Structures Research Report
Final Report

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TEMPORARY LOW PROFILE BARRIER : WIDTH REDUCTION

Principal Investigators:	Ralph Ellis Gary Consolazio Kurt Gurley
Post-Doctoral Research Assistant:	Jae Chung
Project Manager:	Sastry Putcha

Department of Civil & Coastal Engineering
College of Engineering
University of Florida
Gainesville, Florida 32611

Engineering and Industrial Experiment Station

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1. Introduction

In a previous study (Consolazio et al. 2003), a low-profile roadside safety barrier was developed using computer simulation techniques. This system, which has a total width of 28 in., was validated using full-scale crash testing. In the present report, the feasibility of reducing the width of this previously developed system is evaluated. Impact finite element simulation techniques have been used to evaluate the performance of reduced-width barrier sections under a variety of different conditions. In all cases, the ability of the barrier to redirect errant vehicles was determined. In addition, the *effective width* of the barrier—defined as the physical width of the barrier plus the maximum sustained lateral deflection—was also computed.

2. Finite Element Analysis Models

2.1 Barrier Widths

Computer simulations were performed for four different barrier widths (Table 1) in order to evaluate the response of reduced width barrier systems. The 11.75 in. eccentricity (Figure 1) between the shear connector and the tension connector of the original low-profile safety barrier (28 inch total-width barrier) was maintained in each of the reduced-width barriers considered. Given the proven performance of the existing connection system—the combination of shear pin; shear slot; and tension connector—it was desirable to maintain a similar type of connection system in the reduced-width barrier systems so as to minimize possible future design and testing costs. Therefore, the minimum width barrier considered (Table 1) was constrained by the 11.75 in. width.

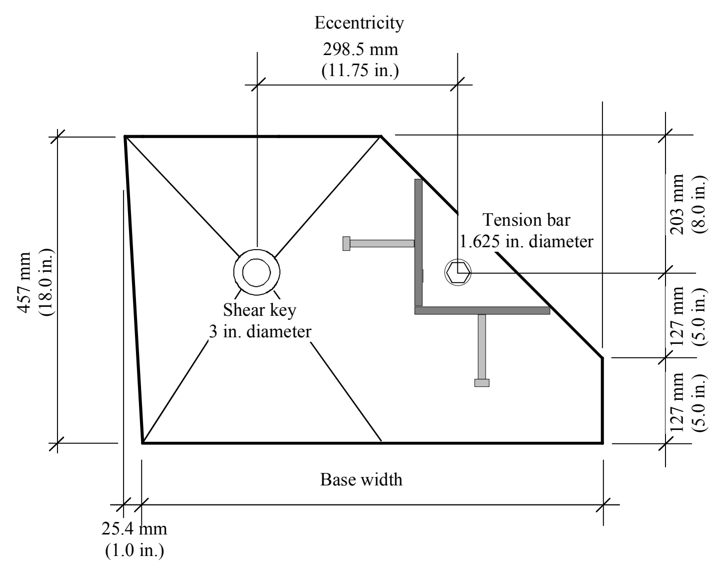


Figure 1. Cross-section of Florida Low-Profile Safety Barrier

Based on the constant 11.75 in. eccentricity, a set of total-width dimensions representing several reduced-width barrier systems were selected and used for generating four different finite element models (B, C, D, and E of Table 1). These representative barrier models have the same height (18 in.) as the original system. The intent was to maintain: 1) structural connectivity between the barrier segments by transmitting the full shear force, 2) lateral displacement compatibility between adjacent segments to prevent snagging effects, and 3) tensile force component of the joint moments from one segment to another with minimal deformation.

Table 1. Barrier widths and eccentricities

Barrier Model	Total Width (in.)	Eccentricity (in.)
A*	28	11.75
B	13	11.75
C	16	11.75
D	19	11.75
E	22	11.75

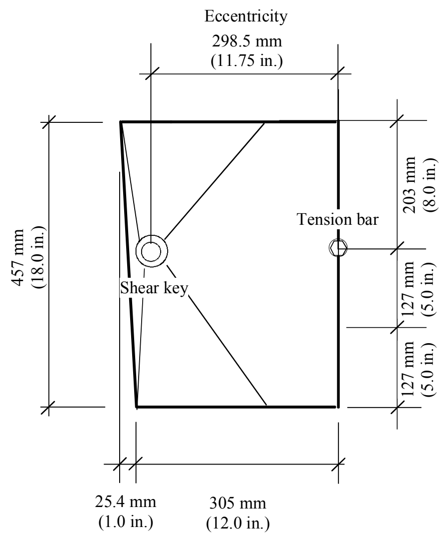
* Previously developed and crash-tested low-profile barrier system (Consolazio et al. 2003)

2.2 Model Description

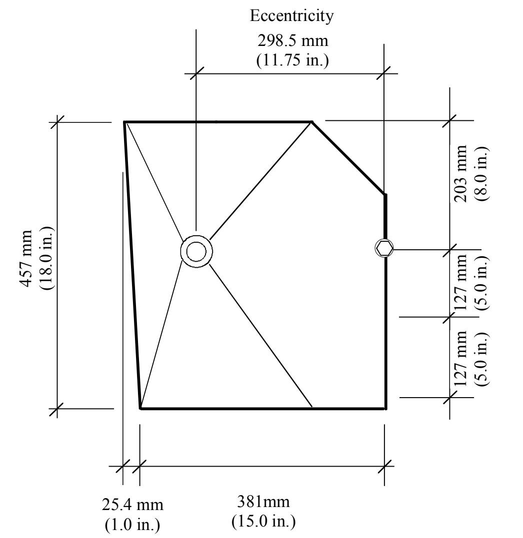
Sketches of the physical dimensions of the new barrier cross-sections analyzed in this study are given in Figure 2. At this preliminary stage in the reduced-width system development process, the physical geometry of the shear pin connector was approximated using appropriate contact definitions and constraints between the pin and slot parts (Figure 3; and Consolazio et al. 2003). The behavior of the vertical channel was modeled with nodal shear constraints allowing segments to move individually in the vertical direction, but in constrained-fashion laterally (i.e. only lateral compatibility between segments was maintained which is consistent with the physical behavior of the pin-and-slot system). Contact definitions were used to model the fact that the shear pin also transmits compression via direct contact with the adjacent segment, but does not transmit tension. In this manner, an opening-and-closing gap mechanism at the joints can be simulated. Previous full-scale crash tests indicated that the original tension bolts remained linear throughout the impact event and flexible enough to prevent undesirable vehicle roll while still providing sufficient tensile load capacity. Thus, the tension-connectors in the reduced width barriers were modeled using linear elastic bars having the mechanical properties of 1.25 in. diameter high-strength threaded rods (Consolazio et al. 2003).

2.3 Friction Modeling

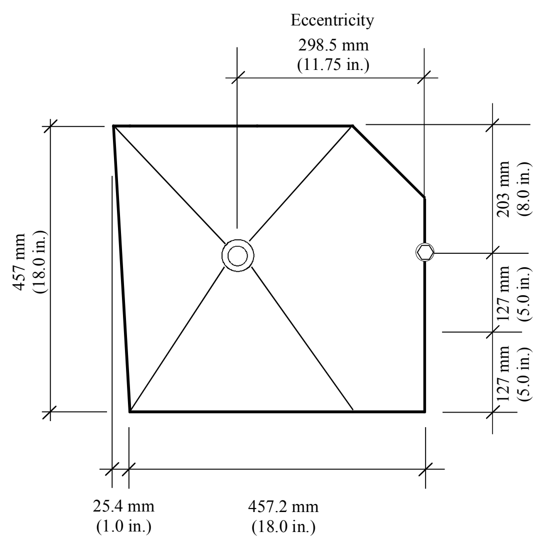
Since the barrier is not mechanically anchored to the roadway, lateral deflection of the segments into a hypothetical work zone located behind the system is determined by mass inertial resistance of the barrier system and frictional resistance between the bottom of the barrier and the roadway. Each reduced-width barrier considered in this study had less mass resistance against lateral movement than the segments of the original 28 in. wide system. The greater the reduction in barrier width considered, the greater the anticipated lateral deflections. The frictional coefficient between the bottom of the barrier and the roadway for each reduced-width barrier model is therefore an important parameter in predicting lateral deflection. After reviewing the results from the full-scale crash testing of the original 28 in. wide system (Consolazio et al. 2003) and studying the corresponding simulation results, it was determined that an appropriate frictional coefficient for preliminary evaluation purposes was f_s = 0.6. This value was thus selected all for finite element simulations described herein.



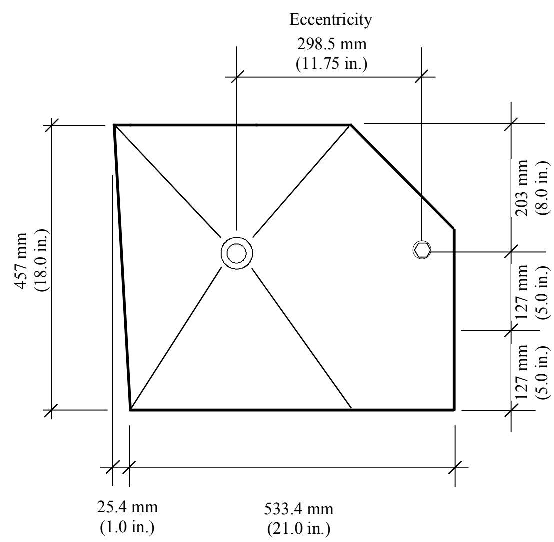
a) 13 in. width



b) 16 in. width



c) 19 in. width



d) 22 in. width

Figure 2. Dimensions of reduced width barrier segments

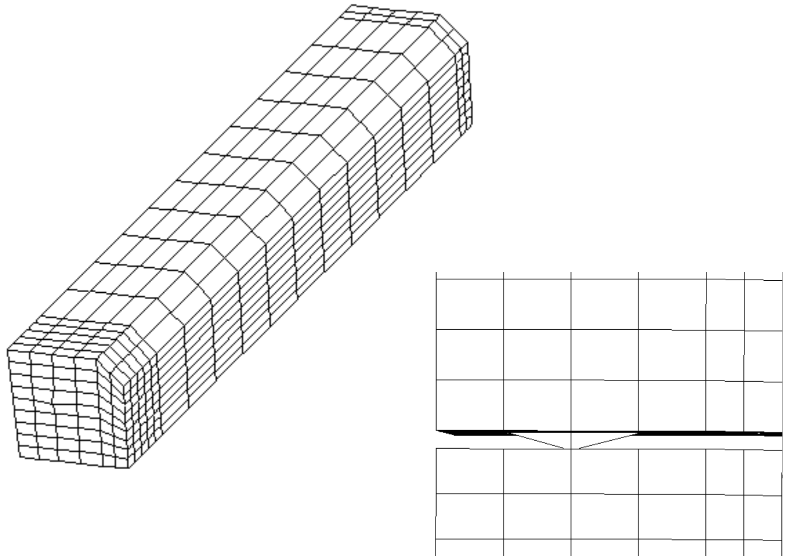


Figure 3. Finite element model of a single 19 in. width
barrier segment and plan view of the shear connection

Overall finite element system models consisting of ten barrier segments, nine shear constraint sets, and nine tension connectors were developed for the purpose of conducting vehicle impact simulations. Individual barrier segments within each system model were meshed using fully integrated 3-D solid elements. Impact conditions that were simulated matched those stipulated by NCHRP 350 for Test Level 2 conditions: a 2000 kg pickup truck impacting the barrier at a 25 degree impact angle and at a speed of 45 mph.

3. Simulation Results

Vehicle impact simulations were conducted for several different scenarios using the LS-DYNA finite element code (Hallquist 1998) in order to determine viable barrier widths. Initially, five simulation cases were conducted to determine the effect of reducing the width of the barrier. In each of these cases, listed as A1 through E1 in Table 2, a material density typical of standard reinforced concrete was used for the barrier segments. Each simulation predicted successful redirection of the impacting vehicle (a 2000kg pickup). However, simulations of the narrowest barriers (cases D1 and E1) indicated that there was potential for loss of interlock between the barrier segments. As Figure 4 indicates, significant vertical displacements of the barrier segments occurred in these cases. Such displacements have the potential to lead to loss of interlock between the shear pin and shear slot. Since the finite element models constructed for this feasibility study used a computationally efficient but approximate model to represent the pin and slot connection, the potential for loss of interlock cannot be further quantified. Additional simulations using refined pin and slot models—similar to those conducted earlier by Consolazio et al. (2003)—would need to be conducted to further evaluate the extent of the potential for interlock loss.

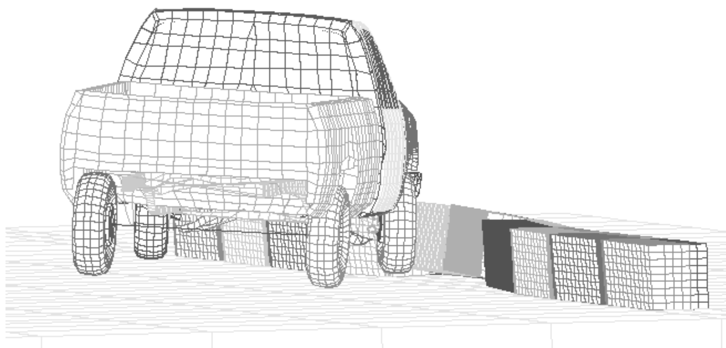
Lateral deflections predicted by each simulation are reported in Table 2. Of particular interest is the column labeled “effective width” which reports the sum of the physical barrier width and the maximum sustained lateral deflection. As the width of the barrier segments are reduced, the maximum sustained lateral deflections increase. This is due partially to the reduced mass of the barrier segments and partially due to the reduced frictional sliding area on the bottom of the narrower segments. In interpreting the data in Table 2, it is important to note that the lateral deflection predicted for case A1 is approximately 2 in. larger than that actually observed in the crash tests that were conducted during the Phase II design process (Consolazio et al. 2003). This is primarily due to approximations made in the friction modeling. As such, it is reasonable to assume that deflections slightly less (by 1 to 2 inches) than those listed in Table 2 would be expected if full-scale crash tests were conducted on these systems.

Table 2. Simulation results

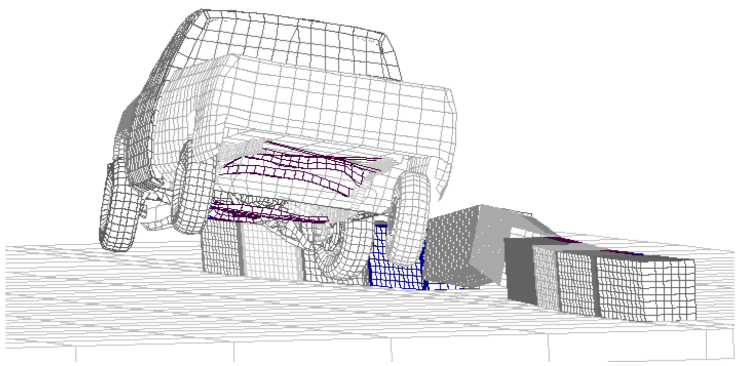
Impact case	Barrier width (in.)	Vehicle redirection	Potential for loss of segment interlock	Dynamic and final lateral deflection (in.)	Effective width (Barrier width plus peak lateral deflection) (in.)	Peak tension connection force (kip)	Barrier-to-roadway friction	Tire-to-roadway friction
A1	28	Yes	None	11 (9)	39	202	0.6	0.2
B1	22	Yes	None	13 (9)	35	191	0.6	0.2
C1	19	Yes	Low	16 (10)	35	191	0.6	0.2
D1	16	Yes	Moderate	19 (14)	35	168	0.6	0.2
E1	13	Yes	High	20 (15)	33	185	0.6	0.2
C2	19	Yes	Low	12 (9)	31	185	0.6	0.2
D2	16	Yes	Moderate	16 (13)	32	161	0.6	0.2

In an attempt to reduce the lateral barrier deflections that occur during vehicle impact, two additional simulations were also conducted. In each of these cases (C2 and D2 in Table 2), the barrier material densities were increased so that the weight of the segments in cases C2 and D2 were the same as that of the full-width barrier (case A1). Such an increase in density (and weight) could be achieved in practice by adding additional reinforcing steel to the sections in question. The purpose of conducting these simulations was to determine if sections having narrower widths but larger weights (and therefore inertial resistances) would be more effective in limiting lateral deflections. As Table 2 indicates, the additional weight of the segments did reduce the lateral deflections but only moderately.

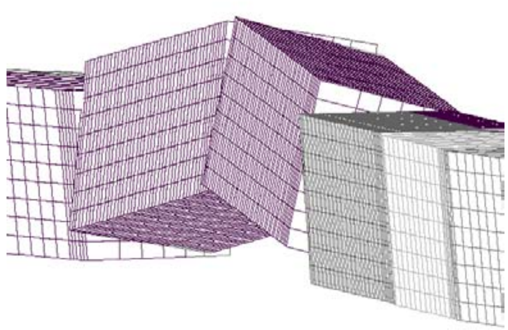
Finally, simulations were also conducted to determine the effect of placing barrier segments immediately adjacent to drop off zones. Using the 19 in. width barrier, a drop-off zone was included in two simulation models to investigate 1) the stability of the barrier segments during impact, and 2) the frictional effects between the barrier system and the roadway. Two different scenarios of roadway friction were simulated 1) $f_s = 0.2$: a worst case roadway surface condition, e.g., a roadway consisting primarily of loose chipped asphalt with a low coefficient of friction, and 2) $f_s = 0.6$: a roadway surface in good condition and without any significant contamination. Simulation results indicate (Figure 5) that the entire barrier system falls into the drop-off zone in the worst-case friction scenario (Figure 5a). When a higher friction value is used instead (Figure 5b), the barrier is prevented from falling into the drop-off zone and is able to successfully redirect the vehicle. However, given the nature of work-zones (e.g. possible presence of loose materials, etc), relying on frictional resistance to ensure adequate system performance would not be advisable.



a) System response at t = 0.1 sec

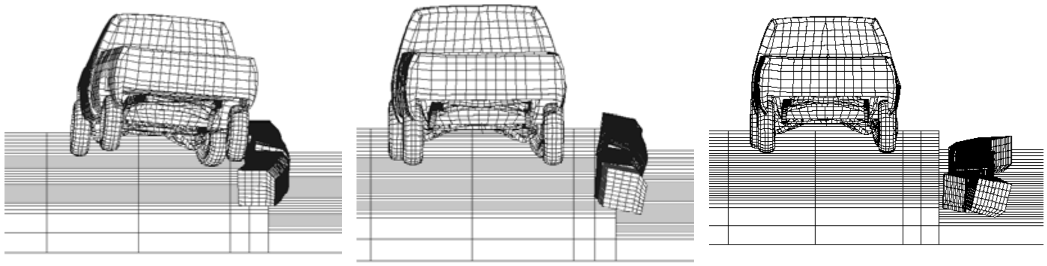


b) System response t = 0.4 sec

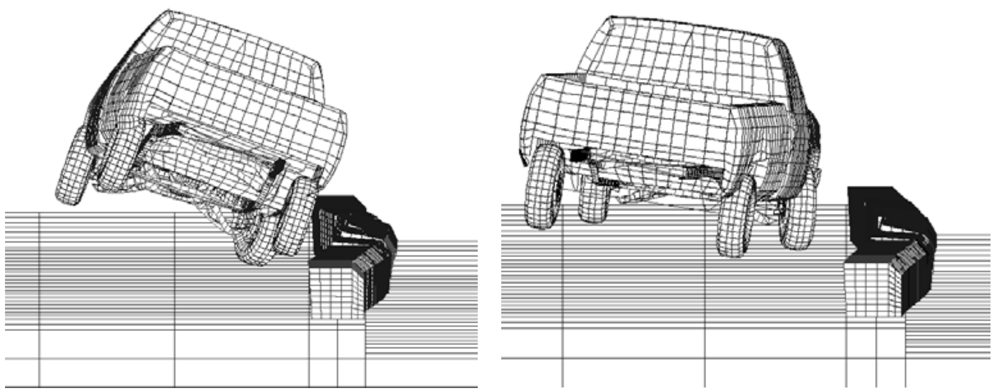


c) Vertical displacements of segments near impact point

Figure 4. Results obtained from impact simulation of a 13 in. wide barrier



a) f_s =0.2



c) f_s =0.6

Figure 5. Results from drop-off zone simulations

4. Conclusion

Based on the results of simulations conducted in this study, it appears that the width of the low-profile barrier system previously developed (Consolazio et al. 2003) can be reduced. Of the systems considered herein, barrier widths in the range of 18 in. to 22 in. appear to be the most viable from the standpoint of ensuring adequate segment interlock during impact loading. It is probable that a new barrier system can be developed that has an effective width (sum of the physical barrier width and the maximum lateral deflection) approximately 4 to 6 inches less than that of the previously developed system. Width reductions beyond this range are unlikely to be achieved for the performance criteria that have been specified.

References

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2. Hallquist, J.O., LS-DYNA Theoretical Manual, Livermore, Livermore Software Technology Corporation, California, 1998.

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