Safety Performance Evaluation of Plate Transitions from Fixed Concrete Barriers to Portable Concrete Barriers Using Simulation

Background
Longitudinal barriers are systems that consist of three basic elements: end treatments, length of need sections, and transitions. Each element needs to be designed and evaluated to assure that safety requirements are met. This applies to transitions for portable concrete barriers (PCB). The specific design features of PCBs and their associated size and mass complicate the design for transition, however.

This research arose from concerns about the effectiveness of transitions from permanent concrete barriers to PCBs. Since permanent concrete barriers are fixed in place, there are limited options for transition design. This effort evaluated various plate and w-beam transition designs developed by state DOTs. Plate transitions are used to span the gap between permanent concrete median barriers and temporary portable concrete barriers with a single steel plate. The w-beam transition designs use various configurations of standard w-beam sections for the same purpose. The objective is to redirect an errant vehicle such that it does not contact the exposed end of the portable barrier. Various plate and w-beam transition designs exist, but most have not been tested.

Finite element (FE) models of the barriers and the transition element were created and the effectiveness evaluated by simulating the NCHRP 350 crash tests. The results are described in this document. This work was undertaken by the National Crash Analysis Center (NCAC) at the George Washington University (GWU) under a cooperative agreement with the Federal Highway Administration (FHWA).

Objectives
This research was undertaken to examine the safety performance of various transition designs for PCBs ranging from steel plates to w-beams. The intent was to understand how these devices performed without the cost of crash testing and to consider redesign options that would enhance their safety performance.

Approach
This study used computer simulation to investigate the crashworthiness of transition devices according to the NCHRP Report 350 guidelines [1]. Three main safety criteria were examined:
- occupant ride-down acceleration and impact velocity,
- vehicle trajectory and stability, and
- occupant compartment integrity.

Computer simulations were performed for Test Level 3 conditions, using a 2,000 kilogram vehicle impacting at an initial speed of 100 km/hr at a 25 degree angle.

The intent was to determine, using FE models and crash simulation, how these designs performed and whether they would pass the crashworthiness criteria for transitions recommended in NCHRP Report 350. The FE models allowed the analysis of the various features of each transition design, provided measures of performance, and generated detailed animations of crashes involving the transition situations. The simulations were undertaken using LS-DYNA software [2].

Transition Designs
The study focused on situations where a permanent concrete barrier needs to be transitioned to a portable concrete barrier, such as when an inner lane is to be closed using PCBs. The study evaluated the safety performance of alternative transition designs, including:
- a short plate design,
- a long plate design, and
- w-beam designs.
Variations or modifications to these designs were also analyzed after review of the initial simulation results.

**Short Plate Design**
The short plate transition design, as shown in Figure 1, consists of two main components:
- A 13 mm thick steel transition plate approximately 1830 mm x 760 mm.
- A special wedge-shaped PCB section to be placed at the beginning of the length of PCBs.

The tapered concrete section is placed in front the permanent median concrete barrier and attached to the temporary barrier using a normal pin and loop connection. The steel plate connected using the six anchor bolts closes the gap between the median barrier and the tapered concrete section as shown.

**Long Plate Design**
A long plate transition design, as shown in Figure 2, was evaluated. In this design, the tapered concrete section was eliminated and the temporary concrete barrier was moved closer to the permanent barrier to reduce the exposed barrier end. The steel plate was extended and connected to the temporary barrier using three anchor bolts at each end.

Variations to the designs included providing blockouts behind the long plate, removing part of the first portable segment to allow it to be moved closer to the fixed barrier, and bringing the PCB sections closer together beyond the transition to reduce the potentials for deflection. The modifications are shown in Figure 3.
W-Beam Designs
The third transition design for closing the gap between the two concrete barriers involved using standard w-beams. This was considered a simpler design as it used commonly available hardware and no special plate, concrete elements, or fixtures were required. The design is similar to the long plate design except that the steel plate is replaced with w-beams. Eight variations were considered, including:
- single length of w-beam
- single length of nested w-beam
- double length of w-beam
- double length of nested w-beam
- paired single lengths of w-beam
- paired single lengths of nested w-beam
- paired double lengths of w-beam
- paired double lengths of nested w-beam

Each of these configurations used standard lengths of w-beam guardrail with end shoes. These design variations are shown in Figure 4.

Crash Simulation Analyses
Finite element models of the fixed and portable barriers and each transition design were created for the crash simulation analyses.

A New Jersey (NJ) barrier shape was assumed for both the permanent and portable barrier sections. The FE model for the NJ barrier reflects material properties for standard concrete and steel reinforcement based upon accepted design standards. The concrete was represented in the model as an elastic material with a modulus of 20,000 MPa. The anchor bolts and the pin and loop connections were also incorporated in the model. The FE models for the fixed and portable sections were drawn from the NCAC FE model array. These models have been used in prior studies [3, 4].

The crash simulation analysis involved combining the FE model of the plate transition with an FE vehicle model. An FE model of the Chevy C2500 pickup truck developed by the NCAC was used in the analysis [5]. It represents the large (2000 kg) vehicle required for NCHRP 350 tests. It has been successfully used in many other crash simulation efforts.

Computer simulations were performed in accordance with NCHRP Report 350 Test Level 3 conditions for an impact speed of 100 km/hr (62 mph) at a 25 degree angle. The crash simulations were set to generate the basic set of NCHRP 350 evaluation metrics. Crash simulations covering one second of time for each case averaged about 50 hours of computer run time.

Short Plate Design
In order to analyze this plate transition design, a detailed finite element model of the plate and the special section of the temporary concrete barriers was created. The FE model included the components shown in Figure 1, including:
- permanent concrete barrier (shown in gray)
- wedge-shaped concrete section (shown in red)
- steel transition plate made of A36 steel (shown in green)
- portable concrete barrier section (shown in light gray or white)
- six mechanical expansion connectors (anchor bolts)
The resulting FE model for the short plate transition design comprised 63 parts and 26,000 elements. The simulation set-up is shown in Figure 5.

To determine the critical impact point of this design, eight simulations were conducted for different initial contact locations including:
- 1 m before the steel plate (a)
- Right at the edge of the plate (b)
- At the center of the steel plate (c)
- At the end of the steel plate (d)
- 1 m after the steel plate (e)
- At the center of the concrete wedge (f)
- 1 m before the start of the PCB section (g)
- 1 meter after the PCB section (h)

The simulations showed that this transition design meets all NCHRP Report 350 requirements at TL 3 for all eight impact points.

The simulations indicated that the vehicle would be redirected, remain upright, and not override the barrier. The occupant ride-down accelerations and impact velocities were lower than the critical values (Table 1) for all impact points. The simulation also indicated that although there was significant damage to the front of the vehicle, occupant compartment intrusions were small.

<table>
<thead>
<tr>
<th>Impact Location</th>
<th>a</th>
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<tr>
<td>Maximum Occupant Ridedown Acceleration (units)</td>
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<td>Maximum Occupant Velocity (units)</td>
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<td>(vz)</td>
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<td>1.0</td>
<td>0.7</td>
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<tr>
<td>Maximum Roll Angle @ 1 second (degrees)</td>
<td>7.5</td>
<td>9.0</td>
<td>10.1</td>
<td>11.0</td>
<td>9.8</td>
<td>11.3</td>
<td>8.8</td>
<td>9.0</td>
</tr>
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</table>

Long Plate Design

The study involved additional analysis to determine if the short plate design could be simplified by removing the wedge-shaped portable concrete section. A similar computer model was created without the wedge-shaped portable concrete section, but with a longer steel transition plate to close the gap between the permanent concrete barrier and the PCB. The length of the steel plate was extended from 1830 mm to 6100 mm. This was considered a simpler design that eliminated the special wedge-shaped concrete piece. This FE barrier model (Figure 6) comprised 59 parts and 10,000 nodes and elements.

The simulation showed that removing the wedge-shaped concrete section degraded the safety performance from that provided by the short plate design. The results show that for impacts at the center of the plate:
- There is a larger deformation of the steel plate.
- The vehicle is much less stable than in the original design due to the deformation of the plate.
- There is a much higher potential for rolling over.
- Considerable tilting of the PCB occurs.

The roll angle data from the simulations suggest that the long plate design would not meet Report 350 requirements for a mid-plate impact. At the midpoint (d), the roll angle was 79.8 degrees due to bending of the plate. This degree of roll exceeds the 70 degree limit considered acceptable under NCHRP Report 350. The data is provided in Table 2.
TABLE 2 – Simulated Roll Angles for Long Plate Design

<table>
<thead>
<tr>
<th>Impact Location</th>
<th>a</th>
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<th>c</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Maximum Roll Angle @ 1 second (degrees)</td>
<td>10.3</td>
<td>12.8</td>
<td>17.2</td>
<td>79.8</td>
<td>35.2</td>
<td>27.5</td>
<td>34.2</td>
<td>15.7</td>
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</table>

Revised versions of the long plate transition design were conceptualized. Revision 1 attempted to reduce the bending near the center of the plate by providing wood blockouts attached to the face of the permanent barrier to fill the gap with the plate. These blockouts were bolted directly to the permanent barrier. The overhead view in Figure 3 better shows the use of the blockouts in Revision 1. Another variation (labeled as Revision 2) used a field modification of a PCB section to shorten the length of the transition plate. The modification involved chiseling away some of the toe area using a jack hammer to allow it to sit closer to the permanent barrier. It allows the length of the plate to be reduced to limit the potential for bending.

W-Beam Designs

The final aspect of this research involved analyzing the safety performance of alternative transition designs where the gap between the two concrete barriers was closed using standard w-beams. These designs are similar to the long plate design except that the steel plate is replaced with w-beams in varying configurations, as shown in Figure 8. Models of different w-beam configurations were created and used in the analysis. The typical FE model for the w-beam transition design comprised 179 parts and 26,000 elements.

Simulations were conducted at the eight different impact locations along the barrier cited previously. Each simulation of one-half second of crash event time required about 62 hours of computer time. The longer computer runs times resulted from the increased complexity of the contacts between parts.

All simulations, with varied w-beam configurations and test levels, showed similar behavior. In all cases, the w-beams failed to redirect the vehicle. Upon impact, pocketing of the w-beam developed, causing the vehicle to snag into the end of the temporary concrete barrier. This snagging led to high vehicle deformation and high occupant ride-down accelerations. Top and bottom views of the snagging at Test Level 3 are shown in Figures 9 and 10.

These designs were also evaluated at different NCHRP Report 350 Test Levels (test level 1 at 50 km/hr, test level 2 at 70 km/hr and test level 3 at 100 km/hr). Snagging was a problem at all test levels. Overall, the simulation showed that these designs did not satisfy the NCHRP Report 350 safety criteria.

The crash simulation for Revision 1 indicated that there would be a high degree of climb up the barrier and a significant amount of roll that might suggest an undesirable level of vehicle instability at a critical point in a work zone. The generated metrics were, however, below the limits, suggesting that this design would be considered acceptable.

The crash simulation for Revision 2 reflected an overall improvement in performance, although a high degree of climb and a significant amount of roll was again observed. The generated metrics were lower than the limiting criteria, suggesting that this design would also be considered acceptable.
Summary & Conclusions
This effort demonstrated that modeling of various transitions for fixed concrete barriers to portable concrete barriers could provide meaningful results. The features of the various designs were reflected in the models and the results for the same impact conditions reasonably reflected differences in safety performance. Based upon these simulation results, the following conclusions were reached:

- The short plate transition design using a wedge shape section worked acceptably for all critical impacts points.
- The long plate designed intended to eliminate the wedge section led to excessive bending of the plate that induced vehicle instability, but the metrics indicated it would pass.
- Revision 1 to the modified design failed to provide adequate resistance to avoid plate bending, but despite similar vehicle instability, it would pass the test criteria.
- Revision 2 performed better than the original and first revised design, and passed all criteria.
- All eight configurations using standard w-beam elements failed due to severe pocketing. This occurred even at the lower test levels.

While this effort provided insights as to the efficacy of various transition designs, and potentials for the application of crash simulations, the scope did not provide resources for crash tests to validate the results and increase confidence in the simulation results.

References

For More Information
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