Sloped-Down End Barriers Used in Diverging Diamond Interchange Designs: Survey of State Practice

Requested by
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Executive Summary

Background

Caltrans is designing approximately 12 diverging diamond interchanges (DDIs). Many state departments of transportation (DOTs) using this interchange design accommodate pedestrian and bicycle traffic by building medians with protective barriers, including concrete barriers with sloped-down ends, to protect the medians.

Currently, Caltrans has very few options to shield the blunt ends of protective barriers that divert pedestrians to the median. Most state DOTs use a sloped-down end barrier in these low-speed facilities, but Caltrans does not have an approved sloped-down end barrier design. A design for this safety hardware has been reviewed, but it has not been crash tested under the new 2016 *Manual for Assessing Safety Hardware* (MASH) criteria.

The Caltrans Division of Traffic Operations seeks to learn what other state DOTs are using with DDIs to protect pedestrians within the median. The division also seeks standard plan details or shop drawings associated with these protective barriers along with information about MASH testing conducted on these safety features.

To inform Caltrans' use of protective barriers with DDIs, CTC & Associates distributed an online survey to selected state DOTs. CTC also consulted state and federal experts expected to have knowledge of DDI designs and MASH testing. A limited literature search of domestic resources supplemented the findings from the survey and interviews.

Summary of Findings

This Preliminary Investigation gathered information in three areas:

- Survey of practice.
- Consultation with experts.
- Related research and resources.

Survey of Practice

An online survey was distributed to members of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Design. Eighteen state DOTs responded to the survey.

Two respondents have DDI projects in process: Maine DOT has begun designing its first DDI, while Connecticut DOT has a DDI in the concept phase. Twelve of the 18 state transportation agencies have constructed DDIs:

- Alabama.
- Arizona.
- Florida.
- Illinois.
- Indiana.
- Michigan.
- Minnesota.
- Mississippi.
- Nevada.
- Oregon.
- Utah.
- Wisconsin.

Two of these agencies—Mississippi and Wisconsin DOTs—constructed DDIs but do not use concrete barriers with sloped-down ends in a pedestrian median. Mississippi has only one DDI, which is a retrofit of an existing interchange. The DDI includes a raised median with no barrier

and no pedestrian access. Wisconsin has a single DDI installation that uses a 42-inch single slope concrete barrier installed for pedestrian safety.

Survey results from the remaining 10 agencies are presented in case studies that begin on page 8. Each case study includes the following information:

- Barrier locations.
- Primary factors determining the use of a protective barrier.
- Agency design guidance or plan details.
- Testing using 2016 MASH criteria or other type of evaluation or assessment.
- Federal Highway Administration (FHWA) approval for use of a protective barrier.

Several case studies also include additional details about the agency's DDI practices. Below is a summary of key findings from these case studies.

Barrier Locations and Factors Determining Use

Most of the 10 states providing information about DDIs using sloped-down end barriers described a single location. The Minnesota DOT respondent was the exception, citing seven locations within the state. Respondents reported on a range of factors considered when determining the use of a protective barrier, most commonly citing limitations that make other device installations undesirable or impossible, design speed, sight distance and safety. The table below summarizes the primary factors for determining an agency's use of a protective concrete barrier with a sloped-down end.

Primary Factors for Using a Sloped-Down End Barrier

Determining Factor	State	Description
Design speed	Florida, Illinois, Michigan, Nevada, Oregon	*Florida*. 35 mph or less. *Michigan*. 40 mph or less. *Nevada*. 20 mph.
Limited options	Alabama, Florida, Illinois, Michigan, Nevada, Oregon	*Florida*. No other crashworthy solution. *Illinois*. Device fits in available space. *Michigan*. Impact attenuator/other roadside safety device not feasible. *Nevada*. Area geometry restricts other safety hardware. *Oregon*. Site location.
Safety	Illinois, Oregon, Utah	*Illinois*. Traffic volumes (exposure). *Oregon*: • Positive protection. • Bicycle and pedestrian safety.

Primary Factors for Using a Sloped-Down End Barrier		
Determining Factor	**State**	**Description**
Safety	Illinois, Oregon, Utah	*Utah*: • Pedestrian volumes. • Other safety considerations.
Sight distance	Nevada, Oregon, Utah	N/A
Successful use in other states	Alabama, Minnesota	N/A
Other	Arizona, Illinois, Indiana	*Arizona*. Prevent vehicle from hitting barrier. *Illinois*. Offset from edge of traveled way. *Indiana*. Discourage pedestrian traffic.

Design Guidance and Plan Details

Respondents from five states—Arizona, Florida, Minnesota, Nevada and Utah—provided agency design guidance, plan details or shop drawings for protective concrete barriers with sloped-down ends. The Minnesota DOT respondent provided a Technical Memorandum that offers guidance for DDI implementation in the state, however, the design is not required. The respondent noted that the agency had implemented concrete barriers based on designs that were successfully implemented in other states. After gaining experience with these designs, Minnesota DOT finds the barrier represents a sight distance obstruction without providing measurable benefits for pedestrian or vehicular safety. The agency is considering excluding this barrier in future designs.

The Alabama DOT respondent was unable to provide formal plans but did report that the agency's barrier has a 10:1 slope and a terminal height of 1 foot at the sidewalk crossing. The Oregon DOT respondent was also unable to provide formal plans but did report that an F-shape bridge rail was used on the median, and a transition was designed for the sloped-down end barrier. Guidance or plan details were not available from Illinois, Indiana and Michigan DOTs.

Barrier Testing

None of the 10 respondents whose agencies used concrete sloped-down end barriers in DDIs reported conducting tests of these protective barriers or planning to conduct tests in the future using the criteria from the 2016 edition of MASH or using other evaluations or assessments.

The Illinois DOT respondent noted that as part of the 2016 MASH implementation, the agency is adding passed devices to its Qualified Products List for guardrail end terminals and crash cushions in addition to a passed cast-in-place barrier. Illinois DOT is also part of the Midwest Roadside Safety Facility and Texas Transportation Institute testing labs, and is developing nonproprietary devices such as concrete barrier through testing and engineering analysis. In Minnesota, the barrier is not in the design to protect pedestrians, and in a low-speed environment, a barrier end treatment is not required. In Oregon, the 3-foot-6-inch F-shape bridge rail is compliant with *NCHRP Report 350* test level 5. Based on a supplement to *NCHRP*

Report 350, the current bridge rail is projected to be compliant with MASH test level 5. There are no other plans to test the bridge rail.

Federal Highway Administration Approval of Protective Barriers

Only four state DOTs reported on their agencies' practices of obtaining FHWA approval for use of the protective barrier in DDI median designs. In Alabama, FHWA has not authorized the DDI project but has been involved with plan reviews that include the barrier detail. In Florida, the design was approved as part of the state DOT's Standard Plans. Illinois DOT only uses approved devices once the implementation dates are passed, and Oregon DOT considers the use of a protective barrier to be a department decision with respect to clear zone and roadside design.

Consultation With Experts

We contacted four experts from state and federal agencies who are known to have experience with DDI designs and the use of appropriate median barriers.

State Departments of Transportation

Two survey respondents—the representatives from Illinois and Minnesota DOTs—provided additional details about the information in their survey responses.

Jon McCormick, engineering policy unit chief in the Bureau of Design and Environment at Illinois DOT, said that there are no standard plans or typical designs for DDIs; each DDI design is distinctive and evolves based on site characteristics, site constraints and traffic requirements. Consequently, applying a design used by another agency can be counterproductive. The concrete sloped-down end barrier examples that he provided in the survey (see pages 10 and 11) are largely "overbuilt," he said, and can create sight distance problems for traffic. Alternatives to a barrier include lower speeds (35 mph and below), a sufficient offset to the pedestrian path and a sidewalk raised 8 inches above the deck (no railing necessary).

Douglas Carter, state geometrics engineer in the Office of Project Management and Technical Support at Minnesota DOT, reiterated McCormick's assessment. According to Carter, the DDI road geometry requirements do not differ from those of other roadways of similar geometry associated with pedestrian paths, and that many of the concrete median barriers within DDIs are unnecessary. States have been recreating the design features of older DDIs because those DDIs were, at one time, the only extant models, he said, with no quantitative data supporting the efficacy or necessity of the design feature. Currently, Minnesota DOT is considering excluding this barrier in future DDI designs.

Federal Highway Administration

Michael Matzke, safety design team leader in the Office of Safety at FHWA, provided insight and further information about the regulatory status of concrete sloped-down end barriers in DDIs. Matzke agreed with the assessments made by the survey respondents from Minnesota and Illinois DOTs, namely that DDIs that do not warrant a barrier outside of the design would not require a barrier within the design, and that in many cases, an 8- or 9-inch curb would suffice to separate the roadway from the median.

Matzke also discussed these issues with Ken Kochevar, safety program manager at the California Division Office of FHWA, and other FHWA staff. They concluded that Caltrans should ultimately determine what characterizes an approved end treatment, if one is needed. In a

follow-up email, Kochevar said that if Caltrans determines that some type of barrier is needed, the agency should consider crashworthy designs, especially if the barrier is to be placed on the National Highway System.

Related Research and Resources

Supplementing the survey results are documents sourced through a limited literature search. These resources include national publications, state manuals and guidance, and MASH implementation guidance.

Gaps in Findings

Survey respondents provided limited information about testing of protective concrete barriers with sloped-down ends using MASH criteria, or using other types of evaluation or assessment. Similarly, survey respondents provided limited information related to obtaining FHWA approval for using protective barriers in DDI median designs.

Next Steps

Moving forward, Caltrans could consider:

- Contacting Ken Kochevar at the FHWA California Division Office to learn more about discussions with FHWA staff regarding the necessity of a barrier within a DDI.
- Following up with the Illinois DOT respondent about alternative approaches to barrier designs and for information about the agency's partnership with the Midwest Roadside Safety Facility and Texas Transportation Institute testing labs in developing nonproprietary devices such as concrete barriers through testing and engineering analysis.
- Contacting the Minnesota DOT respondent for additional information about the state's use of DDIs and the possible exclusion of barriers in future designs.
- Reviewing the DDI design plans and features provided by survey respondents for relevance to Caltrans' needs.
- Reaching out to Maine and Connecticut DOTs about the DDIs in design within those states.
- Contacting experts from the FHWA Office of Safety regarding MASH testing concerns.

Detailed Findings

Background

Caltrans has approximately 12 diverging diamond interchanges (DDIs) in various stages of design. Many state departments of transportation (DOTs) using this geometry accommodate pedestrians and bicycle traffic by means of medians with protective barriers. Some use a concrete barrier with a tapered or sloped-down front end to protect the medians. Currently, Caltrans has very few options to shield the blunt ends of concrete barriers protecting a median, and it lacks an approved concrete sloped-down end barrier for use in these low-speed facilities. The concrete sloped-down end barrier has not been crash tested under new 2016 *Manual for Assessing Safety Hardware* (MASH) guidelines.

The Caltrans Division of Traffic Operations seeks to learn what other state DOTs are using in DDIs to protect pedestrians within the median, and whether other states have conducted MASH testing on barriers, including the concrete sloped-down end barrier. Caltrans also seeks standard plan details or shop drawings associated with both MASH-tested and non-MASH-tested blunt barrier ends.

To gather this information, CTC & Associates conducted a brief survey of selected state DOTs, and consulted state and federal experts expected to have knowledge of DDI designs and MASH testing. In addition, CTC conducted a limited literature search of domestic publications and resources. Findings from this information-gathering effort are presented below in three topic areas:

- Survey of practice.
- Consultation with experts.
- Related research and resources.

Survey of Practice

Survey Approach

Caltrans sought information from other state transportation agencies about the types of pedestrian barriers used for DDIs, and the type and extent of safety testing—both MASH and non-MASH—applicable to the barriers. To gather this information, CTC & Associates distributed an online survey to members of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Design. The survey questions are provided in Appendix A. The full text of survey responses is presented in a supplement to this report.

Summary of Survey Results

Twelve of the 18 state transportation agencies responding to the survey have constructed DDIs:

- Alabama.
- Arizona.
- Indiana.
- Michigan.
- Nevada.
- Oregon.

- Florida.
- Illinois.
- Minnesota.
- Mississippi.
- Utah.
- Wisconsin.

Two of these states—Mississippi and Wisconsin—have constructed DDIs but do not use concrete barriers with sloped-down ends in a pedestrian median. Mississippi has only one DDI, which is a retrofit of an existing interchange; it includes a raised median with no barrier and no pedestrian access. Wisconsin has a single DDI installation on State Highway 26 under Interstate 39 (I-39)/I-94 in Janesville that uses a 42-inch single slope concrete barrier installed for pedestrian safety.

The remaining six of the 18 states responding to the survey—Arkansas, Connecticut, Hawaii, Maine, Montana and North Dakota—have not constructed DDIs. Maine DOT has begun designing its first DDI, while Connecticut DOT has a DDI in the concept phase.

Below are case studies summarizing the survey results from the 10 states using protective concrete barriers with sloped-down ends. Each case study includes the following information (when provided by the survey respondent):

- Barrier locations (with Google Maps links when provided by the survey respondent).
- Primary factors determining use of a protective barrier.
- Agency design guidance or plan details.
- Testing using 2016 MASH criteria or other type of evaluation or assessment.
- Federal Highway Administration (FHWA) approval for use of a protective barrier.
- Additional comments.

Case Studies: Agency Use of Protective Concrete Barriers

Alabama

The state's single DDI is in the design stage.

Location: I-65 and Lakeshore Boulevard in Jefferson County.

Determining Factor: Lack of options that fit site conditions. The respondent noted that the sloped-down end barrier "has been used numerous times across the country."

Design Guidance or Plans: The respondent was unable to provide formal plans but did report that the barrier has a 10:1 slope and a terminal height of 1 foot at the sidewalk crossing.

Testing:

- *MASH*: No.
- *Other*: No.

FHWA Approval: While FHWA has not authorized the project, it has been involved with plan reviews that include the sloped-down end barrier detail.

Arizona

The state has one DDI with sloped-down barrier ends.

Location: I-17 and Happy Valley Road Interchange in Phoenix (under construction).

Determining Factor: Median sidewalk ramp location on vehicle side (to prevent vehicles from hitting the blunt end of the half barrier if they veered into the median).

Design Guidance or Plans:

Detail C: Concrete Half Barrier Transition Bridge Barrier to Roadway Barrier, Roadway Design Services, Infrastructure Delivery and Operations Division, Arizona Department of Transportation, June 2018.
See Attachment A.
Plan details of the I-17 and Happy Valley Road Interchange are provided in this attachment.

Testing:

- *MASH*: No.
- *Other*: No.

FHWA Approval: N/A.

Florida

The state has one DDI with sloped-down barrier ends.

Location: I-75 at University Parkway Interchange in Sarasota County.

Determining Factors:

- Very low design speeds (35 mph or less).
- No other available crashworthy solution.

Design Guidance or Plans:

Section 215.4.2.2: Rigid Barrier End Treatments, *Florida Department of Transportation Design Manual*, Florida Department of Transportation, January 2019.
https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/fdm/2019/2019fdm215roadsidesafety.pdf?sfvrsn=f02156e0_4
Scroll to page 40.
From Section 215.4.2.2: Terminate rigid barrier by either transitioning into another barrier system (e.g., guardrail), or by shielding with a crash cushion. Details and requirements are provided in the Standard Plans.

Sloped concrete end treatment using a vertical height transition, detailed in Standard Plans, Index 521-001, are not permitted within the clear zone of approaching traffic lanes. With sufficient justification the District Design Engineer may grant approval for use of this end treatment within clear zone for very low design speeds (35 mph and less), and only when no other more crashworthy solution is available.

Related Resource:

Index 521-001: Concrete Barrier, Standard Plans—FY 2019-20, Florida Department of Transportation, January 2019.
https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/design/standardplans/2020/idx/521-001.pdf?sfvrsn=89fa9556_2
Scroll to page 22.
Notes and plans for a sloped-end treatment of curb and gutter barriers are provided on this page.

Testing:

- *MASH*: No.
- *Other*: No.

FHWA Approval: The design was approved as part of the Standard Plans (see *Related Resource* above).

Illinois

The state has one DDI with sloped-down barrier ends. This DDI is located outside of the clear zone where speeds are low and the risk of a higher speed hit is minimal.

Locations:

- I-88 and Illinois Route 59 in Naperville:
https://www.google.com/maps/@41.8026546,-88.2037128,3a,75y,354.31h,92.51t/data=!3m5!1e1!3m3!1sq7zhMEuyXbrqGiBaTiljg!2e0!6s%2F%2Fgeo1.ggpht.com%2Fcbk%3Fpanoid%3Dq7zhMEuyXbrqGiBaTiljg%26output%3Dthumbnail%26cb_client%3Dmaps_sv.tactile.gps%26thumb%3D2%26w%3D203%26h%3D100%26yaw%3D62.15137%26pitch%3D0%26thumbfov%3D100

  https://www.google.com/maps/@41.8047508,-88.2038338,3a,75y,173.87h,79.6t/data=!3m6!1e1!3m4!1s01GKlHHABwzcrz2ANovf8w!2e0!7i13312!8i6656

- I-90 and Elmhurst Road in Des Plaines:
https://www.google.com/maps/@42.0191639,-87.9405016,3a,75y,175.01h,73.34t/data=!3m6!1e1!3m4!1s_vBi8xa9wzTxJxiED2AtQA!2e0!7i13312!8i6656

  https://www.google.com/maps/@42.0173189,-87.9405116,3a,75y,61.37h,73.72t/data=!3m6!1e1!3m4!1sx6cKQf7UL6DeFHqREpQRhg!2e0!7i13312!8i6656

- I-57 at Morgan/The Hill Avenue in Marion:
https://www.google.com/maps/@37.7446464,-88.9545678,3a,75y,59.09h,59.16t/data=!3m6!1e1!3m4!1sXK3bnRizdg7I9kAO5ugXKQ!2e0!7i13312!8i6656

https://www.google.com/maps/@37.7447061,-88.9554123,3a,75y,322.56h,66.34t/data=!3m6!1e1!3m4!1s8JrJyKUUAFGarg27f5nkzg!2e0!7i13312!8i6656

https://www.google.com/maps/@37.744769,-88.9575564,3a,75y,337.13h,83.09t/data=!3m6!1e1!3m4!1sEg7GNCDinFyXnuME70nGGA!2e0!7i13312!8i6656

Determining Factors:

- Speed.
- Offset from the edge of the traveled way.
- Traffic volumes (exposure).
- Type of device that will fit in the available space.

Design Guidance or Plans: Not available.

Testing:

- *MASH*: As part of the 2016 MASH implementation, the agency is adding passed devices to its Qualified Products List for guardrail end terminals and crash cushions in addition to a passed cast-in-place barrier. (See *Additional Comments* below.)
- *Other*: The agency uses standard devices at DDIs.

FHWA Approval: The agency only uses approved devices once the implementation dates are passed (based on the letting date).

Additional Comments: The agency is part of the Midwest Roadside Safety Facility (MwRSF) and Texas Transportation Institute (TTI) testing labs and is developing nonproprietary devices such as concrete barrier through testing and engineering analysis. According to the Illinois DOT respondent, the agency would more typically use proprietary devices such as crash cushions or guardrail end sections. Speed, clear zone width, risk of a hit or constraints on device width would dictate if a sloped-down barrier end were the “only option,” and it is lower on the agency’s list of preferred options. The respondent said that the treatment will never be “crashworthy”; if the wall end cannot be shielded, then a sloped end may be marginally better than a blunt end.

He added that there is nothing unique about DDIs. The agency supports sidepaths on many arterials, and where these pass over bridges, there is always the question of how to shield the end of the required barrier between the two-way path and the roadway. Flaring is seldom feasible. Guardrails have snagging issues, and the terminals cannot be modified from what has been crash tested. Crash cushions must be deployed in accordance with the testing constraints and within the available space. Intersection sight distance at adjacent locations is often a concern (such that right turn on red is curtailed at signals, which impedes capacity). Because there are many issues to consider when using DDIs, the agency assesses implementation on a case-by-case basis.

Indiana

The state has two DDIs with sloped-down barrier ends.

Locations:

- I-69 and Dupont Road (State Route 1) in Fort Wayne.
- I-65 and County Road 750 North (East Worthsville Road), south of Greenwood.

Determining Factor: Pedestrian traffic discouraged in the median, where trash can accumulate.

Design Guidance or Plans: Not available.

Testing:

- *MASH*: No.
- *Other*: N/A.

FHWA Approval: N/A.

Michigan

The state has two DDIs with sloped-down barrier ends.

Locations:

- I-96 and Cascade Road in Kent County: https://www.google.com/maps/@42.9469029,-85.5670236,325a,35y,124.67h/data=!3m1!1e3

- I-75 and University Drive in Oakland County: https://www.google.com/maps/@42.6658733,-83.2409061,416m/data=!3m1!1e3

Determining Factors:

- Design speed (40 mph or less).
- Restrictions or limitations that make impact attenuator or other roadside safety device installation undesirable or impossible.

Design Guidance or Plans: Not available.

Testing:

- *MASH*: No.
- *Other*: No.

FHWA Approval: No.

Minnesota

The state has seven DDIs with sloped-down barrier ends.

Locations:

- Trunk Highway 101 (TH 101) and County State Aid Highway 144 (CSAH 144) in Rogers.
- I-94 and TH 75 in Clay County.
- US 169 and TH 41 in Scott County.
- I-35 and CSAH 96 in Ramsey County.
- I-35 and TH 97 in Washington County.
- I-35 and CSAH 2 in Scott County.
- I-94 and Ridgeview Crossing in Dayton.

Determining Factor: Designs successfully implemented in other states.

Design Guidance or Plans: The following Technical Memorandum offers guidance for DDI implementation in Minnesota. Additional information about DDI use in the state is available from the respondent.

> **Diverging Diamond Interchange Design and Implementation Guidance**, Technical Memorandum 16-07-TS-03, Minnesota Department of Transportation, December 2016. http://dotapp7.dot.state.mn.us/eDIGS_guest/DMResultSet/download?docId=1786834 This Technical Memorandum provides guidance for the design and implementation of DDIs in Minnesota.

Testing:

- *MASH*: No. The barrier is not in the design to protect pedestrians. In a low-speed environment, no barrier end treatment is required.
- *Other*: Based on the agency's assessment of the risks involved in a low-speed DDI, no barrier is required.

FHWA Approval: No.

Additional Comments: Initially, Minnesota implemented concrete barriers based on designs that had been successfully implemented in other states. After having gained experience with the design, the agency finds the barrier represents a sight distance obstruction without providing measurable benefit for pedestrian or vehicular safety. While the design is currently identified in an agency Technical Memorandum, it is not required, and the agency is considering excluding this barrier in future designs.

Nevada

The state has one DDI with sloped-down barrier ends.

Location: I-580 and Moana Lane in Reno.

Determining Factors:

- Low design speed (20 mph).
- Sight distance.
- Area geometry.

Design Guidance or Plans: Plans detailing the barrier and median for the I-580 and Moana Lane interchange are provided below.

Special Details: Raised Island ADA Ramps, Nevada Department of Transportation, undated.
See Attachment B.
Sectional views and plan details for this treatment are provided in this document.

Special Details: Raised Island, Nevada Department of Transportation, undated.
See Attachment C.
This document provides sectional views of a raised island.

Special Details: NW and NE Raised Islands, Nevada Department of Transportation, undated.
See Attachment D.
Plan details for the NW island and NE island are provided in this document.

Special Details: SW and SE Raised Islands, Nevada Department of Transportation, undated.
See Attachment E.
Plan details for the SW island and SE island are provided in this document.

Special Details: Median Shared Use Path, Nevada Department of Transportation, undated.
See Attachment F.
Plan and isometric views of a median in a shared use path along with sectional details are provided in this document.

Testing:

- *MASH*: No.
- *Other*: No.

FHWA Approval: No.

Additional Comments: While design speed and sight distance are the primary concerns for traffic safety in Nevada, the respondent noted that the agency would consider using impact attenuators if the tangent between crossovers is long enough to facilitate installation. For the

I-580 and Moana Lane Interchange, the geometry was too tight, and since speeds were low, the sloped ends were considered appropriate.

Oregon

The state has one DDI with sloped-down barrier ends.

Location: I-5 at Exit 24 (Fern Valley Interchange) in Phoenix.

Determining Factors:

- Sight distance.
- Positive protection.
- Bicycle and pedestrian safety.
- Speed.
- Site location.

Design Guidance or Plans: The respondent was unable to provide formal plans but did report that an F-shape bridge rail was used on the median, and a transition was designed for the sloped-down barrier end.

Testing:

- *MASH*: According to the respondent, the 3-foot-6-inch F-shape bridge rail is compliant with *NCHRP Report 350* test level 5. Based on a supplement to *NCHRP Report 350*, the current bridge rail is projected to be compliant with MASH test level 5. There are no future plans to test the bridge rail.
- *Other*: Currently, there are no future plans to test the bridge rail.

FHWA Approval: The Fern Valley DDI was contracted in 2013, before MASH requirements were in place. Using a protective barrier is more of a department decision with respect to clear zone and roadside design than getting FHWA approval to use a protective barrier.

Utah

The state has two DDIs with sloped-down barrier ends.

Location:

- I-15 and 500 South in Bountiful.
- I-15 and South Cedar City Interchange.

Determining Factors:

- Pedestrian volumes.
- Sight distance.
- Safety considerations.

Design Guidance or Plans:

DDI Guideline: A UDOT Guide to Diverging Diamond Interchanges, Utah Department of Transportation, June 2014.
https://udot.utah.gov/main/uconowner.gf?n=14769524027177477
From the executive summary:

> The purposes of this DDI Guideline are to accelerate understanding of the DDI's strengths and limitations to aid decision making, to encourage a comprehensive alternative selection process that evaluates DDIs in context with other favorable alternatives, to formalize critical design elements, and to help foster acceptance of critical decision factors and design elements. The DDI Guideline promotes these goals by providing a detailed accounting of the following items, as experienced during DDI implementations throughout the State:
>
> - Key concept principles.
> - Design variations.
> - Decision making factors.
> - Evaluation standards.
> - Design standards.
> - Construction practices.
> - Public involvement tools.
> - Lessons learned.

Design considerations associated with the movement of pedestrians at DDIs, including the use of barriers, are addressed on pages 4, 16 and 36 of the guide (pages 12, 24 and 44 of the PDF, respectively).

UDOT Diverging Diamond Interchange (DDI) Observations and Experience, Utah Department of Transportation, April 2012.
https://www.udot.utah.gov/main/uconowner.gf?n=10172614219775523
From the abstract: This report presents the results of a functionality evaluation, by the I-15 Utah County Corridor Expansion (CORE) traffic team, of the first Diverging Diamond Interchange (DDI) in Utah, located at the intersection of American Fork Main Street (Pioneer Crossing) and I-15. The Pioneer Crossing DDI was opened to traffic in August 2010. This evaluation incorporates a review of population trends, traffic patterns, detoured traffic, and design features to understand how this new interchange operates for the traveling public. In general, this evaluation determined that the application of a new-construction DDI at this location resulted in better than expected traffic operation.

Testing:

- *MASH*: No.
- *Other*: No.

FHWA Approval: No.

Consultation With Experts

We contacted the following experts from state and federal agencies who are known to have experience with DDI designs and the use of appropriate median barriers. The state DOT representatives also participated in the survey for this report.

State Departments of Transportation

- Jon McCormick, Engineering Policy Unit Chief, Bureau of Design and Environment, Illinois Department of Transportation.
- Douglas Carter, State Geometrics Engineer, Office of Project Management and Technical Support, Minnesota Department of Transportation.

Federal Agencies

- Michael Matzke, Safety Design Team Leader, Office of Safety, Federal Highway Administration.
- Ken Kochevar, Safety Specialist, California Division, Federal Highway Administration.

Below are summaries of email and phone conversations with these subject matter experts.

State Departments of Transportation

We followed up with the survey respondents from Illinois and Minnesota DOTs to obtain further information about their responses. Summaries of those inquiries are presented below.

Illinois Department of Transportation

We contacted Jon McCormick, engineering policy unit chief in the Bureau of Design and Environment at Illinois DOT, about the agency's experience with DDI designs and the use of appropriate median barriers.

Design Practices

McCormick said that there are no "standard DDI" plans and "no typical DDI design." Instead, each DDI design evolves based on site characteristics, site constraints and traffic requirements. Consequently, applying a design used by another agency can be counterproductive.

When faced with an area that presents a possible crash hazard, Illinois DOT considers:

- Relocation.
- Shielding.
- Lower speed.

Possible solutions to the median/barrier issue could be lower speeds (35 mph and below), a sufficient offset to the pedestrian path and a sidewalk raised 8 inches above the deck. No railing would be necessary.

McCormick added that DDIs are not unique. The design approach to DDI medians accessible to pedestrians should be identical to the design approach to any roadway with an associated pedestrian path. He considers the concrete sloped-down end barrier examples provided in his

survey response (see pages 10 and 11) to be largely "overbuilt." Further, the barriers have been shown to create sight distance problems for traffic in Illinois (for example, slowing the right-turn-on-red traffic and reducing traffic flow). In addition, McCormick said that focused concern about the sloped-down ends seems to ignore the presence of signal posts and other similar obstructions sited on corner islands.

Recommendations

According to McCormick, agencies that wish to be more forward-looking and incorporate more extensive bicycle routes within their roadways should consider this sort of concrete barrier as it may become an integral part of the growing trend toward separated facilities for bicycles that has been supported by AASHTO.

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Minnesota Department of Transportation

We spoke with Douglas Carter, state geometrics engineer in the Office of Project Management and Technical Support at Minnesota DOT, about DDI designs and the use of appropriate median barriers in the state.

Design Practices

Carter noted that many of the concrete median barriers within DDIs are not required. Many of the concrete sloped-down end barrier examples that he provided (see page 13) are installed on the inside radius of a low-speed curve, which is a road geometry that would not call for such a barrier. Minnesota DOT used this design feature in early DDIs because other states had done so, but agency engineers soon realized that there was no quantitative data supporting a concrete sloped-down end barrier's effectiveness. A 9-inch curb and a reasonable offset would be sufficient to define the pedestrian path and deflect low-speed traffic in this area. No railing or wall would be necessary in this road geometry.

Like Jon McCormick from Illinois DOT, Carter said that the DDI road geometry requirements do not differ from those of other roadways of similar geometry associated with pedestrian paths. Protecting the sloped-down end barrier to 2016 MASH standards should not be an issue in the DDI design because the barrier itself need not be there. Incorporating the barrier needlessly creates a regulatory or testing problem. He also said that concrete barriers can create a sight distance obstruction, and mentioned that signal posts, sign posts and pedestrian actuators are frequently present in these areas without cushions or other crash attenuators, as also noted by McCormick.

Recommendations

Carter reiterated that these are low-speed areas, which reduces the probability of crashes. He believes that states have been recreating the design features of older DDIs because those DDIs were, at one time, the only extant models. These older DDI design features, such as concrete barrier walls along medians, may have been incorporated to give pedestrians a feeling of safety

without actual data supporting the efficacy or necessity of the design feature. Carter also noted that Minnesota DOT is considering excluding this barrier in future DDI designs.

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Federal Highway Administration

We spoke with Michael Matzke, safety design team leader in the Office of Safety at FHWA, who noted that his office had not received previous inquiries about the concrete barrier with sloped-down ends used in many DDIs but would consider these issues in the new MASH standards. He agreed with the Minnesota and Illinois DOT survey respondents' assessments that if the road geometry of a DDI does not warrant a barrier outside of a DDI design, it would not require a barrier within the design, and that in many cases an 8- or 9-inch curb would sufficiently separate the roadway from the median.

Matzke suggested contacting Ken Kochevar, safety program manager at the California Division Office of FHWA. In an email exchange, Kochevar said that he and Matzke had discussed Caltrans' questions and concerns with other FHWA staff. They concluded that Caltrans has its own process for MASH product review and determination of crashworthiness, as required by FHWA, and that Caltrans should ultimately make the final decision on what characterizes an approved end treatment, if needed.

In a follow-up email, Kochevar provided other examples of DDIs:

- Center pedestrian pathways with lower height barriers (see Attachment G):
    - I-85 at State Route 140 (Jimmy Carter Boulevard) in Gwinnett, Georgia:

      https://www.google.com/maps/@33.9121303,-84.2076406,18.55z
    - US 36 and McCaslin Boulevard in Superior, Colorado:

      https://www.google.com/maps/@39.9588206,-105.1635142,16.9z
- MASH-tested designs by Texas DOT:
    - Low-profile design (26 inches, test level 3):

      https://www.roadsidepooledfund.org/longitudinal-barrier/mash-tl-3-low-profile-concrete-barrier/
    - Sloped concrete barrier (from 20 inches to 4 inches, test level 2):

      https://www.roadsidepooledfund.org/terminal/low-profile-end-treatment/

      (*Note*: Both Texas DOT barriers passed testing. Kochevar was unsure of the DOT's plans for additional testing or if it was satisfied with the results from previous *NCHRP Report 3*50 testing.)

Kochevar also referred to the Every Day Counts, Round 2 web site on innovative intersection and interchange designs (see *Related Resource* below), although information about barriers could be limited.

He concluded that whether or not a barrier is actually needed for the median on DDIs is “the bigger issue,” and that if Caltrans determines that some type of barrier is needed, it should consider crashworthy designs especially if the barrier is to be placed on the National Highway System.

Related Resource:

Intersection and Interchange Geometrics, Center for Accelerating Innovation, Federal Highway Administration, undated.
https://www.fhwa.dot.gov/innovation/everydaycounts/edc-2/geometrics.cfm
This web page provides information about roundabouts, DDIs and intersections with displaced left-turns or variations on U-turns.

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Related Research and Resources

Note: Many of the publications cited below do not specifically address the use of concrete barrier with sloped-down ends in DDI designs, and instead address DDI design, pedestrian barriers and barrier testing more generally.

The publications below are organized into four topic areas:

- National resources.
- State practices and guidance.
- Pedestrian barriers and testing.
- Related resources.

National Resources

Diverging Diamond Interchange Informational Guide, Bastian Schroeder, Chris Cunningham, Brian Ray, Andy Daleiden, Pete Jenior and Julia Knudsen, Federal Highway Administration, August 2014.
http://www.virginiadot.org/FHWA-SA-14-067_DDI_Informational_Guide.pdf
From the abstract: This document provides information and guidance on the Diverging Diamond Interchange (DDI). To the extent possible, the guide addresses a variety of conditions found in the United States, to achieve designs suitable for a wide array of potential users. This guide provides general information, planning techniques, evaluation procedures for assessing safety and operational performance, design guidelines and principles to be considered for selecting and designing Diverging Diamond Interchanges.

Alternative Intersections/Interchanges: Informational Report (AIIR), Warren Hughes, Ram Jagannathan, Dibu Sengupta and Joe Hummer, Office of Safety, Federal Highway Administration, April 2010.
https://www.fhwa.dot.gov/publications/research/safety/09060/09060.pdf
Among the six alternative intersection treatments examined in this report is the double crossover diamond interchange, also referred to as a DDI. The authors review geometric design features, operational and safety issues, access management issues, costs, and construction sequencing and applicability for each alternative treatment.

State Practices and Guidance

The resources in this section begin with a web site for practitioners followed by state guidance for the design and construction of DDIs.

Practitioner Resources

Diverging Diamond Interchange, ATS/American, 2017.
https://divergingdiamond.com/
This web site includes general information about 89 DDI locations constructed from 2009 through July 2017 in the following 28 states:

- Colorado.
- Delaware.
- Florida.
- Georgia.
- Idaho.
- Illinois.
- Indiana.
- Iowa.
- Kansas.
- Kentucky.
- Maryland.
- Michigan.
- Minnesota.
- Missouri.
- Nebraska.
- Nevada.
- New Mexico.
- New York.
- North Carolina.
- Ohio.
- Oregon.
- Pennsylvania.
- Tennessee.
- Texas.
- Utah.
- Virginia.
- Wisconsin.
- Wyoming.

California

Design Information Bulletin 90: Diverging Diamond Interchange, California Department of Transportation, December 2017.
http://www.dot.ca.gov/design/stp/dib/dib90.pdf
Pedestrian facilities associated with DDIs are addressed on page 17 of the bulletin (page 21 of the PDF); see page 18 (page 22 of the PDF) for a discussion of center walkways.

Missouri

234.6 Diverging Diamond Interchanges, *Engineering Policy Guide*, Missouri Department of Transportation, December 2015.
http://epg.modot.org/index.php/234.6_Diverging_Diamond_Interchanges
This web site provides Missouri DOT's design guidance for DDIs. *From Section 234.6.2.2.7, Sight Distance*:

> If a median barrier is installed between the opposing directions of traffic to allow for a sidewalk or physical separation of vehicles, care should be taken to provide adequate sight distance. If the concrete barrier wall interferes with sight distance, it should be constructed using a shorter wall that tapers from 24 in[ches] near the ends to the full height of 42 in[ches] when sight distance is no longer obstructed.

Diverging Diamond Interchange Performance Evaluation (I-44 and Route 13), Venkata Chilukuri, Smith Siromaskul, Michael Trueblood and Tom Ryan, Missouri Department of Transportation, February 2011.
https://library.modot.mo.gov/rdt/reports/tryy1013/or11012.pdf
From the abstract: Performance evaluation was conducted on the first "diverging diamond interchange (DDI)" or "double crossover interchange (DCD)" constructed in the United States. This evaluation assessed traffic operations, safety and public perceptions to determine the changes between the previous standard diamond interchange and the new DDI/DCD.

Missouri's Experience With a Diverging Diamond Interchange: Lessons Learned, Missouri Department of Transportation, May 2010.
https://library.modot.mo.gov/RDT/reports/UnNumbrd/or10021.pdf
From the abstract: The first DDI in the nation opened to traffic on June 21, 2009, in Springfield, Missouri. The interchange in Springfield where the Kansas Expressway (MO-13) passes over I-44 is a huge success. A diverging diamond interchange (DDI), sometimes referred to as a double crossover diamond (DCD), is a diamond interchange that more efficiently facilitates heavy left-turn movements. While the ramp configuration is similar to a traditional diamond interchange, traffic on the cross route moves to the left side of the roadway for the segment between signalized ramp intersections. By moving traffic to the left, left-turning vehicles can

enter the limited access highway without the need for a left-turn signal phase at the signalized ramp intersections. Also, left-turning vehicles on the cross route do not conflict with opposing through traffic and may turn without stopping.

South Carolina

"General Design Criteria," Diverging Diamond Interchange (DDI) Criteria, South Carolina Department of Transportation, February 2019.
https://www.scdot.org/business/pdf/I26Widening/AttachB/Roadway/DDI%20Criteria.pdf?v=2
From the document: The DDI design shall provide a pedestrian access area in the center of the roadway for pedestrians between the interchange ramps. This area shall be protected by concrete barrier between the crossovers. Transition the barrier from normal height to 6 inches in height with a 4:1 slope at the approach end of the crossover. The barrier shall be offset one foot horizontally from the face of the raised concrete island on the approach side. Provide concrete pavement under and between the median barriers in areas beyond the bridge. Provide concrete barriers where warranted at the crossover intersection to restrict sight distance in the direction of opposing vehicles and reduce the potential for wrong way movements.

Pedestrian Barriers and Testing

AASHTO Guidance: Roadway Departure, Federal Highway Administration, August 2017.
https://safety.fhwa.dot.gov/roadway_dept/countermeasures/reduce_crash_severity/aashto_guidancecfm.cfm
This web site provides links to a wealth of AASHTO guidance associated with roadway departure, including MASH and other barrier-related guidance.

Longitudinal Barriers, Federal Highway Administration, April 2019.
https://safety.fhwa.dot.gov/roadway_dept/countermeasures/reduce_crash_severity/listing.cfm?code=long&filter=MASH
This web site provides a list of barriers such as guardrail, median barrier, bridge railings and transitions that have been issued an Eligibility Letter by FHWA based on AASHTO MASH criteria.

"MASH Implementation," Timothy E. Barnett, ALDOT Pre-Construction Conference, Alabama Department of Transportation, April 10-12, 2017.
https://conferences.dot.state.al.us/Preconstruction/files/2017presentations/MASH.pdf
This presentation presents information delineating the changes required by the 2016 edition of MASH and the steps agencies must take to comply.

Memorandum: AASHTO/FHWA Joint Implementation Agreement for Manual for Assessing Safety Hardware (MASH), Federal Highway Administration, January 7, 2016.
https://safety.fhwa.dot.gov/roadway_dept/countermeasures/reduce_crash_severity/docs/memo_joint_implementation_agmt.pdf
This two-page memorandum clarifies aspects of the implementation of the 2016 edition of MASH, including letting dates after which the new standards are applicable.

Related Resources

"Observations of Pedestrian Behavior and Facilities at Diverging Diamond Interchanges," Bastian Schroeder, Innovative Intersections for Pedestrians and Bicycles, Transportation Research Board, August 19, 2015.
http://onlinepubs.trb.org/Onlinepubs/webinars/150819.pdf
Slides 1 through 43 of this webinar presentation address pedestrians and their use of DDIs.

"Learning From Eight Operational Diverging Diamond Interchanges in the United States," Gilbert Chlewicki, *TRB 92nd Annual Meeting Compendium of Papers,* Paper #13-4023, 2013.
Citation at https://trid.trb.org/view/1242334
From the abstract: This paper investigates a dozen different design elements of eight operational DDIs in the US and analyzes how those elements may affect the safety and/or operations of the interchange. The main goals of the research are to understand the operational effects of the different design elements within the DDI, separate theory and antidotal evidence from reality and science, and prioritize the important elements within the DDI. The biggest lesson learned from these operational DDIs is that there needs to be a greater emphasis on sight distance in the design. This relates to viewing signs and signal heads properly. It also relates to decision, stopping and intersection sight distance issues. Other lessons learned include using signing and striping properly, giving drivers clear guidance, and that there are several acceptable ways to design elements within the DDI as long as there is an attention to detail.

"Diverging Diamond Interchange Design 101: Things to Know Before You Start," Smith Siromaskul, *ITE 2010 Annual Meeting and Exhibit*, 2010.
Citation at https://trid.trb.org/view/982022
From the abstract: The presentation is intended to introduce engineers to the operational benefits of the diverging diamond interchange concept, to identify when and where the greatest amount of benefits may be realized, to discuss when it should be considered as a viable option, and to stress that this concept is not the perfect solution for every situation. Along with design and operations, topics that will be covered include pedestrian and bicycle treatments, conflict reduction, and public perception. Content within the presentation will be based on lessons learned in past conceptual and design level layouts as well as the author's participation in the development of DDI design guidelines for the State of Utah.

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Appendix A: Survey Questions

The following survey was distributed to members of the AASHTO Committee on Design to gather information about DDIs.

Note: Responses to the question below determined how respondents completed the survey:

- *Respondents who answered "no" to the first question were offered an opportunity to provide additional comments before finishing the survey.*
- *Respondents who answered "yes" to the first question were directed to the remaining questions.*

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1. Has your agency designed and/or constructed one or more diverging diamond interchanges (DDIs)?

Use of Protective Concrete Barrier

1. Has your agency designed a DDI that includes a protective concrete barrier for pedestrians in the median that uses a tapered or sloped-down end to protect the blunt ends of the barrier?

Nonusers of Protective Concrete Barrier With Sloped-Down Ends

1. Please describe the type of barrier or other safety hardware your agency uses to protect pedestrians in DDI median designs.
2. Please describe one or more locations where this type of barrier or safety hardware has been used in the median of a DDI design.
3. Has your agency developed design guidance for DDIs that includes design specifications for the barrier or other safety hardware used to protect pedestrians in the median? If yes, please provide a link to this guidance or an electronic file.
4. Can you provide plan details or shop drawings that illustrate how your agency employs barriers or other safety hardware in the median of a DDI design? If yes, please provide links or electronic files.
5. What are the primary factors that determine when your agency includes this type of barrier or other safety hardware in a DDI median design?
6. Has your agency conducted testing of these barriers or other safety hardware using criteria from the 2016 edition of the AASHTO *Manual for Assessing Safety Hardware* (MASH)?

Users of Protective Concrete Barriers With Sloped-Down Ends

1. Please identify one or more locations where a protective concrete barrier with a sloped-down end has been used in the median of a DDI design.
2. Has your agency developed design guidance for DDIs that includes design specifications for protective concrete barrier with a sloped-down end? If yes, please provide a link to this guidance or an electronic file.
3. Can you provide plan details or shop drawings that illustrate how your agency employs protective concrete barriers that use a sloped-down end in the median of a DDI design? If yes, please provide links or electronic files.

4. What are the primary factors that determine when your agency includes a protective concrete barrier with a sloped-down end in a DDI median design?
5. Has your agency conducted testing of protective concrete barrier with sloped-down ends using criteria from the 2016 edition of the AASHTO *Manual for Assessing Safety Hardware* (MASH)?

No *Manual for Assessing Safety Hardware* Testing

1. Does your agency plan to conduct MASH testing for the barrier used to protect pedestrians in the median of a DDI? If yes, please provide details of these plans.
2. Has your agency conducted any other type of evaluation or assessment of the protective barrier used in DDI median designs? If yes, please describe this evaluation or assessment.
3. Has your agency received FHWA approval for use of the protective barrier used in your agency's DDI median designs? If yes, please describe this approval.

***Manual for Assessing Safety Hardware* Testing**

1. Please provide information about your agency's MASH-related test results associated with the protective barrier used in DDI median designs.

Wrap-Up

1. Please use this space to provide any comments or additional information about your previous responses.