Using Vehicle Dynamics Simulation as a Tool for Analyzing Cable Barrier Effectiveness

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This working paper summarizes recent efforts and findings derived from NCAC research. It is intended to solicit feedback on the approach, scenarios analyzed, findings, interpretations, and implications for practice reported by the research team. The statements contained herein do not necessarily reflect the views or policy of the FHWA. Please forward comments or questions to the authors noted above. These efforts will ultimately be documented and made available to advance research efforts related to this topic and guidance for practice.

ABSTRACT
The primary purpose of longitudinal safety barriers, such as cable barriers, is to contain and/or redirect errant vehicles that depart the roadway, hence keeping them from entering opposing travel lanes or encountering terrain features and roadside objects that may cause severe impacts. In this paper, vehicle dynamics analysis is used to study the effect of median configuration and cable barrier design on the safety performance of cable median barriers. Median configurations vary by width, side slope and slope combinations, and cross-section. Cable designs for this effort considered the number, arrangements, and height (note: tension, post spacing and features, cable type, and anchorages were not addressed). Vehicle dynamics analyses (VDA) were conducted to compute the vehicle trajectories based upon the dynamics associated with the type, weight, and suspension features of various vehicles as they cross the sloped terrain of the median. The trajectory of the frontal interface region generated by the analysis allows assessment of the potential interface effectiveness with the barrier. Vehicle dynamics analysis allowed a range of vehicles and impact conditions to be studied. These efforts led to the generation of various plots which provide insights on the optimal placement locations for various cable systems considering the influences of median slope, cross-sectional shape, and width. This paper describes the insights derived from the VDA approach and the efforts to generalize the information derived into design guidance. The information generated provides a robust basis for the development of improved guidelines for design and placement.
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INTRODUCTION

Over the past decade, cross-median crashes have grown to be a serious problem for a variety of reasons, including the growth of traffic, higher speeds, more variation in the mix of traffic, and/or driver issues (e.g., aggressive and distracted driving). Higher traffic volumes alone increase the probability that a vehicle might leave the roadway, as well as the probability that it will encounter an oncoming vehicle if it crosses the centerline or traverses the median. The problem is particularly serious for older, high-speed, divided highways where narrow medians were used. State DOTs have recognized the problem and have attempted to mitigate it in various ways. One approach has been to deploy cable barriers in the medians to redirect or capture errant vehicles before a cross-median crash can occur [1-6]. Cable median barriers are considered attractive because of low costs, short implementation time, ease of installation, and adaptability for sloped conditions. Both generic and proprietary designs for cable barriers exist and have been improved in recent years in response to the needs of the DOTs. The general consensus is that median cable barriers are highly effective (some agencies citing over 90% effectiveness rates), but cases of underride or override have still occurred with catastrophic results.

The FHWA has embarked on research to understand the causes for barrier-to-vehicle interface problems and improve the guidance to agencies to help get the maximum effectiveness possible. FHWA research has shown that cable barrier effectiveness is related to barrier design (number and height of cables, tensioning), configuration of the median (shape, width, slopes, and depth), and lateral position of the barrier within the median [7, 8]. Insights on the problem were revealed through computer simulations (using a variety of software tools) and crash testing. Under NCHRP Project 22-25 “Development of Guidance for the Selection, Use, and Maintenance of Cable Barrier Systems” ongoing research efforts are building on findings from the FHWA studies to develop a comprehensive set of guidelines for the use of all types of cable barriers (roadside and median) on the wide variety of median configurations that exist, for the variety of crash conditions that are possible.

This document provides background on the extensive use of vehicle dynamics analyses for investigating the vehicle-to-barrier interface for cable barrier placement in medians having varying configurations, widths, and side slopes. The results are based upon the premise that a barrier will be effective only if there is a good interface between the vehicle and the cable barrier. A summary of the approach, the assumptions, and typical results is presented. These efforts are considered useful to understanding the causes for barrier-to-vehicle interface problems and provide the basis for improved the guidance to agencies to maximize effectiveness.

VEHICLE DYNAMICS ANALYSIS

The motion of the vehicle can be very complex especially at highway speed. However, the vehicle motion is primarily governed by the forces and moments generated by the pneumatic tires at the ground. In most vehicle dynamics studies, only six degrees of freedom—longitudinal, lateral, vertical displacements and roll, pitch, yaw angles—are studied. Each is represented in Figure 1 along with the Society of Automotive Engineers vehicle-fixed coordinate system [9]. Generally, the vehicle-fixed
coordinate system is placed directly at the center of gravity (CG) of the vehicle. Vehicle position and orientation angle will be given in a global coordinates relative to the earth.

![Vehicle coordinate system (SAE)](image)

**Figure 1: Vehicle coordinate system (SAE)**

The concept of using vehicle dynamics simulation software to analyze off-run vehicle behavior and motion is gaining recent popularity. Indeed, McMillan in 1998 has conducted many simulation studies to analyze driver response to roadway departure [10]. His work helped to evaluate the ability of collision countermeasure systems to prevent run-off road accidents. Similar analyses were performed by Pape in 1996 and Hadden in 1997 where they extend the VDANL (Vehicle Dynamics Analysis, Non-Linear) model of the vehicle/driver to assess the effectiveness of the countermeasure system [11, 12]. Other studies have focused on the results of an off-road crash. Day and Garvey used EDVSM (Engineering Dynamics Vehicle Simulation Model) to perform rollover simulations [13]. They also discuss limitations of rollover simulation to help on-road and off-road accident reconstruction. The use of simulation software for the analysis of off-road crashes has been very broad. Claar concentrated on suspension modeling for improving off-road ride comfort whereas some studies have focused on friction influences in case of water or snow, as did Mancosu in 2002 [14, 15].

However, only a few research efforts using vehicle dynamic simulations have been performed to analyze and enhance the roadway design itself. In 2004, Sicking and Mak presented a paper which suggests that efforts should focus on developing better vehicle and roadside safety hardware models [16]. It was also indicated that significant effort must be devoted toward improving the capability of computer simulations for modeling run-off-road crashes. The NCAC (National Crash Analysis Center) staff used the HVE simulation program to study the effect of edge drops for guardrail roadside barrier performance [17]. They used different initial conditions and different vehicles as well as different edge drop profiles and analyzed the behavior of the vehicle encountering an edge drop. Given that two critical points on the W-beam guardrail were defined for determining barrier effectiveness, they performed many simulations to study whether there is an underride or the vehicle is vaulting. Lastly, a study conducted at Pennsylvania State University utilized a commercially vehicle dynamic simulation software to analyze the effect of highway median width along with slope on vehicle stability [18]. Brennan and Hamblin used CarSim package simulation programs where they ran thousands of simulations using different vehicles, median widths and slopes, steering conditions as well as different initial conditions to analyze roll, lateral velocity, and related factors. The results indicated tradeoffs in the size and slope of median profiles versus the type of accidents observed. However, this study was too limited to quantify the result noticed. More research is ongoing.

In the remainder of this study, a non-linear vehicle simulation model (commercially-available via CarSim®) will be used to analyze vehicle-roadway interaction. This software is a tool for vehicle safety
research or vehicle design which allows better decisions related to vehicle dynamic influences [19]. CarSim was used because of its global acceptance by the world’s largest vehicle manufacturers, and because its physical/mathematical vehicle model provides a detailed description of the vehicle’s trajectory that considers the influence of weight, suspension system, and other factors [20]. It provides capabilities of working with third party control development tools such as MATLAB/Simulink to extend its possibilities even further. CarSim can perform simulations up to 15 times faster than real-time, and allows fully automated links with MATLAB scripts, making it highly efficient for the study of large ranges of conditions.

VALIDITY OF CARSIM SIMULATION SOFTWARE

Partial confirmation of CarSim simulation accuracy was obtained in order to ensure the validity of CarSim use. This simulation software was compared to another simulation software HVE, Human Vehicle Environment by The Engineering Dynamics Corporation [21]. HVE is a computer environment developed for use by engineers and safety researchers to study interactions between humans, vehicles, and their environment. It is a high-level simulation tool aimed at creating 3-dimensional models of vehicles and environments and allows the study of their dynamic interaction under selected conditions. Its database includes a wide range of high-fidelity vehicle models that can be used in dynamic reconstructions and simulations. HVE provides physical and visual environment models to simulate selected 35 conditions. Weather attributes, road geometry, and pavement frictional properties can be computed and their effects on the vehicle dynamics can be analyzed. Drive actions (e.g., throttle, brakes, steering and gear selection) can also be used as inputs to reconstruct specific scenarios.

The HVE program has been used extensively in vehicle dynamics and accident reconstruction analyses. It has been thoroughly validated, and it was found to accurately predict vehicle trajectories for different terrain profiles. The HVE-predicted vehicle trajectories matched the full-scale crash tests by FHWA as shown in Figure 2. Figure 2 shows that the cable barrier was not fully engaged in the first test, which meant that the vehicle was underriding. The same test was performed in HVE. The vehicle properties were taken into consideration so that both tests were identical. The same observation was made in HVE where the vehicle was underriding the barrier. However, in the second test, the vehicle fully engaged the cable barrier. It was noticed that the impact between the vehicle and the cable barrier was very similar in both tests.

![Figure 2: Comparison of HVE and full-scale crash test results](image-url)
Figure 3: Results from the comparison

Since HVE has been compared to full-scale crash tests and can accurately predict vehicle trajectories, two identical tests were performed in both software, CarSim and HVE, in order to compare the results. For this comparison, a Chevrolet pick-up truck was used. The vehicle properties are identical with those from the real vehicle and were incorporated into both vehicle dynamics software packages [22]. Two approach angles were given to the vehicle, 10 degrees and 25 degrees. The vehicle had an initial velocity
of 96 km/h (60 mph). The road profile developed had a 6H:1V V-shaped median in the middle of two roads. Two simulations were performed with each set of conditions to compare the vehicle trajectory when it leaves the road. In the first simulation, the Chevrolet pick-up started with an initial velocity of 96 km/h and an approach angle of 10 degrees and in the second simulation, the vehicle had the same velocity but an approach angle of 25 degrees. Five different output variables—vehicle CG position (Y and Z) and roll, pitch, and yaw angles—were compared as a function of the lateral coordinate of the vehicle expressed in meters. Results can be observed in Figure 3. The first column displays the results for the 10 degree approach angle whereas the second column shows the 25 degree yaw angle. The dashed line indicates the position of the median V-shape bottom in these simulations. The red line shows the results from HVE and the blue line from CarSim.

The different graphs in Figure 3 show that the HVE and CarSim outputs are similar. Thus, there is confidence that vehicle trajectory predictions generated by CarSim will provide the necessary accuracy for an analysis of cable barrier effectiveness.

ANALYSIS APPROACH

Vehicle dynamics simulations are conducted to compute vehicle trajectories as they traverse a median on a diagonal path. Vehicle dynamics software was used to do the computations and generate an animation showing what happens in such events. In these analyses two points were defined for each type of vehicle and were considered to represent the primary interface (engagement) region on the vehicle. These points are labeled 1 and 2 on Figure 4a. If one is standing in the center of the median downstream from the point a vehicle leaves the roadway, the trace of Points 1 and 2 on the front of the vehicle would be seen as the blue lines in Figure 4b.

These same data points can be plotted on a diagram of the median cross-section (as shown in the lower part of Figure 4b). It can be noted that in moving from left to right, after passing the breakpoint between the shoulder and the median, the vehicle will be airborne or at least have a low compression load on its suspension system. At some point the vehicle will land or return to a distribution of weight on all wheels, and the suspension will compress to absorb the load. As the vehicle continues its movement across the median, there will be a rebound of the suspension as it dissipates energy. Thus, as the vehicle traverses the median the height of its interface area will vary depending on the state of the vehicle’s suspension system and the slopes of the median. Effective lateral placement of the barrier involves
finding the locations where the vehicle’s interface area matches the barrier’s cable heights. For median applications, finding these locations is complicated by the need to have an effective interface for impacts from either direction.

This research considered a broad set of influencing factors as shown in Figure 5. This figure shows a typical divided highway where the median is the green area between the shoulders. The median can be of different widths and cross-sections. Paved shoulders with widths of 4 to 8 feet with negligible slopes were assumed, but the analysis only considered the vehicles crossing the median itself. The cable median barrier is placed somewhere in the median and can be hit from either side. For the situation shown in Figure 5, a vehicle leaving the bottom roadway would have a “nearside” hit on the barrier. From the upper roadway the vehicle would have a “farside” hit. A cable median barrier has to be located such that it functions effectively for both nearside and farside hits. The vehicles crossed the median on a diagonal as shown in Figure 5.

The VDA approach allowed the consideration of virtually any passenger car or light truck vehicles found in the current fleet. This analysis focused on a small passenger car and a pick-up truck that were considered representative of the range of vehicles under NCHRP Report 350. The specific weight, size, frontal geometry, and suspension system characteristics of these vehicles were incorporated into the vehicle dynamics analysis. A range of impact conditions and median configurations can be analyzed under this approach, but a subset of these was selected (as will be defined in the following paragraphs).

Defining “effective interface conditions” for any cable barrier design and any median configuration can be accomplished in various ways. For this analysis, effective interface conditions were determined by:

- Assessing relative positions of the vehicle to the barrier such that:
  - To minimize the potential for override, the top cable should contact the vehicle above Point 1 (lower critical point).
To minimize the potential for avoid underride, lower cable should contact the vehicle below Point 2 (upper critical point).

- Defining the impact conditions to be considered. While one approach would be to follow NCHRP 350 or MASH requirements, in this analysis, a broader view was taken requiring that the conditions should reflect a broader range of approach angles, speeds, and vehicle types.
- Establishing a criterion for the number of cables that need to effectively engage. For low-tension systems it has been assumed that a minimum of two cables need to engage and for a high-tension system one cable.

The viability of these criteria need to be discussed further and endorsed as the basis for the guidelines.

Using VDA software, the trace paths of Points 1 and 2 for both directions of a vehicle crossing a median were generated and plotted in a normalized fashion with each individual trace representing a specific vehicle, speed, impact angle, and crossing direction. The process for using these results to assess the potential effectiveness of various cable median barrier designs in different lateral positions is described in the following paragraphs.

**ASSESSING BARRIER EFFECTIVENESS**

The approach involved analyzing the generated plots, as described above, to determine the vehicle interface with standard cable barriers in varying lateral positions. In this analysis, effective interface conditions were determined by assessing the relative position of the vehicle to the barrier for a range of impact conditions and determining whether the resulting interfaces met the engagement criterion above.

Concerning the specific median configurations, the dynamics of the vehicle was studied on a wide range of off-road profiles. According to the AASHTO roadside design guide, cable barriers are installed for various unlevel terrains, which can be symmetric median, non-symmetric median, V-shaped, or trapezoidal [23]. In this paper only a wide range of symmetric, V-shaped medians were considered. Moreover, these V-shape profiles were selected such that they represent the majority of the medians typically used on U.S. roads from 4H:1V to 12H:1V. For this analysis, 55 median profiles were taken into account.

To address the effect of vehicle type on the barrier performance, two vehicle models were used in the vehicle dynamics analysis to create an envelope of the vehicle trajectories. A 2000 kg pick-up truck (Chevy C2500) and a 775 kg Honda Civic were utilized to represent the two vehicles in NCHRP (National Cooperative Highway Research Program) Report 350 [24].

Finally, the analysis was conducted for a wide range of impact conditions: road departure angle from 10 degrees to 25 degrees with 5 degrees increment and road departure speed of 30 mph, 40 mph, 50 mph, and 60 mph.

For this study, a total of 2 vehicles, 4 approach angles, 4 speeds, and 55 profiles were simulated for a total of 1760 runs. A MATLAB text script was developed to run each combination automatically. Outputs of the simulations, including the vehicle’s CG position and angle of orientation, were saved in an output text file for each simulation for post-processing using other programs.

In order to study the interface between the vehicle and the cable barrier, two points on the front of the vehicle that were considered likely to engage the cables were tracked as the vehicle traversed the median.
V-shape. These two points are located at the extreme outboard corner of the vehicle front-right that would potentially be the first contact with the cable barrier and were likely to have sufficient structural integrity to hold the cables. The first point is selected such that the cable would go under the vehicle if the cable impacts the vehicle below this point, which means that the vehicle overrides the barrier. Similarly, the second point is selected such that the cable would go over the vehicle if the cable impacts the vehicle above this point, which means that the vehicle underrides the barrier. If the cable impacts between those two points, there is a full engagement and the cable would remain in contact with the vehicle. The location of these two points on both vehicles used in the analysis is shown in Figure 6.

![Figure 6: Location of the two critical points on both vehicles used](image)

A FORTRAN program was developed to generate the VDA inputs for the 1760 combinations of factors cited above. The VDA software computed the lateral trajectories for each set of conditions and generated files of the trajectory every hundredth of a second as text files. These output text files were then processed via MATLAB routines in order to compute the lateral trajectories of the two critical points necessary for analyzing the interface between the vehicle and cable. Lastly, another computer program was developed to automate the process of plotting the lateral trajectory of both critical points for each simulation. This program generates plots for each simulation. HYPERVIEW software was used to manipulate all the plots and analyze the data.

**RESULTS**

For any set of conditions, the trajectory of the two critical points can be plotted as a function of the lateral coordinate to establish the change in height of the vehicle as it traverses the sloped median, as shown in Figure 7. The shaded region between these two trajectories depicts the area where a cable would engage the vehicle. In this case the vehicle is airborne (or at least partially airborne) from the point that it leaves the shoulder until it crosses the center of the median. The effects of gravity bring the vehicle back to the ground and the suspension system absorbs the energy of the impact (i.e., the springs compress) on the farside of the median. As the springs release their energy, the vehicle again rises and may even become airborne. The point where the trajectory envelope is the lowest corresponds to the point where the vehicle’s interface region is at its lowest. At the low point, the risk of underriding is the greatest if the cables do not sufficiently cover this region.
Similarly normalized plots (where the sloped profile is subtracted from the trajectories) were generated for an easier evaluation of the cable barrier performance evaluation. These normalized plots give a direct measure of the relative height between the barrier and the vehicle, and make it easier to visualize the number of cables that will be engaged if the barrier is placed at any location across the median. Figure 8 shows the normalized plot of the two selected points on the vehicle as it traverses the median for the case depicted in the previous figure. The dashed lines indicate the relative height of the cables in a four-cable design for this case. The span of these cables (from the lowest to the highest) represents the barrier interface area. It can be clearly noted that where the trajectory curve is the lowest, the vehicle’s interface area would be below that provided by a barrier placed in that lateral position.

These plots provide useful information for selecting a barrier for that single set of conditions. Obviously, vehicles can leave the road and cross the median under a much wider range of conditions. The multi-colored array of lines in Figure 9 represents the traces for a broader set of impact cases for the parameters set. In this case the traces for Points 1 and 2 are plotted individually. The heavy blue line represents the overall maximum heights for Point 1 for the set of impact cases associated with this median configuration. Similarly, plotting all cases for Point 2 yielded the multi-colored array of lines on the right side in Figure 9 for the set of impact cases for a given median configuration. The heavy green line represents the overall minimum heights for Point 2. These overall maximum and minimum heights provide the basis for undertaking barrier effectiveness analysis considering all conditions. Comparing the resulting blue line (minimum) as the Override Limit and green line (maximum) as the Underride Limit for a given median provides a means of determining the interface effectiveness across all lateral positions for any given barrier design. Where the blue line goes above the top yellow line there is the opportunity for an override to occur. Where the green line falls below the lowest yellow line, an underride is possible.
Figures 10 and 11 depict the usefulness of graphs that show these override and underride limits for given median configurations and cable barrier designs. For a basic median profile, two summary plots are generated. The two plots are similar except for the cable barrier system evaluated. The system used in the first plot consists of a generic three-cable barrier system with cable heights set at 21, 25.5, and 30 in from ground level. This system has one of the narrowest cable spreads. The system used in the second plot is a generic four-cable system with cable heights set at 13.5, 24, 34.5, and 45 in from ground level. This system has one of the widest cable spreads.

Figure 10 shows a sample of the results. The upper portion shows the normalized representation of the interface envelope, the minimum upper cable height curve, the maximum lower cable height curve, and the relative position isobars for a specific type of cable barrier (i.e., generic, low-tension, 3-cable system). The Barrier Interface Envelope is the gray shaded area that surrounds all of the trace bars for different vehicles traversing the median at varying angles and speeds from both directions. These curves are normalized to relate the relative heights of individual cables in the barrier, or the height of the effective interface area on the front of a vehicle to a horizontal plane. For any position across the median, the vertical height of the normalized plot to actual sloped surface is equivalent.

The lower portion of Figure 10 shows the profile or cross-section of the median related to the upper graph. The gray hatched portions indicate the lateral positions where this specific barrier will be effective. Since the median is symmetric, the effectiveness regions are a mirror image on the opposite side. The red hatched area defines the lateral positions where the specific barrier has a cable
arrangement that has a lower cable above the maximum lower cable height curve (green) and/or an upper cable below the minimum upper cable height curve (blue). Effective lateral placement occurs where both criteria are met. It can be noted that for this specific barrier system, the red region corresponds to the lateral placement range where the maximum lower cable curve falls below the lowest cable in the system. This plot would indicate that for this 24’ wide median with 6:1 side slopes, there is an area from about 1’ to 7’ from the center of the median where placement of this generic cable barrier system is not recommended because of a risk of underriding.

Figure 11 displays the same as before but for another generic system (i.e., generic, low-tension, 4-cable system). It can be observed that for this specific barrier system, the red region corresponds to the lateral placement range where the maximum lower cable curve falls below the lowest cable in the system. This plot would indicate that for this 24’ wide median with 6:1 side slopes, there is an area from about 3’ to 5’ from the center of the median where placement of this generic cable barrier system is not recommended because of a risk of underriding.

Several plots of this type, for different median profiles, were generated and used to aid efforts to determine effective placement locations. Efforts currently underway are compiling a large set of these plots to serve as nomographs for designing cable median barrier systems. Since median profiles change along the highway, using such nomographs for each change can be an extremely tedious task. To address this issue, it was realized that by using the normalized plots and the override and underride limits for each case, it would be possible to develop a more streamlined procedure for determining median barrier effectiveness. This procedure is described below.

Figure 12 illustrates the composite, normalized representation of the minimum upper cable height curves (override limit) for various slope conditions. The relative position isobars for a system that has its highest cable at 45 inches is shown by the dashed line. Clearly, at this top cable height, the override limits for all the different specific sloped conditions are satisfied. It can be seen that the minimum upper cable height curve increases as the slope augments. This plot also indicates that the risk of overriding escalates as the slope grows. Similarly, Figure 13 displays the normalized representation of the isobars for a cable system with the highest cable at 30 inches. This plot demonstrates that using this specific cable barrier system on 12:1, 10:1, 8:1, and 6:1 sloped medians would avoid overriding. However, it can be observed that this specific cable barrier system would not prevent overriding for 4:1 sloped medians.
Figure 12: Minimum upper cable height curve compared to highest cable of the generic system 2 for all sloped median considered

Figure 13: Minimum upper cable height curve compared to highest cable of the generic system 1 for all sloped median considered

Figure 14 shows the composite, normalized representation of the maximum lower cable height curve (underride limit), and the relative position isobars for a system with lowest cable at 14 inches for different slopes. It can be noticed that the maximum lower cable height curve decreases as the slope augments. This plot indicates that the risk of underriding escalates as the slope grows. Also, it shows that placing this specific cable barrier system within the median with 12:1, 10:1, and 8:1 side slopes would prevent underriding. However, this plot demonstrates that for a median with 4:1 side slopes, there is an area from about 1’ to 7’ from the center of the median where placement of this generic cable barrier system is not recommended because of a risk of underriding. The same observations can be made for a median with 6:1 side slopes where there is an area from about 2’ to 5’ from the center of the median where placement of this generic cable barrier system is not recommended because of a risk of underriding.
Similarly, Figure 15 illustrates the normalized representation of the maximum lower cable height curve, and the relative position isobars of the lowest cable system for a specific type of cable barrier (i.e., generic, low-tension, 3-cable system) for all the different specific sloped medians. This plot indicates that placement of this specific cable barrier system within the median with 4:1, 6:1, and 8:1 side slopes would not prevent underriding. However, this plot demonstrates that for a median with 10:1 and 12:1 side slopes, there is an area from about 0.5’ to 15’ from the center of the median where placement of this generic cable barrier system is not recommended because of a risk of underriding.

**SUMMARY AND CONCLUSIONS**

Extensive vehicle dynamics simulations were performed to analyze the lateral placement of different generic cable barriers within various symmetric median configurations. Vehicle dynamics simulations allowed consideration of a broad range of vehicles and impact conditions. Scores of plots were generated so as to enhance the overall effectiveness of cable median barrier deployment. The results of
this analysis were aggregated into five different categories corresponding to the five different sloped median configurations taken into consideration.

For a median with 4:1 side slopes, in the best cases, i.e. for a low-tension generic 4-cable barrier system, there is an area from about 1’ to 7’ from the center of the median where placement of this generic cable barrier system is not recommended because of a risk of underriding. On the other hand, in the worst cases, i.e. for a low-tension generic 3-cable barrier system, placement of this specific cable barrier within the median is not recommended at all because of a risk of underriding and/or overriding.

For a median with a 6:1 side slopes, in the best cases, i.e. for a low-tension generic 4-cable barrier system, there is an area from about 2’ to 5’ from the center of the median where placement of this generic cable barrier system is not recommended because of a risk of underriding. However, in the worst cases, i.e. for a low-tension generic 3-cable barrier system, placing this specific cable barrier within the median is not recommended at all because of a risk of underriding and/or overriding.

For medians with 8:1, 10:1, and 12:1 side slopes, in the best cases, i.e. for a low-tension generic 4-cable barrier system, placement of this specific cable barrier system within the medians would prevent the vehicle from underriding and overriding. However, in the worst cases, i.e. for a low-tension generic 3-cable barrier system, the placement of this specific cable barrier within a median with 8:1 side slopes is not recommended because of a risk of underriding whereas there is an area, for medians with 10:1 and 12:1 side slopes, from about 0.5’ to 15’ from the center of the median where placement of this generic cable barrier system is not recommended because of a risk of underriding.

These results could be used to develop improved guidance for the design and placement of cable barrier systems. However, some work is still needed to be accomplished to generalize these results for all kinds of off-road geometries. Also, full-scale crash tests could strengthen these findings.

REFERENCES


