Crash Test and Evaluation of a Precast Concrete Median Barrier

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Median barriers are used on high-volume, high-speed traffic facilities to prevent errant vehicles from crossing a median and conflicting with the opposing traffic stream. A secondary function for some designs of median barriers is to minimize the glare of opposing headlights. The cast-in-place concrete median barrier has proved to be an effective and economical barrier in Texas and other states. Investigation of the use of a precast concrete median barrier (PCMB) stemmed from the interest in using a barrier to be prefabricated concurrently with roadway construction. This more effective usage of work force as well as early project completion and acceptance could provide measurable potential savings to both the contractor and the state. In addition, when this barrier is installed on existing facilities, the traffic may be disrupted for a considerable period of time if it is cast in place. Consequently, PCMB that can be quickly installed on active facilities with a minimum period of traffic disruption is needed. For a precast concrete median barrier to function properly in redirecting vehicles, the relatively short precast sections must be adequately connected after they are placed in the highway median. Engineers of the Texas Department of Highways and Public Transportation and the Texas Transportation Institute developed working drawings for precast sections of a PCMB and two connection details. Full-scale crash tests were conducted on the PCMB and connections in order to verify the stability and strength of the installation.

Median barriers are used on high-volume, high-speed traffic facilities to prevent errant vehicles from crossing a median and conflicting with the opposing traffic stream. Current warrants proposed by the National Cooperative Highway Research Program for the installation of median barriers are based on a 2-year traffic projection and median width (1). In a typical case, the warrants state that, for a median width of 6.1 m (20 ft) or less and a predicted average daily traffic (ADT) of 20 000 or more, a median barrier should be installed. Facilities with less traffic than this frequently do not have median barriers. If the ADT increases to 20 000 or more, installation of a median barrier on an existing facility will often become necessary.

Texas median barrier warrants are based on the width of the median. In brief, the Texas warrants require that for medians up to 7.3 m (24 ft) in width a concrete barrier should be used. For medians from 5.5 to 7.3 m (18 to 24 ft) in width, either the concrete or the double steel type of beam should be used. For medians from 7.3 to 9.1 m (24 to 30 ft), the double steel type of beam should be used.

The cast-in-place concrete median barrier (CMB) has proved to be an effective and economical barrier in Texas and other states. Investigation into the use of a precast concrete median barrier stemmed from the interest in using a barrier to be prefabricated concurrently with roadway construction. This more effective usage of work force as well as early project completion and acceptance could provide measurable potential savings to both the contractor and the state. However, when this barrier is installed on existing facilities, the traffic may be disrupted for a considerable period of time if it is cast in place. As a consequence, a precast concrete median barrier (PCMB) that can be quickly installed on active facilities with a minimum period of traffic disruption is needed. In addition, sections of a PCMB can also be used as a temporary barrier during construction of a new facility since the precast sections are portable and can be moved after the need no longer exists.

For a PCMB to function properly in redirecting a vehicle, the relatively short precast sections must be adequately connected after they are placed in the desired location. Engineers of the Texas Department of Highways and Public Transportation (DHPT) and the Texas Transportation Institute (TTI) developed working drawings for 9.1-m-long (30-ft-long) precast concrete sections of a PCMB and two different connection details. Three sections of the PCMB were precast, hauled to the Texas A&M University Research Annex, and installed by using the two different connection details. Full-scale crash tests were conducted on each of the connections to verify the stability and the strength of the installation.

DESIGN AND INSTALLATION

Design

The cross section used for the PCMB is shown in Figure 1. This shape is standard in Texas and is essentially the New Jersey cross section with minor modifications. The

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concrete median barrier of the New Jersey cross section has been extensively tested to determine the adequacy of the shape and redirection capabilities. Since these tests, the CMB has been subjected to testing by numerous organizations including TTI (3, 4, 5). These reports attested to the sufficiency of the CMB particularly for narrow medians and shallow impact angles. In all of the successful tests, the CMB was attached to a simulated bridge parapet (2) or the barrier was long, massive, and rigid.

The Texas DHPT has used precast CMB sections on bridges for some time. These precast sections varied from 4.6 to 9.1 m (15 to 30 ft) in length and were rigidly attached to the bridge deck with anchor bolts at 0.6 m (2 ft) maximum spacing.

California had tested twelve 3.8-m-long (12.5-ft-long) precast sections approximately 2268 kg (5000 lb) each pinned together with a steel rod inserted into eyebolts cast in the ends of the sections to form a 45.7-m (150-ft) barrier free standing on asphalt concrete. Two tests were conducted with a 2177-kg (4800-lb) vehicle at a nominal speed of 104.6 km/h (65 mph). In the first test, which was moderately successful, the vehicle impacted the barrier at 7 deg. The second test was at a 25-deg-impact angle and was less than successful. The barrier rotated and displaced laterally, and the vehicle snagged. A second barrier of five 6.1-m (20-ft) sections of approximately 3629 kg (8000 lb) was constructed and tested at 104.6 km/h (65 mph) and 35 deg, that is, more than the normal 25 deg. This test was even less successful than test 2. The barrier segments rotated, displaced laterally, and the vehicle rolled over.

In view of the California experience, engineers with the Texas DHPT elected to test 9.1-m-long (30-ft-long) precast sections approximately 6804 kg (15 000 lb) in mass (Figure 2). This length and mass appeared to be the maximum that could be readily transported and handled.

Two slightly different dowel-joint details were used to connect the 9.1-m (30-ft) precast sections together (Figure 3). The male-female dowel connection used three No. 8 dowels [2.54 cm (1 in) in diameter] 0.46 m (18 in) long precast in one end and three mating 5.08-cm-diameter (2-in-diameter) tapered holes cast in the opposite end as shown in Figure 2. A pressure grout hole was cast vertically behind the tapered female holes. The second connection used was the grooved connection, which also used three No. 8 dowels [2.54 cm (1 in) in diameter] 46 cm (18 in) long as shown in Figure 3. The grooved connection was believed to be more desirable when the precast sections would be used as a temporary barrier. It was believed that the grout and dowels could be chipped out of the grooved blockouts and the precast sections more readily reused. This latter connection detail was arrived at after the PCMB sections were cast; therefore these grooves were sawed instead of being precast in as would be desirable.

The lower slope dimension on the PCMB sections was increased from 7.6 to 10 cm (3 to 4 in) so that the section would maintain the standard 81-cm (32-in) height after the 2.54 cm (1 in) of asphalt concrete fill is placed on the pavement (Figure 1). This asphalt concrete pavement (ACP) fill is an integral and necessary part of the barrier design for permanent installation because it prevents lateral displacement and cracking at the connections during vehicle impact.

Engineers and precast concrete contractors first indicated that the PCMB units would be cast right side up and lifted at the ⅕ points from each end. An analysis of the section indicated that the maximum concrete stress to be expected in tension was 393 kPa T (57 lbf/in^2) for an uncracked section. This value was well within the limits suggested by ACI-318-71. The recommended safe ultimate concrete stress in tension is $f_t = \sqrt{7.5f'_c}$ or 2827 kPa (410 lbf/in^2) for 20 684-kPa (3000-lbf/in^2) concrete. A cracked section analysis was made by using No. 4 bars [1.27 cm (0.5 in) in diameter] in each corner of the section. The steel stress would be approximately 7584 kPa T (1100 lbf/in^2) with the concrete compressive stress less than 827 kPa (120 lbf/in^2). All of these values are well within limits published by the American Association of State Highway and Transportation Officials and the American Concrete Institute.

Installation

Three 9.1-m (30-ft) precast sections were installed on the concrete parking apron at the Texas A&M University Research Annex as shown by Figure 2. An asphalt concrete leveling course was applied; each section, the mass of which was approximately 6804 kg (15 000 lb), was set in place; the two different joints were grouted; and the 2.54-cm (1-in) ACP backup fill was placed on both sides of the PCMB. After they were grouted, the joints were covered with wet burlap to aid in curing.

A concrete grout of about a 10-cm (4-in) slump composed of 15 kg (33 lb) of portland cement, 45 kg (100 lb) sand, and 6.8 kg (15 lb) water was used to grout the groove joint. The same mix was used for the dowel connection except that the slump was increased to 15 cm (6 in). Two 10-cm (4-in) cylinders were cast from the mix used to grout each joint. These were cured and tested in compression just before each impact test. The 5-day strength of the cylinders placed in the groove joint was 37 232 kPa (5400 lbf/in^2). The samples from the dowel joints tested 39 576 kPa (5740 lbf/in^2) at 6 days of age.

Crash test 1 was conducted on the groove connection with the 2.54-cm (1-in) ACP located on both sides of the PCMB to prevent lateral displacement of the barrier under the vehicle impact. Because this test proved successful, it was decided to remove the ACP from behind the barrier for crash test 2 on the male-female dowel connection. This test would give an indication of how the doweled connection would behave if the precast sections were used as a temporary barrier with no ACP backup.

VEHICLE CRASH TESTS

Test 1: Grooved Joint Connection

The vehicle used for test 1 was a 2040-kg (4500-lb) 1966 Pontiac. The impact point of the left front fender and the barrier occurred 2.1 m (7 ft) upstream from the groove joint as shown in Figure 2. The actual impact angle was 23.5 deg and the actual impact velocity was 97.4 km/h (60.5 mph). Figure 4 shows the vehicle before and after impact. The vehicle was smoothly redirected and the exit angle was 7 deg. The maximum vehicle roll angle of 18 deg occurred while the vehicle was in contact with the barrier. The vehicle remained upright during the test. The front wheel and steering linkage were damaged and the vehicle was inoperable after the impact. The sequence of the impact is shown in Figure 5.

The average lateral deceleration taken from the high-speed film data was 7.5 *g* taken over 206 ms. The average longitudinal deceleration over the same period was 1.6 *g*. The barrier did not roll or slide laterally. Figure 6 shows close-up views of the joint before and after impact. A hairline or shrinkage crack had appeared in the vertical face before impact. There was no evidence that this crack was altered after impact or that any other cracking at the connection occurred during impact. Damage to the precast barrier and joint was nil.

Test 2: Male-Female Joint

The asphalt concrete base was removed from the back side of the PCMB before test 2 to determine whether the barrier had to be stabilized when used as a temporary installation.

The vehicle used for test 2 was a 2060-kg (4540-lb) 1965 Oldsmobile. The impact point of the left front fender occurred 2.1 m (7 ft) upstream from the male-female dowel joint as shown in Figure 2. The actual impact angle was 24.2 deg, and the actual impact velocity was 96.2 km/h (59.8 mph). The vehicle was smoothly redirected and the exit angle was 3 deg. Again the maximum vehicle roll angle of approximately 18 deg occurred while

Figure 1. PCMB cross section.

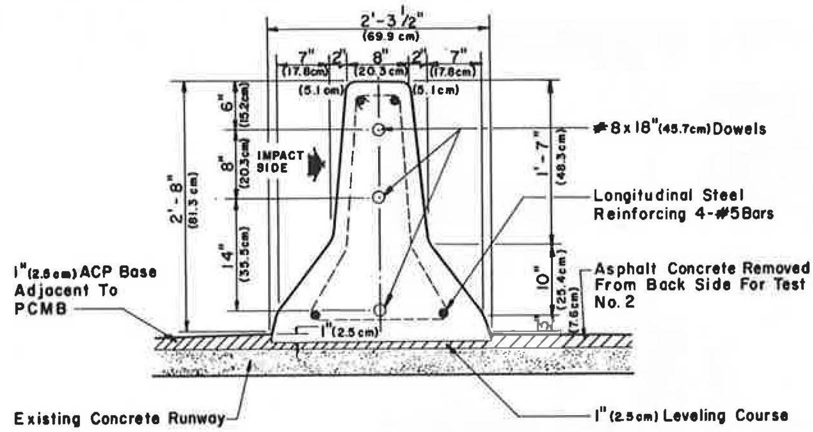


Figure 2. PCMB connection test installation.

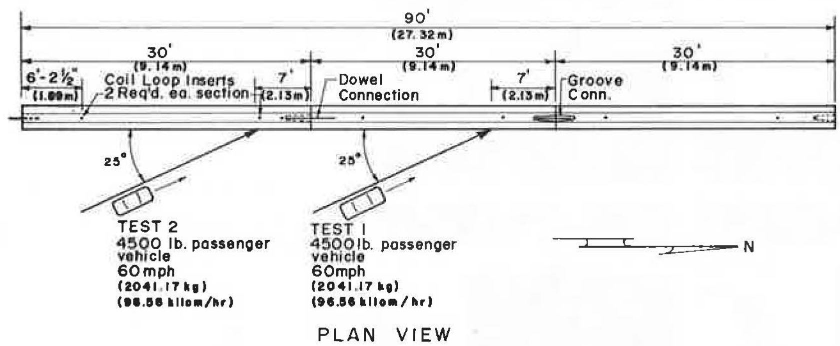


Figure 3. PCMB test connection details.

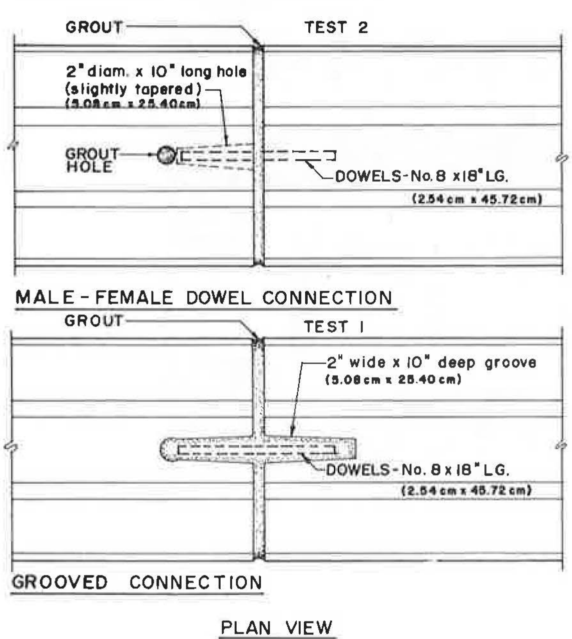


Figure 4. Test vehicle before and after impact.

(a) Before Impact

(b) After Impact

Figure 5. Overhead view of concrete median barrier in test 1.

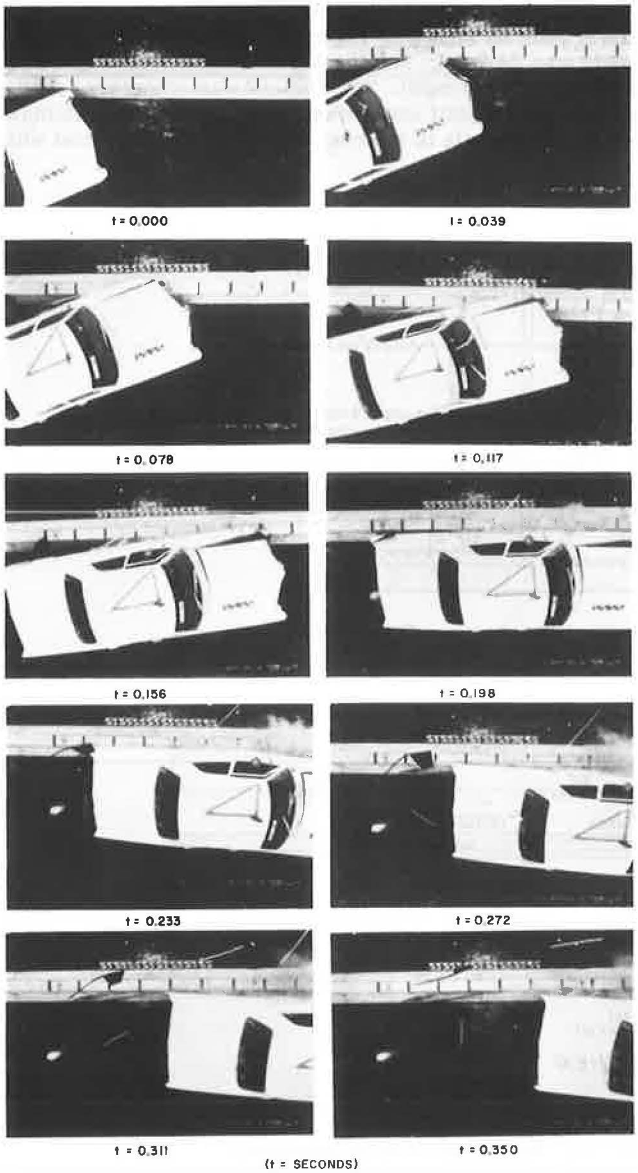
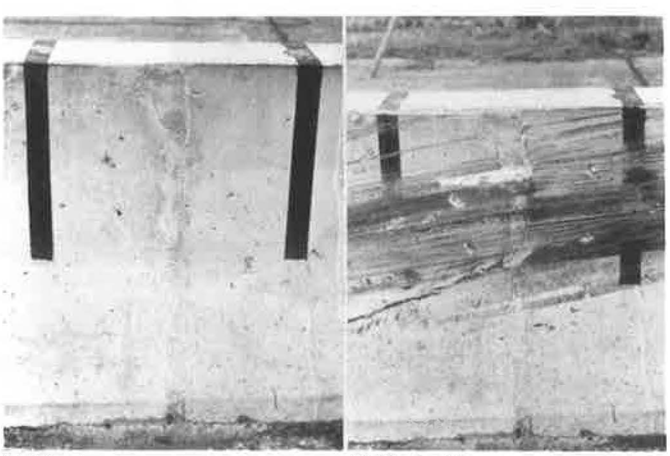


Figure 6. Groove joint before and after test 1.



(a) Before Impact (b) After Impact

the vehicle was in contact with the barrier. The vehicle remained upright during the test. The left front wheel and steering linkage were damaged, and the vehicle was inoperable after the impact.

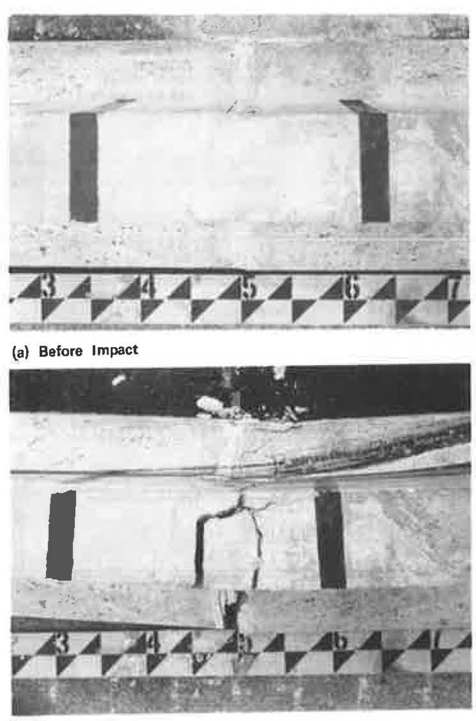
The average lateral vehicle deceleration taken from the film was 6.3 *g* over 223 ms. The average longitudinal deceleration over the same period was 1.1 *g*. The barrier did not roll or rotate during the impact. The precast barrier did displace 34.3 cm (13.5 in) laterally at the connection during vehicle redirection, and significant cracking of the concrete, apparent on both the tension and compression sides of the joint (Figure 7), occurred. The joint held together, however, and smoothly

Table 1. Summary of test data.

Item	Test 1	Test 2
Vehicle year	1966	1965
Vehicle make	Pontiac	Oldsmobile
Mass, kg	2040	2060
Impact angle, deg	23.5	24.2
Initial impact speed, km/h	97.4	96.2
Speed at parallel, km/h	77.2	79.3
Longitudinal distance to parallel, m	4.57	5.02
Permanent barrier displacement, m	0	0.34
Lateral distance to parallel, m	0.55	0.98
Time to parallel, ms	206	223
Average longitudinal deceleration parallel to barrier, *g*	1.6	1.1
Average lateral deceleration normal to barrier, *g*	7.5	6.3
Departure angle, deg	7.0	3.0
Vehicle damage classification		
TAD[a]	FL-5.5	FL-4.5
Society of Automotive Engineers	11FLEW3	11FLEW2

Note: 1 kg = 2.2 lb, 1 km/h = 0.621 mph, 1 m = 3.3 ft.
[a]Traffic Accident Data Project, National Safety Council.

Figure 7. Dowel joint before and after test 2.



(a) Before Impact

(b) After Impact

redirected the vehicle. The groove joint 9.1 m (30 ft) downstream also was fractured. This allowed the center section to rotate slightly in the horizontal plane between the two joints. The last section downstream from the groove joint (Figure 2) did not move.

DISCUSSION OF TESTS

A brief summary of the test data is given in Table 1. In both tests the vehicle was smoothly redirected and remained upright. The barrier did not rotate in either test.

When the PCMB was supported laterally by the 2.54-cm-thick (1-in-thick) asphalt paving material (test 1), it did not displace laterally and no damage was inflicted on the precast concrete segments or connection. For a permanent installation, the 2.54-cm-thick (1-in-thick) asphalt paving material or some other lateral support should be used so that maintenance or repair cost would be small or nil.

If the PCMB is to be used as a temporary barrier, test 2 indicates that lateral support by the 2.54-cm (1-in) asphalt concrete is not absolutely necessary. However, the barrier can be expected to displace laterally under vehicle impact approximately 0.3 m (1 ft), and significant cracking of the concrete will occur at the segment joints. Under low-speed or low-angle impacts or both, the lateral displacement and cracking of the concrete would probably be minimal.

One can conclude from these two tests that the PCMB will function as designed when the 9.1-m (30-ft) sections are connected by either of the two connections used and backed up with 2.54 cm (1 in) of ACP. This type of installation is recommended for permanent installations. If the PCMB is used as a temporary installation, either connection should be acceptable; however, considerable maintenance can be anticipated if the ACP or some other backup is not used to prevent sliding.

CONCLUSIONS

Past experience has shown that the CMB is an economical and effective traffic barrier. Investigation into the use of a precast concrete median barrier stemmed from the interest involved in using a barrier to be prefabricated concurrently with roadway construction. This more effective usage of work force as well as early project completion and acceptance could provide measurable potential savings to both the contractor and the state. When one installs this barrier on existing facilities, it is frequently desirable to precast the concrete median barrier so that the units can be quickly installed during low traffic volume periods. The 9.1-m-long (30-ft-long) sections with grouted dowel connections and the 2.54-cm (1-in) ACP fill material behind the barrier proved to be an effective barrier in redirecting 2040-kg (4500-lb) vehicles impacting at 96.6 km/h (60 mph) and 25 deg.

If the 2.5-cm (1-in) ACP or some other backup device is not used to prevent lateral sliding, then the doweled connections tested here appear to be adequate; however, considerable maintenance can be anticipated after high-speed, high-angle impacts. This type of installation (without backup device) should only be used as a temporary barrier.

Four No. 4 longitudinal reinforcing bars are adequate for handling and lifting requirements provided that the sections are cast right side up. Where the units will be cast bottom side up (for simpler form design and removal), four No. 5 longitudinal bars are recommended provided two pickup points located approximately 1.9 m (6.21 ft) from each end are used.

The recommendations for reinforcing steel are intended to produce added safety during installation and reduced maintenance when in service. These concrete sections could have been designed as plain, unreinforced concrete members.

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