Positive Protection

Guidance for Work Zones

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(Written in support of NHDOT Policy 601.01: Work Zone Safety and Mobility for Department Projects and Activities)

New Hampshire Department of Transportation

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Introduction

Federal Highway Administration (FHWA) regulations (23 CFR 630.1102-1110) requires states to establish guidance and procedures to guide when and where "positive protection" is to be used in work zones including assistance for the type of protection that will be provided.

> **Positive Protection Devices**: This term is defined by FHWA as devices which contain and/or redirect vehicles and meet the crashworthiness criteria contained in National Cooperative Highway Research Program (NCHRP) Report 350. Such devices would be used to minimize vehicle intrusion into workspace.

Positive protection devices have commonly been used to protect the motorist from entering an unsafe area within the highway work zone, to provide separation between traffic flows, and/or separate workers from traffic. In the use of positive protection, the Department has always acknowledged that these hardware systems will minimize the vehicle intrusion into the workspace, not necessarily prevent the intrusion, and the level of effectiveness is highly dependent upon field selection for the application and the *Manual for Assessment of Safety Hardware* (MASH) test level acceptance for the selected system.

These guidelines address the use of positive protection devices in the work zone to protect the motorist and to protect the workers within the work zone. The intent of the guidelines is to supplement the Work Zone Safety and Mobility Policy and comply with the FHWA Final Rule Subpart K to CFR Part 630. These guidelines are not intended to be a rigid standard; rather, they are intended to provide general guidance to be used in conjunction with solid engineering judgment. These guidelines are not a stand-alone document on work zone application of positive protection and must be used in conjunction with other components of the traffic management plan.

Work zone safety is a priority to NH Department of Transportation (NHDOT). Fatal work zone crashes in the USA show an upward trend over the past decade and now represent about 2.5% of all highway crash fatalities nationwide. It is widely recognized that workers in the highway construction industry are at considerably higher risk of serious injury and death than workers in other industries including other construction building trades and industries.

Currently NHDOT is using several effective types of positive protection devices to enhance worker and motorist safety in construction and road maintenance area. This guidance is intended to provide consistency into the decision making process for the selection and application of the positive protection devices for the work zone to protect the motoring public and the construction workers.

I. Typical NHDOT Work Zone Exposures

On a typical workday NHDOT personnel are exposed to traffic while performing routine maintenance or construction activities. These operations can vary considerably in duration. In accordance with Chapter 6, Section 6G.01 of the Manual on Uniform Traffic Control Devices (MUTCD), maintenance or construction activities can be categorized as follows based on the work duration:

- **Long-term stationary** is work that occupies a location more than 3 days.
- **Intermediate-term stationary** is work that occupies a location more than one daylight period up to 3 days, or nighttime work lasting more than 1 hour.
- **Short-term stationary** is daytime work that occupies a location for more than 1 hour within a single daylight period.
- **Short duration** is work that occupies a location up to 1 hour.
- **Mobile** is work that moves intermittently or continuously.

Depending upon the type of maintenance activity, long-term stationary, intermediate-term stationary, short-term stationary or mobile operations may need consideration of some type of higher order positive protection for the work zone safety of the worker. Design issues and strategies for possible consideration for the particular work zones are discussed later in the guidance.

A. Work Zone Experiences

Some typical examples of intermediate-term stationary, short-term stationary, short duration or mobile operations currently undertaken by NHDOT within the Divisions of Operations and Project Development are:

1) Bureau of Highway Maintenance and Bureau of Turnpike
   a) Mowing
   b) Maintenance of drainage systems
   c) Guardrail repairs
   d) Sweeping
   e) Crack filling
   f) Shoulder leveling
   g) Pavement shimming
   h) Tree work
   i) Litter pickup
   j) Slope stabilization
   k) Traffic control setup/removal
   l) Field survey assistance to Design
   m) Rumble strip installation;

2) Bureau of Bridge Maintenance
   a) Deck crack sealing
   b) Deck joint repair

c) Deck patching
d) Bridge rail repair
e) Concrete curb repair
f) Flagging for bridge maintenance operations
g) Assist in bridge inspection – install staging
h) Traffic control setup/removal

3) Bureau of Traffic
   a) Striping
   b) Signal installation/maintenance
   c) Sign installation/maintenance
   d) Installation of pavement sensors – loops/piezos
   e) Traffic control setup/removal

4) Bureau of Materials & Research
   a) Drilling
   b) Asphalt coring
   c) Bridge deck survey
   d) Pavement testing
   e) Pavement marking testing
   f) Traffic control setup/removal

Long-term stationary operations are typically longer than 3 days and depending on the scope of the project may require different degrees of positive protection. Typically, only the Bureau of Construction and the Bureau of Bridge Maintenance personnel manage these long-term stationary operations. Some examples of long-term stationary operations are:

1) Bureau of Construction
   a) Resurfacing projects
   b) Highway construction/widening projects
   c) Bridge construction/widening projects
   d) Highway sign structure replacement projects
   e) Traffic control setup/removal
   f) Lighting installation/maintenance

2) Bureau of Bridge Maintenance
   a) Deck replacements
   b) Rail/curb replacements
   c) Widening/wing repairs
   d) Traffic control setup/removal

II. Reference Guidance for Positive Protection within the Work Zone

Several guidance documents are available as references to assist in the selection of positive protection within the varying types of work zones and to determine the appropriateness of barriers types under consideration. These reference sources are used to assist in the engineering decisions as to type of barriers, placement of devices and crash worthiness of the selected systems in conjunction with engineering judgment. These guidance documents include:

- AASHTO, *A Policy on Geometric Design of Highways and Streets* (Green Book)
- AASHTO, *Roadside Design Guide* (RDG)
- AASHTO, *Manual for Assessing Safety Hardware, 2009* (MASH)
- FHWA, *Manual on Uniform Traffic Control Devices* (MUTCD)
- FHWA, *Developing and Implementing Transportation Management Plans for Work Zones (December 2005)*

In addition, several reports from National Cooperative Highway Research Program (NCHRP) are available. Some notable sources are NCHRP Report 581, *Design of Construction Work Zones on High-Speed Highways* (2007); NCHRP Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (1993); and NCHRP Report 476, *Guidelines for Design and Operation of Nighttime Traffic Control for Highway Maintenance and Construction* (2002). Several additional reports are available through Transportation Research Board (TRB) with many available in electronic format.

III. Design Factors for Positive Protection

The design of construction work zones involves many of the same decision factors that pertain to road design. However, there are two specific differences in the design factors of work zones when considering safety and mobility: (1) construction work zones have limited service life and (2) the design of work zones is far more restrictive than the design consideration for permanent roads.

Exposure along the work zone is directly related to the length of time needed for the construction activity. This is a key point in the design decisions involving worker safety and the level of necessary protection for the traveling public. In addition, the designs for work zones are more restrictive due to limiting alignments and cross-sectional areas. These basic components for temporary work zone design are uniquely more challenging than the design of permanent roads.

A. Factors for Consideration in Design

Several of the design considerations are factors that lie outside the designer's discretion but will have a direct and indirect impact on the traffic control and design solutions. These factors can be grouped as follows.

1. Human Factors

Vehicle operators and pedestrians have individual ranges of capability and performance with respect to visual acuity, cognition, attentiveness, dexterity, coordination and judgment. These elements vary widely for the vehicle operator and can be greatly affected by age and driving experience. Individual drivers can react to the <u>same</u> traffic control design conditions <u>differently</u>. Accommodating such a large and diverse set of individualized performance levels and expectations is a major challenge in the consideration of the appropriateness of the work zone protection. In the consideration of positive protection, the designer should be aware of the environment around the work zone within the community. The need for different type of protection may exist for an elderly housing complex versus college campus environment, or an urban school zone versus rural school zones.

2. Vehicles

Vehicle characteristics and performance capabilities have significant affects on the design criteria and barrier consideration. These considerations include vehicle dimensions, height of vehicle, vehicle weights, acceleration and deceleration (i.e., braking) capability, vehicle center-of-gravity, and cornering and turning stability. Considering the varying vehicle types and performance characteristics, several key decisions (e.g., minimum lane width and maximum grades) are strongly influenced by traffic volume and its composition (i.e., type of vehicles).

3. Locations

Highways are woven into communities and natural settings. The characteristics of a project location are referred to as the highway setting, and can affect design criteria and specific design choices. Examples of setting include area type (e.g., rural or urban), terrain, density and type of adjacent land use, natural and human-made environmental features, and community characteristics. Each setting has its own characteristics that need to be taken into account during the design of the work zone.

4. Traffic

The magnitude and intensity of vehicle usage on a specific roadway facility are generally beyond the control of the design process. These factors, measured by average daily traffic (ADT), design hour volume (DHV) and percent of trucks (%T), have a substantial influence on design criteria and design choices. For some transportation management plans, it may be appropriate to consider factors that could reduce the traffic loads or restrict certain type of vehicle classifications (i.e.: larger vehicles) due to limiting widths and clearances within the construction work zone.

5. Facility Type

Construction work zones are designed and exist within the context of one or more existing transportation facilities. Traffic routinely using the facilities and traffic approaching the work zone may have previous expectations based on previous experience with a facility type. These expectations typically involve the number and width of lanes, the shoulder width and type, appropriate speeds, the location of decision points, and access arrangements.

6. Scope of Construction

There may be some latitude in scope (e.g., pavement overlay and reconstruction), but a project's basic purpose generally lies beyond the designer's discretion for work zone consideration and has substantial influence on the time and space required for construction. The time and space requirements, in turn, affect work zone design. Several elements of the scope of construction will factor into the selection of worker protection and includes project scope and duration (short-term versus long-term), anticipated traffic speeds through the work zone, traffic volumes, vehicle mixes, offset distance from traffic and construction workers, available construction access and departure areas, etc. Each component is inherent with the type of construction activity. One of the items of noteworthy concern for scope of construction considerations is edge drop-offs from traffic flows.

B. Principle Elements for Design of Positive Protection

Both the mobility and land access functions are essential to community and personal vitality. Temporary restrictions in these basic highway functions are sometimes required in work zones. The design objective specifically related to work zones is to minimize any reduction in the mobility and access functions while minimizing the level of risk to the workers and the traveling public.

With careful consideration of design alternatives and their respective probable impacts for construction, designers should look to minimize negative impacts during the design development process and assess the ability to safely construct the highway improvements. Some of the design elements can reasonably be quantified, but others have to be considered on a qualitative basis.

The feasible range of design alternatives is often constrained by cost and setting (e.g., right-of-way, environmental and utility features). Designs for highways in work zones are often more restricted than designs for permanent roadways, since work zones must also accommodate work operations while being closely aligned with the permanent road. Several principles used to develop design criteria and to make choices at the project level for safety and mobility are outlined below.

1. Safety

All movement and travel involves some level of risk. Regrettably, property damage, injuries, and death occur in conjunction with highway travel. A primary objective of the Department's design policies and processes, including those used for work zones, is to minimize the frequency and severity of crashes. The objective of design is to provide maximized benefits while implementing cost-effective worker protection strategies. Therefore, substantive safety is a principal, but not sole consideration, in developing design guidance for work zones.

Simply put, safety is a function of exposure. Exposure is the degree to which a highway element is subject to potential crash occurrence and is directly related to its location, geometry, traffic, speeds and duration of work. Safety analysis can be performed using an increment of time for all relevant factors (e.g., number of crashes, traffic, and infrastructure costs). ADT is one suitable indicator of exposure, when all else is equal. Studies have shown that as ADT increases on a highway, the level of risks also increases as a result of the higher level of exposure.

Work zones exist for a finite period of time, whereas, it is more appropriate to think of exposure in different terms. A specific construction activity may exist for a period ranging from hours to years, but not indefinitely. For construction work zones, exposure can be characterized by accounting for both traffic loads (e.g., ADT) and duration (time). Some overall conditions that may not be acceptable indefinitely (i.e., as part of a permanent roadway) may be acceptable for a low level of exposure (i.e., for a short duration and delay).

2. Design Consistency

Drivers continually interpret and respond to the roadway environment. Repeated exposure to, as well as successful experience with, certain roadway environments creates driver expectancies. These expectancies instill an inclination by drivers to respond to common situations in predictable ways that have been successful in the past. Design consistency calls for the production of designs that reinforce (rather than violate) prevailing expectancies. Design consistency is the use of design elements that meet driver expectancies and that avoid unexpected geometric conditions and features. Work zone designs should conform to the reasonable expectations of drivers based on their previous experience in similar environments. Information sources, including the roadway and associated traffic control devices, should provide positive guidance and be presented consistent with the principle of primacy.

3. Primacy

Primacy refers to how drivers prioritize information received from various sources (e.g., traffic control devices, smart work zones, geometry, traffic, and terrain). Construction work zones often present drivers with higher information loads than permanent roads. Under the principle of primacy, safety-critical and other important information should be clearly, conspicuously, and prominently presented to drivers.

4. Speed Management

Speed is one of the most significant factors in road crash severity and is an important component in regards to work zones. Speed reduction measures are a prominent topic in work zone practice and published research. Many non-roadway related factors can influence the speed at which a motorist drives, including driver age, gender, attitude, and perceived risks of law enforcement or crash. Therefore, different drivers will choose different speeds for the same roadway conditions. Speed choice is also influenced by factors such as weather, road and vehicle characteristics, speed zoning, speed adaptation, and impairment. The speed management practices discussed below are intended to influence mean speeds and speed variance and are considered appropriate for application to work zones.

The AASHTO Green Book and other design policies employ a design speed approach for the design of permanent roads. The design speed for the facility will greatly influence the design criteria as established through the AASHTO Green Book and Roadside Design Guide for sight distance, minimum radii, maximum grade, vertical curvatures, cross-sectional dimensions, superelevation, taper rates and selection of safety hardware. Within the work zone, speed reduction over the posted speed for sustainable work zones plays a key role in design decisions for temporary traffic control plans (TCP) and the development of traffic management plans (TMP). As noted in the MUTCD, temporary TCP plans should be designed to provide for reasonably safe travel with a speed limit reduction of no more than 10 mph. This work zone design speed establishes the design criteria within the work zone for sight distance, minimum radii, maximum grade, vertical curvatures, cross-sectional dimensions, superelevation, taper rates and selection of safety hardware.

Although the MUTCD suggests designing TCP plans for reasonably safe travel with speed limit reductions of no more than 10 mph, the potential for greater speed reductions may be required by more restrictive design conditions is also recognized. In such a case, the work zone target speed would be based on the restrictive elements such as limiting geometry, lane widths, sight distances, work zone offsets, etc. When limiting geometry or limiting sight distances requires consideration of a speed limit reduction greater than 10 mph, gradual speed step-down consistent with guidance in the MUTCD should be implemented over a greater distance prior to the actual work zone and greater driver notification should be provided through consistent, credible, and complementary information sources. Although static signage (i.e., advisory and regulatory through MUTCD) is a fundamental and important source of information, other sources for driver notifications should be considered. These additional means are enhanced smart work zones and increased enforcement through management measures such as dedicated enforcement patrols, drone radar, portable changeable message signs, transverse rumble strips, speed feedback trailers, warning devices, and variable speed limits.

5. Sight Distance

The Green Book identifies four types of sight distance for design considerations consisting of decision sight distance, intersection sight distance, passing sight distance and stopping sight distance. Each of these sight distance types may be applicable to work zones, although providing for passing opportunities in work zones is not a priority. Work zone designs that provide good visibility are desirable.

Typically, AASHTO Green Book values are used based upon the work zone design speed. Although it is not always obtainable, decision sight distance is desirable to achieve approaching the work zone. Within the work zone, as a minimum, stopping sight distance for the work zone design speed shall be achieved unless a design exception is obtained.

6. Forgiving Roadside

Vehicles leave the traveled way for a variety of reasons. Regardless of the reason for the departure, a roadside environment free of fixed objects with stable, relatively flat slopes enhances the opportunity for reducing accident severity as defined by the AASHTO Roadside Design Guide (RDG).

Although a vehicle may depart from any roadway, the roadway itself can influence the probability of a departure. Within work zones, several factors may increase the chances of the vehicle leaving the travel way such as unexpected cross-over, tapers, reduced lane widths, unexpected surface changes, edge drop offs, loss of shoulders, cross-slopes, etc. Whenever possible, a forgiving roadside should be provided and if not achievable, appropriate traffic control devices should be employed as prescribed in the MUTCD.

7. Alignment Principles

Although there are similarities in the design of permanent road alignments and alignments through work zones, there are also substantial differences. A key difference is that of service life. Costs, impacts, and right-of-way acquisition are more difficult to justify when the corresponding usefulness is short lived. Roads designed in conjunction with construction work zones are typically more constrained by the type of work activity, and the setting of that activity, than permanent roads. Yet temporary roads must connect to existing roads and provide sufficient space for work operations. Consequently, there is a strong and appropriate motivation to use and integrate permanent infrastructure elements (e.g., embankments, pavements, structures, and appurtenances) into work zone roadway alignments. Constructing and removing temporary infrastructure is warranted and when doing so, it is necessary to provide the desired levels of access, mobility, and safety.

The degree to which a work zone roadway requires temporary infrastructure is influenced by the horizontal and vertical alignment. The design of construction work zones, including alignments, is an exercise of balancing cost, impacts, and service provided over a finite period of time and applies the same AASHTO design principles from the Green Book and Roadside Design Guide.

8. Roadway Surface and Cross Section

Driving surfaces, especially roughness and friction, have an influence on motorist comfort and tire-road interaction. On high-speed facilities, a paved travelway is always desirable. On lower speed facilities, the use of unpaved surfaces may be considered for short duration work and/or on low volume roads. The duration may be dependent upon the type of construction activity and available work zone. Typically, use of unpaved travelway should be minimized in duration. In general, paved travelways should be provided for highways having a work zone speed greater than 40 mph and volumes greater than 6,000 ADT.

Unpaved driving surfaces are difficult to maintain and will require greater maintenance over its use and other considerations. Changing travelway surface types requires clear advanced signage and effective marking of transition point in order for the driver to adjust speed and travel expectations. Unpaved surfaces should not be sustained for any excessive length of time. If unpaved travelways are implemented within the temporary TCP due to restrictive design constraints beyond the designer's control, then consideration of limiting the duration to no more than five working days is recommended.

9. Horizontal Alignment Considerations

A variety of techniques are used by agencies to attain superelevation along an alignment for various types of permanent roads. The superelevation transition techniques used for high-speed permanent roads should be applied to roadways within construction work zones on high-speed highways. In addition to cross slope and superelevation, sight distance is a consideration in designing horizontal alignments. Cross sections and other features common to construction projects (e.g., barriers, material stock piles, and equipment) may limit sight distance on the inside of horizontal curves and should be limited when practical.

10. Vertical Alignment Considerations

Generally, the same AASHTO Green Book maximum grade criteria applicable to the highway under construction should be applied to work zone roads. However, marginally exceeding these criteria is often justified in consideration of all factors. Grades below the maximum are desirable. When designing work zone, temporary roadways, the potential effect of grades on operations and capacity should be carefully considered. The minimum length of vertical curves for permanent roads is typically established on the basis of sight distance considerations, the same considerations should also be applied to work zones.

IV Work Zone Protection Strategies

All projects will require a strategy that can accommodate the short and/or long term construction operations while maintaining acceptable mobility and safety for the traveling public. A transportation management plan (TMP) will be developed for each project that outlines the selected construction operation strategy(s) for the particular project. As a minimum, the TMP will consist of the temporary traffic control plan (TCP) for the particular construction operation. Depending upon the project's significance, the TMP may also include the defined strategies for transportation operation and public outreach. Prior to including positive protection in a temporary TCP within the TMP, careful consideration must be given to alternatives, which would avoid or minimize exposure for workers and the road user. Any of the following strategies should be considered within construction work zones to minimize exposure.

- Alternating one-way operation
- Detour
- Full road closure/ramp closure with traffic detoured
- Intermittent closure
- Road closure with diversion (i.e. onsite detour, median crossover...)
- Lane closure or constriction

- Use of shoulder
- Performing work during off-peak periods when traffic volumes are lower (i.e.: night work)
- Rolling roadblocks
- Accelerated construction techniques

Further summary of the basic work zone strategies is as follows:

A. Alternating One-Way Operation

A construction work zone mitigation strategy used on two-way roadways wherein opposing directions of travel take turns using a single travel lane. Flaggers, with or without pilot vehicles; stop signs or signals are normally used to coordinate the two directions of traffic. Automated flaggers should be considered as an option. For longer durations temporary traffic signals should be employed. This strategy compensates for the removal of permanent travel lanes from service and is sometimes referred to as one-lane, two way operation. In some circumstances and under low volume flow, a single lane operation could be accommodated through the use of portable traffic signals.

This strategy provides additional safety by reducing speeds and positively controlling vehicle flow. However, it does typically result in a close proximity of the vehicles to the worker(s), and particularly, flaggers. The threat to flaggers can be minimized by use of automated flaggers.

B. Detour

A construction work zone mitigation strategy wherein traffic in one or both directions is rerouted onto an existing highway to avoid a construction work zone. Detoured vehicles may travel on permanent or temporary roads. This strategy compensates for the removal of permanent lanes from service. Use of this strategy allows construction activities to proceed with little restraint, increase efficiency, and improved quality.

C. Diversion

A construction work zone mitigation strategy wherein traffic in one or both directions on a designated route is carried by a temporary roadway alignment around a work area and reconnected with permanent infrastructure of the designated route. This strategy compensates for the removal of permanent travel lanes from service and is sometimes referred to as the shoofly or runaround. Use of this strategy allows separation of construction activities from traffic. Diversions are often used for bridge projects, including bridge replacements, but are also used for other work. When used on bridge projects, a temporary bridge or culvert may be requested.

This strategy allows shortening of the duration of the work and may result in increased separation of the traffic from the worker(s). When the facility is entirely closed it has all the benefits listed under full road closure.

It is limited to facilities where a reduced number of lanes in each direction will adequately convey the traffic without excessive backup. It does involve additional construction costs, and could involve additional environmental, utility, and/or property impacts. This will increase the highway users' exposure to conflicts with opposing traffic when using a median crossover detour and will require addressing departure guardrail terminal units adjacent to the diverted traffic as well as changing the pavement markings to reflect the altered traffic pattern. This strategy also exposes motorists to unanticipated travel conditions and risks, especially for divided highways, where they have no prior exposure to oncoming traffic and now they do. This requires significant advance notice and may require positive protection devices to implement safely.

D. Road Closure

A construction work zone mitigation strategy wherein traffic operations are removed or suspended in either one or both directions on a segment of roadway or ramp. When roadway traffic is completely eliminated, construction efficiency and resultant quality of permanent features are maximized, while the time of completion is minimized. Innovative contract provisions should be considered and reflect the degree of disruption that this strategy involves. Under full road closure, consideration of a detour route needs to be developed.

Partial Road closure is a strategy that diverts a large proportion of the traffic away from the work area. It also allows the work to be expedited by offering a less restricted work site. Available buffer space between traffic flow and the work area will vary based upon site conditions. An assessment of the detour widths, geometry (sight lines), and exiting lane use needs to be evaluated for acceptable cost effective use under this strategy.

Full Road closure is a strategy that provides the safest work environment for the worker(s) by entirely removing the traffic from the facility. It eliminates the need for positive protection for safety of the worker(s) within the work site. It also greatly expedites construction activities, resulting in lowered construction costs. However, numerous other factors may make this inexpedient to consider. Similar to partial road closures and detours, an assessment of the detour route will be needed to determine its ability to handle the increased traffic load.

E. Intermittent Closure

A construction work zone mitigation strategy wherein traffic in one or both directions is stopped for a relatively short period to allow construction operations. This work zone strategy is generally not adequate for an entire construction project. It is often employed during specific operations (e.g. setting bridge beams, blasting operations, and moving equipment) for which project personnel can select a beginning point and reasonably predict the duration.

This strategy removes the traffic from all or part of the work site for a short period of time, usually during the non-peak traffic times. This results in the same benefits and many of the same detriments listed under partial and full closure for that period of closure. The alternate route, however, would typically not need the same degree of improvements that would be necessary for a longer duration detour. The detour signage package will need to be fully implemented each day the strategy is utilized with removal at each end of the workday.

F. Lane Closure

A construction work zone mitigation strategy wherein one or more travel lanes and adjacent shoulders are closed to traffic. As defined here, this term is not limited to closing one lane of a multilane highway. Lane closures are inherent to median crossovers.

Lane closures may be used when not necessitated by the work to provide greater protection to the worker. This strategy normally allows the traffic to be maintained on the facility but with a reduced capacity. It may be used as a strategy to aid in controlling traffic speeds as well as increase the buffer to the work site, plus the additional space allowed to the work zone may decrease construction duration.

It is only appropriate as a preferred strategy where the volume of traffic can be accommodated with the restricted capacity or where the experienced traffic delay is at an acceptable level. This strategy will require significant advance notice and will require consideration of positive protection devices to enhance worker safety through the lane closure or, as a minimum, at the lane closure introduction area with use of channelization devices along the lane closure.

G. Lane Constriction

A construction work zone mitigation strategy wherein the width of one or more travel lanes is reduced. The number of travel lanes may be retained (possibly through median or shoulder use) or reduced. The use of this work zone strategy is often associated with traffic in close proximity to construction operations. This also creates the possibility of conflict among construction equipment operators, workers, and roadway traffic. In addition to raising safety concerns, the proximity may interfere with construction quality.

Lane constrictions may be used when not necessitated by the work to provide greater protection to the workers. This strategy normally allows the traffic to be maintained on the facility under construction but with a reduced capacity. It may be used as a strategy to aid in controlling traffic speeds as well as increase the buffer to the work site, plus the additional space allowed to the work zone may decrease construction duration.

It is only appropriate as a preferred strategy where the volume of traffic can be accommodated with the restricted capacity or where the experienced traffic delay is at an acceptable level. This strategy will require significant advanced warning and consideration of positive protection devices to enhance worker safety through the lane constriction areas.

H. Median Crossover

This construction work zone mitigation strategy is generally used on expressways (including freeways) to establish two-way traffic on a normally divided facility. In this strategy:

- The number of lanes in both directions is reduced.
- At both ends, traffic in one direction is routed across the median to the opposite-direction roadway on a temporary roadway constructed for that purpose.
- Two-way traffic is maintained on one roadway while the other direction is closed.

This strategy is highly dependent on traffic volumes and roadway capacities. Substantial separation of construction from traffic is provided by this work zone strategy. Generally, this strategy allows construction of an entire roadway with little conflict between roadway traffic and equipment, workers, or onsite material movement. The work is generally more expedient and results in higher construction quality than would be produced with the lane-constriction approach. However, this strategy also exposes motorists to unanticipated conditions and risks, where as on a normally divided highway they have no exposure to oncoming traffic, now they do. This requires significant advance notice and may require positive protection devices to implement safely.

I. Use of Shoulders

This construction work zone strategy involves the use of right side or median shoulder as all or a part of a temporary traffic lane. This strategy compensates for the removal of permanent travel lanes from service. Employing this strategy may require constructing or upgrading pavement structures to adequately support traffic loads. This strategy normally allows the traffic to be maintained on the facility often with no or little change in capacity. It may be used as a strategy to increase the buffer to the work zone with channelization devices and could result in a decrease of construction duration. Shoulders with existing rumble strips will require some filler treatment to address temporarily shifting of traffic within this strategy.

J. Night Construction:

Night construction allows for conducting construction operations during reduced demand. Night traffic volumes are generally significantly lower than daytime volumes. The advantages of night work are associated with lower traffic volumes and lower traffic impacts. The disadvantages are higher agency costs, higher safety risks, disruption of normal social patterns of the work force, noise, and possible compromise in construction quality.

This strategy typically is employed where there is a very high traffic volume that would result in unacceptable delays with any reduction in capacity introduced by either constricting or reducing the number of lanes during that time. It normally is used in conjunction with lane constriction and closures, and has those benefits and detriments for the worker(s). However, when night work is proposed there are other factors that the designer should take into consideration.

Statistically there are a higher percentage of impaired drivers within the traffic flow. This may lead to an increased need for police presence and positive protection. Also, it is challenging to provide lighting such that the work site and all its components are accurately recognized and appropriately responded to by the vehicle user. Additionally, worker and driver fatigue effects reaction time, and judgment.

K. Rolling Slowdown/Roadblock

A rolling slowdown or rolling roadblock is a legitimate form of traffic control commonly practiced by contractors and highway maintenance crews. Their use is valuable for emergency or very specific short duration closures (i.e., to set bridge girders, blasting operations, or to pull power lines across the roadway). The traffic control vehicles form a moving blockade well in advance of the work site, which reduces traffic speeds and creates a large gap (or clear area) in traffic, allowing very short-term work to be accomplished without completely stopping traffic. Other traditional forms of traffic control should be considered before the rolling slowdown is chosen.

This strategy is typically employed to provide a very short period of time where the traffic is not passing adjacent to the work site. It is typically used for limited duration tasks that require full closure of the facility. For those periods of time it results in the restriction of traffic within the work zone, which provides good worker safety with limited need for positive protection devices.

L. Alternative Contracting Techniques

Avoiding and reducing work zone impacts is the driving force for alternative contracting techniques. Other reasons for using alternative contracting techniques is to centralize accountability, improve quality and reduce project delivery time. The alternative contracting processes with the closest relationship to work zone strategies are:

- **A+B Bidding**: A + B bidding is also known as *Cost Plus* bidding, where each bid is computed using the equation "Bid=A+Bx. Where;
  - ❖ A = the dollar amount to perform all work identified in the contract, as submitted by the bidder;
  - ❖ B = the total number of calendar days required to complete the project, as estimate by the bidder;
  - ❖ x = road user cost per day as designated by the agency

This equation is used to determine the lowest bid. A+B bidding is a method of rewarding the contractor for completing a project as quickly as possible. By providing a cost for each working day, the contract combines the cost to perform the work (A component) with the cost of the impact to the public (B component) to provide the lowest cost to the public. The bidder with the lowest overall combined bid (A+Bx) is awarded the contract. In the actual contract, the contractor will only be reimbursed for unit items (A). The time allowed to complete the project is set by the bidder's time component (B). Under A+B bidding the contractor will minimize the exposure to workers and road users by completing the project as efficiently as possible through critical path method scheduling (CPM).

However, careful oversight through constructability reviews by the highway agency is needed to ensure the contractor meets the policies and guidelines for worker protection. For success with this strategy, unanticipated delay of utility relocations, unexpected subsurface utilities and soil conditions, environmental requirements, pavement conditions, and unanticipated bridge conditions need to be addressed early in the development phase. In A+B bidding method, contractors often shift more experienced staff to night work and use multiple shifts. The staff assigned by the agency needs to be experienced in agency policies, have decision-making authority, and be supplemented with support staff as to not delay the contractor's operations.

- **Design-Build Contracting**: Under this contracting method, an agency-owner procures a single contract providing for both design and construction. This avoids questions of responsibility and coordination between project designer and project constructor. Benefits attributed to design-build contracting include timesavings, contractor innovation, and administration efficiencies. Under design-build contracting, work zone design is generally the responsibility of the contractor within agency guidelines. This contracting method allows the contractor to be innovative and work as efficiently as possible through critical path method scheduling (CPM) to maximize construction while minimizing the exposure of road workers and road users. For design-build contracting to be successful, unanticipated delays of utility relocations, unexpected subsurface utilities and soil conditions, environmental requirements, pavement conditions, and unanticipated bridge conditions need to be addressed early in the development phase. The staff assigned by the agency needs to be experienced in agency policies and have decision-making authority and be supplemented with support staff as to not delay the engineer's design and contractor's operations.

- **Incentive-Disincentive Provisions**: Incentive-Disincentive contract provisions provide for specified financial consequences to contractors based on completion of identified work relative to the scheduled completion. The schedule for critical work items and daily incentive-disincentive amounts are determined by the agency. Additional payment is made for each day that the identified critical work is completed ahead of schedule, and contract payment is reduced for each day that the contractor overruns the scheduled completion. Incentive-disincentive provisions are intended primarily to minimize work zone impacts on critical projects, thus minimizing exposure of road workers and road users.

- **Lane Rental**: Lane rental is used to minimize the impacts on the traveling public. It is a method of transferring the roadway user cost to the contractor. The contractor must rent a lane at a specified cost per period of time in order to close it. This creates a monetary incentive for the contractor to be innovative and minimize the duration of lane closures. By providing a more aggressive scheduling package, a contractor may be able to gain a competitive advantage by decreasing the overall impact to the traveling public and thereby reducing the amount for bid consideration by minimizing lane rental time. Less lane rental time leads to less exposure of the roadway worker and the roadway user.

The strategy that is most responsive to the evaluation factors on an overall basis should be selected. A decision can then be made as to the use of positive protection based on the exposure levels that the workers and road users are subjected to. The information assembled and the evaluation process should then be sufficiently detailed to insure the feasibility of the selected strategies.

V. Work Zone Protection Strategy Determination

This section is intended to provide guidance to those who are responsible for deciding when and where it is appropriate to use positive protection to protect workers within a work zone and what type of positive protection should be considered. The actual decision on whether positive protection is needed, and the best type of device(s) to use for a specific work zone situation should be determined by an engineering assessment that considers the actual conditions expected to be encountered in the work zone combined with the characteristics of the various devices that may be available. In all cases, positive protection hardware must conform to NCHRP Report 350 and/or the Manual on Assessment of Safety Hardware (MASH) criteria with written acceptance letter through FHWA.

Characteristics that should be considered in combination in arriving at a decision as to whether to provide positive protection and, if so, what type, include, but are not limited to:

- Project scope
- Project duration
- Anticipated traffic speeds through the work zone
- Specific driver characteristics due to local population
- Anticipated traffic volume
- Anticipated vehicle mix
- Vehicular decision points such as entrance and exit ramps, merges, diverges, etc., within or within close proximity to the work zone,
- Type of work
- Distance between traffic and workers (also known as buffer)
- Escape paths
- Time of day work area restrictions
- Roadway departure issues for users
- Access to and from the work space
- Type of roadway
- Impacts on project cost and duration
- Known vehicle crash history at work zone location
- Other hazards
- Cost of protection

The need for positive protection is not easy to quantify but relies on a realistic, objective assessment of the threat upon entering the work zone and the probability of it being actualized. But it should always be assessed in the view of the exposure and risk posed to the worker(s).

Primary to the assessment of the degree of positive protection is predicting the intermediate phases of operations between the existing conditions and the post-completed work conditions. The exposure of both the worker and the traveling public are usually well covered by the permanent protective measures provided when the work is completed. But those individual operations that are required to get to the completed work require more analysis to gain an appreciation of the discrete tasks to be done, the methods typically employed to do it, and what the state of the worksite will be for different phases of different operations. Some of these intermediate operations for construction type activities include clearing and grubbing, earth excavations, rock blasting and removal, embankment construction, installation of drainage, construction of structural box, paving, bridge deck removal, bridge deck repair, sign removal and installation, curbing and concrete island installation, guardrail installation, conduit installation, slope reinforcement, retaining wall construction, signal installation, etc. For maintenance type operations these include mowing, grading, ditching, painting, excavating, pavement repair, striping, installing and renovating signing, repairing drainage, maintaining and modifying signals, bridge repair, etc. Each operation normally includes a mobilization of equipment and workers and subsequent demobilization, which also needs to be considered. Each operation and its phases need to consider site preparation, individual operations, durations of the operations, limitations and restrictions imposed by equipment, and environmental, utility, and right of way constraints, etc. **Each decision must reflect the individual, unique situation and not merely be a rote decision.** But in general the decision regarding the degree of positive protection appropriate for any work ultimately reflects the exposure and risk posed to the worker(s) at any point during the work.

The main consideration is the threat posed to the worker(s). The primary threat consists of the possibility of a vehicle entering the work zone and directly or indirectly causing physical harm or death of the worker(s), either by striking the worker(s), or some other item in the work zone that in turn becomes a projectile or generates flying debris or poses some other hazard such as electrical, chemical, etc., or other secondary cause and effects of intruding into the work site. The degree that an intrusion is probable will be proportional to the speed of the traffic, the amount of traffic, the proximity of the traffic, the percentage of truck traffic, and the duration of the operation. These are major elements of the risk assessment.

The first criterion is speed. From a simple energy standpoint, kinetic energy equals one half times the mass of the intruding vehicle times the square of its speed. More speed also means more distance traveled before corrective action can occur. It also means less reaction time before a worker can take evasive action, if there is an evasive action that can be taken.

The second criterion is the volume of traffic. The probability of vehicles leaving the travelway increases as the percentage of traffic increases. The higher the traffic volume and the higher percentage of heavy vehicles adjacent to the work area, the more intrusions within the work zone can statistically be predicted. The constraints of the work zone (i.e., lane widths, geometry, visibility, sight distances, abruptness of transitions, etc) will influence the highway user's ability to safely travel through the work area as traffic volume increases.

The third criterion is the proximity to the work area or "the distance from the vehicles to the worker(s)." Proximity to the work area is based on the same principle as that of the clear zone. With all other things being equal, the greater the distance the more opportunity is available for the highway user to avoid intruding into the work area and the more time for the worker(s) to take evasive action, if evasive action is possible, or for the highway user to recover and return to the travel lane without incident. Proximity is influenced by the geometry of the roadway and effectively a work area on the outside of a curve should be considered as needing more distance than one on a tangent alignment as it is in a location more prone to errant vehicles.

Duration of the work zone is a fourth criterion that poses similar risk as the traffic volume and work zone exposure. The longer the work zone is in place the greater risk is to the worker. Limiting duration to off-peak travel demands will reduce the potential for vehicle intrusion into the work zone and could affect the type of barrier protection to be selected.

Other unique factors to be considered include locations where there is a higher likelihood of encountering drivers with limited experience or with drivers who have physical, visual or reflex limitations, such as sites near high schools, colleges, or facilities servicing the elderly and/or handicap. In addition, work sites that have numerous access points or other decision points for drivers may add to the distraction or confusion factor and, in turn, heighten the probability of driver error and provide an environment with additional work zone intrusions. The goal is to provide positive protection measures that protect the highway user and the highway worker. Favoring one over the other is likely detrimental to both.

A. Positive Protection Selection

Proper positive protection selection and design involves the consideration of a number of specific factors including, but not limited to:

- The anticipated operating speed, impact conditions and design vehicle classification will form the basis for determining the barrier type. Acceptable barrier types are rated in accordance with actual crash testing based on barrier crash test criteria as defined in MASH and/or NCHRP Report 350.
- The duration devices will be in place, versus the ease of installation, maintenance, and removal.
- Available space for barrier installation and lateral deflection (perpendicular to traffic flow), and less frequently, longitudinal deflection.
- Need for access through the work zone for side roads, driveways, and construction vehicles.
- Effects on sight distance from all access points.
- The potential traffic impacts during installation and removal of the device(s).
- Exposure of the workers during device(s) installation/removal versus the benefits to the workers for the duration the device(s) are in place.

- Impact on winter maintenance.
- Impact on lane capacity for peak events such as fairs, major races, etc.
- Impact on use of facility for legally allowed oversize loads.
- Method of transitioning from positive barrier to impact attenuations and terminal ends.

The NHDOT typically uses several different measures to provide temporary positive protection:

- ❖ Portable Concrete Barrier
- ❖ Guardrail
- ❖ Traffic Control Barrier
- ❖ Terminal End Treatments
- ❖ Impact Attenuators (mechanical)
- ❖ Sand Barrel Arrays
- ❖ Truck Mounted and Trailer Mounted Impact Attenuation

Although these are the measures commonly used, that does not restrict the use of another method that meets appropriate Crash Test Criteria.

1. Lateral Protective Devices:

a. Portable Concrete Barrier

A portable concrete barrier (PCB) is a set of freestanding, precast, concrete segments typically 10 feet in length with built-in connection devices. Their profiles follow the same contours as other permanent safety shaped concrete barriers, that being typically the New Jersey or the "F" shape. Configurations within any one run of barrier should be consistent to provide the best performance.

The latest version of the *Roadside Design Guide* (RDG) highlights eight PCB systems, all of which have been tested to meet the latest acceptable crash test criteria. The FHWA roadside safety website (http://safety.fhwa.dot.gov/roadway_dept/road_hardware/index.htm) includes acceptance letters for other portable concrete barriers that can be used on highway projects. Thus, a variety of specific designs for PCB meeting the latest crash test criteria and accepted by FHWA are available for use. Additional details on PCB are provided in the report *Performance Evaluation of the Portable Concrete Barriers (7)*.

i) Use - Portable Concrete Barrier (PCB)

PCB is placed between the traffic and workspace to prevent vehicle intrusions, and may also be placed between opposing traffic lanes, and between travel lanes and roadside hazards. Because PCB consists of individual segments connected by flexible joints, PCB is subject to lateral deflection (movement of the barrier perpendicular to traffic flow) when impacted. The PCB characteristics that determine the amount of impact deflection include section length, the joint connection system used, and other factors. To control or eliminate lateral deflection close to pavement edge drop-offs and in other situations where deflection space is limited, barrier sections may be anchored to the pavement. On bridge decks, overpasses, retaining walls or any other large edge drop off where no deflection can be accommodated, anchoring of the barrier by bolting it is required. Placing an anchor behind a PCB is not allowed, as it does not provide significant rollover resistance and could result in the barrier overturning on impact.

ii) Design Considerations - Portable Concrete Barrier

The RDG discusses a number of design considerations that need to be addressed in the application of PCB. These include the following:

- Flare rate – the flare rate is the angle at which the PCB diverges and/or approaches the traveled way. Unless otherwise specified, the maximum recommended flare rates for free standing PCB are as follows:

Operating Speed	Maximum Flare Rate
≤ 30 MPH	7:1
40 MPH	8:1
50 MPH	11:1
60 MPH	14:1
70 MPH	15:1

- Minimum offset – a minimum offset of 2 feet from the edge line of the travel lane to the PCB is desirable for non-winter maintenance operations and traffic flow considerations. Where the PCB would be in place during the winter, a 6' minimum offset is preferred to accommodate snow removal operations. Low lateral clearances may adversely impact traffic flow.
- Joint connections – because PCB consists of individual segments, adequate joint strength and continuity is essential to ensuring good impact performance. The RDG and FHWA website describe several acceptable options for joint connections that permit PCB to deflect from less than one foot to more than seven feet. Base coarse friction and barrier-to-base connection are parameters that control the amount of lateral impact deflection (see RDG). NHDOT Standard Specifications call for a triple loop connection for new PCB barrier.
- Performance level – Many PCB designs have been tested at NCHRP Report 350 test level three (TL3) and are acceptable for use on higher speed roadways. Some designs are approved at NCHRP Report 350 and MASH test level two (TL2) but may be used only when approved and only on roadways with speeds of 45 MPH, or less. Ultimately, the performance level of the barrier should match the expected traffic exposure of the site taking into consideration the vehicle types and anticipated speeds.

b. Guardrail

Temporary guardrail consists of a metal beam rail with wood/plastic block-outs and metal or wood posts that are the same as those allowed by the NHDOT for its permanent installations. The only significant difference is the materials employed for temporary barrier do not need to be new, although they must be in like-new condition. The two metal beam types of temporary rail typically used are the W and Thrie beam sections, and are generally specified in available lengths of 12'-6."

i) Guardrail - Use

Guardrail in work zone applications can be used in a similar manner as PCB. Typically, it is placed between the traffic and workspace to prevent vehicle intrusions, and may also be placed between travel lanes and roadside hazards. As with PCB, consideration must be given to impact deflection, which is a function of rail tension provided by anchorages and from soil resistance at the posts. To reduce the deflection when approaching areas where there is an obstruction behind the rail or the work zone cannot sustain the normal degree of deflection, the rail may be double nested and/or the post spacing reduced by half to as much as a quarter normal spacing lengths. However, care must be taken to gradually transition to the stiffer rail section in order to avoid the potential for vehicles snagging (pocketing) or tearing the rail segment.

This temporary guardrail is normally used where the construction situation requiring the protection would be of relatively long duration, thereby making the installation and removal time frames economically justifiable. Some of the advantages over PCB include allowing sheet flow drainage under the rail, ease of winter maintenance, less vertical obstruction for sight lines, and ability to accommodate sharp curves, particularly at driveways and intersections.

ii) Guardrail – Design Considerations

As with PCB, the RDG discusses a number of design considerations that need to be addressed in the application of guardrail:

- Flare rate – the rate at which Temporary Guardrail approaches the traveled way – recommended flare rates are provided in the RDG
- Minimum offset – a minimum offset of 2 feet from the edge line of the travel lane to the Temporary Guardrail is considered desirable and acceptable for winter maintenance. Low lateral clearances may adversely impact traffic flow.
- Deflection is a function of rail tension provided by anchorages and from soil resistance of the posts.
- Performance level – Temporary guardrail designs have been tested at NCHRP Report 350 and MASH test level three (TL3) and are

acceptable for use on higher speed roadways, including their terminal units. However, some terminal unit designs are approved at NCHRP Report 350 and MASH test level two (TL2) and may only be used when required or approved and only on roadways with speeds of 45 MPH or less.

c. Temporary Traffic Control Barrier

Temporary traffic control barrier may be guardrail, portable concrete barrier or any equal positive protection with appropriate end treatment that meets approved crash test criteria. It is specified when the actual type of barrier to be used is not critical as long as it meets specific design criteria for the construction scenario. The contractor determines the ultimate choice of the specific type of barrier during his bid.

i) Use of Temporary Traffic Control Barrier

Temporary traffic control barrier is used the same as other barriers stated earlier. In those cases where the design criteria such as deflection, height of barrier, etc. can allow significant leeway without compromise of the protection of the workers or traveling public, then any of a number of NCHRP Report 350 and MASH approved treatments may be used. This approach allows bidders on a project the opportunity for fitting the protection to the work operations they plan. It also negates the need to predict what positive protection measure is the best suited to the construction scenario, what operations will be performed using what equipment, in what sequence, and so on, without compromising the workers' protection.

As with the other previously mentioned means of positive protection, deflection, flare rate, offset, joints, height, test level, and any other pertinent parameter will need to be considered when approving the contractor's ultimate choice.

ii) End Terminal Treatments

Both the RDG and the MUTCD require proper end treatments on temporary barriers to reduce the severity of impacts on the barrier end. Acceptable end treatments include:

- An approved crashworthy terminal connection to an existing crash-worthy temporary barrier.
- Provisions for an approved crashworthy end treatment such as an impact attenuator.
- Flaring the end of the barrier at the approved rate beyond the edge of the clear zone (an area off the edge of the travel way that should be free of hazards). Guidance on the flare rate and grading can be obtained within the RDG.
- Burying the end in the backslope appropriately so that vehicles avoid direct impact with the end and instability when they

encounter the backslope. (Placing fill, sand, etc., in attempt to cushion an impact at the end of the barrier will not be permitted)

d. Temporary Impact Attenuation (mechanical)

The term "mechanical" has been added to that of Temporary Impact Attenuation to differentiate it from other non-mechanical attenuator systems such as sand barrel arrays. This is a protective device that is specifically designed to control deceleration of an impacting vehicle at an acceptable rate. These devices must meet approved crash test criteria for the application in which they are being used.

i) Use of Temporary Impact Attenuation (Mechanical)

Typically this consists of a device that connects to the end of PCB, Temporary Guardrail (double faced), or Temporary Traffic Control Barrier in order to protect errant vehicles from the blunt end of those barriers. These devices may also be used to protect traffic from encountering a fixed object of fairly limited size such as a concrete pillar or similar item. These devices absorb much of the energy of impact by transferring it into mechanical resistance or by deformation of certain components of the attenuator. These devices can be relatively expensive but may be necessary due to the need for access within worksites along runs of barrier while providing protection, or where flaring the barrier to outside of the clear zone is not practical.

ii) Work Zone Considerations of Use of Temporary Impact Attenuation (Mechanical)

There are a number of considerations for the appropriate use of Temporary Impact Attenuation (Mechanical):

- Performance Level: as with the other devices, Temporary Impact Attenuation devices are designed for and approved at different crash test levels.
- Redirectional versus non-redirectional devices: These are also referred to as non-gating and gating devices. Redirectional, in this context, means that a vehicle impacting into the attenuator is redirected away from the barrier back towards the traveled way with similar performance as longitudinal barrier. Non-redirectional means that the vehicle is not redirected toward the travelway, but actually can pass through the attenuator and enter the space behind the barrier. When using non-redirectional devices, a rectangular area of 75 feet behind the terminal (parallel to the barrier system) and 20 feet perpendicular to the barrier system should be relatively traversable, free of fixed objects, and unobstructed of construction activity including construction equipment and supplies.

- Width: some devices are wider than others and due to space limitations such as narrow medians, restricted work zones, etc. narrower devices may be necessary.
- Length: due to restricted work areas, mechanical attenuator devices that are generally shorter than other attenuation systems, like sand barrel arrays, may be necessary to fit the situation.
- Functionality after an impact: There are devices that are more serviceable and often can be easily restored after suffering a relatively minor impact. The effort to restore devices to full function ranges from very modest, to very intensive. It may require only repositioning and a few inexpensive parts, or it could require full replacement of substantial portions of the device. Some continue to function at full, or near full, capability even after a significant impact without any restorative work. The probability of being impacted must be weighed against the cost of more resilient devices along with the difficulty to restore the devices after impact and the safety implications to the worker(s) doing the restorative work.
- Site preparation: Some devices require substantial preparation to the site such as grading of the fore-slopes not to exceed 10:1 and possible installation of a concrete pad. These conditions may affect the ability to economically relocate the device if the positive protection configuration will be altered during the work effort. The preparatory work may not be practical due to site conditions and impacts to permanent features of the roadway that would not otherwise be disturbed.

f. Sand Barrel Arrays

Sand Barrel Arrays consist of a number of drums that are filled with sand to a specified weight that provide protection to the vehicle user from impacting an obstacle or restrict intrusion into an area. This is accomplished by transferring the energy of the vehicle to the mass of the sand, which is released from the frangible barrels and slows or brings the vehicle to a stop. The number of barrels required, weight of sand fill needed in each, and the placement pattern are determined by the anticipated traffic speeds at the site it is being used and the manufacture's design specifications.

i) Use of Sand Barrel Arrays

Typically these are used to shield the ends of temporary traffic control barrier in order to protect errant vehicles from the blunt end of any of those barriers. Also these are used to shield traffic from encountering a fixed object of fairly limited size such as a concrete pillar or similar item. Additionally they can be used to shield a work area from intrusion.

ii) Work Zone Considerations of Use of Sand Barrel Arrays

- Expense: This type of device usually has a very modest installation and removal cost. Intermediate repairs may be more problematic and usually require replacement of all barrels impacted. Damage is typically adjacent to where the traffic is being maintained.
- Weather/Seasonal restrictions: Sand barrels are prohibited by the Standard Specification to be used between November 1st and April 15th, unless they are at least ten feet away from the travelway (measured to the face) or specifically approved in writing by the Engineer (Section 606.2.12.2.1). If used during these times, the sand must be treated to prevent freezing and located beyond the influence for winter maintenance. The barrels themselves are made from plastic and can become brittle in inclement conditions, thus being very susceptible to damage from snow removal operations. Proper performance of these devices is dependent on the sand not freezing into a solid mass. Untreated sand may freeze making the system rigid and non-attenuating, thereby becoming a significant hazard itself to errant vehicles.
- Functionality after an impact: This device usually undergoes significant degradation of functionality even after a relatively minor impact. Significant clean up of the sprayed sand and replacement of substantial portions of the device are typically required. During the time between when the device is impacted and fully restored there is commonly very little to no protection offered by the device. If the device is near the traveled way, cleanup needs to be done promptly as the resultant sand on the pavement may cause instability in vehicles traveling through the site.
- Site preparation: There is very little site preparation outside of ensuring that the placement of these is on a firm, stable, relatively level area. Removal does not result in significant damage to the area.
- Width: Sand Barrel Arrays are usually wider than any other type of attenuation as they almost always require a multiple barrels in width to provide adequate protection. As with other wider attenuation, this is not well suited to physically restricted work areas, narrow medians, etc.
- Length: The length of the sand barrel array is dependent on speed. The higher the speed, the longer the barrel array required to resist the impact forces, which again may make it unsuitable if this dimension of the work zone is restricted.

g. Truck or Trailer Mounted Attenuation (TMA)

This type of device is a temporary impact attenuator that is mounted on a truck or trailer of suitable size, as specified by the manufacturer. It provides attenuation by deformation of cartridges within the attenuator or some other manner of making the impact energy dissipate mechanically.

i) **Use of Truck or Trailer Mounted Attenuation**

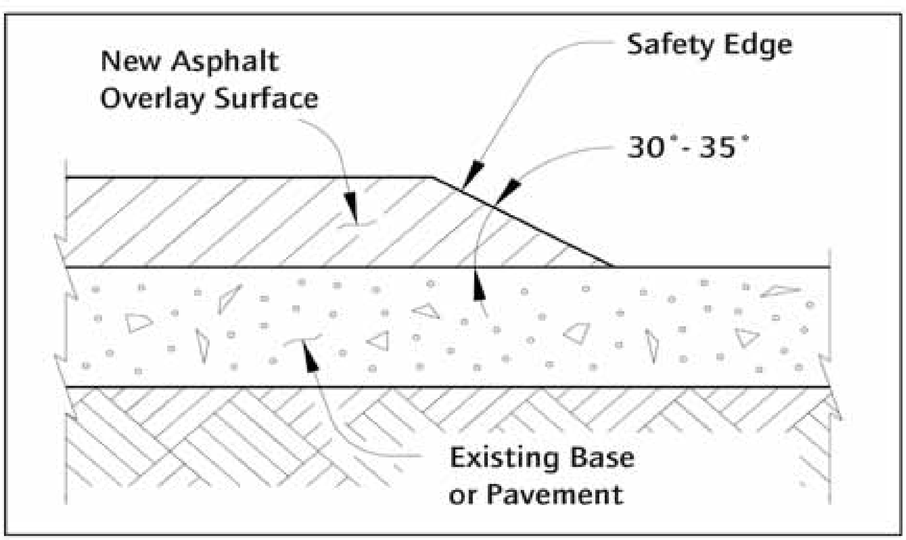
This type of device is effectively used to shield mobile and shorter duration operations from traffic. TMA should be considered for many short duration operations in construction work zones such as at access point protection, delivery points for materials, and any miscellaneous operations that place workers near traffic for short durations. A TMA may also be used to shield fixed objects, materials, or other hazardous situations that move or are relocated frequently. TMAs are becoming more common in many work zone applications because of their flexibility and versatility of operation.

ii) **Work Zone Considerations of Use of Truck or Trailer Mounted Attenuation**

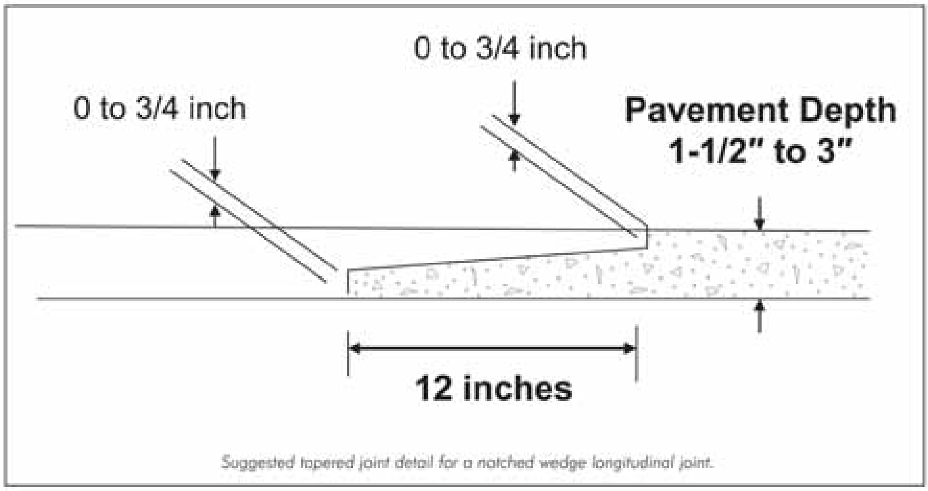
- Work duration: This device is best suited to mobile or very short duration work operations as it is easily moved and positioned.
- Portability: This is the primary benefit of this type of attenuation. However, while being moved, and particularly during mobile operations, the driver of the vehicle supporting the TMA is exposed to some risk. Care should be taken while a TMA is being moved the driver of the vehicle be not put in excessive risk unnecessarily.
- Protection: This device provides protection from intrusion over a relatively short work area and therefore is generally not suitable for lengthy workspaces.
- Performance: As with other attenuation, this device can be acquired to protect at different test levels. Usually, larger more expensive devices are required for high-speed roadways due to the vehicle mix and speeds. The FHWA roadside safety website http://safety.fhwa.dot.gov/roadway_dept/road_hardware/index.htm includes acceptance letters for TMAs that are acceptable for use on highway projects. The designer needs to choose the specifications that best suit the device to the application.
- Functionality after an impact: These devices are typically capable of handling minor impacts with minimal damage and often will continue to provide some level of protection after minor impacts. After more significant hits, these devices often will need to be completely replaced. These devices are almost always a cost effective means to provide protection for mobile and shorter-term operations.

B. Guidance on Longitudinal Edge Drop-Offs and Signage

In discussing the impact of various depths of a pavement edge drop-off on different types of highway with traffic traveling at different speeds, it is important to recognize that not all drop-offs are equal. Shear edge drop-offs, which are usually produced by milling, cold-planing, saw cuts, or other similar machine work are more difficult for a vehicle to traverse than rounded edge drop-offs usually produced by paving operations. Similarly, creating a pavement wedge between two pavement elevations allows for much easier traversing by vehicles moving between lanes having minor to moderate pavement elevation changes. Two pavement wedge formations have been shown to substantially increase safety and assist in pavement maintenance and compaction. The "Safety Edge" with a 30°-35° slope is most commonly used at shoulder edge drop-offs, but can also be used to soften the transition between different elevations of pavement surfaces. The "Notched Wedge Joint" has a slightly steeper slope than the Safety Edge, and is the newest promising wedge joint used between longitudinal pavement joints during paving operations.



Safety Edge Joint



Notched Wedge Joint

In addition, the vehicle types and volumes must be considered when determining the edge drop-off exposure, which will be allowed. Obviously, vehicles such as motorcycles and bicycles are at a much greater risk of instability attempting to traverse a drop-off of any significance, especially if the transition between the elevation changes is at all shear or just slightly rounded. Other vehicles could also experience instability in attempting to traverse an edge drop-off, resulting in over steering and leaving its lane.

The cases described below were developed to provide some level of guidance on typical applications but do not cover all potential scenarios. The cases are built around the depth of the edge drop-off, the type of facility it will be used on, and the posted speed limit of the roadway. It should be clear to the designer and construction personnel overseeing the work that there are many other factors that must be considered in assessing the overall risk the particular edge drop-off produces and the appropriate measures which will be applied to mitigate the determined risks. This guidance is not a rigid standard, as each situation should be analyzed individually as for location and overall duration of exposure.

Special consideration must be taken for duration of time the edge drop-off will be in place and whether the edge drop-off will be left when work is completed for the day. During working hours the guidance provided would still apply, but greater latitude in its application is appropriate as drivers generally will be more cautious when driving through an active work site knowing that unexpected things can occur at any time, and that work activities are dynamic and may require different measures. Much of the guidance below was developed considering an edge drop-off that will be left after construction activity is completed at the end of the work day (unless otherwise noted).

Provided below are three cases for guidance on how to address various pavement edge drop offs between lanes and general guidance for shoulder edge drop-off for all highway conditions. The lane edge drop-off cases are divided up by general highway type and the posted speed limits. As with all the scenarios described below, the contractor's operations producing the drop off should be limited, where reasonably possible or practical, to daily production in order to limit exposure during non-work hours. When this is not possible, a Notched Wedge Joint or Safety Edge treatment should be considered where appropriate.

1) LANE EDGE DROP-OFFS

CASE I – Multi-lane, Divided Highways with Posted Speeds Greater than 45 MPH

< ¾-Inch Edge Drop-Offs:

- Use appropriate signage;
  - UNEVEN LANES
  - PASS WITH CARE
- Contractor's operation for length of edge drop off should be limited to daily production to limit exposure during non-work hours.

1-Inch to 1 ½-Inch Edge Drop-Offs:

- No lane changes recommended (unless safety edge is provided);
- Use appropriate signage;
  - UNEVEN LANES
  - STAY IN LANE
  - MOTORCYCLES USE CAUTION
- Use appropriate channelizing devices;
  - With lane change to be maintained – RPM's and/or temporary pavement markings (paint or tape);
  - With lane change to be temporarily restricted after work hours – RPM's and tubular markers;
- Use Notched Wedge Joint or Safety Edge treatment on exposed edge drop-offs.

> 1 ½ -Inch to 2-Inch Edge Drop Offs:

- Restrict lane changes;
- Requires Notched Wedge Joint or Safety Edge treatment, if not behind barrier;
- Use appropriate signage;
  - DO NOT PASS
  - STAY IN LANE
  - LANE CLOSED
- Use channelizing devices – at minimum, use cones during work hours, and drums, tubular markers, etc. during off hours.

> 2-Inch Edge Drop Offs:

- Not allowed during non-work hours;
  - The contractor should be required to "square up" at the end of each work shift, leaving no exposed lane drop-off during non-work hours;
- Use appropriate channelizing devices – cones or barrels during work hours.

CASE II – Undivided Highways with Posted Speeds Greater than 45 MPH

<u>< ¾ -Inch Edge Drop-Offs</u>:

- Passing may be allowed;
- Use appropriate signing –
  - UNEVEN LANES
  - PASS WITH CARE
  - MOTORCYCLES USE CAUTION
- Suitable pavement markings- RPMs or temporary pavement markings (paint or tape).

<u>1-Inch to 1½ Inch Edge Drop-Offs</u>:

- No passing allowed (unless safety edge is applied);
- Use appropriate signing;
  - UNEVEN LANES
  - DO NOT PASS
  - STAY IN LANE
- Use appropriate channelizing devices;
  - RPMs or temporary pavement markings (paint or tape)
  - Cones during work hours;
  - When passing to be restricted – drums or tubular markers during non-work hours;
- Consider the use of the Notched Wedge Joint or Safety Edge Joint treatment.

<u>> 1½-Inch to 2-Inch Edge Drop-Offs</u>:

- No passing allowed;
- Use larger channelizing devices during non-working hours – tubular markers, drums, etc.;
- Appropriate signing;
  - UNEVEN LANES
  - NO PASSING ZONE
  - DO NOT PASS
- The contractor should be required to "square up" at the end of each work shift, leaving no exposed lane drop-off during non-work hours.

<u>> 2-Inch Drop-Offs</u>:

- Not allowed during non-work hours;
  - The contractor should be required to "square up" at the end of each work shift, leaving no exposed lane drop-off during non-work hours.
- Use appropriate channelizing devices – cones or barrels during work hours.

CASE III – Any Highway, Posted Speed Less than or Equal to 45 MPH

<1½-Inch Edge Drop-Offs:

- Passing may be allowed;
- Use appropriate signing –
    - UNEVEN LANES
    - PASS WITH CARE
    - MOTORCYCLES USE CAUTION
- Suitable pavement markings- RPMs or temporary pavement markings (paint or tape);
- Notched Wedge Joint or Safety Edge should be considered when passing is allowed.

> 1½ Inch to 3 Inches Edge Drop-Offs:

- No passing allowed;
- Use appropriate signage;
    - UNEVEN LANES
    - DO NOT PASS
- Use appropriate channelizing devices
    - Cones or barrels during work hours;
    - RPMs or temporary pavement markings (paint or tape) and tubular markers or barrels during non-work hours.

> 3-Inch Edge Drop-Offs:

- Not allowed during non-work hours.
    - The contractor should be required to "square up" at the end of each work shift, leaving no exposed lane drop-off during non-work hours.
- Use appropriate channelizing devices – cones or barrels during work hours.

2) SHOULDER EDGE DROP-OFFS

< 1 ½-Inch Edge Drop Offs:

- Use appropriate warning signs
    - SHOULDER DROP OFF
    - LOW SHOULDER

> 1½-Inch to 3-Inch Edge Drop Offs:

- Close Shoulder (unless safety edge is applied);
- Use appropriate signing;
    - SHOULDER CLOSED (with distance)
- Use appropriate channelizing devices – cones during work hours, and tubular markers, drums, etc. during non-work hours;
- Consider Notched Wedge Joint or Safety Edge treatment (especially when edge drop-off approaches higher elevation changes);

- Notch Edge Joint or Safety Edge Joint should be required where shoulder intersects on/off ramps and intersection side streets.

<u>> 3-Inch to < 5-Feet Edge Drop-Offs</u>:
- Close Shoulder;
- Use appropriate signing;
    - SHOULDER CLOSED (with defined distance)
- Use appropriate channelizing devices – cones during work hours, and tubular markers, drums, etc. during non-work hours;
- Provide Safety Edge treatment for elevation difference from 3 inches to 5 inches during non-work hours;
- Provide 4:1 or flatter edge treatment for elevation differences greater than 5 inches during non-working hours;
- Consider the use of Positive Barrier Protection if edge treatments are not possible or if length of exposure requires added protection for workers and/or traveling public.

<u>> 5 Feet Edge Drop-Offs</u>:
- Close Shoulder <u>with</u> Positive Barrier Protection;
- Use appropriate signage - SHOULDER CLOSED, etc;
- Ensure barrier has appropriate delineator markings, impact attenuation and temporary lighting for traffic condition.

3) RECOMMENDED CHANNELIZATION DEVICE SPACING

Unless otherwise specified by the MUTCD, all channelizing devices and raised pavement markers should be spaced at the following recommended intervals.

i) **Raised Pavement Markers (RPM)**

(1) For solid, single line delineation – use single line of RPMs spaced at no more than 40 foot intervals;

(2) For double solid line delineation – use double line of RPMs, set 4 inches apart and spaced at no more than 40 foot intervals;

(3) For broken-line delineation (permitted passing areas) – use three RPMs for delineation of dash line, set 5 feet apart, and space at 30 foot intervals

ii) Channelization Devices (Barrels, Cones, Tubular Markers, etc)

The spacing distances between channelization devices are classified by two types of general layouts, which are "lane taper" transition zones (encompassing lane merges, shifts and shoulder tapers) and longitudinal, "tangent" zones. A lane merging transition generally requires the longest taper distance to allow the driver to merge into common road space. A shifting transition is used for a lateral traffic shift without vehicle changing lanes and, as such, can be achieved at a sharper taper. The taper rates for construction zones are established under Part 6 of the MUTCD. A longitudinal "tangent" zone is referred to the non-tapered areas where channelizing devices are being used to separate traffic from the workspace or to restrict traffic movement as drivers are traveling along the roadway horizontal alignment.

The following spacing is recommended for each zone:

(1) Lane taper zones (merge, shift transitions and shoulder tapers) – spacing of channelization devices should not exceed the distance (ft) equal to the 1.0 time the speed limit in mph (i.e.: 30 mph – spacing set at 30 feet between device);
(2) Non-taper (tangent) zones – spacing of channelization devices should not exceed the distance (ft) equal to 2.0 times the speed limit in mph (i.e.: 50 mph – spacing set at no more than 100 ft between devices). Shorter spacing should be considered on sharp horizontal curves or in other situations where better delineation may help traffic clearly define the intended travel path;
(3) Tubular markers used in conjunction with RPM's or other temporary markings to prohibit passing should be spaced at 200 feet apart.

4) RECOMMENDED SPACING FOR WARNING SIGNS

Unless otherwise specified, the typical minimum spacing between reminder warning signs of lane and shoulder drop-offs should be as follows:

Speed	Spacing
20 mph	1,000 ft
30 mph	1,300 ft
40 mph	1,800 ft
50 mph	2,200 ft
60 mph	2,600 ft
70 mph	3,000 ft

C. Software for Evaluation of Traffic Control Operations

Traffic software programs are available to assist the designer in evaluating the appropriateness of the traffic control strategies. The use of the traffic software is intended to supplement the decision process and evaluate the effects of lane reduction, lane restrictions, shoulder use, and detour routes. The traffic software can provide a tool for assessing delay and back-up predictions. The analysis is dependent upon traffic data for the temporary traffic conditions and will likely rely on projected peak traffic flows for the effective evaluation period. Key traffic data that assists the designer in the evaluation of reduced lanes is the 24/7 hourly traffic counts. General "rule-of-thumb" is a traffic lane has a theoretical lane capacity under ideal conditions of 2,000 vehicles per hour. However, the effects of lane width reduction, loss of shoulder offset to positive barrier protection, increasingly tight geometric horizontal and vertical alignments and reduced operating speeds through a work area will have a negative affect on the capacity of the roadway section. The theoretical lane capacity under these conditions may limit lane capacity between 900 vph to 1,400 vph per lane. A theoretical construction capacity of 1,200 vph per lane is supported as a planning rate for evaluation of temporary traffic control strategies. Several software programs are available to assist the designer to further evaluate the capacity and predict delay.

The following three traffic analysis software programs are readily available for the designer to use in evaluating a particular temporary traffic control strategy. The software programs vary from a simple two-phase signalization planning evaluation to more diverse program evaluations for intersection and work zones. The programs are as follows:

1 Two-Phase Highway Capacity Manual Software

The Microsoft "excel" base traffic program is a simple two-phase analysis program developed by Highway Design (Preliminary Design) and is intended to evaluate a single lane operation with or without traffic signals. The result from this quick assessment will provide the designer a fair understanding as to the viability of a single lane operation under a Level of Service (LOS) and delay evaluation. The program can be located at "G:\prelim\detour.xls"

2. Synchro plus SimTraffic 6

Synchro plus SimTraffic analyzes traffic operations of signalized and unsignalized intersections and networks using the methodology from Highway Capacity Manual with incorporation of propriety software language. As part of the SimTraffic module within Synchro, an animated simulation of the network traffic flows can be developed. The software can develop the surface transportation network model (arterial streets, freeway interchanges, etc) for managing traffic signal timing. In addition, Synchro will analyze network traffic operations including constraints imposed by construction (i.e.: loss of turn lanes, through lanes, etc) to determine the most effective design configuration for the least costs and establish optimize signal timing.

3. QuickZone 2.0

QuickZone is interactive and analytic software developed by FHWA to estimate and quantify work zone delays. QuickZone allows for a quick and flexible estimation for work zone delay supporting four phases of project development (policy, planning, design and operations). The software allows users to: 1) Quantify corridor delay resulting from capacity decreases in work zones; 2) Identify delay impacts of alternative project phasing plans; and 3) Support tradeoff analyses between construction costs and delay costs. QuickZone is designed to quantify work zone impacts in terms of queues, user delays, travel behavior and costs. QuickZone is able to model various types of two-way, one-lane operations with lane dimension and restricted geometry under flagging operations. In addition, QuickZone is capable of evaluating driver behavior during non-peak and peak traffic conditions and assigns diversion flows to a detour network.