

EVALUATION OF TIMBER BARRICADES AND PRECAST CONCRETE
TRAFFIC BARRIERS FOR USE
IN HIGHWAY CONSTRUCTION AREAS

by

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ABSTRACT

On August 15, 1975, the National Transportation Safety Board submitted a number of recommendations to the Administrator of the Federal Highway Administration and the Governor of Virginia regarding safety practices in the construction zone of I-495 in Northern Virginia. Subsequently, officials of the Virginia Department of Highways and Transportation requested that the Virginia Highway and Transportation Research Council evaluate the recommendations that pertained to the use of timber barricades.

The scope of the evaluation included (1) a survey of the literature on the subject of legal requirements for temporary barrier systems in highway construction zones, (2) an analysis of crash data on I-495 for periods before and during construction, and (3) an analysis of the technical operational, and economic feasibility of the timber barricade and the precast concrete traffic barrier.

The evaluation has revealed that there is no adequate national standard for traffic control in construction zones. Consequently, as in the case studied here, engineers are left to exercise their judgement as to the proper use and placement of delineators, barricades and other channelizing devices, and traffic barriers. The evaluation also has indicated that the frequency of accident occurrence during construction on I-495 was approximately 119% higher than before construction. Of the reported crashes during construction, 52.5% involved vehicle contact with the timber barricades. Among barricade-involved crashes, 73.5% involved vehicles which straddled or penetrated the barricades. Thus, in service on the I-495 site the timber barricades have proved to be ineffective as positive barriers. The precast concrete traffic barrier was found to cost approximately \$5.60 per linear foot more than the timber barricade employed on I-495.

Testing of the precast concrete traffic barrier in a freeway construction zone is recommended prior to its general use in the Commonwealth.

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Appreciation is due all personnel of the Virginia Department of Highways and Transportation who participated in this study; especially, W. B. Shelton, L. W. Campbell, Jr., and W. R. Noble for furnishing accident data, and W. C. Mitterer and Mike Rebakov for computer processing accident data.

Finally, the staff of the Virginia Highway and Transportation Research Council is acknowledged for their contribution. In particular, thanks go to Harry Craft for editing the report, to Toni Thompson for typing the rough draft, and to Jean Vanderberry for typing the final manuscript.

SUMMARY OF FINDINGS

1. There are no adequate national standards to guide highway engineers in the selection of "positive barrier systems" for construction zones. On this subject, the Manual on Uniform Traffic Control Devices (MUTCD) addresses only "Barricades and Channelization Devices" that do not provide adequate protection for motorists and workmen at freeway construction sites.
2. In the traffic control plan on I-495 the timber barricade was used principally as a positive barrier, lane edge delineator, and channelization device.
3. The timber barricades were placed on the entire length of each construction project on I-495 when work was initiated and were left in place, independent of the hazards present or the level of construction activity in progress.
4. With due consideration of the effects of the energy crisis, the frequency of accident occurrence on I-495 during construction was 119% higher than the frequency during a pre-construction baseline period.
5. While the increased frequency of accident occurrence was experienced along the entire length of I-495 during construction, high concentrations of accidents were noted at interchanges and transition zones.
6. The amount of estimated property damage per accident during the construction study period increased 41%, rising to \$1,364 compared to the before construction baseline figure of \$965.
7. Of the total reported crashes for the construction study period, 52.5% involved vehicle contact with one or more of the timber barricades.
8. Of those vehicles identified in reported crashes as having contacted the timber barricades, 90.6% were traveling in the lane adjacent to the barricades just prior to the crash.
9. The typical (average) barricade-involved crash for the during construction period damaged or destroyed seven timber barricade sections.
10. Of those vehicles identified in reported crashes as having contacted the timber barricades, 26.5% were arrested or re-directed; 28.2% straddled the barricades; and 45.3% penetrated the barricades.

11. There were shifts in crash distributions during construction toward crashes involving property damage only, fixed objects and impaired drivers. Also there was a greater percentage of accidents during the hours of darkness.
12. During construction with a posted speed limit of 45 mph, the 85th percentile speed on I-495 generally ranged between 54 and 58 mph.
13. The average costs to the state of the timber barricades employed on I-495 were \$13.40 per linear foot for placement and \$6.12 per linear foot for moving. The total barricade cost to the state was over \$5 million, or 6.6% of the cost of the entire project.
14. In tests performed under controlled conditions in Texas and California, the concrete safety shape barrier redirected vehicles at speeds up to 60 mph and impact angles up to 10° with minimal damage to the vehicle or injury to its simulated occupants. These tests involved permanent, rather than portable, barrier systems.
15. Based on cost estimates from manufacturers and cost data from other states, the precast concrete traffic barrier sections could be manufactured, delivered, and placed on a construction site in Virginia at a cost of about \$16 to \$20 per linear foot. Moving costs should be much the same as those experienced for timber barricades, or approximately \$6 per linear foot.

CONCLUSIONS

1. There is a need for a national standard to provide guidance in designing a system for the safe movement of traffic through construction zones. Functional criteria and guidelines are needed for the appropriate use and placement of cones, pylons, barricades, barrels, barriers, impact attenuators, etc.
2. The choice of the timber barricade for use on I-495 was part of a good faith attempt to provide safety for both motorists and workmen.
3. The utilization of the timber barricades where no roadside hazard justified their use or where no construction activity was in progress was contrary to the principles set forth in the MUTCD.
4. The more than doubling in the frequency of accident occurrence during the construction study period reflects a need for improved control of traffic through high volume, high speed road segments undergoing construction.
5. The high concentrations of accidents at interchanges and transition zones identify those roadway locations where extreme care and meticulous effort must be exercised in the selection, utilization, and maintenance of the traffic control devices.
6. Though 52.5% of the reported crashes for the during construction study period involved vehicles contacting the timber barricades, the possible degree to which the barricades contributed to the overall increase in accidents is not known.
7. Since 90.6% of the vehicles which struck the timber barricades in reported accidents had been traveling in the adjacent lane, it can be speculated that most of these vehicles struck the barricades at angles of less than 10° and would have been redirected by concrete safety shape barriers.
8. The timber barricades did not prove to be effective as positive barriers for the traffic conditions in the I-495 construction zone, since 73.5% of the vehicles impacting the barricades straddled or penetrated them.
9. Use of the precast concrete traffic barrier in place of the timber barricade on I-495 would reduce each of the traffic lanes by approximately 4".

RECOMMENDATIONS

1. The Federal Highway Administration, the American Association of State Highway & Transportation Officials, and the National Joint Committee on Uniform Traffic Control Devices should amend Part VI of the MUTCD so as to provide clear guidance to users on safe traffic control practices for construction and maintenance zones. Such a standard should provide guidelines for the use and placement of cones, pylons, barricades, barrels, barriers, impact attenuators, and such other devices as may be needed for both motorists and workmen safety.
2. The Virginia Department of Highways & Transportation should incorporate the use of precast concrete traffic barriers where a positive barrier is warranted on a freeway construction project and evaluate all aspects of the barriers' performance.

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INTRODUCTION

On January 11, 1975, a single vehicle crash occurred on I-495 near the Backlick Road overpass in the Springfield area of Fairfax County, Virginia. The police investigation into the crash revealed that the vehicle, occupied by the driver and two passengers, was traveling east in the inner lane of I-495 when it veered from its lane of travel into construction barricades placed along the median. After contacting the timber barricades, the sliding vehicle started turning counterclockwise, with its front wheels mounting and penetrating the timber barricades such that the front wheels were in the median and the rear wheels were in the inner lane of eastbound I-495. The vehicle came to rest 98'-4" east of the point of initial contact with the timber barricades. The collision with the barricades resulted in a 4" split in the seam on the right-hand side of the gas tank which allowed gasoline to come in contact with the vehicle's exhaust system. The resultant explosion and fire fatally injured the three occupants of the vehicle.

Immediately after this fatal crash, the National Transportation Safety Board (NTSB) initiated an investigation into its cause. During its investigation, the NTSB learned of other serious crashes within the construction zone on I-495, and expanded the scope of its investigation to include an examination of all hazards to the motorists who drive through the construction zone.

On August 15, 1975, the NTSB submitted the findings from its investigation in Safety Recommendation(s) H-75-16⁽¹⁾ to The Honorable Norbert T. Tiemann, Administrator, Federal Highway Administration (FHWA), and The Honorable Mills Godwin, Jr., Governor of Virginia. The Safety Recommendation(s) "identified the following hazards within the I-495 construction zone:

- (1) Lane markings are too faint to see, especially at night or when the road is wet; some lane markings which are no longer current are still visible, which can confuse motorists; and the lane markings which indicate transitional lanes on the shoulders are too abrupt for the posted speed limit.

- (2) The timber barricades, which are used both as traffic barriers and road edge delineators can be knocked into the roadway by a vehicle or blown onto the roadway by the wind; the barricade rail forms a spear when it is hit by a vehicle; and when struck, the barricades are inadequate, at posted speeds, to safely redirect traffic onto the roadway.
- (3) Stored materials, fuel, and equipment are not adequately protected from traffic.
- (4) Construction materials and debris have reduced the effectiveness of such safety facilities as bridge rails and guardrails. For example, construction debris piled in front of guardrails makes it possible for vehicles to vault the guardrails.
- (5) Shoulders either do not exist or are inadequate.
- (6) Hazards such as excavations and barriers are adjacent to the roadway even in areas where work is not presently being done.
- (7) When lanes are closed temporarily, traffic control procedures are poor and present hazards to flagmen and to motorists."(2)

The Recommendation(s) continued by stating: "In addition to specific hazards identified in the construction zone, the Safety Board investigation indicated that the Federal Highway Administration (FHWA) has not established safety standards for the design and use of temporary traffic barriers in construction zones."(3)

The Recommendation(s) concluded by recommending that the FHWA and The State of Virginia "Investigate the above-mentioned hazards to determine if they still exist, and, if so, take appropriate action to correct them."(4)

On August 18, 1975, officials of the Virginia Department of Highways & Transportation (VDH&T) requested that the Virginia Highway & Transportation Research Council (VH&TRC) evaluate the Board's recommendations concerning the timber barricades and compare the characteristics and performance of the timber barricades with those of the precast concrete traffic barriers (PCTB).

To provide insight into the Board's recommendations the authors of this report visited the Safety Board's investigator and discussed the findings of his investigation on I-495. The results of that discussion and findings expressed in the investigator's unpublished

report revealed the following additional issues concerning the timber barricade:

1. The timber barricades were placed along the full length of the roadway at the time the contract work commenced.
2. The timber barricades were used along the construction zone randomly and indiscriminately for various purposes, such as supporting traffic control devices and delineating hazards.
3. The timber barricades were linked together but were not fastened to the road surface.
4. The timber barricades were associated with an increase in the number of accidents in 1974.
5. The timber barricades were involved in 75% of the police accident reports for the period November 1 to December 11, 1974, along a 15-mile section of I-495.
6. The timber barricades violate federal standards for permanent barriers since -
 - (a) the 10" x 10" base constitutes a curb on an interstate roadway, and
 - (b) they are not continuous to prevent a vehicle from pocketing into the rail.(5)

The NTSB investigator further maintained that many of the problems identified in the report (including, perhaps, the aforementioned fatal crash) could have been eliminated or ameliorated through the use of the PCTB. The report said: "Research studies including dynamic crash tests and field evaluation of the safety shape barrier [PCTB] have shown it to have exceptional qualities for redirecting errant vehicles, including heavy trucks."(6) In 1971, "Idaho's installed cost for the precast barriers[was]\$7.20 to \$12 per foot and Missouri's from \$5.50 to \$8. While these costs were for a period prior to 1971, recent FHWA research indicates that precast units can be installed for about the same range as the Idaho cost."(7) These costs were contrasted to "The contract price for furnishing and installing the timber barricades westerly of I-95 [on I-495 which] was \$15 to \$16 per foot."(8) Thus, the NTSB's investigator contended that the PCTB is safer for the motoring public and the construction workers and is lower in installation cost than the timber barricade used on I-495.

The reader is referred to the Appendix of this report for a more detailed presentation by the authors of NTSB's findings as they pertain to timber barricades and barrier systems.

PURPOSE AND SCOPE

The purpose of this research was to evaluate the NTSB's findings concerning the timber barricades, and to compare the characteristics and performance of the timber barricades with those of the PCTB's.

To achieve this purpose this research had four objectives as listed below.

1. Identification of the legal requirements for traffic barricades in highway construction zones.
2. A determination of the nature and severity of the traffic crash problem on I-495 associated with construction activities and timber barricades as identified from traffic accident data.
3. A comparison of the efficacies of timber barricades and PCTB's in handling traffic operation problems in construction zones.
4. Preparation of an estimate of the costs of timber barricades and PCTB's.

METHOD

The Widening of the Capital Beltway (I-495) In Virginia

General information on the need for widening the Beltway and facts concerning the construction project were obtained from the Construction Division and Traffic and Safety Division of the VDH&T. The general information included a description of the roadway geometrics and the average daily traffic volumes on I-495. The facts concerning the construction project included contract bid prices, a brief overview of the work requirements, and a description of the three stages of construction.

Selection of the Timber Barricade Control System

The process used by VDH&T officials to study and select traffic control devices for I-495 was examined by questioning the officials in the Construction Division, the Location and Design Division, the Traffic and Safety Division, and the Fairfax Residency who participated in the selection of the timber barricade. FHWA officials in Richmond and Washington were also queried as to what devices were considered and why the timber barricade was chosen. The engineering consulting firm of Howard, Needles, Tammen and Bergendoff, which concurred in the selection of the barricade, was contacted to obtain additional data. Records of the Construction Division of the VDH&T were examined to determine the approval dates of the traffic control plan by the FHWA.

Legal Guidance in Barrier Selection

The current federal statutes passed by Congress pertaining to highways and construction safety and relevant to this study were examined. Likewise, the rules promulgated by the FHWA under its authority in federal highway projects which were safety related, had the force of law prior to approval of the Beltway project, and had any bearing on construction practices were studied. Particular attention was given to those statutes and rules that might be interpreted as either approving or forbidding the use of timber barricades or concrete barriers. Regulations pertaining to worker safety as enforced by the Occupational Safety and Health Administration (OSHA) were analyzed for the purpose of determining Virginia's compliance or noncompliance. Finally, the Virginia Manual on Uniform Traffic Control Devices for Streets and Highways⁽⁹⁾ was studied for relevant construction requirements.

Accident Analysis

Data on the accidents before and during construction on I-495 were obtained from the Traffic and Safety Division. These data were used to determine the magnitude of the traffic safety problem associated with construction on I-495.

An extensive accident analysis was performed over a limited time period to identify any changes in accident characteristics which could be associated with the construction activities and the role of the timber barricade in these changes. The time periods were determined for each construction contract based on the time construction was initiated. A listing of the accident report information recorded and retained by the VDH&T was obtained from the

Traffic and Safety Division. Fifteen data elements were selected from this listing for each accident. These elements were verified against the information contained on the accident report form and ten additional data elements concerned with the timber barricade were recorded. The twenty-five data elements were keypunched and processed through a computer program which provided cross tabulations of the desired information.

A literature search was performed on construction zone accident analyses on file with the Highway Research Information Service of the Transportation Research Board and in the VH&TRC library.

Barricade and Barrier Feasibility

The characteristics of the timber barricade and the PCTB were analyzed in terms of their technical, operational and economic feasibility. The technical feasibility of the timber barricade was analyzed in terms of crash tests performed on its component parts, and of the PCTB in terms of crash tests performed on the concrete median barrier (CMB). The operational feasibility of the timber barricade was analyzed in terms of its physical characteristics and its performance on I-495, and of the PCTB in terms of its performance in other states which utilize it. The economic feasibility of the timber barricade was analyzed in terms of its contract cost on various projects in Virginia, the cost to replace damaged barricades resulting from accidents, and the economic loss due to injuries and deaths in accidents which involved the timber barricade on I-495. The economic cost of using the PCTB's was obtained from other states' experiences and the limited experience in Virginia. The cost of replacing PCTB's damaged by traffic accidents and the economic loss due to injuries and deaths associated with the PCTB could not be determined due to the lack of available Virginia data.

THE WIDENING OF THE CAPITAL BELTWAY (I-495) IN VIRGINIA

Interstate 495 is the Beltway for Washington, D. C. and carries a traffic volume in the range of 80,000 to 100,000 vehicles per day. The Virginia portion of the highway is 22.1 miles in length from the Cabin John Bridge at the northerly limit to the Woodrow Wilson Memorial Bridge on the easterly limit (see Figure 1). The section of I-495 west of I-95 is a four-lane roadway and the section east of I-95 has six lanes. Starting in the late sixties, the heavy commuter concentration created "stop and go" traffic conditions during the morning and evening peak hours. The state of Virginia felt that an eight-lane facility was warranted to adequately handle the commuters plus the north-south traffic diverted from I-95 through the District of Columbia.

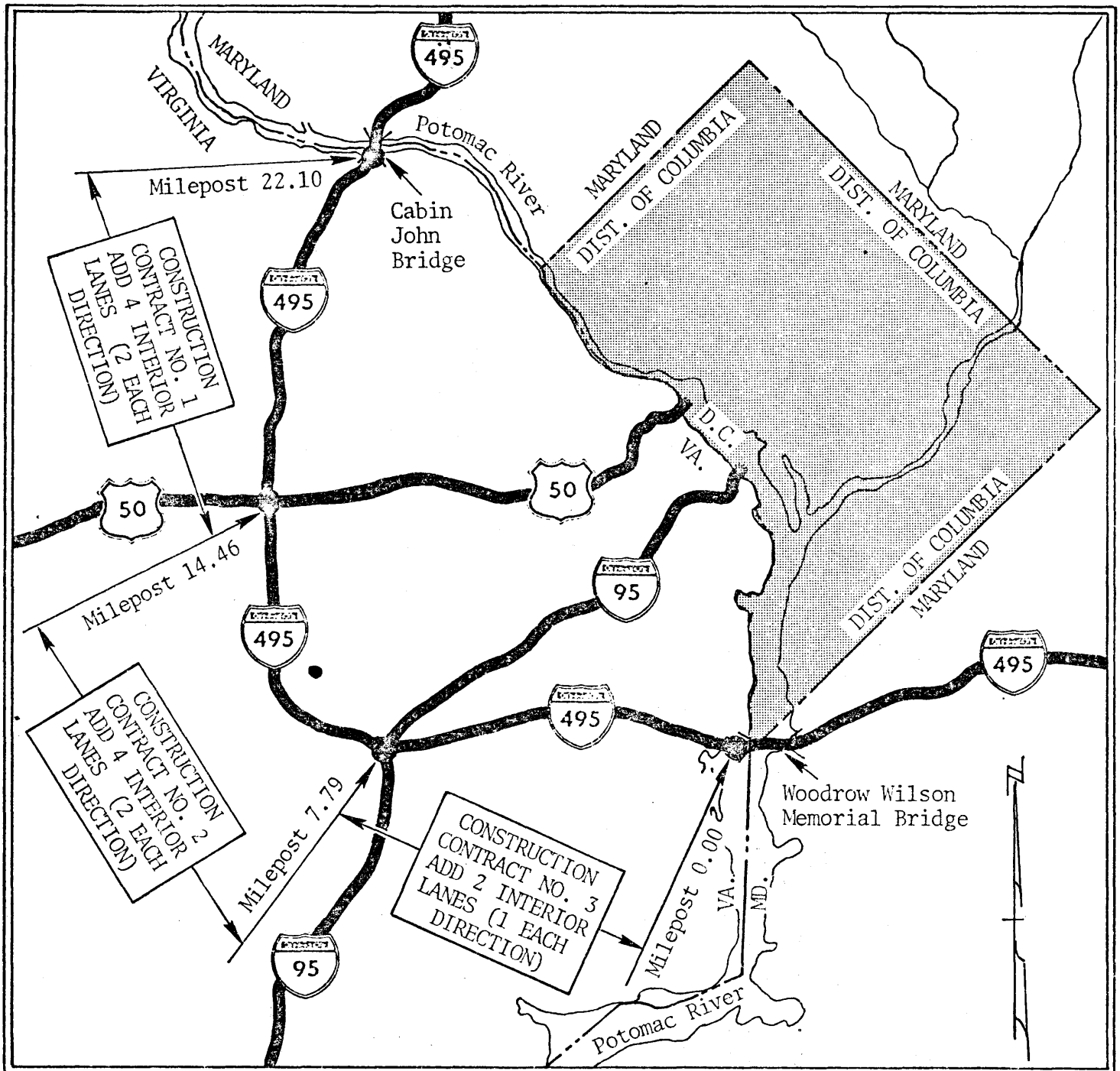


Figure 1. Location of I-495 in Virginia.

The widening of the Virginia portion of I-495 to eight lanes is being performed in three construction contracts. Construction contract No. 1 covers the section from the Cabin John Bridge to U. S. Route 50, a distance of 7.64 miles (see Figure 1). The bid price for this contract is \$27,881,216.79, and work commenced in February 1974. Construction contract No. 2 covers the 6.67 miles from U. S. Route 50 to I-95 (see Figure 1). The bid price for the contract is \$22,764,799.20, and work commenced in May 1974. The work required in contract Nos. 1 and 2 consists primarily of adding two lanes in each direction to the existing four-lane roadway and a safety shape concrete median barrier. Figure 2 shows the existing 24' (two 12' lanes) roadway and the 19' widening in the median area and the 5' widening on the right shoulder to achieve the new 48' (four 12' lanes) roadway. Construction contract No. 3 covers I-495 from I-95 to the Woodrow Wilson Memorial Bridge, a distance of 7.79 miles. The bid price for the contract is \$35,748,936.55, and work commenced in November 1974. The work in the third contract consists primarily of adding one lane in each direction to the existing six-lane roadway and a safety shape concrete median barrier.

The widening of I-495 is being accomplished in three stages of construction. Construction stage one consists of widening the roadways within the median area (see Figure 3). Traffic is maintained over the existing roadway and ramps. Construction stage two consists of widening the roadway on the right of the traveled way, and repairing the joints in the existing pavement and overlaying it with a bituminous concrete surface (see Figure 4). During this stage, traffic is maintained on the newly completed paved area within the existing median. Construction stage three consists of accomplishing all tasks that could not be completed in the previous stages.

Construction contracts Nos. 1 and 2 have a completion date of July 1, 1976, and contract No. 3 has a completion date of November 1, 1976.

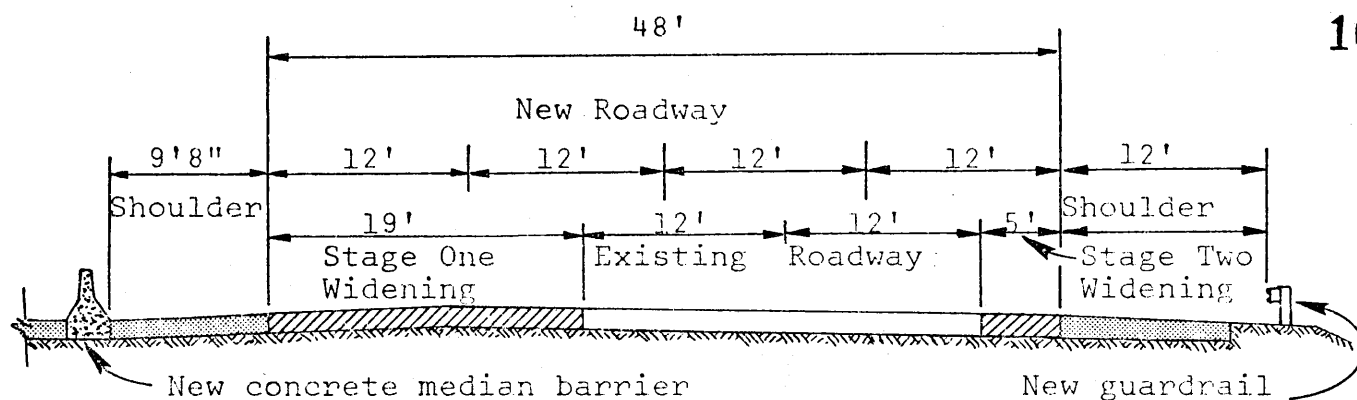


Figure 2. Reconstructed mainline I-495 cross section for one direction of travel.

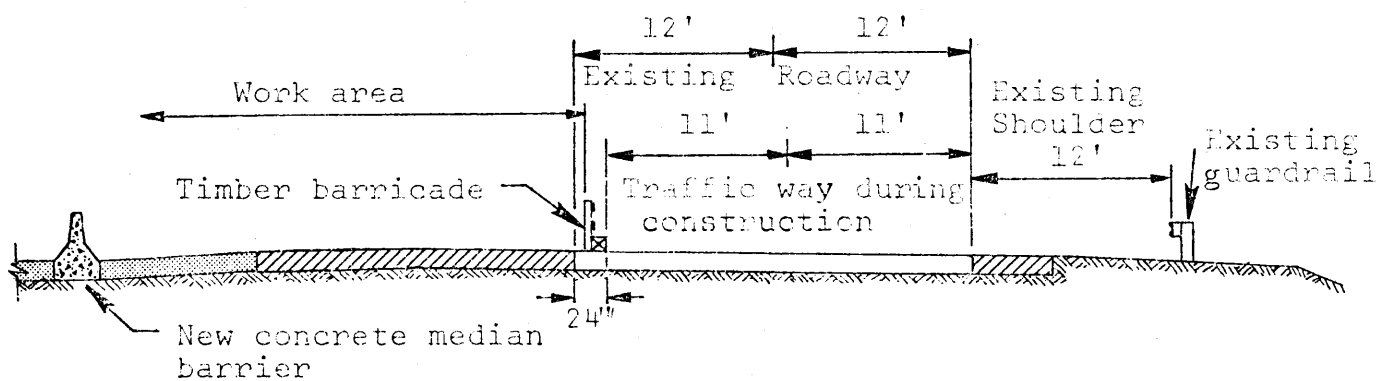


Figure 3. Reconstructed I-495 cross section for one direction of travel during construction stage one.

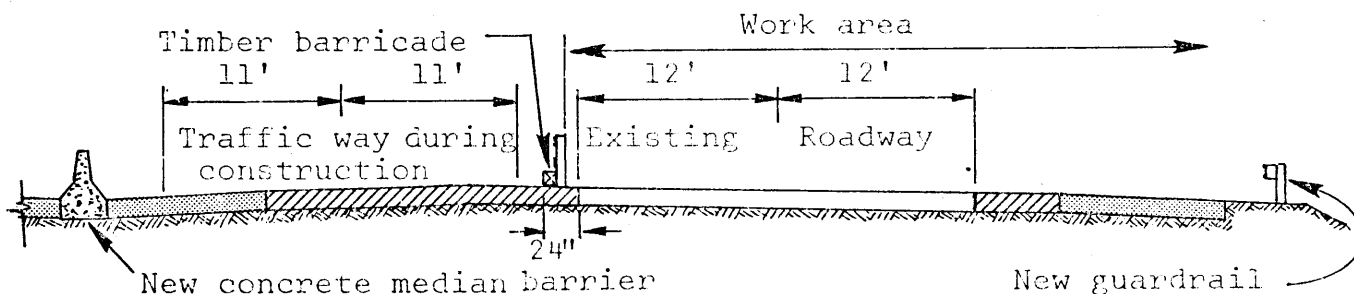


Figure 4. Reconstructed I-495 cross section for one direction of travel during construction stage two.

SELECTION OF THE TIMBER BARRICADE CONTROL SYSTEM

General

The safest possible practice to employ during a road widening project is to close the road and divert the traffic onto an alternate route. Where this practice is highly impractical, an alternative is to leave the road open but divert traffic to the shoulder, or block off a lane so that a safety zone separates the work area and the traffic stream. Nearly all high capacity roads in the Washington, D. C. area diverge radially from the city and are congested at commuting hours, so a closing of any portion of I-495 was deemed an unrealistic measure. Because of the load bearing capacity of the right shoulder, diversion of traffic to the right lane and right shoulder was also not practical. Repairs of distress in the pavement joints just prior to the widening project had to be terminated because the diversion of traffic onto the shoulder was causing the shoulder to disintegrate. A plan to open the shoulder to cars but require trucks to use the left lane was rejected, because experience had shown that truck drivers either could not or would not obey signs requiring them to "keep left" on near-capacity roads such as I-495.(10) Reduction of the traveled way in each direction by one lane, which would function as a safety zone, was judged unacceptable, and this decision has proven to be well-founded, since the existing lanes of traffic are often at or near standstill during peak commuting hours.

During construction stage one for contracts No. 1 and No. 2 (from Cabin John Bridge to I-95), the four lanes of traffic (two lanes in each direction) had to be carried on the two existing 24' roadways. Two new 19' slabs separated by a concrete median barrier were to be added in the median between the two existing roadways. Construction of these 19' slabs required that excavations (up to 18"), heavy equipment, and workmen be located immediately to the left of the traffic stream. For the safety of the motorists and workmen, the traffic control plans required that work in the median be completed prior to initiation of work on the outside of the existing roadways. This requirement provided usable shoulder on the right of the traveled way during construction stage one. During construction stage two, the existing roadway was upgraded and a 5' slab and a new shoulder were added on the outside of each of the existing roadways. A similar sequence of operations was called for in construction contract No. 3 from I-95 to Woodrow Wilson Memorial Bridge, where one lane in each direction and the concrete median barrier were added. The plans were largely followed, but exceptions were made at some bridge sites and at some locations at which pipes had to be jacked under the roadway.

Separation of Traffic and Workmen

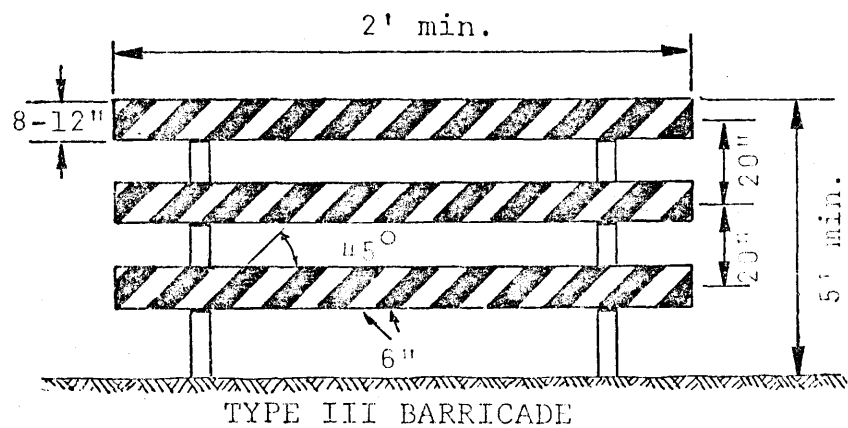
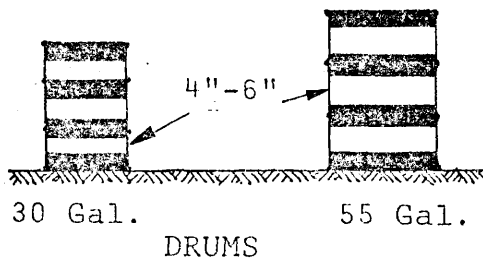
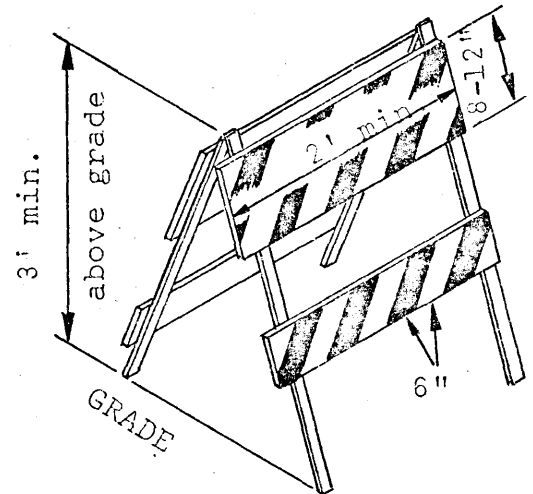
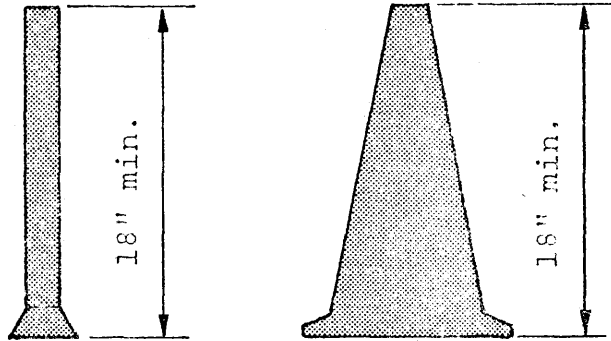
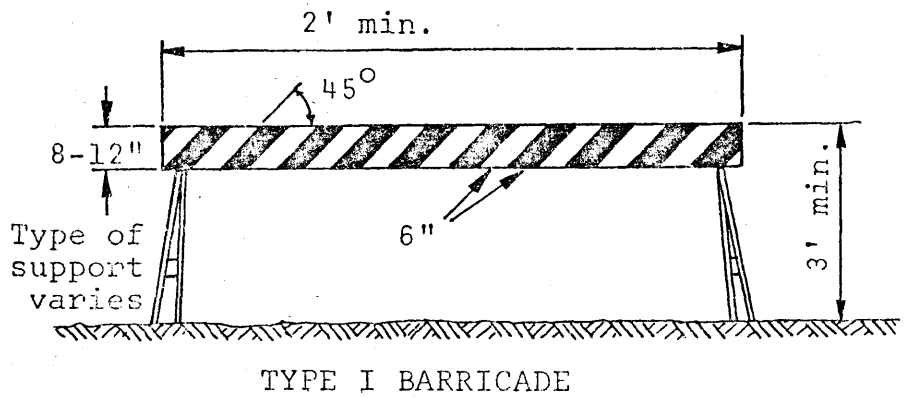
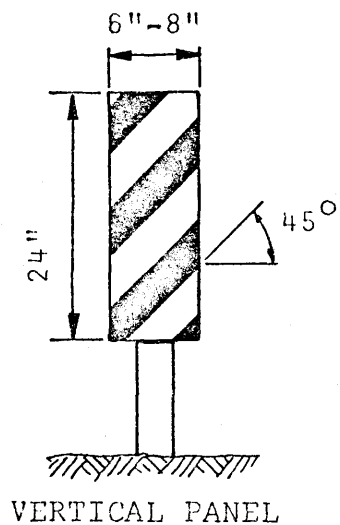
Because of the close proximity of the existing roadway to the work area, a safety device was required to separate the traffic from the workmen. According to a VDH&T official, "the purpose [of the safety device to be employed] was to create a barrier between the construction work area and the traffic area used by the traveling public, and provide a large measure of safety for both segments."(11)

The customarily used left lane edge marking, a yellow stripe, was deemed inadequate, since there was often to be no left shoulder and there was insufficient width on the existing slab to move all traffic to the right and create a shoulder. Hence, some device was sought that functioned as both a delineator and barrier, and yet would occupy minimal space on the existing roadway. It was decided that the device should be (1) highly visible, (2) as thin as possible, (3) strong enough to protect vehicle occupants from roadside hazards such as excavations and equipment, (4) sufficiently impenetrable to protect the work crews, and (5) so designed as to do minimal damage to errant vehicles. Further, the device would have to be sufficiently mobile to allow installation, several displacements, and subsequent removal.

Safety Devices Considered Inadequate or Unsited

Because of the need for a positive barrier, devices designed strictly for warning were considered inadequate. This decision ruled out cones, vertical panels, raised reflectors, rumblers, and Type I and Type II barricades (see Figure 5). Drums were considered ill suited because their inherent discontinuity would offer minimal redirection capability and they would not prevent entry of errant vehicles into the work area. A continuous beam mounted on drums was examined but rejected due to width restrictions. This latter device is not fastened down and so requires a recovery area behind the drums to operate properly.

The Type III barricade as described in the MUTCD was considered to be ill suited for use on I-495. The width of the base for a moveable Type III barricade is necessarily deep for stability and hence too wide for the available space. Since the Type III barricade is 5' high and has three rails, a narrow base would render it especially susceptible to being blown over by the wind. Also in a collision with the end of the barricade, the top rail would act as a spear at a windshield level. The Type III barricade is not recommended as a longitudinal barrier in the MUTCD.



WARNING OR CHANNELIZING DEVICES

STANDARD BARRICADES

Figure 5. Channelizing or warning devices and standard barricades. Source: MUTCD.

The Timber Barricade

The device chosen to separate traffic and workmen was not new and engineers have generally considered it effective (see Figure 6). For want of a better name it is called a "timber barricade," and it was used for ten years on the widening of the Shirley Highway (I-95 south of Washington, D. C.). In monitoring that use of the barricades, personnel of the Construction Division of the VDH&T had found from field reports of contractors and police, and from personal evaluation, that they seemed to function satisfactorily. Based on the aforementioned consideration of alternative devices and the apparent effectiveness of the timber barricade in the Shirley Highway work, when the VDH&T sent the specifications to the design consultant on July 5, 1972, the timber barricade was designated as the device to use as the delineator and barrier. The design consultants, the engineering firm of Howard, Needles, Tammen and Bergendoff, had employed the timber barricade for widening projects on many high speed, high volume roads, including the Shirley Highway and the New Jersey Turnpike. The firm believed that the timber barricade was an effective device for this type of project and so endorsed its use in the plan submitted to the VDH&T. On April 16, 1973, representatives of this firm, the VDH&T and the FHWA made a field inspection of the first stretch of road to be let for contract. During this inspection it was unanimously agreed that the timber barricade would be employed. (12) The Traffic and Safety Division of the VDH&T checked the final plans and saw no reason for any objection.

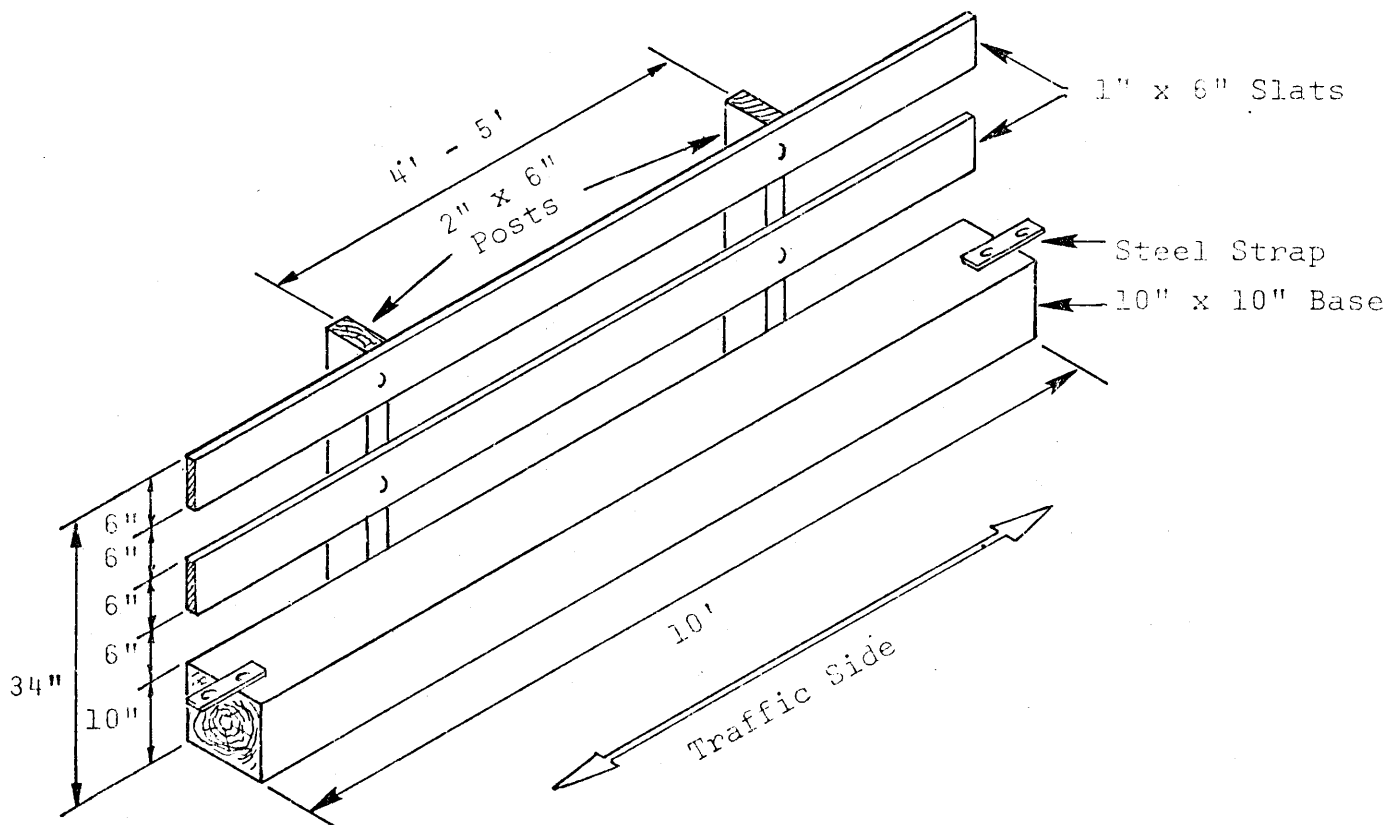


Figure 6. Typical timber barricade used on I-495.

The timber barricade was considered to offer good delineation. The 10" x 10" base and horizontal railings at heights of 34" and 22" were painted white, and lights were installed every 75' for delineation during periods when visibility was poor. The obvious mass of the barricade was considered psychologically effective for keeping the traffic stream from traveling close to it. The 16" width of the barricade also made it the thinnest device considered suitable as a positive barrier. Although conceded to be penetrable, it was considered to provide much more protection for drivers and workmen than would cones or other warning devices. To ensure continuity, the barrier units were required to be connected by steel straps nailed into their bases.

The redirection capability of the timber barricade was considered to be good at shallow angles of impact. Engineers were aware that fixed vertical curbs along high speed roadways are inherently dangerous and that barrier curbs (relatively high and steep faced) "should not be used where design speeds are above 50 mph." (13) Several factors seemed to make this prohibition inapplicable to the timber barricade. First, the timber base was not fixed to the ground, so engineers envisaged that it would slightly displace and redirect rather than be mounted. The traffic side of the barricade was placed 24" from the edge of the roadway, thus allowing 8" for displacement behind the barricade. Secondly, the specifications cited above apply to the elements of the finished highway, not to those used in the various stages of construction. Finally, during construction, accidents are usually controlled by speed reduction and increased use of warning devices. Experience has shown that vehicles on I-495 could not be kept to the planned speed of 45 mph.

As for the speeds at which motorists were traveling through the construction zone, the Traffic and Safety Division of the VDH&T conducted speed studies during construction on I-495. These studies were performed in March 1975, October 1975, and April 1976. The results of these studies indicate that the 85th percentile speed on I-495 has varied generally from 54 to 58 mph during construction. The ineffectiveness of speed zoning alone is well documented by field studies which generally conclude that most of the drivers selected speeds that they considered to be safe and proper for the prevalent roadway and traffic conditions, regardless of regulations. In order to reduce the speed below a level deemed reasonable by motorists, high enforcement activity is essential.

Table 1 outlines the advantages and disadvantages of various devices used as a delineator/separator on road widening projects having restricted roadway widths as perceived by the VDH&T during planning in 1972-73. At that time, the PCTB was still in the developmental stage and its use was not considered.

Table 1
Comparison of Delineation/Separation Devices

Delineation/Separation Devices	Protection		Delineation	Mobility	Width (b)	Maint.	Cost
	Driver	Worker(a)					
Cones (including plastic pylons) Type I/II Drums Drums w/beam Timber barricade	Poor	None	Good	Excellent	Excellent	Fair	Excellent
	Poor	Poor	Good	Excellent	Poor	Fair	Good
	Fair	Fair	Good	Excellent	Poor	Poor	Good
	Good	Good	Good	Fair	Poor	Poor	Fair
	Good	Good	Good	Good	Good	Fair	Fair

(a) Field reports indicate the noise of errant vehicle penetration alone affords some warning and hence protection.

(b) Every extra inch of width must be taken from lane width.

LEGAL GUIDANCE IN BARRIER SELECTION

In order to receive funds under the federal-aid system, the states must comply with two Acts of Congress: the Federal-Aid Highway Act of 1973 (as amended) and the Highway Safety Act of 1973. The first Act requires, among other things, that road design be "conducive to safety" and that states comply with Department of Transportation (DOT) "safety standards". The second requires that states comply with uniform safety standards set by the DOT.

Federal-Aid Highway Program Manual

The Federal-Aid Highway Program Manual (FHPM) contains all the FHWA standards (rules) promulgated under the Federal-Aid Highway Act of 1973. The rules are therefore binding, as opposed to advisory. The FHPM fills six binders and is the basic instrument employed by the FHWA to regulate state activities funded with federal highway funds. This manual sets forth a great number of specifications relating to items ranging from highway markings to pavement design; unfortunately, it is silent on temporary barrier use during construction.

The FHPM does, however, in Volume 6, Chapter 2, Section 1, Subsection 1: "Design Standards for Federal-Aid Projects" list all other publications "that are acceptable to the Federal Highway Administration (FHWA) for application in the geometric and structural design and traffic control features of Federal-aid highway projects...." This subsection separates all regulatory material outside of the FHPM, yet under the Federal-Aid Highway Act of 1973, into three groups:

- (1) Highway design standards and specifications are those design principles and dimensions derived from basic engineering knowledge, experience, research, and judgment that are officially designated and adopted by highway authorities as the specific controls for designs of highways.
- (2) Highway design policies are general procedures and controls which are less specific than design standards, often with a range of acceptable values, and which are officially adopted or accepted for application in the design of highways.
- (3) Highway design guides include information and general controls that are more flexible and indefinite than policies but which are valuable in attaining good design and in promoting uniformity. (14)

There are currently 12 references in the first group, 7 in the second, and 17 in the third. The subsection cited above provides that "Approval may be given to plans, specifications and estimates that are found to be in conformance with [these references]." Further, it states that "Approval may be given to designs on a project basis which do not conform to [the first and second groups] only after due consideration is given to all project conditions such as maximum service and safety benefits for the dollar invested..." The last group, Guides, "are not project requirements and no specific approval for deviations from the guides is required."

Standards and Specifications

The first group, Standards and Specifications, includes information regarding geometric designs for completed highways, grade-crossing practices, bridges, signs, light standards, and sampling methods. The only reference related to the topic of highway construction practices is the MUTCD.

Part VI of the MUTCD, "Traffic Controls for Street and Highway Construction and Maintenance Operations" is the only federal standard that provides specific information concerning traffic operations practices. For example, Figure 6-10 in the MUTCD schematically indicates the appropriate location of all signs, barricades and channelizing devices for the closing of 2 lanes of a 4-lane highway for repair purposes.⁽¹⁵⁾ The MUTCD does not indicate recommended signing or barricading for road widening projects. However, part VI, section C, "Barricades and Channelizing Devices," is provided to aid in the selection of proper traffic control devices in varied construction zone circumstances. Section C begins by stating that

The functions of barricades and channelizing devices are to warn and alert drivers of hazards created by construction or maintenance activities in or near the traveled way, and to guide and direct drivers safely past the hazards.⁽¹⁶⁾

This paragraph clearly indicates that the "functions" of barricades and channelizing devices are visual: to warn and alert and to guide and direct — not to physically restrain vehicles.

Section C continues by identifying the "requirements" of barricades and channelizing devices as follows:

In fulfilling these two functions, barricades and channelizing devices are often required to

satisfy two opposing requirements. For example, a channelization installation should be constructed in a substantial manner to provide protection for men working in the roadway. At the same time, however, the channelization devices should provide a smooth and gradual transition which reduces the width of the traveled way, and in this case the channelizing devices should not inflict any severe damage to a vehicle that inadvertently strikes them. (17)

Hence, the MUTCD indicates that although barricades and channelizing devices have two "functions", both visual, they have three "requirements": visibility to provide a smooth roadway transition; indemnity to minimize damage to errant vehicles; and substantiality to protect workers. Section C continues by stating the "objective" of a traffic control plan:

The objective should be the development of a traffic control plan which uses a variety of traffic control measures in whatever combination necessary to assure smooth, safe vehicular movement past the work area and at the same time provides maximum safety for the equipment and the workmen on the job. (18)

So the "objective" of the traffic control plan includes two requirements of the barricades and channelizing devices: safe vehicle passage and worker safety.

No device or mix of devices listed in the MUTCD could fulfill all of the "functions," "requirements," and objectives" in the restricted work area on I-495. The devices that minimize vehicle damage while guiding vehicles would be cones and vertical panels. Yet these devices would afford no protection to workmen and would permit severe damage to errant vehicles if a hazard such as excavations was adjacent to the traveled way. Type I and II barricades would increase vehicle damage relative to cones while affording no more real protection for workers from errant vehicles or for drivers from roadside hazards. Drums would certainly damage errant vehicles more than the preceding devices, allow errant vehicles to contact roadside hazards, and perhaps increase worker jeopardy by increasing the number of dangerous objects set in motion by a collision.

Part VI of the MUTCD does provide that: "As an effective channelizing method, barrels or drums may be used to support conventional guardrail sections." (19) This method may be appropriate if a limited recovery area is available, for the drums are not attached to the road surface. However, use of this method on I-495 is questionable, because hazards and workmen were frequently immediately behind the traffic control devices.

The only other warning or channelizing device in Part VI is the Type III barricade. Since only two of its dimensions are specified, its strength is variable. It would certainly seem that the more worker protection it offered by rugged construction, the more damage it would inflict on errant vehicles. However in the MUTCD the Type III barricade was clearly not intended for use parallel to a roadway. Rather, it is designed to close roads, or give the illusion of a narrowed roadway by emplacement on the shoulder. (20) For both purposes its axis is perpendicular to the road.

The MUTCD, therefore, sets out in Part VI the logical goals of traffic control devices in the construction zone as being to guide drivers, minimize damage to errant vehicles, and protect workmen. It does not mention the serious problem of errant vehicle collision with roadside hazards. For a situation such as the road widening on I-495 the manual offers no device that can fulfill even the goals it sets forth. Neither the PCTB nor the timber barricade is listed in the MUTCD, and no provision appears which would ban or recommend the use of either.

The MUTCD does require that traffic control devices employed during construction "shall remain in place only as long as they are needed and shall be immediately removed thereafter. Where operations are performed in stages, there shall be in place only those devices that apply to the conditions present." (21)

Whereas this provision does not mention the device employed, it prescribes against extensive use of control devices in areas where no work or hazards exist. Hence, the placing of timber barricades for the full length of each contract on I-495, in some sections for months without any work being done near the roadway, was contrary to this provision.

The NTSB's investigator stated that signs should be mounted on supports which will yield upon impact to minimize hazards to motorists. However, the MUTCD states that within a construction zone "it is often necessary and/or desirable to erect signs on portable supports placed within the roadway itself. It is also permissible to mount appropriate signs on barricades." (22)

Policies

The second grouping in the FHPM, Policies, includes geometric design for rural highways, location of police stations, utility accommodations in rights-of-way, U-turn policies, railroad access, and stopping sight distances. Included as a policy is the AASHTO publication, A Policy on Design of Urban Highways and Arterial Streets 1973, which lists the geometric properties desirable in the final design of freeways, arterial streets, collector and local streets, and interchanges, and various other information such as provisions for buses and parking. It has a brief section called "Maintaining Traffic During Construction", but this concerns itself largely with capacity considerations and refers the reader back to the MUTCD. It also has a section called "Barrier Curbs", which states that:

Barrier [relatively high and steep faced] curbs should not be used on freeways and are considered undesirable on other high-speed arterials. Generally, barrier curbs should not be used where design speeds are above 50 mph.(23)

The unpublished NTSB report says that this AASHTO provision would forbid the use of the timber barricade on I-495. As mentioned earlier, the planned speed for construction on I-495 was 45 mph, the base of the barrier is not fixed as is a curb, and is probably harder to surmount since it consists of painted wood while curbs are generally concrete. If this policy provision was intended to alert construction planners of the unsafe nature of the timber barricade, it failed to so alert the FHWA (which endorsed the I-495 project) and the many states that continue to employ this barricade.

Guides

The last group, Guides, (which may be deviated from without specific approval) deals with various definitions, bicycle routes, drainage, pavements, landscaping, environment, rest areas, lighting, utility accommodations, mail boxes, screening of overpasses, fencing, driveways, and highway capacity. Included as a guide is the AASHTO publication, Highway Design and Operational Practices Related to Highway Safety.(24) This publication deals generally with the safety of finished roads, "forgiving" roadsides, traffic operations and the like. It does include a chapter entitled "Construction and Maintenance Operations," which indicates, among other things, the necessity for continuous, around-the-clock surveillance of construction areas. This section further provides that

Where maintenance or construction operations are under way adjacent to passing traffic, a 10-foot wide clearance should be provided wherever possible

between the work and the passing traffic. Many times a positive barrier is justified, such as a temporary median barrier or precast concrete rail. The roadway near falsework openings should be well lighted and delineated.

The practical maximum roadside recovery area should be provided, along with yielding delineation devices such as traffic cones, lightweight barricades and delineators. If a recovery area is not available, properly designed barricades should be provided to protect drivers from immediate hazards.

Temporary barriers should be provided in narrow medians with high traffic volumes. Concrete barriers with a sloping face have sometimes been used in such situations when they could be incorporated in the final design, or in a tight traffic situation to protect workers, as well as motorists from hazards. Where exposed ends of protective rails are vulnerable to impact by out-of-control vehicles, temporary impact attenuator devices should be utilized.(25)

This guidance was not available in 1973 when the timber barricade was chosen. It supports the decision not to use lightweight barricades where recovery is not possible. It is also highly permissive regarding the positive barrier warranted. By providing that the barricade be "properly designed," it begs the question here at issue. It lists "precast concrete rail," and "concrete barriers with a sloping face" as examples rather than recommendations. The timber barricade employed would fit within these guidelines.

Also included as a guide is the Highway Research Board publication, NCHRP Report 118, "Location, Selection, and Maintenance of Highway Traffic Barriers."(26) This publication makes no reference to temporary barriers of any kind — but does recommend the safety shape concrete median for permanent installation in narrow medians. It shows the MB5 concrete barrier with a 24" base and the MB6 concrete barrier with a 30" base, and indicates their status as "operational (qualified)." A footnote explains that the "System is structurally adequate for 4,000-lb. vehicle impacting at 60 mph and 25-deg angle; however, use of system should be restricted to locations where probability of impact angle is less than 15 deg for vehicle occupant's safety."(27)

This reference, of course, does not deal at all with temporary barricades. The admonition to employ barriers only "where the severity of a collision with the roadside feature would be greater than that with the traffic barrier...."(28) could be construed to militate against the extensive use of timber barricades on the Capital Beltway, particularly at those times when the shoulder was serviceable and empty so that a delineator such as plastic pylons would have sufficed.

Highway Safety Program Standard 12

Pursuant to the Highway Safety Act of 1973, 19 uniform safety standards have been promulgated by the FHWA and NHTSA. Highway Safety Program Standard 12 is under the administration of the FHWA and titled "Highway Design, Construction, and Maintenance."(29) It requires that every state shall have a program of highway design, construction, and maintenance to improve highway safety. Further, it states that the program shall provide, as a minimum, that "There is guidance, warning, and regulation of traffic approaching and traveling over construction or repair sites and detours."(30) The extremely general nature of this regulation, of course, was not designed to require or bar the use of any reasonable device.

Occupational Safety and Health Administration

Because the barriers also protect workers, the Occupational Safety and Health Administration (OSHA), has promulgated rules in the area of roadside construction. The Safety and Health Regulations for Construction dictates that no contractor shall require any laborer to work in surroundings hazardous or dangerous to his safety, as determined by OSHA regulations.(31) In the area of highway safety OSHA has incorporated the Federal-Aid Highway Act of 1973 in its regulations.(32) The OSHA regulations require that for the protection of employees, barricades shall conform to the MUTCD, and further that if signs, signals and barricades do not provide the necessary protection adjacent to a highway, flagmen or other appropriate traffic controls "shall be provided".(33)

ACCIDENT ANALYSIS

The purpose of this accident analysis was to determine the effect of the construction work on I-495 on traffic crashes and the role of the timber barricade in these crashes. There were three phases: (1) A general analysis of the accident experience on I-495 before and during construction to determine the magnitude

of the traffic safety problem associated with construction; (2) a detailed analysis of the accident experience on I-495 before and during construction to determine the characteristics of the traffic crashes, the effects of construction on these characteristics, and the role of the timber barricade in the crashes; and (3) an analysis of previous studies or accident statistics on construction zone crashes to determine if the changes in crashes on I-495 were within "acceptable" limits.

Magnitude of the Traffic Safety Problem on I-495

The first phase in the accident analysis was a general study of the accident experience on I-495 before and during construction to determine the magnitude of the traffic safety problem associated with construction. To identify the appropriate approach, the numbers of reported accidents on I-495 by month were obtained from the VDH&T's Traffic and Safety Division and plotted (see Figure 7). From January through October 1973 the number of accidents per month on the Virginia portion of I-495 fluctuated around an average of 96. In November 1973, the effects of the energy crisis were noted as a decrease in the number of accidents. The lowest number of accidents, 38, was recorded in January 1974. Work on the first construction contract was initiated in February 1974, and a rise in the number of accidents was noted. This rise may be attributed to the construction activity, to a decrease in the effects of the energy crisis, or both. Work on the second construction contract was begun in May 1974, and the number of accidents continued to rise. Work on the third contract was initiated in November 1974. The number of accidents in December 1974 was recorded at 170, or 4.5 times higher than the number recorded for the lowest month in 1974.

A review of the data presented in Figure 7 revealed that the effects of the energy crisis and the effects of the construction activities on three projects initiated at different times could not be segregated in an analysis of the entire I-495 roadway. Thus, each construction zone was analyzed separately.* However, to permit a comparison of the accident experiences for the three segments of I-495, and thus an evaluation of the accident trends, the numbers of

*The analysis in contract segments prohibits the inclusion of approximately 5% of the total number of accidents which were not locatable on I-495. The basic assumption is that these unlocatable accidents were evenly distributed along I-495.

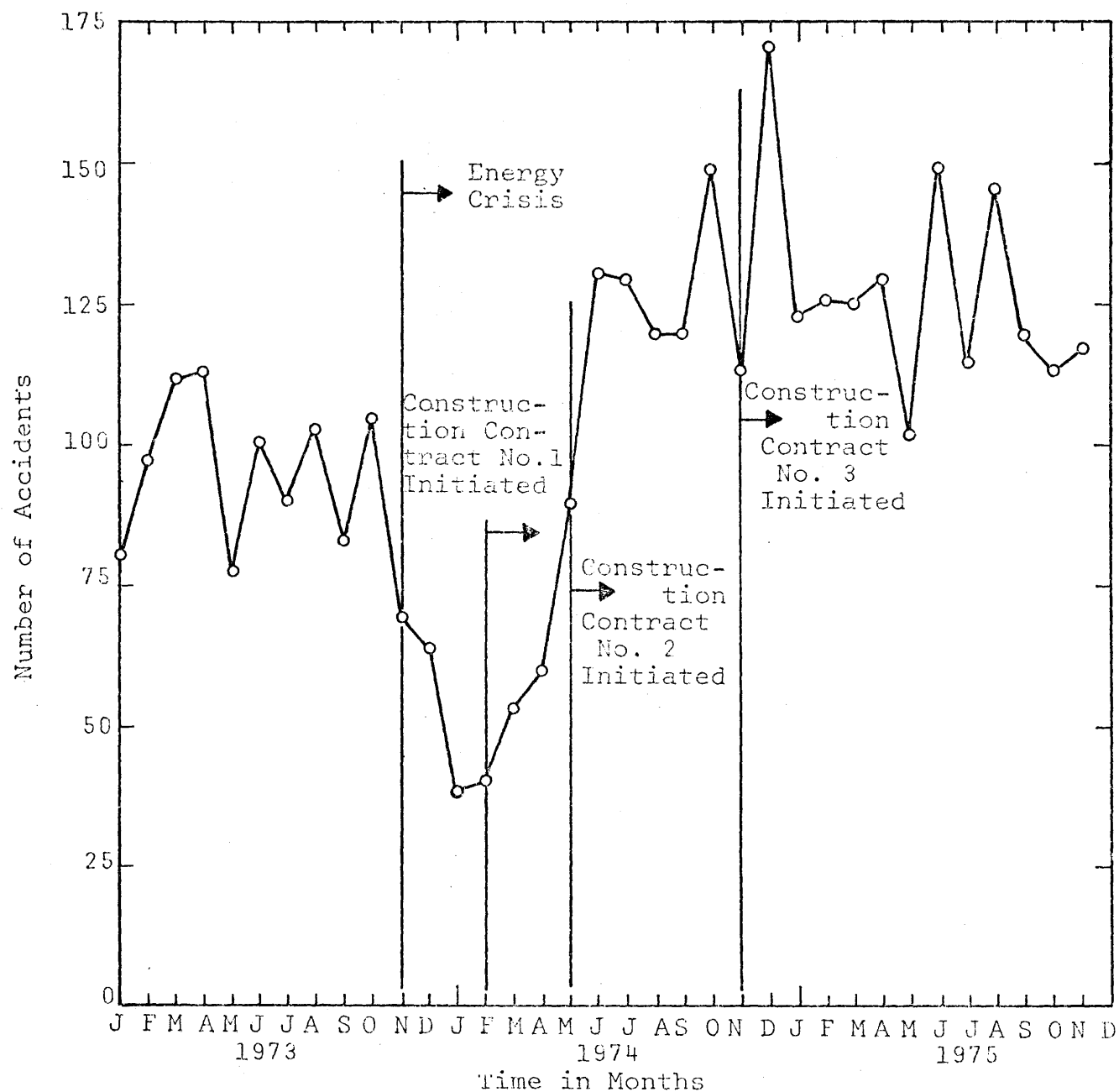


Figure 7. Total number of accidents on I-495 by months.

accidents were converted into standardized accident scores.* The standardization of numbers of accidents removes the differences in statistical distributions between the three zones, controls for the unique roadway characteristics of each zone, and allows an accurate comparison of the accident trends.

Figure 8 depicts the accident trends for construction contract No. 1. While there were month to month fluctuations in the number of accidents, the standardized accident scores were fairly constant until November 1973. At that time, the energy crisis was first felt. In keeping with energy crisis trends in other areas of Virginia, the number of accidents fell between December of 1973 and April 1974. Although the entire length of project No. 1 was not under construction until June of 1974, construction was started in February. The increase in accidents between February and June was the result of a combination of the recovery from the energy crisis and the effects of construction. From June 1974 to November 1975, accident scores were higher than during the period before construction began.

In general, accident trends for contract No. 2 were consistent with those for contract No. 1 (see Figure 9). The scores were fairly constant until the energy crisis, then they fell sharply. They began to rise in May, when construction was begun and the effects of the energy crisis began to diminish, and they continued to rise until July, when the entire length of project No. 2 was under construction. These scores remained higher than those for the pre-energy crisis/pre-construction period, even though they tended to drop during 1975.

Trends for contract No. 3 were slightly different from those for the other segments, since construction was not initiated until November 1974 (see Figure 10). Since work was under way on the other contracts and not on contract No. 3, Figure 10 can be used to gain an indication of what might have happened on I-495 if construction had not been undertaken. As in the other trend figures, the accident scores were fairly constant before November 1973, and then fell during the energy crisis. As was the case for contracts No. 1 and No. 2, a recovery began in March and extended until June.

*Standardized accident scores are calculated by finding the difference between the number of accidents for a given month and the mean number of accidents for all months, and then dividing by the standard deviation for the construction zone. In essence, this calculation adjusts the distribution for each zone so that it has a mean of zero and standard deviation of one.

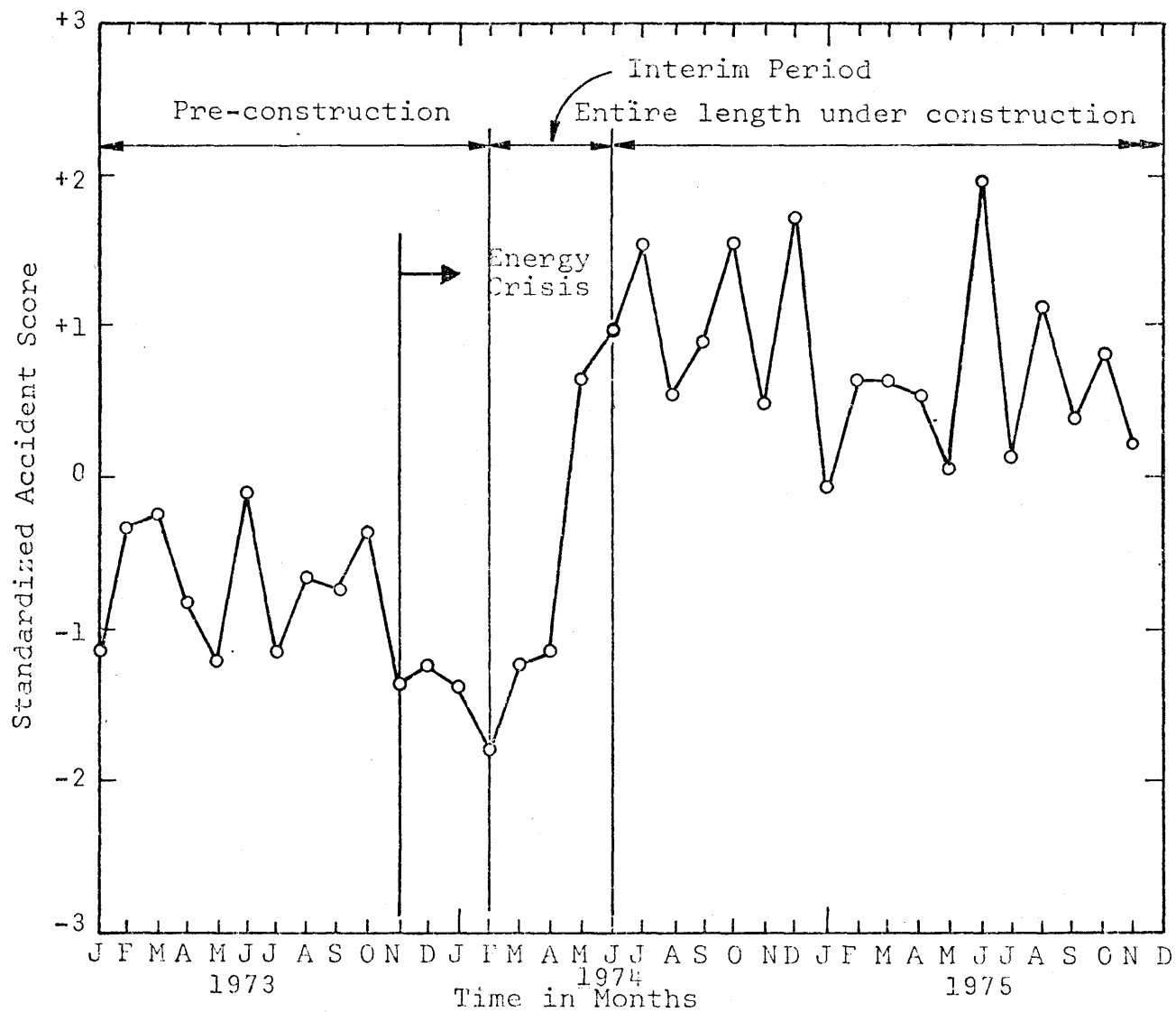


Figure 8. Standardized accident scores for construction contract No. 1.

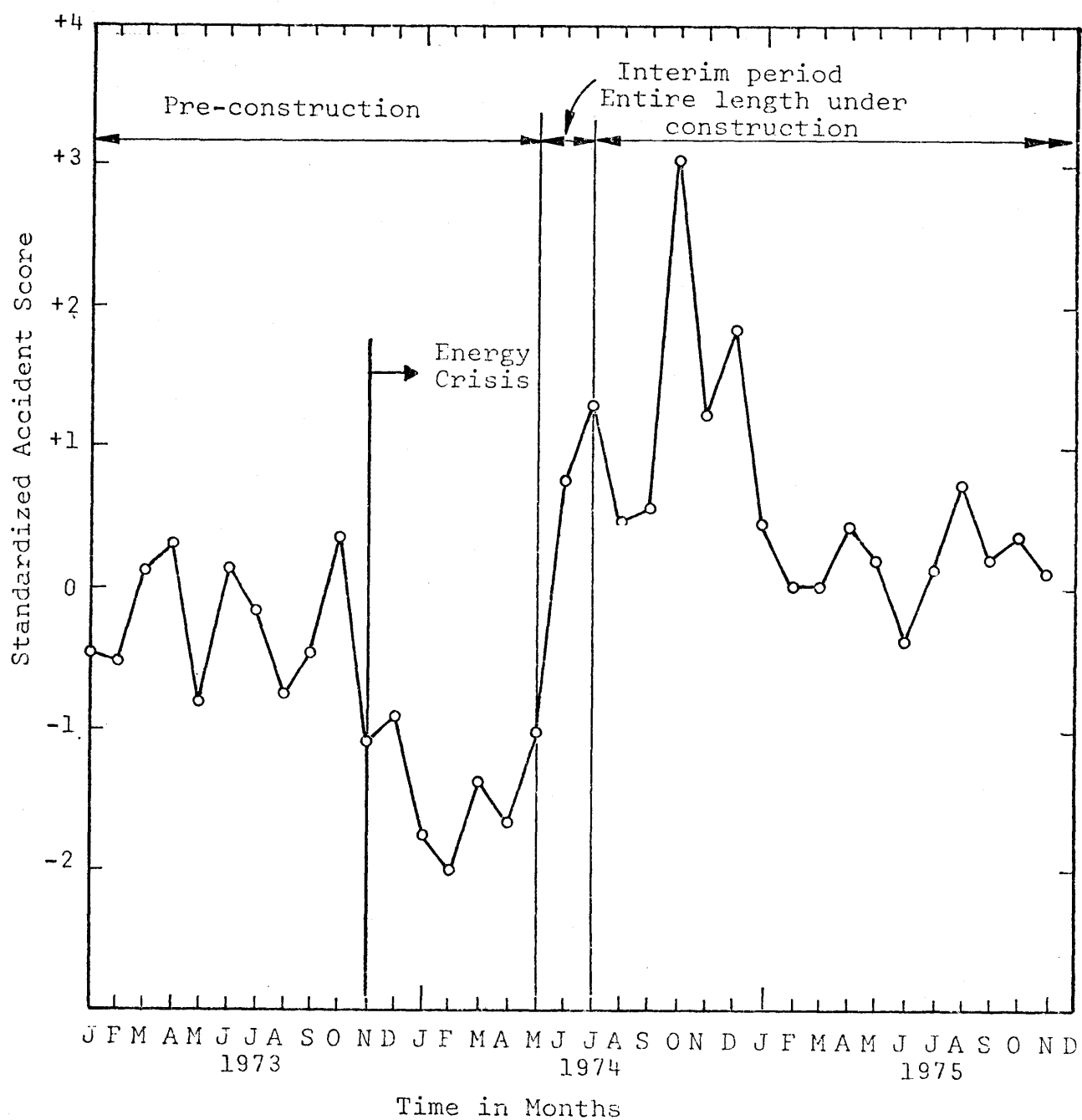


Figure 9. Standardized accident scores for construction contract No. 2

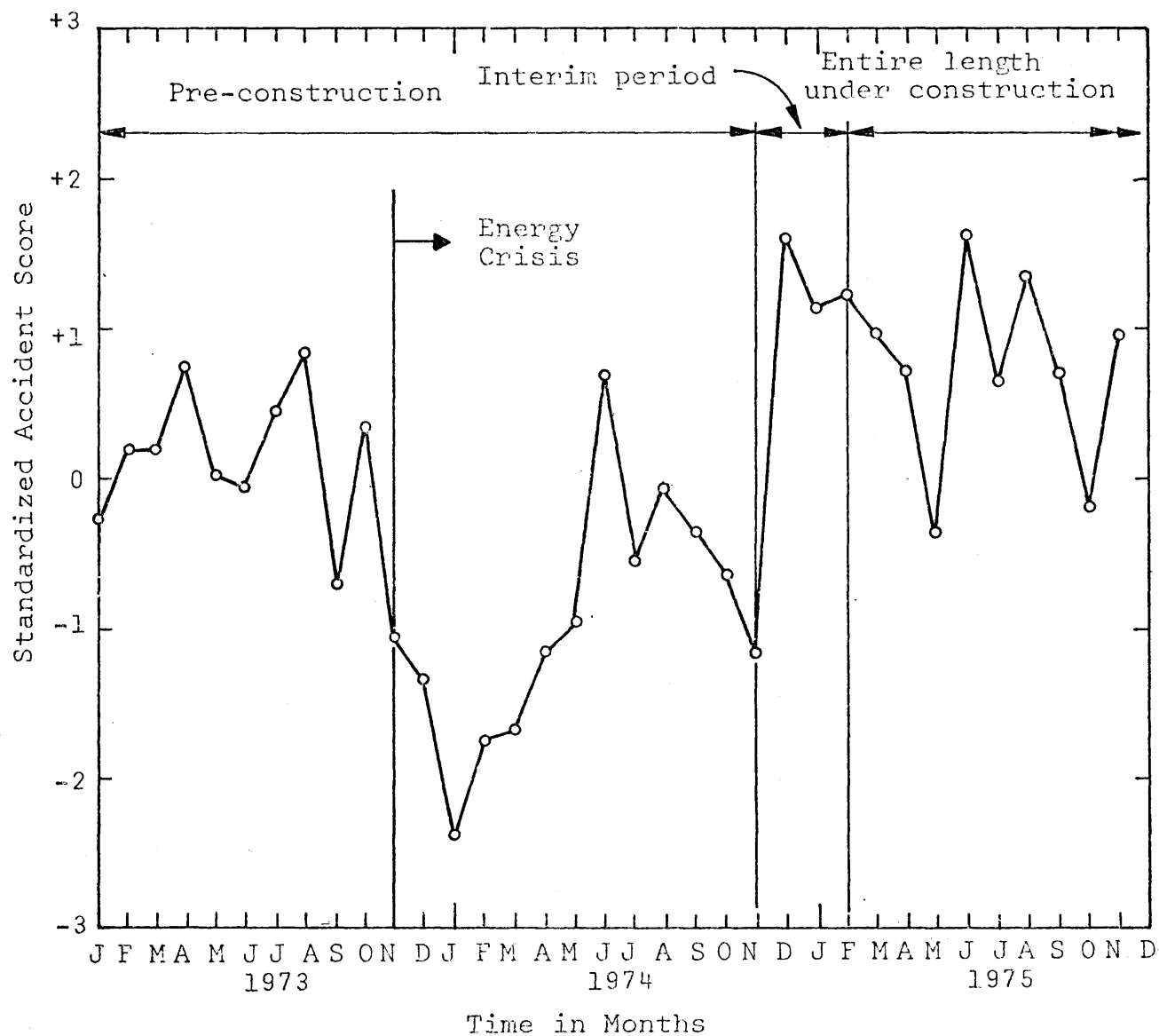


Figure 10. Standardized accident scores for construction contract No. 3.

However, instead of the scores increasing and remaining high after June as happened on contract No. 1 and 2, the scores for contract No. 3, on which work had not begun, declined and remained low until construction started. This finding would indicate that the construction activity was a major factor in changing the accident trends and that the energy crisis recovery trend played less of a role in the increase.

To separate the effects of the energy crisis from the effects of construction, it was necessary to identify a control roadway which was affected by the energy crisis but not by major construction. I-95 was chosen as the best available control roadway since it was similar to I-495 in geographic location and most roadway characteristics, with the exception of the major construction project. The traffic volume on I-95 is somewhat lower than that on I-495, but remained relatively constant at 31.3% of that on I-495 for the five-year period from 1970 through 1974. Note that this period includes the energy crisis.

The possibility was considered, however, that due to unavoidable differences in interstate roadways, the energy crisis could have affected various interstate roadways differently, and that I-95 would not be a viable control roadway for I-495. However, the effects of the energy shortage were quite consistent across Virginia's interstates and I-495 in Maryland. The total accident rate on the Maryland portion of I-495 dropped by 30.1% from 1973 to 1974 (from 138.70 to 96.96). Similar drops were found for I-95 in Virginia (30.6%, from 180 to 125), for I-86 (30.4%, from 79 to 53), and for the average for all Virginia interstate roadways excluding I-495 (32%, from 136 to 93). Thus, it appeared that I-95 was suitable for use in comparisons to remove the effects of the energy crisis from those of construction. The portion of I-95 from the Richmond-Petersburg Turnpike to the 14th Street Bridge in Washington, D. C. was utilized for this purpose.

A ratio was computed by dividing the number of accidents on I-495 during a given month by the number of accidents on I-95 during the same time. In using this ratio, it was hypothesized that if I-495 and I-95 were similar, at least before the construction period, the accident ratios between each segment of I-495 and I-95 should be constant or linear across time. As seen in Figure 11, this assumption proved to be true. The accident ratios for the years 1970-1973 inclusive were almost constant. However, in 1974 this relationship changed. At that time the ratio for the segment covered by construction contract No. 1, the segment which was under construction for the longest time period (11 months), exhibited the highest ratio, which indicated that accidents on that section of I-495 increased relative to those on I-95. Since the only major

change in either I-495 or I-95 roadways was the construction on I-495, this change in the accident ratio in 1974 must have been due to something involved with the construction on I-495. The segment covered by contract No. 2, the portion which was under construction for the second longest time period (8 months), exhibited the second highest ratio; while that covered by contract No. 3, which was under construction for only 2 months, had the lowest ratio.

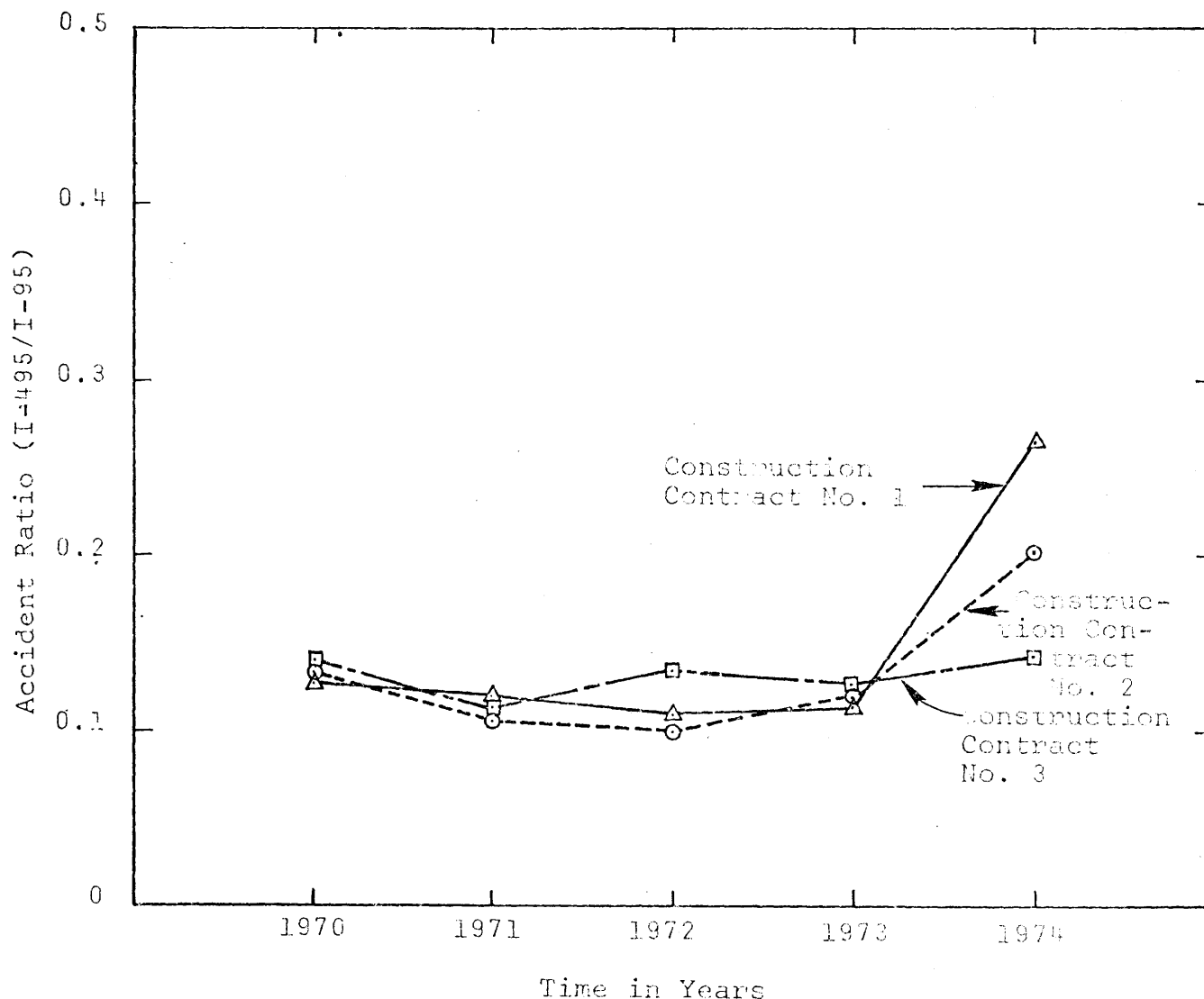


Figure 11. Ratio of the number of accidents on I-495 to those on I-95.

A more detailed analysis was then performed on a month by month basis using these accident ratios. Figure 12 depicts accident ratio trends for construction contract No. 1. For each of the study periods, a mean line representing all the points in that period was constructed using linear regression analysis. During the pre-construction phase on contract No. 1, the mean line was nearly constant at a ratio of 0.105, with a very small negative slope. During construction, however, this ratio increased 162% to 0.276, and the slope was then steeper and positive; that is, the number of accidents on I-495 increased across time relative to that for I-95. Note that the dispersion of data points during construction is greater than before construction. The dispersion of data points during construction may be an indication of the effects of the dynamic nature of construction activities on the traffic safety environment. A similar trend is shown in Figure 13 for contract No. 2. The mean line exhibited a negative slope at an accident ratio of about 0.114. During construction, this ratio rose 114% to 0.243. Finally, on the third construction contract (see Figure 14), the mean line exhibited a very small positive slope at an accident ratio of 0.135 prior to construction. During construction, this ratio rose 108% to 0.281, and the slope of the mean line became more strongly positive.

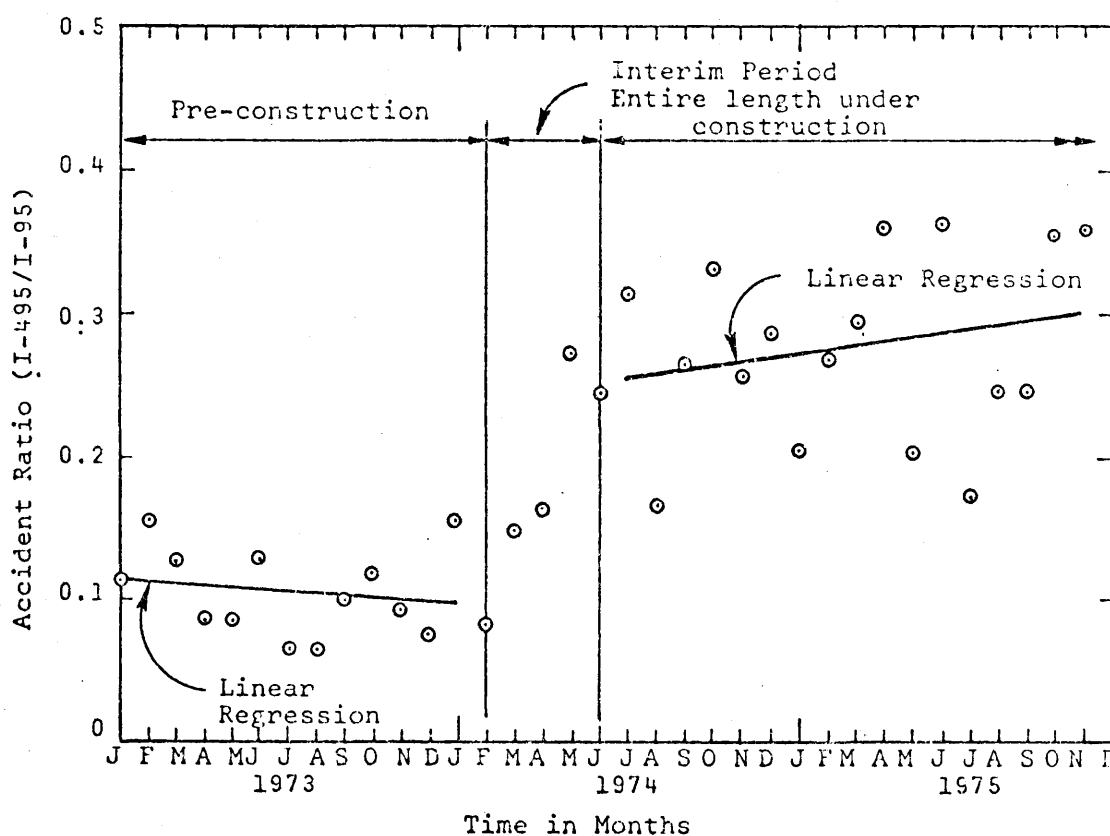


Figure 12. Accident ratio trend analysis for construction contract No. 1.

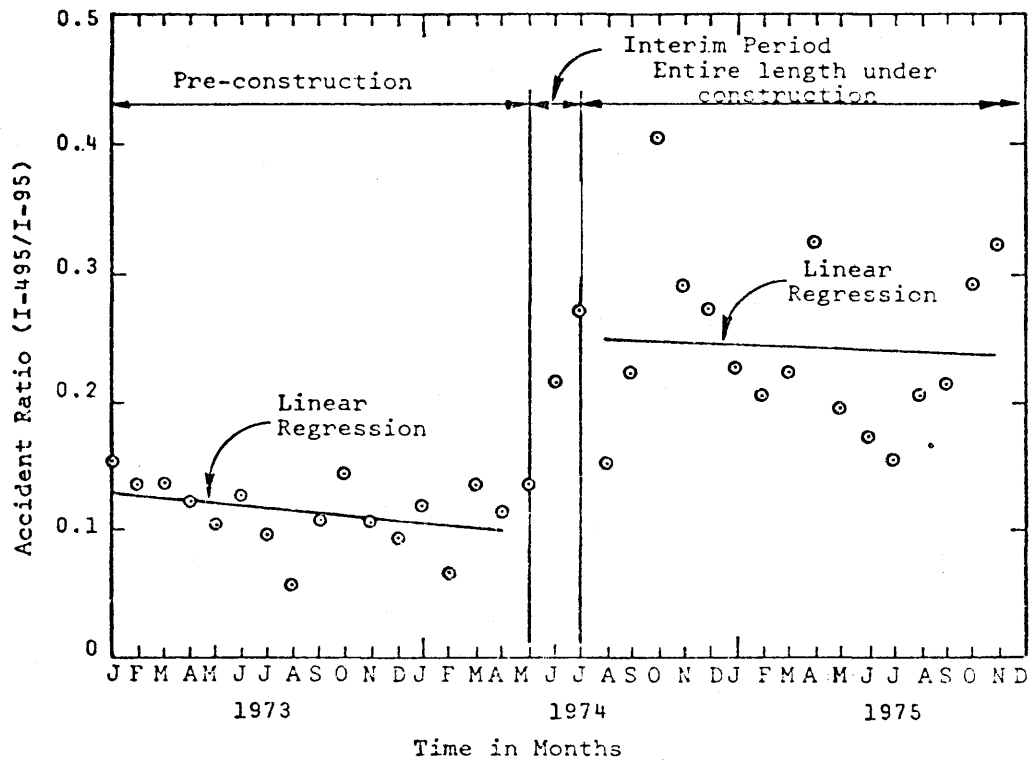


Figure 13. Accident ratio trend analysis for construction contract No. 2.

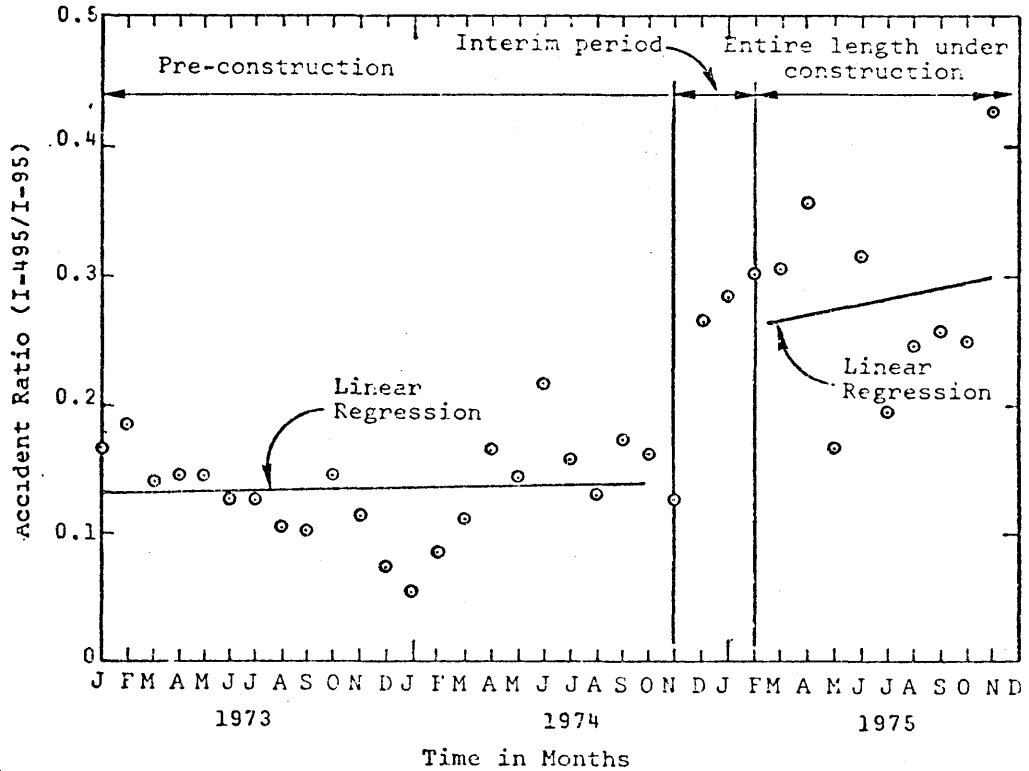


Figure 14. Accident ratio trend analysis for construction contract No. 3.

The combined ratio for the three road segments before construction was 0.121; during construction, it rose 119%* to 0.264. This increase is statistically significant at the 99% confidence level (F ratio). Thus, with the effects of the energy crisis accounted for, the accident experience on I-495 during construction increased by 119%.**

*A similar analysis was conducted utilizing corresponding months of the year in the two study periods to account for possible seasonal variation in the accident ratios. This analysis identified an increase in accident experience of 130%. However, this method of analysis reduced the number of data points available in contract No. 3, thus reducing the reliability of the results.

**There are two alternative lines of thought concerning the determination of the increase in the accident experience as it is affected by the change in the "property damage only" traffic accident reporting threshold in the Commonwealth from \$100 to \$250 effective January 1, 1975.

The first line of thought considers it appropriate to eliminate all "property damage only" reported accidents below \$250 from the two study periods in order to establish a common base. However, considering the traffic congestion associated with the overcrowded roadway and construction activities, an increase in the low dollar value property damage accidents relative to the total number of accidents is likely. Therefore, the elimination of the "property damage only" accidents below \$250 would remove a disproportionate number of accidents from the period during construction and thus lower the percentage change in the accident experience. This would also result in the removal of an accident category (below \$250) which may be characteristic of construction accidents. This line of thought would provide a percentage increase less than the 119% determined above.

The second line of thought proposes the concept that the change in the "property damage only" reporting threshold from \$100 to \$250 would cause a decrease in the number of accidents reported following the change in the reporting threshold. Thus, the number of accidents reported after January 1, 1975, would be lower than if the reporting threshold had remained unchanged and the percentage increase in the number of reported accidents would be lower than the percentage increase actually experienced. This line of thought would produce a percentage increase higher than the 119% determined above.

Changes in the Distribution of Accident
Characteristics on I-495

The second phase in the accident analysis was a detailed study of the accident experience on I-495 before and during construction to determine the effects of construction on the characteristics of traffic crashes and the role of the timber barricade in the crashes.

In this phase, FR-300 accident reports were compiled by accident date and location to provide a comparison of crash data for periods before and during the construction. Because of the staggered starting times for the three construction projects, different time periods were used for the road segments as shown in Table 2. The time periods during construction were not started until the entire length of the segment was under construction. The months before construction were matched to the same months during construction to avoid seasonal fluctuations. The selection of the study periods in this manner provided 7 months in the before and 7 months in the during construction periods for contract No. 1, 9 months for contract No. 2, and 4 months for contract No. 3. The entire extent of all three during construction periods is included in construction stage one. Thus, the barricades were located adjacent to the left lane of the traveled way in most areas. Some areas, such as those in which bridge widening took place, had barricades on both sides of the traveled way.

Table 2

Description of Study Periods and Contract
Segments on I-495

Construction Contract	Before Construction	During Construction
#1 Milepost 14.47-22.10	July 1973 - Jan. 1974	July 1974 - Jan. 1975
#2 Milepost 7.80-14.46	Aug. 1973 - April 1974	Aug. 1974 - April 1975
#3 Milepost 0-7.79	March 1974 - June 1974	March 1975 - June 1975

Effects of the I-495 Construction on Accidents

The general crash data for all contract segments were combined and are displayed in Table 3. Note that the increase in total number of traffic crashes calculated in this section of the report is 99% as compared to the 119% determined in the previous section.

Table 3
Crash Data Before and During Construction

Crash Severity	Before Construction		During Construction		Change In	
	Number	Rate*	Number	Rate*	Number	Rate
Fatal	2	0.5	8	2.3	300%	320%
Injury	100	27.2	130	36.8	30%	35%
Property Damage Only	331	90.1	724	205.3	119%	128%**
Total	433	117.8	862	244.4	99%	107%**

*100 Million Vehicle Miles of Travel

**Statistically Significant Change (F ratio, $p < .05$)

This difference is attributed to the effects of the energy crisis. In essence, the numbers of accidents in the before construction periods selected for this detailed analysis underestimated the effects of the energy crisis in reducing the numbers of accidents. However, the distribution of accident characteristics within each study period is considered to be an accurate reflection of the changes in the traffic safety environment.

The fatal crash rate in this detailed study increased by 320%, the injury rate by 35%, the property damage only rate by 128%, and the total crash rate by 107% from the periods before construction to the periods during construction. Note that the statistically significant increases in accident rates are in property damage only crashes and total crashes. The increases in the fatal crash rate are not statistically significant in spite of the size of the increase. In the case of the fatal crash rate, this finding can be explained by the comparative rarity of fatal crashes, which leads

to numbers too small to be dealt with by statistical tests. As for the injury crash rate, the increase of 35% was simply not large enough to rule out chance as the causal factor.

Table 4 displays the same crash data as in Table 3, with an indication of the distribution of crashes by severity. Prior to construction, property damage only crashes accounted for 76.4% of all crashes, injury crashes for 23.1%, and fatal crashes for 0.5%. During construction, property damage only crashes accounted for 84.0% of the total, injury crashes for 15.1% and fatal crashes for 0.9%. There was a significant shift in the distribution by crash severity away from injury accidents toward property damage only crashes (chi-square = 12.41, $p < .01$). This result is reinforced by the fact that 91.6% of the increase in crashes during construction consisted of property damage only crashes and only 7.0% was attributable to injury crashes. While the total number of accidents on I-495 more than doubled during construction, the only significant increase occurred in the least severe type of crash, the property damage only crash.

To provide added insight into the effects of construction on traffic crashes, a study of the type of collision was deemed warranted. As shown in Table 5, the type of collision most often occurring on I-495 before construction was the rear end collision (51.3% of the total), followed by sideswipe (19.4%), and fixed object (19.2%). During construction the type of collision most often noted was the fixed object collision (52.0% of the total), followed by rear end (28.2%), and sideswipe (15.6%). This shift to fixed object collisions during construction is further reinforced by noting that this category accounted for 85.1% of the increase in the number of incidences during construction, and only 4.9% were rear end. The shift in the distribution in the type of collisions before construction compared to that during construction was statistically significant (chi-square = 140.35, $p < .01$).

Further insight into the effects of construction on traffic crash characteristics can be gained by studying the changes in major factors in accident causation (see Table 6). Before construction, the major cause of accidents was driver inattention, 64.7% of all crashes, followed by driving under the influence (DUI) at 8.3%, and speeding at 7.9%. During construction, driver inattention continued to be the major cause of accidents at 48.1%; and it again was followed by DUI at 20.2% and speeding at 10.6%. This shift in the distribution in the major causative factor toward DUI during construction compared to before construction was statistically significant (chi-square = 58.00, $p < .05$). This finding is reinforced by the fact that 32.2% of the increase in accidents was attributed to DUI and 31.5% was attributed to driver inattention.

Note also that speeding accounted for 13.3% and "Phantom Vehicle"* accounted for 12.8% of the increase. The conclusion to be drawn from this information is that while driver inattention is the major causative factor in accidents, other indicators of driver impairments increased in significance as the cause of accidents during construction.

Table 4

Distribution of Crashes by Crash Severity

Crash Severity	Before Construction		During Construction		Difference	
	Number	Percent of Total	Number	Percent of Total	Number	Percent of Total
Fatal	2	0.5	8	0.9	6	1.4
Injury	100	23.1	130	15.1	30	7.0
Property Damage Only	331	76.4	724	84.0	393	91.6
Total	433	100.0	862	100.0	429	100.0

Table 5

Distribution of Crashes by Type of Collision

Type of Collision	Before Construction		During Construction		Difference	
	Number	Percent of Total	Number	Percent of Total	Number	Percent of Total
Rear End	222	51.3	243	28.2	21	4.9
Fixed Object	83	19.2	448	52.0	365	85.1
Sideswipe	84	19.4	135	15.6	51	11.9
Angle	12	2.7	16	1.9	4	0.9
All Others	32	7.4	20	2.3	-12	-2.8
Total	433	100.0	862	100.0	429	100.0

*A "Phantom Vehicle" accident is a traffic crash which was caused by the actions of another vehicle which left the scene of the accident. Contact between the vehicles is not required.

Table 6

Distribution of Crashes by Major Causative Factor

Major Factor	Before Construction		During Construction		Difference	
	Number	Percent of Total	Number	Percent of Total	Number	Percent of Total
Driver handicap (asleep, etc.)	13	3.0	32	3.7	19	4.4
DUI (driving under the influence)	36	8.3	174	20.2	138	32.2
Speeding	34	7.9	91	10.6	57	13.3
Inattention	280	64.7	415	48.1	135	31.5
Vehicle defective	17	3.9	31	3.6	14	3.3
Road slick	16	3.7	19	2.2	3	0.7
"Phantom Vehicle"	13	3.0	68	7.9	55	12.8
All others	24	5.5	32	3.7	8	1.8
Total	433	100.0	862	100.0	429	100.0

The pattern of accidents by time of day also changed during construction. Table 7 displays the accident distribution during five time periods and how this pattern shifted during construction. Before construction, midday (9 a.m. to 4 p.m.) accidents accounted for 32.3% of the total crashes; followed by evening crashes (6-12 p.m.) at 19.2%; afternoon peak (4-6 p.m.) at 17.8%; early morning (12 p.m. - 7 a.m.) at 15.7%; and morning peak (7-9 a.m.) at 15.0%. During construction midday accidents accounted for a slightly lower percentage (31.2%) of the total crashes; followed by evening accidents at 23.0%; and early morning accidents at 21.9%. Both peak volume time periods showed decreases, with the afternoon peak accounting for 13.7% of the total, and the morning peak 10.2%. All time periods showed increases in numbers of accidents, and the midday period accounted for 30.0% of the total increase. The early morning period accounted for 28.2% of the total, and the evening period accounted for 26.8%. The information presented in Table 7 indicates that the distribution of accidents by time of day shifted significantly from

peak volume time periods to the evening and early morning time periods. This shift was statistically significant (chi-square = 16.49, $p < .01$).

Table 7
Distribution of Crashes by Time of Day

Time Period	Before Construction		During Construction		Difference	
	Number	Percent of Total	Number	Percent of Total	Number	Percent of Total
Early morning (12 p.m. - 7 a.m.)	68	15.7	89	21.9	121	28.2
Morning peak (7 - 9 a.m.)	65	15.0	88	10.2	23	5.4
Midday (9 a.m. - 4 p.m.)	140	32.3	269	31.2	129	30.0
Afternoon peak (4 - 6 p.m.)	77	17.8	118	13.7	41	9.6
Evening (6 - 12 p.m.)	83	19.2	198	23.0	115	26.8
Total	433	100.0	862	100.0	429	100.0

Another accident characteristic which provides insight into the effects of construction on the traffic safety environment is the crash location. A survey of crashes on I-495 by location indicated a concentration at interchanges and bridge overpasses. Figure 15 is an accident histogram for construction project No. 2 for the study period before and during construction. The analysis of the other two projects produced similar results. For the study period before construction, four separate accident clusters, or peaks, are noted in the histogram. These clusters occurred in the area of mileposts 8, 10, 12, and 14, and they correspond to the interchanges for I-95, Route 620, Route 236 and Route 50, respectively. Clusters are also noted at these locations for the during construction period. The number of accidents during construction within these interchanges was approximately twice the number of accidents before construction. The data presented in Figure 15 indicate that more accidents per mile occurred within interchanges than within any other section of roadway, independent of construction.

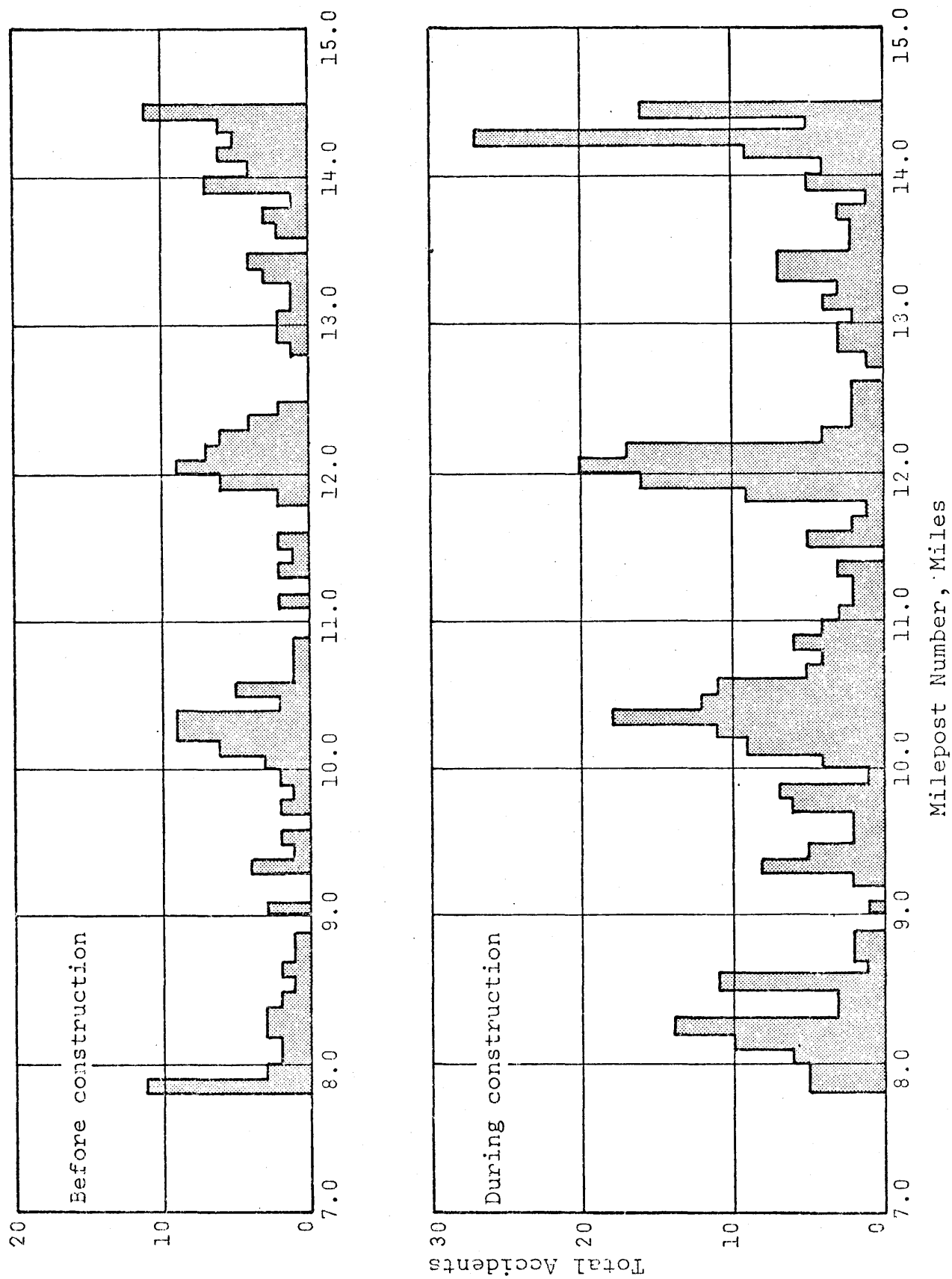


Figure 15. Accident histogram for construction project No. 2.

Further analysis of the data presented in Figure 15 revealed that there were a number of clusters of accidents during construction which had no counterpart in the before construction period. The most prominent of these clusters was at milepost 8.2, which is the Backlick Road overpass. At this site, the bridge overpass was being widened on the median side, so traffic was shifted to the right lane of the existing roadway and the right shoulder. The 0.30-mile section of roadway adjacent to the Backlick Road overpass had 4.3 times more accidents during construction than before construction. A closer examination of the accident data for the area of the Backlick Road overpass showed that the traffic accidents were not evenly distributed. Of the 24 accidents occurring within 0.10 mile of the overpass during construction, 17 (68%) occurred within 0.03 mile (160') of the bridge. These data indicate that the construction environment at Backlick Road during the study period was a contributing factor in the increase in the number of accidents.

Role of the Timber Barricade in Accidents on I-495

The primary objective of the research reported under this subheading was to identify and evaluate the role of the timber barricade in accidents during construction on I-495. The general crash data for the during construction period indicate that the timber barricade was involved in 52.5% (453 of 862) of all the traffic crashes. In regard to crash severity, the timber barricade was involved in 50.0% (4 of 8) of the fatal crashes, 45.4% (59 of 130) of the injury crashes, and 53.9% (390 of 724) of the property damage only crashes. Of those vehicles contacting the timber barricade, 90.6% were traveling in the lane adjacent to the barricade, 3.3% had changed lanes just prior to the crash, and 6.1% were not traveling in the lane adjacent to the barricade. These figures indicate that possibly more than 90% of the vehicles contacting the timber barricade did so at an impact angle of less than 10° . Also 97.8% of the vehicles contacting the timber barricades did so on the left side of the traveled way. This latter finding is consistent with the fact that the study periods fell wholly within construction stage one in which most of the barricades were located adjacent to the left lane of travel. An average of 7 barricades were damaged or destroyed for each accident in which the barricade was involved. If the frequency of accident occurrence and the number of barricades damaged per accident continues at the same rate, some 20 to 25 miles of timber barricades will be damaged or destroyed during the I-495 widening project.

The distribution of crashes by crash severity revealed that 86.1% of the crashes involving the timber barricade were property damage only crashes, 13.0% were injury crashes, and 0.9% were fatal crashes (see Table 8). The distribution of crashes not involving the timber barricade shows similar results; 81.7% were property damage only crashes, 17.3% were injury crashes, and 1.0% were fatal crashes. The difference in distribution was not statistically significant (chi-square = 3.18, N.S.). Thus, the involvement of the timber barricade in crashes during construction does not appear to have been associated with the severity of the crash.

Table 8

Distribution of Crashes During Construction by Crash Severity

Crash Severity	Crashes Involving Barricade		Crashes not Involving Barricade	
	Number	Percent of Total	Number	Percent of Total
Fatal	4	0.9	4	1.0
Injury	59	13.0	71	17.3
Property Damage Only	390	86.1	334	81.7
Total	453	100.0	409	100.0

An alternate method of defining the severity of a crash is to do so in terms of the amount of property damage it causes. The total amount of property damage increased 181%, from \$417,954 in the before period to \$1,175,476 in the period during construction. On a per accident basis, the average amount of property damage increased 41%, from \$965 in the before period to \$1,364 in the period during construction. However, 52.5% of the accidents during construction involved vehicle contact with the timber barricade, thus the damage figure included the cost to replace the damaged timber barricade. The cost per accident in which the timber barricade was involved was \$1,836. Of this amount, \$861 was the cost to repair the timber barricades, and the remainder of \$975 was almost identical to the \$965 per accident for the before construction period. The during construction cost per accident in which the timber barricade was not involved was \$840, or 13% lower than the average before construction cost per

accident. The 13% difference may represent costs to replace non-vehicular items damaged in the before construction period. Thus, for crash severity measured in terms of the amount of property damage, the costs per accident exclusive of the replacement cost of the barricade were similar for the before and during construction periods.

There was a difference in the distribution of crashes by type of collision between those accidents involving the barricade and those not involving it. The data in Table 9 show that 87.4% of the total crashes involving the timber barricade were of the fixed object type, 8.9% were categorized as sideswipe, and only 2.4% as rear end. However, for those during construction accidents in which the timber barricade was not involved, 56.7% were rear end accidents, 23.2% were sideswipe, and 12.7% were fixed object (other than the timber barricade). The difference in the distributions of traffic crashes between those involving the timber barricade and those not involving it by type of collision was statistically significant (chi-square = 502.61, $p < .01$). Thus, the accidents involving the timber barricade were associated with a high incidence of fixed object accidents (most of the fixed objects being the timber barricade), and most of the non-barricade involved accidents were associated with rear end and sideswipe crashes.

A study of the distribution of crashes during construction by major causative factor was conducted to gain an insight into the possible association between driver impairments and timber barricade involvement. It can be seen in Table 10 that 31.4% of the crashes involving the timber barricade were attributed to DUI, 24.9% were attributed to driver inattention, 13.9% to a "Phantom Vehicle," and 13.7% to speeding.

Table 9
Distribution of Crashes During Construction
by Type of Collision

Type of Collision	Crashes Involving Barricade		Crashes Not Involving Barricade	
	Number	Percent	Number	Percent
Rear end	11	2.4	232	56.7
Fixed object	396	87.4	52	12.7
Sideswipe	40	8.9	95	23.2
Angle	3	0.7	13	3.2
All other	3	0.7	17	4.2
Total	453	100.0	409	100.0

Table 10

Distribution of Crashes During Construction
by Major Causative Factor

Major Factor	Crashes Involving Barricade		Crashes Not Involving Barricade	
	Number	Percent	Number	Percent
Driver handicap (asleep, etc.)	26	5.7	6	1.5
DUI (driving under the influence)	142	31.4	32	7.9
Speeding	62	13.7	29	7.1
Inattention	113	24.9	302	73.8
Vehicle defective	21	4.6	10	2.4
Road slick	7	1.5	12	2.9
"Phantom Vehicle"	63	13.9	5	1.2
All others	19	4.3	13	3.2
Total	453	100.0	409	100.0

For those during construction accidents in which the timber barricade was not involved, 73.8% were attributed to driver inattention and 7.9% to DUI. The difference in the distributions of traffic crashes by the major causative factor between those involving the timber barricade and those not involving the barricade was statistically significant (chi-square = 234.26, $p < .01$). Thus it appears that the timber barricade accidents were associated with driver impairments. Note that the location of the timber barricades adjacent to the traveled roadway may have been a prime factor in the increase in the number of accidents associated with driver impairments. Prior to construction, the movement of a vehicle off the traveled roadway could have been corrected without resulting in a crash. Thus, the location of the timber barricade and not its physical characteristics may have been a contributing factor to the overall increase in the number of accidents during construction.

There was a difference in the distribution of crashes by time of day between the accidents involving the barricades and those not involving it. Table 11 shows that 32.7% of the crashes involving the timber barricade were in the early morning, 25.8% were in the evening, 24.5% in the midday, 9.5% in the afternoon peak, and 7.5% in the morning peak. For those accidents in which the timber barricade was not involved, 38.6% were in the midday, 19.8% in the evening, 18.3% in the afternoon peak, 13.2% in the morning peak, and 10.1% in the early morning. The difference in these distributions was statistically significant (chi-square = 86.54, $p < .01$). The data in Table 11 indicate that the incidence of barricade involved accidents was consistently more prominent in the off peak hours; they were highly associated with the early morning (12 p.m. - 7 a.m.) and evening (6 - 12 p.m.) hours.

Table 11

Distribution of Crashes During Construction by Time of Day

Time of Day	Crashes Involving Barricade		Crashes Not Involving Barricade	
	Number	Percent	Number	Percent
Early morning (12 p.m. - 7 a.m.)	148	32.7	41	10.1
Morning peak (7 - 9 a.m.)	34	7.5	54	13.2
Midday (9 a.m. - 4 p.m.)	111	24.5	158	38.6
Afternoon peak (4 - 6 p.m.)	43	9.5	75	18.3
Evening (6 - 12 p.m.)	117	25.8	81	19.8
Total	453	100.0	409	100.0

The effectiveness of the timber barricade in keeping vehicular traffic out of the work area was also studied. Table 12 provides accident data on the extent of vehicle contact with the timber barricade by type of vehicle involved. The reader is again reminded that these data include only reported accidents. There

is a possibility that numerous vehicles contacted the barricade and were driven away from the accident scene, but there are no data to indicate the numbers of vehicles that might have been involved. Column (1) includes those vehicles which were arrested/redirected by the timber barricade without mounting or penetrating it; column (3) includes those vehicles on which one or more but not all the wheels penetrated the barricade; and column (5) includes those which completely penetrated it. For all vehicles striking the barricade, 45.3% penetrated it; 28.2% straddled it; and 26.5% were arrested/redirected. Since 73.5% of those vehicles contacting the timber barricade straddled or penetrated it, the apparent conclusion is that the barricade was not effective in keeping vehicular traffic out of the work area.

Table 12

Extent of Vehicle Contact With Timber Barricade

Vehicle Type	Arrested/Redirected		Straddled		Penetrated		Total Involved	
	Number (1)	Percent By Vehicle Type (2)	Number (3)	Percent By Vehicle Type (4)	Number (5)	Percent By Vehicle Type (6)	Number (7)	Percent Of Total (8)
Car	103	27.6	99	26.6	170	45.7	372	81.4
Truck	15	20.5	25	34.2	33	45.2	73	16.0
Tractor Trailer	2	22.2	4	44.4	3	33.3	9	2.0
All other	1	33.3	1	33.3	1	33.3	3	0.6
Total	121	26.5	129	28.2	207	45.3	457	100.0

Traffic volume counts taken on I-495 during construction indicated that 81% to 85% of the traffic volume were cars, 12% to 13% were trucks, and 3% to 7% were tractor trailers. Note that 81.4% of the vehicles involved in barricade crashes were cars, 16.0% were trucks, and 2.0% were tractor trailers. This information indicates that the percentage of vehicle involvement with timber barricades by vehicle type is approximately equivalent to its percentage of the vehicle mix.

As regards the maintenance of proper alignment of the barricade during construction, Table 13 indicates the number of accidents by pre-crash position of the barricade. There were only 3 accidents involving barricades that had been blown or knocked over and 16 accidents involving barricades that had been knocked out of alignment. In 95.8% of all accidents involving the timber barricade, it was correctly positioned.

Table 13

Number of Accidents by Pre-Crash Barricade Position

Barricade Position	Barricade Accidents		Percent of all Accidents
	Number	Percent	
Correctly positioned	434	95.8	50.3
Horizontal (knocked down)	3	0.7	0.3
Out of line (protruding into traffic lane)	16	3.5	1.9
Total	453	100.0	52.5

Construction Zone Crash Studies

A review of the literature on crash analysis in construction zones revealed that the subject has often been superficially mentioned but has very seldom been studied. In most instances, the rise in the number of crashes and the crash rates is taken as a known and expected result of roadway construction. As an example, the Highway Safety Program Manual, Vol. 12, "Highway Design, Construction, and Maintenance," states,

Sites where construction or maintenance is in progress can be very hazardous. Serious safety problems of traffic movement occur when traffic must move through or around road construction and maintenance operations. Because of the temporary nature of these operations which rarely follow the normal pattern of operations, the possibility of an accident is much greater than under normal highway conditions.(34)

While most references to construction traffic accidents are similar to the one cited above, one study was found which attempted to analyze them. This was a 1972 California study.(35) The report on the study presents a comparison of two accident analyses in construction zones. The first analysis included 1965 data for accidents occurring before and during construction at 10 sites. The results are presented in Table 14, where it can be seen that the total accident rate increased 21.4% from pre-construction to the construction period.

Table 14

Construction Zone Accidents — 1965 California Study

Crash Severity	Before Construction		During Construction		Percent Change in Rate
	Number	Rate*	Number	Rate*	
Fatal	11	3.95	28	9.18	132.4
Injury	251	90.2	334	109.5	21.1
Property Damage Only	297	106.7	383	125.5	17.8
Total	559	200.9	745	244.2	21.4

*100 Million Vehicle Miles of Travel

Source: California Division of Highways.

After initiation of safety procedures in construction zones, the second analysis was performed. It included 1970 data for 31 construction sites. The results of this analysis, presented in Table 15, show that the total accident rate increased by 6.8% from the pre-construction to the construction period.

Table 15

Construction Zone Accidents — 1970 California Study

Crash Severity	Before Construction		During Construction		Percent Change in Rate
	Number	Rate*	Number	Rate*	
Fatal	75	3.13	83	3.18	1.6
Injury	1,645	68.7	1,954	75.0	8.7
Property Damage Only	2,522	105.4	2,890	110.9	5.7
Total	4,242	177.2	4,927	189.1	6.8

*100 Million Vehicle Miles of Travel

Source: California Division of Highways.

The report concluded:

It can now be shown that increased accident rates during construction need not occur. The accident rate during construction can be held very nearly to the rate experienced prior to beginning construction.

In July 1965, this Department published a progress report which indicated that a safety problem existed in construction zones. At that time California was experiencing approximately 1340 accidents yearly as a result of construction zones.

During the years following 1965, many new principles for handling traffic in a construction zone were put into practice in California.

In 1970 accident rates in construction zones were studied to determine the validity of these new practices. The results of this study were most gratifying. The accident rates of the construction period went up only slightly from the rates experienced before construction. California had taken a major step toward making the construction zones safer for the traveling public. (36)

While the results of the 1970 California study appear to show an improvement in safety conditions for the traveling public, there is some question as to the comparability of the 1965 and 1970 data. For example, the 1965 analysis was performed on data from 10 construction projects which involved adding lanes to existing two- and four-lane roadways. In contrast, the 1970 analysis was on data from 31 construction projects which consisted of adding lanes to existing two-four-five- and six-lane roadways and resurfacing two roadways. Furthermore, the results of the study do not specifically attribute the reduction in the accident rates to the "new practices" or to any other events which might have taken place during the five-year period between the two analyses. Thus, while the results are indicative of an improved traffic safety environment, the comparability of the two analyses and the specific cause of the improvement have not been established.

A more specific and germane question is whether the results of the California study can be validly compared to the accident analysis for I-495. The answer requires a close scrutiny of the data from both analyses.

An examination of Table 3 shows that the fatal crash rate for I-495 was 0.5 before construction and 2.3 during construction. These rates are both lower than the 3.95 and 3.13 rates in the before construction periods in the California study. A similar comparison can be made of the injury crash rates; the I-495 injury rate increased from 27.2 in the before period to 36.8 in the during construction period. The injury rates before construction for the California study were 90.2 and 68.7. These data indicate the dissimilarities in the roadways studied, and in terms of being involved in a fatal or injury crash, one could argue that I-495 was safer to travel during construction than the California roadways were before construction.

Thus, while the 1970 California research attributed the lower increases in accident rates during construction to improved safety practices, the construction zones used in the study do not compare closely to I-495. This fact, however, does not discount the possibility that the use of such safety practices on I-495 would reduce the number of accidents associated with that construction.

BARRICADE AND BARRIER FEASIBILITY

This section of the report deals with the characteristics of the timber barricade and the precast concrete traffic barrier (PCTB) for usage as temporary traffic control devices in highway construction areas. The characteristics of each device are evaluated in terms of its technical, operational, and economic feasibility. Technical feasibility refers to the ability of a device to perform a particular task, operational feasibility refers to the successful use of a device in performing its intended task, and economic feasibility refers to the dollar value in benefits achieved by utilizing a particular device.

Technical Feasibility

The Timber Barricade

The purpose of the timber barricade is

... to create a barrier between the construction work area and the traffic area used by the traveling public, and provide a large measure of safety for both segments.⁽³⁷⁾

The ability of the timber barricade to perform this safety task can best be evaluated through crash tests and accident data analyses. To date there have been no crash tests conducted with the timber barricade and this report contains the only accident data analysis. Southwest Research Institute is scheduled to perform crash tests with the timber barricade for the FHWA in the near future.

Even though no crash tests have been conducted with the timber barricade, the technical feasibility can be evaluated in terms of its component parts: the 10" x 10" timber base, and the posts and slats. The 10" x 10" timber base is classified as a nonmountable "barrier curb" (historically the basic criterion for classification as a "barrier curb" has been a curb height greater than 6"). The

posts and slats in the upper portion of the timber barricade are intended mainly for delineation of the road edge. However, upon impact a vehicle which penetrates the barricade will shear off the posts, thus dissipating some of the impacting vehicle's kinetic energy. The primary responsibility for restraining or redirecting an errant vehicle must therefore lie with the 10" x 10" base.

The initial testing of curb configurations and their effects on impacting vehicles was conducted by the California Division of Highways in 1953.⁽³⁸⁾ One design tested was approximately 9" high and had a 0° batter,* a vertical face. This design closely resembles the 10" vertical faced curb of the timber barricade, although the tested curb was made of concrete. Test vehicles were driven by professional drivers into the curb at various speeds and angles of approach. The curb was not permanently fixed to the pavement; its mass kept it in place. After contacting the curb, the driver attempted to safely maneuver the vehicle back into the roadway. In the tests, the vertical curb served "reasonably" well as a barrier, but its performance was not consistent. There was a "tendency for the car to climb the curb." (Climb refers to the vertical rise of the tire up the face of the curb, not to actual mounting of the curb.) This curb inflicted severe damage on the wheel rims, which had to be repaired after each test, because the tire deformed on impact and allowed the rim to bite into the curb. The contact with the curb was also responsible for the vehicle's tendency to climb up the curb. Curbs with a higher batter were noted to perform much better than the vertical faced curb in preventing climb because they provided less rim contact. Actual curb mounting occurred at 20 mph and an impact angle of 15° with the 9" vertical curb. No tests were conducted with a 10" vertical faced curb; however, tests of other curb designs at both 9" and 10" heights revealed that the 10" curb was slightly more effective at preventing mounting.

During the California testing in 1953, it was also found that impact with the vertical curb caused a sharp jolt, or shock, to the vehicle's steering mechanism. The shock appeared to disorient the driver and make it difficult for him to control his vehicle. Curbs with a sloping face were found to produce less shock and the driver was observed to use smooth counteraction to redirect the automobile.

*The batter is the angle of slope of the curb face from vertical.

In later California testing of curbs with concrete and steel facings, it was found that a major contributor to the climbing and mounting tendency was the coefficient of friction of the curb material.⁽³⁹⁾ The findings showed that the higher the coefficient, the more pronounced was the climbing tendency. Thus, the fact that timber has a high friction coefficient may be a contributing factor in the mounting of the timber barricade.

Further testing of curb configurations and their effects on impacting vehicles was conducted at the Texas Transportation Institute (TTI), and the findings were published in NCHRP Report 150 in 1974. The researchers noted that

the most promising highway barrier concepts are the New Jersey safety shape, the General Motors Proving Ground bridge parapet design, and the California Type 20 bridge barrier. Although none of these designs fits the curb classification, it is clear from the present study and previous work that a curb height of 32 in. is required to achieve vehicle re-direction.⁽⁴⁰⁾

The findings of the TTI study and the California studies indicate that the timber barricade is not designed to redirect errant vehicles. Thus, if the timber barricade is to achieve its safety task it must contain the impacting vehicle within the barricade system. From the accident analysis on I-495, it was found that 45.3% of the vehicles that contacted the timber barricade penetrated it. Therefore, under the prevailing conditions on I-495, the timber barricade did not perform its safety task.

There are, however, three facts concerning the crash performance of the timber barricades on I-495 that should be noted. First, there was a significant shift in the distribution of crashes by crash severity away from injury accidents toward property damage only crashes during construction. Second, there was an average of seven barricades damaged or destroyed in each accident involving the timber barricade, which indicates that approximately 70' of timber barricades were expended while the vehicle decelerated from the impacting speed to zero miles per hour. The cushioning effect provided by the seven barricades contributed to the dissipation of kinetic energy and thus reduced the potential injury to occupants. Third, of the four fatal crashes involving vehicle contact with the timber barricade, two resulted in the vehicle catching fire. The significance of this fact cannot be evaluated with the sample size used in this study, but should be evaluated in any future studies on the performance of the timber barricade.

The PCTB

The PCTB is a positive portable barrier designed to restrain and redirect impacting vehicles. The PCTB's use as a temporary barrier followed from the successful use of the concrete median barrier (CMB) in safely restraining and redirecting impacting vehicles. The term CMB as used here refers to a permanent installation of the concrete median barrier on a completed roadway. The ability of the PCTB to safely restrain and redirect impacting vehicles lies in the design characteristics of its forerunner, the CMB.

CMB projects in Louisiana (1942) and in California (1946) provided the initial insight into the performance capabilities of the CMB. Based on these experiences, New Jersey highway officials developed a specially contoured profile to give vehicle redirection capabilities to the concrete barrier. The earliest New Jersey designed barriers (1955) were only 18" high, but when it was found that vehicles climbed these barriers the height was increased to the present 32". The width and thickness were made sufficient to prevent the barrier from fracturing or overturning when impacted by a vehicle.⁽⁴¹⁾

Today's standard New Jersey barrier, often referred to as the "Safety Shaped" barrier, is 32" high and has a 24" base with a 6" top width as shown in Figure 16. It incorporates a 55° batter curb face with an upper portion which is almost vertical.

The theory of the CMB performance in the field is relatively simple. When a vehicle strikes the barrier at angles less than 15°, the initial contact is between the 3" vertical curb and the vehicle tire. This contact deforms the tire and tends to slow the vehicle. The front wheel then climbs up the 55° batter curb face, and the vehicle body on the impact side lifts from the roadway. Through this action, energy is absorbed by the barrier, and the driver may be able to regain control of his vehicle and guide it back into the roadway. If the impact speed is high and the impact angle is more than a few degrees, the vehicle may not be controllable immediately following impact but may continue to climb up the sloped face until the upper (near-vertical) portion of the barrier is reached. Contact in this area creates a strong counterforce on the vehicle wheel, and redirects the vehicle back into the roadway.⁽⁴²⁾

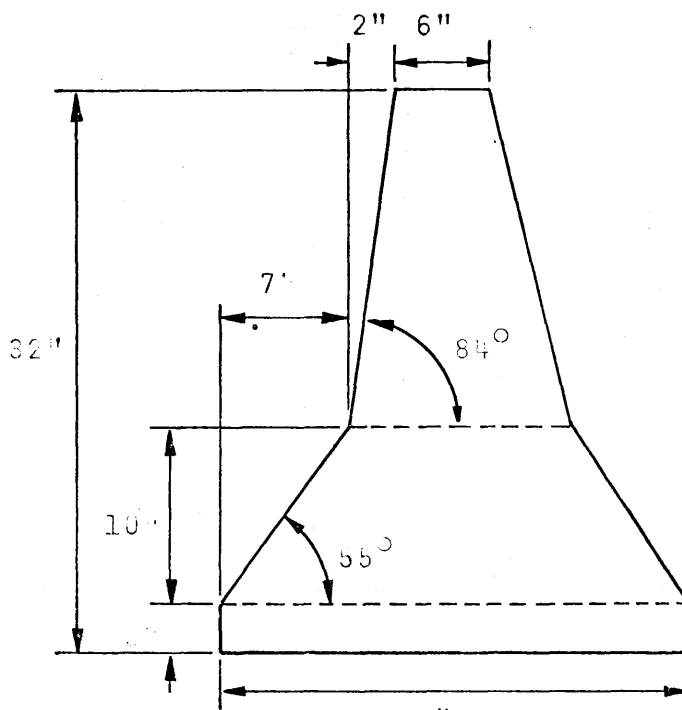


Figure 16. Profile of the New Jersey "Safety Shaped" concrete median barrier.

Crash tests have been performed in California⁽⁴³⁾ and Texas^(44,45) to determine the strength of the CMB's and to evaluate their effectiveness in redirecting impacting vehicles. The crash tests were performed with the CMB's permanently fixed to the roadway. The principal results of these studies indicate that the CMB is effective in restraining vehicles at all speeds and impact angles, and safely redirecting an impacting vehicle at high speeds in combination with impact angles of less than 15° . At angles of 15° and greater, the impact with the CMB becomes a fixed object accident rather than a sideswipe accident.

Concern had also been expressed over the danger that a vehicle might overturn after striking the barrier. Crash tests showed that rollover was not a problem with the standard size vehicle. However, the subcompact size vehicle appeared to present a different problem due to its light weight and short wheelbase. Crash tests were conducted at Southwest Research Institute to determine if the subcompact size vehicle would experience rollover problems.⁽⁴⁶⁾ The tests were conducted with the standard New Jersey concrete barrier design and with various other designs. The test results indicated that all designs performed well at restraining the vehicle from penetrating the barrier and most did not cause major damage to the vehicle on impact. However, one design did cause rollover problems at 15° and 25° impact angles. Generally, those designs which incorporated a low batter curb height were found to be least likely to cause rollover of subcompact cars.

Crash tests with the CMB have demonstrated the performance characteristics and limitations of the barrier in safely re-directing impacting vehicles, and thus providing an indication of the capabilities of the PCTB. However, crash tests and rigorous field evaluations are required to evaluate the performance characteristics of the PCTB, especially in the areas of redirected vehicle recovery zone limitations, end connection strengths, versatility in moving the units, protection of exposed ends from errant vehicles, lateral displacement on impact, support surface bearing and friction requirements, warrants for its use with respect to fixed objects, excavations, and men working, and its effects on the psychological and driving characteristics of the motoring public.

Operational Feasibility

The Timber Barricade

The timber barricade is relatively simple to construct. The timber base is rough hewn, and the rail structure bolted to it is made up of standard sized lumber available at any lumber yard. The painting takes only minutes. The 10' barricade weighs between 150-200 pounds and can be handled by two men, although the usual practice on the I-495 project was to move it with a forklift or crane. The structures are easily transported to the work site and installation is rapid; several thousand feet of the barricade can be placed per work day.

Maintenance has been a problem. The white painted barricades rapidly collect road grime and this must be removed quite often if the units are to serve effectively as delineators. The reflective devices and lights attached to the structures at 75' intervals dull rapidly and must be cleaned. The timber barricades are severely damaged when vehicles strike and mount the curb. In the accident study period, 3,199 barricades were damaged by vehicles. The damaged barricades had to be quickly detected, the debris cleaned from the roadway, and new units placed in the system. The barrier system must be monitored around-the-clock to make certain that the units are in proper position.

Given the space limitations imposed by the construction plans for the I-495 project, the timber barricade is well suited in size to fit the need. Its total width is 16"; 10" for the timber curb plus 6" for the 2" x 6" upright slat support. The timber width plus an 8" spacing behind the barricade yields a minimum operational width of 24", leaving 22' of space for the traveled roadway of the preexisting 24' roadway.

The PCTB

In the past few years, many states (including Florida, Oregon, Idaho, Washington, North Carolina and California) have used PCTB's for temporary traffic control devices during construction, and have found them to be reasonably portable and to perform satisfactorily with little maintenance. However, no published or informal studies have been found which include accident statistics relating to the use of PCTB's. The satisfactory performance cited above is based on the opinion of highway engineers and construction personnel, which may be nurtured by the lack of user complaints.

The process for manufacturing PCTB's requires about two man-hours of direct labor for each unit. Two units can be cast per day in each steel form. The finished units can be stored indefinitely in an open area unprotected from the elements. Eight 10'-12' units can be carried per truck to the job site, where a truck-mounted crane is required to unload and place the two-ton barriers on the road edge. On a project in North Carolina an average of 1,650' of PCTB's were placed each day by use of a truck-mounted crane.⁽⁴⁷⁾ Various types of end connections have been used, including a tongue and groove (male-female) design, various I-bolt and pin connections, and a wire rope and lock connection through holes in the base of the units. The length of the PCTB unit provides sufficient flexibility to allow uniform alignment.

A concern during construction is the encroachment of construction operations onto the traffic lanes. Narrow, high volume roads can be hazardous, especially when traffic speeds exceed those determined for the prevailing conditions as was the case on I-495. In view of the 24" wide base of the PCTB as contrasted with the narrower 16" base of the timber barricade, the latter may have an advantage in this area. Another concern is for the continuity of any system utilizing PCTB's. An opening in the system would create a fixed object hazard. The use of a few selected openings in the PCTB system with appropriate attenuation sections or cushioning devices should minimize this hazard.

The PCTB is 24" wide and may need to be placed 8" from any excavation to allow room for construction equipment to work adjacent to the barrier. Thus, the effective width of the PCTB is about 32", and if it had been used on the I-495 project, an additional 8" of roadway width would have been sacrificed. In most areas the road width would have been reduced to less than 22' for the two traffic lanes.

Economic Feasibility

The Timber Barricade

Timber barricades have been used in Virginia on many construction projects in recent years. Their costs have varied, with the \$7 per linear foot for furnishing, maintaining, and relocating timber barricades on a 1973 project (#195-127-101-C502) in the Sandston area being representative of most costs during that period. This price does not include the cost of furnishing and maintaining lights on the barricades. These lights were rented at a rate of 28 cents per light per day.

More recent experience in Virginia includes a project in the Richmond area. This project is the widening of the Richmond-Petersburg Turnpike (I-95), where an additional lane is being added to the present two lanes in each direction. One of the major contractors on this project quoted a price of \$7.50 per linear foot for furnishing and maintaining the barricades, excluding light costs, and an additional \$1.50 per foot for relocating them.

On the I-495 project, the cost for barricades was substantially higher than the prices found on the projects previously cited. The total I-495 project consists of three contracts. The contract prices for furnishing and maintaining the barricades were \$15 per linear foot on contract No. 1, \$16 per linear foot on contract No. 2, and \$9.70 per linear foot on contract No. 3. The contract prices for relocating the barricades were \$6.50 per linear foot on contract No. 1, and \$6 per linear foot on contracts No. 2 and No. 3.

As calculated from the above bid prices and the length of each contract, the average barricade cost for the entire I-495 project was \$13.40 per linear foot and the average price charged for relocating the barricades was \$6.12 per linear foot. Based on the total I-495 project cost of \$78,540,866, which included the furnishing of over 44 miles of barricade and the movement of these barricade sections totaling over 62 miles under the relocation bid item, the cost to the state of Virginia for the timber barricade system was over \$5 million and represented 6.6% of the entire project cost.

The fact that timber barricades have been furnished on projects at less cost in other parts of the state does not necessarily mean that the costs on I-495 were unreasonable. Differences in local material costs and labor rates significantly affect the cost of barricades, and the cost of living in Northern Virginia is known to be the highest in the state. The length of time necessary to complete construction is also important, since longer projects

require more maintenance. Another factor which affects the cost of maintenance is the volume of traffic using the roadway. In high volume areas such as I-495, barricades must be continuously monitored to ensure proper alignment and visibility. Still another reason for high barricade costs is the practice of unbalanced bidding by contractors. Contracts are awarded on the basis of the total bid price only, not on the basis of individual component costs. Since payment is usually made to the contractor as work is completed, it is good economics to charge more for items which can be worked on early in the contract period and proportionately less for late completion items. Since barricades were one of the first items to be worked, it is likely that they are overpriced on the bid.

Bid prices are not the only relevant costs involved in the use of traffic control devices. Other less obvious costs are those to the users of the highway.

The average accident involving barricades during the accident study period damaged or destroyed seven barricades. The barricade damage for this period as recorded on the accident reports and generally substantiated by the contractor's records was \$390,000. Since the study included only an average of seven months of data in any construction area and the entire project will require more than two years to complete, a conservative estimate for the total barricade damage during the entire construction period might be three times this figure, or \$1,170,000. Thus, there is an operational cost involving the use of timber barricades not included in the contract of approximately \$1,170,000, or \$5.04 per linear foot, to replace damaged or destroyed barricades.

An additional cost is the non-barricade cost incurred by users due to automobile-barricade crashes. During the accident study period, a total of 453 accidents involved vehicles striking the timber barricades. Fortunately, 86.1% of the accidents (390 of 453) involving the timber barricade did not result in injury or death. There were, however, 4 fatal accidents resulting in 6 deaths, and 59 accidents resulting in injuries to 74 persons. Considerable cost resulted from these accidents: Various organizations, including the NHTSA and the National Safety Council (NSC), attempt to measure the economic loss associated with automobile accidents. Using the conservative NSC values and the accident data of the accident study period for vehicle-barricade accidents on I-495 yields the accident profile given in Table 16. If it is again assumed that the accident experience is only one-third what could be expected during the entire I-495 project, the vehicle-barricade accident cost would be over \$3 million.

Table 16

Estimated Accident Cost on I-495 for Study Period

Type	No.	Economic Loss*	Cost
Death	6	\$97,000	\$582,000
Injury	74	4,000	296,000
Property Damage Only	390	530	206,000
Total			\$1,084,700

*NSC estimated economic loss for traffic accidents. (48)

Any other traffic control device which would have been employed in place of the timber barricade would necessarily have been involved in traffic accidents. The extent to which another device would have been involved under similar circumstances is unknown at this time. However, from the NSC figures for economic loss, any device which would be associated with fatal or injury accidents would be identified as a dangerous device.

The PCTB

CMB's have been used for many years as permanent positive barriers to separate opposing traffic on high speed roadways. The concrete safety shape has recently grown in popularity as the most effective design for bridge parapets. Both these uses have found wide acceptance among the states, but only recently have PCTB's (Figure 17) been manufactured for temporary use during construction. Because of this relatively new practice, there are wide variations in the prices for this item.

In the spring of 1974, FHWA conducted a study of concrete barrier manufacturing operations in the states of Washington and Oregon. (49) There are differences in the type of reinforcement, connection methods, and labor methods employed between the two designs. Washington used three #5 steel reinforcing bars to provide adequate strength during movement while Oregon used only a wire mesh reinforcement, which created a considerable material cost difference. The FHWA study quoted delivered prices of \$9.12 per linear foot for the Washington barrier and \$6.35 per linear foot for the Oregon barrier as of May 1974.

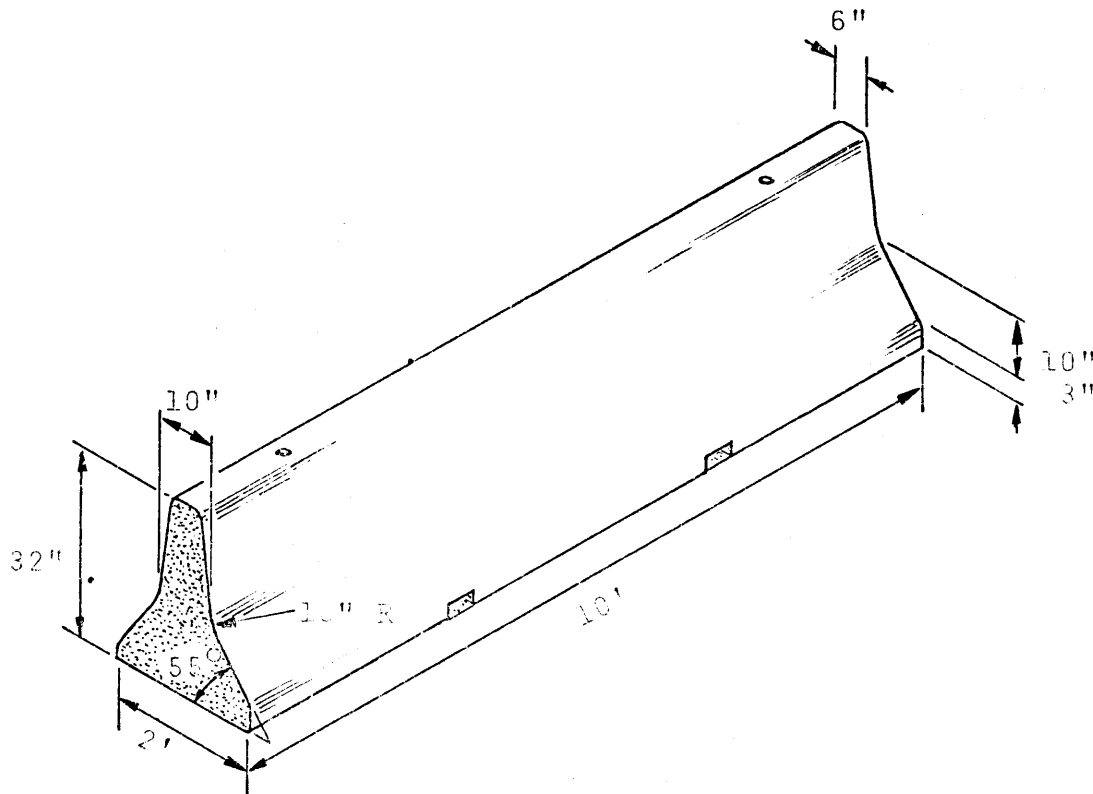


Figure 17. A New Jersey shaped precast concrete traffic barrier.

The state of Florida used temporary concrete barriers on two recent (1974) projects.⁽⁵⁰⁾ On one job requiring 5,750 linear feet of barriers, the cost was \$20 per linear foot, including furnishing, initial placement, and four moves of the barriers during construction. The second project required more than 13,000 linear feet, and the cost was \$11 per linear foot, also including four moves. In both cases the barrier remained the property of the state after construction. These examples may indicate the substantial reduction in unit price to be expected on large projects.

Other states also have experienced wide ranges in prices. On the Illinois Tollway project of four years ago, the cost for furnishing barriers to the work site ranged from \$12-\$20 per linear foot, and placement ranged from \$1.45-\$10.50 per linear foot. In 1970, Idaho paid \$7.20-\$8.00 per linear foot for the furnishing and placing of barriers. California appears to have experienced the lowest bids, only \$5 per linear foot on

a project about six years ago that required a total of 27,800' of barriers.⁽⁵¹⁾ Information was not available to determine whether this price was F.O.B. plant or an installed price.

North Carolina has some of the more recent data. On a March 1974 project, the cost was \$17.50 per linear foot for 11,000' of standard New Jersey type barriers delivered and placed at the site. The barriers were obtained for temporary use during construction and will later be moved into the median as a permanent road feature. North Carolina officials estimate that these barriers might cost \$18-\$20 if purchased today. They also have received estimates to show that movement of the concrete barriers into permanent position will cost approximately \$1.25 per linear foot.⁽⁵²⁾

The first use of the PCTB's as temporary traffic control devices in construction areas in the state of Virginia was on a construction project near Lynchburg, Virginia, in early 1974, and involved the use of 260' of concrete barrier at a total cost of \$10,300, or approximately \$40 per linear foot. The design used did not utilize any steel reinforcing and the unit was larger than the standard New Jersey barrier. Although no provisions were made in the contract as to who would own the barriers after completion of the project, the concrete company relinquished them to the state, which is now using them on another project in the area. There was no charge to the state for movement to the second site.

In a 1975 project on I-95 in Chesterfield County, temporary concrete bridge parapets were used during construction activity on the structure. The parapet element was similar in design to the concrete barrier, but was bolted to the bridge deck and was vertical on the off-traffic side. The average delivered price was \$25 per linear foot including placement, but the units were custom-made and the project was small, so the cost of the special steel forms (at approximately \$2,000 each) was probably a large part of the total cost.

The most recent Virginia experience is a project at the I-95 and I-495 interchange, where 1,300' of concrete safety shape barrier are being used. A Central Virginia concrete contractor supplied the barrier sections to the work site under subcontract for a price of \$15.69 per linear foot in December 1975. However, during subsequent handling and placing by the prime contractor, the price was raised to \$21.65 per linear foot.

As has been shown, prices for PCTB's have varied around the country, but it appears that the larger projects experience the best prices. A summary of the cost information is given in Table 17, which is not a complete listing of all projects that have utilized PCTB's but is representative of the historical data.

Table 17

Historical Cost Experience of PCMB's

(Price Per Linear Foot)

Year	State	Final Ownership	Quantity	Price	Delivery	Placement	Removal	Comments
1969	Calif.	State	27,800	\$ 5.00	Unknown	Unknown	Unknown	Price may include delivery, placement, and removal but information was unavailable.
1970	Idaho	State	Unknown	7.20-8.00	Included	\$2.00-2.40	Unknown	Idaho was first state to employ concrete barriers for temporary use (1968).
1972	Ill.	State	Unknown	12.00-20.00	Included	1.45-10.50	Unknown	Project was on Illinois Tollway
1974	N.C.	State	11,000	17.50	Included	Included	\$1.25 (est.)	Will be moved into permanent median position.
1974	Wash.	State	N/A	7.49	\$1.63	Unknown	Unknown	Contractor produces for inventory; State is responsible for placement and removal.
1974	Ore.	State	N/A	4.62	\$1.73	Unknown	Unknown	" " "
1974	Fla.	State	5,750	20.00	Included	Included	Included	Price includes delivery, placement and 4 moves during construction.
1974	Fla.	State	13,000	11.00	Included	Included	Included	" " "
1974	Va.	State	260	39.62	Included	Included	Included	Barriers are now being used on another project at no cost.
1975	Wash.	Precaster	N/A	12.21	Included	Included	Included	Precaster retains ownership.
1975	Cre.	Precaster	N/A	8.20	Included	Included	Included	" " "
1975	Va.	State	50-100	25.00	Included	Included	Unknown	Bridge parapet bolted to the deck.
1975	Va.	State	1,300	21.65	Included	Included	Unknown	Removal is assumed to be included.

Given the price experience of Virginia and other states and the current estimates by Virginia precasters, the authors feel that the temporary New Jersey type concrete barrier could be purchased for \$16-\$20 per linear foot, including delivery to the site, initial placement and maintenance. The actual price would depend on the volume purchased and the lead time available to the barrier manufacturer. Indications from the construction industry are that relocation expense during construction would be comparable to that charged for moving the timber barricades on I-495 -- approximately \$6 per linear foot. When construction is complete, removal of the PCTB's from the site to a state owned storage area would probably cost about \$3 per linear foot. If the barriers were to be moved to another construction site and placed either in a permanent position or as a temporary barrier, the charge would probably be about \$6 per linear foot plus freight based on present contractor estimates. If the original construction project required permanent concrete medians, the barrier could be moved into permanent position for less than \$3 per linear foot. If Virginia were to use these barriers regularly and companies were given orders on a frequent basis, then additional savings might be realizable due to economies of scale. The total cost for supplying, maintaining, and removing the concrete barriers for a large project in Virginia should be approximately \$19 per linear foot, or about \$5.60 more than that charged for timber barricades. This price does not include any allowance for the subsequent reuse of the concrete or timber barricades by the state, but the state would own the barriers.

The maintenance cost and accident cost associated with the PCTB cannot be predicted from the available Virginia data. However, based on the experience of other states, the cost to replace damaged PCTB's would be considerably less than the \$5.04 per linear foot estimated for the timber barricades on I-495. There is no way to predict whether accident costs would be reduced with PCTB's or, conversely, if accidents might increase in number and/or severity. The results of the crash tests cited earlier suggest that a large percentage of the vehicles striking such barriers would be redirected rather than disabled. As the accident analysis previously presented has shown, only 26.5% of the reported vehicles striking the timber barricade were restrained or redirected. More than 45% penetrated the barrier, and thus posed a threat to the safety of the vehicle occupants and the construction personnel. It is reasonable to assume that with the use of concrete barriers, no vehicles would penetrate and the undercarriage damage characteristics of timber barricade accidents would be reduced. However, the number and severity of secondary collisions with other vehicles after being redirected from the PCTB into a limited recovery area cannot be determined at this time.

Based on the available information, the PCTB shows promise of providing the performance characteristics of a positive barrier. However, further evaluation of its performance in construction zones is necessary before extensive use would be recommended.

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APPENDIX

Partial Abstract of the Unpublished NTSB Report on I-495

The NTSB conducted an investigation of safety practices in the I-495 construction zone after a fatal crash at Backlick Road in January 1975. The result of that investigation, Safety Recommendation(s) H-75-16,⁽⁵³⁾ was sent to the FHWA and to the state of Virginia on August 15, 1975. The purpose of this Appendix is to present the NTSB's findings as they pertain to the timber barricade and to barrier systems, so that the reader will be familiar with the NTSB's views on the I-495 safety practices as expressed in the Safety Board's unpublished report.⁽⁵⁴⁾ The opinions and conclusions expressed here are those of the NTSB investigator as determined by the authors from conversations with him and from perusal of his unpublished report.

Use of Timber Barricade on I-495 (NTSB)

To accommodate construction work in the median area on I-495, a number of roadway characteristics had to be changed. "The lanes, which are normally 12-foot wide, were reduced to 11 feet. Timber barricades were placed along the edge of the interior lane to act as both a traffic barrier and a lane edge delineator."⁽⁵⁵⁾ Figure 18 shows a typical roadway section during construction stage one (construction work in median with traffic on existing roadways). Note that "the timber barricades remain at the edge of the left traveled lane rather than being moved back from the roadway"⁽⁵⁶⁾ onto the completed concrete slab.

In locations west of I-95 "where two interior lanes (same direction) and the median barrier are completed, the traffic is transitioned to the new lanes."⁽⁵⁷⁾ Figure 19 shows a typical roadway section during construction stage two (construction work on existing roadway and outer shoulder with traffic on the new roadway). The timber barricades are repositioned to the right edge of the new 2-lane roadway. Note that under this configuration, no shoulder exists on either side of the roadway for a disabled vehicle to exit from the traffic lanes.

The timber barricades were also placed in interchange gore areas where no work was being performed. Figure 20 shows the use of timber barricades at Exit 11 on I-495. The purpose of the timber barricades in these instances appeared to be for channelization. The gore areas are hazardous locations and should be free of fixed objects. In addition, "timber barricades were placed along the full length of the roadway at the time contract work was commenced."⁽⁵⁸⁾ Figure 21 shows a section of roadway on which "as

much as five months elapsed before any substantive work was commenced."⁽⁵⁹⁾ The timber barricades were also "used along the construction zone randomly and indiscriminately for various purposes such as supporting traffic control devices and delineating hazards."⁽⁶⁰⁾ Figure 22 shows the timber barricades used to support a traffic sign. In regard to the erection of signs in construction zones the Manual on Uniform Traffic Control Devices (MUTCD) states that "signs mounted on portable supports are suitable for temporary conditions. All such installations should be constructed to yield upon impact to minimize hazards to motorists."⁽⁶¹⁾



Figure 18. Timber barricades placed on edge of existing roadway adjacent to the median during construction stage one. Source: NTSB.

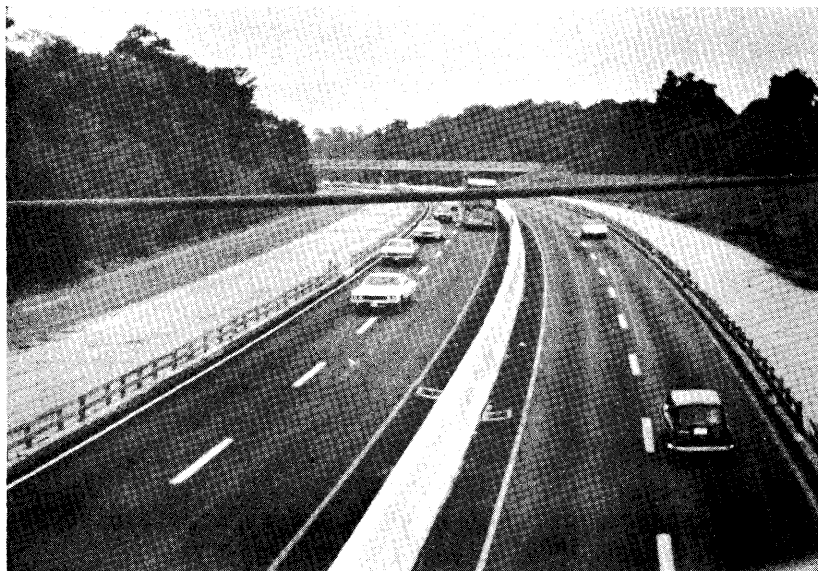


Figure 19. Timber barricades placed on the right edge of new roadway during construction stage two. Source: NTSB.



Figure 20. Timber barricades used for channelization at Exit 11 on I-495. Source: NTSB.



Figure 21. Timber barricades on a section of I-495 where for long periods of time no substantive work was being performed.
Source: NTSB.



Figure 22. Timber barricades used to support traffic signs.
Source: NTSB.

Hazards Associated With the Timber Barricade (NTSB)

According to officials of the VDH&T, the timber barricades are employed

... to create a barrier between the construction work area and the traffic area used by the traveling public, and provide a large measure of safety for both segments.... [However, the] timber barricades have proved, at times, to be a disadvantage when vehicles 'straddle' these sections and motorists as well as construction personnel become involved.(62)

The officials indicated that the

timber barricades have not fared so well on Route I-495 construction. Many problems have resulted, largely as a result of excessive speeds which ... have been uncontrollable.(63)

The posted speed limit is 45 mph for the total construction zone, and in some sections it is 30 mph. However, the 85th percentile speed on I-495 ranged from 56 mph to 59 mph.(64)

"The 10 x 10 base [of the timber barricade] constitutes a curb. The use of such a curb design on an interstate roadway violates federal standards."(65) In regard to the use of a curb on freeways, A Policy on Design of Urban Highways and Arterial Streets states:

Barrier curbs should not be used on freeways and are considered undesirable on other high-speed arterials. Generally, barrier curbs should not be used where design speeds are above 50 mph. When accidentally struck at high speeds, it is difficult for the operator to retain control of the vehicle. Also, most barrier curbs are not adequate to prevent a vehicle from leaving the roadway. Where positive protection is required, such as long narrow medians or adjacent to bridge substructures, suitable median barrier or guard-rail should be provided...(66)

The 10' length of the rail is ineffective since "the traffic barrier rail [must] ... be continuous to prevent a vehicle from pocketing into the rail. The short lengths of individual rails create a continuous exposure of vehicles, that may encroach, to the possibility of being speared by the numerous rail ends."(67) Figure 23 shows a vehicle that was speared by a timber barricade rail.

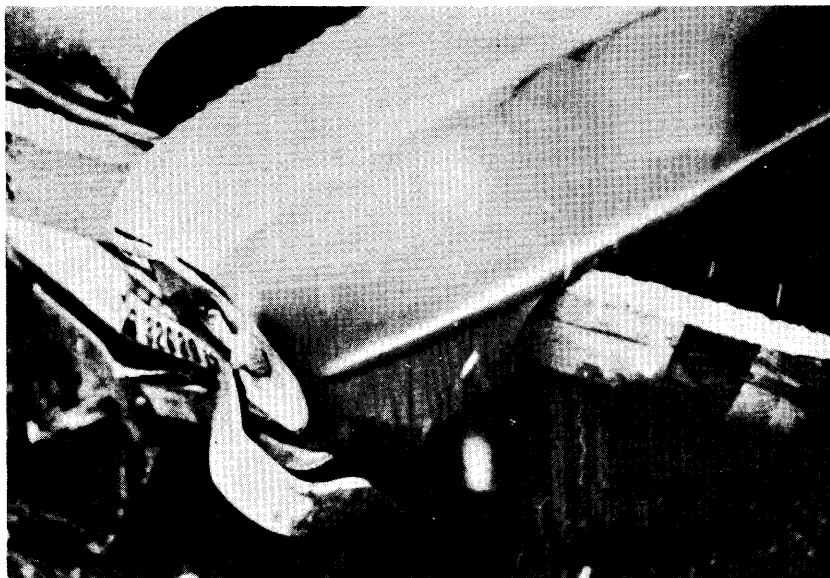


Figure 23. Vehicle "speared" by a timber barricade rail. Source: NTSB.

"With the railing that shatters on impact, the timber barricade becomes nothing more than a curb that is unattached to the pavement."⁽⁶⁸⁾ Tests conducted by the California DOT in 1953 show that "a passenger vehicle striking a 9-inch curb at a 10 degree angle at 30 mph will vault the curb and severe damage will be sustained by the vehicle."⁽⁶⁹⁾ On vehicles which mount or straddle the barricades on I-495 the "wheels are bent causing the tire to deflate; tire sidewalls may be cut; the suspension and steering system substantially damaged or destroyed."⁽⁷⁰⁾ Figure 24 shows a vehicle wheel after mounting the 10" x 10" timber barricade base. "This is the same as the severe damage described in the California Tests."⁽⁷¹⁾

The timber barricades were blown onto the roadway by wind on December 1, 1974, and again in April 1975. They have also been knocked into the traffic lane by vehicles. Accident reports indicate that overturned barriers have been struck on such occasions.⁽⁷²⁾

Thus, there are many hazards associated with the timber barricades used on I-495. Add the substandard lane width and the results of the General Motors Corporation research "that reveals that competent drivers can be expected to occasionally and unintentionally allow their vehicles to diverge from the intended course of travel,"⁽⁷³⁾ and the barriers can be said to constitute a hazardous condition even for competent drivers.

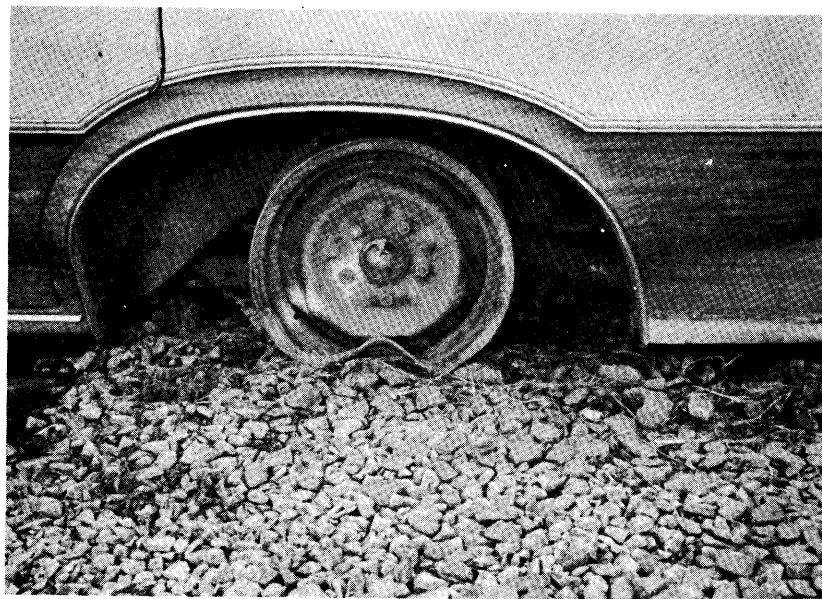


Figure 24. Vehicle wheel bent while mounting the 10" x 10" timber barricade base. Source: NTSB.

Accident Analysis (NTSB)

The performance of the timber barricades can be measured in terms of the number and characteristics of accidents occurring on I-495. The numbers of traffic accidents occurring on the section between Cabin John Bridge and U. S. Route 50 (7.64 miles) during the first seven months of 1972, 1973, and 1974 were identified. The total numbers of accidents so identified for 1972 and 1973 were averaged and are plotted in Figure 25 along with the accidents for the corresponding period in 1974. "Note that 1974 accidents prior to construction were lower than the average of 1972 and 1973 combined, which could reflect the effects of the energy crisis." (74) However, by May the monthly number of accidents in 1974 was greater than the average monthly number of accidents in 1972 and 1973. By the end of July, the monthly number of accidents in 1974 was more than twice the average monthly number of accidents in 1972 and 1973.

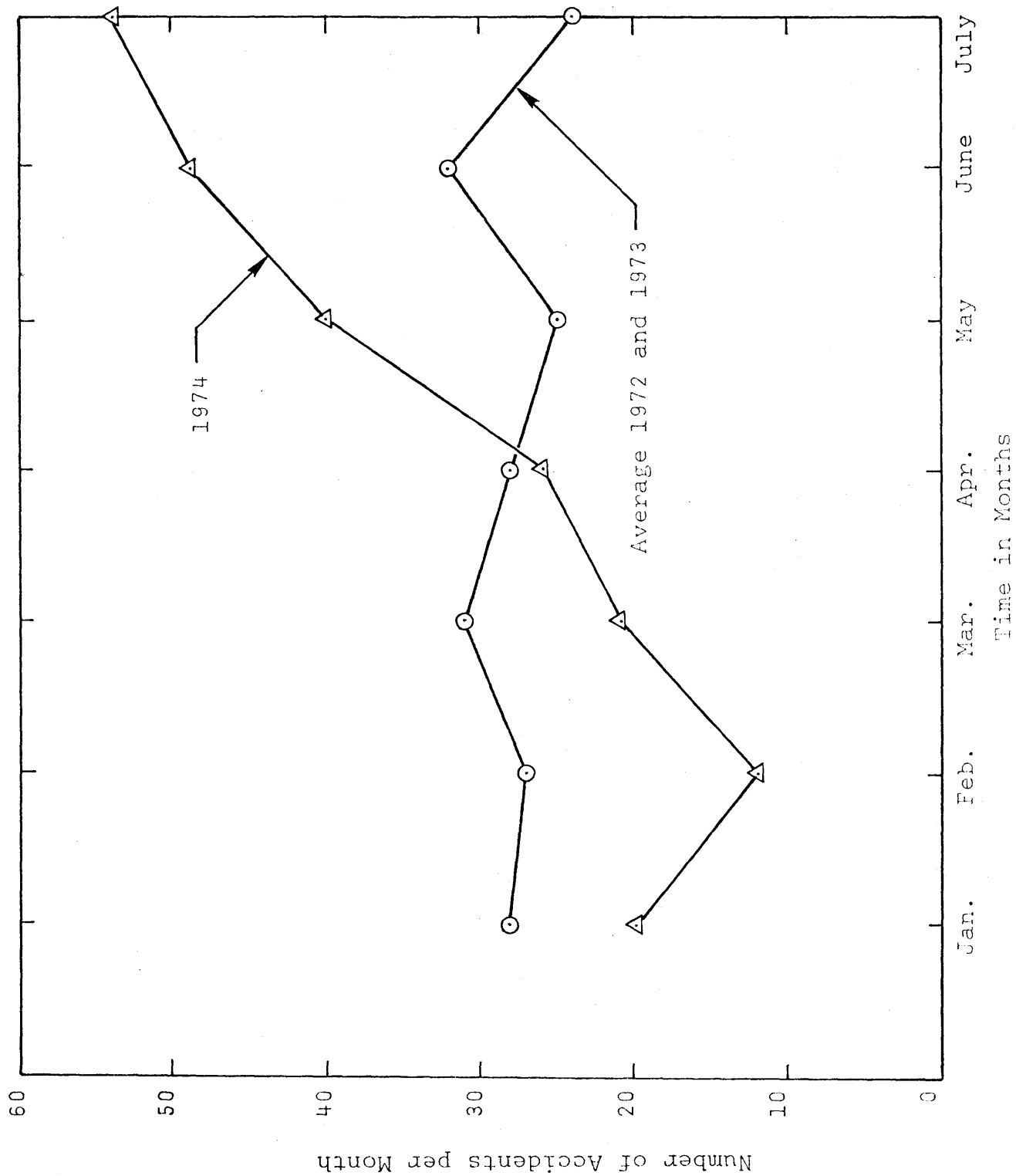


Figure 25. Number of accidents occurring on I-495 between Cabin John Bridge and U. S. Route 50. Source: NTSB.

Individual accident reports for I-495 between Cabin John Bridge and I-95 (14.31 miles) during the 41-day period from November 1, 1974, to December 11, 1974, were reviewed. A total of 94 accidents were reported. "Seventy-one of the 94, or 75 percent, involved contact with the timber barricades." (75) Twenty-five percent of those accidents involving the barricades (18 of 71), involved a vehicle being forced into the barricades. Ten percent of those accidents involving the barricades (7 of 71), involved a vehicle "striking barricades that were either blown by wind or knocked onto the roadway by another vehicle." (76) Five of the seventy-one accidents involving the barricades "occurred due to lane changing at the points of transition of a lane to the shoulder, resulting in a vehicle being forced into the barricade." (77) There was one rear end accident involving a construction vehicle stopping in the left lane to turn into the median construction zone. The traffic accident reports also indicated that vehicles penetrated the timber barricades into the construction work area.

Quoting from the 1972 California study, Construction Zone, Detour and Temporary Connection Accidents: "It can now be shown that increased accident rates during construction need not occur." (78) The study indicated that on major freeway lane addition projects similar to the work on I-495, accidents and the severity of the accidents can actually be lowered in comparison to prior years when improved traffic safety operation techniques are employed.

Traffic Barrier Standards (NTSB)

The Highway Safety Program Manual, Vol. 12, "Highway Design, Construction and Maintenance," issued in 1971 and administered by the FHWA, provides the following guidance to state officials:

The out-of-control vehicle can produce deaths and injuries by striking another vehicle, striking a fixed object such as a bridge abutment, or leaving the roadway and thereby crashing. Whereas a vital part of the overall safety effort in highway design, construction, and maintenance is to reduce the likelihood of vehicles going out of control, no less important are the aspects of highway engineering that increase survivability when drivers lose control of their vehicles. These cover a wide range of techniques and devices including: the elimination of roadside obstacles; proper location of traffic control devices and highway lighting; use of breakaway supports and protective devices that afford maximum protection to the occupants of vehicles; bridge railings and parapets which are designed to minimize severity of impact and guardrails and other design features which protect

pedestrians from out-of-control vehicles. Every state and local agency, therefore, should have a program in all phases of highway design, construction, and maintenance to protect the occupants of an out-of-control vehicle and to avoid collisions with other vehicles and pedestrians.⁽⁷⁹⁾

However, the FHWA has not extended these general guidelines into specific "standards for the design and use of traffic barriers to protect temporary work sites. The absence of standards permits untested designs to be used on temporary work without adequate technical knowledge of what protection can be expected for both construction workers and motorists."⁽⁸⁰⁾

For permanent barrier systems, the FHWA has adopted standards as contained in NCHRP Report 118. The following excerpts from that report illustrate the required use and characteristics of a permanent (longitudinal) barrier system:

1. The purpose of traffic barriers is to reduce accident fatalities and injuries by decreasing severity of crashes.
2. The longitudinal barrier system affords only a relative degree of protection to vehicle occupants as a collision with this type of barrier can result in a severe accident; hence, longitudinal barriers are warranted only at highway locations where the severity of a collision with the roadside feature would be greater than that with the traffic barrier.
3. A longitudinal barrier must restrain a selected vehicle. This implies that when a vehicle of specific weight, dimensions, velocity, and approach angle strikes a barrier it will not climb over, break through, or wedge under the installation.
4. A longitudinal or crash cushion barrier should redirect or stop the selected vehicle in such a manner as to minimize hazard to following or adjacent traffic. Ideally, the vehicle should remain close to the barrier installation and not be redirected back into the traffic stream.

5. During impact, the longitudinal or crash cushion barrier must function in such a fashion that vehicle occupants and other traffic are not likely to be endangered by vehicle or barrier fragments or barrier elements that could intrude into the passenger compartment or be deposited on the traveled way.
6. A longitudinal barrier that does not prevent vehicle penetration (i.e. by vaulting, breaking through, or wedging under the rail) can be a greater hazard due to its relative length than the roadside feature being shielded. Hence, only longitudinal barrier systems that successfully restrain the selected vehicle are acceptable for operational use.
7. Roadway and bridge cross sections can significantly affect barrier performance. Curbs, dikes, sloped shoulders, and stepped medians can cause errant vehicles to vault a barrier or to strike it so that the vehicle overturns. Optimum barrier system performance is provided by a level surface in front of the barrier.(81)

The basic concept exemplified in the above excerpts is the reduction of accident severity. The concept of vehicle occupant safety is also expressed in the FHWA standard for traffic barriers on bridges. The Standard Specifications for Highway Bridges provides the following:

While the primary purpose of traffic railing is to contain the average vehicle using the structures, consideration should also be given to protection of the occupants of a vehicle in collision with the railing, to protection of other vehicles near the collision, to vehicles or pedestrians on roadways being overcrossed.... Traffic railings should provide a smooth, continuous face of rail on the traffic side with posts set back from the face of rail. Structural continuity in the rail members, including anchorage of ends, is essential. The railing system shall be able to resist the applied loads at all locations.(82)

The point to be emphasized is that the safety of the motoring public is a primary consideration in the design and use of a permanent barrier system and should also be a primary consideration in the design and use of temporary barrier systems.

Concrete Safety Shape Median Barrier (NTSB)

Dynamic crash tests and field evaluation of the concrete safety shape barrier have shown it to have exceptional qualities for redirecting errant vehicles. In 1967, California subjected the barrier (New Jersey type) to full-scale crash tests using a 4,000-lb. automobile, with impacts up to 63 mph and a 25° impact angle. They concluded, "This barrier design effectively re-directs a medium weight sedan impacting at acute angles (less than 10°) with no or minimal vehicle damage and no barrier damage, indicating that this design would be particularly applicable to narrow medians." (83) The fact that the barrier sustains little damage when impacted eliminates costly repairs and exposure of maintenance crews to vehicular hazards when making repairs. This barrier also satisfies the requirements identified in NCHRP Report 118.

The use of the concrete safety shape barrier as the permanent median barrier is becoming widespread. The barrier system is usually built by either casting the barrier in place or precasting units and transporting them to the site. The I-495 project provides for the cast-in-place design of the barrier using a moving slip form. However, the concrete quality control problems associated with the moving slip form method have "resulted in delays to the work because sections of the barrier have to be removed." (84)

A number of states are using precast barrier units as a temporary barrier during construction work. The free-standing units provide a safe, positive barrier and effective delineation through construction work areas that might otherwise be confusing to the motorist. After serving as a temporary barrier system, the barrier units can be used on other construction projects or permanently installed in the median. The free-standing feature avoids the need for costly drilling or driving of posts, while providing a degree of portability necessary in construction work. The installed cost for precast barriers in Idaho varied between \$7.20 and \$12 per foot and in Missouri between \$5.50 and \$8 per foot. "While these costs were for a period prior to 1971, recent FHWA research indicates that precast units can be installed for about the same range as the Idaho cost." (85) California, Oregon and Washington are also noted as using precast barriers.

"One major advantage of using the precast procedure for a permanent barrier is the expected reduction in the time that construction workers and equipment are in the roadway area. This procedure coupled with other improvements in sequencing and scheduling of the work can substantially reduce the exposure of the traveling public to the construction activities." (86)