Safety Performance Evaluation of Concrete Barriers on Curved and Superelevated Roads

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Abstract

Highways are comprised of tangent and curved sections. It has been established that there is a difference in safety between these types of sections. Roadside safety hardware, however, is not specifically designed or tested to address the differences in behavior that may be associated with placement of curves relative to tangent sections. The differences in safety performance may be negligible due to a host of intervening factors, but given little formal attention on this matter, that remains an open question at present. This effort stems from a crash into a barrier that occurred on a superelevated curve. It represents an attempt to determine if simulation tools can provide useful insights on the impact dynamics, influencing factors, and the likely outcomes.

Simulation analyses were undertaken for three curvature conditions for NCHRP Report 350 crashworthiness criteria for the 2000P and 820S vehicles. Three types of concrete barriers were evaluated based upon NCHRP Report 350 metrics. The results suggest that adverse safety performance is more likely for the more highly sloped barriers when impacted on the sharper curves. The influences of various factors were analyzed and a criticality table was generated to indicate the effects of combination of factors for barriers on curved roads. The influence of vertical slope and superelevation were also considered to a limited degree.

1. INTRODUCTION

In a recent crash, a small car traveling above the speed limit on a curved, downhill freeway off-ramp struck a curved concrete barrier adjacent to the shoulder and vaulted the barrier and ultimately came to rest in a second floor office of a building adjacent to the ramp. Investigations of this crash raised questions about the adequacy of barrier designs on curved road sections and the associated placement guidelines for such situations. Curved sections of roadway are inevitable, but there has been very little research to address the safety design requirements for these situations. Current crashworthiness criteria only require tests on “straight” or “tangent” sections of barrier, subsequently there is limited knowledge about safety performance for deployment of barriers on curved sections.

1.1 Background

Highways are comprised of tangent and curved roadway sections with varying features. Typically, basic road features are developed for the “normal” or tangent sections. In some cases, such as curve design, there are special features associated with the curve (e.g., superelevation, curve widening) that change the road configuration from that on a tangent. This raises several questions including; given these differences, do other elements associated with the roadway function the same? More specifically, does roadside safety hardware function with similar effectiveness on curved sections? Do roadside hardware elements deployed on curves need variations in design or placement to offer comparable safety performance?

There are concerns that the curvature in a concrete barrier can cause a higher ride-up on a barrier and thus increase the potential for a vehicle to vault the barrier. This is considered particularly problematic for concrete safety shapes which have more pronounced sloped faces (e.g., New Jersey shapes) where this rise in the vehicle’s height may lead to the vehicle overriding the barrier or becoming unstable and rolling over. . There is a need to analyze the degree of this rise to determine if it is a problem, and if it is, to determine whether there is a better way to treat such highway situations.

It has been reported that horizontal curve crash problems are known to account for about 30% of the highway fatalities. It is not clear however, the percentage of these that involve curved sections of barrier or the specific types of barrier that might be suspect. The increased likelihood of a crash on a curve suggests that it is important to understand the performance of barriers deployed on curves.

A TRIS literature review indicated that there has been little attention on the subject of barriers on curves. A 1939 study indicated that a different impact angle should be considered for barriers on curves due the potential for vehicle skidding into the barrier on a curve [1]. An FHWA study entitled "Traffic Barriers on Curves, Curbs, and Slopes" dated August 1993 seems to represent the single most comprehensive study to date on the subject [2]. It was initiated with analyses of crash data to isolate the relative differences in crashes into barriers on curves versus tangent sections. The authors concluded that, as might be expected, barriers on curves performed differently than they do when tested on tangent sections with level terrain. In this effort a number of crash tests were conducted. Two tests involved impacts with an 1800 pound small car and a 5400 pound pick-up truck both at 60 mph and 20 degrees for standard w-beam guardrail on a 1192 foot radius curve on level terrain. These tests indicated that the barrier would meet the crashworthiness requirements.

Four additional tests were conducted with the 5,400 pound pick-up at 60 mph and 20 degree impact angle but approaching the barrier on the diagonal of a 10% superelevation upslope. Four different barrier and placement conditions were tested as noted in Table 1. As can be noted, in all cases for the standard w-beam guardrail at normal heights the outcome was negative – that is the vehicle vaulted the barrier or rolled over. The thrie-beam barrier passed the tests. The report did not cite specific issues with the vehicle-to-barrier interface that might be a focal point for barrier redesign on curves. While these tests provided some useful insights, they only considered a curve radius of 1,192 feet, superelevation slope of 10%, speed of 60 mph, impact angle of 20 degrees, and a 5,400 pick-up. There is the need to consider a broader set of impact conditions consistent with the updated crashworthiness evaluation criteria.

The initial bibliographic search on curved barriers identified no research effort that focused specifically on the effect of barrier curvature issues. Curvature seems only to be discussed in the literature only in the context of short-radius barrier for intersection applications or transitions, which was not considered relevant here. There were no provisions for testing of curved barriers in NCHRP Report 350 [3] or its update, the Manual for Assessment of Safety Hardware (MASH) [4].

This study was undertaken by the staff of the National Crash Analysis Center (NCAC) at The George Washington University (GWU) under a contract with FHWA. The NCAC used computer simulation tools and available finite element models to conduct simulations of various impacts to isolate the relative effect of curvature for varying radii, barrier shapes, vehicles, speeds, and angles of impact. Various performance metrics were captured from the simulations to provide insights on the phenomena and the likely outcomes.

1.2 Objectives

The objectives of this research effort were to take an analytical look at the impact behaviors of vehicles as they engaged curved section of typical concrete barriers. The metrics and insights gained were expected to provide a basis for determining whether there is a need for modification in the cross section design of the barrier, placement relative to the travelled way, and/or influence of super-elevation or other pavement design features on curves. This effort was considered a pilot study for deeper analysis and testing of barriers on curved sections of roadway. Certainly, these efforts would support future work to improve existing barriers on curves or develop new ones.

2.0 RESEARCH APPROACH

Modeling and simulation techniques have been applied to study the effectiveness of various types of roadside barriers and impact situations. This effort was initiated to build upon the demonstrated effectiveness of models and simulation for barrier analyses. The basic steps in the analysis included:

- define the problem & establish the relevant analysis parameters,
- identify validated simulation models for vehicle & barrier impacts useful for the analysis,
- demonstrate that it is possible to model vehicle impacts on curved barriers,
- evaluate concrete barrier performance when impacted on curved roads of varying radius, and
- assess the influence of various factors on safety performance.

The analysis was planned to initially focus on curved barriers for typical NCHRP 350 test conditions with a focus on the 2,000 kg vehicle impacting at 100 km/h (62 mph) and 25 degrees. This larger, higher vehicle was considered to be the most likely to vault of the barrier. The models would be used to analyze the effects of various factors and the results serve as a benchmark for assessing barrier performance under other conditions.

The second round of efforts would focus on the most critical factors identified in the first round and attempt to explain the reasons for the crash cited earlier. In this round, superelevation and slope factors were investigated. This effort was not specifically intended to assess the effective effectiveness of current practices, and/or develop & analyze mitigation measures for specific problems.

2.1 Design Conditions

The curved sections of existing roads have widely varying designs owing to the type of road, era when it was designed, site factors, the evolution of design standards, variation in practices between the states, and other reasons. This analysis simply considered three road curvature cases – 75 meter radius, 150 meter radius, and the tangent condition. The tightest radius condition was considered to be an example of a freeway interchange ramp as shown in Figure 1. The 75 meter radius was scaled from a Google Earth image of a typical interchange in Northern Virginia. It was considered to be the "worst case scenario" particularly since ramps also implies a transition from traffic moving at high speeds to the lower speeds required to negotiate the curve or transition to the speeds of a different class of highway. The relative degree of curvature for the three cases is shown in Figure 2.

Similarly, various concrete barrier types and conditions can be found on existing highways. This analysis considered three different concrete safety shape barrier types, namely:

- New Jersey shape,
- F-shape, and
- Vertical Wall.

The cross sections of these barrier shapes are shown in Figure 3. All were modeled to have a height of 32 inches. The specific dimensions for each shape conformed to standards and these were reflected in the finite element models of these barriers. The models assumed that the barriers were rigidly attached to the surface and would be strong enough not to deflect under impact conditions. The shape features were assumed to be identical for tangent or curved sections.

2.2 Impact Conditions

For this study, it was determined that impacts with a large vehicle at a high speed would be the most critical. Following the NCHRP Report 350 crashworthiness criteria, the simulations were conducted using a Chevrolet C2500 pick-up truck model [5,6,7]. This vehicle conforms to the 2000P vehicle under NCHRP 350. Impacts were at 100 km/h (62 mph) as specified in NCHRP 350 and the basic impact angle of 25 degrees was used. To reflect the potential that a vehicle could impact at either a sharper or shallower angle, simulations were also conducted for impacts at 20 and 30 degrees.

2.3 Simulation Strategy

Considering three barrier radius conditions, three impact angles, and three barrier shapes resulted in an analysis matrix that reflected 27 different cases. Therefore, 27 simulation runs were initially planned. For each simulation a set of comparison metrics was derived. These were:

- Vehicle lift – based upon the maximum height reached by a point on the front of the vehicle's frame rail on the impact side.
- Vehicle roll angle – typical measurement of vehicle roll as measured by the accelerometer at the vehicle's center of gravity (CG).
- Occupant ride-down acceleration – the maximum acceleration that would be experienced by the vehicle occupant as defined by NCHRP Report 350. An acceleration of 20 g's is the maximum, but 15 g's is desirable.
- Occupant impact velocity – the maximum velocity that would be experienced by the vehicle occupant as defined by NCHRP Report 350. A velocity of 12 m/s is the maximum, but 9 m/s is desirable.
- Vehicle penetration – the extent the vehicle went into or though the barrier.

These metrics were generated in each simulation. Other metrics are possible, but were not summarized in this effort. The middle three conformed to those measures focused upon in a typical NCHRP 350 crash test.

2.4 Model Validation

The credibility of the simulation results is a function of the degree to which the simulation model can replicate actual crash tests. In Figure 4, a sequence of oblique views of the crash test of a C2500 pick-up impacting at 100 km/h (62 mph) and an angle of 25 degrees is shown adjacent to the animation generated by the crash simulation [8]. Figure 5 shows the same crash from the top view. It can be noted that visually, there is a good comparison of the model to the test. Figure 6 shows comparison of the vehicle rotation motion between the test and simulation. Since the simulation models were extensively used in other NCAC efforts related to concrete median barriers and portable concrete barriers, a more rigorous validation effort was not undertaken for this research [9,10]. Simulation analysis was undertaken using LS DYNA [11].

3.0 ANALYSIS

The analysis was conducted in two stages. It the first sage, the analysis efforts focused on investigating the effects of barrier curvature on the barrier performance. In the second stage, additional simulations were performed to develop understating of the factors that contributed to the crash that was referenced earlier. A summary of these two stages of the analysis are presented in the following sections.

3.1 Basic (Benchmark) Conditions

The first round of the analysis involved simulations of the pick-up truck into the various combinations of barrier designs (e.g., shape, curvature, & impact angle). Figure 7 shows the sequential views of the impacts simulated for a various barrier shapes for a tight radius curve (75 meter radius) for a 30 degrees impact angle and a speed of 100 km/h. It can be noted that there is more lift and roll for the New Jersey shaped barrier and the F-shape than for the vertical wall. The results from the 27 simulation runs are summarized in Table 2. The numeric values for the four metrics (i.e., lift, roll angle, occupant ridedown acceleration, and occupant impact velocity) are provided for the combinations of barrier shape, impact angle, and curvature. These results were extracted from the simulation results.

Figure 8 summarizes the lift and roll metrics generated from the above simulations. The graphs show the data generated over the duration of the crash event for lift and roll. The simulation shows a higher degree of lift for the New Jersey shape. The lift increases to a point about 896 mm and then begins to fall. While the passenger side wheels both got above the barrier, the indication was that the vehicle would not fully vault the barrier. A secondary impact into the barrier seems likely downstream from the initial impact point, but the simulations were not run long enough to confirm it. A similar lift plot was generated for the F-shape and the maximum lift from the simulation was 884 mm, lower that the New Jersy barrier case. The corresponding impact into a vertical wall showed a maximum lift of only 151 mm. Similarly, maximum roll angles of 37.8, 25.7, and 7.5 degrees were noted from the three simulation results. It can be noted that the lift is some cases exceeded the height of the barrier, but with roll away (to the inside) from the barrier the vehicle did not vault the barrier.

To understand these results more deeply, the effects of various factors were isolated and these are shown in a series of graphs in Figure 9. The graphs reflect the relationships between the comparison metrics and impact angle for each barrier shape. Figure 9-a provides a comparison of the effects of barrier shape on lift. As might be expected, the shapes with the inclined toes tend to lead to more lift that increases with the sharpness of the impact angle. Since the vertical wall does not have a sloped toe, there is much less lift. It is not clear why the lift for the New Jersey and F-shapes is so similar, but it may be due to the higher basic front profile of the pick-up truck.

Figure 9-b provides a comparative examination of the effects of barrier shape on roll angle. These results are similar to the previous lift results, but the lower toe on the F-shape may be contributing to less roll for the highest impact angle.

Figure 9-c provides a comparative examination of the effects of barrier shape on occupant ridedown acceleration. Since the vertical wall does not use lift as a means to dissipate energy it would be expected to have the greatest ride-down acceleration. Conversely, the greater lift associated with the New Jersey shape leads to less ride-down accelerations. In all cases, the levels are below the maximum limits of 20 Gs.

Figure 9-d provides a comparative examination of the effects of barrier shape on occupant impact velocities. The impact velocities are similar for all with only a 1.5 m/s difference for the sharpest impact angle. The impact velocities are the greatest for the vertical wall as would be expected. All are below the maximum allowed of 12 m/s.

Since the New Jersey barrier was shown to have the highest values for the various metrics considered, an analysis of the factors for this type barrier was conducted. The results are shown in Figure 10.

Figure 10-a compares the effects of curvature on vehicle lift for the New Jersey shape is provided here. These results may suggest that the lift effect is not very different between curved and tangent sections at the impact angles considered. Figure 10-b depicts the relationship for roll angle and Figure 10-c shows the effects of curvature for the New Jersey shape on occupant ride-down acceleration. Values vary more as a function of impact angle than radius for the New Jersey barrier. Last, Figure 10-d compares the effects of curvature for the New Jersey shape on occupant impact velocity. Again the departure angle has the greatest effect.

Given the analysis of the various factors derived from the 27 simulation runs, the numbers in Table 2 were used to identify the "criticality" of the various impact conditions. For most cases (shaded green in Table 2) the values of the four metrics are in an acceptable range. However, for the 75 and 150 meter radii for New Jersey and F-shape barriers at 25 and 30 degree impact angles, the metrics are considerably higher. These are shapes in orange. The most critical conditions occur for the New Jersey shaped barriers on 75 meter curves. These are shade in red.

3.2 Crash Causation Analysis

A motivation for this research was the interest in trying to understand the factors that contributed to the crash that was referenced earlier. A small passenger car (1993 Subaru Impressa) traveling on a downward sloping exit ramp with superelevation lost control and struck the 32 inch F-shape concrete barrier placed along the ramp. The vehicle vaulted the barrier and struck a building some 12-15 feet beyond while airborne. From a safety standpoint, was there something about the deployed curve barrier at this location that might have contributed to the crash?

Since, it was not known what speed the vehicle was traveling at on the ramp, or what actions, if any, the driver took, it was necessary to simulate varying impact conditions. For this analysis, the FE model of the 1998 Dodge Neon was used. It was the most robust of the small vehicle models available. It was similar in weight to the vehicle involved in the crash.

The simulation was set to replicate the following impacts conditions:

- Curve radius 75 meters
- Impact angle of 25 degrees
- Impact speeds of 100 and 150 km/h
- 6% superelevation
- 7.2% ramp downgrade
- Barrier perpendicular to the road surface and true vertical

In addition, one additional simulation was undertaken under the assumption that a front-wheel drive vehicle might ride up the barrier if the wheels continue to rotate during the impact. This was hypnotized to permit side friction of the drive wheel to pull the vehicle higher up the barrier. In the other cases, the wheel was not active as if the vehicle had rear wheel drive. This analysis focused on the most critical conditions noted in Table 3.

A series of simulations were generated for the small car striking the concrete barrier on curved sections. A summary of the results are shown in Figure 11. These simulations show the crash event involving a New Jersey shaped barrier on a 75 meter radius curve being impacted by the small car at 30 degrees, representing the most critical scenario. As noted above, they also reflect the fact the ramp had a downhill slope and was superelevated at 6.2%. These factors contributed to the dynamics on the vehicle in the crash. It can be noted that at 100 km/h under these slope and superelevation conditions, the simulation show significant roll but the vehicle does not seem to vault the barrier. The simulation of the crash at 150 km/h (Case B in Figure 11) leads to higher lift and roll motion while airborne above the barrier. The simulations were not run long enough to see a final outcome, but they suggest that excessive speed may have been a factor. One variant in this analysis was the orientation of the barrier wall. It was noted that at this crash site the barrier was constructed to “true vertical” and not perpendicular to the superelevated road section. This contributed to the ability of the vehicle to climb the wall as shown in Case C. The last simulation was run with the front wheels spinning at a constant speed during the impact. As expected, in this case (Case D) a significant increase in vehicle lift was observed compared to Case D where the no constrained motion was applied to the wheels.

4.0 SUMMARY AND CONCLUSIONS

This effort applied a simulation approach to develop an understanding of concrete barrier performance when deployed on curved sections of highway. The simulations were executed using models that had been previously validated and applied for other safety analyses. A more rigorous validation for the model would be prudent, but resources were not available for this study.

The animations generated in the simulations indicated that the pick-up truck would ride-up the barrier on impact in all cases, but the degree varied by the shape of the barrier and the departure angle. The most critical result noted in the simulations was that the front and rear wheels of the vehicle got to the top of the barrier, but vaulting did not occur. This occurred most for the sharpest curve with the sharpest impacts angle for the New Jersey shape, but the vehicle dropped on the impact side of the barrier or on top of the barrier. The curvature may have influenced keeping the vehicle on the impact side despite a large amount of lift.

The analyses of the overall results from the 27 simulations led to the following conclusions:

- Since the impact of vehicles with barriers on tangents or curves involves an angle, there is lift observed, but there was no clear trend that curvature increased the lift over that note for impacts on tangent sections.
- There is an increased amount of lift for impacts with sloped face barriers on curved sections. The greatest lift was noted for the New Jersey shaped barrier, but there was almost as much lift for the F-shaped barrier. The least lift was noted for the vertical wall.
- Roll effects were similar to lift relative to curvature and angle of impact.
- Occupant ridedown acceleration was greatest for the vertical wall shape as more energy was absorbed into the wall since the dissipation of energy via the lift effect was minimal. It increased with the sharpness of the impact angle.
- Occupant impact velocity indicated trends similar to occupant ridedown acceleration.
- Looking at the New Jersey shape, it was noted that the effects of impact angle were more significant than curvature.

These inferences were derived for a small set of barrier designs and curvature conditions. This analysis did not consider the influences of roadway vertical alignment or superelevation. It seems that simulation would provide a viable means to isolate the effects of other curve conditions. It would also be useful to review current practices relative to the placement of barriers on curves in terms of offset and orientation to the road/shoulder surface.

The criticality matrix indicates where problems with barriers on curves may be most critical. Each of the cells is shaded to reflect the simulated outcomes. It can be noted that for most cases the barrier on tangent or curved sections was able to redirect the vehicle. These cells are shaded green. In some cases, the front wheel of the vehicle on the impact side got on top of the barrier. Since this may be problematic, they are shaded orange. It occurs primarily for the New Jersey and F-Shapes on the curved sections for sharp 25 and 30 degree impacts.

It needs to be pointed out that the conditions analyzed do not represent all possible impact conditions. There will be difference in the results if the vehicle is more heavily loaded, traveling at a higher speed, manages to impact at an even sharper angle, or some combination of these and other factors. There may be a need to consider the implications of barrier designs for curves on other vehicles as well.

Future research needs to look more closely at other conditions beyond those analyzed here. The nature of the interaction between roadway slope and superelevations would be useful. Further validation will be critical in future efforts that involve considerations of slope and superelevation effects.

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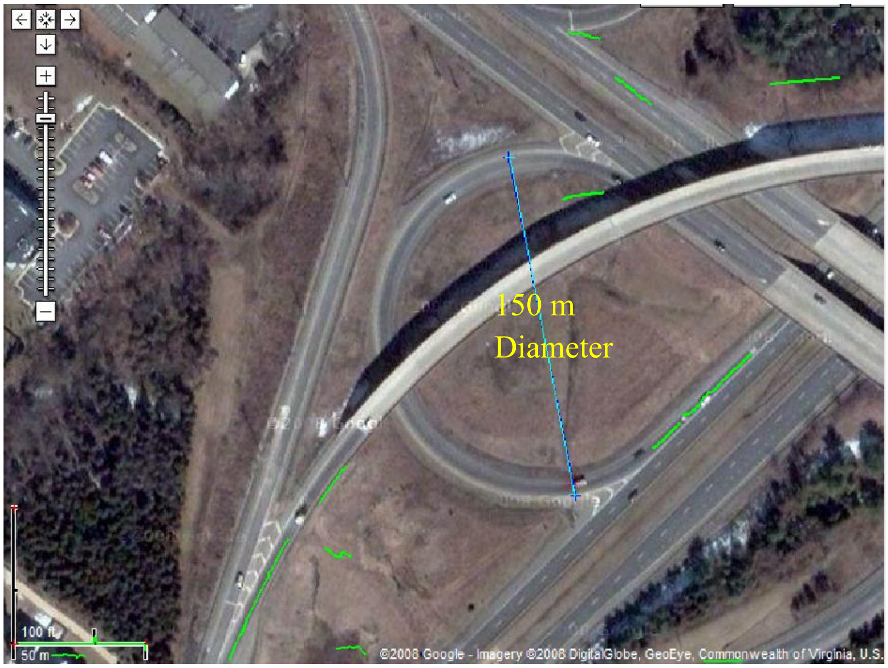


Figure 1 – Typical Tight Radius Freeway Interchange Ramp Design (75 meters)

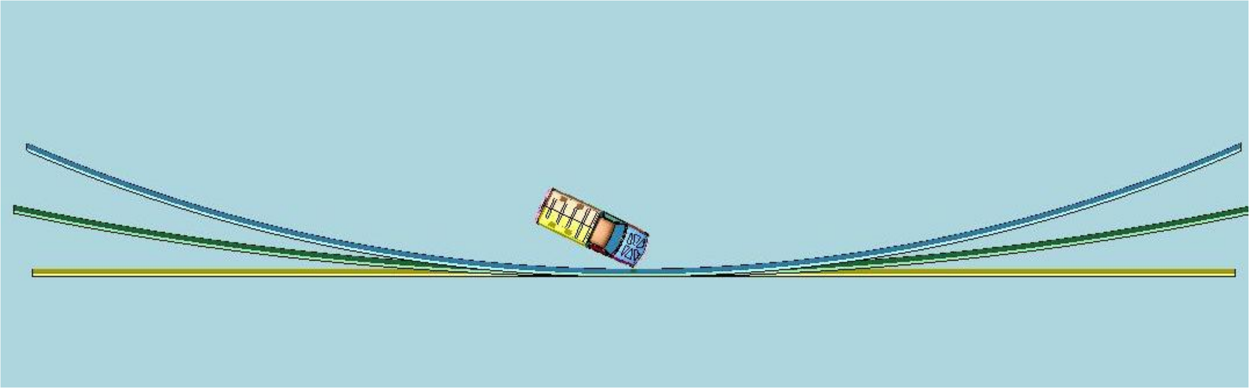


Figure 2 – Roadway Horizontal Curvature Conditions Analyzed (tangent, 75m radius, and 150m radius)

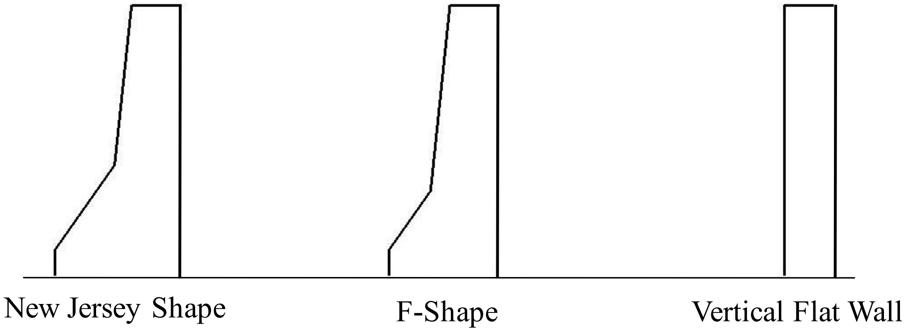


Figure 3 – Typical Cross Sections for the Concrete Barrier Types Considered

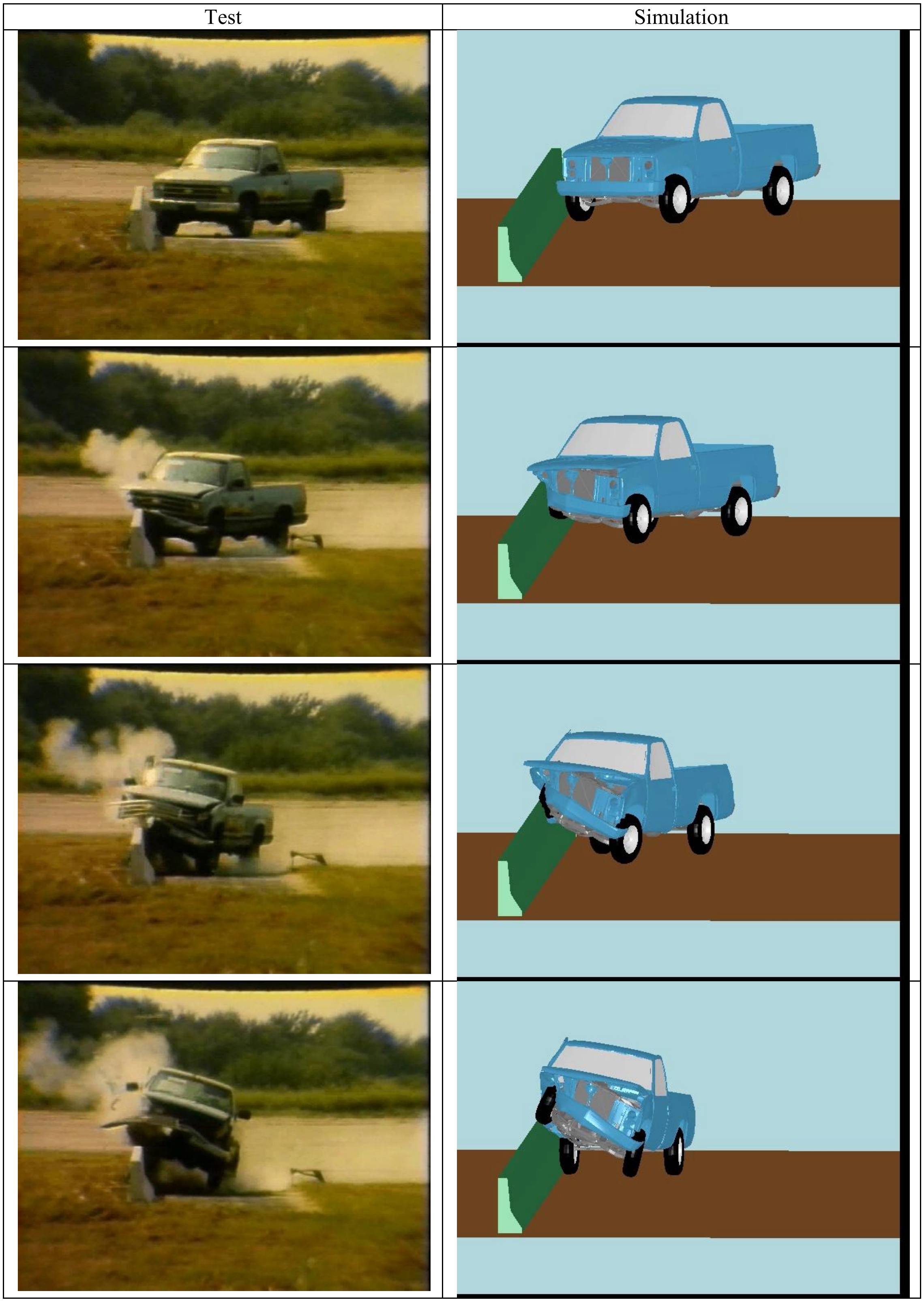


Figure 4 – Comparison of Crash Test to Crash Simulation (Front View)

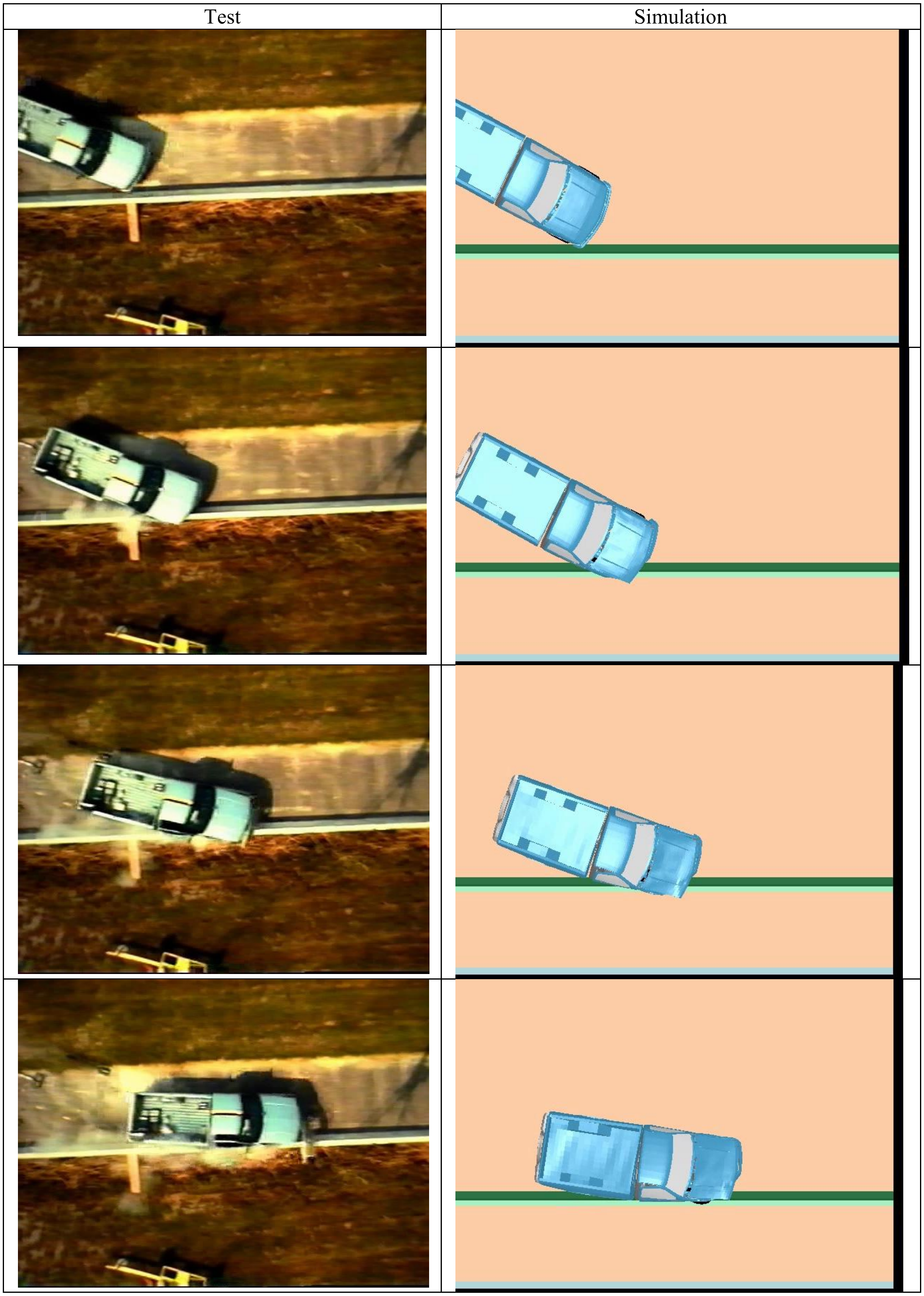


Figure 5 – Comparison of Top View of Crash Test (Top View)

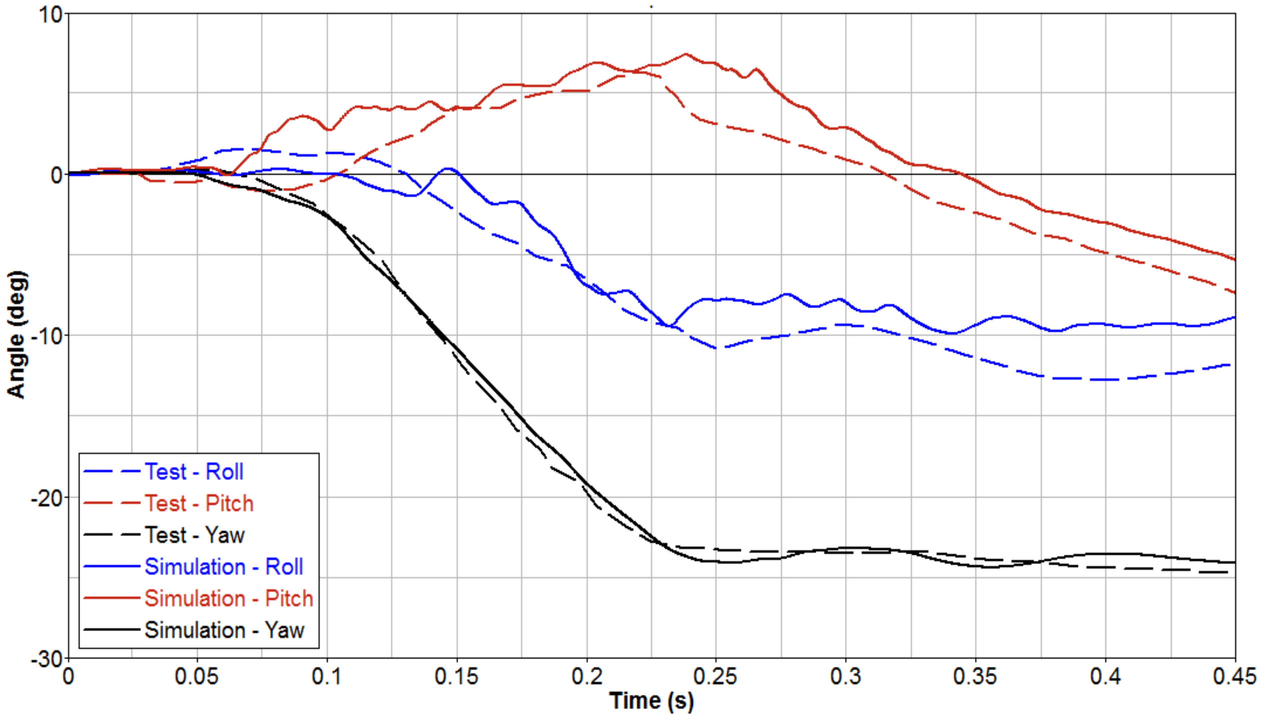
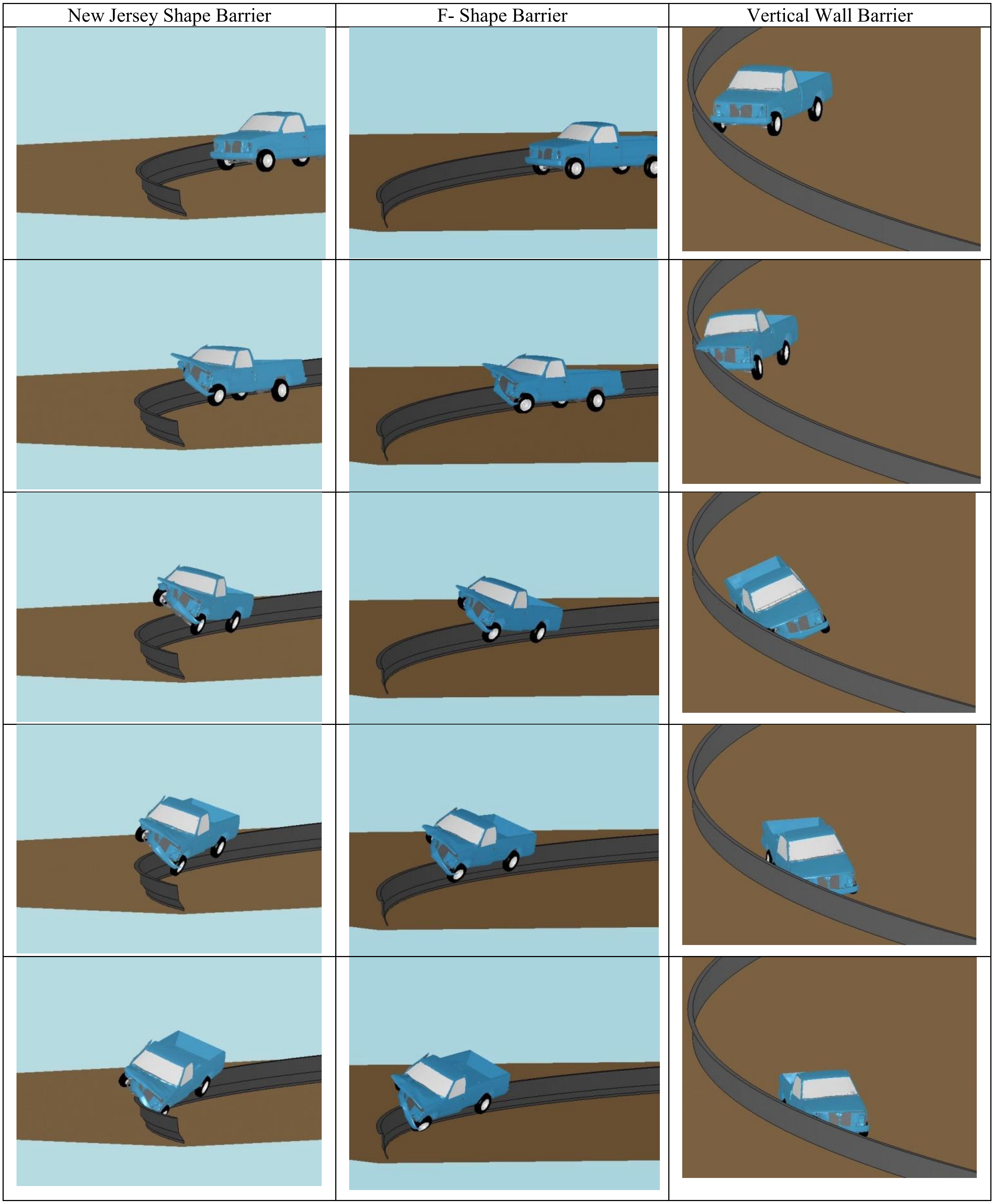


Figure 6 – Comparison of Vehicle Rotations between Test and Simulation



New Jersey Shape Barrier

F- Shape Barrier

Vertical Wall Barrier

Figure 7 – Sequential Views of Pick-up Truck Impacting Various Barrier Shapes

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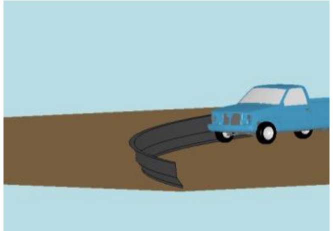
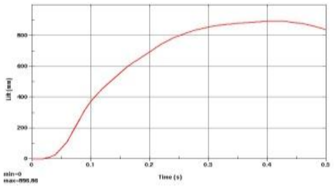
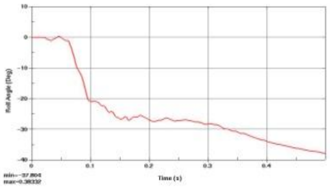
100 km/h</td><td></td><td>
</td><td>
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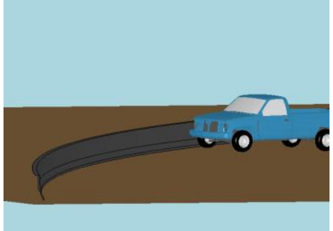
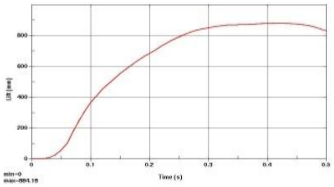
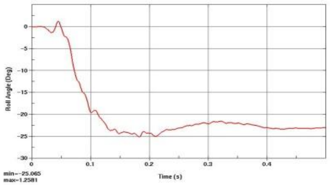
100km/h</td><td></td><td>
</td><td>
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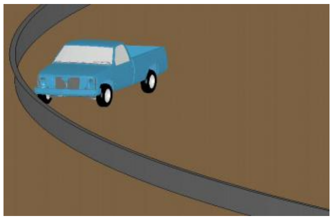
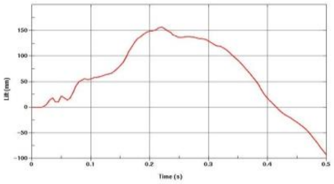
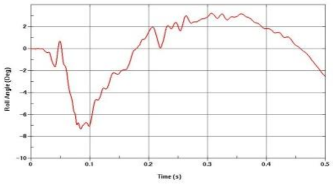
100km/h</td><td></td><td>
</td><td>
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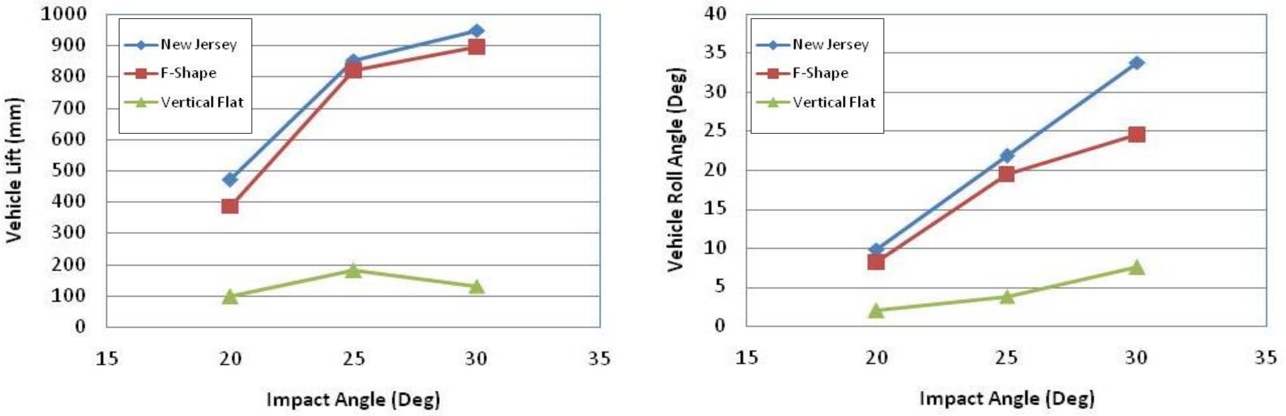
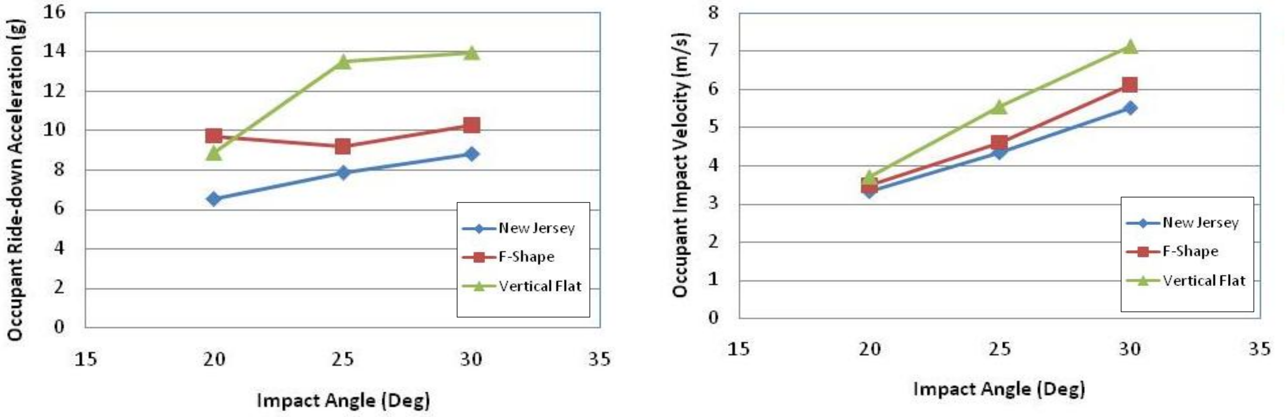
Figure 8 – Comparative Analysis of Shape Effects Considering Roll Angle & Lift for C2500 Pickup

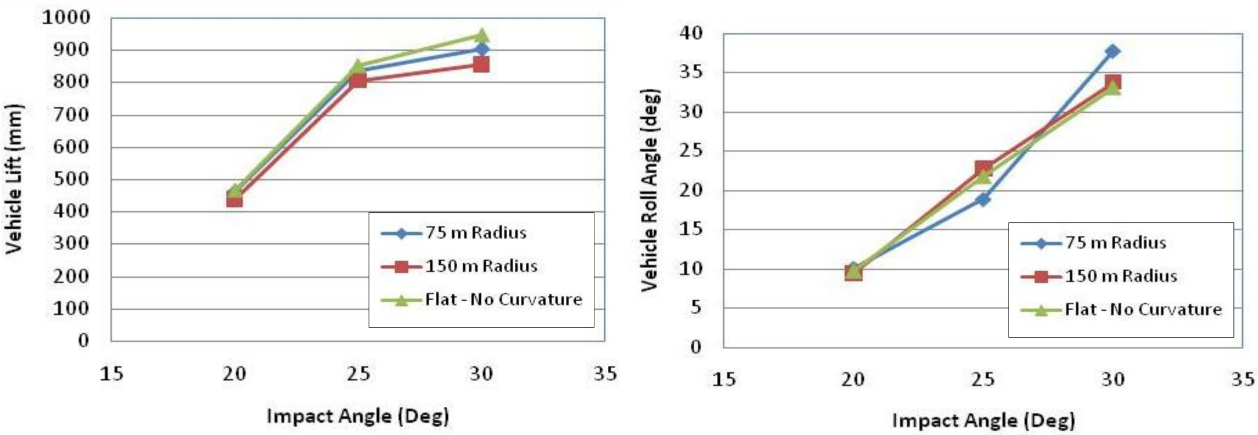


(a) Vehicle Lift (b) Vehicle Roll Angle

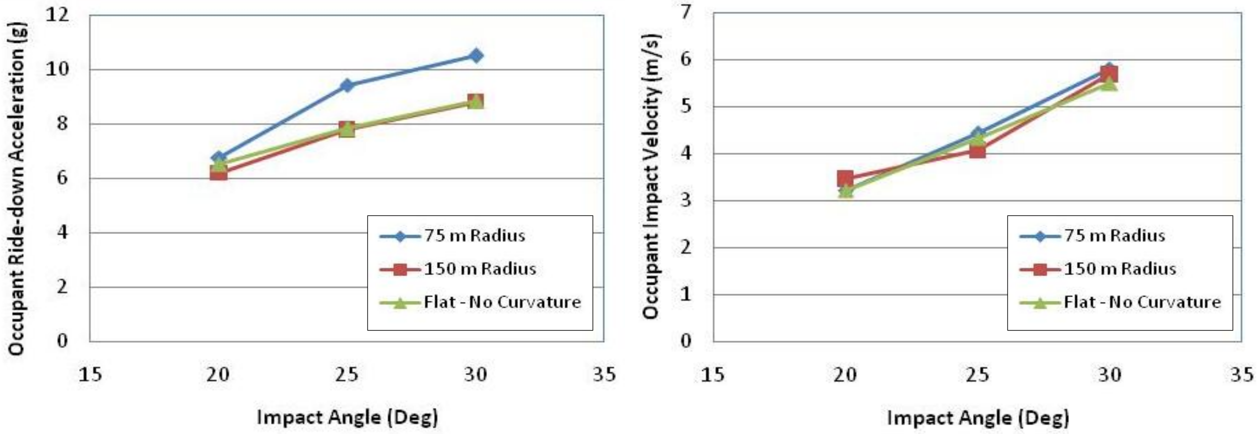


(c) Occupant Ridedown Accelerations (d) Occupant Impact Velocity

Figure 9 – Simulation Result Comparisons for Varying Impact Angles and Barrier Shape



(a) Vehicle Lift (b) Vehicle Roll Angle



(c) Occupant Ridedown Accelerations (d) Occupant Impact Velocity

Figure 10 - Simulation Result Comparisons for Varying Impact Angles and Barrier Curvature

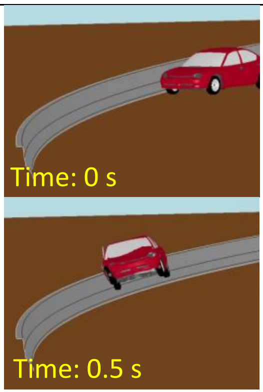
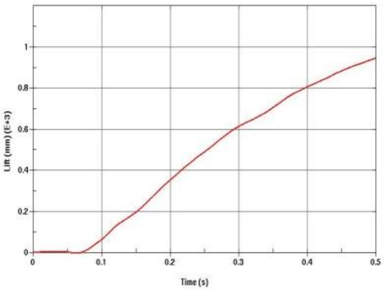
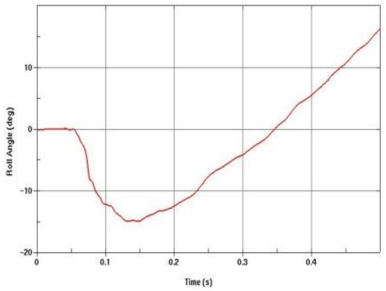
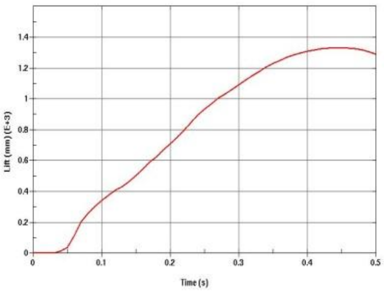
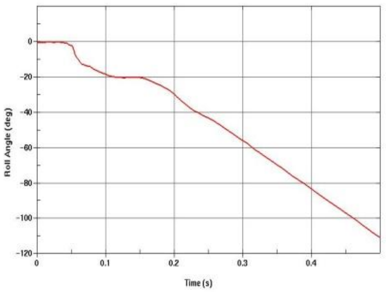
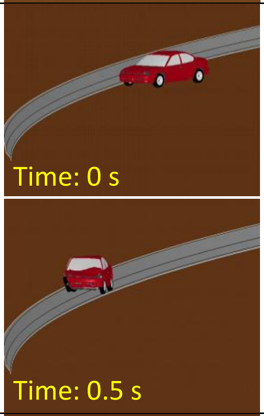
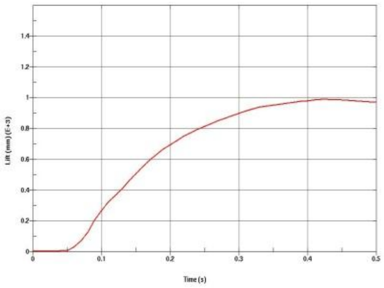
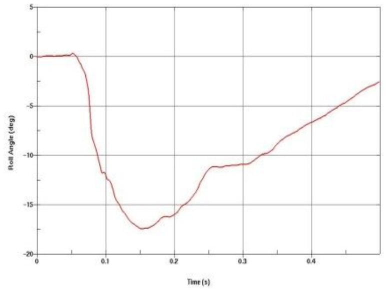
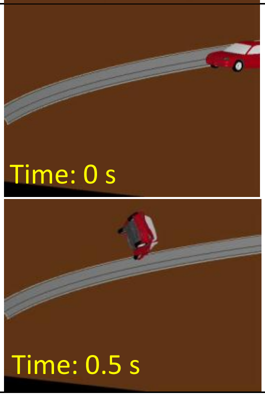
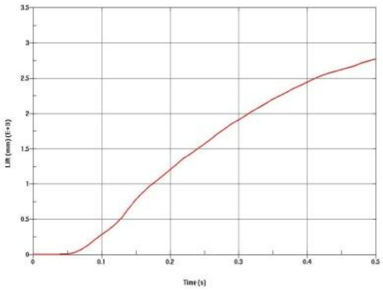
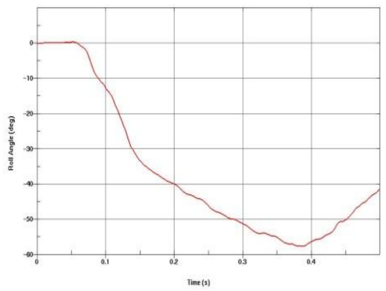
Condition		Lift (mm)	Roll Angle (degrees)
Case A: NJ Shape 75m radius 25 degree impact 100 km/h 6% superelevation 7.2% gradient			
Case B: NJ shape 75m radius 25 degree impact 150 km/h 6% superelevation 7.2% gradient			
Case C: NJ shape 75m radius 25 degree impact 100 km/h 6% superelevation 7.2% gradient True vertical			
Case D: NJ shape 75m radius 25 degree impact 150 km/h 6% superelevation 7.2% gradient True vertical			

Figure 11 – Summary of Results from Small Car Simulations

Table 1 – Summary of Ensco Testing of Barriers on Superelevated Curved Sections

Test	Barrier	Placement	Outcome
1862-6-89	Standard W-beam guardrail w/6 foot posts	Beyond 10’ shoulder	The vehicle was redirected on the traffic side of the barrier, but rolled over.
1862-9-90	Standard W-beam guardrail w/ 7 foot posts	Beyond 10’ shoulder	The vehicle vaulted the rail and rolled over. The lateral torsion in the longer posts increased buckling.
1862-10-90	Thrie beam guardrail	Beyond 10’ shoulder	The vehicle was redirected by this high performance barrier.
1862-16-91	Standard W-beam guardrail w/6 foot posts	At edge of traveled way.	This placement option was intended to eliminate the possibility that the vehicle would become airborne at the break point of the superelevated section and the shoulder, but the vehicle still vaulted and rolled.

Table 2 – Summary of the Performance Metrics Generated for the Initial Set of Simulations.

		New Jersey Shape				F- Shape				Vertical Wall			
Impact Angle	Curvature	Lift (mm)	Roll (deg)	ORA (g)	OIV (m/s)	Lift (mm)	Roll (deg)	ORA (g)	OIV (m/s)	Lift (mm)	Roll (deg)	ORA (g)	OIV (m/s)
20	75 m radius	464	10.12	6.76	3.22	392	8.15	8.33	3.39	100	2.00	9.87	3.63
	150 m radius	437	9.49	6.18	3.46	372	7.95	11.82	3.57	97	1.70	8.82	3.50
	Flat	468	9.81	6.51	3.32	384	8.11	9.71	3.57	100	1.60	8.83	3.70
25	75 m radius	834	18.90	9.42	4.44	863	21.04	8.76	4.92	152	5.00	12.89	5.62
	150 m radius	805	22.79	7.78	4.06	837	21.53	7.37	4.60	181	4.00	12.37	5.48
	Flat	852	21.80	7.83	4.33	840	19.46	9.15	4.48	157	3.80	13.50	5.53
30	75 m radius	896	37.80	10.5	5.80	884	25.07	11.13	6.46	151	7.50	13.14	7.44
	150 m radius	855	33.80	8.82	5.67	890	24.72	9.36	6.06	130	8.01	12.36	7.07
	Flat	948	33.12	8.80	5.50	894	24.51	10.26	6.11	142	7.50	13.95	7.13