposed to the hazards of closely passing vehicles. Also, the concrete barrier design assures maximum protection for motorists who must drive through construction work areas.

Taylor (23) gives applicable theory for delineation of traffic barriers such as the concrete barrier. The follow-up report by FHWA (25) also has applicable theory. Mullowney (30) demonstrated that barriers could be made highly visible, in fact even more visible under wet night conditions than under dry night conditions. He attributes his findings to the fact that reflective devices used were "washed" by the rain. Glass reflectors were found to have superior

Table 1. Visibility requirements for reflective devices at work zones.

85th Percentile Speed (mph)	Detection Thru Maneuver Time (Seconds) Low	High	Visibility Distance (ft) Computed	Rounded For Design
30	10.2	11.7	449 - 515	450 - 525
35	10.2	11.7	524 - 600	525 - 600
40	10.2	11.7	598 - 686	600 - 675
45	10.2	11.7	673 - 772	675 - 775
50	10.2	11.7	748 - 858	750 - 850
55	10.2	11.7	823 - 944	825 - 950
60	10.2	11.7	898 - 1030	900 - 1025

1 mph = 1.609 km/h   1 ft = 0.3048 m   SOURCE: REF. 18

Table 2. General specifications for arrow boards.

- Mounting Height: 7-8 ft. (2.1-2.4 m)
- Panel Background: Flat Black
- Lens Flash Rate: 30-60 flashes/min (50% dwell)
- Lens Size: 4-1/2 inch diameter (114 mm) PAR 36
- Lens Color: Amber
- Lens Hood: 360° (for close-up glare reduction)
- Bulb Intensity: 8,800 candle power (4 x 8 and 3 x 6 ft sizes)
- Intensity Adjustment: Automatic 50% reduction in intensity when ambient light falls below 5 foot candles.
- Number of Lamps:

	Size of Arrow Board: 2 x 4' (0.6 x 1.2 m)	3 x 6' (0.9 x 1.8 m)	4 x 8' (1.2 x 2.4 m)
Flashing Arrow	12	13	15
Sequential Chevron	22	22	22

SOURCE: REF. 22

intensity. Glass reflectors when dirty were superior to other types that had been cleaned.

Ross, et al (16) reported on the use and delineation of traffic barriers in work zones. Although they found no uniform criteria for the need of traffic barriers, the report does have good commentary on use, crash safety aspects, and delineation of various barriers.

Another aspect of construction zones having visibility ramifications is transition taper lengths. Graham, Harwood and Sharp (31) reviewed the two commonly accepted formulae for computing lengths of tapers. They recommend both as giving good results. For rural areas the following formula is suggested by Graham as well as the MUTCD (14):

$$L = S \times W$$

where L = length of taper in feet
S = 85th percentile speed
W = width of lane closure to be effected

In urban areas the following is recommended:

$$L = WS^2/60$$

where L, S, & W are the same as previously. Designing tapers according to these formulae should provide conditions of good visibility input.

Obviously, there are other parameters having a modifying effect on all that is done to provide visibility. Among these are adverse weather (32), fog (33), and such things as glare from opposing headlights. Drivers share an added responsibility under these conditions.

Closure

This circular has discussed several documents that will assist the engineer in planning, designing, and maintaining safe construction zone visibility. Special aids, such as the Traffic Control Inspection Report shown in Figure 1, may also prove beneficial.

Figure 1. Traffic control inspection report.

District ______ Marked Route ______
Date ______ General Location ______
Inspected by ______
Report No. ______ for this section ______ County ______
Traffic Control Auth. Request approved ______ Construction Section ______
Type of Work ______ Contractor ______
Est. Date of completion ______ Resident Engineer ______

Control Device	Evaluate (Good, Fair, Not Acceptable)				Description, comments or correction measures recommended
	Condition	Placement	Night Visibility	General Effectiveness	
Signs					
Lights					
Barricade					
Flagmen					
Pavement Marking					
Traffic Signals					
Channelizing Devices					

Comments on: Pavement condition ______
Detour condition ______
Other ______
Have previously reported deficiencies been corrected? ______ If so, describe ______

______ Submitted by: ______
Reviewed by: ______
District Traffic Engineer

The Manual on Uniform Traffic Control Devices (14) has resulted from many years experience and specific signs, signals, markings, delineations, and barricades are illustrated that can be used for high visibility purposes. Design, location, placement, operation, and maintenance of the devices are covered. The Work Zone Traffic Control Standards and Guidelines (34), a separate publication of Part VI of the MUTCD, is a document that should be made available to all working participants in construction and maintenance zones.

A combination of good engineering judgment, resource material such as that presented in this circular, and compliance with the MUTCD should give the public all the necessary visibility to safely travel through work zones. The reader is encouraged to obtain copies of the MUTCD, the Work Zone Traffic Control Standards and Guidelines, and the reviewed documents as a working library in the area of construction zone visibility. Using what we already have should certainly improve the state of the art in practice.

References

1. "Day and Night Visibility of Public Employees on the Streets and Highways", Klassen, D.J., National Safety Congress Transactions, National Safety Council, Vol. 8, pp. 47-50.
2. "Identification of Traffic Management Problems in Work Zones", FHWA Report No. FHWA - RD - 79 - 4, Washington, D.C., 1979.
3. "Traffic Operation at Sites of Temporary Obstruction", Organization for Economic Cooperation and Development, Road Research Group, Paris, France, February, 1973.
4. Juergens, W.R., "Construction Zone, Detour, and Temporary Connection Accidents", Business and Transportation Agency, Division of Highways, State of California, 1972.
5. "Traffic Protection for Highway Work Areas", Rural and Urban Roads, Vol. 10, No. 10, October 1972, pp. 46-48.
6. Graham, J.L., Paulsen, R.J. and Glennon, J.C., "Accident and Speed Studies in Construction Zones", Midwest Research Institute, Report FHWA-RD-77-80, Washington, D.C., June 1977.
7. Lisle, N., Reilly, J. and Beale, D., "Evaluation of Timber Barricades and Precast Concrete Traffic Barriers for Use in Highway Construction Areas", Virginia Highway and Transportation Research Council, 1976.
8. Russell, G.L., "Construction Zone Safety: Giving Drivers Half a Chance" California Street and Highway Conference, Proceedings 21st Conference, 1969, pp. 39-40.
9. "Traffic Safety in Highway and Street Work Zones - Two Way Traffic Maintained on One Roadway of a Normally Divided Highway", FHPM6-4-2-12, FR23 CFR, Part 630J, October 1978.
10. Seltzer, R.N., "Construction Zone Safety: Planning, Design, Inspection", California Street and Highway Conference, Proceedings 21st Conference, 1969, pp. 42-43.

11. Clark, N.B., "Construction Zone Safety: Tailor-Made Guidance", Calfornia Street and Highway Conference, Proceedings 21st Conference, 1969, pp. 41-42.
12. Brevoord, G., "Maatregelen BLJ Werk In Uitvoering OP Verschillende Typen Wegen", Koninklijke Nederlandsche Toeristenbond ANWB, Wassenaarseweg 220, The Hague, Netherlands.
13. Rowe, J.O., "Construction Area Safety", International Bridge, Tunnel and Turnpike Association, Washington, D.C., 1975, pp. 3-4.
14. Manual on Uniform Traffic Control Devices, Federal Highway Administration, Washington, D.C., 1979.
15. Bender, L.E., "What Should You Do About Detours", American City, Vol. 87, No. 2, February 1972, pp. 69-70.
16. Ross, H.E., et al, "Use and Delineation of Traffic Barriers in Work Zones - State of the Art and Current Practices", FHWA Report RF-4151-1, March 1980.
17. "Traffic Control is Job Pay Item - And Contractors Like It", Roads and Streets, Vol. 113, No. 1, January 1970, pp. 92-93, 96.
18. McGee, H.W., and Knapp, B.G., "Visibility Requirements of Work Zone Traffic Control Devices", FHWA Report No. FHWA-RD-78-143, Washington, D.C., July 1978.
19. Humphreys, J.B., Mauldin, H.D., and Sullivan, T.D., "Identification of Traffic Management Problems in Work Zones, "FHWA Report RD-79-4, Washington, D.C., March 1979.
20. King, G. and Lunenfeld, H., "Development of Information Requirements and Transmission Techniques for Highway Users", NCHRP Report No. 123, Highway Research Board, Washington, D.C., 1971.
21. McAllister, J.J. and Kramer, D.L., "Advance Warning Arrow Sign Study, State of Claifornia, Department of Transportation, 1974.
22. Graham, L., Migletz, J., and Glennon, J.C., "Guidelines for the Application of Arrow Boards in Work Zones", FHWA Report No. RD-79-58, December 1978.
23. Taylor, James I., et al "Roadway Delineation Systems", NCHRP Report No. 130, Highway Research Board, Washington, D.C., 1972.
24. Construction Zone Delineation - Raised Pavement Markers, Nine Reports from State Highway Departments, Federal Highway Administration, Washington, D.C.
25. Bali, S.G., McGee, H.W., and Taylor, J.I., "State of the Art on Roadway Delineation Systems", FHWA, 1976.
26. McGee, H.W., Pain, R.F., and Knapp, B.G., "Evaluation of Traffic Controls for Highway Work Zones", Vols. I and II, NCHRP Project 17-4, Transportation Research Board, Washingtion, D.C., February 1979 (Unpublished).
27. Lokken, E.C., "Portable Precast Concrete Safety Barriers", Public Works, Vol. 164, No. 12, December 1973, pp. 44-46.
28. Bronstad, M.E. and Kimball, C.E., "Temporary Barriers Used in Construction Zones", Report 03-3716-3, Southwest Research Institute, December 1977.
29. Bronstad, M.E. et al, "Concrete Median Barrier Research", Report No. FHWA-RD-77-4, Federal Highway Administration, Washington, D.C., March 1976.
30. Mullowney, W.L. "Center Barrier Visibility Study", New Jersey Department of Transportation, January 1978.
31. Graham, J.L., Harwood, D.W., and Sharp, M.C. "Effects of Taper Length on Traffic Operations in Construction Zones", FHWA Report FHWA-RD-77-162, Washington, D.C., 1979.
32. "Driver Visibility Under Varying Adverse Weather Conditions", Transportation Research Circular 193, Transportation Research Board, Washington, D.C., 1978.
33. Wachtel, J.A. "The Escalating War on Reduced Visibility", Public Roads, Vol. 41, No. 3, December 1977, pp. 112-118.
34. Work Zone Traffic Control Standards and Guidelines, Part VI, MUTCD, Federal Highway Administration, Washington, D.C., 1980.