WYOMING DEPARTMENT OF TRANSPORTATION

QUARTERLY PROGRESS REPORT

Project title: Pooled Fund for the Development of Approach Guardrail Transitions for Box Beam and MGS

Project Number: TPF-5(393)

Progress period: 5/1/2021 – 7/31/2021

Principal Investigator and all others who have worked on the project (provide name and ORCID number): Roger Bligh (#0000-0001-5699-070X), Nauman Sheikh (#0000-0003-1718-4881), Nathan Schulz (#0000-0002-7527-9419), James Kovar (#0000-0002-1542-7010)

1. Please state whether the project is ahead of schedule, on time, or behind schedule:

Initiation of testing of the box beam transition was further delayed approximately one month due to weather. On several occasions, rain saturated the soil in which the transition was installed and drying time was required for the soil to regain strength and meet MASH requirements. During the first test of the box beam transition (MASH Test 3-20 with the passenger car on the downstream end of the transition), head contact was noted between the onboard crash dummy and the transition connection plate. After discussing this with the technical representatives, the researchers were asked to develop concepts for design modifications to mitigate the head contact prior to resuming testing. It is not yet known how much additional delay will result, but it will be at least one month and possibly longer depending on the design option ultimately selected and the associated fabrication time.

2. Percentage of overall work completed.

75%

3. Activities and Accomplishments:

a. What are the major goals and objectives of the project?

The research objective is to develop two non-proprietary approach guardrail transition systems from box beam and MGS guardrail that are MASH Test Level 3 (TL-3) compliant. The transitions are being designed to connect the guardrail systems to the Texas Department of Transportation (TxDOT) Type C2P TL-4 bridge rail system. Direct connection between the transition section and bridge rail is desired to avoid use of a solid concrete parapet end that could hinder snow clearing operations. The work plan for the project is divided into seven tasks. These include:

Task 1: Engineering Design and Drawing Development
Task 2: Finite Element Modeling & Simulation

Task 3: Test Installation Construction
Task 4: Crash Testing of the Box Beam Transition
Task 5: Crash Testing of the MGS Transition
Task 6: Concrete Transition Parapet Design and Analysis
Task 7: Development of Box Beam Transition to Concrete Parapet
Task 8: Full-Scale Crash Testing – Box Beam Transition to Concrete Parapet
Task 9: Final Report
Task 10: FHWA Eligibility Letter

b. Describe what was accomplished under these goals.

Task 1: Engineering Design and Drawing Development (previously completed)

Task 2: Finite Element Modeling & Simulation (previously completed)

Task 3: Test Installation Construction (completed)

Work on Task 3 was completed during the reporting period. Construction of the simulated bridge rail system, box beam transition system, and MGS transition system were completed. The box beam and MGS transition systems were installed on opposite ends of the C2P bridge rail system.

Task 4: Crash Testing of the Box Beam Transition (ongoing)

After some weather delays, the first test of the box beam transition was performed. *MASH* Test 3-20 was performed on both the downstream end of the box beam transition system on July 19. The downstream end is where the transition attaches to the C2P bridge rail. Test 3-20 involves a 2,420-lb passenger car impacting the transition at a nominal speed and angle of 62 mi/h and 25 degrees. The target impact point was 36 inches upstream from the end of the bridge rail curb as determined through finite element impact simulations.

The 1100C test vehicle was successfully contained and redirected in a stable manner. MASH occupant risk criteria were satisfied. The occupant impact velocity (OIV) was 10.7 m/s (12 m/s max) and the ridedown acceleration was 8.5 g (20 g max). Although there was considerable damage to the exterior to the vehicle, the occupant compartment deformation met MASH requirements. Thus, the test satisfied MASH criteria.

Video and photos of the test were shared with the technical representative. There was very little deflection or damage to the transition system. However, there were several diagonal cracks that developed in the curb around the first C2P bridge rail post. It was decided that the concrete curb should be broken out and recast prior to conducting MASH Test 3-21 with the pickup truck on the downstream end of the box beam transition.

During subsequent film analysis being performed in support of the test documentation, head contact of the onboard crash dummy was observed with the face of the steel transition connection plate. Although this is not a pass/fail evaluation criteria, MASH does recommend that such contact be reported. The technical representative was informed of this observation on July 23, and a subsequent meeting was scheduled and held on July 28. After review and discussion, the technical representatives asked TTI researchers to develop some design concepts for mitigating the head contact. TTI researchers have developed four different concepts. Drawings of these concepts are being prepared and will be transmitted to the technical representatives for review and approval.

Task 5: Crash Testing of the MGS Transition (completed)

The test installation drawings and test plan for the MGS transition were previously submitted and approved. Revisions to the transition connection plate are recommended to provide needed in-field construction tolerance. The modified drawings are being resubmitted to WyDOT for review and approval. If approved, the transition connection plates will be refabricated. The testing program will then be executed after completion of Task 4.

After some construction delays that were reported in the last progress report, *MASH* Test 3-20 was performed on both the downstream end of the MGS transition system on June 11. The downstream end is where the transition attaches to the C2P bridge rail. Test 3-20 involves a 2,420-lb passenger car impacting the transition at a nominal speed and angle of 62 mi/h and 25 degrees. The target impact point was 76 inches upstream from the upstream flange of the first C2P bridge rail post as determined through finite element impact simulations.

The 1100C test vehicle was successfully contained and redirected in a stable manner. MASH occupant risk criteria were satisfied. The occupant compartment deformation was minimal and satisfied MASH requirements. Thus, the test satisfied MASH criteria.

Video and photos of the test were shared with the technical representative. There was minimal deflection and damage to the transition system. The concrete curb sustained only minor cracking that was not considered to decrease the structural capacity of the C2P bridge rail system.

After repair of the transition system, *MASH* Test 3-21 was performed on the downstream end of the MGS transition system on June 17. Test 3-21 involves a 5,000-lb pickup truck impacting the transition at a nominal speed and angle of 62 mi/h and 25 degrees. The target impact point was 84 inches upstream from the upstream flange of the first C2P bridge rail post as determined through finite element impact simulations.

The 2270P test vehicle was successfully contained and redirected in a stable manner. MASH occupant risk criteria were below the preferred limit. The occupant compartment deformation satisfied MASH requirements, and the test satisfied MASH criteria.

Video and photos of the test were transmitted to WyDOT. The damage to the installation was less than expected. In particular, the concrete remained in good shape with only small cracks.

The upstream end of the MGS transition will not be evaluated because it is similar in design to a system that was already crash tested and determined to be *MASH* compliant. Thus, based on these tests, the MGS transition to C2P bridge rail is considered MASH compliant.

Task 6: Concrete Transition Parapet Design and Analysis (ongoing)

A modification to the contract was processed to add additional tasks to develop concrete transition parapet options for connecting box beam guardrail to different bridge rails or independent concrete barrier. The two design cases that will be investigated include 32-inch vertical concrete parapet to 42-inch single slope and 32-inch vertical concrete parapet to 32-inch New Jersey barrier. The researchers received details of the 42-inch single slope and 32-inch New Jersey barriers from the technical representative.

The researchers initiated development of a shape transition between the vertical parapet and the single slope concrete barrier. The vertical parapet was 32 inches tall and transitioned to a 42-inch tall single slope barrier. The box beam transition rails will be attached to the vertical parapet. The length of the vertical parapet is 36 inches to allow sufficient room for attaching the box beam and tubular rubrail that are part of the box beam transition. The shape transition section was selected to be 72 inches long. It was 32 inches tall at the end connected to the vertical wall and transitioned 10 inches vertically to a 42-inch height at the end attached to the single slope barrier. The vertical to single slope profile transition was achieved using two triangular planes on the impact side, as shown in Figure 1.

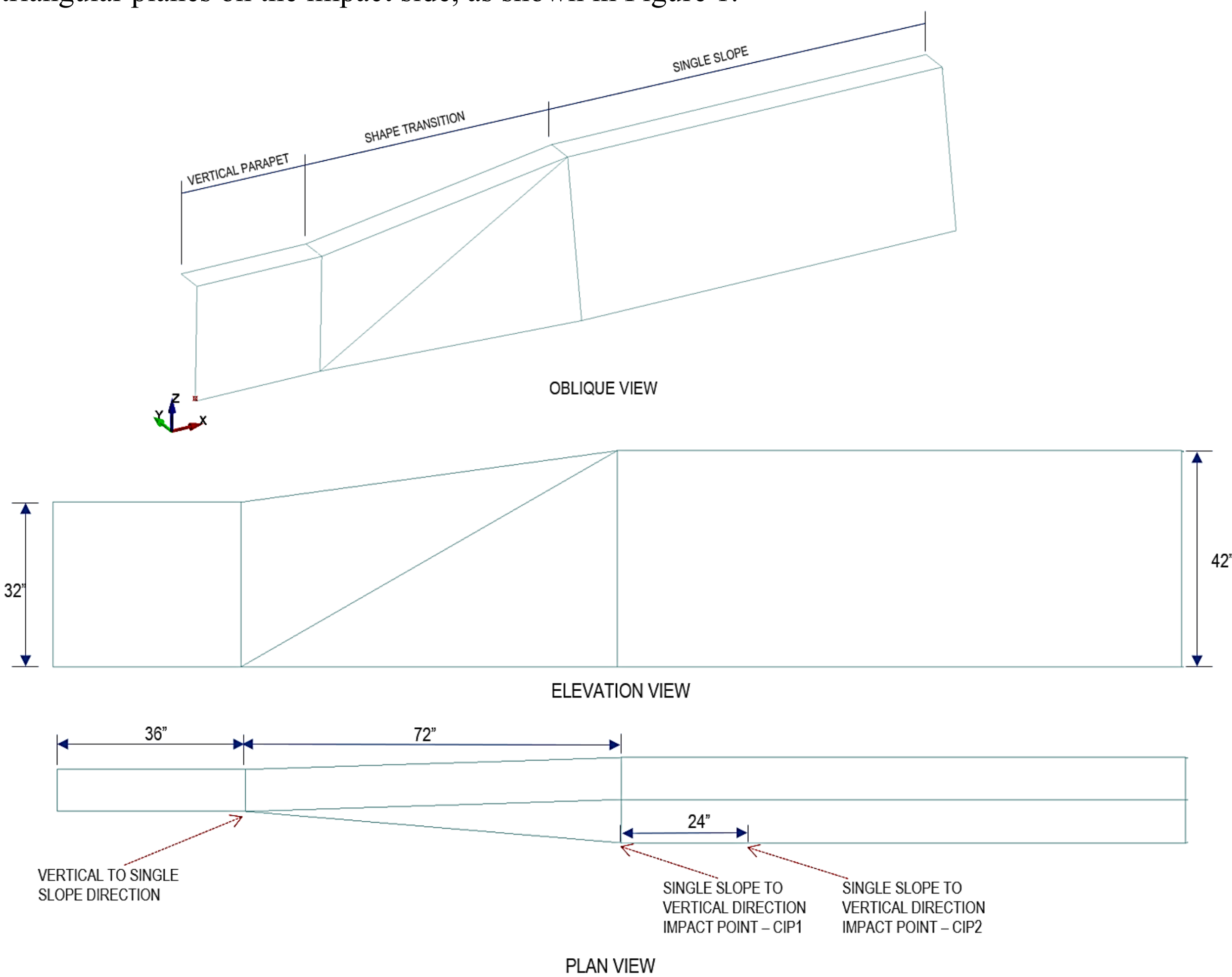


Figure 1. Vertical to Single Slope Barrier Shape Transition Design and Impact Points

To evaluate the impact performance of the shape transition, the researchers developed a model of the transition system and barriers attached at each end. Impact simulations were performed using the finite element (FE) method. LS-DYNA, which is a commercially available general purpose FE software, was used for all the analyses.

The barriers and the transition section were modeled using rigid material representation. A 5,000-lb Dodge RAM pickup truck model was used to simulate MASH Test 3-21 impact conditions. This involves the 5,000-lb pickup truck impacting the transition at a speed of 62 mph and an angle of 25 degrees. Figure 1 shows the three impact points at which the impact simulations were performed. The direction of the vehicle and the location of the impact points was as follows.

- **Vertical to Single Slope:** The first simulation was performed with the vehicle impacting the vertical parapet at the point where the shape transition begins.
- **Single Slope to Vertical – CIP1:** The second simulation was performed with the vehicle impacting the single slope barrier at the point where the shape transition begins.
- **Single Slope to Vertical – CIP2:** A third simulation was performed with the vehicle impacting 2 ft upstream of the point where the single slope barrier begins the shape transition to vertical parapet.

Note that an impact further upstream on the vertical parapet was not performed due to the short length of the vertical parapet (36 inches total length) and the fact that the box beam transition rails will be attached in this region. Figure 2 shows the model of the vehicle positioned to impact the shape transition from Single Slope to Vertical at critical impact point two (CIP2).

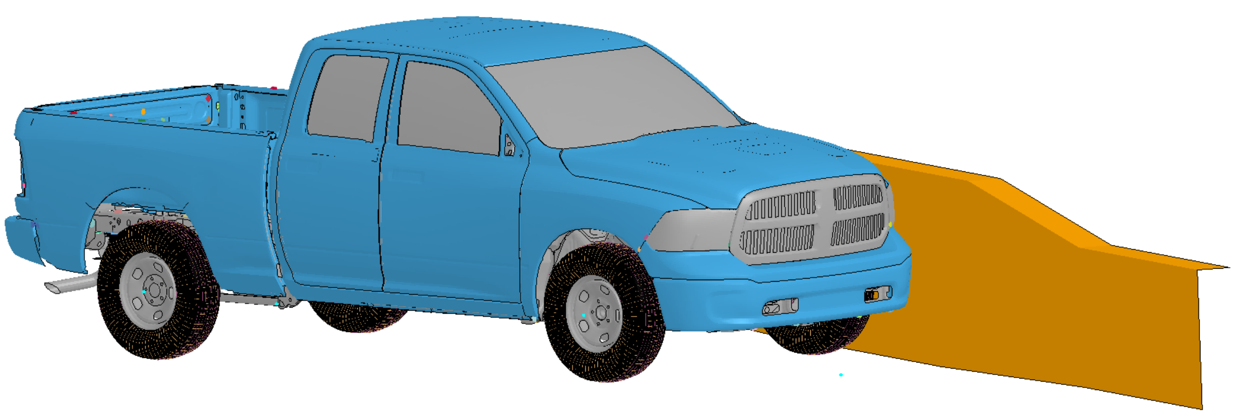
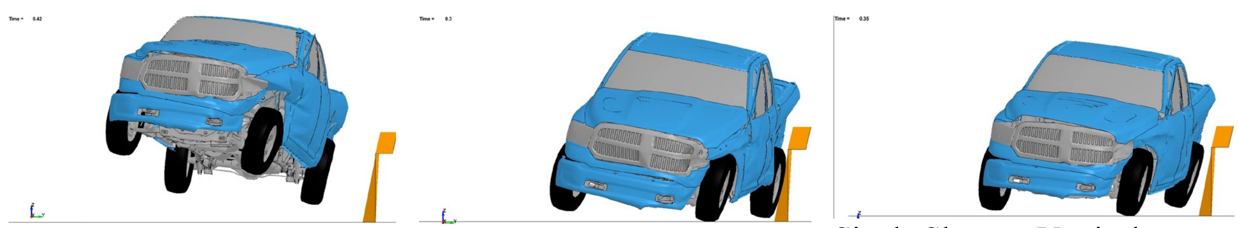


Figure 2. FE vehicle model at point of impact with shape transition (single slope to vertical).

In all three simulations, the vehicle was successfully contained and redirected. Table 1 shows the results of the Occupant Impact Velocity (OIV) and Ridedown Acceleration (RA) values for all three impact simulations, along with the maximum vehicle roll in each simulation. Figure 3 shows the vehicle at the point of maximum kinematic instability for each of the impact points simulated.

Table 1. Simulation Results

Test 3-21 (Pickup Truck Impact)	Max. Ridedown Acceleration (g)	Maximum Occupant Impact Velocity (ft/s)	Maximum Vehicle Roll (degrees)
Vertical to Single Slope	13.2	28.3	7.2
Single Slope to Vertical – CIP1	9.9	29.5	8.5
Single Slope to Vertical – CIP2	9.4	28.0	5.7



Vertical to Single Slope | Single Slope to Vertical – CIP1 | Single Slope to Vertical – CIP2

Figure 3. Vehicles at maximum kinematic instability during simulations of various impact points.

The impact from the direction of the vertical parapet to the single slope barrier resulted in more vehicle climb than the impacts traveling in the direction from single slope barrier to vertical parapet. That simulation also had the highest OIV and RA values. This impact point was, therefore, determined to be the critical impact point for Test 3-21 for this shape transition. Sequential images from this impact simulation are presented in Figure 4.

Task 7: Development of Box Beam Transition to Concrete Parapet (ongoing)

Under this task, the research team is developing a transition design connecting a box beam guardrail to a vertical concrete parapet. The initial design evaluated consisted of similar components and details to those utilized for the box beam transition to C2P bridge rail with the exception of the transition connection plate, which was not needed. Figure 5 shows an elevation and plan view of the box beam transition section. The box beam transition system was connected to a 32-inch vertical concrete parapet. There will be a shape transition on the concrete parapet transitioning from the vertical parapet to a concrete bridge rail or median barrier shape (either single slope or New Jersey shape), but it was not included in these simulations as the purpose is to investigate the transition from the box beam rail to the vertical concrete parapet. Figure 6 shows the transition system attached to the vertical concrete parapet.

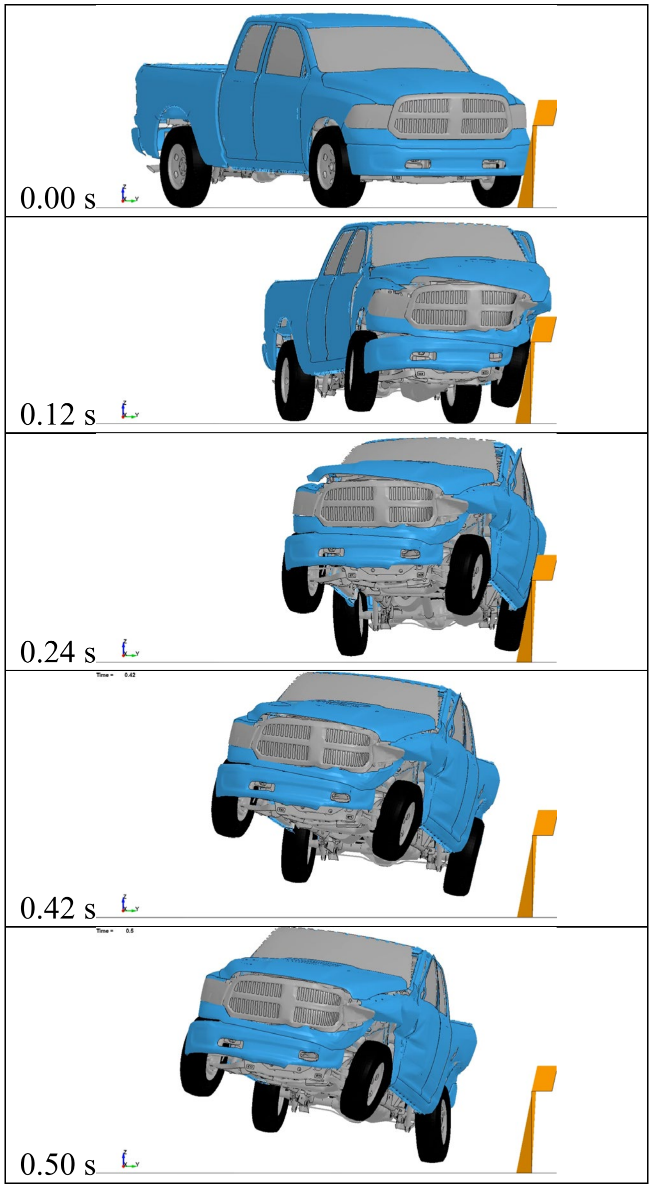


Figure 4. Simulation of pickup truck impacting in direction from vertical parapet to single slope barrier.

The box beam rail and rub rail are attached directly to the face of the vertical concrete parapet with two anchors bolts on each rail. The first anchor for each rail is located 6 inches from the parapet edge and the second anchor for each rail is located 12 inches from the parapet edge. Each rail element has a taper on the downstream end to reduce snagging severity for traffic traveling in the opposite direction. Additionally, a cover plate is attached across the tapered portion of the deeper box beam rail to prevent snagging of vehicle components in the end opening. Figure 7 shows the transition connection. The anchor bolts are not shown in the figure.

The research team utilized finite element computer simulation to investigate the impact performance of the Wyoming box beam transition to a vertical concrete parapet. Impact simulations were performed to evaluate the performance of the downstream end of the box beam transition system according to MASH Test 3-20 and 3-21 impact conditions. Test 3-20 involves a 2,420-lb passenger car impacting the transition at a nominal speed and angle of 62 mi/h and 25 degrees. Test 3-21 involves a 5,000-lb pickup truck impacting the transition at a nominal speed and angle of 62 mi/h and 25 degrees. The initial impact location for each simulation was the same as the impact locations used on the box beam transition to C2P bridge rail. The impact location for the MASH Test 3-20 simulation was 3 ft upstream of the parapet end, and the impact location for the MASH Test 3-21 was 4 ft upstream of the parapet end.

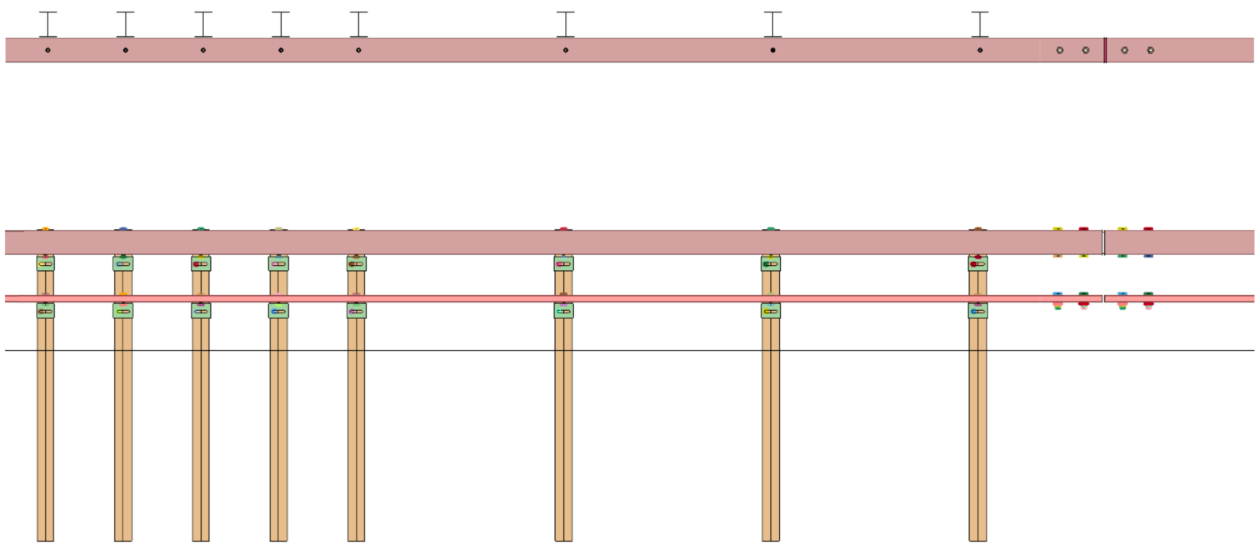


Figure 5. Box Beam Transition Rail Section.

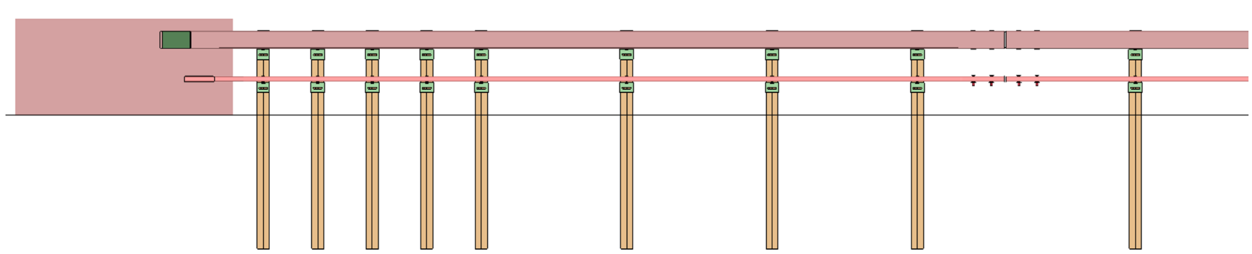


Figure 6. Box Beam Transition to Concrete Parapet.

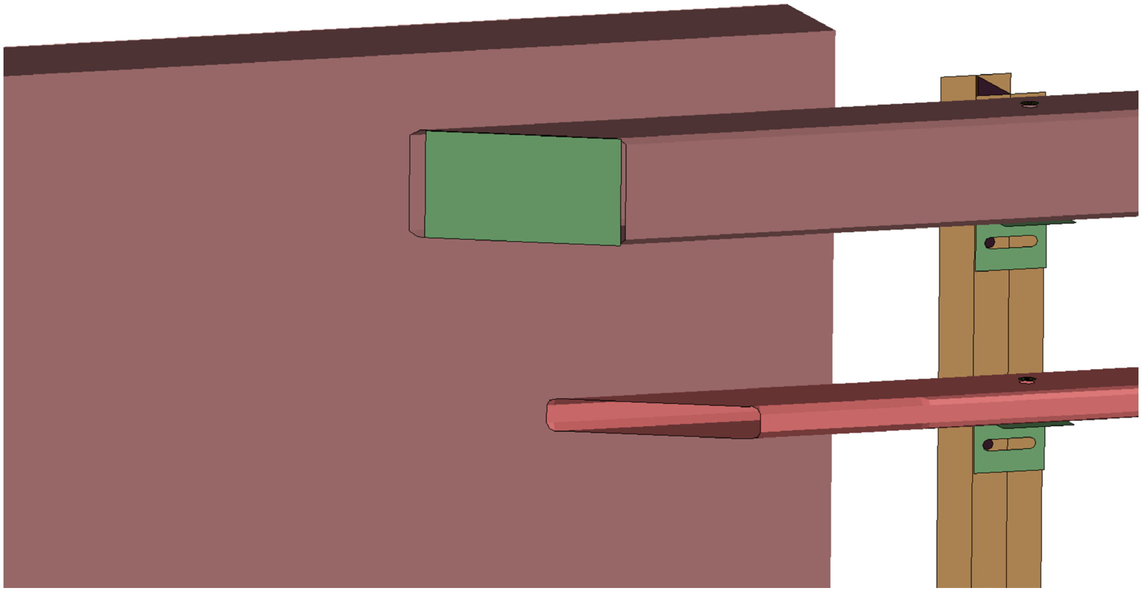


Figure 7. Box Beam Transition Connection to face of Vertical Concrete Parapet.

The two primary MASH evaluation factors are structural adequacy and occupant risk. In each simulation, the vehicle was successfully contained and redirected and the vehicle remained stable throughout the impact event. Table 2 and Table 3 show the occupant risk values for MASH Tests 3-20 and 3-21, respectively. All occupant risk values were within MASH limits.

Table 2. MASH Test 3-20 Occupant Risk Results.

CIP Location	OIV-x (m/s)	OIV-y (m/s)	RDA-x (g's)	RDA-y (g's)	Roll (°)	Pitch (°)	Yaw (°)
3ft upstream of Parapet End	5.6	8.9	4.2	9.7	10.0	5.4	42.1

Table 3. MASH Test 3-21 Occupant Risk Results.

CIP Location	OIV-x (m/s)	OIV-y (m/s)	RDA-x (g's)	RDA-y (g's)	Roll (°)	Pitch (°)	Yaw (°)
4ft upstream of Parapet End	4.6	6.5	6.2	15.0	33.6	8.0	33.6

Overall, the simulations of the box beam transition to a vertical concrete parapet showed satisfactory performance for MASH evaluation criteria. Additional simulations are being conducted to evaluate other impact locations and determine the critical impact point for each test condition. This is being accomplished by incrementing the impact point and selecting the most critical location in terms of MASH evaluation criteria (e.g., occupant risk indices, vehicle stability, etc.).

c. **What opportunities for training and professional development has the project provided? If the research is not intended to provide training and professional development, state "Nothing to Report". Otherwise, describe opportunities for training and professional development, training activities, and professional development.**

Nothing to report.

d. **How have the results been disseminated to communities of interest? Describe what results have been disseminated and in what manner, including publications, conference papers, and presentation. Please list ALL derivative reports/publications which were generated from this project, and provide an electronic copy of the report/publication.**

Nothing to report.

e. **What do you plan to do during the next reporting period to accomplish the goals and objectives? Describe briefly what you plan to do during the next reporting period to accomplish the goals and objectives.**

Task 4: Crash Testing of the Box Beam Transition

Design concepts to mitigate the potential for head contact with components of the box beam transition to C2P will be completed and submitted to Wyoming DOT for review and selection. Once a design concept is selected, detailed construction drawings will be prepared. After approval of the construction drawings by Wyoming DOT, the box beam transition system will be modified accordingly for full-scale crash testing.

MASH Test 3-20 and Test 3-21 will be performed on both the downstream and upstream ends of the box beam transition system. The downstream end is where the transition attaches to the C2P bridge rail. The upstream end is where the box beam approach guardrail attaches to the transition. Test 3-20 involves a 2,420-lb passenger car impacting the transition at a nominal speed and angle of 62 mi/h and 25 degrees. Test 3-21 involves a 5,000-lb pickup truck impacting the transition at the same nominal impact conditions.

Finite element impact simulations were used to determine the critical impact point for each test. On the downstream end of the box beam transition, the CIPs for *MASH* Test 3-20 and Test 3-21 were determined to be 36 inches and 60 inches upstream from the end of the bridge rail curb, respectively. On the upstream end of the box beam transition, the CIPs for *MASH* Test 3-20 and Test 3-21 were determined to be 8 ft and 12.25 ft upstream of the end of the lower rubrail element, respectively.

Dates for these tests will be determined and shared with the technical representatives. Time will be included between tests to permit for repair of the C2P bridge rail, box beam transition system, and box beam guardrail as needed.

Task 6: Concrete Transition Parapet Design and Analysis

Work on Task 6 will be completed. MASH Test 3-20 will be simulated on the shape transition from 32-inch vertical concrete parapet to 42-inch single slope barrier. This test involves a 2,420-lb passenger car impacting the transition at an impact speed and angle of 62.2 mph and 25 degrees. Simulations will be performed from both directions (i.e., vertical parapet to single slope, and single slope to vertical parapet).

A shape transition from 32-inch vertical concrete parapet to 32-inch New Jersey concrete parapet will be developed, modeled, and evaluated through finite element simulation. MASH Tests 3-20 and 3-21 will be performed from both directions (i.e., vertical parapet to single slope, and single slope to vertical parapet). The impact conditions for both tests involves a speed of 62 mph and an angle of 25 degrees. Criteria that will be used to assess ability to meet MASH performance requirements include occupant risk indices (i.e., occupant impact velocity and ridedown acceleration) and vehicle stability. The length and slope transitions will be changed as needed to achieve acceptable MASH impact performance.

One of the design objectives will be to minimize the length of the concrete transition parapet, with a goal of 10 ft or less. Different impact locations will be simulated for each test condition to define the critical impact point from each direction of travel. The simulation results will be used to select the critical test condition, direction of travel, and impact location for further evaluation through full-scale crash testing if deemed necessary.

Once the geometry of the two concrete shape transitions is finalized, engineering analyses will be performed to detail the reinforcement and anchorage for each. Drawings for the design of the concrete shape transitions will then be developed and submitted to WYDOT for review and approval along with any recommendations for full-scale crash testing needed to confirm MASH compliance of the shape transitions.

Task 7: Development of Box Beam Transition to Concrete Parapet

Work on Task 6 will be completed. Additional simulation runs will be performed on the box beam to vertical concrete parapet transition design to determine the Critical Impact Point (CIP) for MASH Tests 3-20 and 3-21 on the downstream end of the transition. This will be accomplished by incrementing the impact point and selecting the most critical location in terms of MASH evaluation criteria (e.g., occupant risk indices, vehicle stability, etc.).

f. List any products resulting from the project during the reporting period. Include in this list:

1. Publications, conference papers, and presentations.
2. Website(s) or other internet sites (List the URL).
3. Technologies or techniques.
4. Inventions, patent applications, and/or licenses.
5. Other products, such as data or databases, physical collections, audio or video products, software or NetWare, models, educational aids or curricula, instruments or equipment.

Nothing to report.

g. Impact:

1. How will this project impact WYDOT?
2. How will this project impact other agencies?

WYDOT's Mission Statement is to "provide a safe, high quality and efficient transportation system." One of the goals within the mission statement is to "improve safety on the state transportation system." Successful implementation of the transitions developed under this project into WYDOT's standard plans will provide an improved level of safety. The transitions will provide continuity of motorist safety from MASH guardrail systems to MASH bridge rail systems. Full implementation of MASH compliant roadside safety devices, including transition systems, will provide an enhanced level of safety that will help reduce the severity of lane departure crashes that represent over 75% of highway fatalities in Wyoming. Additionally, the AASHTO/FHWA MASH Implementation Agreement requires state DOTs to provide MASH compliant roadside safety features to obtain federal funding reimbursement on projects. The results of this research will be useful to other agencies. This project is being funded as a pooled fund effort between WYDOT and Montana DOT. It will provide transition details that will be immediately implementable by both of these agencies as well as other agencies that use similar guardrail and bridge rail systems.

h. Changes to Scope of Work. Provide the following changes, if applicable:

1. Scope of work or objectives of the project.
2. Changes in key persons.
3. Disengagement from the project for more than three (3) months, or a twenty five (25) percent reduction in time devoted to the project.
4. The inclusion of costs that require prior approval.
5. The transfer of funds between line items in the budget.
6. The subawarding, transferring or contracting of work.
7. Changes in the approved cost-sharing or match.

At the request of Wyoming DOT, a modification to the current project agreement was prepared and submitted. The modification adds additional tasks to the project scope. These additional tasks relate to the development and testing of a box beam transition to concrete parapet. The modification includes additional scope, time, and budget for the proposed work. The modification agreement was approved and executed in May 2021.