Evaluation of the Influences of Cable Barrier Design and Placement on Vehicle to Barrier Interface

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This working paper is a compilation of recent efforts and findings intended to solicit feedback on the approach, scenarios analyzed, findings, interpretations, conclusions, and implications for practice resulting from the efforts of the research team. 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 designs on the safety performance. 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 were conducted to compute the vehicle’s trajectory and dynamics as it crossed the sloped terrain and interfaced the barrier. Vehicle dynamics analysis allowed a range of vehicles and impact conditions to be studied. The various plots generated provide insights on the optimal placement locations for 3- or 4-cable systems, the differences between degree of slope, cross-section shape, and median width, and varying impact conditions. The information generated provides a robust basis for the development of improved guidelines for median barrier design and placement.
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INTRODUCTION

Cable barriers have served roadside safety applications for more than ninety years. Recent increases in cross median crashes have given rise to the search for cost-effective barriers that could be deployed widely on varying side-slope conditions in a limited amount of time. A variety of new cable median barrier designs have emerged over the last ten years to meet that need. While cable median barriers have been reported to be highly effective in reducing cross median crashes, there is a need for improved guidelines for their deployment to maximize effectiveness for all applications. Research conducted by the FHWA Turner Fairbank Highway Research Center through the National Crash Analysis Center (NCAC) has identified that there are influences between the design of the cable barrier system and where it is placed in medians having varying configurations. The research is providing the insights needed to develop guidelines for effective deployment of cable median barriers, but it is expected to improve the understanding of vehicle-to-barrier interfaces that will enhance the application of other types of barriers as well.

The FHWA was approached by a state in 2002 for help in understanding why they experienced some cross median crashes after the installation of cable median barriers on many miles of rural freeways. Generally, the state was convinced that the barriers were significantly reducing cross median crashes, but they wanted to know if further improvements were possible to address the occasional occurrences of vehicles underriding the barrier.

The generic three-strand, low-tension cable barrier shown in Figure 1 is a longitudinal barrier used to contain and/or redirect errant vehicles that depart the roadways. This barrier gradually redirects an impacting vehicle by deflecting, elastic stretching of the cables and dissipation of energy by breaking and bending of the posts to minimize forces on the vehicle and its occupants. This type of barrier has lower installation costs, provides effective vehicle containment and redirection for a wide range of vehicles, and can be installed and repaired quickly. Cable barriers are an option for use in locations where there is sufficient space to accommodate the large lateral deflections that are characteristic.

![Figure 1: Typical median cable barrier](image)

It became apparent through these investigations that the design and placement of the cable median barriers were strongly influenced by the configuration of the median. This suggested the need for a comprehensive analysis of the various combinations of cable median barrier designs, placement practices, and median configurations for a range of impact conditions with different types of vehicles.
The ultimate objective is to translate the findings into guidelines that will promote design decisions that will lead to maximum effectiveness.

RESEARCH APPROACH

Crash Data Analysis
The NCAC analysis started with a detailed review of the cross median crashes that occurred in the sections where cable median barriers had been installed by the state that posed the question. The examination of the accident reports for cable barrier failures indicated that underrides were the most common reason the cable barrier failed in narrow medians even though the side slopes were gentle (i.e., 6:1). It was further noted that a mid-sized sedan, like a Ford Crown Victoria, was the most prone to underride the barrier for the standard placement practice of placing the barrier 4 ft offset from the center of the sloped section. Static comparisons of the front profile of the vehicle on a slope show that the lowest cable is near the upper portion of structurally rigid portions of the vehicle’s front end, but in cross median events the dynamic effects alter the interface with the barrier. While this analysis provided some useful insights, they were not based on many cases and hence were deemed insufficient in providing a solid explanation for the underrides.

Finite Element Modeling and Crash Simulation
A more rigorous analysis was begun thinking that crash simulations using finite element models (FE) would be the best approach to understanding the complex interactions of the various factors previously noted. Vehicle models for a range of vehicle types were available, but an FE model of the cable median barrier system had to be developed. After successful modeling of a generic cable median barrier and validation of the crash simulations through full-scale crash tests, it was concluded that it was possible to analyze cable median barrier crash scenarios and vary crash parameters, like impact angle and vehicle speed, barrier design, median configurations, and/or barrier placement to assess safety performance [1,2]. This approach also enables identification of the crash sensitive components of the 3-strand cable guardrail safety system.

However, these simulations typically took days to run, limiting the number of alternative scenarios that could be analyzed. It became apparent, particularly when the results indicated an override or underride (implying issues with interface, not barrier strength) that the critical aspect (at least for initial barrier design and placement considerations) was the vehicle-to-barrier interface. To support the crash simulations, vehicle dynamics analyses were conducted to compute the effects or dynamics of the vehicle’s suspension as it crossed the sloped terrain. It became apparent that the vehicle dynamics analysis could more expeditiously provided the data needed for vehicle-to-barrier interface analysis.

Vehicle Dynamics Analyses
The vehicle dynamics analysis (VDA) was determined to provide a more effective way to conduct an interface analysis. Once an effective basic interface with the barrier is established, further analysis of the “strength” of the barrier can be undertaken to assure effectiveness in capturing or redirecting an errant vehicle. It has become easier to undertake VDA using commercial software packages that have seen considerable use in the automotive industry.

The HVE (Human Vehicle Environment, from The Engineering Dynamics Corporation) was used for this effort [3]. It (and other commercial software tools) is a high-level simulation tool aimed at creating 3-dimensional models of vehicles and environments that allows the study of their dynamic interaction
under selected conditions. This physical/mathematical vehicle model provides a detailed description of a motor vehicle trajectory that considers the influence of weight, suspension system, speed, terrain, and other factors. Its internal database includes a wide range of high-fidelity vehicle models that can be used in dynamic reconstructions and simulations. HVE outputs physical data and visual animations of the simulated conditions. Weather attributes, visual occlusion, road geometry, and pavement frictional properties can be computed and their effects on the vehicle dynamics analyzed. Driver actions (e.g., throttle setting, braking, steering, and gear selection) can also be computed. The HVE program has been used extensively in vehicle dynamics analysis and accident reconstruction. It has been thoroughly validated and it was found to accurately predict the vehicle trajectory under different terrain profiles.

HVE can easily compute the heights of defined points on the vehicle under different terrain conditions for varying speeds, impact angles, and types of vehicles and provide animations that show the dynamics associated with a vehicle crossing a median. This software can provide analysis over a wide range of conditions, but it is less effective for analyzing sharp bumps (e.g., curbs) or situations where there is excessive surface drag by the bottom of the vehicle (e.g., in 3:1 to 3:1 slope transitions). The analysis considers the differential distribution of vehicle weight, the contacts of the wheels with the surface, and the suspension response.

SCOPE

Median Configurations

A median on a typical divided highway is defined to be the “grassy” area between the roadway lanes and shoulders of the opposing flows of traffic. The median can vary in width and have varying cross-sectional features. Paved shoulders with widths of 4-8 feet with negligible slopes were assumed for this analysis.

The cable median barrier is placed laterally somewhere in this median area. The barrier can be hit from either side and depending on the relative proximity of where the vehicle leaves the roadway and the placement of the barrier (i.e., nearside and farside hits) and has to function effectively for hits from either side.

Median Crossing Events

The “basic” median crossing event involves a vehicle leaving the roadway and shoulder and traversing the median on a diagonal path. While cross median events can occur in many ways, for this effort, the event was simplified to a straight path, no driver inputs, an initial speed defined at the point of leaving the shoulder, for a vehicle with a single occupant. The vehicle was allowed to react to the responses of the suspension system while traversing the median. The median was assumed to have a firm surface so that there was no ploughing of the tires into the surface that would alter the dynamic effects.

Vehicles and Impact Conditions

This analysis considered different vehicles typically found in the traffic stream on a highway. The large vehicle was the Chevy C2500 pick-up truck, the small vehicle was the GeoMetro, and the mid-sized vehicle was the Ford Crown Victoria. The specific weight, size, frontal geometry, and suspension system characteristics of this set of vehicles was obtained from the vehicle features library in the HVE software. Recent updates to the crashworthiness standards for roadside hardware will necessitate further analysis for the larger vehicles that have been proposed.
Since it is understood vehicles can leave the roadway at varying speeds and angles, an attempt was made to consider the implications of a broader set of impact conditions than the normal 100 km/h (62 mph) and 25 degree angle specified for evaluating the crashworthiness of longitudinal barriers. The analysis considered initial speeds of 50, 70, and 100 km/h (30, 42, & 62 mph) and impact angles of 5 to 25 degrees. The vehicles crossed the median on a diagonal for these conditions in this analysis.

**Cable Median Barriers**

A variety of designs for cable median barriers have emerged as various manufacturers have responded to the interest in cable systems. Cable barrier systems vary in many ways, as easily noted in Figure 2. This variation complicates interface and effectiveness analyses that were the focus of this effort.

![Figure 2: Sample cable barrier designs variations](image)

Other factors such as the softness of the soil, the wear on the suspension system of the vehicle, the loading of the vehicle, and the installed and maintained tolerances of the cables will influence actual performance, but no attempt was made to analyze these effects in this study. These factors may be the focus of future research.

**ANALYSES**

**Dynamic Response Information**

VDA was used to develop trace plots for various cross median events (i.e., combinations of vehicle type, median configurations, and impact conditions). Figure 3 depicts a still scene from a typical VDA animation and the corresponding trace of the upper and lower trace points of the primary structural region of the front of a mid-sized sedan. The trace plot represents what an observer standing in the center of the median downstream of the median crossing would see. The tendencies of the right front wheel to be airborne, the dip when the weight of the vehicle is absorbed by the suspension on landing, and the rebound effect as spring forces release energy can be noted in the animations.

The usefulness of the trace plot is depicted in Figure 4. While this figure depicts a semi-rigid median barrier, it shows the criticality of an effective vehicle-to-barrier interface. The critical area (i.e., primary structural region) indicates where and how much interface is likely for any lateral position across the median. A good interface implies that the critical area squarely meets the barrier and thus allows safe redirection of the vehicle. Vaulting occurs when the primary area is higher than the barrier or only
allows a partial interface with the barrier to capture the vehicle (e.g., above the top hump of the w-beam shape). Underride occurs when the primary area is too low to interface with the barrier effectively (e.g., below the bottom hump of the w-beam shape). For a vehicle moving from left to right across this diagram (Figure 4), it can be seen that a w-beam guardrail median barrier placed at the leftmost position shown would have a partial, but probably sufficient interface to engage the errant vehicle. For the median barrier shown in the middle (note that only one of these three positions would be selected for the placement of the barrier), the interface regions of the vehicle would pass fully over the barrier causing an override condition. Similarly, for the right most median barrier, the interface trace passes under the barrier suggesting the potential for an underride (something more likely to occur if this were a cable barrier). An effective placement location for a median barrier requires that there would be a positive interface for impacts from either direction.

Figure 3: Height of vehicle’s primary structural region varies as it crosses the median

Figure 4: Vehicle-barrier interface at different barrier positions in the median

Figures 3 and 4 indicate the interface potentials for a single vehicle type, speed, and impact angle for the narrow v-shaped median configuration with 6:1 side slopes. Ideally the placement of a given cable median barrier will be such that it can function effectively across a much broader range of vehicles and impact conditions.

It is important to note that many of the interface traces in this paper have been “normalized.” Normalization translates the relative position of the trace point across the median to a horizontal plane. Thus, the height above the ground surface in the actual trace is equivalent to a horizontal plane in the normalized plot. Figure 5 shows both an actual and a normalized trace path for a vehicle moving from
the left to right. The blue band represents the actual trajectory while the red band reflects the normalized view. These normalized views are important for the comparison of the vehicle dynamics effects across varying types of medians.

![Figure 5: Actual trace plot compared to the normalized plot](image)

In the process of searching for the ideal placement location the potential interface regions were plotted for bi-directional impacts. For a symmetric median cross-section, this was easily accomplished by plotting the mirror image of the interface trace from one of the directions on the same graph as shown in Figure 6. The areas where the red and blue interface plots overlap represent those areas where the barrier would work equally well for impacts from either direction. Again, this is for a specific vehicle type, set of impact conditions, and median configurations.

![Figure 6: Normalized, bi-directional interface plots for a typical v-shaped median](image)

- Impacts at 25 degrees and 100 km/h
- Isobars showing cable heights (i.e., yellow lines) showing the relative positions of the three cables in a generic low-tension system

Plotting an isobar of the relative heights of the cables for a three-cable design as horizontal lines across the graph depicts the places where effective interface will occur. The isobar represents the height of the
cable for a placement anywhere across the median profile. In this case, it can be noted that the isobars show that the three-cable design could be effective in each of the overlap locations. The information provided in the figure alone is not sufficient, however, to determine the most effective cable barrier (or any other type of barrier for that matter) lateral position if a broader set of cross median events is to be considered.

**Interface Envelopes**

The VDA involved many runs of the HVE software to characterize the position (or trace) of points on the front of the vehicle for a range of possible paths in traversing the median. For comparative analysis, interface envelopes were developed to represent the aggregated range of trace points that would be created for combinations of vehicle types and impact conditions.

![Normalized Vehicle Interface Envelopes](image)

**Figure 7: Normalized Vehicle Interface Envelopes**
- Honda Civic – Crown Victoria, and C2500 Pickup
- 6:1 Slope - V-Shaped Median – 32 ft Median (without shoulder)
- 50, 70, and 100 km/hr – 5,10,15,20, and 25 deg Angles – Near and Far Side

Figure 7 shows the bi-directional trace envelopes individually for the three vehicle types analyzed for 32-foot wide v-shaped medians across all speed and impact angle combinations considered. The plots
show that, as expected, the trace envelopes increase with the mass of the vehicle. The combined plot in the bottom frame reflects the cumulative trace envelope for all vehicles. To maximize safety, any barrier system must be capable of covering the breadth of this plot at the position where the barrier is placed. It is interesting to note that there is a symmetry in the plot and clearly positions where the barrier would have to cover a broader range (e.g., at plus or minus 4 feet from the center). There are also locations (e.g., the center) where the breadth is minimal. This could suggest that for this median configuration the center is a viable placement location for the barrier despite the usual concerns about drainage and soils conditions at the center.

SELECTED RESULTS

Since the research objective was to develop the basis for improved guidelines for the design and placement of cable median barriers, many plots were generated to cover a variety of median types, impact conditions, and vehicles. Selected results are presented here to provide a sample of the insights gained. Results are presented for v-shaped, flat bottomed, and non-symmetrical median configurations as well as some comparisons between them.

V-Shaped Medians

The effect of width for v-shaped medians is depicted in Figure 8. It can be noted that for increasing width the characteristic “bounce” effect is noted by the symmetrical low spot in each graph. From a vehicle dynamics standpoint, the vehicle is launched at the point it reaches the median. It will travel to some degree either partially or fully airborne while the suspension system drops to meet the surface. At some point, the vehicle lands and the suspension system absorbs the energy of this landing by compressing. The lowest points represent the end of the compression stage and in some cases there may even be dragging of the vehicle bottom on the surface of the median. The last aspect is the rebound as the suspension releases the energy. Since this happens gradually over the crossing, smooth trace curves result. The figure shows that the width of the median influences the positions of the various points relative to the center as well as the amplitude of the response.

Figure 8: Relative effect of suspension response for a specific vehicle, set of impact conditions, and v-shaped cross-section of varying widths (actual trace plots)
The simple v-shaped median provides a basis for comparison of the speed factors influencing dynamic response for vehicles crossing the median. The influence of vehicle speed (assumed to be the speed at the time the vehicle reaches the median) is shown in Figure 9. These normalized plots show the relative differences of speed on dynamic response for a large, mid-sized, and small vehicle leaving the shoulder on a v-shaped, 16-foot wide median with 6:1 side slopes at a 25 degree angle for speeds of 50, 70, and 100 km/h. It can be readily noted that the width of the trace band is greater for the large vehicles because of their weight, frontal characteristics, and wheelbases. The weight probably contributes more to the differences in the location of the low point of the vehicle for any angle. A similar pattern of effect is evident for the smaller vehicles albeit with correspondingly narrower bands reflecting differences in weight and front characteristics.
Figure 10 provides the comparison of angle effects for 5, 15, and 25 degree departures from the shoulder at 100 km/h. The figure shows the normalized trace plots for a large, mid-sized, and small vehicle leaving the shoulder on a v-shaped, 16-foot wide median with 6:1 side slopes at various angles. The red band indicates the trace for a 25 degree angle of departure. It can be seen that the duration of being airborne, the distance before bottoming out, and the rebound heights are the most extreme for the sharper impact angles, as might be expected. This is true for all vehicle types with the larger vehicles inducing the greatest dynamic response. Similar response patterns were observed for other speeds (but they are not shown here).
The normalized interface envelopes that result from aggregating all the trace plots create interface envelopes that allow comparison of various median configuration factors. Figure 11 depicts the interface envelopes for the mid-sized sedan across five different median widths. It can be noted that the response as indicated by the breadth of the interface envelope is the greatest for the narrowest medians. It can be noted these interface envelopes have a characteristic set of bulges around the center of the median. This results from the full compression aspect of the suspension response considering both crossing from both directions. The breadth of the interface area tapers off towards the shoulder with increasing width. The center position again is a point where the interface region is minimal.
Flat Bottom Medians

The research has also studied flat-bottomed medians, which are widely used. Figure 12 provides vehicle interface envelopes for flat-bottomed medians with 6:1 side slopes and widths of 29 and 36 feet. It can be noted that the dynamic response effect as reflected in the trace envelopes is better distributed over the wider median. There is less vertical variation and breadth for the wider median. The overall effect is also clearly more uniform than that for the v-shaped median.

![Normalized vehicle interface envelopes](image)

Figure 12: Normalized vehicle interface envelopes
- Honda Civic, Crown Victoria, and C2500 Pickup
- 6:1 Slope, 10-foot Flat Bottom Median
- 50, 70, and 100 km/hr – 5, 10, 15, 20, and 25 deg Angles – Near and Far Side

Figure 13 provides a similar set of plots, but these depict the interface envelopes corresponding to a 4:1 side slope. The sharper slope leads to more pronounced and variable effects than for the 6:1 slope condition noted in the previous graph. This indicates that the same barrier design would not work equally well for these two median configurations.
Figure 13: Normalized vehicle interface envelopes
- Honda Civic, Crown Victoria, and C2500 Pickup
- 4:1 Slope – 10-foot Flat Bottom Median
- 50, 70, and 100 km/hr – 5, 10, 15, 20, and 25 deg Angles – Near and Far Side

Non-symmetrical Medians

Figure 14 shows normalized trace plots for a mid-sized sedan traversing a non-symmetrical median from either side. On one side of the median the slope is 4:1 and on the other it is 6:1. It is important to note here that the assumption in this study is that the barrier would always be placed on the 6:1 sloped section. It is quickly obvious from just the plots of a single type of vehicle and set of impact conditions that effective lateral placement becomes more of a challenge for such cases. The VDA approach is, however, still applicable for determining the effective locations.

The blue interface envelope in Figure 14 reflects the case when the vehicle moves from left to right first coming down the 4:1 slope. As might be expected, there is a more intense loading or compression of the suspension due to the steepness of the slope. The maximum compression is reached when the 6:1 slope side is reached. This is followed by an intense rebound effect before a gradual dampening. The red interface envelope shows the case when the vehicle is approaching the barrier from the opposite direction (right to left). The response pattern is different. The plots indicate that there are positions that
a barrier could be placed to engage the vehicle with two or more cables, but the cable that would be involved might be different for each direction.

The above findings provide insights into the vehicle dynamics effects and hence interface effectiveness for cable barriers that are dependent on the median configuration and specific design features of the cable barrier system and its lateral placement. The data shown here represents only a few examples of the many that have been generated in the current research. More cases still await analysis, but the bigger challenge may be translating these across the various median configurations into guidelines for effective placement.

**Comparative Analyses**

A second step towards developing guidelines for effective deployment of cable median barriers involves comparing the varying median factors to identify the optimal placement conditions. The analyses results allowed the comparison of the vehicle dynamics responses for medians of differing configurations or features. These provide insights on what may be a preferred configuration in design or consideration in the selection of a specific median barrier design once all median configurations are considered. Comparisons across varying types of medians are presented to understand the influences on effectiveness. In each case, the interface envelope considering impacts of a Honda Civic, Ford Crown Victoria, and a Chevy C2500 pick-up for impacts at 5, 15, and 25 degrees at 100 km/h is presented.

One example of an early comparison that was done under the research focused on the question of preferred shape (i.e., v-shape, rounded bottom, flat-bottomed). Figure 15 compares the trace plots for a mid-size vehicle (e.g., Ford Crown Victoria) and impact conditions of 100 km/h and 25 degrees for a 40-foot wide median. It can be noted that the bounce pattern varies by the cross-section. The bounce is less intense for a flat bottom median. The rounded median has less effect than the v-shape, but more than the flat bottomed. The gradual transition of loading on the vehicle suspension might have been thought to make the rounded bottom the preferred shape.
In Figure 16, a comparison between v-shape and flat-bottom medians with a 32-foot width and 6:1 side slopes is presented. The green interface envelope with two distinct lower nodes is associated with the v-shaped median. The interface envelope in blue depicts the condition for a flat bottom median (as noted in the lower portion of the graph). The lower nodes which create the potential for underrides are absent from this interface envelope. The blue envelope is slightly lower overall, but otherwise similar. This would suggest that a flat bottom median is a better design that allows a greater range of possible positions for the lateral positioning of the cable median barrier.

Figure 17 compares v-shaped medians 32 feet wide with 6:1 and 8:1 side slopes. The green trace envelope is associated with a 6:1 side slope condition. The superimposed red envelope shows a more uniform band across the median that has shallower lower nodes because there are less intense impulses on the vehicle’s suspension as it traverses the median. These results would suggest that keeping the side
slopes flatter increases the lateral positions that the cable barrier can be placed and makes it easier to find a barrier that will offer the capability to capture the range of vehicles reflected by the interface envelope.

Figure 17: Comparison of interface envelopes for v-shaped medians with 6:1 and 8:1 slopes
- Honda Civic, Crown Victoria, and C2500 Pickup
- 5, 15, and 25 deg Angle - 100 km/hr 6:1 and 8:1 Slope
- 32 ft Median (without shoulder)

Figure 18 similarly shows slope effects comparing 6:1 and 8:1 side slopes for the 32-foot wide, flat bottomed median. This result suggests that variations in the median side slope along the length of the median may have minimal effects on the interface envelope for errant vehicles.

Figure 18: Comparison of normalized interface envelopes for flat-bottomed medians with 6:1 and 8:1 side slopes
- Honda Civic, Crown Victoria, and C2500 Pickup
- 5, 15, and 25 deg Angle - 100 km/hr
- 6:1 and 8:1 Slope – 32 ft Median (without shoulder)
- 10-foot wide flat bottom section
TRANSLATING FINDINGS INTO GUIDELINES

The objective of this research was to translate the insights gained into guidelines for effective lateral placement of cable median barriers of varying designs. This analysis is nearing completion, but several examples are provided here.

Figure 19 depicts the summary of interface envelopes for various widths of v-shaped medians. Assuming that lateral positions where the dynamic response is most variable should be avoided, then placement in the areas adjacent to the lower nodes (bulges) would be avoided. Guidelines that would suggest avoiding placement in this area or limit the types of cable designs that could be used plus or minus 1 to 8 feet from the center would apply to all widths of v-shaped medians. These limits are depicted by the heavy red bars.

Figure 19: Possible limits on the lateral placement of cable median barriers to avoid the regions were dynamic response is most intense
Another approach involves determining the bidirectional traces of the upper and lower frontal points (i.e., primary structural region) for all vehicles and impact conditions using VDA simulations. Figure 20 shows all the trace paths of the upper point or the primary region for both directions of a vehicle crossing a v-shaped median plotted in a normalized fashion with each individual trace representing a specific vehicle, speed, impact angle, and crossing direction. The multi-colored array of lines represents all impact cases (for the parameters set). The heavy blue line then represents the maximum heights for the upper point for all cases. Similarly, the minimum heights for the lower frontal point could be plotted.

![Figure 20: Individual normalized trace plots to define Minimum Upper Cable Height limits to determine effective lateral placement of cable median barriers](image)

Figure 21 shows an example of the resulting Minimum Upper Cable Height (heavy blue line) and Maximum Lower Cable Height (heavy green line) curves that result for a specific flat-bottom median configuration. The upper portion of this graph 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. The Barrier Interface Envelope is the gray shaded area 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 design, 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. Normalization is useful for comparing various types and features of medians and cable barriers.

The lower portion shows the profile or cross-section of the median related to the upper graph. The gray shaded 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 blue shaded areas define the lateral positions where the specific barrier has a cable arrangement that puts a lower cable below the maximum lower cable height curve (green) and/or an upper cable above the minimum upper cable height curve (blue).

Effective lateral placement occurs when 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 36’ wide median (measured from edge of shoulder to edge of shoulder) with 4:1 side slopes, there are areas in either side of the slope break point (near the shoulder) where placement of the median is not recommended because of a risk of underriding.

Figure 21: Using maximum and minimum cable heights to define effective barrier placement

Figure 22: Comparison of effective lateral placement regions for cable median barriers for flat-bottomed medians of varying widths
Figure 22 compares the effective regions for flat-bottomed medians of varying widths. It can be noted that there are some recurrent patterns, but variations in these associated with the width for depth-constrained, flat bottom medians. Efforts are underway to compile the minimum and maximum cable height curves for all common median configurations into a single graph. Preliminary results suggest that these can be used to set design requirements for cable median barriers that are independent of specific median configuration factors. The results also suggest that it may be useful to segregate median regions (e.g., near the center) to optimize the establishment of design requirements.

The final format of the guidelines that are expected from this research has not yet been determined, but a considerable amount of information will be available to support them.

SUMMARY AND CONCLUSIONS

Problems noted by a state agency with occasional underiding of otherwise effective cable median barrier systems prompted the need for explanations and the analysis of options to mitigate the situation. The NCAC undertook crash analysis and finite element modeling and crash simulation in search of answers. These efforts led to the discovery that cable barrier design, placement, and median configuration were highly correlated to safety performance. It was recognized that the simpler VDA approach had the potential to analyze these effects. The VDA approach was used to generate scores of plots that allowed the development of insights about the effects of the various factors. The VDA analysis allowed consideration of a broader range of vehicle and impact conditions to enhance the overall effectiveness of cable median barrier deployment. The results clearly indicated that for each combination of median configuration, impact conditions, and vehicle type, the vehicle dynamics yielded an interface envelope that could be used to determine the optimal locations for a given type (i.e., design) for a cable median barrier. The bigger challenge is generalizing the effects of these factors to establish guidelines for barrier placement. The insights resulting from these efforts are being used to develop improved guidance for the design and placement of cable median barrier systems. The findings are also useful in the deployment of other kinds of barriers.

Further research is needed to develop a comprehensive set of design, placement, and maintenance guidelines for cable barriers. Research is underway or needed to address a variety of topics, including:

- What is the appropriate placement of cable median barriers relative to longitudinal features?
- How should cable median barriers be transitioned were the median cross-section changes?
- What are the trade-offs related to placement and the likely frequency of hits and hence repair needs?
- How is deflection influenced by post spacing and embedment?
- What is the appropriate type and spacing of anchorage systems?
- How do the features of the wire rope influence the effectiveness of cable barriers?
- What is the most effective means to transition cable median barriers systems to other types of barriers?
- How do maintenance practices affect performance?
- How will changing features of the vehicle fleet influence the design requirements for cable barrier systems?
- What are the opportunities for new deployments on rural, two-lane roads to address their safety problems?
The FHWA and others are working to find answers to these questions. The results will serve to improve the evolving guidelines for cable median barrier systems.

REFERENCES


