Development of an IBC MK-7 Barrier Capable of Restraining and Redirecting an 80,000-lb Tractor Van-Trailer

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This paper summarizes the results of an effort to develop an International Barrier Corporation (IBC) MK-7 barrier that can contain and redirect an 80,000-lb tractor van-trailer. After evaluation of various options, the approach of using portland cement–stabilized sand as the fill material was selected. The developmental effort included laboratory testing to determine the appropriate mix for the stabilized sand fill material, computer simulation to investigate the bending moments and shear strength required for the barrier to contain and redirect various vehicle types and weights, and full-scale crash testing of the smaller IBC MK-9 barrier with automobiles to obtain baseline data for use in developing the MK-7 truck barrier. A mix of 100 lb sand, 10 lb portland cement, and 10 lb water was selected for use as the fill material for the IBC MK-7 truck barrier. The barrier was struck by an 80,000-lb tractor van-trailer at 50.9 mph and 15.0 degrees. The tractor-trailer was contained and smoothly redirected by the barrier. The tractor-trailer rolled considerably toward the barrier during the impact sequence but remained upright with the bottom of the left side of the trailer sliding on top of the barrier. The vehicle was severely damaged, but the barrier sustained only minor damage. The results of the crash test indicate that the IBC MK-7 barrier with stabilized fill material meets the guidelines set forth in *NCHRP Report 230* for a high-performance truck barrier.

The results of an effort (*1,2*) undertaken at Texas Transportation Institute (TTI) to develop an International Barrier Corporation (IBC) MK-7 longitudinal barrier capable of restraining and redirecting an 80,000-lb tractor van-trailer are presented.

The standard IBC MK-7 barrier consists of modules with corrugated side panels attached to vertical bulkheads. Each module is 10.5 ft long, and a barrier installation may consist of any number of modules as required. The side panels and bulkheads are made of 14-gauge galvanized steel sheet metal. The overall cross-sectional dimensions of the barrier are 46 in. high and 44 in. wide. The barrier modules are filled with sand to the top of the barrier and covered with nonstructural 20-gauge galvanized sheet metal lids. The dimensions and details of the IBC MK-7 barrier are shown in Figure 1.

Previous crash tests of the standard IBC MK-7 barrier indicated that the existing barrier did not have the needed capability to restrain and redirect a heavy truck under standard test conditions. (There have been several impacts by large trucks on field installations of IBC MK-7 barriers, all of which resulted in containment of the vehicles without rollover or penetration of the barrier.) Various means of strengthening the barrier for the required loading from impact by a heavy truck were investigated. The approach eventually selected to strengthen the standard IBC MK-7 barrier was to stabilize the fill material by mixing the sand with portland cement and water. In this case, the basic fill material was a "pit run" siliceous sand available from a local quarry. By stabilizing the basic fill material, the strength of the barrier was increased 22 times over the original design with untreated fill material. This was accomplished by making the corrugated side panels work compositely. Another advantage of using stabilized fill material was to significantly reduce damage to the barrier from vehicular impacts.

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STUDY APPROACH

The study effort consisted of four major activities:

1. Laboratory study,
2. Computer simulation study,
3. Crash testing of MK-9 barriers with and without stabilized fill using 4,500-lb full-size automobiles, and
4. Crash testing of MK-7 barriers with stabilized fill using an 80,000-lb tractor van-trailer.

Brief descriptions of these activities are presented as follows.

Laboratory Study

A limited laboratory study was conducted on the pit run siliceous sand fill material to determine the amount of cement and water to be added to the mixture to achieve the desired strength. A standard compaction test was first conducted on the untreated sand to determine the optimum moisture content for maximum unit weight. The test results indicated that the optimum moisture content for this material was about 10 percent.

Using this moisture content, a number of mixes and test cylinders were prepared using varying amounts of cement to determine how much cement was required to achieve the desired shear strength. Standard compression and split cylinder tests were conducted on the test cylinders for the various mixes to determine their compressive, tensile, and shear strengths as well as their modulus of elasticity.

The mix eventually selected for use with the barrier was 10 lb of cement and 10 lb of water for every 100 lb of sand. This yielded a "stabilized soil" with a dry unit weight of approx-

PARTS LIST-ASSEMBLY NO. 000A00			
ITEM	PART NO.	DESCRIPTION	QTY
1	000A01	STANDARD PANEL	4
2	000A02	STANDARD BULKHEAD	1
3	000A03	STANDARD LID	1
4	000A04	STRAP NUT	12
5	000A05	5/8" HEX BOLT 1-3/4"L	24
6	000A06	5/8" FLAT WASHER	24
7	000A07	SELF TAPPING SCREW AND WASHER	8

NOTES:

1. STANDARD ASSEMBLY SHALL RECEIVE FILL MATERIAL AFTER CONNECTING WITH AN ADJACENT STANDARD OR OTHER ASSEMBLY. FILL MATERIAL SHALL BE LEVEL WITH TOP OF SIDE PANELS.

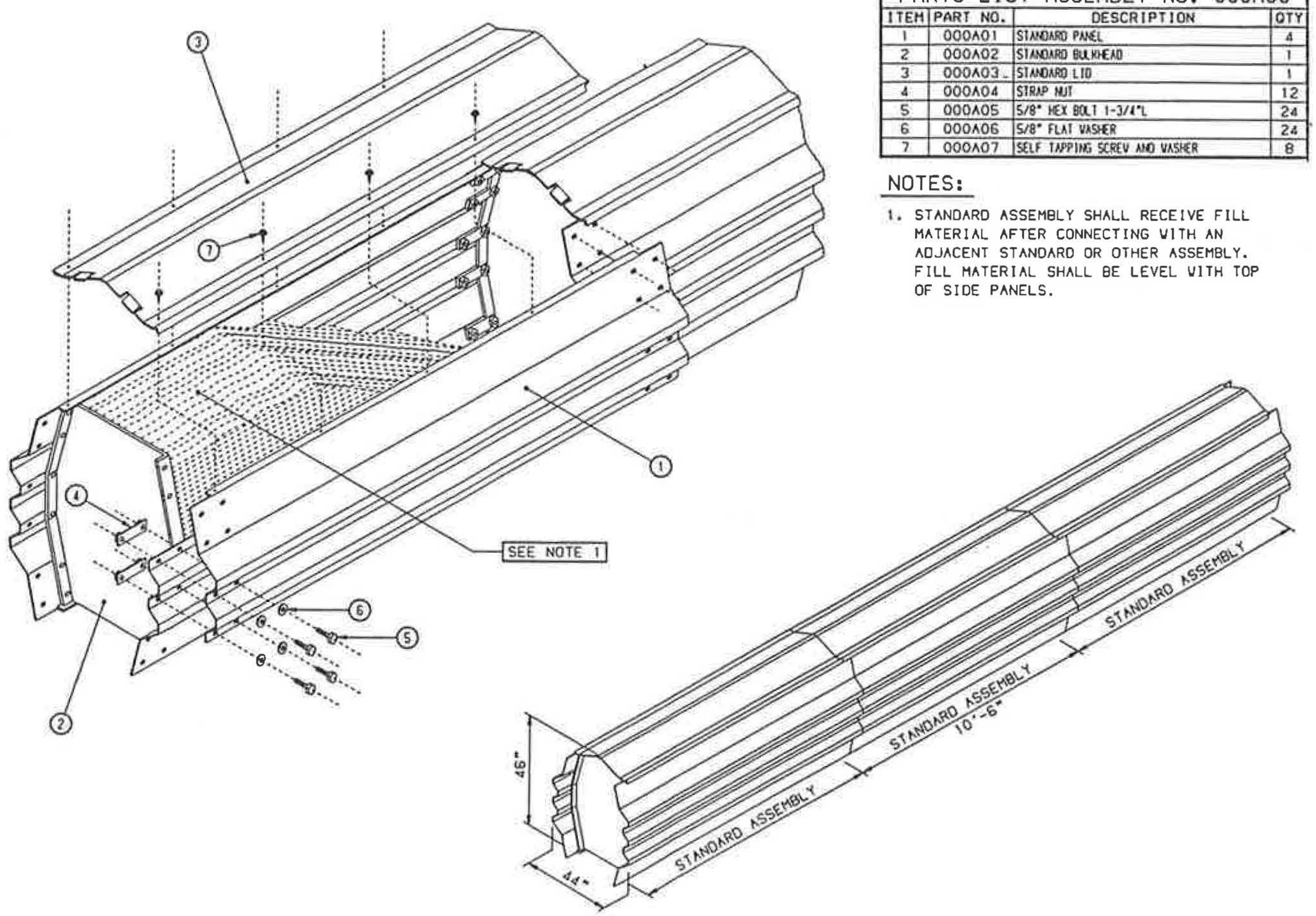


FIGURE 1 Details of MK-7 standard barrier assembly.

imately 110 lb/ft^3, a compressive strength of about 700 psi, a tensile strength of about 85 psi, a shear strength of about 117 psi, and a modulus of elasticity of about 1,000,000 psi.

Computer Simulation Study

To arrive at the barrier design, a TTI computer program called SABS (Simulation of Articulated Barrier Segments) was used to evaluate the structural behavior of the IBC MK-7 and MK-9 barriers as well as the various means of strengthening these barriers. The program indicated the magnitude of the bending moments and shear forces required to redirect various types of vehicles, from an 1,800-lb passenger car to an 80,000-lb tractor-trailer.

The SABS program was first calibrated using crash test data from previous crash tests conducted by or for IBC using 2,100-lb and 4,500-lb cars and a 20,000-lb school bus. The program was then used to investigate various methods of strengthening the barrier. The simulation results, along with a structural analysis of the barrier, indicated that the stabilized fill material needed to have a shear strength of approximately 85 psi in order for the IBC MK-7 barrier to redirect an 80,000-lb tractor-trailer.

Crash Tests of MK-9 Barriers with Automobiles

As part of the developmental effort, two full-scale crash tests were conducted on the smaller IBC MK-9 barrier with 4,500-lb full-size automobiles. The purpose of the IBC MK-9 barrier crash tests was to obtain baseline data for use in developing the IBC MK-7 truck barrier without incurring the high expenses of conducting multiple full-scale crash tests with tractor-trailers.

The standard IBC MK-9 barrier, like the IBC MK-7 barrier, consists of corrugated side panels attached to vertical bulkheads spaced 10.5 ft apart. The side panels and bulkheads are made of 14-gauge galvanized steel sheet metal. The overall dimensions of the barrier are 29.65 in. high (versus 46 in. for the MK-7 barrier) and 33 in. wide (versus 44 in. for the MK-7 barrier). The barrier is filled with sand to about 2 in. below the top of the barrier and covered with a nonstuctural lid made of 20-gauge galvanized steel sheet metal. The approximate weight of the barrier is 500 lb per lineal foot (versus 1,100 lb for the MK-7 barrier).

The test installations for both crash tests were identical except for the fill material. Each installation consisted of 18 bins (10.5 ft for each bin) of MK-9 barrier placed directly on top of a concrete pavement. The total length of the barrier was 189 ft. The first installation was filled with untreated sand and the second installation was filled with portland cement–stabilized sand, except for the bottom 2 to 3 in., which consisted of untreated sand to prevent the stabilized fill material from bonding with the pavement surface. The dimensions and details of the IBC MK-9 barrier are shown in Figure 2. Photographs of the test installation are shown in Figure 3.

The crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 230* (*3*). The test vehicles were instrumented with three rate transducers to measure roll, pitch, and yaw rates and a triaxial accelerometer near the vehicle center of gravity to measure acceleration levels.

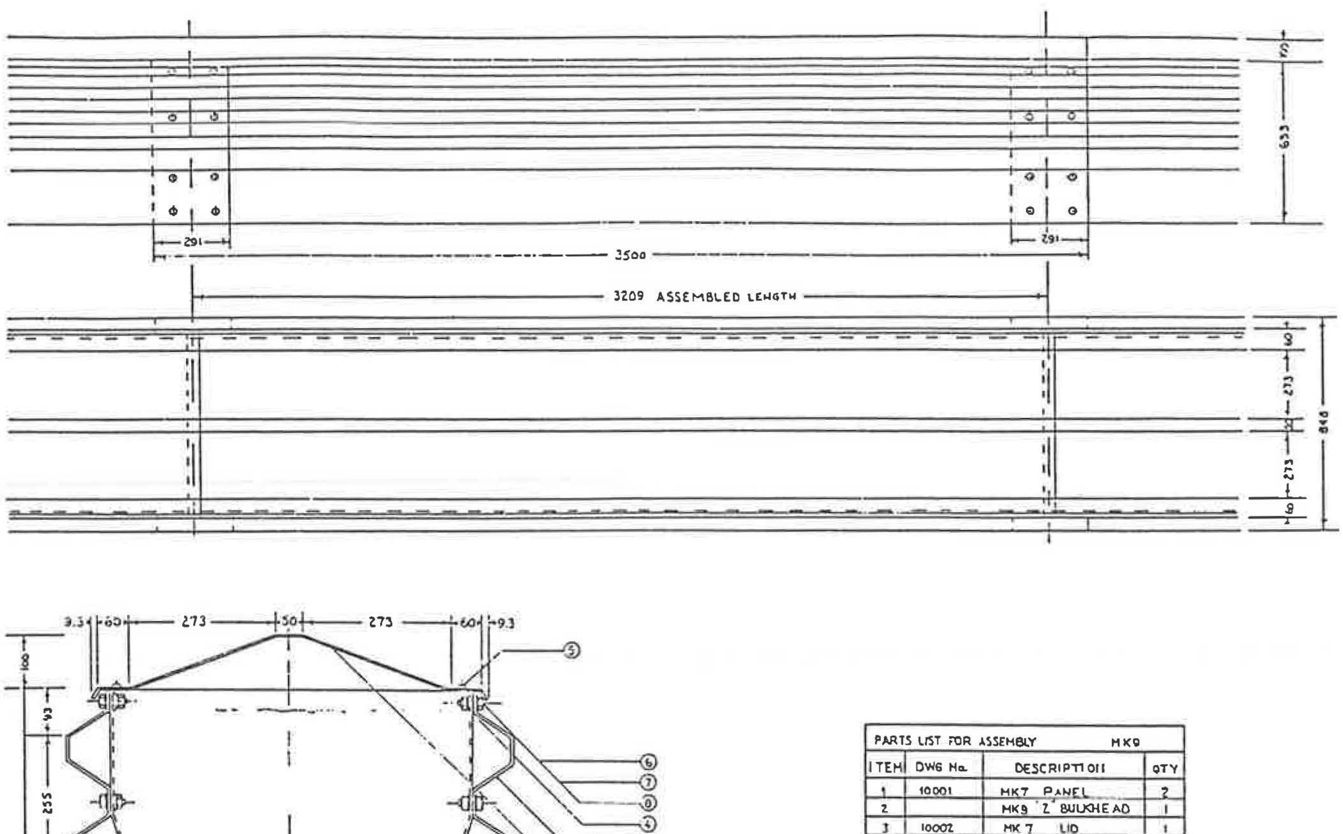
Test 1 (7091-2)

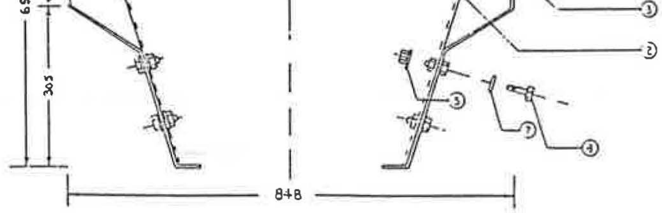
A 1981 Oldsmobile Ninety-Eight struck the standard IBC MK-9 barrier with untreated fill material at 61.96 mph and 25.2 degrees. The point of impact was the midpoint of the eighth bin, approximately 79.0 ft downstream from the beginning of the barrier. On impact, the vehicle began to ride up the face of the barrier. The right front wheel then climbed the barrier and the vehicle became completely airborne. The vehicle came down to the ground behind the barrier 15.0 ft from the point of initial impact. The brakes were then applied. The vehicle bounced and yawed counterclockwise and came to rest approximately 142.5 ft from the point of initial impact.

The barrier sustained severe damage, as shown in Figure 4. The permanent residual deformation was 29.0 in. laterally, located approximately 5 ft from the point of initial impact. The vehicle was in contact with the rail for 22.5 ft.

The vehicle sustained severe damage, as shown in Figure 5. Maximum crush was 13.0 in. at the left front corner of the vehicle. The left front wheel and control arm were severely bent and pushed rearward 9.0 in., causing damage to the floor pan under the driver's feet. The entire left side of the vehicle was dented and scraped. There was also considerable damage to the hood, bumper, grill, and radiator.

Sequential photographs, a summary of the test results, and other information pertinent to this test are given in Figure 6. The maximum 0.050-sec average acceleration experienced by the vehicle was −6.6 *g* in the longitudinal direction and −4.9 *g* in the lateral direction. Occupant impact velocity in the





PARTS LIST FOR ASSEMBLY MK9			
ITEM	DWG No.	DESCRIPTION	QTY
1	10001	MK7 PANEL	2
2		MK9 'Z' BULKHEAD	1
3	10002	MK 7 LID	1
4		MK9 LID BRACKET	2
5		SELF PLUG RIVET 1/4 x 9/32 LG	4
6	10005	STRAP NUT	8
7		FLAT WASHER 5/8 STD	16
8		HEX HD BOLT 5/8 x 1 1/4 LG	16

FIGURE 2 Details of IBC MK-9 standard barrier assembly.

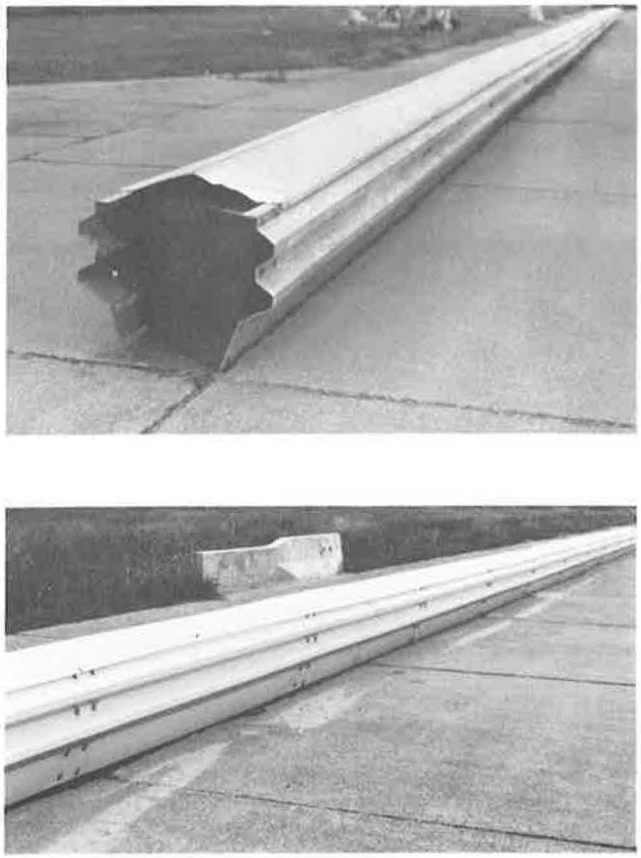


FIGURE 3 MK-9 barrier test installation.

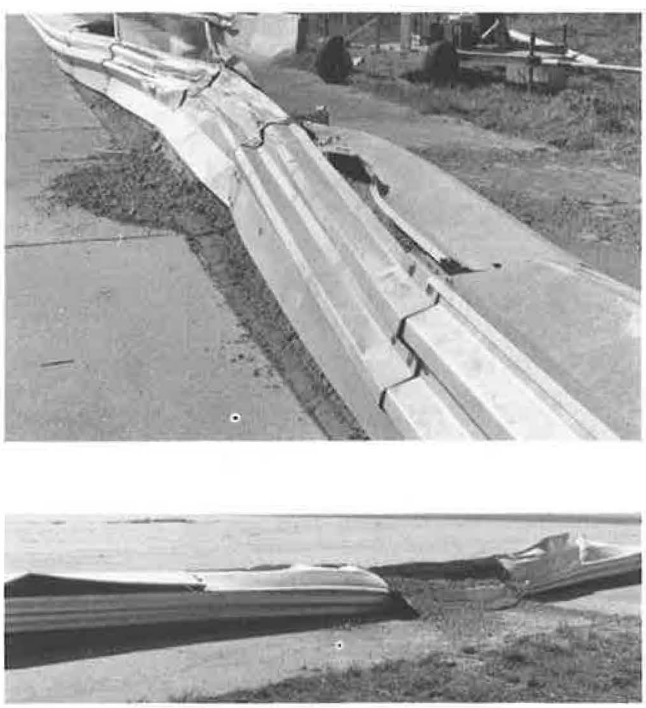


FIGURE 4 MK-9 barrier after Test 7091-2.

FIGURE 5 Vehicle after Test 7091-2.

longitudinal direction was 22.9 ft/sec and 13.0 ft/sec in the lateral direction. The highest 0.10-sec occupant ridedown accelerations were $-7.8\,g$ (longitudinal) and $-5.0\,g$ (lateral). The occupant risk criteria are not applicable to this test but are reported for information purposes.

In summary, the barrier failed to contain and redirect the vehicle. There was severe damage to the barrier due to penetration by the vehicle. The vehicle was also severely damaged, but there was only minimal deformation and intrusion into the occupant compartment. The vehicle, although airborne shortly after impact, remained upright during the initial test period and after leaving the barrier. The researchers had predicted that this test would not be successful, but the test was conducted to provide a baseline for comparison purposes.

Test 2 (7091-10)

A 1979 Cadillac struck the center of the ninth module of the MK-9 barrier with stabilized fill material (or approximately 89 ft from the beginning of the barrier) at 61.7 mph and 24.2 degrees. The vehicle was contained and smoothly redirected with an exit speed of 48.8 mph and an exit angle of 6.3 degrees. The brakes were applied as the vehicle exited the barrier. The vehicle yawed counterclockwise and came to rest approximately 218.0 ft from the point of impact.

The barrier sustained minor damage as shown in Figure 7. The maximum permanent residual deformation to the barrier was 1.0 in. laterally. The barrier moved laterally 4.5 in. on impact. The vehicle was in contact with the barrier for 14.0 ft.

The vehicle sustained severe damage, as shown in Figure 8. Maximum crush was 16.0 in. at the left front corner of the

0.000 s | 0.140 s | 0.290 s | 0.500 s

Test No	7091-2
Date	03/14/88
Test Installation	IBC MK9 Barrier
Length of Installation	189.0 ft (57.6 m)
Vehicle	1981 Oldsmobile 98
Vehicle Weight	
Test Inertia	4500 lb (2041 kg)
Vehicle Damage Classification	
TAD	11LFQ6
CDC	11FLEK3 & 11LFES3
Maximum Vehicle Crush	13.0 in (33.0 cm)

Impact Speed	62.0 mi/h (99.7 km/h)
Impact Angle	25.2 degrees
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal	-6.6 g
Lateral	-4.9 g
Occupant Impact Velocity	
Longitudinal	22.9 ft/s (7.0 m/s)
Lateral	13.0 ft/s (4.0 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-7.8 g
Lateral	-5.0 g

FIGURE 6 Summary of results for Test 7091-2.

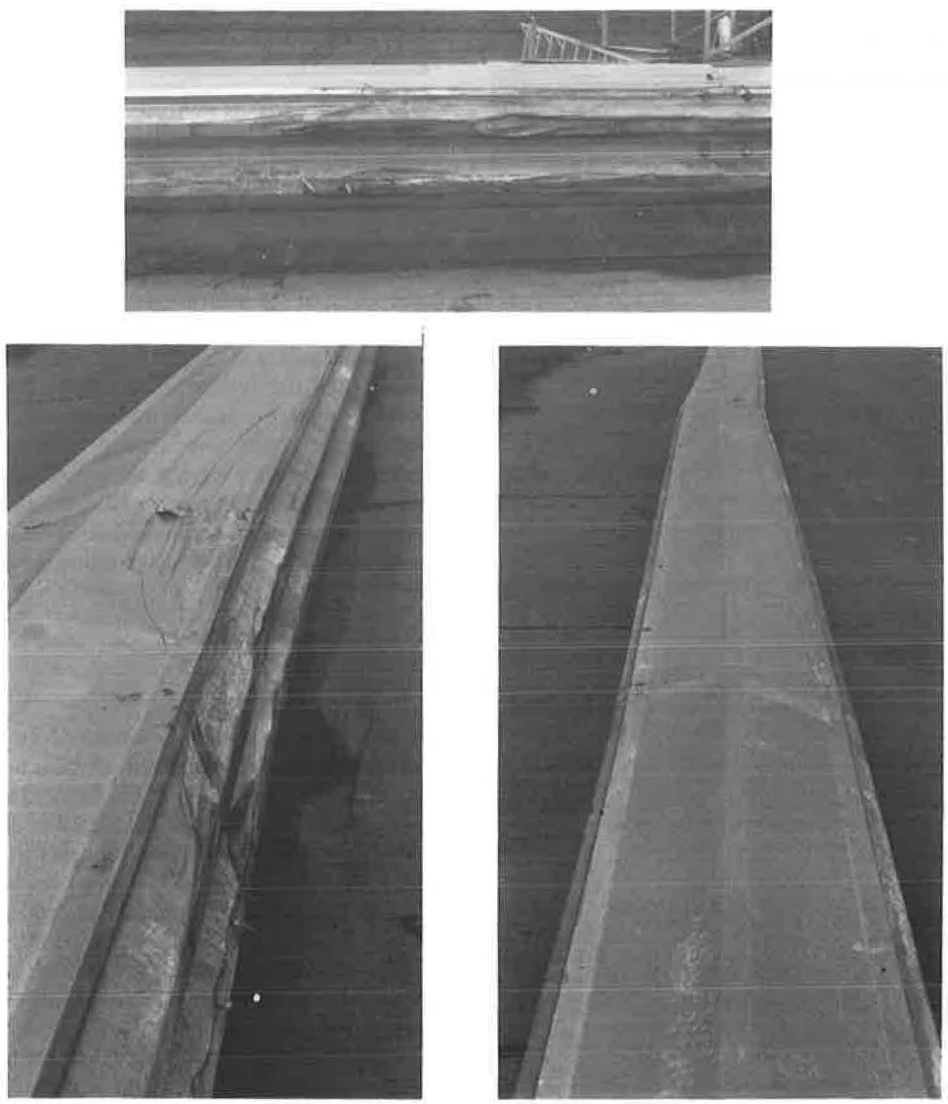


FIGURE 7 MK-9 barrier after Test 7091-10.

FIGURE 8 Vehicle after Test 7091-10.

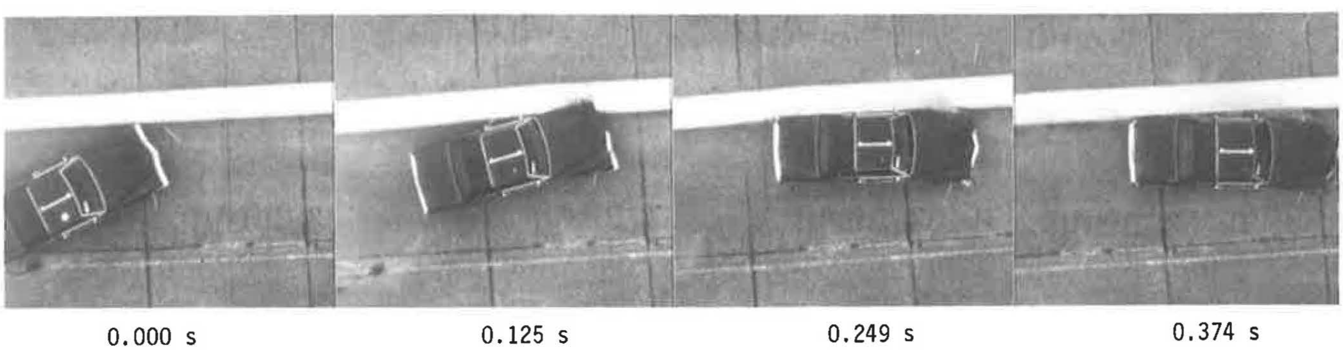
vehicle. The left front wheel was severely bent and pushed rearward 4.3 in. In addition, the subframe was bent. The entire left side of the vehicle, including the front and rear fenders and the door, was dented and scraped. The entire front end of the vehicle sustained considerable damage.

Sequential photographs, a summary of the test results, and other information pertinent to this test are given in Figure 9. The maximum 0.050-sec average acceleration experienced by the vehicle was -6.3 *g* in the longitudinal direction and -12.5 *g* in the lateral direction. The occupant impact velocity was 18.6 ft/sec in the longitudinal direction and 27.0 ft/sec in the lateral direction. The highest 0.10-sec occupant ridedown accelerations were -5.9 *g* (longitudinal) and -10.8 *g* (lateral). The occupant risk criteria are not applicable to this test but are reported for information purposes.

In summary, the barrier contained and redirected the vehicle. The vehicle sustained severe damage, but the barrier sustained minimal damage. There were no detached elements or debris. There was minimal deformation and intrusion into the occupant compartment. The vehicle remained upright and stable during the initial test period and after leaving the barrier. The exit speed and trajectory of the vehicle indicate minimum potential intrusion into the adjacent traffic lanes.

Test 3 (7132-1)—Crash Test of MK-7 Barrier with 80,000-lb Tractor Van-Trailer

The test installation consisted of 33 modules (10.5 ft for each module) of the standard MK-7 barrier for a total length of



Test No	7091-10
Date	01/17/89
Test Installation	IBC MK9 Barrier
Length of Installation . . .	189 ft (57.6 m)
Vehicle	1979 Cadillac Coupe DeVille
Vehicle Weight	
Test Inertia	4500 lb (2041 kg)
Vehicle Damage Classification	
TAD	11FL4 & 11LD2
CDC	11FLEK4 & 11LDES1
Maximum Vehicle Crush	16.0 in (40.6 cm)

Impact Speed	61.7 mi/h (99.3 km/h)
Impact Angle	24.2 degrees
Exit Speed	48.8 mi/h (78.6 km/h)
Exit Angle	6.3 degrees
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal	-6.3 g
Lateral.	-12.5 g
Occupant Impact Velocity	
Longitudinal	18.6 ft/s (5.7 m/s)
Lateral	27.0 ft/s (8.2 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-5.9 g
Lateral	-10.8 g

FIGURE 9 Summary of results for Test 7091-10.

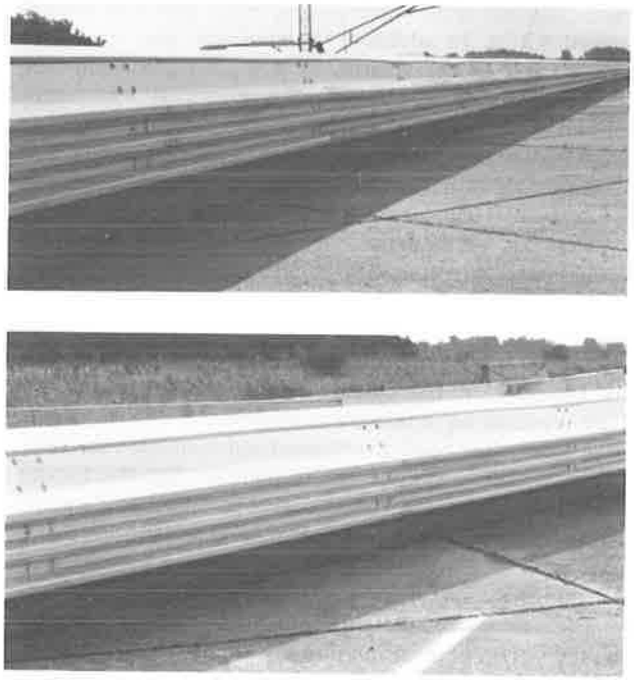
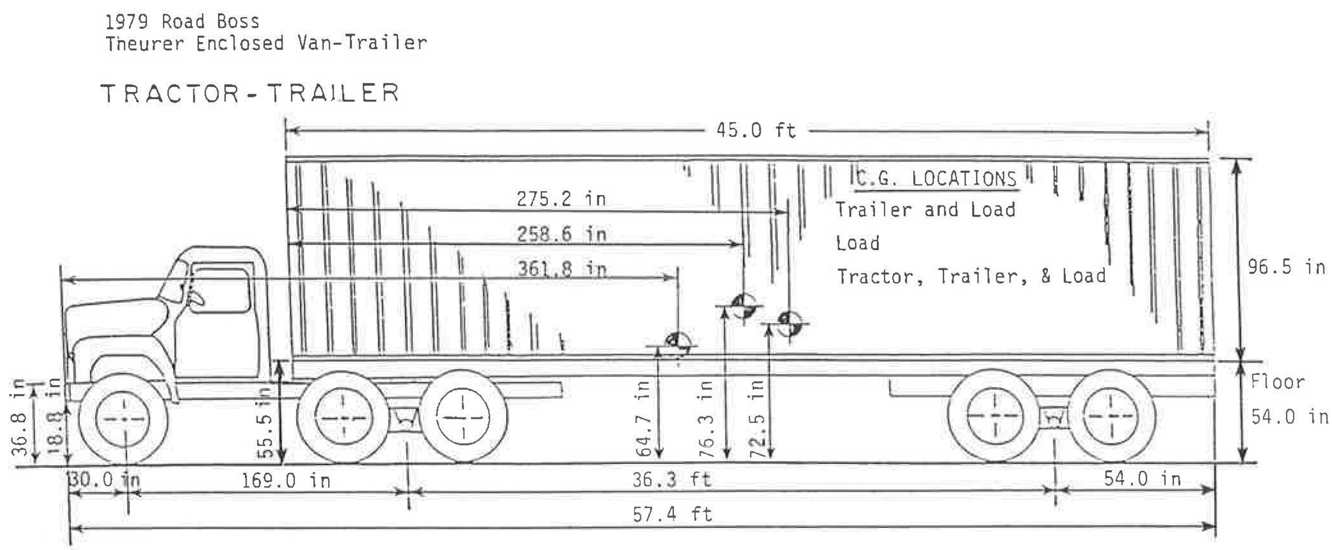


FIGURE 10 IBC MK-7 barrier test installation.

FIGURE 11 Tractor-trailer before Test 7132-1.



EMPTY WEIGHTS:	
Weight on front axle	8,720
Weight on center axles	11,920
Weight on rear axles	8,840
Total Empty Weight	29,480

LOADED WEIGHTS	
Weight on front axle	11,230
Weight on center axles	34,510
Weight on rear axles	34,260
Total Loaded Weight	80,000

FIGURE 12 Vehicle properties for Test 7132-1.

346.5 ft. The barrier modules were filled with portland cement–stabilized sand and the sand was mechanically compacted. The stabilized sand consisted of pit run sand mixed with 10 percent portland cement with a 10 percent moisture content (i.e., 100 lb sand mixed with 10 lb portland cement and 10 lb water). The test installation was placed directly on a concrete pavement surface with no anchorage to the pavement. A layer of untreated sand 2 to 3 in. high was placed at the bottom of the test barrier installation. The purpose of using a layer of untreated sand was to prevent the stabilized sand from bonding with the pavement surface. Photographs of the test installation are shown in Figure 10.

The crash test procedures were generally in accordance with guidelines presented in *NCHRP Report 230*. The test tractor was a 1979 White Road Boss with an empty weight of 16,240 lb. The trailer was a Theurer enclosed van-trailer with an empty weight of 13,060 lb. The combined tractor-trailer empty weight was 29,480 lb. Photographs of the tractor-trailer are shown in Figure 11.

The tractor-trailer was loaded with sandbags and wooden pallets to a test inertia mass of 80,000 lb, in accordance with *NCHRP Report 230* requirements. The height of the center of gravity (c.g.) for the combined tractor-trailer was 64.7 in., which compares with the c.g. height of 65 in. ± 1 in. used in most other 80,000-lb tractor-trailer crash tests. The key dimensions of the tractor-trailer; the actual locations of center of gravity for the load, trailer and load, and the combined tractor-trailer and load; and the empty and loaded axle weights are shown in Figure 12.

The test tractor-trailer was instrumented with three rate transducers to measure roll, pitch, and yaw rates. In addition, the tractor-trailer was instrumented with one set of triaxial accelerometers and three sets of biaxial accelerometers to measure acceleration levels during the impact. The triaxial accelerometers were mounted near the rear of the fifth wheel. The three sets of biaxial accelerometers were located at the front of the tractor, near the front of the trailer, and at the rear of the trailer.

The tractor-trailer struck near the center of the 11th module, approximately 110 ft from the beginning of the barrier, at 50.9 mph and 15.0 degrees. The tractor-trailer was smoothly redirected and remained in contact with the barrier through the end of the barrier. When the truck lost contact with the end of the barrier, the brakes were applied, and the tractor-trailer turned to the left and came to rest almost perpendicular to the barrier. The tractor-trailer traveled 275 ft from the initial point of impact to the point of rest. The tractor-trailer rolled considerably toward the barrier during the impact sequence but remained upright, with the bottom of the left side of the trailer sliding on top of the barrier.

The barrier sustained minor damage as shown in Figure 13. The maximum permanent residual deformation to the barrier was 4.0 in. and the maximum permanent lateral movement was 7.0 in. The stabilized sand fill material remained basically intact after the impact with only localized areas of crushing. Although the vehicle was in contact with the barrier for 239.0 ft, the major damage to the barrier was confined to the first three modules (or roughly 30 ft) downstream from the point of initial impact. Damage to the other modules was limited to scrapes and tears of the side panels as the tractor-trailer slid along the barrier to its final rest position.

The vehicle sustained severe damage, as shown in Figure 14. The front left corner of the bumper was deformed, and the left side of the tractor was damaged. The left front wheel was deformed from impact with the barrier, and the wheel was displaced 18 in. rearward from its normal position into the battery box. The rearward displacement was a result of the fracturing of one right-side and both left-side U-bolts, which mount the front axle to the front leaf springs. The lower left front and upper right front shock absorber mounts were

FIGURE 13 IBC MK-7 barrier after Test 7132-1.

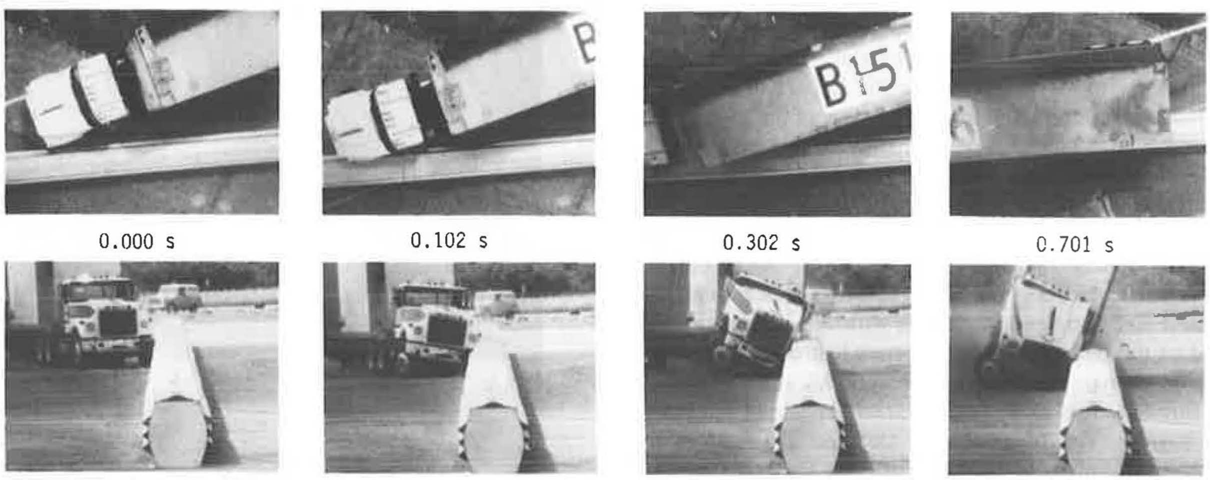
FIGURE 14 Tractor-trailer after Test 7132-1.

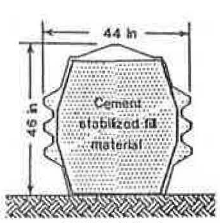
separated from the axle assembly, and the pitman arm separated from the steering assembly as the axle was displaced rearward. The battery box was deformed and displaced rearward into the front surface of the left fuel tank, but the fuel tank remained intact with only minor deformations.

The left frame rail was displaced rearward 6 in. relative to the right rail. The left outer tires of the tractor's rear tandem axles were deflated and the rims were severely deformed as a result of contact with the barrier. The tractor's rear tandem axles were shifted back on the left side approximately 2.0 in.

The trailer sustained direct contact damage along the entire lower left side. The left rear suspension mounting rail was fractured, allowing the floor to drop down approximately 22.8 in., forming a V-shaped left side surface. The left wall of the trailer shifted to the left approximately 40 in. (when viewed from the rear) and separated from the roof structure at the top joint. The right wall was deformed slightly due to induced damage. Both left outer tires on the trailer axles were deflated and the rims were damaged extensively. The trailer landing gear also sustained minor damage.

Sequential photographs, a summary of the test results, and other information pertinent to this test are given in Figure 15. The maximum 0.050-sec average accelerations experienced by the tractor-trailer at the various accelerometer locations along the tractor-trailer are summarized in Table 1. For instance, the maximum 0.050-sec average acceleration experienced by the tractor near the fifth wheel was $-5.4\ g$ in the





Test No. 7132-1
Date 05/31/89
Test Installation . . . . IBC MK-7 Median Barrier w/stabilized fill material
Installation Length . . . 346.5 ft (105.6 m)
Vehicle . . . . 1979 White Road Boss Tractor w/van-trailer
Vehicle Weight
Test Inertia . . . . . . 80,000 lb (36,287 kg)
Gross Static . . . . . . 80,000 lb (36,287 kg)

Impact Speed . . . . . . 50.9 mi/h (81.9 km/h)
Impact Angle . . . . . . 15.0 deg
Exit Speed . . . . Not Applicable
Exit Trajectory . . . . Not Applicable
Vehicle Accelerations (near fifth wheel)
(Max. 0.050-sec Avg)
Longitudinal . . . . . -5.4 g
Lateral . . . . -10.2 g
Occupant Impact Velocity (passenger compartment)
Longitudinal . . . . . 8.8 ft/s (2.7 m/s)
Lateral . . . . 13.9 ft/s (4.2 m/s)
Occupant Ridedown Accelerations
(passenger compartment)
Longitudinal . . . . . -2.6 g
Lateral . . . . -4.6 g

Note: A layer of untreated sand, two to three inches in depth, was placed at the bottom of the test barrier installation.

FIGURE 15 Summary of results for Test 7132-1.

TABLE 1 SUMMARY OF MAXIMUM 0.050-SEC AVERAGE ACCELERATIONS AT VARIOUS LOCATIONS ALONG TRACTOR-TRAILER

Location of Accelerometer	Maximum 0.050-Second Average Acceleration (g) Longitudinal	Lateral	Vertical
Front of Tractor	- 3.2	- 5.5	N/A
Near Fifth Wheel of Tractor	- 5.4	-10.2	3.2
Front of Trailer*	- 1.7	- 4.1	N/A
Rear of Trailer	- 2.5	-10.3	N/A

N/A - Not applicable

* Note: Signal loss for this accelerometer group at 0.460 second after impact.

longitudinal direction, −10.2 *g* in the lateral direction, and 3.2 *g* in the vertical direction.

Occupant impact velocity in the longitudinal direction was 8.8 ft/sec and 13.9 ft/sec in the lateral direction. The highest 0.10-sec occupant ridedown accelerations were −2.6 *g* (longitudinal) and −4.6 *g* (lateral). These occupant impact velocities and ridedown accelerations are from the accelerometers mounted in the passenger compartment at the front of the tractor.

In summary, results of the crash test indicate that the IBC MK-7 barrier with stabilized fill material meets the guidelines set forth in *NCHRP Report 230*. The barrier successfully contained and redirected the 80,000-lb tractor van-trailer. The barrier sustained only minor damage with maximum permanent deformation of 4.0 in. and maximum lateral movement of approximately 7 in. The tractor-trailer sustained severe damage, but there were no detached elements or debris and no deformation or intrusion into the occupant compartment. The vehicle traveled along the barrier after impact to the end of the barrier, indicating minimal potential for intrusion into adjacent traffic lanes. The vehicle remained upright throughout the test.

SUMMARY

The results of an effort to develop an IBC MK-7 barrier that could contain and redirect an 80,000-lb tractor van-trailer were summarized. The developmental effort included laboratory testing, computer simulation, and full-scale crash testing of the smaller IBC MK-9 barrier with automobiles. A prototype IBC MK-7 barrier with stabilized fill material was constructed and crash tested with an 80,000-lb tractor van-trailer at 50.9 mph and 15.0 degrees. The tractor-trailer was contained and smoothly redirected by the barrier. The tractor-trailer rolled considerably toward the barrier during the impact sequence but remained upright, with the bottom of the left side of the trailer sliding on top of the barrier. The vehicle was severely damaged, but the barrier sustained only minor damage. The results of the crash test indicate that the IBC MK-7 barrier with stabilized fill material meets the evaluation guidelines set forth in *NCHRP Report 230* for a high-performance truck barrier.

ACKNOWLEDGMENTS

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3. J. D. Michie. *NCHRP Report 230: Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*. TRB, National Research Council, Washington, D. C., 1981.