Challenges of Predicting Impacts with Roadside Safety Hardware: Recent Case Studies

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Abstract

As an integral part of engineering safer roads, road side safety devices passively interact with errant vehicles to redirect them safely back to the road or bring them to a safe and controlled stop. These devices take the form of crash cushions, cable barriers, concrete barriers, steel barriers, guardrails, guardrail terminals and others. Placement criteria and warrants are established in the AASHTO Road Side Design Guide (1). However, before those devices are placed on the roadways, they have to be evaluated under objective test conditions. Given that possible combinations of impact speeds, impact angles, vehicle characteristics and roadway characteristics are infinite, it is impossible to design roadside safety hardware for all those combinations. Thus a "Practical Worse Case" philosophy derived from crash data analyses is followed to determine such impact conditions. In the USA, the evaluation methodologies are established in the Manual for Assessing Safety Hardware (MASH) guidelines (2). As with any design process, gone are the days of try and error experimentation due to increased cost of testing and the increased accuracy and efficiency of simulation. Hence, state of the art nonlinear finite element methodology has been gaining tractions in designing and enhancing the safety of roadside devices. LS-DYNA® established itself as the code of choice for simulating vehicular impact scenarios with roadside hardware. This paper will highlight roadside safety hardware (3, 4) that was designed through extensive LS-DYNA simulations and had subsequent crash tests per the latest MASH guidelines. Signals and phenomena from simulations are compared with those from the subsequent tests and presented within this paper.

Introduction

Researchers and practitioners in the roadside safety area have been investigating the short-radius issue for many years. Although numerous tests were conducted for different short-radius guardrail designs, none of them passed National Cooperative Highway Research Program (NCHRP) Report 350 Test Level 3 (TL-3) (*1*) requirements. Manual for Assessing Safety Hardware (MASH) (*2*) became the updated crash testing guidelines in 2009. Part of the updates are the increased impact severity for TL-3 tests. Satisfying that impact severity became even more challenging for the short-radius system.

This paper presents a MASH TL-3 short-radius design that was designed via simulation and successfully crash tested for sloped terrain applications. The key model components of the short-radius guardrail system are:

- A lagrangian steel thrie-beam representing the short radius rail
- Four 700-lb SPH sand barrels placed on the inner side of the short radius
- Rotating boundary condition on the driveway side representing the rigid rotating anchor
- Rigid concrete parapet on the primary roadway side
- Steel post with elastic-plastic material behavior adjacent to the parapet
- Wood posts with fracture on the nose section
- A key cable to provide tensile capacity for the primary rail on the upstream side

Figure 1 shows an isometric view of the model. The model includes a representation of a ditch placed 5 ft. offset from the thrie-beam on each side. The ditched is sloped at 3H:1V starting at the 5-ft offset.

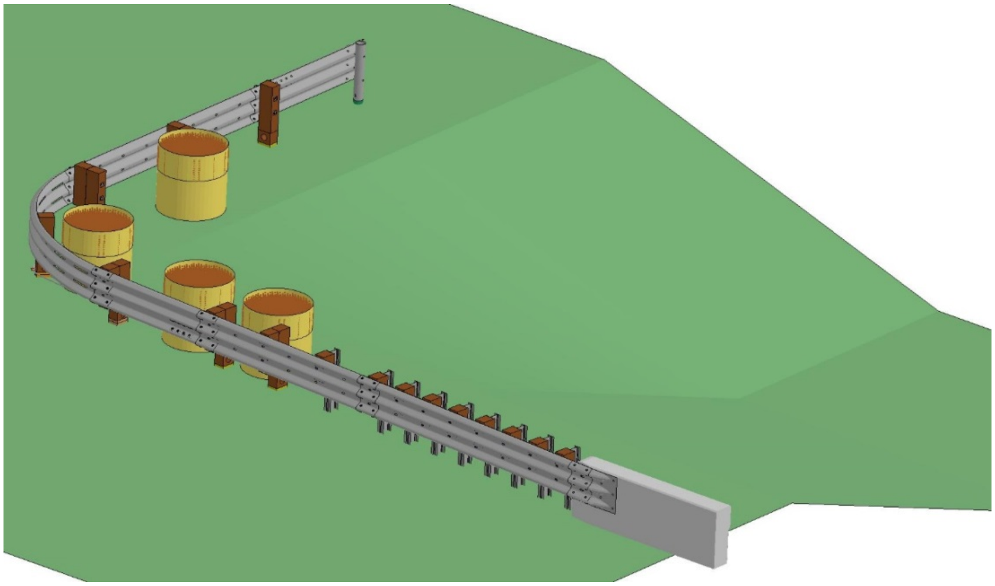

Figure 1. **ISOMETRIC VIEW OF SHORT RADIUS GUARDRAIL**

Modeling History

Several concepts were developed throughout the development effort of the short radius system. In summary, earlier simulation effort narrowed the potential design to focus on augmenting the short-radius railing with inertial contribution from frangible sand barrels. These sand barrels helped attenuate the impact just enough to slow down the vehicle without violating occupant impact criteria. LS-DYNA finite element code was used to perform the simulations throughout all phases of this study to design.

Simulation of Short Radius Impact with 3H:1V Ditch

The simulations presented were conducted to evaluate TxDOT's 0-6711 short radius on a small car (TL 3-32) and a truck (TL 3-33) with the inclusion of a ditch, and with an impact angle of 15° on the nose of the radius. However, when using 25° impact angle, a potential under ride for the small care was observed To keep the Occupant Impact Velocity (OIV) below the limit, the barrels were spread out behind the rail system instead of clustered behind the radius as in previous simulations. This way, the car will see less mass at any single given moment in the simulation and contribute to the success towards adequately capturing the vehicles within an acceptable distance behind the rail. As shown in Figure 2, the earlier barrels arrangement included two barrels grouped closely together along the primary roadway, another barrel in the center of the radius, and one barrel approximately halfway up the (secondary) driveway.

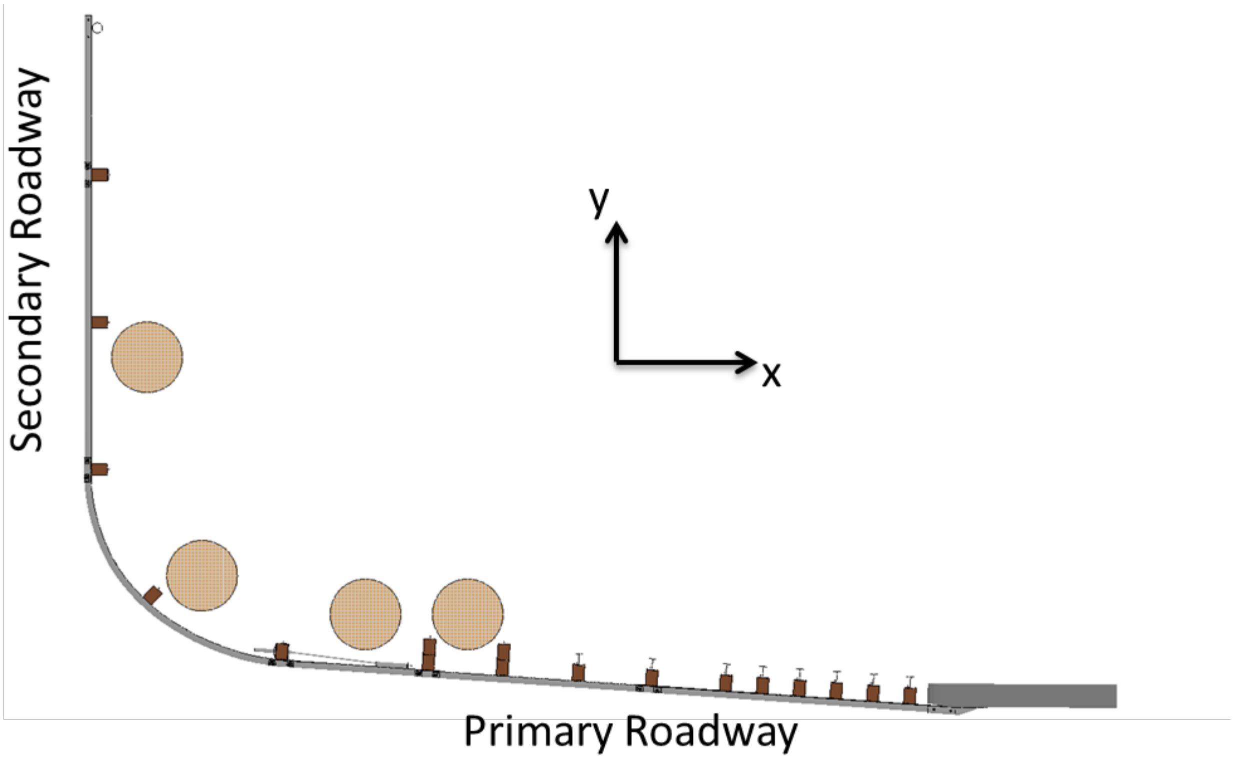

Figure 2. FLARE AND SPREAD OUT OF THE 700-LB BARRELS FOR A FLAT TERRAIN APPLICATION.

Simulation of Short Radius Impact with 3H:1V Ditch

MASH Test 3-32 — Impact Angle of 15° vs. 25° with Four Sand Barrels

This is the test with the small car (1100 kg) impact the device at 100 km/h. The impact angle for this simulation was either 15° or 25° from the face of the parapet with impact point at the nose of the radius. This impact purpose is to check the system adequacy to capture the vehicle. The simulation results show success in containing the vehicle. However, Figure 3, Figure 4, Figure 5, and Figure 6 indicate that the there is a greater potential for the vehicle to under ride as compared the 15° impact angle simulation in which there was no potential underride. Ultimately, an impact angle of 25° seems to be more critical for the short radius with 3H:1V ditch than an impact angle of 15°. Thus, an impact angle of 25° was used to quantify the system performance.

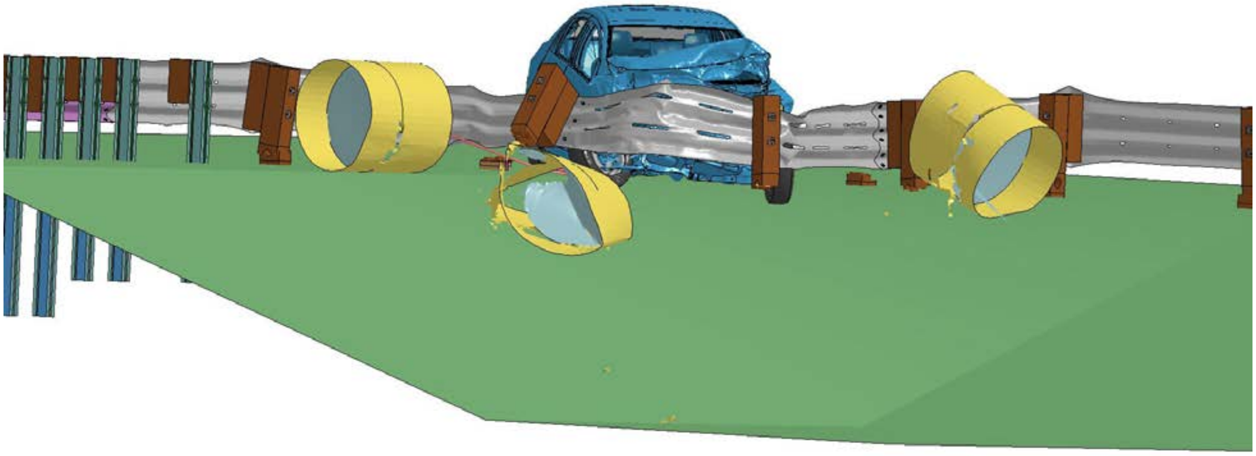

Figure 3. **Front View of Vehicle after Collision with 15° Impact Angle.**

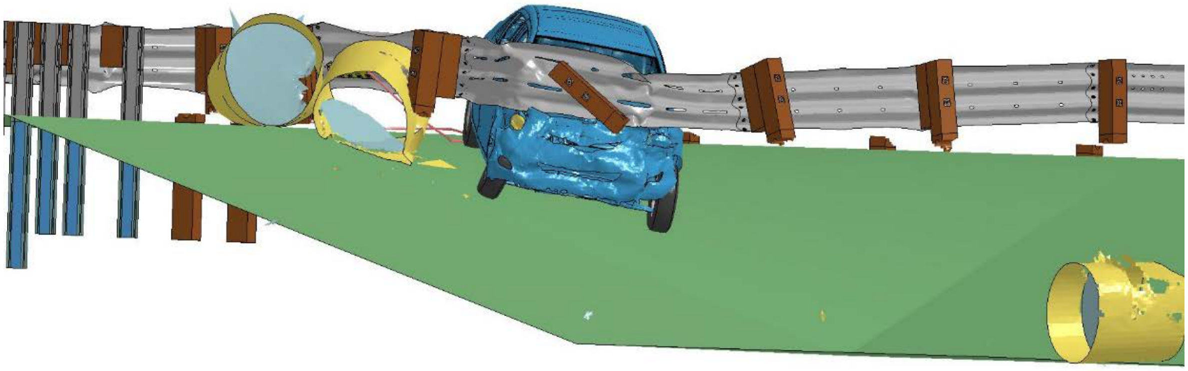

Figure 4. **Front View of Vehicle after Collision with 25° Impact Angle.**

Figure 5. **Side View of Vehicle after Collision with 15° Impact Angle.**

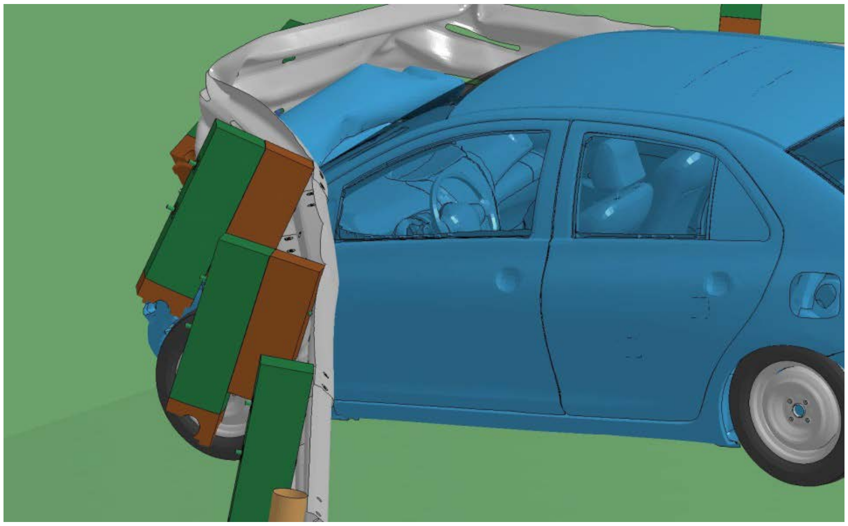

Figure 6. SIDE VIEW OF VEHICLE AFTER COLLISION WITH 25° IMPACT ANGLE.

MASH Test 3-32 — Impact Angle of 25° with Six Sand Barrels

This simulation represents a design solution to reduce the under-ride potential observed with an impact angle of 25° by adding two additional barrels. Figure 7 shows the short radius with six sand barrels was able to contain the vehicle. The increased number of sand barrels reduced the potential of underride of the rail as shown in Figure 8. The hood buckled inward but did not interact with the windshield of the car as shown in Figure 9.

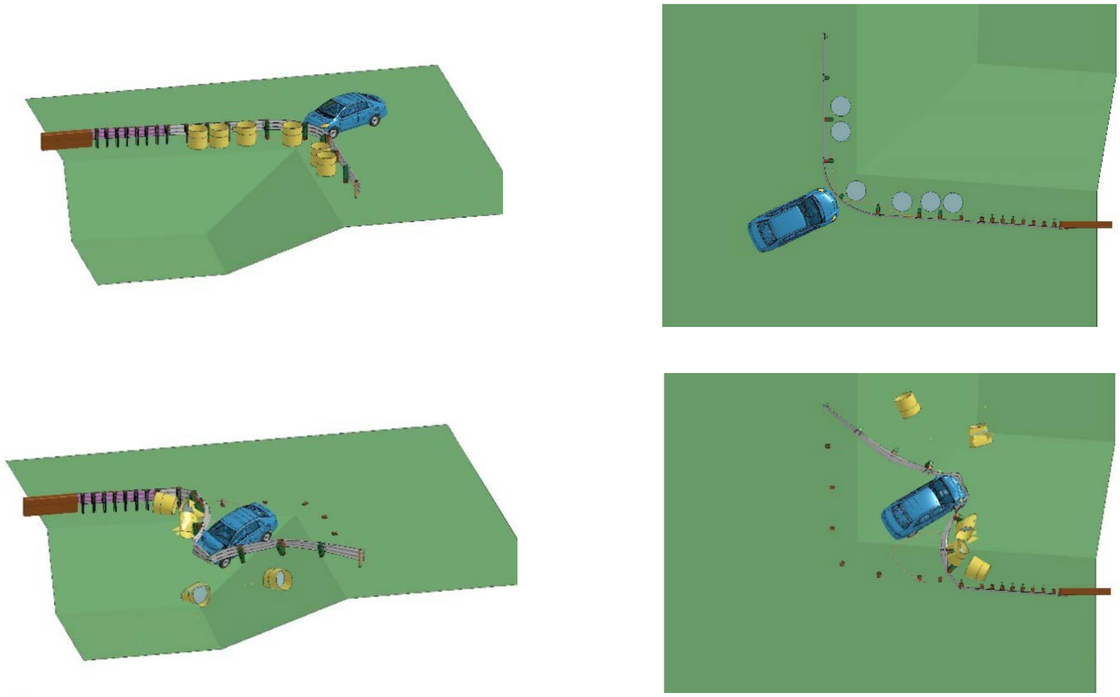

Figure 7. PHOTOS FROM SIMULATION BEFORE AND AFTER IMPACT WITH SHORT RADIUS.

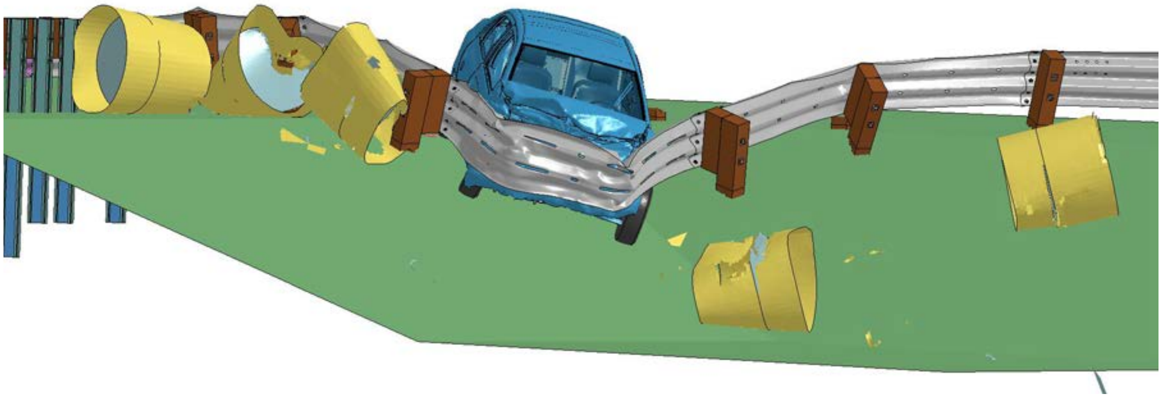

Figure 8. Front View of Vehicle at the Conclusion of Impact.

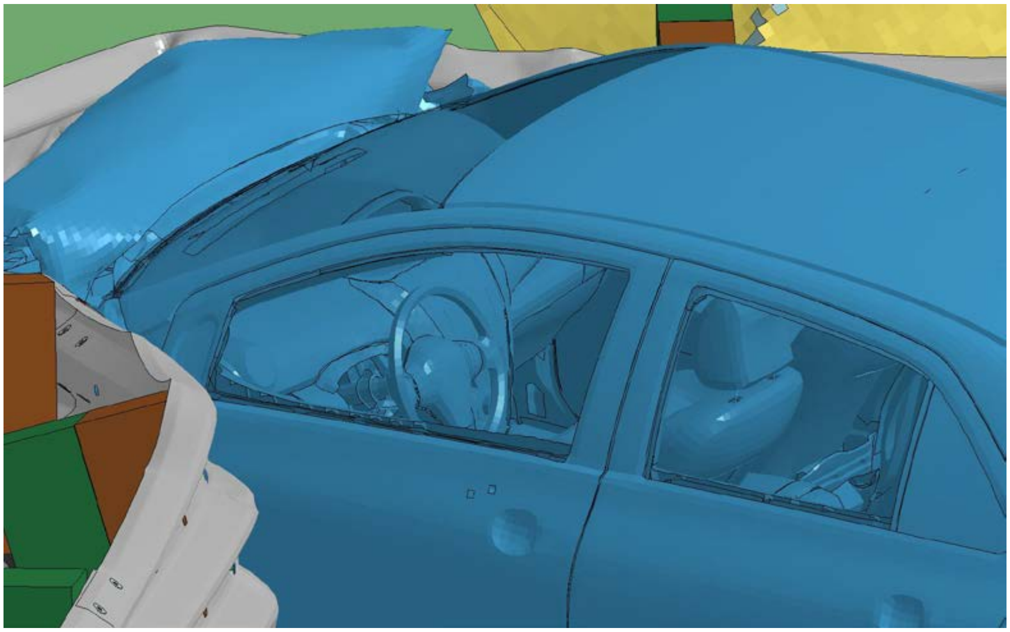

Figure 9. Side View of Vehicle after Collision.

MASH Test 3-33 — Impact Angle of 25° with Six Sand Barrels

This simulation was conducted to evaluate the effect of the additional barrels on system performance once impacted by the pickup truck (2270 kg test vehicle). Although the short radius with six barrels successfully contained the truck, it is worth noting from Figure 10 that there is still a possibility for the rear right wheel of the truck to straddle the rail. This is not considered an adverse outcome since the truck was safely contained and remained stable on the sloped terrain.

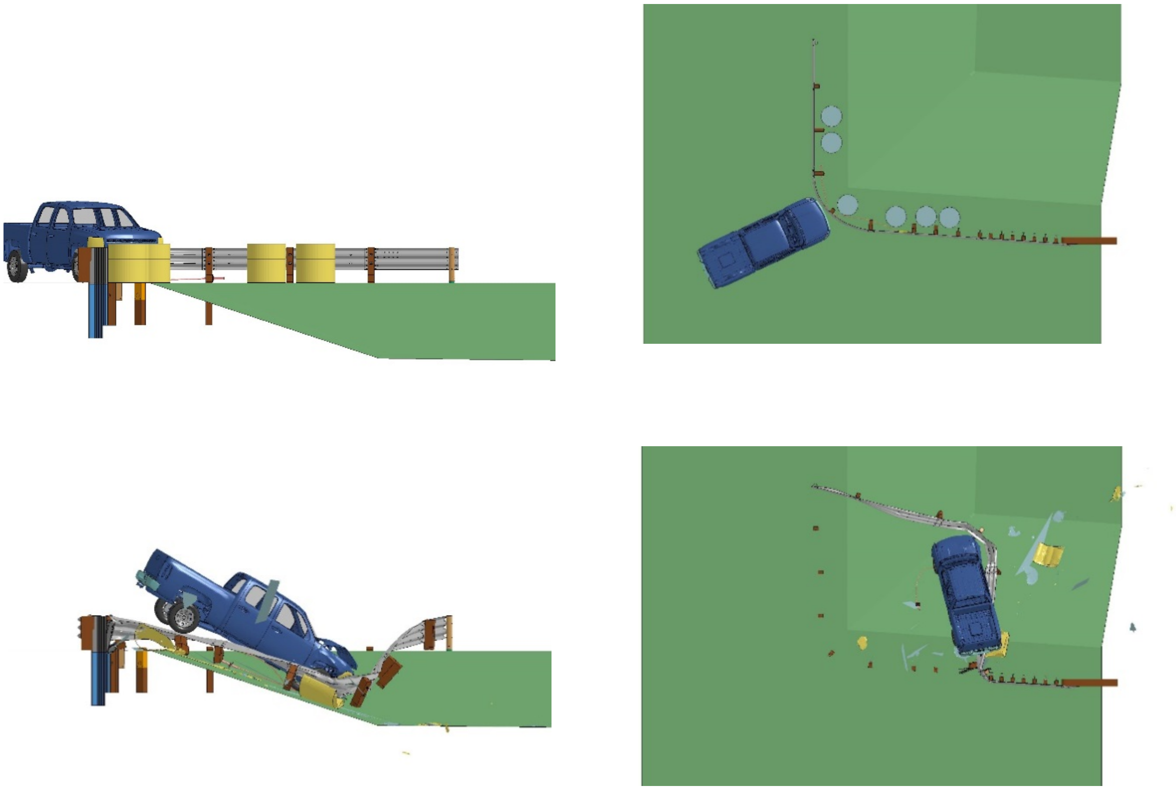

Figure 10. Pickup Truck Impact with the Short Radius

Full-Scale Crash Tests for Short Radius on Sloped Terrain

The system configuration for the test installation is shown in Figure 11. There six 700lb sand barrels as designed by the simulation process. The ditch is placed 5-ft behind the rail at a slope of 3H:1V.

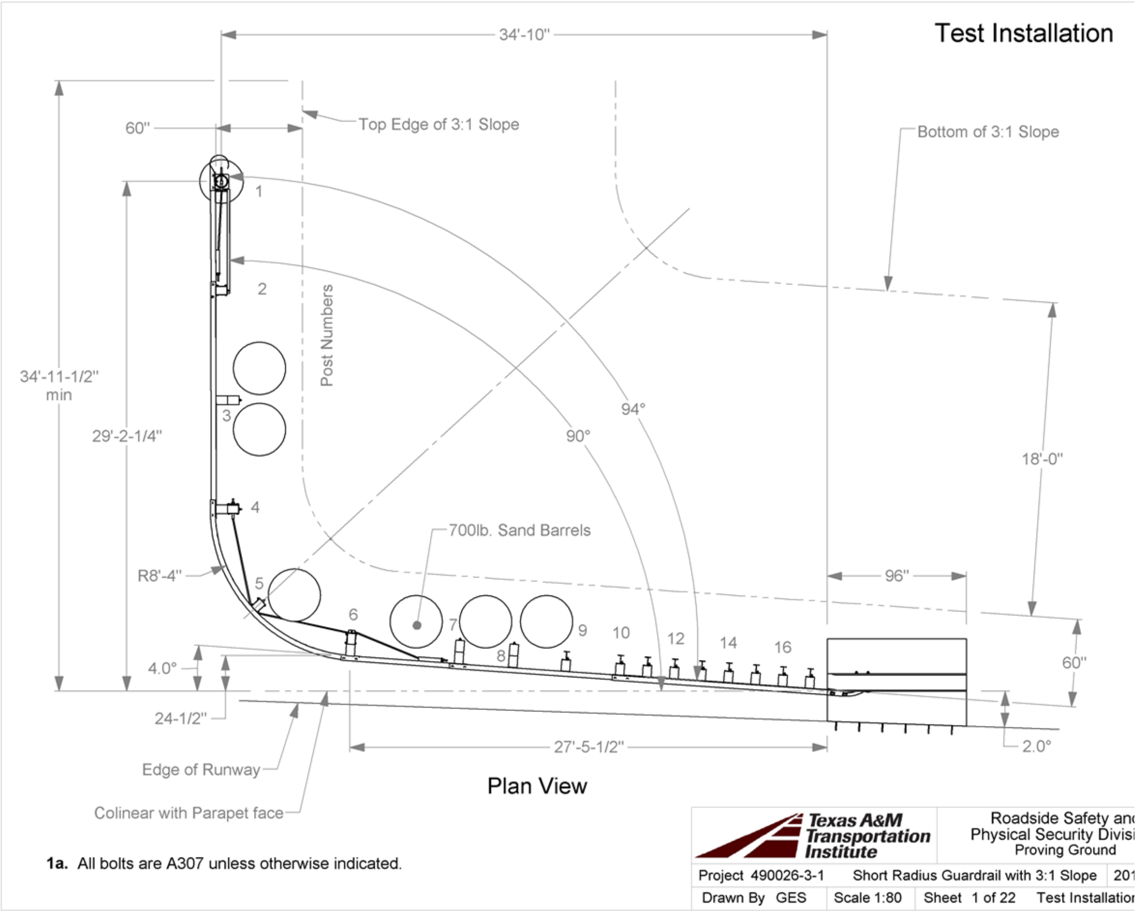

Figure 11. An overall view of the short-radius installation for MASH 3-33 and MASH 3-32 tests for sloped terrain.

MASH Test 3-32

MASH Test 3-32 examined the behavior of the short-radius system during an oblique impact on the nose of the system. Occupant risk and vehicle trajectory were the main concerns with regard to this test. The 1100C vehicle impacted the center of the radius of the system at a 25° angle and 62 mph (100 km/h). The system was able to capture the vehicle and bring it to a controlled stop, as shown in Figure 12.

Figure 12. MASH Test 3-32 (sloped terrain) at impact and final vehicle position.

MASH Test 3-33

MASH Test 3-33 involved a 2270P vehicle weighing 5,000 lb. (2,270 kg) traveling at 62 mph (100 km/h) and impacting the nose section of the short radius at 25° relative to the main roadway. This test examines the rail structural integrity under heavy passenger vehicle (pickup truck). Although the right rear wheel of the pickup truck straddled the thrie beam, as shown in Figure 13, the system was able to capture the vehicle and bring it to a controlled stop.

Figure 13. MASH Test 3-33 (sloped terrain) at impact and final vehicle position.

Table 1 and Table 2 show the occupant risk numbers from simulations and tests to be within the accepted MASH evaluation limits.

Table 1. TRAP Summary Data of Simulation with Flare and Spread Out 700-Lb Barrels.

TRAP Results: Small Car TL 3-32		
Impact Velocity, km/h		100.0
Impact Angle (degrees)		25
Occupant Risk Factors	**Simulation**	**Crash Test**
Impact Velocity (m/s)		
x-direction	10.8	10.5
y-direction	1.1	1.3
Ride-down Accelerations (Gs)		
x-direction	11.0	6.6
y-direction	11.7	10.1
Max Roll, Pitch, and Yaw Angles (degrees)		
Roll	12.4	8.5
Pitch	17.4	17.7
Yaw	19.2	40.4

Table 2. TRAP Summary Data of Simulation with Flare and Spread Out 700-Lb Barrels.

TRAP Results: Pick Up Truck TL 3-33		
Impact Velocity, km/h		100.0
Impact Angle (degrees)		25
Occupant Risk Factors	**Simulation**	**Crash Test**
Impact Velocity (m/s)		
x-direction	7.8	7.2
y-direction	2.6	2.1
Ride-down Accelerations (Gs)		
x-direction	6.8	6.3
y-direction	4.9	5.0
Max Roll, Pitch, and Yaw Angles (degrees)		
Roll	27.7	28.5
Pitch	28.5	25.3
Yaw	79.3	84.8

Conclusions

A MASH TL-3 compliant short-radius system was developed and tested by TTI for a 3H:1V sloped terrain configuration. LS-DYNA simulations were extensively used to iteration and evaluate different design concepts. Although simulations predicted phenomena and risk numbers were close to those observed in subsequent crash testing, there are challenges in predicting roadside safety tests. Key challenges are:

1. The use of materials with scattered response such as soil and wood.
2. The longer duration of impact that can go up to two seconds or even more.
3. The scatter of failure phenomena such as suspension and tire components.
4. Vehicle models are not reflective of test vehicle make and models.
5. Friction and connection modeling.
6. Test vehicle variations.
7. Signals are limited to one or two locations on the vehicle.

Having said that, the introduction of sensitivity analyses with tools such as LS-OPT® can help designers with better understanding the envelope of performance of such systems.

Acknowledgements

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