# Impact Performance Testing of Roadway Safety and Security Barriers

# (Phase 2)

Misty L. Butler
Richard M. Gutkowski, Ph.D., P.E.

Department of Civil Engineering
Colorado State University

October 2005

## Acknowledgements

Support for this project was provided through the Mountain Plains Consortium as part of the University Transportation Centers Program (UTCP). MPC member universities include North Dakota State University (lead institution), Colorado State University, University of Wyoming, and University of Utah. The UTCP is funded by the U.S. Department of Transportation.

Dr. Jeno Balogh gave excellent advice during the development of this project.

Horacio Garza, Jr., Engineering Research Center shop supervisor is much appreciated for his tireless efforts to build the ramp, and countless ideas to help improve the site. His knowledge and skills were priceless during this project.

Bill Tempero, owner of Safety Barriers Corporation of Colorado, kindly donated his E-Z Barriers to be tested in the trial run. Thank you for your patience and generosity.

Andy Darrow, Engineering Research Center Hydraulics lab manager, donated his time and skills when needed is greatly appreciated. Thank you also to graduate students Steve Babcock and Travis Burgers, and undergraduate student interns Katherine Sednek and Paul Espinoza. Without help from each of these people the task of constructing the ramp and conducting the test would have been nearly impossible.

## Disclaimer

# Abstract

A testing facility for temporary longitudinal barriers was constructed at Colorado State University's Engineering Research Center which will allow manufacturer's the opportunity to test their safety barriers prior to full-scale federal testing. This facility enables manufacturers to subject their products to a simplified, yet standard test according to federal regulations at a much lower cost. This simplified test gives the manufacturers the opportunity to observe the likely performance of their product and make any necessary improvements before subjecting their products the federal tests.

The facility consists of a 14.3-meter (46-foot) high ramp built on the side of a hill out of recycled materials and concrete. This facility has room for a line of up to 11 barriers to be placed on a rough concrete pad at the base of the ramp. During testing a vehicle released from the top of the ramp gains speed by rolling down the incline, makes a transition to a horizontal position at the base, and then impacts the barriers. This testing site allows a manufacturer to observe two of three appraisal factors listed in the National Cooperative Highway Research Program Report 350: structural adequacy of the barrier, and post-collision vehicle trajectory.

The test described in this report involved the testing of an "E-Z Barrier," a product of Safety Barriers Corporation of Colorado. The E-Z Barrier is a low-density polyethylene shell that is noted for being lightweight when empty and can easily be set up and filled with water and/or sand with less effort than placing heavy concrete barriers.

The main objectives of the test were to ensure the facility was adequate and sound and to observe how closely the facility came to implementing the intended simplified vehicle impact testing procedures. Overall, the ramp proved to be structurally sound for vehicle acceleration, the trail test exceeded expectations when the test vehicle impacted the barriers at a higher energy than predicted, and the facility allowed enough room at the base of the ramp to observe both the structural adequacy of the barriers as well as the vehicle's path of trajectory after impact. The facility is available and capable of testing roadside safety features. A few minor improvements are being planned as well.

# Table of Contents

# List of Tables



# List of Figures

# 1. Introduction

## 1.1 Background

Traffic barrier systems are used for many different traffic-related safety concerns. Barriers are used to prevent cars from head-on collisions, stop rollovers because of a steep incline next to the road, or protect motorists from anything that may pose a threat to their lives while on the road. There are many types of temporary barriers in use today, but recently temporary barriers consisting of a lightweight plastic shell filled with water or sand was conceived as an alternative to the heavy, concrete "New Jersey" or "F-shape" barriers. Such barriers are currently being used to direct traffic in road construction, public events, and other temporary situations where barriers are needed. These new plastic barriers are designed with the intension of minimizing the penetration of out-of-control vehicles and reducing the cost of replacing barriers in high-accident locations with narrow shoulders or medians.

Because of the importance barriers play in roadway design, there are a series of requirements a barrier has to meet to be deemed "effective." The National Cooperative Highway Research Program (NCHRP) has strict requirements for testing barriers. These requirements are slated in the NCHRP Report 350: "Recommended Procedures for the Safety and Performance Evaluation of Highway Features" (1). The intent of the procedures specified in that report are to promote the uniform testing and in-service evaluation of roadside safety features so that highway engineers may confidently compare the safety performance of designs that are tested and evaluated by different agencies. The three primary appraisal factors presented for evaluating the crash performance include structural adequacy, occupant risk, and after-collision vehicle trajectory. These performance criteria are described in detail, subsequently.

The heightened concern about terrorist attacks creating nationwide security needs has brought more interest to the portable barriers. Indeed, the Fort Collins Army Reserve, the City of Fort Collins Justice Center, and the Platte River Power Authority's Rawhide Power Plant are all using portable barriers as a safety shield for their facilities. A local manufacturer was also belatedly approached about potential use of portable barriers at the Salt Lake City Olympic Games site. Lack of credible performance data was a deterrent to immediate acceptance. Thus, a step toward more rigorously verifying impact performance would help overcome that concern as well as encourage conduct of full federal crash tests.

## 1.2 Objective of Project

The series of tests specified in the NCHRP Report 350 are very extensive and costly. Because of a lack of funds, some manufacturers are unable to federally test the reliability of their barriers and must limit their sales to non-federally funded projects. The objective of the research described in this report was to provide an alternative to full federal tests. Designing and constructing a preliminary testing facility as a means of pre-testing the barriers will allow a simplified, yet standard test, with reliable results. The resulting facility, described subsequently, is located at Colorado State University (CSU). This facility enables manufacturers to subject their products to crash tests that simulate those described in federal guidelines at a much lower cost. This enables a manufacturer to observe the likely performance of their product if it were to be subjected to an official test. Then, if necessary, improvements can be made before money is invested toward subjecting the product to an official federal test needed to certify their barriers as “effective” according to the NCHRP 350 regulations.

Preliminary tests of this nature have been done in the past at CSU to assess performance including the load-displacement behavior of timber bridge guardrails under static point loading, as well as under a heavy mass pendulum impact load (3, 4, 5, 6). The static point load test was developed to aid in revealing structural inadequacies of a particular all-timber bridge guardrail prior to full-scale federal testing which lead to improvements needed. The static load tests and pendulum load test were later used to demonstrate the superior performance of an alternative bridge guardrail system developed by the CSU researchers.

## 1.3 Overview of Phase 1

The first phase of the project involved adapting an existing 110-foot long hydraulic flume to enable a crash test to be conducted using a surrogate vehicle (2). Figures 1a, 1b, and 1c show the flume, the surrogate vehicle, and test specimen after impact, respectively. Detailed dimensions of the surrogate vehicle are depicted in Figure 2.

a. b. c.

**Figure 1:** Phase 1 test site setup, surrogate vehicle, and test specimen (2)

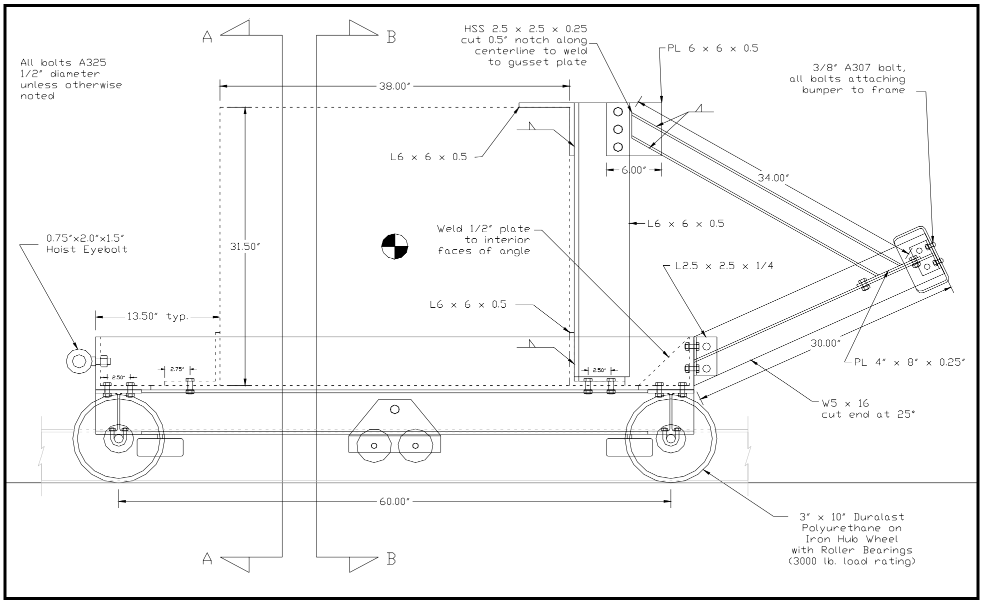


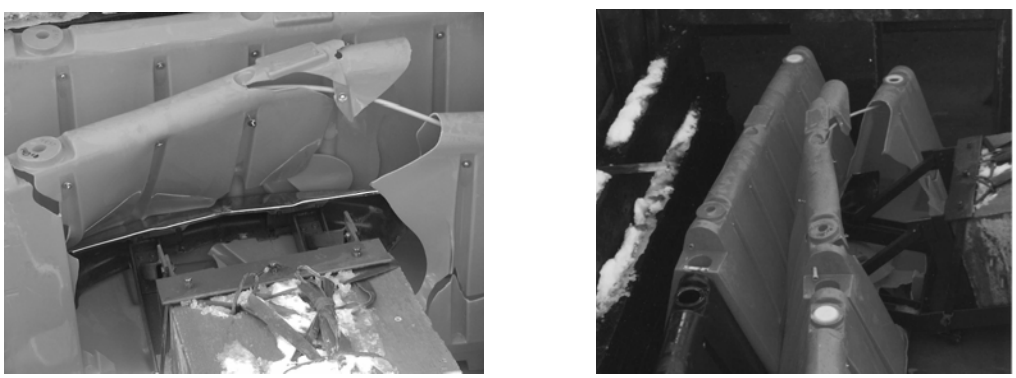

**Figure 2:** The surrogate vehicle (2)

The concept of this simplified test was to roll a wheeled cart (the surrogate vehicle) carrying a concrete mass down the inclined hydraulic flume (located at CSU) to impact a barrier specimen set-up in the trough at the bottom. At the time this set-up option was the most realistic approach because it allowed the use of the flume as a track for the vehicle which would generate a large amount of energy upon impact. As the flume already existed, the test involved only inexpensive modifications to the flume and fabrication of the surrogate vehicle. The concrete block was already available as it was salvaged from the pendulum test previously used to test bridge guardrails. The four-wheeled surrogate vehicle was also expected to simulate the movement and response of an actual vehicle during impact. Overall the facility, intended as a means to test the structural adequacy of the safety barriers, lacked a desired feature and compatibility: it constrained the physical set-up of the safety barriers because of the confined space at the bottom, making it impossible to enable a realistic post-impact vehicle trajectory to occur. Figure 3 shows the results of the first test done at the time to imitate an NCHRP Report 350 Test Level 2 Impact Severity (defined subsequently).

a. b.

**Figure 3:** Deflection position of the test specimen and final position of surrogate vehicle following first test. a. Overhead view. b. View showing tearing of the barrier connector bar (2).

Other limitations of the facility included the angle of attack on the barriers being nearly head-on (90 degrees), and the vehicle approaching the barriers on an inclined path, not the horizontal plane recommended in the NCHRP 350 Report. The angle of attack is shown in Figures 4a and 4b which shows the outcome of a second test conducted to imitate an NCHRP Report 350 Test Level 3.



a. b.

**Figure 4:** Final condition of the barrier specimen and surrogate vehicle after test (2).

In addition, only three barriers or less could fit in the area at the base of the flume. In axial tests, the end of one barrier had to pass into an opening in an adjacent wall. Further, the surrogate test vehicle did not meet all the physical requirements in a vehicle specified in the NCHRP Report 350.

## 1.4 Phase 2

After assessing the outcomes of the Phase 1 tests, involving the surrogate vehicle and the inclined flume, that approach to simulate the NCHRP 350 recommendations was deemed to be inadequate. Thus, an entirely new approach was undertaken as Phase 2 of the development. Phase 2 focused on the construction of a ramp on the side of a hill in an area that would allow sufficient room for more barriers to be used with space to move forward upon impact, and for measurements to be taken of the post-impact vehicle trajectory. A heavily loaded dump truck was used for the test vehicle instead of the surrogate vehicle. Unlike the surrogate vehicle, the suspension and rubber tires on the truck aid in taking some of the shock during collision as well as redirecting the vehicle after impact. In addition, sufficient room was provided at the base of the ramp for up to eleven barriers to be interconnected. There is also a horizontal approach segment at the base of the ramp to allow the vehicle to collide with the barrier on level ground. Finally, the base was paved with rough concrete to simulate the friction of a road way underneath the barrier during impact.

# 2. NCHRP Report 350

The intent of the NCHRP Report 350 is to “present uniform guidelines for crash testing…of temporary highway safety features and recommended evaluation criteria to assess test results.” The guidelines of this report promote a standard safety barrier test procedure that provides a basis for people to compare impact performances among different safety barrier agencies. For vehicle crash testing, certain conditions are specified, including vehicle mass, speed, angle of impact, and point of impact on barrier. The required speed of the vehicle ranges between 35-100 km/h (20-60 mph) and the recommended angle of impact ranges between 0-25 degrees. Three appraisal factors are to be evaluated: structural adequacy, occupant risk, and post-collision vehicle trajectory. According to the NCHRP Report 350 the barriers should act to “contain, redirect, permit controlled penetration of the impacting vehicle, or permit a controlled stop in a predictable manner to satisfy structural adequacy requirements.” Occupant risk evaluates the hazards a person is subjected to inside the vehicle during and after the impact. Post-collision vehicle trajectory is assessed by determining if the path or final position taken by the impacting car could possibly impede the paths of other vehicles in travel.

To meet the performance requirements, temporary longitudinal barriers are put through a series of tests and various impact intensity levels. NCHRP 350 specifies six different intensity levels. Table 1 shows the test levels, the vehicles recommended for testing and their weight, the vehicle velocity, and impact angle during collision with the barrier.

**Table 1:** Test Matrix for Longitudinal Barriers, from NCHRP 350 (1)

TABLE 3.1. Test matrix for longitudinal barriers

| Test Level | Barrier Section | Test Designation | Impact Conditions[c] Vehicle | Impact Conditions[c] Nominal Speed (km/h) | Impact Conditions[c] Nominal Angle, θ (deg) | Impact Point | Evaluation Criteria[e] (See Table 5.1) |
|---|---|---|---|---|---|---|---|
| 1 | Length of Need | 1-10 | 820C | 50 (31) | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | S1-10[a] | 700C | 50 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | 1-11 | 2000P | 50 | 25 | (b) | A,D,F,K,L,M |
| | Transition | 1-20[d] | 820C | 50 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | S1-20[a] | 700C | 50 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | 1-21 | 2000P | 50 | 25 | (b) | A,D,F,K,L,M |
| 2 | Length of Need | 2-10 | 820C | 70 (44) | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | S2-10[a] | 700C | 70 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | 2-11 | 2000P | 70 | 25 | (b) | A,D,F,K,L,M |
| | Transition | 2-20[d] | 820C | 70 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | S2-20[a] | 700C | 70 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | 2-21 | 2000P | 70 | 25 | (b) | A,D,F,K,L,M |
| 3 Basic Level | Length of Need | 3-10 | 820C | 100 (62) | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | S3-10[a] | 700C | 100 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | 3-11 | 2000P | 100 | 25 | (b) | A,D,F,K,L,M |
| | Transition | 3-20[d] | 820C | 100 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | S3-20[a] | 700C | 100 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | 3-21 | 2000P | 100 | 25 | (b) | A,D,F,K,L,M |
| 4 | Length of Need | 4-10 | 820C | 100 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | S4-10[a] | 700C | 100 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | 4-11[d] | 2000P | 100 | 25 | (b) | A,D,F,K,L,M |
| | | 4-12 | 8000S | 80 | 15 | (b) | A,D,G,K,M |
| | Transition | 4-20[d] | 820C | 100 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | S4-20[a] | 700C | 100 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | 4-21[d] | 2000P | 100 | 25 | (b) | A,D,F,K,L,M |
| | | 4-22 | 8000S | 80 | 15 | (b) | A,D,G,K,M |
| 5 | Length of Need | 5-10 | 820C | 100 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | S5-10[a] | 700C | 100 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | 5-11[d] | 2000P | 100 | 25 | (b) | A,D,F,K,L,M |
| | | 5-12 | 36000V | 80 | 15 | (b) | A,D,G,K,M |
| | Transition | 5-20[d] | 820C | 100 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | S5-20[a] | 700C | 100 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | 5-21[d] | 2000P | 100 | 25 | (b) | A,D,F,K,L,M |
| | | 5-22 | 36000V | 80 | 15 | (b) | A,D,G,K,M |
| 6 | Length of Need | 6-10 | 820C | 100 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | S6-10[a] | 700C | 100 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | 6-11[d] | 2000P | 100 | 25 | (b) | A,D,F,K,L,M |
| | | 6-12 | 36000T | 80 | 15 | (b) | A,D,G,K,M |
| | Transition | 6-20[d] | 820C | 100 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | S6-20[a] | 700C | 100 | 20 | (b) | A,D,F,H,I,(J),K,M |
| | | 6-21[d] | 2000P | 100 | 25 | (b) | A,D,F,K,L,M |
| | | 6-22 | 36000T | 80 | 15 | (b) | A,D,G,K,M |

[a] Test is optional. See Section 3.1.
[b] See Figure 3.1 for impact point.
[c] See Section 3.3.2 for tolerances on impact conditions.
[d] Test may be optional. See Section 3.2.1.2.
[e] Criteria in parenthesis are optional.

With the exception of certain rare circumstances, temporary barriers are only required to pass the first three intensity levels. The NCHRP Report 350 states that most crash-tested safety features on the roadways today have been qualified to test level 3 standards. Test levels 1, 2, and 3 serve to evaluate safety barriers used in lower service roadways and some work zones. Test levels 4, 5 and 6 serve to evaluate features used in higher service roadways that demand a stronger safety barrier. The tests conducted with the lighter vehicles, 820 kg (1808 lb) are intended to allow one to observe the overall physical performance of the safety barrier and vehicle occupant risk. Larger vehicles are used to examine the strength of the safety feature and its ability to contain and redirect the vehicle upon impact.

The weight and the speed of the vehicle as well as the angle of impact on the barrier are all factors that contribute to the energy exerted on the barrier by the vehicle, termed the impact severity (IS). The IS is calculated using Equation 1.

$$IS = \frac{1}{2} M (V \sin\theta)^2 \qquad \text{(Equation 1)}$$

Where IS is the impact severity in joules (J), M is the mass of the vehicle (kg), V is the impact speed, and $\theta$ is the angle of impact (deg). For each of the six test levels, various combinations of vehicle mass and corresponding IS values are specified in the NCHRP Report 350. For example, to reach a test level 3 (IS = 138.1 kJ (101.9 ft-lb)) with a 2000 kg (4410 lb) pickup truck a speed of 100 km/h (62 mph) has to be reached and the truck would have to impact the barrier at a 25-degree angle relative to the longitudinal line of the barriers. To reach a test level 3 with an 820 kg (1808 lb) car a speed of 100 km/h (62 mph) is needed and the car would have to impact at a 20-degree angle relative to the longitudinal barriers.

# 3. Test Configuration

## 3.1 Description of Ramp and Location

Various locations for the facility were considered. The chosen location was on a hill, located south of the Engineering Research Center at Colorado State University in Fort Collins, Colo. The hill was surveyed at 14.3 m (46.9 ft) high with a slope of 21.5 degrees, and had room at the base for eleven longitudinal barriers. A plan view and elevation view of the ramp constructed are shown in Figure 5.

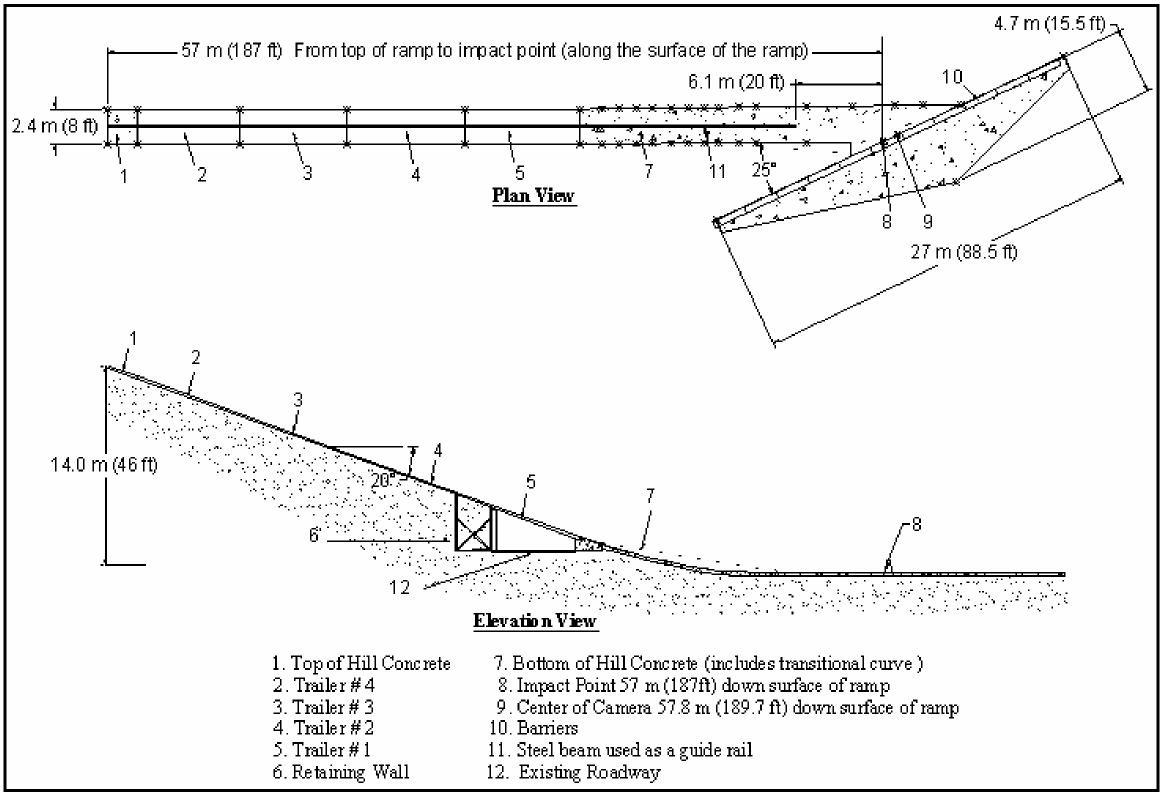



**Figure 5:** Plan and elevation view of ramp

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 20-degree angle to the horizontal. The first trailer bed on the lower end of the ramp passes over a roadway, and thus was designed as a removable bridge. This design feature was included for two reasons: there was a large underground waterline that ran underneath this portion of the ramp that could not be damaged and there was also a highly-used road running over the top of this waterline that needed to stay in service when the ramp was not in use. Therefore, the first 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 low deflection of the trailer beds as the heavy vehicle rolled along them. The combined length of the four trailer beds was 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 2.13 m (7 ft) to bring the ramp all the way to the top of the hill.

At the base of the ramp a curved segment (configured using a spline function) was constructed to ensure a smooth transition of the vehicle from the 20-degree incline of the ramp to a horizontal level before impacting the safety barriers. A 102 mm (4 in) layer of concrete was placed along this curve and continues down into the horizontal base where the safety barriers are located. The horizontal stretch at the bottom of the ramp brings all four tires of the vehicle to a level position before the vehicle impacts the safety barriers. It is intended that the vehicle impact the safety barriers at the desired 25-degree angle relative to the longitudinal line of safety barriers. Thus, a concrete pad was constructed at a 25-degree angle in plan to the ramp and extends 4.72 m (15.5 ft) back to ensure a consistency of friction under the barriers if they slide backwards upon impact. The layout of the concrete is shown in the plan view of the site (Figure 5). A W6 x 12 steel beam was installed as a rail along the centerline of the ramp to guide the test vehicle. This rail extends from the top of ramp down to the base of the curved section of ramp. The rail ends 6.1 m (20 ft) before the impact point on the barriers to permit unrestricted vehicle travel prior to impact.

Effective release of the truck from the top of the ramp was critical. Several safety precautions were taken related to the release of the vehicle. An emergency brake was installed on the vehicle which allows the release of the brake from the rear bumper of the vehicle once it was positioned at the top of the ramp. A trench was dug at the top of the ramp and the rear wheels of the test vehicle rest in this trench before the emergency brake is released and a larger vehicle gives it a slight push over the edge to initiate its rolling down the hill. To prevent the vehicle from careening into the lake or the building at the base of the ramp after impact, sand barricades were built around the bottom of the test site to slow the momentum of the vehicle.

## 3.2 Meeting the NCHRP Recommendations

The goal of the project was to build a facility capable of having a suitable vehicle achieve an impact energy of 138.1 kJ (101.9 ft-lb), consistent with test level 3 in the NCHRP Report 350. Because the ramp was built on a hill and the vehicle is to be rolled down it, the potential and kinetic energy can be equated ($mgh = \frac{1}{2}mv^2$) to determine the height required to reach each specified impact severity. Thus,

$$h = \frac{v^2}{2g} \qquad \text{(Equation 2)}$$

Where m is the mass of the vehicle (kg), g is the acceleration due to gravity (9.81 m/s), h is the height of the hill (m), and v is the velocity of the vehicle (m/s). Solving Equation 1 for velocity and Equation 2 for height, a 39.6 m (130 ft) high ramp is needed to reach the maximum impact severity of a test level 3 with the 2000 kg (4409 lb) vehicle. The ramp is only 14 m (46 ft) high, and it is not possible to generate a test level 3 with a 2000 kg (4409 lb) vehicle. Consequently, modifications to the test recommended in the NCHRP Report 350 were made to achieve an equivalent impact severity with a heavier vehicle.

Only three factors could be changed to reach a level 3 impact severity: the height of the ramp, the angle of impact to the barrier, or the weight of the vehicle. Building a higher ramp would require increasing the height of the existing hill at a very high cost. The goal of longitudinal barriers is to contain and redirect the vehicle. If the barriers were placed at a flatter angle (such as in the initial test in the flume), the post-impact vehicle trajectory would be affected. This might invalidate redirecting the vehicle into its original lane of traffic. Therefore, an impact angle of 25-degrees was retained. Consequently, the vehicle weight was the only remaining factor to change. To reach the IS = 138.1 kJ (101.9 ft-lb) impact severity, knowing the maximum height of the ramp is 14 m (46 ft), requires a 5600 kg (12400 lb) vehicle. Therefore, a vehicle that was capable of holding more weight than a small truck had to be found to meet the modified test level 3 requirements.

## 3.3 Vehicle

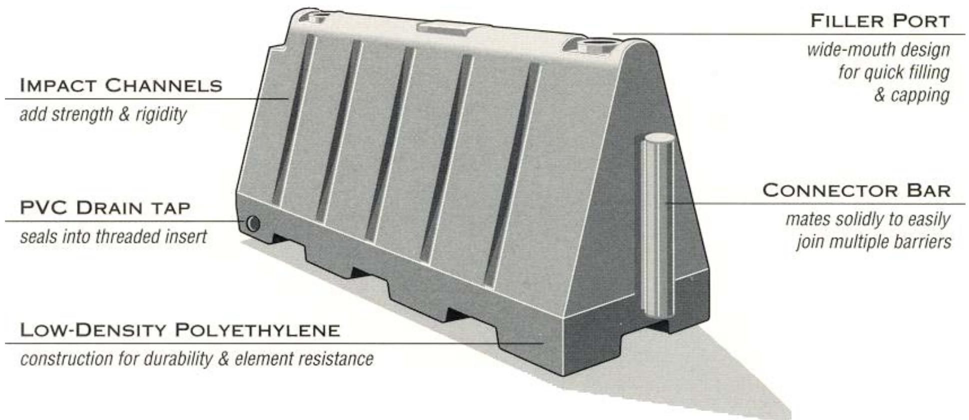
The vehicle to be used had to meet the NCHRP Report 350 requirements as closely as possible. The requirements included: the vehicle must be in good condition and free of major body damage, and the suspension and handling characteristics must be typical of the vehicle. Rubber tires, shocks, ability for the front tires to have free range of motion, a bumper height that fell in to the NCHRP Report 350 recommendations, and the proper weight to reach the impact severity desired were other factors considered when deciding on a vehicle.

The vehicle chosen for the initial impact test was a LoadStar 1700 truck (Figure 6) donated to the project by a local salvage yard. The base weight of the truck was 3338 kg (7470 lbs). To meet test level 3 requirements the total weight of the vehicle had to be 5600 kg (12400 lb). To achieve this total weight, three pre-cast concrete blocks, each weighing approximately 999 kg (2200 lbs), were loaded on the truck. The resulting total weight of the loaded truck was 6414 kg (14140 lbs).

**Figure 6:** The LoadStar 1700 test vehicle

## 3.4 Test Specimen

As previously mentioned, the test specimens used for the trial test on the newly constructed ramp were to be hollow, water and/or sand-filled, portable longitudinal barriers intended only for temporary use. The safety barriers used were provided by Safety Barriers Corporation of Colorado. An illustration describing the physical characteristics of their barrier (trade name "E-Z BARRIER") is shown in Figure 7.




**SPECIFICATIONS**

| | |
|---|---|
| Empty Weight | 125 lbs. |
| Full Weight (water) | 2525 lbs. |
| Capacity | 300 gallons |
| Length | 99" |
| Width | 28" |
| Height | 42" |

**Figure 7:** The E-Z Barrier (from vendor product literature)

The E-Z Barrier is comprised of low-density polyethylene. These temporary barriers, not intended for individual use, are linked together by interconnecting the vertical connector bar of one unit to the formed slot in the adjacent unit. A cable is then strung through the ports at the nose (top) of the barriers from end to end, forming a chain. The setup typically used by the manufacturer is shown in Figure 8.

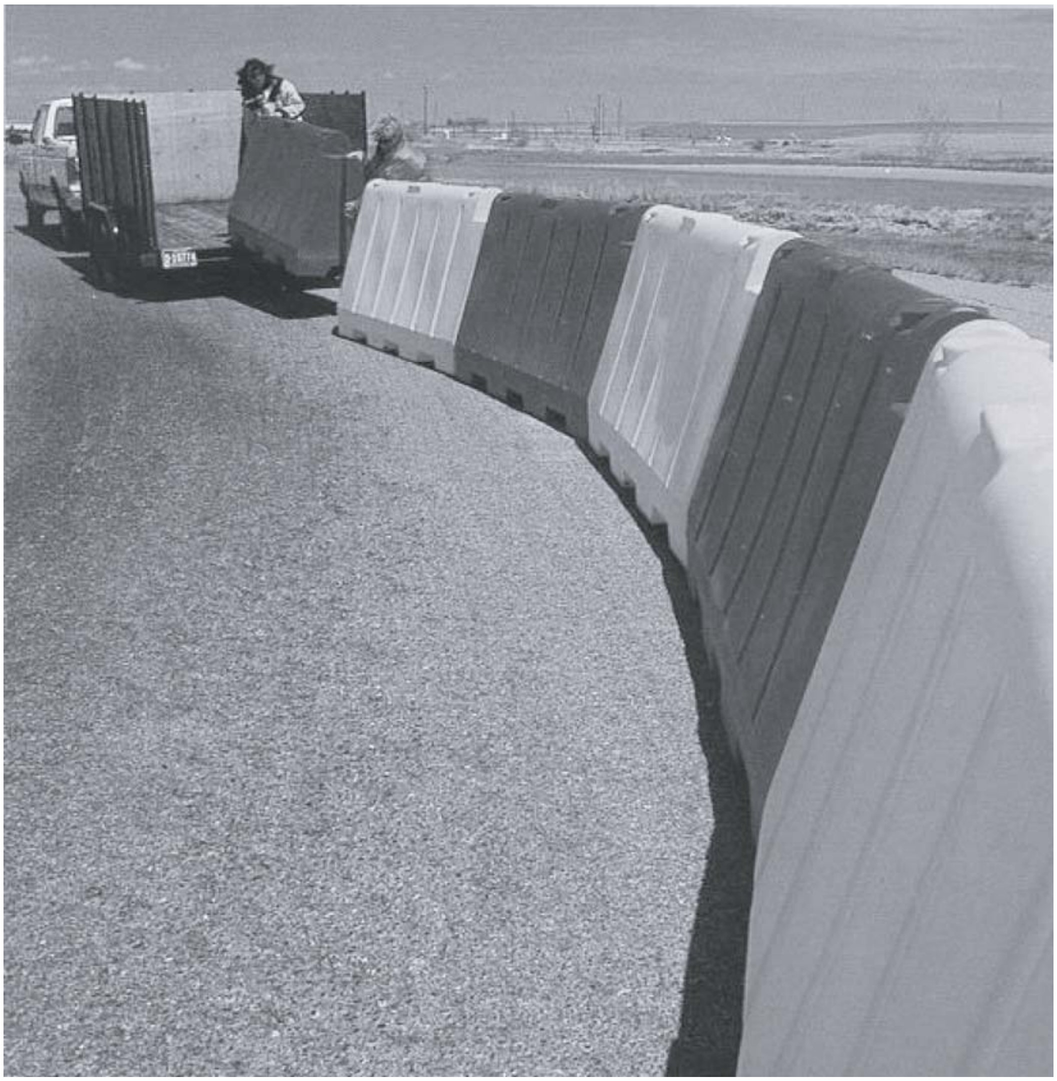


**Figure 8:** Typical set-up of E-Z Barriers (from vender product literature)

Once interconnected, the barriers act to absorb energy like a flexible cable when impacted by a vehicle. However, unlike a cable, the entire mass of the barriers as well as the friction against the bottom of the barrier and the concrete act to slow and eventually stop the vehicle.

The site constructed for this test has space for up to 11 barriers to be placed in a straight line at the desired 25-degree angle. This setup would be similar to that found on the side of a road near a construction zone or around the perimeter of a special event site. In the trial test 11 barriers (hereafter, the "test specimen") were placed so that the middle barrier would sustain the initial impact in the center of the barrier somewhere between 381-559 mm (15-22 in) above the ground (the height of the truck bumper from top to bottom). The specimen was not anchored to the ground at any location, anticipating that the string of 11 interconnected barriers would act as their own anchor to restrain and redirect the oncoming vehicle.

With this setup, two of three appraisal factors recommended in the NCHRP report 350 could be evaluated: structural adequacy and post-impact vehicle trajectory. The simplified preliminary test was not developed to address occupant risk because of liability concerns of human subject-based research.

# 4. The Actual Test

## 4.1 Objectives

The initial test had three objectives. The first objective was to observe the physical adequacy of the ramp. The first objective included: inspecting the soundness of the ramp as to ensure the trailer beds on the inclined portion of the ramp stayed properly in place as the vehicle rolled down the ramp, checking the smoothness of the transitional curve and make certain no large jolts occurred as the truck traveled across it, and examining if the concrete pad was built to a sufficient width and length so that the barriers stayed on the concrete pad during impact. The second objective was to assure the high-speed camera was properly adjusted for timing and in the correct position to record the truck striking the barriers. The third objective was to observe how closely the facility actually comes to implementing the intended simplified vehicle impact testing procedures. The third objective included: assessing the acceptability of the facility for use in examining structural adequacy of the barrier specimen as well as parameters relating to post-impact vehicle trajectory, dynamic defection of barriers upon impact, and permanent deflection of barriers after the truck has come to a rest.

## 4.2 Test Procedure

The trial test was conducted on Dec. 4, 2004, and weather conditions were a factor in the preparation. A heavy snowfall had occurred a week before the test, followed by unusually warm weather which melted most of the snow. Considering the weather limitations, it was decided that only one test would be conducted, with the truck released from the very top of the ramp to observe the facility's ultimate capabilities. Set-up began three days before the test was conducted and included clearing snow and mud from the ramp and concrete pad, setting up the barriers at the 25-degree orientation to the ramp, and positioning of the cameras. The barriers were linked together, centering the middle barrier so that it would receive the direct impact of the vehicle. A 16mm (5/8 in) diameter cable was then strung through the ports at the nose (top) of the 11 barriers and several clamps were attached at the end of the near and far barriers to keep the cable from slipping without being anchored to the ground. On the second day two of the middle barriers were slowly filled with sand to near capacity and "topped off" with water to saturate the sand and fill the void space. After realizing the extended amount of time it took to fill each barrier with the wet sand that resulted from the snow earlier in the week, a new plan to fill the barriers at a quicker pace was attempted. A hole was cut in the top of the barriers and a steel funnel was constructed to allow the wet sand to flow into the barriers at a faster rate. By late morning on the third day, only the middle five barriers had been successfully filled with sand and water. Realizing the limited amount of daylight was going to be a concern for the quality of the high-speed video pictures, it was decided the remaining six barriers were to be filled only with water. It was not feasible to weigh the in-place units, so actual weights are unknown. Figure 9 shows a photograph of the test specimen in its initial position.

**Figure 9:** Test specimen in position before test

The high-speed video camera used to record the initial impact of the vehicle and the test specimen was a Kodak Motion Corder Analyzer Model SR Series 1998. The camera was set to record 250 frames per second. The camera was mounted 4 m (13.1 ft) above the impact point in a wooden box attached to the horizontal member of a steel frame that spanned the concrete pad at the base of the ramp. The wooden box was made with a plexi-glass bottom that permitted a clear picture of the impact point while protecting the lens of the camera from water and debris that might hit it during the impact. This record helped confirm the impact location was proper, calculate the vehicle speed more accurately, and determine the duration of impact. The camera mount is shown in Figure 10. Several video cameras were also placed in various locations to record the test.

A "Barrier Impact Testing Data Sheet," located in Appendix A, was used to record the conditions and results on the day of the test. This data sheet is in accordance with chapter 6 of the NCHRP Report 350 titled: Test Documentation**.** These documentations are intended to standardize the reporting of key parameters by providing a means of data comparison between multiple tests, and allowing the results obtained in each simplified test to be related to the federal test criteria.

To ensure safety of the individuals at the site, tasks were designated to the people directly involved in the test before, during, and after the trial run. A document showing these tasks is located in Appendix B. Students were posted at various stations around the facility to control onlookers and to verify the site was clear of people before the truck was driven to the top of the ramp and set in place. 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 left that area until the test was conducted and the site was deemed safe after impact. A "Safety Alert," which is shown in Appendix C, was distributed out to all onlookers to warn them to stay within the designated spectator boundaries, and inform them of the procedures and objectives of the test. It was necessary to place one person near the impact point to engage the button on the high-speed camera, which had to be done within 18.3 m (60 ft). That person was safely placed on top of a nearby building that was barricaded to ensure the truck could not careen into it. Once everyone at their stations and the site was verified to be clear, the vehicle was driven up to and eased over the top of the ramp until the rear wheels were in the trench. The emergency brake was then engaged. After a final verification that the site was still clear of people and the research observers were ready, the truck's emergency brake was released and the truck was gently pushed onto the ramp.

Figure 11 shows a picture of the truck in its initial position. The truck then engaged the steel rail and rolled down the ramp through horizontal transition and impacted the barrier.

**Figure 10:** The test vehicle placed at the top of the ramp before it is released.

## 4.3 Results

The truck rolled smoothly and 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 was also more than adequate with regard to allowing enough room for the barriers to travel upon impact. The test proceeded as desired, indicating that the design and construction of the facility was a success. Figure 12 shows the post-impact state of the truck and the "E-Z Barriers."

**Figure 11:** Vehicle and test specimen after impact

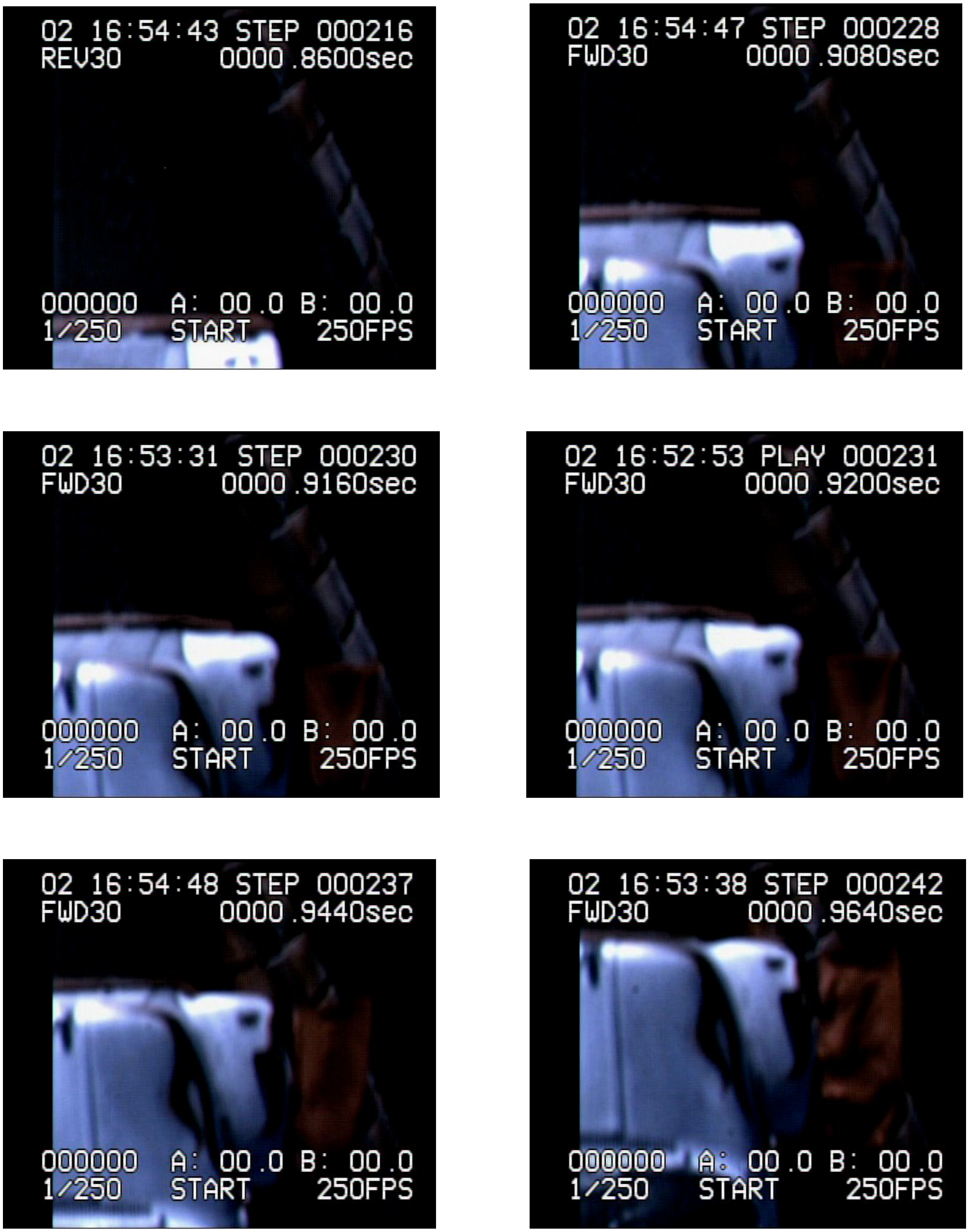



**Figure 12:** Selected frames of the impact from the high-speed camera.

The height, location, and timing of the trigger for the high-speed camera were also correctly estimated. The speed of the truck upon impact according to the high-speed camera was approximately 64.4 km/h (40 mph). The only problem encountered was the loss of daylight that affected the quality of the photos. Selected still-frames from the high-speed camera recordings are shown in Figures 13 and 14. A radar gun placed at the top of the ramp estimated the speed of the truck upon impact to be 62.8 km/h (39 mph). An average speed of 63.6 km/h (39.5 mph) between the two sources results in a speed 3.9 km/h (2.4 mph) faster than required to reach a test level 3. Overall, the impact severity reached during the test was 157 kJ (116.2 ft-lb), 19.5 kJ (14.4 ft-lb) higher than recommended for a test level 3.


**Figure 13:** Selected frames of the impact from the high-speed camera.

The performance of the facility also allowed the barriers to be effectively evaluated for structural adequacy and post-impact vehicle trajectory. The truck impacted the center barrier in the essentially the location it was anticipated to strike. The impact of the LoadStar 1700 truck pushed the center barrier approximately .91 m (3 ft) forward. The truck then changed angle and proceeded to travel along the length (parallel to) of the barriers. The truck traveled approximately 11 m (36 ft) before coming to a complete stop (Figure 15).

**Figure 14:** Barriers and truck after impact

A diagram labeling each of the eleven barriers is shown in Figure 16. The middle barrier (barrier number 6) sustained the initial impact and remained intact but, as stated, was pushed approximately .91 m (3 ft) back from its original position. Barriers 7-10 were crushed and torn apart. Barrier 11 was unmarred, but was pushed 1.8 m (6 ft) forward from its original position and turned on its side. Barriers 2-5 remained undamaged, but barrier number 1 had been crushed like an accordion on the near end due to the large amount of tension in the cable that strung all eleven barriers together. Figures 17a, b, and c show the final position of the truck and the barriers after impact. The cable was still intact after the impact. The truck sustained only minor damage to the passenger side bumper and fender, which were bent toward the front tire. None of the tires on the truck were punctured.

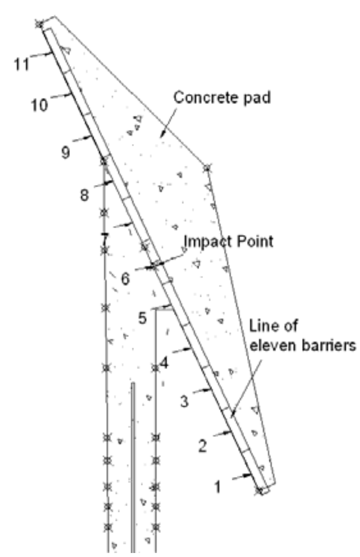



**Figure 15:** Plan view and labeling the eleven longitudinal barriers

a.

b.

c.

**Figures 16 a, b, c**: Final position of truck and barriers following the test run

## 4.4 Observations

The ramp test facility was adequate for conducting a vehicle impact test to give a preliminary indication of the structural adequacy of the safety barrier system and the post-impact vehicle trajectory. However, some limitations to the test configuration were evident. The primary observation made was during the release of the vehicle. Because of the weight of the truck and the limitation in time the mechanism used to release the truck was difficult to configure. Aligning the rollers on the truck with the steel beam on the ramp used to guide the truck was difficult to do as the truck was rolled from a horizontal position at the top of the ramp to the angle it needed to be before releasing it down the hill. As a result about 1.5 m (5 ft) of the steel beam had to be cut off and removed on site before the test was conducted.

The weight of the truck also made it difficult to position and release the truck to roll down the hill. As stated earlier, a trench was dug to hold the rear tires in place before a larger vehicle was used to push it over the edge and send it rolling down the hill. The push from the larger vehicle may have given the truck more acceleration down the hill than that which would have resulted from just gravity itself. This is suggested by the fact that the truck was moving at 63.6 km/h (39.5 mph) at impact, compared to the 59.7 km/h (37.1 mph), which was the predicted value calculated using Equation 2.

Lack of time because of limited daylight resulted in six of the eleven barriers (two on each end) being filled only with water. The barriers may have stopped the truck in less than 11 m (36 ft) if all eleven had been filled with sand and then saturated with water, making them heavier. The lack of daylight towards the end of the day also resulted in dark images from the high-speed camera. The photos recorded during the test were hard to decipher and did not result in very clear images of the barriers' response at the moment of impact.

# 5. Conclusion

A simplified testing facility was built, providing a simple, accurate, and inexpensive test to assess structural adequacy and post-impact vehicle trajectory of roadside safety devices. This facility, which is configured to produce test conditions similar to those of the official federal standards, is an intermediate step for manufacturers towards the more rigorous test recommended by the NCHRP Report 350.

The objective of the trial test was to assess the structural soundness of the ramp, observe the dynamic performance of the vehicle, and examine the structural adequacy of the E-Z Barriers as well as the post-impact vehicle trajectory. Overall, the structural components of the facility remained intact and undamaged. The truck traveled the trajectory smoothly and produced the desired impact speed and location. The vehicle impact resulted in an energy that was consistent with that of a test level 3 impact severity as specified in NCHRP Report 350 for temporary longitudinal safety barriers. The safety barriers successfully redirected the vehicle's travel in a direction parallel to the angle of the barriers and stopped the vehicle at approximately 11 m (36 ft) after impact. Both of these parameters lie within the federal requirements of an effective safety barrier.

Limitations on the facility included difficulty aligning the guide on the vehicle to the steel beam (used as a guide rail) on the ramp. Modifying the top of the ramp to include a dependable and safe release mechanism is needed to improve control at the start of the descent. A device to accelerate lightweight vehicles is also recommended to generate the impact energy required in smaller cars and trucks.

Nevertheless, the facility is available and capable of testing roadside safety features with a few minor improvements. This site enables a manufacturer to make decisions as to the need and merit of doing official crash tests based on better knowledge of their likely outcome.

## 5.1 Recommendations

The results and experience gained through construction and conduction of this test are of value in regard to future efforts that could be made to improve the test while retaining the objectives.

To progress towards an improved testing site and procedure, the following recommendations are made:

1. A release device at the top of the ramp needs to be conceived that will allow the vehicle to be placed on the ramp and released in a more controlled manner.

2. To achieve a high-level impact test on lighter vehicles on the existing ramp, some sort of accelerator should be incorporated into the release of the vehicle to ensure the necessary speed is gained to get the desired impact severity.

3. To maximize the image quality obtained from the high-speed camera adequate daylight and/or bright lighting is essential.

## 5.2 Final Comments

The test exceeded the expectations of simulating a test level 3 impact severity because of the type of truck used and its weight. The impact severity energy required by a test level 3 in the NCHRP Report 350 is 138.1 joules (101.9 ft-lb). The impact severity reached by the facility was 157.6 joules (116.3 ft-lb). This level of severity proves the facility can test roadside safety devices at a higher impact energy than that required of a temporary longitudinal barrier. Therefore, the facility could potentially be used for more extreme tests in the future involving larger vehicles and/or non-temporary roadside safety devices.

The recent development of standard performance tests for security barriers, walls, etc. by the U.S. State Department is an evolving consideration for the site. Among other requirements, 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). Also the payback must not penetrate the barrier beyond tight limits. However, the 6414 kg (14,140 lbs.) vehicle and measured speed of 64.4 km/h (40 mph) nearly achieve the K8 requirements for the vehicle impact energy. The speed achieved at the CSU site satisfies the K4 and K8 requirements. An 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 characteristic of a NCHRP level 3 type test. It provides a means for any interested party to pre-test a potential product to gain information about its effectiveness. Success in the preliminary test would be 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 a 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 performance of the test facility, itself, which was the research objective of the funded project. As demonstrated in the pilot test conducted, the test facility met that objective.

# REFERENCES


1. Transportation Research Board, National Research Council. National Cooperative Highway Research Program Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features. Washington, D.C. 1993.

2. Winkler, Derek J. Simplified Testing of Traffic Barrier Systems. MPC Report # 01-143, North Dakota State University, Fargo, N.D., June 2003.

3. Favre, Pierre-Aime. Ultimate Capacity of Mode of Failure of a Timber Bridge Guardrail. Master of Science Project, Colorado State University, October 1993.

4. Pellicane, Patrick J., Richard M. Gutkowski, and Mark S. Malone. Semi-empirical Studies of a Timber Bridge Guardrail under Static Transverse Loading. T*he Structural Engineer*, July 1990.

5. Gutkowski, Richard M., Patrick J. Pellicane, and Jean-Francois Kalin. Guardrail in Post-tensioned Timber-Bridge Specimen. *Journal of Structural Engineering*, December, 1994.

6. Shigidi, Abdalla M. Static and Dynamic Testing of a Timber Bridge Guardrail Specimen. Master of Science Thesis, Colorado State University, August 1995.

7. Certification Standard – Test Method for Vehicle Crash Testing of Perimeter Barriers and Gates, SD-STD-02.01, Revision A, Physical Security Division, Office of Physical Security Programs, Bureau of Diplomatic Security, U.S. Department of State, Washington, D.C. March 2003.

# Appendix A

1. Barrier Impact Testing Data Sheet

2. Safety Alert Handout

3. Barrier Impact Day: People and Tasks

## Barrier Impact Test
## Data Sheet

Test #: ______ Date: _________________ Time: ______________
Temperature, (F): ____________ Weather: __________________________________________

Ramp Condition: ____________________________________________________________________
Concrete Pad Condition: (Wet/ Dry/ Icy…)____________________________________________

Vehicle mass, lb:___________
Damage to Vehicle Prior to test: ______________________________________________________

Mass of Empty Barrier, lb: ___________________ Mass of Full Barrier:__________________
Barrier filled with: SAND WATER BOTH
Number of Barriers: _______ Total Length of Barriers: ________ Angle of Impact: ______
Set-up of Barriers: __ Cable connection barriers
__ Anchored at ends

Impact Speed, Speedometer (mph): _________
Impact Speed, Radar (mph): _____________
Computed Speed from High-speed Camera (mph):_____________
Computed Speed from line of Paint and Video Camera (mph): ___________

Vehicle Impact Point: Passenger side of front bumper
Barrier Impact Point: Mid-point of barrier @ inches off ground

Max. Dynamic Test Article Deflection, in: ___________
Location of Max. Dynamic Deflection: _______________________________________________
Max. Permanent Test Article Deflection, in: ___________
Location of Max. Permanent Deflection: _____________________________________________

Description of Post-Impact Vehicle Behavior: _________________________________________
__________________________________________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________

Vehicle Damage: ____________________________________________________________________
__________________________________________________________________________________

Description of Test Article Dynamic Performance: ____________________________________
__________________________________________________________________________________
__________________________________________________________________________________

Description of Test Article Damage: ___________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________

# Longitudinal Barrier Impact Testing

## SAFETY ALERT

**Spectators** shall stand only in designated area at top of hill (marked with tape).

* Please see Comments below…

Test Team:

**Be Alert** at all times to the position of the truck on the ramp.  When the **Red Flag** is flying at the top of the ramp, stand clear of the ramp and the concrete pad at the base of the ramp.  When the **Green Flag** is flying, you may proceed with caution around the ramp as necessary.

**Everyone involved** with the set-up of the barriers and the truck shall wear hardhats, steel-toed boots, and gloves.

**Everyone involved** shall stand clear of the ramp and barriers as the truck is mounted on the rail at the top to the ramp.

**When the set-up is complete**, Jeno and Misty will check that the ramp and the concrete pad are clear.  When Misty gives the “All-Clear” command from the top of the ramp (over radio), Jeno with ensure everyone is clear at the base of the ramp, and return the “All-Clear” to Misty (over radio).

**Junior will release the truck** only after Misty and Jeno have identified the ramp as clear, and after he has given one final visual check of the hillside to ensure everything is clear.

Only Junior, Misty, Dr. Gutkowski, and Jeno shall be permitted at the base of the ramp immediately after the impact.  Once observations and measurements have been taken and the ramp is deemed secure, those people designated to assist with the barrier set-up may proceed to the base of the ramp as needed: (Travis, Steve, Jeff Hoss, Dan Olsen, Tempero).

PLEASE report any unsafe activity immediately to Misty or Junior.

*** This is only a test run**.  There are **NO Guarantees** that this test will run smoothly.  Therefore, to ensure everyone’s safety please stay in designated spectator boundaries.

* The overall goal of this test is to ensure the ramp is built properly and the truck will run smoothly down the ramp for future tests.  The barriers may or may not break when the truck impacts them.  The barriers breaking do not mean they failed the impact test.  This test is to see if the barriers will adequately redirect the truck, or if they will stop the truck within a reasonable distance once the truck hits the barriers.

# Barrier Impact Test Day: People and Tasks

**Before Test:**

| | |
|---|---|
| Junior/Misty/Steve/Travis | Place Barriers and fill with sand and water |
| Misty | Annotate test conditions on data sheet |
| Jeff/Dan | Configure High-speed Camera and Light |
| Steve/Travis | Position Video Cameras |
| Dr.Gutkowski/Jeno | Pictures prior to test |
| Misty | Check Rail condition, ramp and concrete pad free of debris |
| Misty/Jeno | Check everyone is clear of ramp, then raise Red Flag |
| Junior | Position Truck at top of ramp |
| Kat | Direct spectators to top of ramp/hand out Safety Alert |

**During Test:**

| | |
|---|---|
| Misty/Jeno | Give all Clear over radio |
| Jeff/Dan | Give Ready signal at top of building |
| Misty | Countdown for vehicle release (five-count) |
| Junior | Release Truck |
| Travis | Video tape truck running down ramp and into barriers |
| Bill | Run radar gun from top of ramp |
| Jeff/Dan | Trigger High speed camera |

**After Test:**

| | |
|---|---|
| Misty | Annotate Test results on data sheet |
| Dr. G/Jeno | Pictures of vehicle and barriers after test |
| Steve/Travis | Retrieve video cameras |
| Jeff/Dan/Misty/Jeno | Transfer of Data from High-speed camera to video. |
| Kat | Insures spectators do not wander down to bottom of ramp |
| Junior/Steve/Travis/Misty | Clean-up of barriers and vehicle |