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   Investigating and Developing a MASH Compliant Contraflow Ramp Closure Gate

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13. Abstract
    The Louisiana Department of Transportation and Development developed a cost-effective portable, swinging gate arm that could be deployed and installed with minimal effort. The device needed to be evaluated as roadside safety hardware because it remains in place even when the ramp is open. Thus, the purpose of this project was to assess the device's performance per *Manual for Assessing Safety Hardware* (MASH) guidelines to evaluate support structures. Texas A&M Transportation Institute (TTI) researchers conducted a thorough review of the ramp gate system and identified the component sizes and material properties. A set of drawings to be used in creating the finite element model of the device was developed. Furthermore, the slip base system was validated using previous crash test data. Next, TTI utilized computer simulation to evaluate the device's performance according to the conditions specified in MASH, including conducting parametric analyses of the device under various configurations. This report describes these activities and related findings. Conclusions and recommendations are also presented.

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Investigating and Developing a MASH Compliant Contraflow Ramp Closure Gate

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Louisiana Transportation Research Center

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Abstract

The Louisiana Department of Transportation and Development developed a cost-effective portable, swinging gate arm that could be deployed and installed with minimal effort. The device needed to be evaluated as roadside safety hardware because it remains in place even when the ramp is open. Thus, the purpose of this project was to assess the device's performance per *Manual for Assessing Safety Hardware* (MASH) guidelines to evaluate support structures.

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Acknowledgments

The authors would like to thank the Louisiana Department of Transportation and Development for providing the resources necessary for this project and the Louisiana Transportation Research Center for the funding of this study. A significant portion of this work relied on technical input from the sponsor during the course of this study. The related help is greatly appreciated. The authors are also grateful to all who participated in this research.

Implementation Statement

The results from the evaluation of the contraflow ramp closure gate system provide insight to the Louisiana Department of Transportation and Development on improving the current ramp gate system.

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Introduction

During contraflow and other emergencies, it is often necessary to close the highway on/off ramps. In 2015, the Louisiana Department of Transportation and Development (DOTD) developed a cost-effective portable, swinging gate arm that could be deployed and installed with minimal effort to replace six Triton Barrier® per contraflow ramp closure. The new gate arm was designed to be installed parallel to traffic at specific locations. Then, when a ramp closure was required, the arm would be rotated into position to close off the ramp. However, since the gate assembly was designed to remain in place even when the ramp was open, the device needed to be evaluated as roadside safety hardware.

DOTD's gate arm is made of aluminum and fiberglass materials and is attached to a steel pole on a standard triangular slip base. In the past, 48-in. × 30-in. "Ramp Closed" signs have been mounted to the gate arm, and 12-in. × 36-in. object marker signs have been mounted to the post. The DOTD ramp closure gate is shown in Figure 1.

Figure 1. DOTD contraflow ramp closure gate

Objective

The overall objective of this project was to provide a thorough crashworthiness evaluation of the DOTD ramp gate through computer simulations. Using the current DOTD gate system as a model, this project assessed the design according to the American Association of State Highway and Transportation Officials *Manual for Assessing Safety Hardware* (MASH), second edition [1].

Scope

The scope for the project included the research and evaluation of the DOTD contraflow ramp gate in accordance with MASH Test Level 3 (TL-3).

The project included the following tasks:

1. Reviewing the device to identify the system's component specifications and develop technical drawings.
2. Constructing the finite element (FE) model of the system based on the identified component specifications.
3. Conducting FE analysis based on the test conditions and evaluation criteria for MASH Tests 3-60, 3-61, and 3-62.

Based on the findings from the project tasks, recommendations to improve the system performance during impact were developed.

Methodology

Texas A&M Transportation Institute (TTI) researchers reviewed the DOTD contraflow ramp closure gate system and identified the component sizes and material properties to satisfy the requirements for Task 1. For Task 2, the FE model of the device and the slip base system were constructed based on the information collected in the previous task.

MASH recommends evaluating support structures (including road closure gates) under Tests 3-60, 3-61, and 3-62. However, the location and angle of the impact on the device are not explicitly defined. In this situation, a parametric analysis of the assembly is required to understand the performance of the device under various impact conditions. Therefore, for Task 3, TTI researchers performed computer simulations at various angles to identify the critical impact angle (CIA). Additionally, impacts at multiple locations along the length of the gate arm were simulated and evaluated. Figure 2 illustrates the two MASH test vehicle FE models. MASH TL-3 conditions for each test number are presented in Table 1. The three areas of evaluation criteria (structural adequacy, occupant risk, and vehicle trajectory after impact) for support structures are listed in Table 2. Additional details are provided in MASH 2016[1]. A summary of the effort for each task is presented in the following sections.

Figure 2. MASH test vehicle models: (a) 1100C (b) 2270P

(a)

(b)

Table 1. Recommended test matrix for support structures under TL-3 conditions [1]

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight, lb	Impact Conditions		Evaluation Criteria[1]
				Speed, mph	Angle, degrees	
Support Structures	3-60	1100C	2,420	19	CIA	B,D,F,H,I,N
	3-61	1100C	2,420	62	CIA	B,D,F,H,I,N
	3-62	2270P	5,000	62	CIA	B,D,F,H,I,N

[1] Evaluation criteria are listed in Table 2.

Table 2. MASH 2016 evaluation criteria for support structures [1]

<table>
<tr><td>Structural Adequacy</td><td>B.</td><td>The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</td></tr>
<tr><td rowspan="4">Occupant Risk</td><td>D.</td><td>Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td></tr>
<tr><td>F.</td><td>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td>H.</td><td>Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:
<table>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal</td><td>10 ft/s</td><td>16 ft/s</td></tr>
</table></td></tr>
<tr><td>I.</td><td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:
<table>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 gs</td><td>20.49 gs</td></tr>
</table></td></tr>
<tr><td>Post-Impact Vehicular Response</td><td>N.</td><td>Vehicle trajectory behind the test article is acceptable.</td></tr>
</table>

Task 1—Reviewing the Device

For this project, TTI reviewed the documents on the contraflow ramp closure gate provided by the sponsor and identified the device's components and their material properties. As a part of this task, TTI developed a set of drawings to be used in creating the finite element model of the device. The preliminary drawings of the device are shown in Figure 3 to Figure 5. The device is comprised of the following main components:

- One 7-ft. 2½-in. diameter Schedule 40 signpost
- One Redi-Torque 280 slip base breakaway attachment
- One pole bracket (galvanized steel)
- One cast adapter (galvanized steel)
- One 30-ft. gate arm (16-ft. aluminum arm with 16-ft. fiberglass extension)
- One buffer leg assembly

Figure 3. Contraflow ramp closure gate—side view and slip base connection

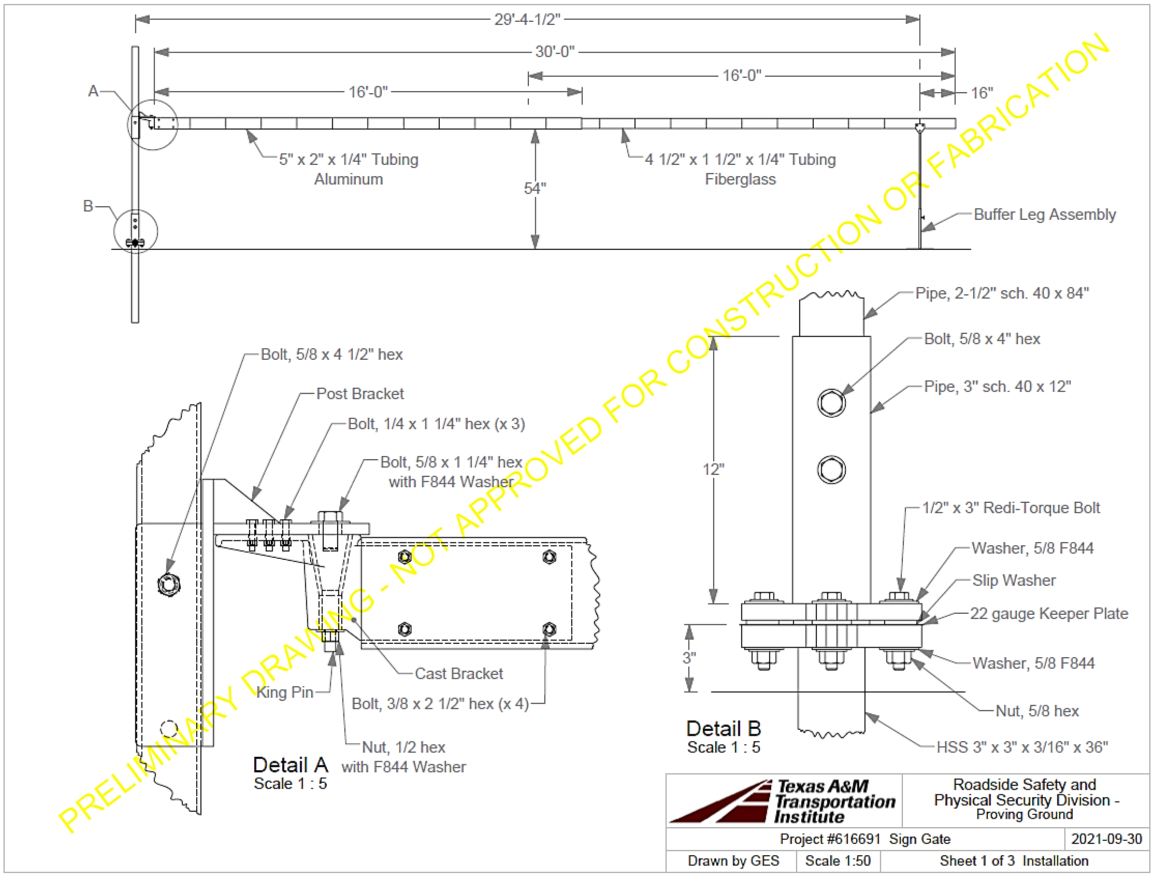


Figure 4. Contraflow ramp closure gate—post bracket and cast adapter

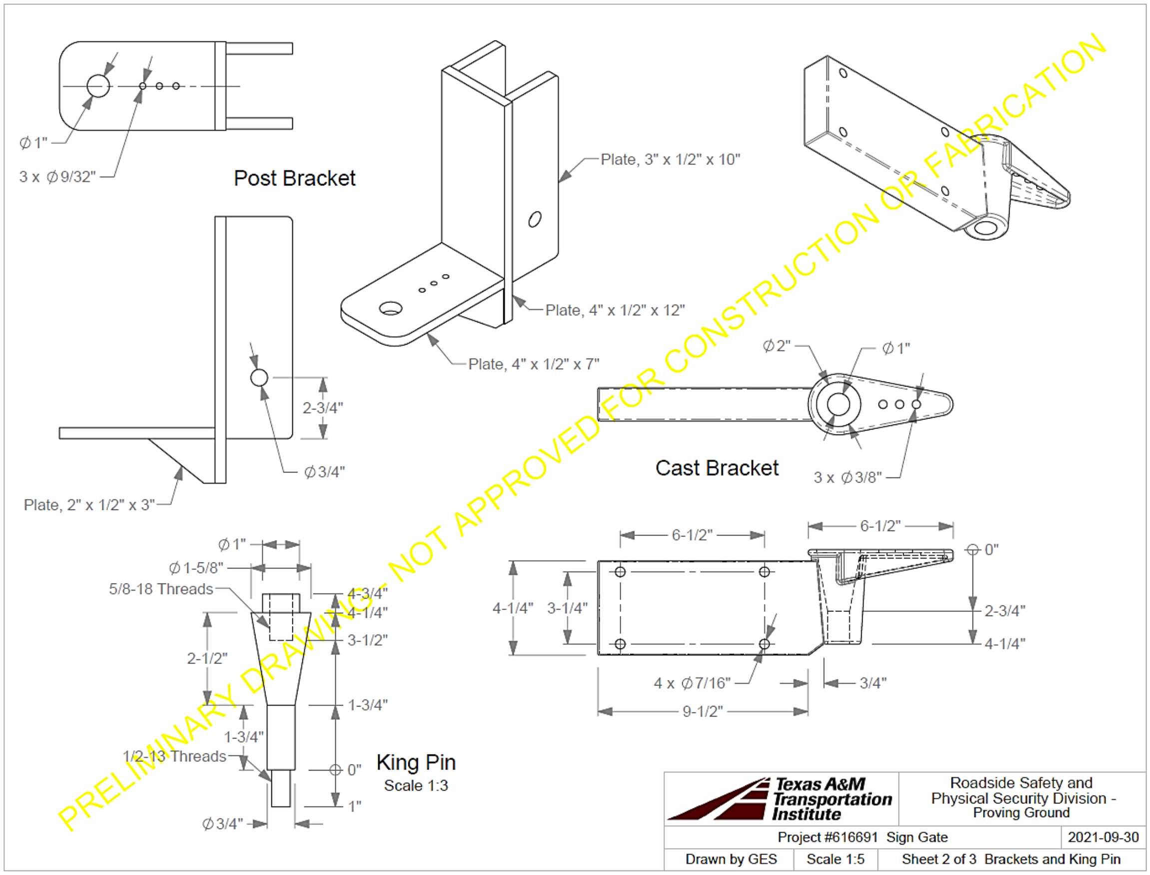
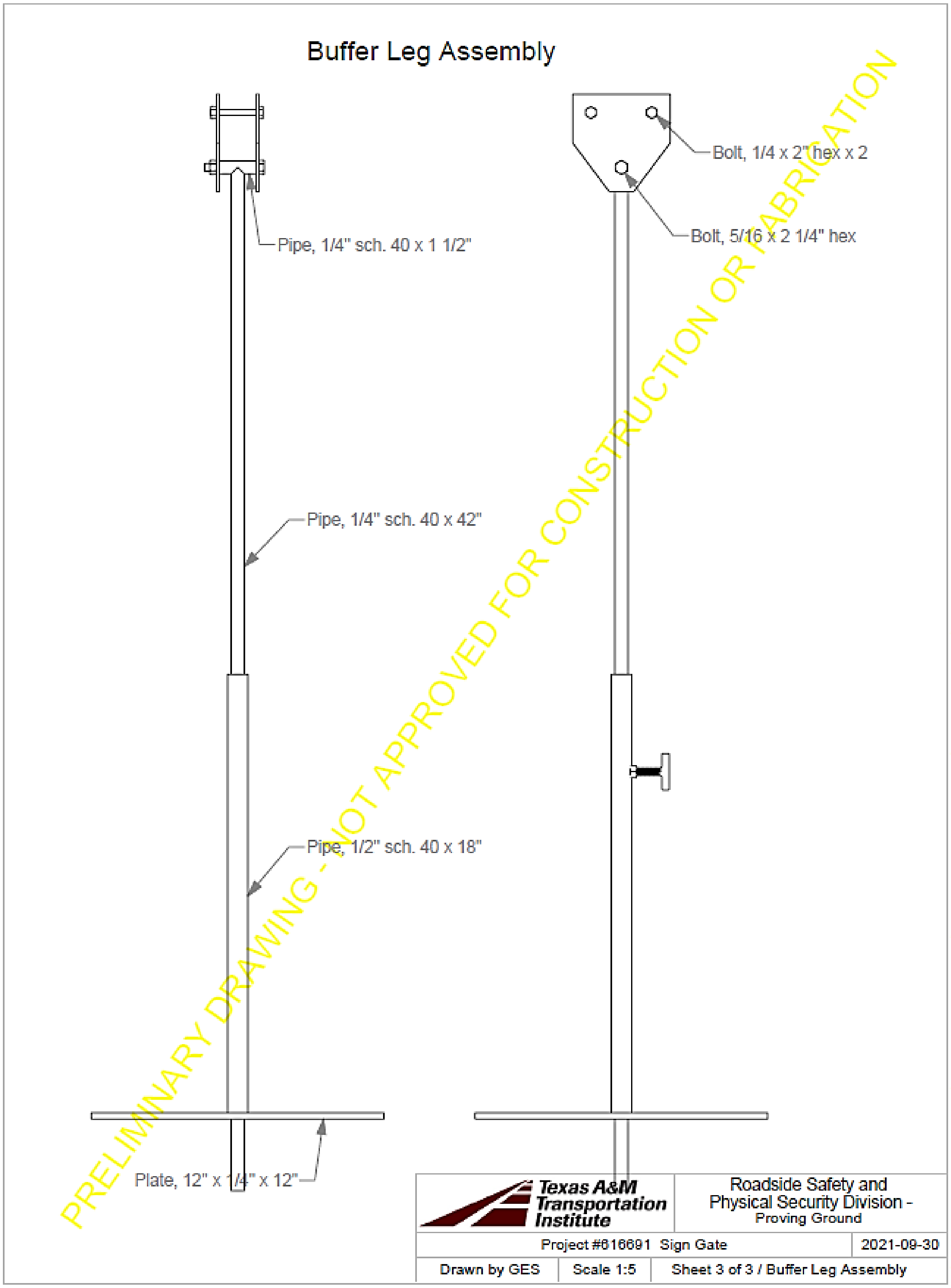


Figure 5. Contraflow ramp closure gate—buffer leg assembly



Task 2—Constructing the FE Model

TTI completed a product review as part of Task 1. In Task 1, information was gathered on the component sizes and material properties. After Task 1 was completed, TTI created a three-dimensional (3D) geometry model of the system according to the gathered information. The geometry model is depicted in Figure 6. After geometry clean-up, TTI developed FE models of each component and defined proper material properties. Furthermore, component connectivity was modeled (ties, shear pins, contacts, etc.).

The system was modeled in the way that it remains locked (using shear pins) in an open or closed position during impact. The FE model components are listed in Figure 7, and the final FE model assembly is presented in Figure 8.

Figure 6. Contraflow ramp closure gate 3D geometry model

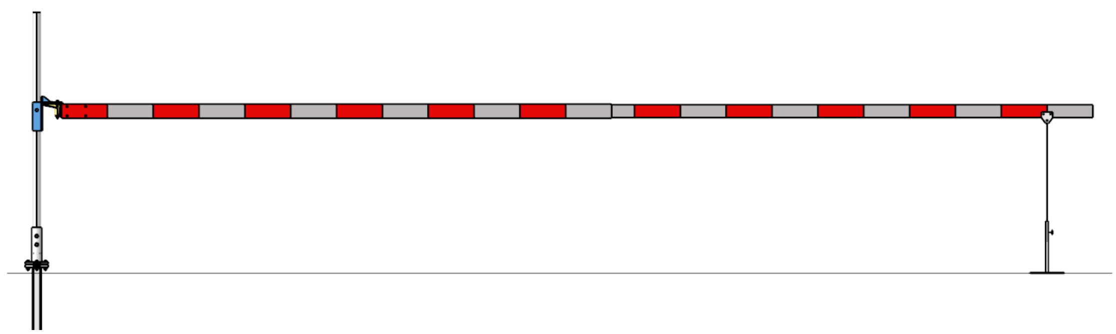


Figure 7. Contraflow ramp closure components

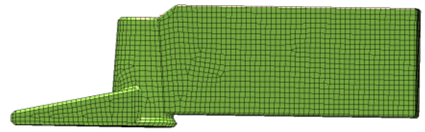
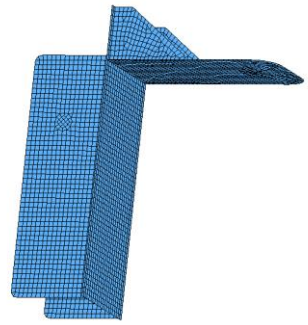
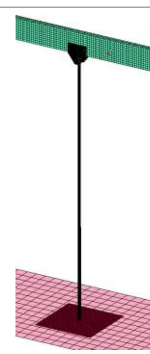
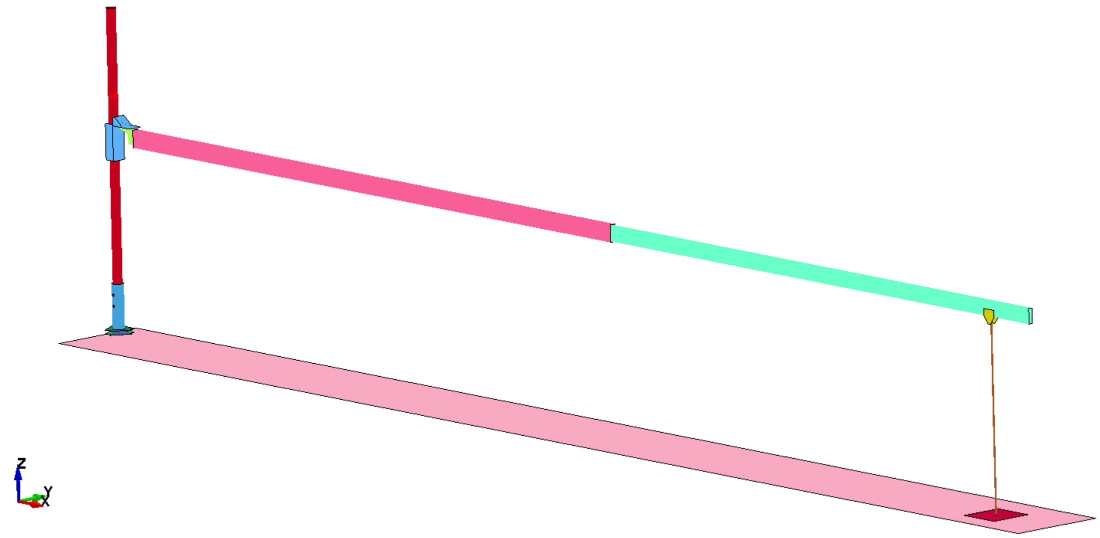
Name	Component	FE Model
Cast Adapter		
Pole Bracket		
Gate Arm and Extension		
Pole and Slip Base System		
Buffer Leg Assembly		

Figure 8. Contraflow ramp closure gate FE model assembly



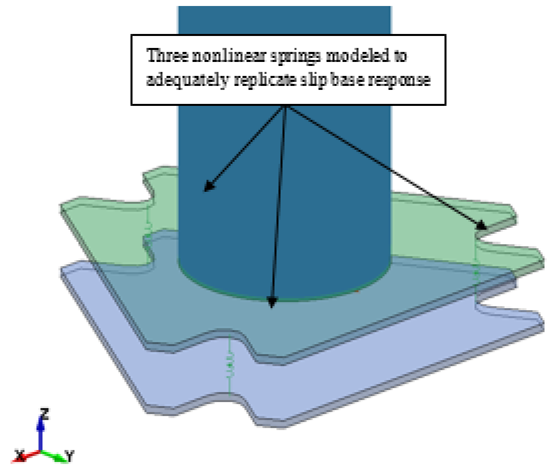
Task 3—Performing FE Simulation of the Device

TTI constructed the FE model of the ramp gate as part of Task 2. The model from Task 2 was used to conduct FE computer simulations to evaluate the system's performance under MASH TL-3 evaluation criteria. As part of Task 3, TTI conducted computer simulations to evaluate the contraflow ramp gate performance under MASH TL-3 conditions, first validating the slip base support model and then performing the parametric analyses. Following is a summary of the FE computer simulation and results.

Slip Base System Validation

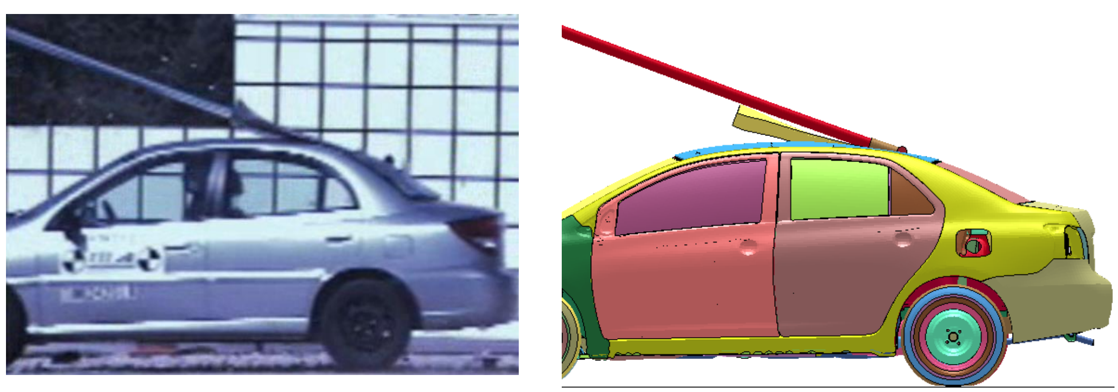
Figure 9 illustrates the triangular slip base casting that was explicitly modeled to properly account for the inertial properties of the sign support system. The system was modeled using shell elements and rigid material property. The bottom of the triangular slip base is fixed, considering that it will not have any significant movement during an impact. Instead of bolts, three nonlinear springs were modeled to replicate the slip base response upon impact. This modeling technique has been used in previous studies [2].

Figure 9. FE model of slip base sign support system



The FE computer model of the slip base system was calibrated against two full-scale crash tests. Figure 10 shows the comparison of the FE computer simulation aimed at replicating the 10 BWG (Birmingham Wire Gauge) steel slip base support with a14-sq.-ft. sign panel and Test No. 463631-3 [2]. A reasonable correlation was achieved between simulation and test results. Similarly, Figure 11 illustrates an acceptable correlation between the crash test of the Texas Department of Transportation burn ban sign on slip base support with its computer model replicating the crash test [3]. The slip base FE model released in a similar timing and manner to the full-scale cash tests.

Figure 10. Comparison between Test No. 463631-3 and the FE model



(a) Test No. 463631-3 (b) FE model

Figure 11. Comparison between Test No. 469469-8 and the FE model

(a) Test No. 469469-8 (b) FE model

Simulation Matrix

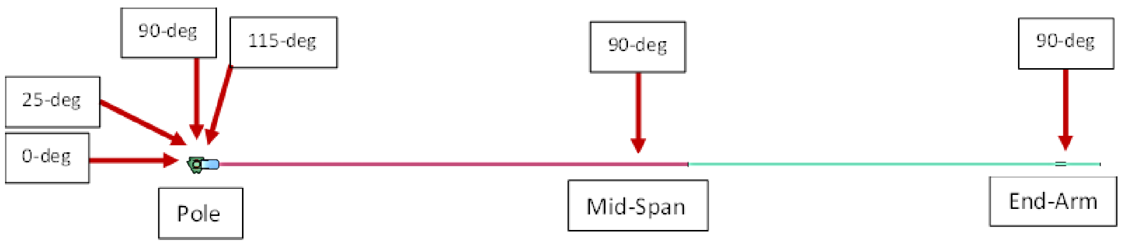
According to MASH, three tests are recommended to evaluate support structures to TL-3:

- MASH Test 3-60: An 1100C (2,420 lb/1,100 kg) vehicle impacting the device at a nominal impact speed of 19 mph and CIA judged to have the greatest potential for test failure. This test investigates a device's ability to successfully activate by a breakaway, fracture, or yielding mechanism during low-speed impacts with a small vehicle.
- MASH Test 3-61: An 1100C (2,420 lb/1,100 kg) vehicle impacting the device at a nominal impact speed of 62 mph and CIA judged to have the greatest potential for test failure. This test evaluates the behavior of the device during high-speed impacts with a small vehicle.
- MASH Test 3-62: A 2270P (5,000 lb/2,270 kg) vehicle impacting the device at a nominal impact speed of 62 mph and CIA judged to have the greatest potential for test failure. This test evaluates the behavior of the device during high-speed impacts with a pickup truck.

Parametric Analysis Results and Discussion

The next step in this research was to conduct predictive FE impact simulations against the ramp gate system. The objective was to evaluate the device's component trajectories during impact for most possible scenarios. Results were then compared with MASH specification criteria for occupant risk to provide any design modifications to improve the system's performance as needed. Figure 12 depicts a plan view schematic of the device with the impact angles and location that were evaluated. A summary of the computer simulations follows.

Figure 12. Schematic of critical impact angles and impact locations

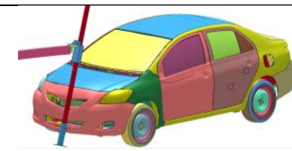
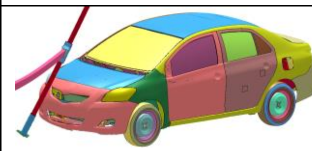
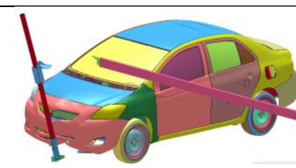
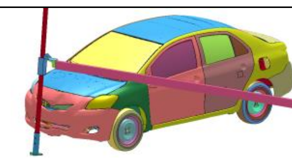
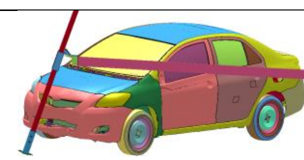


FE Predictive Results for MASH Test 3-60

MASH Test 3-60 was used to evaluate the device's performance during low-speed (19 mph) impact with a small car. For this test, the device was impacted at the pole location at four different angles: 0, 25, 90, and 115 degrees. The device was simulated in two conditions: with shear-pin fail and without shear-pin fail. The original device that was reviewed and documented in Task 1 utilizes a set of shear bolts to be detached upon impact to the pole. The no-fail bolt configuration was analyzed to evaluate the possibility of the shear bolts not failing, especially during the low-speed impact condition. Impact of the device at locations other than the pole was not conducted since it was deemed either not feasible (e.g., 0 degrees at mid-span) or not critical at low speed.

Figure 13 summarizes the configuration of each computer simulation case and illustrates the device's trajectory upon impact by a small car at a low speed. FE predictive analyses of the small car at low speed showed that the impact at 0 degrees had the highest possibility of windshield damage. Case No. 3-60-1 appeared to be the most critical impact, with the pole going through the windshield and resulting in deformation higher than the MASH limit. In Case No. 3-60-4, despite the pole moving out of the way, there was still a possibility of the gate arm impacting the windshield and deformation exceeding the MASH limit. In the other cases, with no shear-pin failure, the post bounced away from the vehicle without impacting the windshield. The occupant impact velocity (OIV) and the occupant ridedown acceleration (ORA) in all the simulations were within MASH limits.

Figure 13. Summary of FE simulation impact predictions with small car at low speed

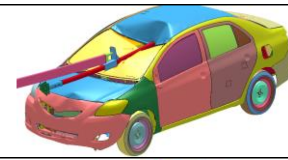
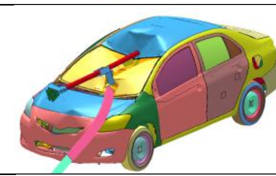
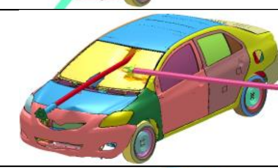
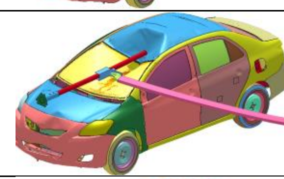
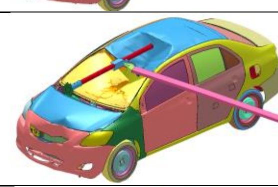
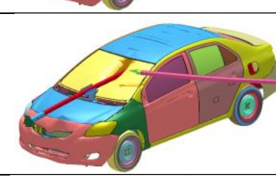
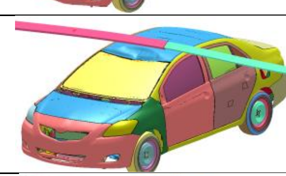
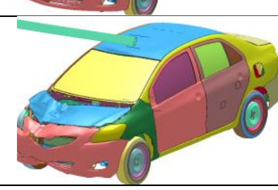
Case No.	Impact Location	Impact Angle (deg.)	Shear-Pin Fail	Post Size	Pass/ Fail	Failed MASH Criterion (Table 2)	Device Response after Impact
3-60-1	Pole	0	Yes	Sch. 40	Fail	D	
3-60-2	Pole	0	No	Sch. 40	Pass	—	
3-60-3	Pole	25	No	Sch. 40	Pass	—	
3-60-4	Pole	90	Yes	Sch. 40	Fail	D	
3-60-5	Pole	90	No	Sch. 40	Pass	—	
3-60-6	Pole	115	No	Sch. 40	Pass	—	

FE Predictive Results for MASH Test 3-61

MASH Test 3-61 was used to evaluate the device's performance during high-speed impacts with a small car. For this test, the device was impacted at all three locations: pole, mid-span, end arm. For the pole location, the small car was impacted at four different angles: 0, 25, 90, and 115 degrees. For the mid-span and end-arm locations, only a 90-degree impact angle was simulated since it is the most critical impact condition and causes the most interaction of the gate arm with the vehicle.

Figure 14 summarizes the configuration of each computer simulation and shows the device's response upon impact by a small car at high speed. All the impact cases for Test 3-61 resulted in the device impacting the windshield and/or the roof of the vehicle. According to MASH, acceptable impact performance requires roof crush of no more than 4 in. and windshield deformation of a 3 in. maximum. In all cases, except Case Nos. 3-61-8 and 3-61-9, the deformations appeared to exceed MASH limits. Using a Schedule 80 pipe section did not improve the system's performance, as shown in Case No. 3-61-6. The OIV and ORA in all the simulations were within MASH limits.

Figure 14. Summary of FE simulation impact predictions with small car at high speed

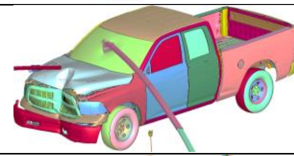
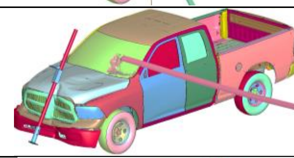
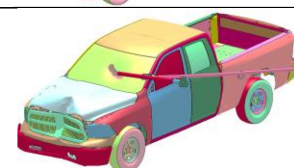
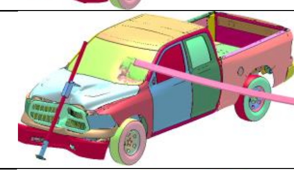
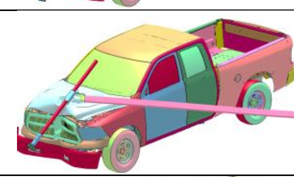
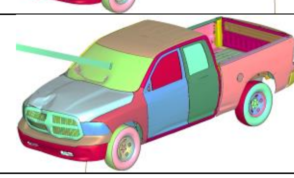
Case No.	Impact Location	Impact Angle (deg.)	Shear-Pin Fail	Post Size	Pass/ Fail	Failed MASH Criterion (Table 2)	Device Response after Impact
3-61-1	Pole	0	Yes	Sch. 40	Fail	D	
3-61-2	Pole	0	No	Sch. 40	Fail	D	
3-61-3	Pole	25	Yes	Sch. 40	Fail	D	
3-61-4	Pole	90	Yes	Sch. 40	Fail	D	
3-61-5	Pole	90	No	Sch. 40	Fail	D	
3-61-6	Pole	90	No	Sch. 80	Fail	D	
3-61-7	Pole	115	Yes	Sch. 40	Fail	D	
3-61-8	Mid-Span	90	No	Sch. 40	Pass	—	
3-61-9	End Arm	90	Yes	Sch. 40	Pass	—	

FE Predictive Results for MASH Test 3-62

MASH Test 3-62 was used to evaluate the device's performance during high-speed impacts with a pickup truck. For this test, the device was impacted at all three locations: pole, mid-span, and end arm. Similar to the small car simulation at high speed, the pickup truck was impacted at four different angles: 0, 25, 90, and 115 degrees. For the mid-span and end-arm locations, the impact was only simulated for a 90-degree angle since it is the most critical condition.

Figure 15 summarizes the configuration of each computer simulation and shows the device's response upon impact by a pickup truck at high speed. The only pole impact to the windshield occurred in Case No. 3-62-4. In the majority of cases, the gate arm impacting the windshield was the reason for the device failing the evaluation. A comparison of Case Nos. 3-62-4 and 3-62-6 in the figure shows how the system performance was improved by swapping the Sch. 40 pole section with a heavier Sch. 80 section. The OIV and ORA in all the simulations were within MASH limits.

Figure 15. Summary of FE simulation impact predictions with pickup truck at high speed

Case No.	Impact Location	Impact Angle (deg.)	Shear-Pin Fail	Post Size	Pass/ Fail	Failed MASH Criterion (Table 2)	Device Response after Impact
3-62-1	Pole	0	Yes	Sch. 40	Pass	—	
3-62-2	Pole	25	Yes	Sch. 40	Fail	D	
3-62-3	Pole	90	Yes	Sch. 40	Fail	D	
3-62-4	Pole	90	No	Sch. 40	Fail	D	
3-62-5	Pole	90	Yes	Sch. 80	Fail	D	
3-62-6	Pole	90	No	Sch. 80	Pass	—	
3-62-7	Pole	115	Yes	Sch. 40	Pass	—	
3-62-8	Mid-Span	90	No	Sch. 40	Fail	D	
3-62-9	End Arm	90	Yes	Sch. 40	Fail	D	

Conclusions and Recommendations

Conclusions

The purpose of the study reported herein was to assess the performance of the contraflow ramp gate upon impact under MASH TL-3 conditions. The predictive FE simulations resulted in the following findings and conclusions.

1. During the MASH Test 3-60 simulation at the 0-degree impact location, the small car experienced significant damage to the windshield. Additionally, the 90-degree impact with failed shear pins indicated a possible impact of the gate arm with the windshield.
2. During the MASH Test 3-61 simulation at the pole location, severe damage/deformation of the windshield and/or the roof was observed. A 90-degree impact to the mid-span caused deformation only to the roof, while the impact at the end arm resulted in the lowest damage to the roof.
3. During the MASH Test 3-62 simulation of the contraflow ramp gate, the majority of the occupant compartment damage occurred as a result of the gate arm impacting the windshield.
4. Utilizing a heavier pole (Sch. 80) improved the system's performance during the impact with a pickup truck when the gate arm stayed attached to the pole. However, the same design change did not affect the failed outcome in small car impacts.

The current device configuration was not found to be MASH compliant for TL-3. Further design modification and testing are warranted to evaluate the crashworthiness of the device.

Recommendations

Based on the conclusions, the following solutions are provided for consideration to improve the system's performance:

1. The gate arm mounting height needs to be adjusted to avoid direct impact with the vehicle's windshield and roof in all three test conditions.

2. Keeping the pole attached to the arm during impact (i.e., not using shear pins) may help keep the system away from the occupant compartment during low-speed impact; however, this may not be helpful for high-speed impact conditions.

Acronyms, Abbreviations, and Symbols

Term	Description
1100C	small (compact) test vehicle
2270P	pickup truck test vehicle
3D	three dimensional BWG
BWG	Birmingham Wire Gauge
CIA	critical impact angle
deg.	degree(s)
FE	finite element
Ft.	foot (feet)
ft/s	foot (feet)/second
g	unit of gravity
kg	kilogram(s)
DOTD	Louisiana Department of Transportation and Development
in.	Inch(es)
lb	pound(s)
LTRC	Louisiana Transportation Research Center
MASH	*Manual for Assessing Safety Hardware*
mph	miles per hour
OIV	occupant impact velocity
ORA	occupant ridedown acceleration
Sch.	schedule
Sq. ft.	square foot (feet)
TL-3	Test Level 3
TTI	Texas A&M Transportation Institute

References

[1] American Association of State Highway and Transportation Officials, Manual for Assessing Safety Hardware, Second ed., 2016.

[2] C. Silvestri, D. Arrington, R. Bligh and W. Menges, "Development Guidance for Sign Design Standards," Texas A&M Transportation Institute, College Station, TX, February 2012.

[3] R. Bligh, W. Menges, B. Griffith, G. Schroeder and D. Kuhn, "MASH Evaluation of TxDOT Roadside Safety Features—Phase III," Texas A&M Transportation Institute, College Station, TX, February 2020.