Applying Vehicle Dynamics Tools to Determine Optimal Median Barrier Placement

Background

A variety of vehicle dynamics analysis tools are commercially available to provide robust descriptions of the response of vehicles to changes in surface features. These software tools embody the design features and response characteristics for vehicle suspension and steering systems, representing a wide array of current and late model vehicles. Recently, the National Crash Analysis Center (NCAC) conducted a vehicle dynamics analysis (VDA) for the Federal Highway Administration (FHWA) to assist a state highway agency in evaluating proposed new median barrier design standards. The agency wanted to effectively position w-beam median guardrails in two new median profiles developed to increase the drainage capacity. This effort applied VDA to determine the effect of the new median profiles (i.e., cross-sections) on the trajectory of vehicles crossing the median and hence the likely interface of vehicles and median barriers considering possible impacts from either side. Background studies indicated that there had been very limited consideration in the past of vehicle dynamics in the development of highway design standards.

Approach

The design challenge underlying the positioning of a median barrier, such as w-beam guardrails, is to determine the best possible placement that will allow effective, bi-directional interfaces for typical barrier installations. An errant vehicle crossing a highway median does not maintain a constant height above the ground due to the effects of speed, weight, slope, and angle of departure on its suspension system. For example, at high speeds the front wheel of the vehicle may actually become airborne as it crosses from the shoulder to the slope. After being airborne, there will be greater dynamic forces on the suspension upon touch down, which will compress the suspension. The greater the drop, the higher the compression. For a barrier to effectively contain and/or redirect an impacting vehicle, the barrier’s effective interface region must engage the primary structural elements at the front of the vehicle. In Figure 1, the primary structural region of the nose of a large sedan and the effective interface region of a guardrail median barrier are highlighted. As shown, those two regions would clearly be engaged during an impact, indicating a successful vehicle-barrier interface. However, this vehicle-barrier interface is on level ground. For depressed medians, the vehicle could be higher or lower, relative to the barrier, at the instant it makes contact with the barrier.

In Figure 2, a large sedan has entered the median at 100 km/hr (62 mph) and a 25 degree angle with respect to the median centerline moving from left to right. When the vehicle first leaves the road and begins to cross the downward sloping median surface, the vehicle (particularly the leading wheel) is likely to become airborne for a short distance. The suspension drops the wheel as gravity pulls it downward. When the vehicle lands, its suspension will be compressed to a degree determined by the speed and change in surface elevation. (In Figure 2 the vehicle has just reached
the far-side slope of the median when it lands, so
its left front suspension is fully compressed.) In
combination with the upward inclination of the far-
side slope of the median, the rebound of the
suspension system will push the vehicle upwards
again as it continues across the median, possibly
even projecting the vehicle back into the air.

In the upper panel of Figure 2, the dark blue
lines represent the paths of the top and bottom
edges of the primary structural region of the front of
the car as it is influenced by the dynamic effects.
The green lines in the plot at the bottom of Figure 2
show the height of the vehicle’s primary structural
region as it crosses the median as it would be seen
by an observer standing in the center of the median
downstream from the crossing. This band formed
by the green lines defines the interface envelope
for this median crossing situation. For any barrier
to be effective, it must be placed to allow the barrier
face to meet this envelope.

In Figure 3, three possible placements of the
median barrier are shown. The left-most barrier
placement is at the shoulder edge of the roadway,
and indicates a good overlap of the vehicle
interface envelope and the barrier. However, for
the placement of the barrier near the middle of the
v-shaped median, the vehicle’s interface envelope
is entirely above the barrier’s face (or effective
interface area). Vehicle vaulting of the barrier is
likely. For the third placement option, the right-
hand barrier placement, it can be easily seen that
the vehicle’s primary structural region is below the
barrier’s effective interface region, indicating a high
potential for the vehicle to underride the barrier.
With a semi-rigid system, this may lead to snagging
on a guardrail post.

Further complicating the issue, different
vehicles have different suspension characteristics,
and medians have varying widths, side slopes, and
shapes. Clearly, a median barrier cannot be placed
just anywhere in the median cross section. For a
particular median design, the ideal placement of a
median barrier will allow it to function effectively
during hits from either side by different types of
vehicles at varying speeds and angles of impact.

Vehicle Dynamics Analyses

The NCAC has refined the application of
vehicle dynamics analysis (VDA) to address these
median and barrier design questions. The NCAC
uses a commercially available VDA software
package, which inputs a vehicle’s size, weight,
inertial properties, suspension characteristics, and
initial speed and angle of approach and calculates
the vehicle’s trajectory as it crosses terrain defined
by the user. (Figure 2 is a snapshot from the output
of one run of that VDA software package.) The end
result is that the NCAC can calculate the position of
the primary structural region of the vehicle at any
moment during the vehicle’s passage across a
median. Wherever a given barrier is placed, VDA
lets the analyst see how well the vehicle’s primary
structural region would engage the barrier’s
effective interface region at the instant of impact.

There are limitations to this analysis that must
be recognized. This application of vehicle dynamics
analysis is strictly an interface analysis—it
considers only whether the vehicle and the barrier
are well aligned at the instant of impact. Thus,
separate consideration of the strength of the barrier
is needed to ensure effectiveness in capturing or
redirecting an errant vehicle. Further, there are the
real world factors not considered in this analysis—
such as the softness of the soil, the wear on the
vehicle’s suspension system, the loading of the
vehicle, and the installed and maintained
tolerances of the barrier itself—which will influence
the barrier's performance. Finally, for impact angles greater than 25 degrees, the underside of vehicles will scrape on the surface while crossing a depressed median. This effect is not easily modeled, so in this VDA it was not addressed.

Two proposed new median profiles were considered for 24 foot wide medians. Profile 1 altered the basic 6:1 side slope for a v-shaped median to accommodate a deeper middle section for the middle ten feet of median (see Figure 4). A 4:1 v-shaped cross section provided the additional hydraulic capacity. The standards proposed placing the median barrier at the slope break points. Profile 2 was similar, but it utilized a 15 foot wide, flat bottom cross section. The barrier was placed about 7 feet from the shoulder (Figure 5).

Findings
For this analysis, the NCAC staff conducted a total of 27 runs of the VDA software for each of the median profiles and placement designs considered. These analyses covered the following range of vehicles, speeds, and approach angles.

- Vehicles:
  - Chevrolet C2500 pickup truck (2000kg)
  - Ford Crown Victoria sedan (1500kg)
  - Honda Civic (820kg)
- Speeds: 50, 70, and 100 km/hr
- Angles: 5, 15, and 25 degrees

For each of the above cases the mid-line of the trace profiles was plotted as a separate color trajectory line. These trajectories represent the mid-line position of the vehicle’s primary structural region during the crossing.

In Figure 4, the proposed Profile 1 standard median design is considered. The barrier in this design is offset 5 feet from the median centerline. (Two barriers are shown so that near-side and far-side vehicle barrier interfaces can be seen on a single plot. Only one median barrier would actually be installed.) The trace lines only depict the vehicle crossing the median from left to right. (Note that for a symmetrical median the trace plots going from right to left would be the mirror image.) The barrier’s effective interface region is indicated by the dotted black lines. For near-side impacts, the vehicle’s primary structural region overlaps the barrier’s effective interface region, implying that the barrier will work as intended. For the far side hits, most vehicle trajectories are near their low points when they intersect the barrier face. It is clear that the “rub rail” mounted below the primary w-beam on this barrier design is needed to effectively capture all the vehicles.

More specifically, the following can be observed from the trace plot for Profile 1 with barriers placed at the slope break points for each vehicle type.

- Pick-up truck
  - Near-side – good interface with the barrier, safe redirections
  - Far-side – high potential for low hits, inward facing rub rails needed to prevent underride or snagging

- Mid-sized car
  - Near-side – good interface, but some hits are at or near the underride limit (the lower of the dashed lines)
  - Far-side – underride likely, rub rail needed

- Small car
  - Near-side – good interface, effective performance likely
  - Far-side – suspension response has vehicle hitting below the main rail of the barrier making rub rail necessary

Figure 5 shows the proposed Profile 2 standard design which includes a different cross-section and barrier positioning. The trace lines show that there is good interface for all vehicles for near-side impacts, but the bounce effect associated with the vehicles hitting the far slope of the median will result in some vehicles being likely to vault in far-side hits. However, these results indicate that this problem could be alleviated by locating the barrier closer to the slope break points.
More specifically, the following can be observed from the trace plot for Profile 2 with barriers placed near the shoulder line for each vehicle type.

- **Pick-up truck**
  - Near-side – good interface
  - Far-side – vaulting likely, rub rail probably unnecessary
- **Mid-sized car**
  - Near-side – good interface
  - Far-side – vaulting likely, rub rail probably unnecessary
- **Small car**
  - Near-side – good interface
  - Far-side – some potential for vaulting at higher speeds, rub rail unnecessary.

**Conclusions**

A vehicle dynamics analysis was conducted and was shown to provide useful information for evaluating the vehicle-to-barrier interfaces for sloped surfaces. Two proposed median profiles were analyzed to demonstrate the varying interface effects with various vehicles under different impact conditions. The analysis assumed a firm median surface to limit soil plowing, which may cause the vehicle to interface at a lower level. The vehicles were only loaded for the equivalent of a single occupant and it is important to note that additional occupants would add weight and influence the results. The analysis also assumed that vehicles would follow a straight path across the median. The analysis did not include angles greater than 25 degrees, as ground scraping effects could not be reliably predicted. The NCAC continues to apply vehicle dynamics analysis and assess the interface effectiveness of various median design configurations, vehicle types, and impact situations.

**Implications for Current Practice**

VDA has not been widely used in determining the lateral position of median barriers. Static analysis ignores the dynamic response of the vehicle’s suspension system. This response has been shown to influence the location of the vehicle’s primary frontal structural region and hence the potential for effective interface with the barrier. An effective interface is defined as there being enough of the vehicle’s structural region in contact with the barrier’s face to capture or redirect the vehicle. With increasing application of barriers on sloped surfaces to address cross median crashes, there needs to be consideration of vehicle dynamics to reflect the influence of the suspension system on the effective of vehicle-to-barrier interface. This is particularly true in the creation of design standards that will be applied repeatedly in future highway design (or redesign efforts). VDA can provide an indication of the potential for underride and override by errant vehicles and it aids in specifying the functional requirements for the barrier. It does not, however, address the barrier strength issue or the need for related treatments (e.g., surface stabilization treatments to limit soil plowing).

**References**


**For More Information**

See the NCAC Website ([www.ncac.gwu.edu](http://www.ncac.gwu.edu)) for more information, or contact:

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