Preliminary impact testing of portable safety/security barriers

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Abstract
This paper describes the development and implementation of a facility to conduct affordable, logistically convenient, preliminary vehicle impact performance tests of roadway safety and security barriers. The facility serves as a means to test barriers at a very low cost compared to comprehensive official federal government tests. Successful performance would be an indicator of likely success in the official tests. A hillside ramp, curved transition, and horizontal approach comprise the main components. A pilot test of eleven interconnected portable barriers was conducted and the test vehicle and ramp performed as envisioned. While not a goal of the project, the barriers themselves met the technical criteria for structural adequacy and after-impact vehicle trajectory. It is anticipated that if tested to official federal standards the barriers would perform successfully.

1 Background
Recently, in the U.S.A., interest in portable safety and security barriers heightened with growing concern about potential terrorist’s attacks creating nationwide security needs. The study described herein concerns the development of a facility for cost-effective, expedient testing of roadway safety and security barriers. While the usual use of barriers is for safety during construction, etc., their use in security has risen, too. The project emanated from an inquiry from a small local manufacturing firm (Safety Barriers Corporation of Colorado, Ft. Collins, Colorado) which had been belatedly approached about potential use of its portable barriers at the Winter Olympic Games site in Salt Lake City. The Fort Collins Army Reserve had begun using their portable barrier system as a safety shield for its facilities.
The firm's barriers had also been used by the City of Ft. Collins Justice Center, at the new Invesco Field at Mile High football stadium in Denver, and at the Platte River Power Authority's Rawhide Power Plant and its substations in Colorado. Lack of credible performance data was a deterrent to immediate acceptance for use at the Olympic Games site. However, the firm was stymied by the short time period remaining before the event. Even with ample time, the firm could not afford the prohibitive cost of conducting federally approved performance tests. The firm approached researchers at the local university, Colorado State University (CSU), about their need. Consequently, the idea of developing a site for conducting a preliminary, but rigorous, vehicle crash test to verify adequate impact performance at a more affordable cost came about. A successful preliminary test would help overcome concerns of hesitant clients and encourage their investing in the conduct of full federal crash tests, based on a known high likelihood of success.

2 Portable safety and security barriers

A variety of portable safety/security barriers for directing traffic (public events, sports facilities etc.) and securing private and public locations against access (court houses, schools, etc.) have been developed. Some higher capacity systems have been developed for use on and around high-speed automobile racing tracks. Generally, the barriers are hollow, plastic composite walls and use dead weight fill (sand, water or both) to resist impact without interconnection to the ground). Heavier solid systems, such as a concrete "New Jersey" and "F-shape" type barrier configurations, are used in highway construction as well. These are much more expensive and require heavy equipment to relocate them. Few of the filled, lightweight (when empty) systems have been crash tested to meet federal standards, although some users have conducted their own impact tests. Typically, as exemplified above, manufacturers are small businesses without the financial resources to conduct comprehensive federal tests similar to crash tests of bridge guardrails. Thus, developing a comparable method to conduct a dependable preliminary (without the "bells and whistles" and extensive, expensive measurements) vehicle impact test has great merit.

3 Impact testing

Full-scale vehicle impact testing is the most effective method of realistically evaluating the safety of roadway appurtenances. National Cooperative Highway Research Program (NCHRP) Report 350 [1] presents specific impact testing conditions for vehicle type, mass, speed, approach angle etc. The NCHRP 350 procedures were devised to subject roadside safety features to severe vehicle impact conditions rather than to typical or average highway situations.

Performance test appraisal factors included in NCHRP Report 350 are structural adequacy, occupant risk, and after-collision vehicle trajectory.
Different criteria must be met in each of a series of tests for a successful outcome. For the preliminary test described, the main criteria implemented were structural adequacy and after-collision vehicle trajectory. For structural adequacy, the primary objective was to achieve a targeted "Impact Severity" (IS) level as detailed in NCHRP Report 350. The IS value is a general measure of the kinetic energy of the moving vehicle at impact and is given by:

\[ IS = \frac{1}{2} m (v \sin \theta)^2 \]  

where: \( m \) is the mass of the vehicle, \( v \) is its speed at impact, and \( \theta \) is the angle between the longitudinal axis of the impacting vehicle and that of the barrier specimen. Six IS levels are prescribed with the lower three for passenger vehicles and light trucks on streets, collectors and arterials. For vehicle crash testing, certain parameters are specified including: vehicle mass and speed, angle of impact, and point of impact on the barrier. The required speed ranges between 35-100 km/h (22.5-62 mph) and angle of impact is between 0-.436 radians (0-25 degrees). The specified values depend on the IS level sought and the criteria being examined.

The initial target chosen for the CSU test facility was a Level 3 test, which is the highest level required of temporary longitudinal barriers. There are various combinations of the parameters which can be used to achieve such a test. By intent of simplifying the NCHRP 350 specifications to the preliminary nature of the tests involved, the specific NCHRP 350 requirements were condensed. Also the geometry of the hillside ramp prevented using some of them in any regard. Instead, the intent from the very origination of the project was to provide four priority capabilities, as follows.

First, an Impact Severity corresponding to an NCHRP Level 3 test in which a 2000 kg (4409 lb) pickup truck traveling at 100 km/h (62 mph) and impacting at an angle of .436 rad (25 degrees) was chosen as the target. This would be achieved by an appropriate vehicle mass moving at the highest speed possible for the given ramp height. For these parameters and using Eq. 1, an Impact Severity of 138 J (187 ft-lb.) is involved as the target energy level. Second, an impact angle of 0.436 radians (25 degrees) was to be used. Third, the impact was to occur in a horizontal plane. Fourth, the specimen was to be placed with sufficient rear space to observe the after-impact vehicle trajectory.

4 Development of the test facility

Development and construction of the facility began in July 2002. A sequence of steps was taken over a 3-year period in two phases.

In Phase 1, a simplified, economic test configuration (figure 1) was used and it closely realized many of the recommendations of NCHRP 350. A surrogate test vehicle was used in an inclined flume on a steep incline and produced the Impact Severity test levels required by NCHRP 350 for Level 1-3 type
approvals. The performance of the inclined flume and track was adequate. However, confinement limitations at the base of the flume constrained the physical set-up of the barriers themselves. Specifically, the angle of attack was nearly head on, not angular, and the vehicle could not approach on a horizontal plane. In addition, only three barriers or less could fit in the area at the base of the flume. Thus, although a test at adequate speed was achieved, the impact event itself was catastrophic and unrealistic. Thus, the set-up of specimens was deemed to be "unfair" and, thus, unacceptable [2].

In Phase 2 the test site was improved by relocating outside the flume and using a real vehicle. An inclined ramp with a vertically curved transition at the bottom and a horizontal approach before impact was constructed on a nearby hillside. A concrete pad for specimen placement was included at the base, which allowed setting up a large number of linked barriers, so the intended "systems" performance could be examined. A roadway at the base of the hill and adjacent open space allow ready access for the placement of the multiple barriers needed.

5 Configuration and construction of the ramp

Initial planning of the ramp facility started in June 2003 and involved selection of a hillside site and geometric dimensions of the ramp. Various locations for the facility were considered. The chosen location was on a hill, located south of CSU’s Engineering Research Center in Fort Collins, Colorado. The hill was surveyed at 14.3 m (46.9 feet) high with a slope of 0.375 radians (21.5 degrees), and had room at the base for eleven barriers. A small model of the site and planned ramp was built and used to test the concept with a toy truck, which proved successful. Construction of the actual ramp began in early March 2004 and was completed in early November 2004. Plan and elevation views of the site are shown in Figure 2.
Recycled materials were used to construct the majority of the ramp. Four salvaged semi-truck trailer beds were incorporated as the major components in the inclined section of the ramp. These trailer beds were laid end-to-end up the hill making a 0.436-radian (20-degree) angle to the horizontal. The first trailer bed on the lower end of the ramp passed over a roadway, and thus was designed as a removable bridge. This trailer is held in place by a concrete pad at the bottom and a steel support towards the top, which allows it to be removed without disturbing the rest of the ramp. The remaining three trailer beds were supported on each end with concrete piles and supported in the center of each span with steel jacks that ensured minimum deflection of the trailers as the heavy vehicle rolled along them. The four trailer beds were not long enough for the ramp to reach the top of the hill therefore, a six-inch layer of concrete was placed along the last 5.18 m (15 feet) to bring the ramp all the way to the top of the hill.

At the base of the ramp a vertically curved segment was constructed to ensure a smooth transition to a horizontal level before impacting the barriers. A 102 mm (4-inch) layer of concrete was placed along this curve and continues down into the horizontal base where the barriers are located. The horizontal stretch of the ramp serves to bring all four tires of the vehicle to a level position before impacting the barriers. A steel beam was installed along the ramp to guide the test vehicle. The beam extends from the top of ramp down to the base of the curved section. A trench was dug at the top of the ramp so the test vehicle’s rear tires would rest in the trench before it was released at the top of the ramp. Sand barricades were built around the bottom of the test site to slow the momentum of the truck if it were to disengage and travel off course. A Kodak Motion Corder Analyzer, Model SR Series high-speed digital camera was mounted on a frame 3.96 ft (13 feet) above the anticipated impact point.
6 Test vehicle

A salvage vehicle was donated to the project from a local source. Several available vehicles were considered and a Loadstar 1700 dump truck was selected for its weight and configuration. The configuration was based on ability to add concrete blocks to increase the total weight, to attach mechanisms needed to mount it on the track, and the height of front bumper related to NCHRP 350 requirements for height of the impact point, etc. The estimated ready position of truck's center of mass was at a height of approximately 14 -14.3m (46-47 ft.) above the elevation of the target impact point. Equating the potential energy and kinetic energy at impact, produces an estimated required impact speed of \( v = (2gh)^{1/2} = 59.7 \text{ km/h} \) (37.1 mph). To achieve the target \( IS = 138 \text{ J} \) (187 ft.-lb) at that speed, a vehicle weight of 5625 kg (12,400 lbs.) is needed. The base vehicle weighed 3338 kg (7470 lbs.) and three precast concrete blocks were added to the back compartment to increase its weight to 6414 kg (14,140 lbs.). Figure 3 shows the vehicle in a ready position at the top of the ramp.

![Vehicle in ready position](image)

Figure 3: Vehicle in ready position [3].

7 Conduct of a pilot test

The capability of the test facility to achieve the criteria of the desired Level 3 performance test was examined by conducting an actual test of a safety barrier system. The test was performed on November 4, 2004. The safety barriers (trade name "E-Z BARRIER") were provided by Safety Barriers Corporation of Colorado. The geometry of an individual barrier is shown in Fig. 4. The barrier is comprised of low-density polyethylene. Multiple barriers are employed by interconnecting the vertical connector bar of one unit to the formed slot in the adjacent unit. Each barrier is filled with either water or sand or a mixture of both. An individual barrier is 251 cm (99 in.) long, 71 cm (28 in.) wide at the base and 107 cm (42 in.) high. It weighs 56.7 kg (125 lbs) empty and 1145 kg (2525 lbs) when full with water (1136 l (300 gal) capacity). With a sand fill, the weight depends on the sand used and is about twice that weight.

On the morning of the test the barriers were linked together on the concrete pad that intercepted the base of the ramp at 25 degrees. A line of eleven barriers...
was employed (figure 5). In addition to the vertical connector bars between each adjacent unit the barriers were interconnected by a longitudinal cable passing through ports at the nose (top) of the barrier ends. The center barrier was positioned so that it would receive the direct impact of the vehicle. The middle five barriers were filled with sand to near capacity and “topped off” with water to saturate the sand and fill the void space. A heavy snowfall had occurred a week before the test, followed by unusually warm weather which melted the snow. Consequentially the stored sand became wet just prior to the testing. After realizing the time it took to fill each barrier with wet sand and the limited amount of daylight left, the remaining six barriers were filled only with water. It was not feasible to weigh the in-place units, so actual weights are unknown.

Figure 4: Individual barrier [Safety Barriers Corporation of Colorado].

Figure 5: Barriers in position before test [3].

A designated area for spectators was roped off at the top of the ramp away from the release of the truck, and a designated individual was in charge of ensuring no one crossed that line until the test was conducted and the site was deemed safe after impact. Several video cameras were placed to record the test from different vantage points. The high-speed digital camera was set to record the event at 250 frames per second. This record served to confirm the impact
location was proper and to determine the vehicle speed more accurately and the duration of the impact. At the base of the ramp a person was safely placed on the roof of a nearby building to trigger the high-speed camera. The vehicle was driven to the top of the ramp and eased over the top of the ramp until the rear wheels caught in the trench. The emergency brake was then engaged. Once a final verification that everything was clear and ready to go was confirmed the trucks emergency brake was released and the truck was gently pushed on to the ramp and allowed to begin moving.

8 Outcome of the test

The truck rolled successfully down the hill on the guide rail. There was no apparent shifting of the trailer beds or any other defects that were apparent with the ramp. The truck made the transition from the incline to a horizontal position using the curve with no jolts of any kind. The ramp proved to be structurally adequate for the test. The concrete pad is also more than adequate with regard to allowing enough room for the barriers to travel upon impact. The design and construction of the facility was a success. Fig. 6 shows the post-impact state.

![Figure 6: Barriers after impact [3].](image)

High-speed camera data has not yet been analyzed. The estimated speed of the truck upon impact, obtained with a radar gun placed at the top of the ramp, was 62.8 km/h (39 mph). This speed was 3.1 km/h (1.9 mph) faster than required to reach a Level 3 test. The truck impacted the center barrier at essentially the location it was predicted to strike. It then pushed the barrier approximately .91 m (3 ft) backwards and then changed angle and proceeded to travel along the length of the barriers. The truck traveled forward approximately 11m (36 ft) parallel to the barrier line before coming to a complete stop. Fig. 7 shows the result of the impact. The four barriers on the far end of the center barrier were crushed and torn apart. The first five barriers remained intact, but the barrier on the near end had been crushed like an accordion due the large amount of tension in the cable that strung the barriers together. The cable was still intact after the impact. The truck sustained only minor damage to the
passenger side bumper and fender, which were bent in toward the front tire. None of the tires on the truck were punctured.

![Figure 7: Truck and barriers after impact [3].](image)

### 9 Conclusions

The test facility performed as intended without irregularities or mishaps. Structural components remained intact and undamaged. The truck traveled the trajectory smoothly and produced the desired impact speed and location. Impact energy was consistent with a Level 3 federal test. The barrier produced an after-impact trajectory of the vehicle within federal requirements. The truck sustained minimal damage. To improve the test site, a release device is needed to improve control at the start of the descent. An accelerator device to impart an initial velocity to the vehicle should be considered to enable an equivalent test to be done with a lighter vehicle.

### 10 Final remarks

One evolving consideration for the site was the recent development of standard performance tests for security barriers, walls, etc by the U.S. State Department. Those tests require a 6804kg (15,000 lb) vehicle to impact the target at 48 km/h (30 mph), 65 km/h (40 mph), and 80 km/h (50 mph), to achieve K4, K8, and K12 Certification Classes, respectively. The criteria for the barrier performance are much more stringent than NCHRP 350 requirements. For example, the impact must be “head on” (perpendicular to the target). However, 6413.8 kg (14,140 lbs.) and estimated speed of 62.8 km/h (39 mph) nearly achieve the K8 requirements for the vehicle impact energy. The accelerator device could enable the speeds required for K8, and K12 Certification Classes to be achieved. Adding the extra mass simply requires a heavier vehicle.
The present facility provides a cost effective means for simulating the primary characteristics of a federal Level 3 type test. It provides a means for any interested party to pre-test a potential product to gain information about its effectiveness. A successful preliminary test is a solid indicator of a high likelihood of surviving a more comprehensive official federal Level 3 test. The researchers believe the E-Z BARRIER has a high probability of surviving such a test. However, the outcome is not to be viewed as certification of the product by CSU as it is not a certifying agency and assumes no responsibility for the product. The E-Z BARRIER was used as a medium for the pilot test of the performance of the test facility, itself, which was the research objective of the funded project.

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