Design Guidance for Construction Work Zones on High-Speed Highways

Kevin M. Mahoney
Penn State University
Overview

- Scope of study
- Method
- Results
Overview

- Scope of study

- Method

Results
Panel, NCHRP 3-69

Michael Christensen, MnDOT (Retired) - Chair

James Kladianos, WY DOT
Russel Lenz, TX DOT
Herbert (Bert) Roy, NYS DOT
Robert Schlicht, FHWA
John Smith, MS DOT

Xiaoduan Sun, U of LA
J. Richard Young, PBSJ
Kenneth Opiela, FHWA
Frank Lisle, TRB
Charles Niessner, NCHRP
<table>
<thead>
<tr>
<th>Reviewers</th>
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<tbody>
<tr>
<td>James Brewer, KS DOT</td>
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<tr>
<td>Debbie Guest, LA DOTD</td>
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<tr>
<td>Mohammad Kahn, OH DOT</td>
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<tr>
<td>Glenn Rowe, PennDOT</td>
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<td>Marcella Saenz, TX DOT</td>
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<td>Norman Schips, NYS DOT</td>
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<td>David Smith, NH DOT</td>
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<tr>
<td>Barbara Solberg, MD SHA</td>
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<tr>
<td>Marty Weed, WS DOT</td>
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<td>Scott Zeller, WS DOT</td>
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</tbody>
</table>
Investigators

Kevin M. Mahoney, Penn State
Richard (R.J.) Porter, Penn State
Gerald L. Ullman, Texas Transportation Institute
Bohdan T. Kulakowski, Penn State
Overview

- **Construction work zone:**
  
  .. area occupied for three or more days ...

- **High-speed highways:**
  
  ... 85th percentile free-flow speed of 50 mph or greater

- **Coverage:**
  
  ... information or guidance not available in another nationally referenced publication
Final Deliverable, NCHRP 3-69

- Research report (summary of methods)

- Hard copy appendix: Design Guidance
  - Dual units: Metric [US Customary]
  - Green Book format and conventions

## Design Guidance

<table>
<thead>
<tr>
<th>Publication</th>
<th>Summary of Coverage</th>
<th>Relationship to Other Publication</th>
</tr>
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<tbody>
<tr>
<td>AASHTO Green Book</td>
<td>Geometric guidance for all types of roads, primarily permanent facilities.</td>
<td>This guidance supplements the limited guidance in the Green Book specifically related to work zones.</td>
</tr>
<tr>
<td>MUTCD</td>
<td>Traffic control devices, including temporary traffic control</td>
<td>This guidance should be used in conjunction with the MUTCD, which is applicable to work zones.</td>
</tr>
<tr>
<td>AASHTO Roadside Design Guide Chapter 9</td>
<td>Roadside safety, including work zone barriers, traffic control devices and other features</td>
<td>This guidance supplements RDG Chapter 9 regarding placement of temporary barriers in construction work zones.</td>
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<tr>
<td>Design Decision Guidance for Work Zones on High-Speed Highways</td>
<td>Geometric and physical features common to construction work zones on high-speed highways</td>
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</table>
Design Guidance

<table>
<thead>
<tr>
<th>Temporary Traffic Control</th>
<th>Construction Work Zone Design Features</th>
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<tbody>
<tr>
<td>Warning signs</td>
<td>Roadside safety</td>
</tr>
<tr>
<td>Arrow panels</td>
<td>Vertical alignment</td>
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<tr>
<td>Pavement markings</td>
<td>Entrance Ramps</td>
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<tr>
<td>Lane closure tapers</td>
<td>Superelevation</td>
</tr>
<tr>
<td>Flaggers</td>
<td>Temporary traffic barriers</td>
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<tr>
<td>Guide signs</td>
<td>Diversion</td>
</tr>
<tr>
<td>Variable message</td>
<td>Use of shoulder</td>
</tr>
<tr>
<td>Regulatory signs</td>
<td>Median Crossover</td>
</tr>
<tr>
<td>Channelizing devices</td>
<td>Sight distance</td>
</tr>
<tr>
<td></td>
<td>Vertical and Horizontal Clearance</td>
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<tr>
<td></td>
<td>Speed change lanes</td>
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<td></td>
<td>Exit Ramps</td>
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<td></td>
<td>Emergency Turnout</td>
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<tr>
<td></td>
<td>Drainage</td>
</tr>
<tr>
<td></td>
<td>Intersection closure/relocation</td>
</tr>
</tbody>
</table>
Design Guidance

State DOT Priorities

- Review of contractor TCPs
- Drainage
- Turnouts
- Travel lane width
- Horizontal alignment
- Stopping sight distance
- Visual barriers
- Traffic barriers & Roadside design
- Shoulder type & width
- Superelevation
- Vertical alignment
- Design speed

Mean priority rating of respondents (1 = high, 3 = low)
Design Guidance

- Guideline ..... not a standard
- Does not supersede “processes and criteria that have been implemented in an operational environment and carefully evaluated”
- Document alone cannot guide user to appropriate decision, must be applied by knowledgeable and experienced personnel
- “minimum” values identified selectively
Design Guidance: Contents

1. Terminology
2. Controls, Concepts and Principles
3. Conceptual Design and Planning
4. Roadway Design
5. Roadside Design and Barrier Placement
6. Ancillary Design Information
Design Guidance: Contents

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Design Controls and Principles

- Controls: “givens” that influence design
- Categories of controls
  - Human
  - Materials
  - Vehicles
  - Setting
  - Traffic
  - Facility type
  - Scope of project
- Generally similar to permanent road design
Principles

- Safety
- Design consistency
- Primacy
- Speed management
- Work zone design speed
- Sight distance
- Forgiving roadside
- Superelevation-horizontal alignment
Principles

- Safety *
- Design consistency
- Primacy
- Speed management *
- Work zone design speed *
- Sight distance *
- Forgiving roadside *
- Superelevation-horizontal alignment *
Principles: Safety

- Substantive v. Nominal
- Function of exposure
- Use completed research, but ...
- Many gaps in design-safety relationships
Principles: Speed Management

- Speed is controversial and prominent WZ topic
- Crash occurrence related to increased speed variance
- Basic speed management steps:
  - Establish reasonable target speeds
  - Employ measures to attain significant speed reductions
**Principles: Speed Management**

1. **Determine pre-project operating and/or posted speeds, approaching and within construction area.**
2. **Establish target speed based on approach speeds and pre-project conditions.**
3. **Establish work zone design speed based on target speed. Design work zone.**
4. **Identify and provide speed management measures needed to attain significant speed reduction.**
5. **All features related to work zone design speed are feasible?**
   - **Yes**: **Provide speed-related features and signing appropriate for target speed.**
   - **No**: **Establish target speed based on constraints.**

**Implement**
Principles: Sight Distance

- Previous research: in the SD ranges studied, limited SSD had no discernable effect on crash frequencies or rates. (NCHRP 400)
- One study: crash frequencies on crest vertical curves with SD less than 300 feet more than 50% higher than those with very long SD
- SD affects speed
Principles: Sight Distance

- Half of states responding to survey (16 of 32) do not apply stopping sight distance criteria to WZ design

- **Recommended guidance:** Provide at least 300 ft of SD with 3.5 ft eye height and 2.0 object height
Principles: Forgiving Roadside

- Principle is similar to permanent roads
- Conventional implementation of principle (i.e., clear zone) problematic in WZs
- Two (current) general approaches
  - Clear zone
  - Judgment based on conditions
Principles: Forgiving Roadside

### Table 5.1 - Example of work zone clear zone distances (continued)

<table>
<thead>
<tr>
<th>Approach</th>
<th>Clear Zone</th>
<th>ADT</th>
<th>Front Looks</th>
<th>Back Looks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low or Medium ADT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35 mph or less</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>35-45 mph</td>
<td>5-10</td>
<td>5-10</td>
<td>5-10</td>
<td>5-10</td>
</tr>
<tr>
<td>45-60 mph</td>
<td>5-10</td>
<td>5-10</td>
<td>5-10</td>
<td>5-10</td>
</tr>
<tr>
<td>60-70 mph</td>
<td>5-10</td>
<td>5-10</td>
<td>5-10</td>
<td>5-10</td>
</tr>
<tr>
<td>70-80 mph</td>
<td>5-10</td>
<td>5-10</td>
<td>5-10</td>
<td>5-10</td>
</tr>
<tr>
<td>80 mph or more</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

Approach posted speed is approx. posted speed prior to the work zone.

- **Guards:**
  - A guardrail should be installed to prevent motorists from crossing the work zone.
  - The presence of guardrails helps to prevent motorists from crossing the work zone.
  - Ensure that the guardrails are maintained and in good condition.
  - The guardrails should be placed at the edge of the work zone.

- **Traffic:**
  - Place traffic signs and signals to alert motorists to the work zone.
  - Provide clear and visible signs to indicate the work zone.
  - Ensure that traffic control devices are functioning properly.

- **Access:**
  - Ensure that access to the work zone is limited.
  - Provide access for emergency vehicles.
  - Ensure that access points are clearly marked.

**Note:**
- Clear zones may be limited to 18 feet for protection.
Principles: Forgiving Roadside

Example of judgment based on conditions

Consider the following factors:

- duration of construction activity (14 days or more),
- traffic volumes (including seasonal and special event fluctuations),
- nature of hazard,
- length and depth of dropoffs,
- work zone design speed,
- highway functional class,
- length of hazard,
- proximity between traffic and construction workers,
- proximity between traffic and construction equipment,
- adverse geometrics which may increase the likelihood of run-off-the-road vehicles,
- two-way traffic on one roadway of a divided highway,
- transition areas at crossovers, and
- lane closures or lane transitions.
Principles: Forgiving Roadside

Guidance

- Summarizes current state DOT practice
- Barrier placement for common WZ scenarios
- Uses cost-effectiveness approach in RSAP to explicitly account for factors (e.g., duration, traffic, proximity)
- Details and results presented later
Principles: Superelevation-Horizontal Curvature

**Green Book:**

- Method 5 used for permanent roads:
  - All rural (high speed, low speed)
  - High-speed urban

- Method 2 used for low-speed urban streets
Principles: Superelevation-Horizontal Curvature
Principles: Superelevation-Horizontal Curvature

- Many DOTs indicated not having an established procedure for SE in WZs
- 8 DOTs use different SE approach for WZs than permanent roads; 7 use Method 2 distribution
- **Recommended guidance**: Method 2 or 5
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Conceptual Design and Planning

- Identify alternatives
- Evaluate
  - Agency cost
  - User cost
  - Non-cost impacts (e.g., emergency services, worker safety, local events)
- Select
- Detailed design in parallel with project
# Conceptual Design and Planning

<table>
<thead>
<tr>
<th>Type/Strategy</th>
<th>Summary</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternating one-way operation</td>
<td>Mitigates for full or intermittent closure of lane(s). Used primarily with two-lane facilities.</td>
<td>Low agency cost and low non-transportation impacts; flexible, several variations available.</td>
<td>Requires stopping of traffic; reduces capacity.</td>
</tr>
<tr>
<td>Detour</td>
<td>Re-routes traffic onto other existing facilities.</td>
<td>Flexible; cost varies depending on improvements to detour route. In some cases, only TTC needed.</td>
<td>Usually reduces capacity; and service and infrastructure on existing roads may be degraded; may need agreement of another agency.</td>
</tr>
<tr>
<td>Diversion</td>
<td>Temporary roadway provided adjacent to construction.</td>
<td>Separates traffic from construction; reduced impact on traffic.</td>
<td>Cost may be substantial, especially if temporary grade separation of hydraulic structure involved; right of way often required.</td>
</tr>
<tr>
<td>Full road closure</td>
<td>Facility closed to traffic for specified (limited) duration.</td>
<td>Generally also involves expedited construction; separates traffic from construction.</td>
<td>Some form of mitigation needed (detour, diversion). Potentially significant traffic impacts.</td>
</tr>
<tr>
<td>Intermittent closure</td>
<td>Traffic stopped for a short period of time.</td>
<td>Flexible and low agency cost.</td>
<td>Useful only for activities that can be completed in short time. Requires stopping traffic.</td>
</tr>
</tbody>
</table>
Conceptual Design and Planning

<table>
<thead>
<tr>
<th>Type</th>
<th>Summary</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane closure</td>
<td>One or more travel lanes closed.</td>
<td>Maintains service; fairly low agency cost.</td>
<td>Reduces capacity, may involve traffic close to active work.</td>
</tr>
<tr>
<td>Lane constriction</td>
<td>Traveled way width reduced.</td>
<td>Maximizes number of travel lanes.</td>
<td>Traveled way width is less than desirable.</td>
</tr>
<tr>
<td>Median crossover</td>
<td>Maintain bi-directional traffic on one roadway of a normally divided highway.</td>
<td>Separates traffic from construction; right of way not required.</td>
<td>Reduced capacity, not consistent with approach roadway; relatively costly; interchanges need special attention.</td>
</tr>
<tr>
<td>Use of shoulder(s)</td>
<td>Use shoulder as travel lane.</td>
<td>Fairly low cost, depending on shoulder preparation.</td>
<td>Displaces traditional refuge for disabled vehicles. Debilitates shoulder pavement structure. Cross slopes may be problematic.</td>
</tr>
</tbody>
</table>
Conceptual Design and Planning

Screening two-lane road strategies

<table>
<thead>
<tr>
<th>Alternating, one way operation (mitigation)</th>
<th>2s</th>
<th>3s</th>
<th>3s</th>
<th>2s</th>
<th>3s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detour (mitigation)</td>
<td>3s</td>
<td>5s</td>
<td>4s</td>
<td>6s</td>
<td>3s</td>
</tr>
<tr>
<td>Diversion (mitigation)</td>
<td>4s</td>
<td>6s</td>
<td>5s</td>
<td>7s</td>
<td>4s</td>
</tr>
<tr>
<td>Full road closure</td>
<td>5s</td>
<td>6s</td>
<td>6s</td>
<td>7s</td>
<td>5s</td>
</tr>
<tr>
<td>Intermittent closure</td>
<td>1s</td>
<td>1s</td>
<td>1s</td>
<td>1s</td>
<td>1s</td>
</tr>
<tr>
<td>Lane closure</td>
<td>2s</td>
<td>3s</td>
<td>2s</td>
<td>3s</td>
<td>2s</td>
</tr>
<tr>
<td>Lane constriction</td>
<td>2s</td>
<td>2s</td>
<td>2s</td>
<td>2s</td>
<td>2s</td>
</tr>
<tr>
<td>Use of shoulder(s) (mitigation)</td>
<td>2s</td>
<td>2s</td>
<td>2s</td>
<td>2s</td>
<td>2s</td>
</tr>
<tr>
<td>Options with unmitigated reduction in lanes</td>
<td>2s</td>
<td>3s</td>
<td>3s</td>
<td>2s</td>
<td>3s</td>
</tr>
</tbody>
</table>

Notes: Numerals indicate general ranking and feasibility. Several strategies often used in combination. Designation “s” indicates possible use in support of other strategy(ies).
Conceptual Design and Planning
Screening multi-lane road strategies

- Multi-lane undivided road, no shoulders
  - Lane construction feasible?
    - Yes: Half-width construction feasible?
      - Yes
        - Alternating, one way operation (mitigation)
          - Detour (mitigation)
            - 4s, 3s, 5s, 3s, 6s, 4s, 4s, 6s, 3s, 6s, 5s, 3s, 5s, 4s, 6s
          - Diversion (mitigation)
            - 5s, 4s, 6s, 5s, 7s, 5s, 7s, 5s, 7s, 4s, 6s, 5s, 7s
          - Full road closure
            - 5, 6, 6, 7, 6, 7, 6, 7, 5, 6, 6, 7
          - Intermittent closure
            - 1, 1, 1, 1, 1, 1, 1, 1, 1, 1
          - Lane constriction
            - 2, 2, 2, 2, 2, 2, 2, 2, 2, 2
          - Lane closure(s)
            - 2, 3, 4, 5, 2, 3, 4, 5, 2, 3, 4, 5, 2, 3, 4, 5, 2, 3, 4, 5
          - Crossover
            - 3s, 2, 2, 2, 2, 2, 2, 2, 2, 2
          - Reversible lane (mitigation)
            - 3s
          - Use of shoulder(s) (mitigation)
            - 2s, 3s, 2s, 3s, 4s, 2s, 3s
          - Options with unmitigated reduction in lanes
            - 2, 3, 2, 2, 2, 4, 3, 2, 3, 2, 4, 2, 3
      - No
        - Crossover
          - 3s, 2, 2, 2, 2
          - Reversible lane (mitigation)
            - 3s
          - Use of shoulder(s) (mitigation)
            - 2s, 3s, 2s, 3s, 4s, 2s, 3s
          - Options with unmitigated reduction in lanes
            - 2, 3, 2, 2, 2, 4, 3, 2, 3, 2, 4, 2, 3

- Multi-lane undivided road, shoulders
  - Lane construction feasible?
    - No
      - Half-width construction feasible?
        - Yes
          - Alternating, one way operation (mitigation)
            - Detour (mitigation)
              - 4s, 3s, 5s, 3s, 6s, 4s, 4s, 6s, 3s, 6s, 5s, 3s, 5s, 4s, 6s
            - Diversion (mitigation)
              - 5s, 4s, 6s, 5s, 7s, 5s, 7s, 5s, 7s, 4s, 6s, 5s, 7s
            - Full road closure
              - 5, 6, 6, 7, 6, 7, 6, 7, 5, 6, 6, 7
            - Intermittent closure
              - 1, 1, 1, 1, 1, 1, 1, 1, 1, 1
            - Lane constriction
              - 2, 2, 2, 2, 2, 2, 2, 2, 2, 2
            - Lane closure(s)
              - 2, 3, 4, 5, 2, 3, 4, 5, 2, 3, 4, 5, 2, 3, 4, 5
            - Crossover
              - 3s, 2, 2, 2, 2, 2, 2, 2, 2, 2
            - Reversible lane (mitigation)
              - 3s
            - Use of shoulder(s) (mitigation)
              - 2s, 3s, 2s, 3s, 4s, 2s, 3s
            - Options with unmitigated reduction in lanes
              - 2, 3, 2, 2, 2, 4, 3, 2, 3, 2, 4, 2, 3
        - No
          - Crossover
            - 3s, 2, 2, 2, 2
            - Reversible lane (mitigation)
              - 3s
            - Use of shoulder(s) (mitigation)
              - 2s, 3s, 2s, 3s, 4s, 2s, 3s
            - Options with unmitigated reduction in lanes
              - 2, 3, 2, 2, 2, 4, 3, 2, 3, 2, 4, 2, 3

- Multi-lane divided road, shoulders
  - Lane construction feasible?
    - No
      - Half-width construction feasible?
        - Yes
          - Alternating, one way operation (mitigation)
            - Detour (mitigation)
              - 4s, 3s, 5s, 3s, 6s, 4s, 4s, 6s, 3s, 6s, 5s, 3s, 5s, 4s, 6s
            - Diversion (mitigation)
              - 5s, 4s, 6s, 5s, 7s, 5s, 7s, 5s, 7s, 4s, 6s, 5s, 7s
            - Full road closure
              - 5, 6, 6, 7, 6, 7, 6, 7, 5, 6, 6, 7
            - Intermittent closure
              - 1, 1, 1, 1, 1, 1, 1, 1, 1, 1
            - Lane constriction
              - 2, 2, 2, 2, 2, 2, 2, 2, 2, 2
            - Lane closure(s)
              - 2, 3, 4, 5, 2, 3, 4, 5, 2, 3, 4, 5, 2, 3, 4, 5
            - Crossover
              - 3s, 2, 2, 2, 2, 2, 2, 2, 2, 2
            - Reversible lane (mitigation)
              - 3s
            - Use of shoulder(s) (mitigation)
              - 2s, 3s, 2s, 3s, 4s, 2s, 3s
            - Options with unmitigated reduction in lanes
              - 2, 3, 2, 2, 2, 4, 3, 2, 3, 2, 4, 2, 3
        - No
          - Crossover
            - 3s, 2, 2, 2, 2
            - Reversible lane (mitigation)
              - 3s
            - Use of shoulder(s) (mitigation)
              - 2s, 3s, 2s, 3s, 4s, 2s, 3s
            - Options with unmitigated reduction in lanes
              - 2, 3, 2, 2, 2, 4, 3, 2, 3, 2, 4, 2, 3

Notes: Numerals indicate general ranking and feasibility. Several strategies often used in combination. Designation “s” indicates possible use in support of other strategy(ies).
Conceptual Design and Planning

Contracting Strategies and Issues

- A+Bx
- Design-Build
- Incentive-Disincentive
- Lane rental
- Night construction
- Review of contractor WZ designs
### Conceptual Design and Planning

#### Perceived Consequences of Night Work

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
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<tbody>
<tr>
<td>Lower traffic volumes and lower traffic impacts</td>
<td>Higher agency cost</td>
</tr>
<tr>
<td>Lower impacts to commercial activity</td>
<td>Higher safety risks</td>
</tr>
<tr>
<td></td>
<td>Disrupts normal social patterns of work force</td>
</tr>
<tr>
<td></td>
<td>Noise</td>
</tr>
<tr>
<td></td>
<td>Possible compromise in construction quality</td>
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</tbody>
</table>
Design Guidance: Contents

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Roadway Design

- Some WZ strategies: TTC only
- Roadway design guidance
  - Diversions
  - Lane constriction
  - Median crossover
  - Use of shoulder
  - Freeway interchange ramp
## Roadway Design

<table>
<thead>
<tr>
<th>Work zone type, mitigation strategy or element</th>
<th>MUTCD guidance</th>
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<tbody>
<tr>
<td></td>
<td>Freeway</td>
</tr>
<tr>
<td>Alternating one-way operation</td>
<td>NA</td>
</tr>
<tr>
<td>At-grade intersections</td>
<td>NA</td>
</tr>
<tr>
<td>Detour</td>
<td></td>
</tr>
<tr>
<td>Diversion</td>
<td></td>
</tr>
<tr>
<td>Full road closure</td>
<td>Need detour</td>
</tr>
<tr>
<td>Interchange ramp</td>
<td>√</td>
</tr>
<tr>
<td>Intermittent closure</td>
<td></td>
</tr>
<tr>
<td>Lane closure</td>
<td>√</td>
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<tr>
<td>Lane constriction</td>
<td></td>
</tr>
<tr>
<td>Median crossover</td>
<td>√</td>
</tr>
<tr>
<td>Use of shoulder</td>
<td>√</td>
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### Roadway Design

<table>
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<tr>
<th>Current ADT</th>
<th>Duration of operation</th>
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<tr>
<td></td>
<td>&lt; 5 days</td>
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<td>&lt; 500</td>
<td>A</td>
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<tr>
<td>500 - 1499</td>
<td>A</td>
</tr>
<tr>
<td>1500 - 6000</td>
<td>B</td>
</tr>
<tr>
<td>&gt; 6000</td>
<td>B</td>
</tr>
</tbody>
</table>

### Traveled Way Surface Type Guide

A = Aggregate or gravel
B = Aggregate or gravel with surface treatment
C = Design pavement structure
Roadway Design: Diversion

Example plan view
Roadway Design: Diversion

Example normal crown and superelevated sections
## Roadway Design: Diversion

<table>
<thead>
<tr>
<th>Current ADT</th>
<th>Traveled way width (ft)</th>
<th>Roadway width (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1000</td>
<td>22</td>
<td>26</td>
</tr>
<tr>
<td>1000 – 3000</td>
<td>22</td>
<td>30</td>
</tr>
<tr>
<td>&gt; 3000</td>
<td>24</td>
<td>36</td>
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</tbody>
</table>

Recommended roadway and travel way widths
Roadway Design: Diversion

Other design decisions:

- Work zone design speed
- Superelevation-horizontal alignment
- Vertical
  - Max grades: functional class
  - Crest: SD if applicable
  - Sag curves: Comfort
- Roadside design
Roadway Design: Lane Constriction

- Primarily TTC
- Undesirable - - yet often appropriate
- DOT practice varies
- Factors considered:
  - Facility type
  - Traffic volumes and mix
  - Curvature
  - Duration and length
  - Constraint
## Exhibit 6 - Example Framework for Selecting Directional Lane Constriction

<table>
<thead>
<tr>
<th>Number</th>
<th>Right</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>150</th>
<th>180</th>
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<tbody>
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<td>32</td>
<td>82</td>
<td>77</td>
<td>72</td>
<td>67</td>
<td>63</td>
<td>59</td>
<td>55</td>
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<tr>
<td>63</td>
<td>54</td>
<td>46</td>
<td>39</td>
<td>33</td>
<td>28</td>
<td>23</td>
<td>18</td>
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<td>93</td>
<td>84</td>
<td>75</td>
<td>66</td>
<td>57</td>
<td>49</td>
<td>41</td>
<td>34</td>
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</tbody>
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<th>90</th>
<th>120</th>
<th>150</th>
<th>180</th>
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<td>6</td>
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</tr>
<tr>
<td>72</td>
<td>63</td>
<td>56</td>
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<td>58</td>
<td>52</td>
<td>46</td>
<td>40</td>
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<td>37</td>
<td>31</td>
<td>25</td>
<td>20</td>
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<td>12</td>
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<tr>
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<td>75</td>
<td>69</td>
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<tbody>
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<td>54</td>
<td>47</td>
<td>40</td>
<td>34</td>
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<td>32</td>
<td>26</td>
<td>20</td>
<td>15</td>
<td>10</td>
<td>6</td>
<td>2</td>
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<td>52</td>
<td>46</td>
<td>40</td>
<td>34</td>
<td>28</td>
</tr>
</tbody>
</table>

**Legend:**
- **Required width (m):**
  - 26
  - 24
  - 22
  - 20
  - 18
  - 16
  - 14
  - 12
  - 10
  - 8
  - 6
  - 4
  - 2

- **Required number of lanes:**
  - 1
  - 2
  - 3
  - 4
  - 5
  - 6
  - 7
  - 8
  - 9
  - 10

- **Required number of access lanes:**
  - 1
  - 2
  - 3
  - 4
  - 5
  - 6
  - 7
  - 8
  - 9
  - 10

- **Required number of storage lanes:**
  - 1
  - 2
  - 3
  - 4
  - 5
  - 6
  - 7
  - 8
  - 9
  - 10

- **Required number of stop lanes:**
  - 1
  - 2
  - 3
  - 4
  - 5
  - 6
  - 7
  - 8
  - 9
  - 10

**Legend:**
- **Travelled way with (9):**
  - 26
  - 24
  - 22
  - 20
  - 18
  - 16
  - 14
  - 12
  - 10
  - 8
  - 6
  - 4
  - 2

- **Travelled way with (m):**
  - 26
  - 24
  - 22
  - 20
  - 18
  - 16
  - 14
  - 12
  - 10
  - 8
  - 6
  - 4
  - 2

- **Us Customary:**
  - 26
  - 24
  - 22
  - 20
  - 18
  - 16
  - 14
  - 12
  - 10
  - 8
  - 6
  - 4
  - 2

**Legend:**
- **Travelled way with (9):**
  - 26
  - 24
  - 22
  - 20
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  - 16
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  - 12
  - 10
  - 8
  - 6
  - 4
  - 2

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  - 26
  - 24
  - 22
  - 20
  - 18
  - 16
  - 14
  - 12
  - 10
  - 8
  - 6
  - 4
  - 2

- **Us Customary:**
  - 26
  - 24
  - 22
  - 20
  - 18
  - 16
  - 14
  - 12
  - 10
  - 8
  - 6
  - 4
  - 2
Roadway Design: Median Crossover

Connecting Roadway

Directional roadway used for two-way traffic

Example plan view
Roadway Design: Median Crossover

Connecting Roadway

- Work zone design speed
- Cross section
  - Travel lane width: 12 – 16 ft; higher end of range recommended
  - Shoulder width: 2 – 7 ft; symmetrical/asymmetrical
- Superelevation-horizontal alignment
- Vertical
  - Max grades: functional class; use lower values to maintain speed
  - Crest: SD if applicable and speed
  - Sag curves: Comfort
- Barrier and roadside design
Roadway Design: Median Crossover

Directional Roadway

- Cross section allocation
  - Asymmetrical
  - Shoulder width and pavement
  - Rumble strips

- Median and roadside design
  - Separating directions of travel (covered later)
  - “Trailing” bridge ends (covered later)
  - Other roadside
Roadway Design: Use of Shoulder

Example plan view

Temporary Concrete Barrier
Roadway Design: Use of Shoulder

- Shoulder pavement
  - Cross slope/superelevation
  - Structure
  - Surface condition (friction and ride)

- Roadside design
Roadway Design: Interchange Ramps

- Combination of TTC and geometry

- Entrance and exit ramps
  - Temporary ramps (with crossovers)
  - Minimum acceleration/deceleration lane lengths
Roadway Design: Interchange Ramps

Entrance Ramps: minimum acceleration lane lengths

- Most desirable: design criteria for permanent facilities
- Rules of thumb in use by DOTs:
  - Minimum 300 feet
  - 70% design criteria for permanent
- Traffic volumes (mainline and entrance ramp) and sight distance sometimes considered
Summary of process

1. The minimum acceleration lane length is determined using *Green Book* criteria. The top figure is the base value that may need adjustment for grade.

2. If an acceleration lane length equal or greater than the minimum criteria value is provided, no YIELD sign is warranted.

3. If an acceleration lane length less than the minimum criteria value is provided, the bottom figure is applied to determine appropriate signing.
Roadway Design: Interchange Ramps

Parallel Design

Taper Design
Roadway Design: Interchange Ramps

Cross section, entrance and exit

- Travel lane: 15 feet
- Shoulder:
  - Right: 6 feet minimum
  - Left: 2 feet minimum
Design Guidance: Contents

1. Terminology
2. Controls, Concepts and Principles
3. Conceptual Design and Planning
4. Roadway Design
5. Roadside Design and Barrier Placement
6. Ancillary Design Information
Roadside Design and Barrier Placement

**Principles of Roadside Design**
- forgiving roadside/clear zone
- identification and treatment of hazards
- benefit-cost analysis
- other considerations
  - length of need
  - flare rates
  - end treatments
  - crash cushions

**Existing Guidance (DOTs, RDG)**
- adjusted clear zone
- types of construction hazards requiring analysis
- gaps

**Roadside Safety Analysis Program**
- adaptation to work zones
- benefit-cost analysis
- common scenarios
Roadside Design and Barrier Placement

Roadside Safety Analysis Program (RSAP)

- NCHRP Report 492
- Capable of cost-effectiveness analysis of roadside safety improvements
- Used for development of warrants and guidelines of safety features
- Adapted for construction work zones
Roadside Design and Barrier Placement

Adaptation of RSAP
Roadside Design and Barrier Placement
Adaptation of RSAP

Severity Index vs. Impact Speed (Workers)

SI = 10
Average repair cost = $2000
Severity Index vs. Impact Speed (Light Equipment)

Severity Index SI = 0.1143 * impact speed

Average repair cost = $4000
Roadside Design and Barrier Placement

Adaptation of RSAP

Severity Index vs. Impact Speed (Heavy Equipment)

Severity Index

Impact Speed (mph)

SI = 0.1429 * impact speed

Average repair cost = $8000
Roadside Design and Barrier Placement

Adaptation of RSAP

- Adjustments to encroachment rate
  - 1.4 for 12-foot lanes
  - 1.5 for 11-foot lanes
  - 1.6 for 10-foot lanes

- FHWA KABCO crash costs to 2004
  - Fatal $2,938,000
  - Severe injury $203,400
  - Moderate injury $40,680
  - Minor injury $21,470
  - PDO $2,260
Roadside Design and Barrier Placement

- Installation Costs
  - PCB $27/LF
  - Guardrail $9/LF
  - Temporary impact attenuator $4000/each
  - Guardrail end treatment $600/each

- Repair Costs: vary by crash type
Guidance for Generic Scenarios:

1. Right Lane and Shoulder Closure for Part-Width Construction on a Four-Lane Divided Highway
2. Shoulder Closure on a Four-Lane Divided Highway with Minor Encroachment
3. Median Work on a Four-Lane Divided Highway with Minor Encroachment
4. Bridge Reconstruction with Temporary Diversion/Runaround on a Two-Lane, Two-Way Highway
5. Separation of Two-Lane, Two-Way Traffic on a Normally Divided Facility (*Results based on Ross & Sicking*)
6. Protection of a Normally Downstream Barrier End for Two-Lane, Two-Way Traffic on a Normally Divided Facility
Roadside Design and Barrier Placement

Scenario 1: Shoulder Closure on a Four Lane Divided Highway with Minor Encroachment
Generic Scenario 1: Shoulder Closure on a Four-Lane Divided Highway with Minor Encroachment

Typical Cross Section (Before Construction)

Typical Cross Section (During Construction)
Generic Scenario 1: Shoulder Closure on a Four-Lane Divided Highway with Minor Encroachment

Results of Benefit Cost Analysis

Exposure ($10^6$ vehicles) = Two-way ADT (veh/day) x Work Zone Duration (days) x 1/1,000,000
Generic Scenario 1: Shoulder Closure on a Four-Lane Divided Highway with Minor Encroachment

Results of Benefit Cost Analysis

Exposure (10^6 vehicles) = Two-way ADT (veh/day) x Work Zone Duration (days) x 1/1,000,000
Generic Scenario 1: Shoulder Closure on a Four-Lane Divided Highway with Minor Encroachment

Results of Benefit Cost Analysis

\[
\text{Exposure (10}^6\text{ vehicles)} = \text{Two-way ADT (veh/day)} \times \text{Work Zone Duration (days)} \times 1/1,000,000
\]
Generic Scenario 1: Shoulder Closure on a Four-Lane Divided Highway with Minor Encroachment
Scenario 1 Design Guidance (Alternative 1): Language from AASHTO Subcommittee on Design with the Following Divisions

- **Barrier recommended (B/C ratio ≥ 1.0)**
- **Barrier recommended (see note) (0.5 ≤ B/C ratio < 1.0)**
- **Barrier not normally considered except in special circumstances (B/C ratio < 0.5)**

Note: States are encouraged to conduct a study to determine whether or not a barrier is appropriate in these locations.
Scenario 1 Design Guidance (Alternative 2): Language from AASHTO Subcommittee on Design with the Following Divisions

- **Barrier recommended** (B/C ratio $\geq$ 2.0)
- **Barrier recommended (see note)** (1.0 $\leq$ B/C ratio < 2.0)
- **Barrier not normally considered except in special circumstances** (B/C ratio < 1.0)

Note: States are encouraged to conduct a study to determine whether or not a barrier is appropriate in these locations.
Roadside Design and Barrier Placement

Scenario 2: Shoulder Closure on Four Lane Divided Highway with Minor Encroachment
Generic Scenario 2: Shoulder Closure on a Four-Lane Divided Highway with Minor Encroachment
Roadside Design and Barrier Placement

Generic Scenario 3: Median Work on a Four-Lane Divided Highway with Minor Encroachment
Generic Scenario 3: Median Work on a Four-Lane Divided Highway with Minor Encroachment
Roadside Design and Barrier Placement

Scenario 4: Bridge Reconstruction with Temporary Diversion/Runaround on a Two-Lane, Two-Way Highway
Generic Scenario 4: Bridge Reconstruction with Temporary Diversion/Runaround on a Two-Lane, Two-Way Highway
Generic Scenario 5: Separation of Two-Lane, Two-Way Traffic on a Normally Divided Facility

Carry barrier through or terminate?
Generic Scenario 5: Separation of Two-Lane, Two-Way Traffic on a Normally Divided Facility

Typical Cross Section (During Construction — No Barrier)

Concrete Barrier Separating TLTW Traffic

Typical Cross Section (During Construction — Barrier)
Roadside Design and Barrier Placement

Scenario 6: Protection of a Normally Downstream Barrier End for Two-Lane, Two-Way Traffic on a Normally Divided Facility
Roadside Design and Barrier Placement

Scenario 6: Protection of a Normally Downstream Barrier End for Two-Lane, Two-Way Traffic on a Normally Divided Facility
Generic Scenario 6: Protection of a Normally Downstream Barrier End for Two-Lane, Two-Way Traffic on a Normally Divided Facility
Generic Scenario 6: Protection of a Normally Downstream Barrier End for Two-Lane, Two-Way Traffic on a Normally Divided Facility

- Normally Downstream Parapet Blunt End

| 12 m [40 ft] Bridge Width |

Typical Cross Section
(Departing Bridge Before Construction)

- Normally Downstream Parapet Blunt End
- Channelizing Device

| 6 m [20 ft] | 6 m [20 ft] |

Typical Cross Section at Interface Between Approach and Bridge for TLTW Traffic
No Protection of Blunt End

- Guardrail to Barrier Transition
- Channelizing Device

| 6 m [20 ft] | 6 m [20 ft] |

Typical Cross Section at Interface Between Approach and Bridge for TLTW Traffic
Protection of Blunt End with Guardrail
Design Guidance: Contents

1. Terminology
2. Controls, Concepts and Principles
3. Conceptual Design and Planning
4. Roadway Design
5. Roadside Design and Barrier Placement
6. Ancillary Design Information
Ancillary Design Information

- Drainage
- Temporary bridges
- Emergency turnouts
- Screens *
- Portable Changeable Message Signs *
- Arrow Panels *
- Lighting *
- Rumble strips

* Primarily references MUTCD
Ancillary Design Information

Example: Emergency Turnout
The End

- Questions
- Comments

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