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16. Abstract Under this research effort, the performance of concrete median barrier placed on or adjacent to medians with 6H:1V cross slopes was investigated. The ability to place concrete median barrier on steeper cross slopes may permit placement of the barrier farther from the travelway. This, in turn, can reduce the frequency and possibly severity of median barrier crashes. Full-scale vehicular impact simulations were conducted for several impact scenarios associated with placement of concrete barrier on typical depressed median configurations. Simulations results indicated that the F-shape concrete barrier has a reasonable probability of acceptable impact performance when placed on slopes as steep as 6H:1V. However, since the finite element pickup truck model used in the simulation analyses has not been thoroughly validated for encroachments across median slopes and ditches, it is recommended that one or more full-scale crash tests be conducted to verify simulation results.					
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**ANALYSIS OF THE IMPACT PERFORMANCE OF CONCRETE
MEDIAN BARRIER PLACED ON OR ADJACENT TO SLOPES**

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data, and the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT), Federal Highway Administration (FHWA), The Texas A&M University System, or the Texas Transportation Institute. This report does not constitute a standard, specification, or regulation, and its contents are not intended for construction, bidding, or permit purposes. In addition, the above listed agencies assume no liability for its contents or use thereof. The names of specific products or manufacturers listed herein do not imply endorsement of those products or manufacturers. The engineer in charge of the project was Roger P. Bligh, P.E. (Texas, #78550).

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CHAPTER 1. INTRODUCTION

Under this multi-year project, various roadside safety related issues identified by Texas Department of Transportation (TxDOT) personnel are being addressed on a priority basis. This may include enhancing impact performance and/or maintenance characteristics of existing hardware through design modification, developing new and improved hardware for selected applications or field conditions, and updating guidelines and procedures related to the selection, placement, and use of these devices.

In the first year of the project, researchers conducted analyses to investigate the performance of concrete median barrier when placed on or adjacent to slopes that are steeper than 10H:1V. Results of these analyses are reported herein.

BACKGROUND

Median barriers perform the important function of shielding errant motorists from hazards such as non-traversable slopes, fixed objects, and opposing traffic. A barrier is typically warranted when the consequences of a vehicle leaving the traveled way and striking a fixed object or traversing a terrain feature is judged to be more severe than striking the barrier.

In general, it is desirable to design median slopes as flat as possible. This enhances a motorist's ability to regain control of an errant vehicle and/or bring it to a safe stop. However, even in the absence of steep slopes and fixed objects, median barriers are often warranted to reduce severe cross-over crashes. When a median barrier is deemed appropriate based on roadway characteristics and operating conditions, the American Association of Highway and Transportation Officials (AASHTO) *Roadside Design Guide* and the TxDOT *Roadway Design Manual* currently suggest that concrete barrier should not be placed on slopes steeper than 10H:1V (1, 2). This has limited the placement of concrete barriers to narrow, flat, paved medians or at the edge of the shoulder. When placed at the edge of the shoulder, the recovery area for traffic adjacent to the barrier is significantly reduced, and the frequency of barrier crashes can be significantly higher than a case in which the barrier is offset to the center of the median.

Concrete barriers that have recently been installed in the Austin, Texas area in medians with slopes greater than 10:1 have successfully contained and redirected vehicles. This has prompted a desire to investigate whether impact performance of median barriers can be maintained when the barriers are placed on cross slopes greater than 10:1. Increasing the maximum slope on which median barriers can be placed will allow many installations to be placed further from the travelway, which in turn can lead to a reduction in barrier impact frequency and severity.

OBJECTIVES/SCOPE OF RESEARCH

The objective of this research was to determine critical slopes where concrete median barriers can be placed on or adjacent to the slopes and still maintain their crashworthiness. TxDOT indicated a desirable median cross slope value of 6H:1V.

The research team conducted analyses using full-scale finite element simulations of vehicular impacts into F-shaped concrete barriers placed on selected median configurations with 6H:1V cross slopes. Consideration was given to vehicles traversing a median foreslope prior to striking a barrier placed in the center of a depressed median and impacts occurring on the back side of a barrier after a vehicle encroaches across a median with a V-ditch cross section.

This report summarizes the findings of the simulation analyses and makes recommendations for future testing. [Chapter 2](#) describes the simulation analyses performed for the different median configurations and barrier placement alternatives. Conclusions resulting from this research are presented in [Chapter 3](#), and implementation recommendations are presented in [Chapter 4](#).

CHAPTER 2. SIMULATION ANALYSES

Researcher evaluated the placement of F-shape concrete median barrier using full-scale finite element impact simulations. A depressed median configuration, generalized in [Figure 1](#), was used in the analyses. The cross slope of the symmetric median ditch was defined to be 6H:1V based on TxDOT design practices and typical roadway sections for which concrete barrier might be considered. The research plan called for reducing the cross slope to 8H:1V if the performance of the concrete median barrier was found unacceptable on 6H:1V slopes.

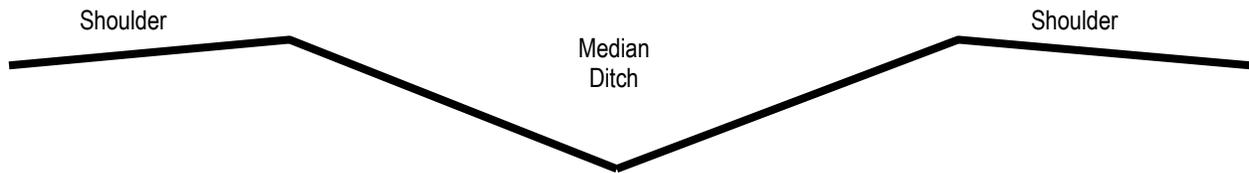


Figure 1. Typical Depressed Median Configuration.

Simulations were performed using LS-DYNA, which is a general-purpose explicit-implicit finite element code capable of simulating complex nonlinear dynamic impact problems. It incorporates an extensive material model library and provides a wide variety of contact algorithms that can be used to model vehicular collisions with roadside objects.

A finite element model of a 4581-lb pickup truck was used as the impacting vehicle in the simulations. This vehicle model, which represents the 2000P design test vehicle of National Cooperative Highway Research Program (NCHRP) *Report 350*, was originally developed by the National Crash Analysis Center (NCAC) under sponsorship of the Federal Highway Administration (FHWA) (3). The reduced version of the model that was used under this project contains approximately 16,550 elements. This version is more computationally efficient than larger, more detailed versions of the pickup truck model, which makes its use in parametric analyses more practical.

This model has been successfully used in previous studies involving roadside safety applications. However, like all numerical models, the pickup truck model has some limitations that may affect its predictive capabilities for the analyses conducted under this project. For example, suspension and steering systems of the model are not well validated and need further enhancement. Suspension response can directly affect pre-impact orientation and post-impact stability. Further, suspension failure (which is not incorporated into the current model) can influence vehicle response in impacts with safety shape barriers.

Due to the need to traverse a slope and/or ditch in advance of impacting the F-shape concrete barrier, suspension response is particularly critical to the evaluation of vehicle-barrier interaction in this project. The latest available version of the reduced NCAC pickup truck model was modified during the course of this research to further improve its suspension performance. The front suspension was made deformable, and various components were re-meshed to provide

more accurate deformation response. Leaf-springs from the latest version of the detailed NCAC pickup truck model were incorporated into the rear suspension. This modified pickup truck model incorporated the benefits of lower computer processing usage (CPU) times due to a reduced model size, and improved pre and post-impact vehicle kinematics due to the suspension changes. However, it should be noted that the modified suspension model has not been thoroughly validated and, therefore, the results of the simulation analyses should be used with caution and verified through full-scale crash testing.

SIMULATED ROADWAY CONFIGURATIONS

During the course of this research, researchers evaluated three different barrier placement scenarios. The median configurations used in the analyses were specific cases of the generalized median configuration shown in [Figure 1](#). Presented below are the details of each configuration modeled and the results of simulations performed to evaluate barrier performance at specified locations in the median.

Roadway Configuration 1

[Figure 2](#) shows the first configuration that was evaluated for a concrete barrier placed in the center of a symmetric median with 6H:1V cross slope. The vehicle begins its encroachment on a roadway with a 2 percent cross-slope at an initial velocity of 62 mi/h and an angle of departure of 25 degrees. The roadway has a 6-ft shoulder with a 20H:1V cross slope, followed by a ditch section having a 6H:1V cross slope. An F-shape concrete barrier is placed at the bottom of the 6H:1V cross slope.

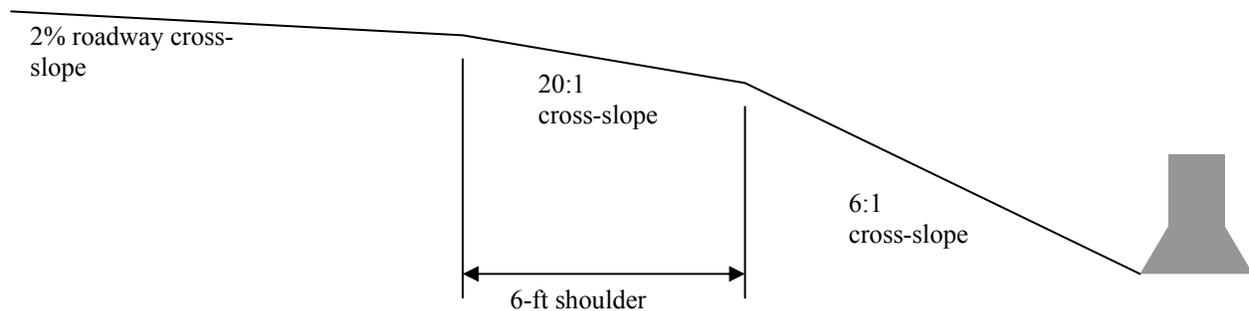


Figure 2. Simulated Roadway Profile (Configuration 1).

Due to the inclination in the roadway, the initial heading velocity of the vehicle could only be applied by defining its components along global Cartesian coordinates. To simplify the process, instead of applying three components of initial velocity to all vehicle parts, effective gravity load components were applied along the three global coordinates. Using this equivalent gravity field, a single heading velocity could be applied, and the vehicle could be defined to

travel on a horizontal roadway surface while accounting for the effects of the roadway cross slope. This setup is equivalent to the inclined plane setup, shown in [Figure 3](#), for a two-dimensional case.

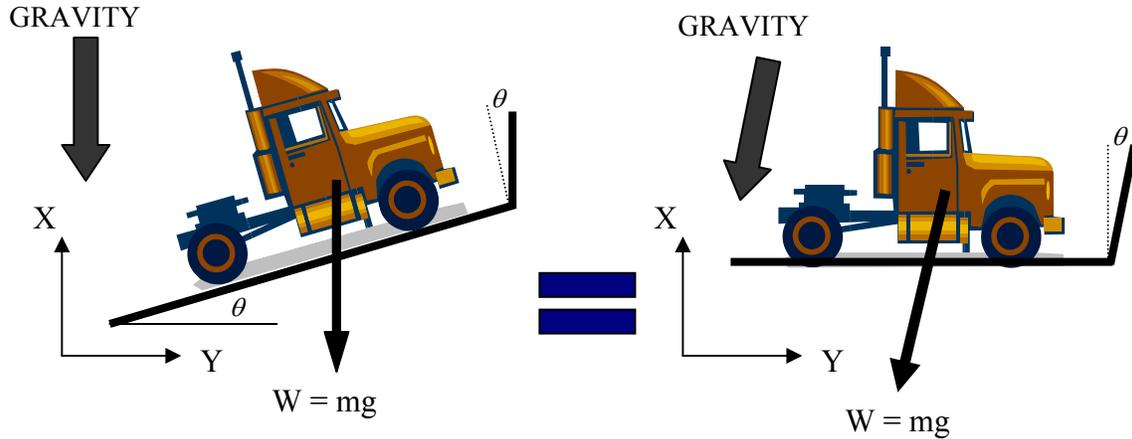


Figure 3. Equivalent Gravity Loads for Vehicle on Inclined Plane.

Given that median width can vary, it was important to determine the lateral offset position(s) of the barrier most likely to result in vehicle override and/or instability. Toward this objective, an initial simulation was performed to determine the encroachment trajectory of the vehicle as it travels freely across an infinite 6H:1V slope in absence of a barrier. Researchers used the results of this simulation to obtain the path of the vehicle's bumper (impact side corner) with respect to the local ground elevation as a function of the vehicle's lateral movement down the 6H:1V slope (see [Figure 4](#)). From this bumper trajectory plot, two critical barrier locations were identified:

Case 1: point of maximum nominal bumper height above the local terrain elevation (i.e., 13.25 ft offset from roadway edge) and,

Case 2: just beyond the point of minimum nominal bumper height at which the vehicle suspension has been compressed to its greatest extent and is beginning to rebound (i.e., 23.5 ft offset from roadway edge).

Even though the vehicle's suspension undergoes maximum compression at the point of minimum nominal bumper height, it is believed that positioning the barrier a short distance beyond this point would provide a more critical case (i.e., Case 2). The vehicle suspension at this position would already be rebounding, giving the vehicle more of a tendency to move upwards, thus potentially inducing more vehicle climb and greater vehicle instability as it interacts with the F-shape barrier.

Having defined the critical barrier locations for placement on a 6H:1V downslope, impact simulations for Case 1 and Case 2 were performed. Since a cast-in-place concrete safety shape

barrier is expected to experience virtually no movement or damage under *NCHRP Report 350* Test Level 3 (TL-3) impact conditions, the F-shape concrete barrier was modeled as rigid to improve computation speed.

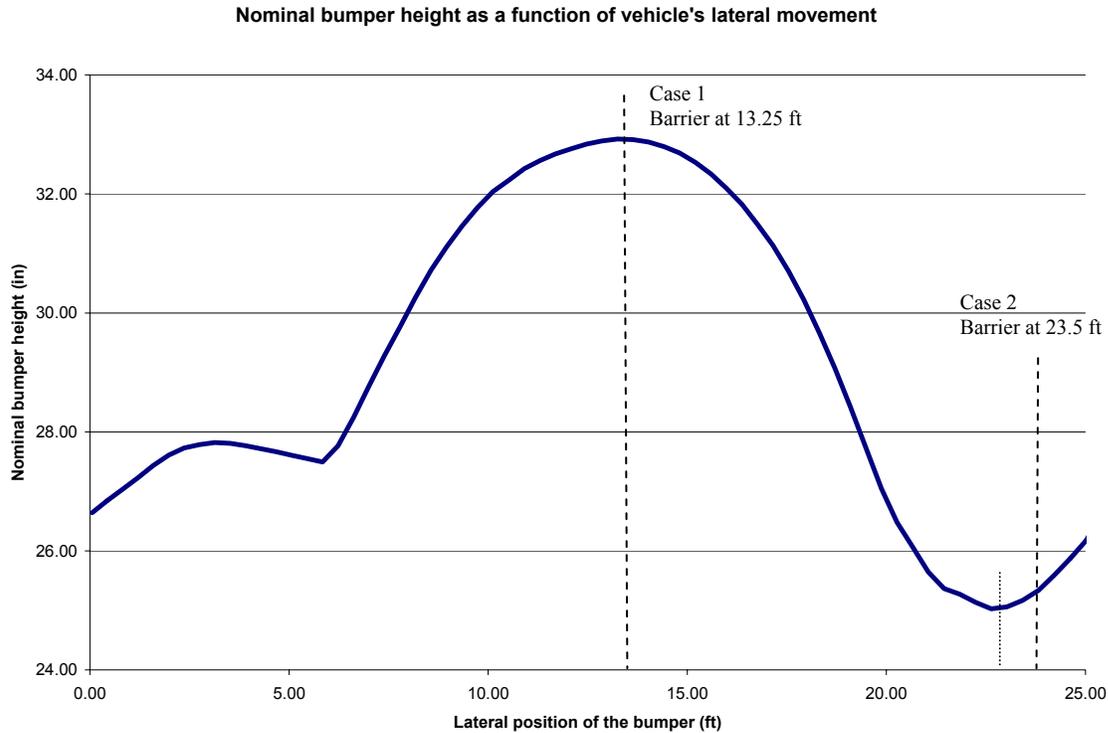


Figure 4. Height of Vehicle Bumper Relative to Local Terrain Elevation.

Figure 5 and Figure 6 show sequential images of the simulations for Case 1 and Case 2, respectively. As can be observed from these figures, the vehicle is successfully contained and redirected in an upright manner in both cases.

Within the accuracy of the current finite element model pickup truck model, noting that the suspension system has not been thoroughly validated, the simulation results appear to indicate a reasonable probability of acceptable impact performance when an F-shape barrier is placed on a 6H:1V cross slope. This configuration is analogous to the F-shape barrier being placed in the center (i.e., bottom of the ditch) of a median with 6H:1V cross slopes.

Given that the critical barrier locations (i.e., Case 1 and Case 2) were found to provide acceptable performance, it can be concluded that barrier performance anywhere along the 6H:1V cross slope should also be acceptable. Thus, the simulation results are applicable for any width of depressed median conforming to the generalized layout depicted in Figure 1 and Figure 2. Further, similar or better performance would be expected for similar barrier placements on more gentle (e.g., 8H:1V) slopes.

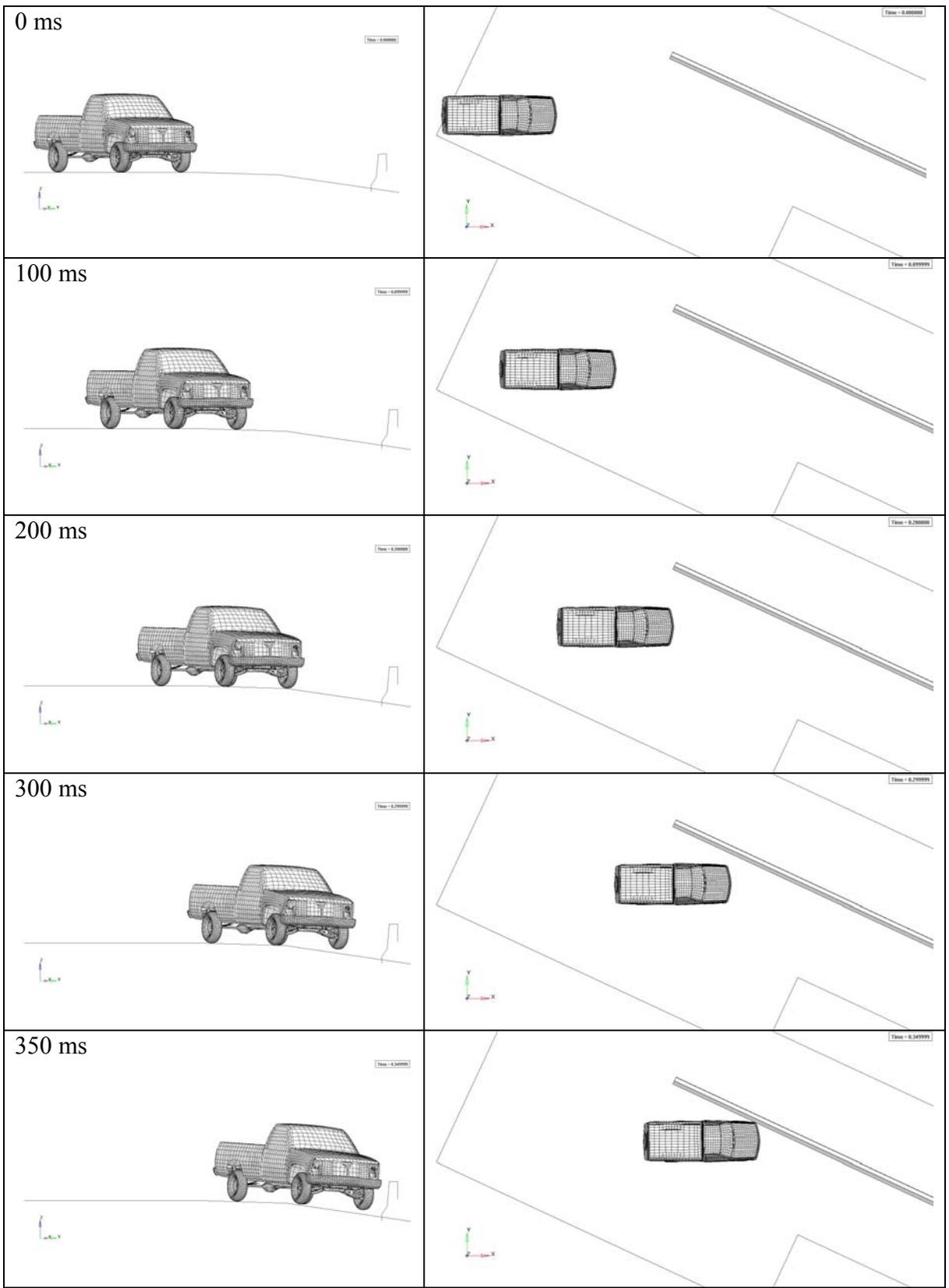


Figure 5. Simulation Results for Case 1 (Barrier 13.25 ft from Edge of Roadway).

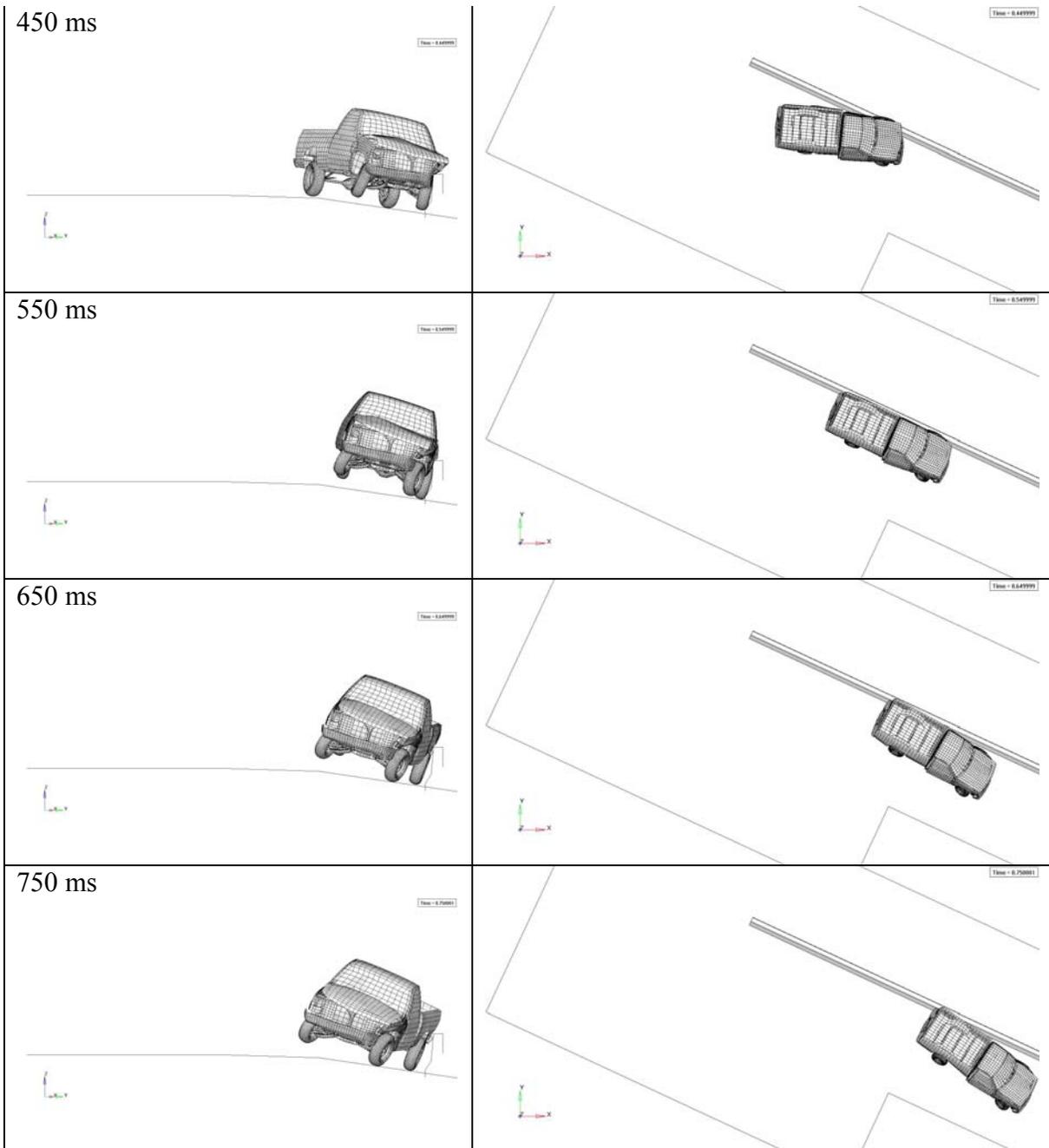


Figure 5 Simulation Results for Case 1 (Barrier 13.25 ft from Edge of Roadway) (Continued).

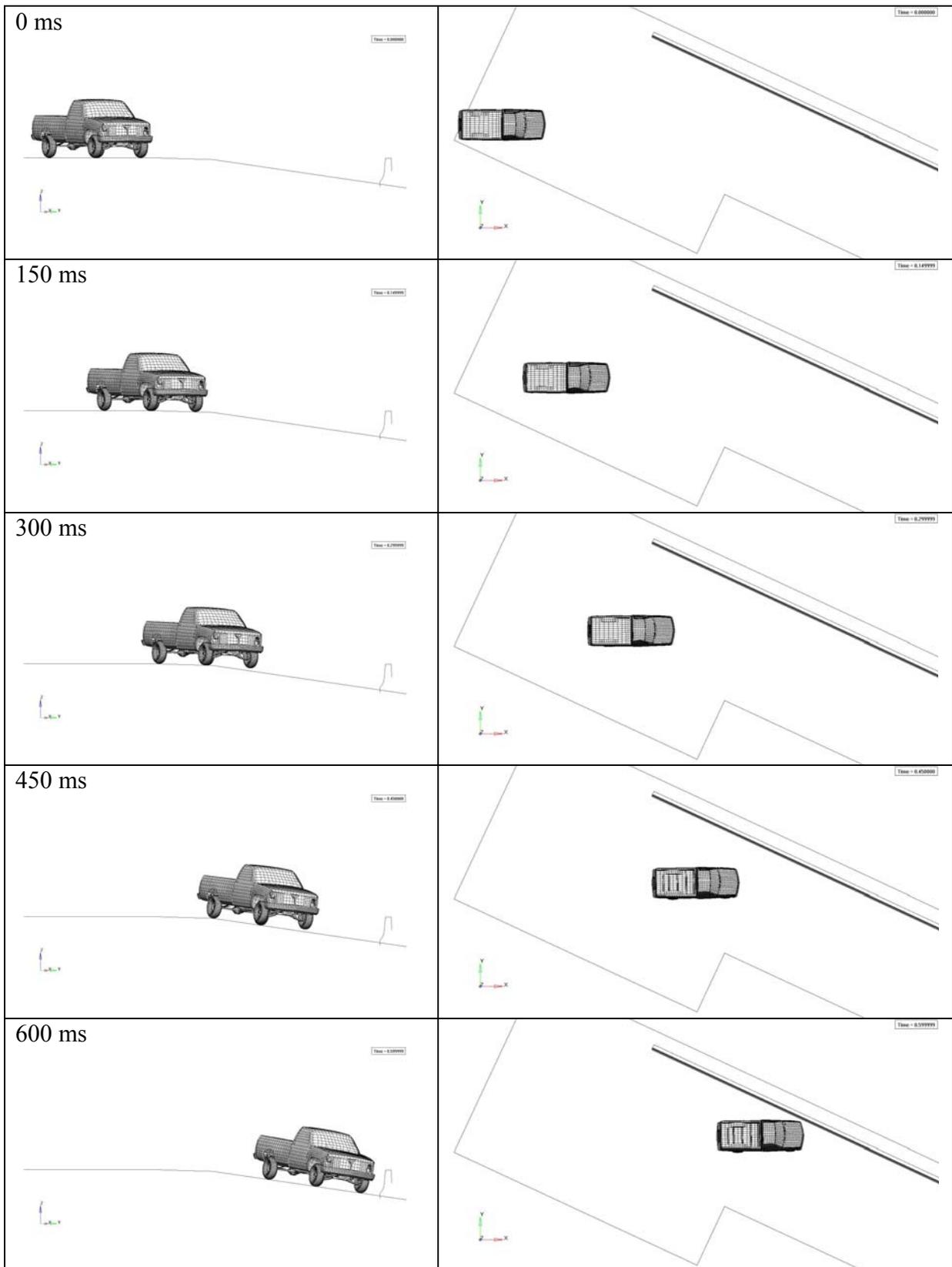


Figure 6. Simulation Results for Case 2 (Barrier 23.25 ft from Edge of Roadway).

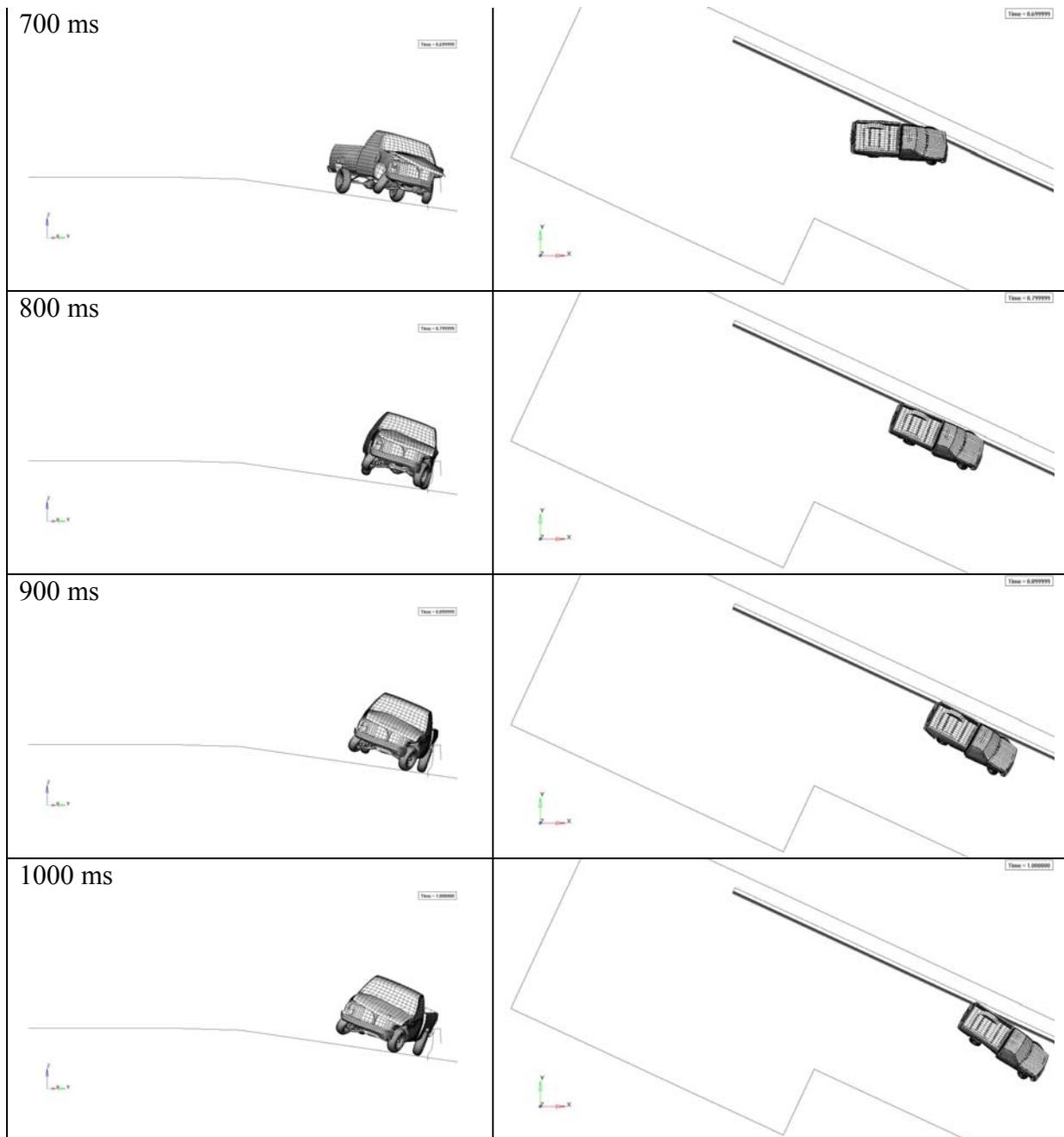


Figure 6. Simulation Results for Case 2 (Barrier 23.25 ft. from Edge of Roadway) (Continued).

Roadway Configuration 2

The next step in the analysis process was to investigate impacts on the back side of the concrete median barrier after an encroaching vehicle has traversed through the bottom of the V-ditch and is climbing the 6:1 backslope. This impact scenario can occur when the median barrier is placed on the edge of the inside shoulder for the lanes in one direction of travel rather than in the center of the median. Placing the barrier on the edge of the shoulder is more cost effective

because it can eliminate the need for constructing a foundation pad and modifying drainage at the bottom of the ditch. However, the proximity of the barrier to vehicles in adjacent travel lanes will likely result in an increased frequency of barrier impacts than if the barrier were offset in the middle of the median, and the reduction in available shoulder width may have an adverse effect on other aspects of highway safety.

Additional simulations investigated impacts on the back side of the barrier after an encroaching vehicle has traversed across the bottom of a V-ditch and climbed a 6:1 backslope. In addition to the steepness of the slope, the vehicle behavior will be influenced by the median width, which, for a given slope, controls the ditch depth.

The TxDOT *Roadway Design Manual* recommends that a median barrier be used on high-speed, high-volume highways having median widths (including shoulders) of 30 ft or less. The research team therefore selected a roadway cross section with a 30 ft median width, which included a 6 ft inside shoulder in both directions of travel. The roadway configuration used for the backslope simulation cases is shown in [Figure 7](#).

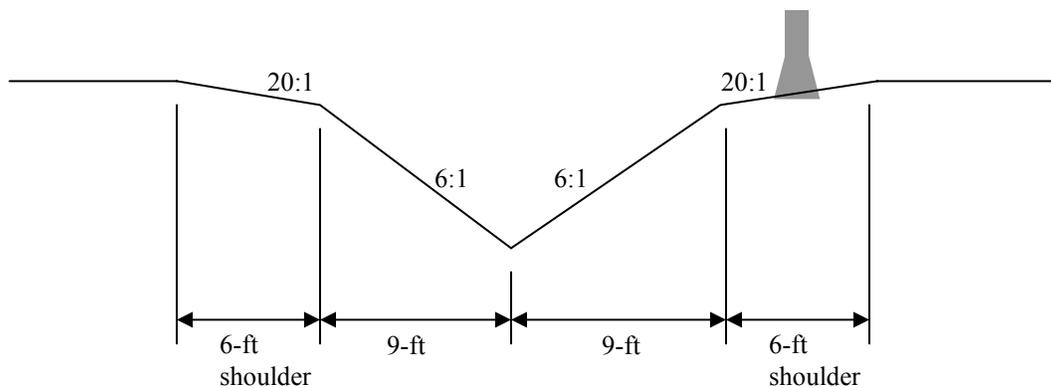


Figure 7. Simulated Roadway Profile (Configuration 2).

In the simulations, the vehicle begins its encroachment on a flat roadway surface at an initial velocity of 62 mi/h and an angle of departure of 25 degrees. The 2 percent roadway cross slope modeled in cases simulated for Configuration 1 was not incorporated into the terrain model for Configuration 2. The effect of the roadway cross slope on vehicle trajectory is negligible, so the cross slope was removed to simplify the modeling process.

TxDOT personnel indicated that a barrier on top of a backslope is typically placed in a range of zero to 4 ft from the break point of the slope. To determine the critical lateral offset position(s) of the barrier at the top of the backslope within this range, a vehicle encroachment simulation was performed in which the vehicle traversed the median ditch and backslope in the absence of a barrier. The results of this simulation were used to monitor the path of the vehicle's bumper (impact side corner) with respect to the local ground elevation as a function of the vehicle's lateral movement (see [Figure 8](#)).

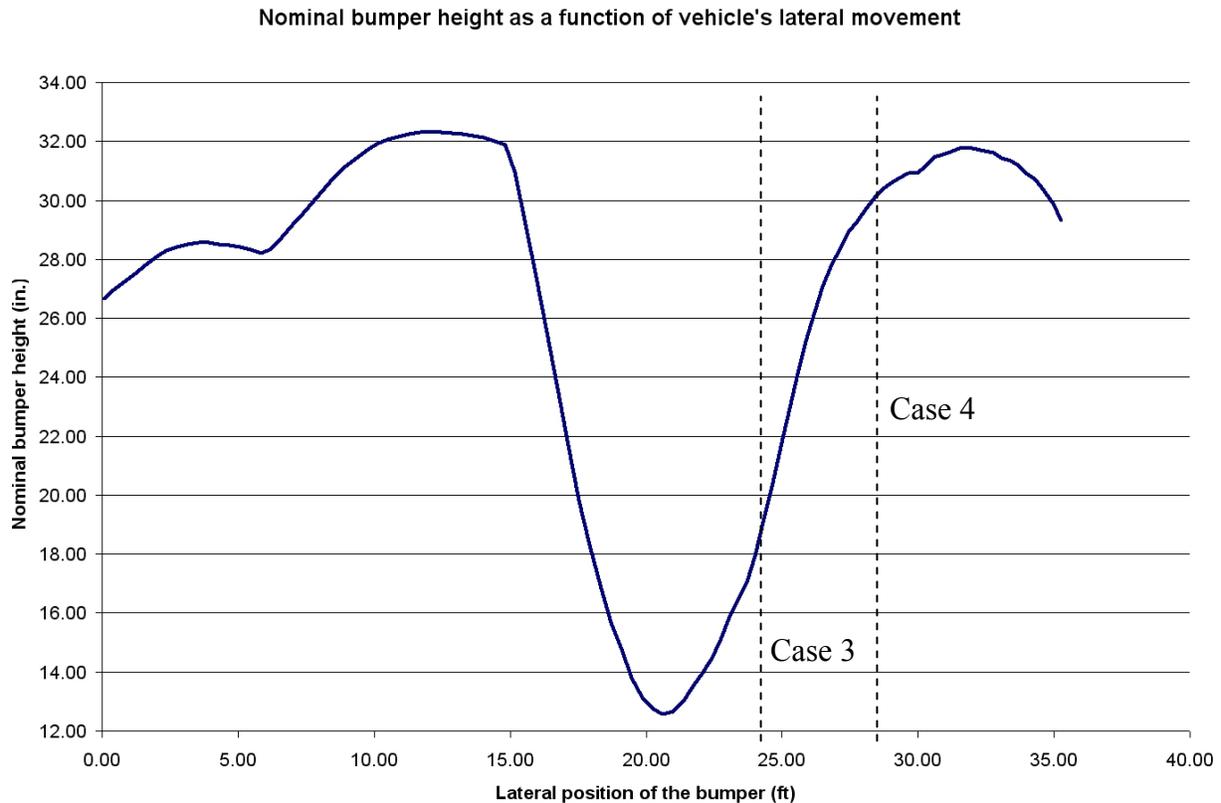


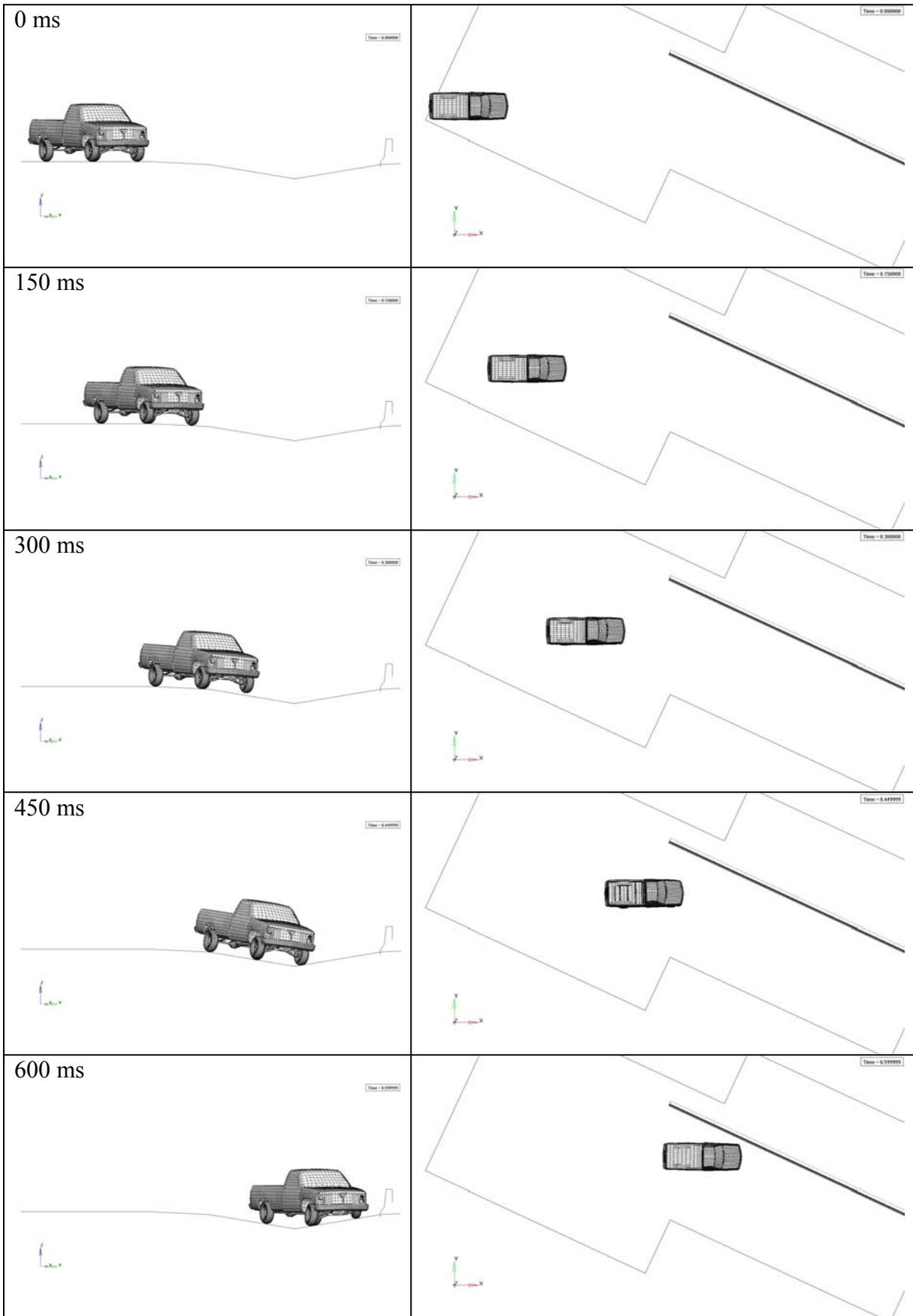
Figure 8. Height of Vehicle Bumper Relative to Local Terrain Elevation.

This curve identified two critical barrier locations:

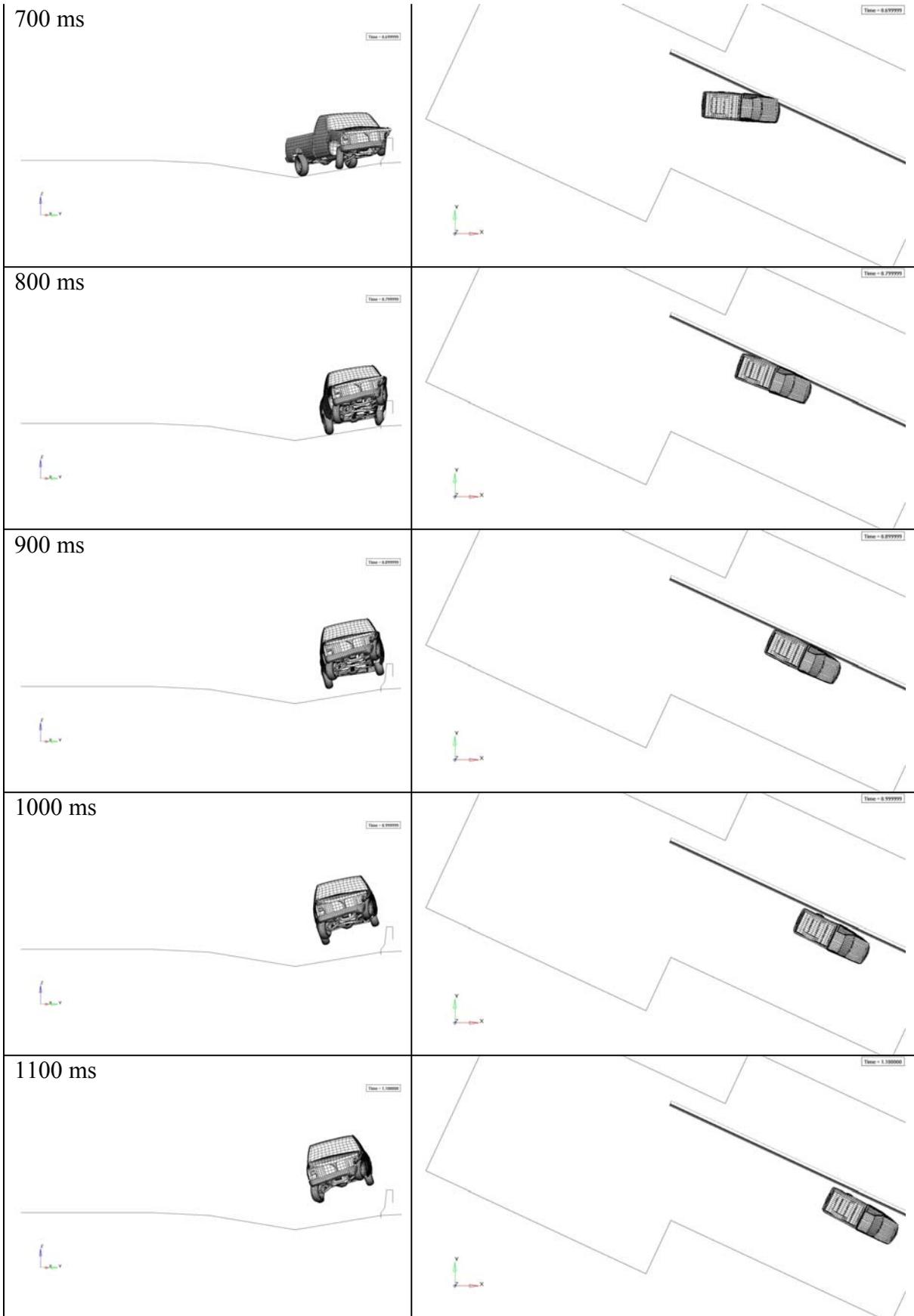
- Case 3: back edge of barrier is placed at the slope break point at the top of the V-ditch and,
- Case 4: back edge of barrier is offset 4 ft from the slope break point.

Case 3 corresponds to the lowest vehicle bumper height within the 4-ft range of interest for barrier placement. At this point, the vehicle suspension is still rebounding from its compression resulting from interaction with the ditch. Case 4 corresponds to the highest bumper height within the barrier placement range of interest.

Figure 9 and Figure 10 show sequential images captured from the simulations for Case 3 and Case 4, respectively. As can be observed from these figures, the vehicle was successfully contained and redirected in an upright manner in both cases. While the vehicle suspension in the pickup truck finite element model has not been thoroughly validated, these simulation results appear to indicate a reasonable probability of acceptable performance for impacts into the back side of a barrier placed on top of a V-ditch with a 6H:1V foreslope and backslope.



**Figure 9. Simulation Results for Case 3
(Back Edge of Barrier at Slope Break at Top of V-Ditch).**



**Figure 9. Simulation Results for Case 3
(Back Edge of Barrier at Slope Break at Top of V-Ditch) (Continued).**

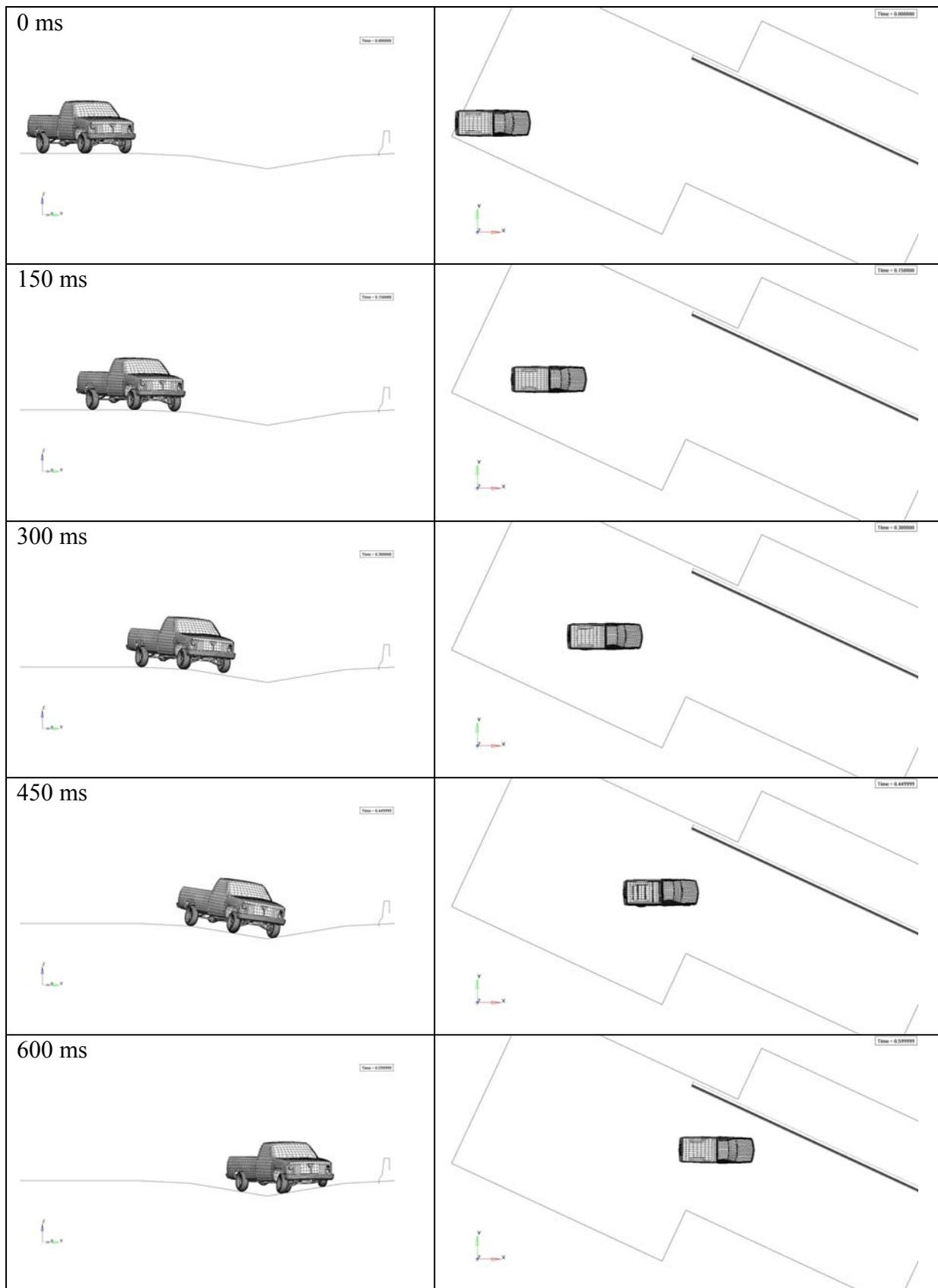


Figure 10. Simulation Results for Case 4 (Back Edge of Barrier Offset 4 ft from Slope Break at Top of V-Ditch).

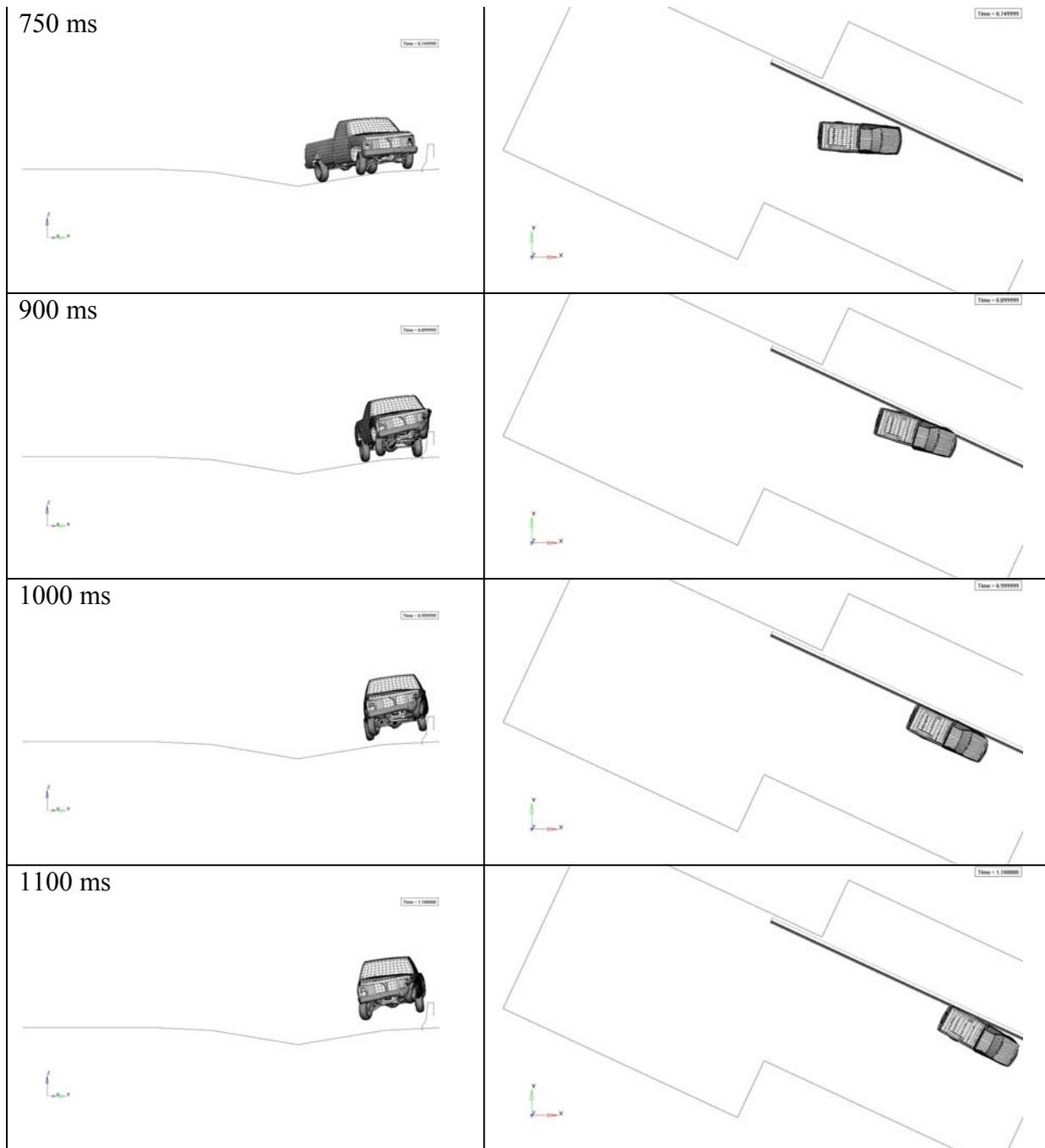


Figure 10. Simulation Results for Case 4 (Back Edge of Barrier Offset 4 ft from Slope Break at Top of V-Ditch) (Continued).

However, it should be noted that vehicle trajectory and behavior can vary as a function of the shoulder width and ditch width. Further, the influence of soil conditions on the stability of the vehicle as it re-contacts the ground after impact with the barrier is not known.

Roadway Configuration 3

In consultation with TxDOT personnel, another typical median configuration that may be a candidate for installation of concrete median barrier was identified and modeled, as shown in Figure 11. This configuration incorporates a 40-ft wide median with 4-ft shoulders and 6H:1V cross slope. The front traffic edge of the barrier is placed on the inside edge of the existing shoulder. A 2-ft wide surface for placement of the barrier is created by regrading the median back slope such that the slope break point is offset 2-ft further from the travel lanes. This approach maintains the full width of the existing shoulder and the associated safety the shoulder provides. The regrading increases the back slope of the median and makes the V-ditch unsymmetrical. For the particular median configuration that was modeled, the regrading increased the steepness of the back slope from 6H:1V to 5.25H:1V. The back edge of the concrete median barrier was placed at the new slope break point.

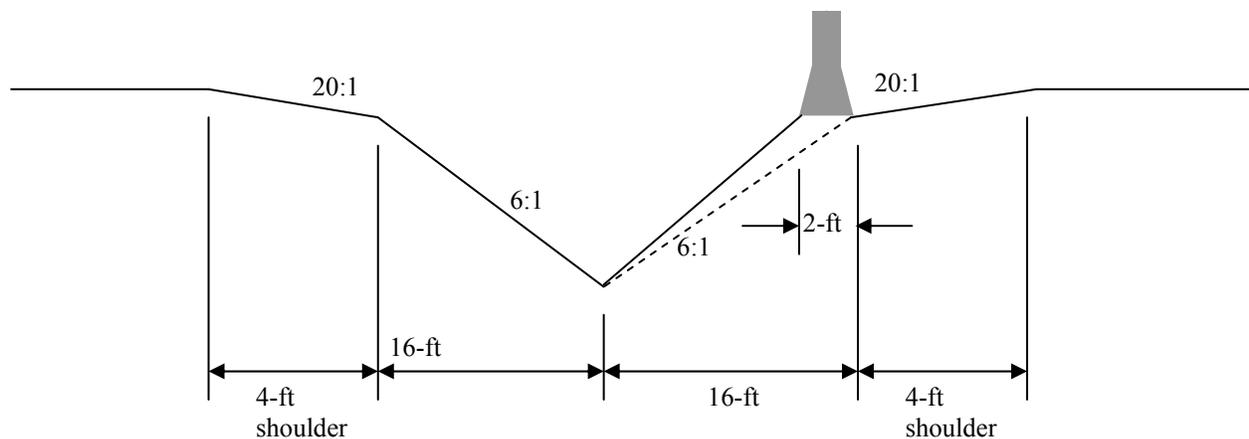
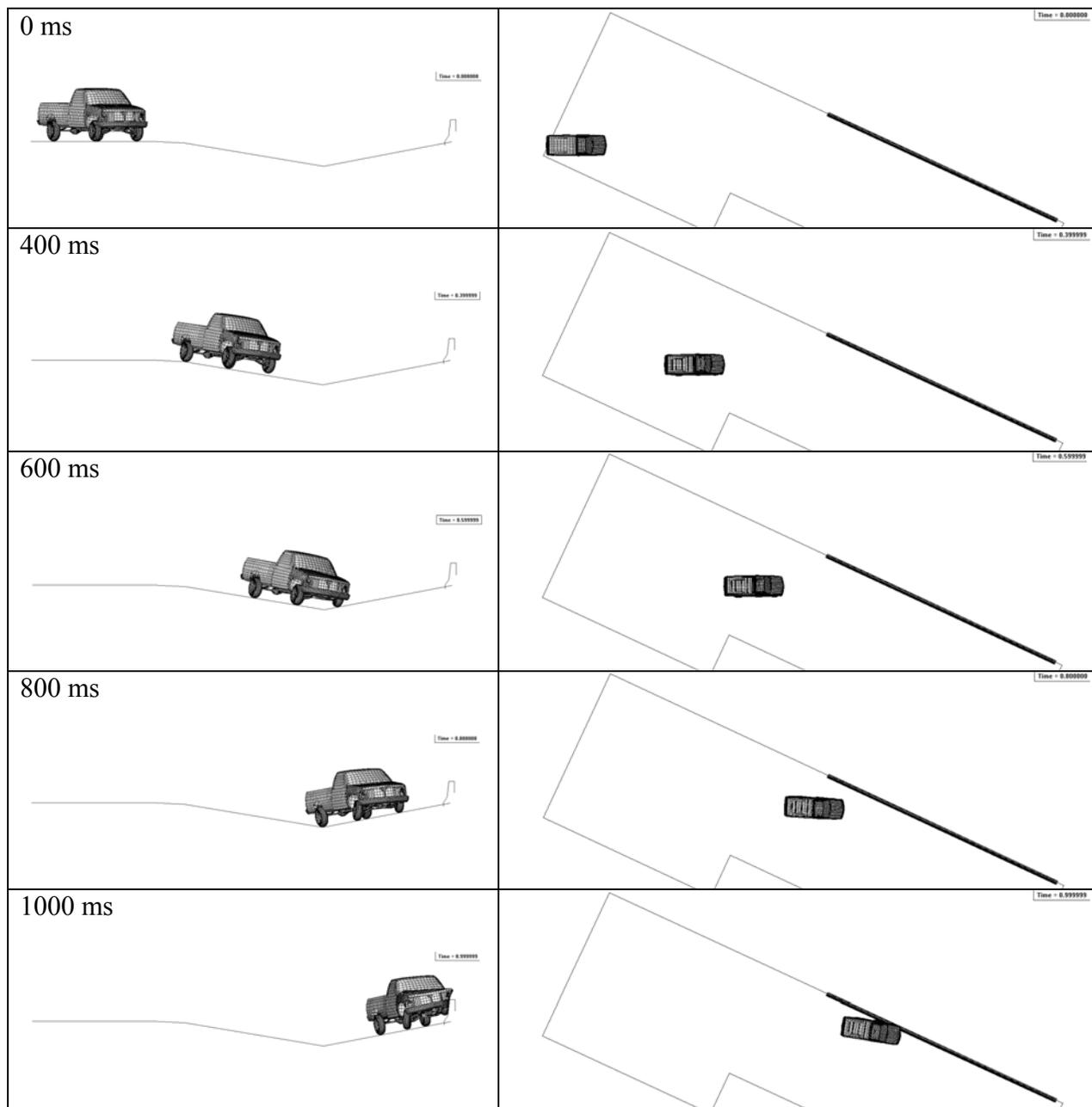


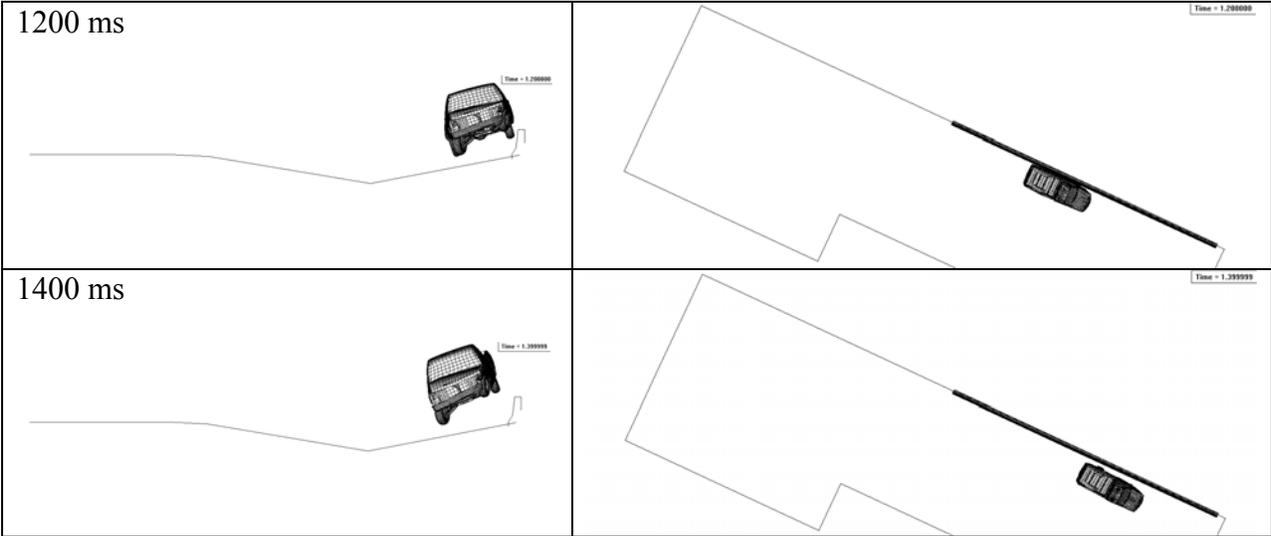
Figure 11. Simulated Roadway Configuration 3.

A finite element simulation of a pickup truck traversing the median and impacting the back side of the concrete median barrier was performed. As with the other simulations, the vehicle encroached off the travel lanes on the opposite side of the median at a speed of 62 mi/h and an angle of 25 degrees. Figure 12 presents sequential images from the simulation results.

As can be observed from this figure, the vehicle was successfully contained and redirected in an upright manner. Noting that the suspension of the pickup truck finite element model has not been thoroughly validated, the simulation results appear to indicate a reasonable probability of acceptable performance for impacts into the back side of a barrier placed on top of the regraded 5.25H:1V median slope. It should also be noted that the influence of soil conditions and/or soil furrowing on the stability of the vehicle as it recontacts the ground after impact with the barrier is not known.



**Figure 12. Simulation Results for Configuration 3
(Back Edge of Barrier at Break of Regraded Back Slope).**



**Figure 12. Simulation Results for Configuration 3
(Back Edge of Barrier at Break of Regraded Back Slope) (Continued).**

CHAPTER 3. SUMMARY AND CONCLUSIONS

Finite element simulations evaluated the impact performance of an F-shape concrete safety barrier installed on or above a 6H:1V median cross slope. Simulations were performed for various barrier placement locations on three different median configurations. When the barrier location on a given median configuration was variable and not defined by geometry or practice, critical barrier placement locations were determined by examining the trajectory of a vehicle encroaching across the selected median geometry.

The first configuration evaluated involved placement of a concrete median barrier in the center of a symmetric depressed median with 6H:1V cross-slope. Given the impact performance of the barrier was found to be acceptable at the critical barrier placement locations, it can be concluded that barrier performance anywhere along a 6H:1V cross slope should be acceptable. Thus, the simulation results are applicable for any width of depressed median conforming to the generalized layout that was analyzed. Further, similar or better performance would be expected for similar barrier placements on median with slopes less than 6H:1V.

The second and third configurations investigated placement of a concrete median barrier on or just inside of the inside shoulder of the highway, respectively. The simulations examined the scenario of a vehicle impacting the back side of the concrete barrier after traversing the median ditch and climbing the backslope.

Placing the barrier on the inside of an existing shoulder is less expensive because it eliminates the need for constructing a foundation pad and either regarding the median back slope or modifying drainage at the bottom of the ditch. However, the proximity of the barrier to vehicles in adjacent travel lanes will likely result in an increased frequency of barrier impacts than if the barrier were offset in the middle of the median, and the reduction in available shoulder width may have an adverse effect other aspects of highway safety.

Placing the barrier inside the inside edge of the shoulder requires construction of a 2-ft wide pad for placement of the barrier created by regrading the median back slope. This approach maintains the full width of the existing shoulder and the associated safety benefits provided by the presence of the shoulder. The regrading increases the back slope of the median and makes the V-ditch unsymmetrical.

For all of the above simulation cases, the vehicle was successfully contained and redirected. Within the accuracy of the current finite element model pickup truck model, and noting that the suspension system has not been thoroughly validated, the simulation results appear to indicate that median barriers placed on or above a cross slope that is less than or equal to 6H:1V have a reasonable probability of remaining crashworthy under design impact conditions. However, given the limitations and limited validation of existing vehicle models for median encroachments of this nature, caution should be used when considering any application of the results reported herein. A definitive evaluation of impact performance and verification of the simulation results can only be accomplished through full-scale crash testing.

CHAPTER 4. IMPLEMENTATION STATEMENT

Current guidelines contained in the AASHTO *Roadside Design Guide* and TxDOT *Roadway Design Manual* suggest that concrete barriers should not be placed on medians with cross-slopes greater than 10H:1V. These guidelines limit the placement of concrete barriers to narrow paved medians or at the edge of the shoulders. Recent in-service experience in Austin, Texas, indicates that some concrete median barriers placed with approach slopes greater than 10H:1V have successfully contained and redirected vehicles.

Under this research effort, researchers investigated the performance of concrete median barrier placed on medians with cross slopes as steep as 6H:1V. The ability to place concrete median barrier on steeper cross slopes may permit placement of the barrier farther from the travelway. This, in turn, can reduce the frequency and possible severity of median barrier crashes.

Full scale vehicular impact simulations were conducted for several impact scenarios associated with placement of concrete barrier on typical depressed median configurations. Simulation results indicate that the F-shape concrete barrier has a reasonable probability of acceptable impact performance when placed in the center of a depressed median with slopes as steep as 6H:1V (see [Figure 2](#)). Further analyses indicate acceptable impact performance when a concrete barrier is installed at the break of a depressed median with 6H:1V cross slopes (see [Figure 7](#)); or when the back slope has been regraded to 5.25V:1V to provide a pad for placement of the barrier along the inside edge of the shoulder, as shown in [Figure 11](#). However, it should be noted that the finite element pickup truck model used in the simulation analyses has not been thoroughly validated for encroachments across median slopes and ditches. Since vehicle response is critical to the assessment of barrier performance for the placement scenarios of interest, it is the recommendation of the research team that one or more full-scale crash tests be conducted to verify simulation results.

Should crash testing demonstrate that placement of concrete barrier on median slopes steeper than 10H:1V is acceptable, the practice can be implemented through revision of the TxDOT *Roadway Design Manual*.

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