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WYOMING ROAD CLOSURE GATE

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ABSTRACT

Road closure gates are used to close certain highways when the driving conditions become too hazardous under severe winter weather conditions. The Wyoming Department of Transportation (WYDOT) developed a new road closure gate design that had not been crash tested to determine if it would meet nationally recognized safety standards. The WYDOT sponsored a study at the Texas Transportation Institute to crash test and evaluate the new road closure gate design and, as appropriate, to improve the design from the standpoints of safety performance, cost and practicality. The original road closure gate design was crash tested and failed to meet guidelines set forth in NCHRP Report 350 and the 1985 AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*. The design was then modified and crash tested with successful results. The modified road closure gate design consists of: a standard 8.84 m (29 ft) high luminaire support pole structure with a mast arm and light standard; a 4-bolt slip base breakaway base; a telescoping fiberglass/aluminum gate arm with an electric in-line linear actuator lift mechanism; and a gate arm bracket to restrict the lateral movement of the gate arm in the up position. The road closure gate design has been adopted by the Wyoming Department of Transportation and accepted by the Federal Highway Administration for use on the National Highway System.

INTRODUCTION

The Wyoming Department of Transportation (WYDOT) uses road closure gates to close certain highways when the driving conditions become too hazardous under severe winter weather conditions. Gates are typically located at the outskirts of most cities on the State's highway system. The WYDOT and other States have used a swing gate design for years. However, many problems were identified with the swing gate design. The swing gates were difficult for field personnel to close during conditions of high winds and blowing snow normally associated with the need to close these highways. Field personnel had to walk out onto the roadway to close these gates, placing themselves at high risk during low visibility and icy road conditions. The swing gates had cables to anchor the gates in the closed position, but would occasionally become tangled during windy conditions. Furthermore, the swing gates require extensive maintenance to keep them operational. Also, the swing gates were not believed to be crashworthy if impacted.

The WYDOT formed a committee consisting of patrol, maintenance, construction, and design personnel to develop an improved method of road closures. The Highway Patrol indicated that it would be very difficult to enforce road closures without a physical barrier in place. The committee explored various ideas and eventually arrived at a design that would incorporate a railroad arm mounted on a luminaire pole with a breakaway base. It was believed this would be a much safer design than the existing swing gates, both for the field personnel and for the traveling public. Also, many of the components required for the new gate design already existed in maintenance stockpiles so that replacement with the new gate design could proceed promptly without incurring major expenses.

The road closure gate design developed by the committee had not been crash tested to determine if it would meet nationally recognized safety standards, i.e., the performance criteria outlined in National Cooperative Highway Research Program (NCHRP) Report 350[1] and the 1985 American Association of State Highway and Transportation Officials (AASHTO) *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*[2]. The WYDOT therefore initiated a study with the Texas Transportation Institute (TTI) to evaluate the gate design, to make recommendations for improvements, and to conduct full-scale crash testing to insure that the road closure gate design would meet nationally recognized safety standards.

The objectives of this study were to crash test and evaluate the new Wyoming road closure gate design to determine if the design would meet the appropriate impact performance guidelines and specifications and to improve the design from the standpoints of safety performance, cost and practicality. The scope of the study included engineering analysis of the existing road closure gate design, followed by full-scale crash testing and evaluation of the design.

ROAD CLOSURE GATE DESIGN

A schematic of the modified road closure gate design which was successfully crash tested is shown in Figure 1. Photographs of the test installation are shown in Figure 2. The major components of the design are:

- Support pole structure,
- Breakaway mechanism,
- Gate arm, and
- Gate arm attachment and lift mechanisms.

Brief descriptions of these components are presented as follows.

Support Pole Structure

A standard 8.84 m (29 ft) high luminaire support pole structure, with a 2.44 m (8 ft) long mast arm and light standard, is used with the road closure gate, a schematic of which is shown in Figure 1. The pole shaft and mast arm shaft are made from 11-gauge hot rolled ASTM A595 Grade A carbon steel and are hot-dip galvanized in accordance with ASTM standard A123. The pole shaft has an outside diameter of 203 mm (8 in) at the base and 102 mm (4 in) at the top with a linear taper rate of 1.2 mm/m (0.14 in/ft). The stub height of the permanent lower slip base assembly is 102 mm (4 in), making the height to the top of the support pole structure 8.94 m (29 ft-4 in). The approximate weights of the components are: 109 kg (240 lb) for the pole shaft including the top slip base plate, 20 kg (44 lb) for the mast arm, and 18 kg (40 lb) for the light standard assembly.

Breakaway Mechanism

A 4-bolt slip base design, shown in Figure 3, is used with the road closure gate. This 4-bolt slip base design was successfully crash tested previously with a 15.2-m (50-ft) luminaire support weighing approximately 408 kg (900 lb).[3] In actual field installations, the permanent lower slip base assembly is bolted to a concrete foundation with four 25.4-mm (1-in) diameter AASHTO M314 Grade 55 anchor bolts on a 406-mm (16-in) diameter bolt circle. However, for the test installation, the base assembly was bolted to an existing universal steel mounting plate with four 25.4-mm (1-in) diameter ASTM A325 bolts. The permanent lower slip base assembly has a stub height of 102 mm (4 in). The top and bottom base plates are fastened together with four 25.4-mm (1-in) diameter ASTM A325 slip bolts on a 330-mm (13-in) diameter bolt circle and 76.2-mm × 50.8-mm x 12.7-mm (3-in x 2-in x ½-in) plate washers. The slip bolts are held in place with a 28-gauge keeper plate fabricated from ASTM A526 material. The slip bolts are first tightened to a torque of 5.5 N-m (80 ft-lb), then released and re-tightened to a torque of 4.8 N-m (70 ft-lb), which is estimated to develop approximately 19.2 kN (4,300 lb) of tension per bolt.[3]

Gate Arm

The gate arm used in the test installation was a commercially available fiberglass/aluminum gate arm consisting of a 3.7 m (12 ft) long base section of rectangular shaped extruded aluminum and a second telescoping section made of pultruded fiberglass. The maximum recommended length of the gate arm is 9.8 m (32 ft). The length of the gate arm used with the test installation was 7.3 m (24 ft). The gate arm is attached to the support pole structure with a cast aluminum breakaway mounting adapter which uses three 7.9-mm (5/16-in) diameter brass bolts. These bolts are designed to fail when the gate arm is impacted by a vehicle, which allows the arm to rotate around a pivot rod, thus preventing major damage to the arm or impacting vehicle. The arm is covered with retro-reflective sheeting in red and white stripes with three red-lensed lamps to provide better visibility.

Gate Arm Attachment and Lift Mechanisms

Schematics and details of the gate arm attachment and lift mechanisms are shown in Figure 4. The gate arm assembly is attached to the support pole structure through a 38.1-mm (1-1/2 in) diameter ASTM A36 steel pivot rod. Two gate arm plates are mounted onto the pivot rod using 2-bolt flange-mounted sleeve bearings. These sleeve bearings have Teflon coated housings and chemical and corrosion resistant self-lubricating polymer sleeve inserts and are designed for operation in adverse environments.

Two channel spacers, one 381 mm (15 in) long for attachment of the gate arm and the other 127 mm (5 in) long for the upper connection of the electric in-line linear actuator (jack), are mounted between the gate arm plates. The electric jack is mounted onto the support pole structure with a bottom connection assembly. The electric jack has a 3,400 rpm, 110-volt A. C. motor with a maximum stroke of 460 mm (18-1/8 in) and a maximum load capacity of 6.7 kN (1,500 lb). Testing with the actual installation showed that it takes approximately 2-1/2 minutes to raise the gate arm from the down to the up position.

A gate arm bracket, shown in Figure 5, is attached to the support pole structure to restrict the lateral movement of the gate arm in the up position. The bracket for the test installation was mounted at a height of 5.5 m (18 ft) above the ground. However, this mounting height of the bracket may vary depending on the length of the gate arm. Also, to avoid interference with the luminaire mast arm when the gate arm is in the up position, the mast arm is offset at an angle of 25 degrees as shown in Figure 5.

Original Road Closure Gate Design

The road closure gate design described above is the design that was successfully crash tested. The original road closure gate design by the WYDOT was first crash tested and failed to meet guidelines set forth in NCHRP Report 350 and the 1985 AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*. The original design was then modified and subsequently crash tested with successful results.

The original design was similar to the final design except for the height of the pole structure and the absence of a mast arm and light standard. The pole support structure in the original design was 5.5 m (18 ft) high and had an outside diameter of 229 mm (9 in) at the base and 165 mm (6.5 in) at the top. The weight of this 5.5 m (18 ft) support pole and attachments, including the top slip base plate, was approximately 91 kg (200 lb). The other design details, including the breakaway mechanism, the gate arm, and the gate arm attachment and lift mechanisms, were identical to those of the final design.

COMPLIANCE TESTING

Two compliance crash tests are required to evaluate the performance of a breakaway support structure in accordance with guidelines set forth in NCHRP Report 350 and the 1985 AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*:

1. Test Designation 3-60. An 820-kg (1,808-lb) passenger car impacting the support pole structure head-on at a nominal impact speed of 35 km/h (21.8 mi/h). The objective of this test is to evaluate the breakaway mechanism of the support structure.

2. Test Designation 3-61. An 820-kg (1,808-lb) passenger car impacting the support pole structure head-on at a nominal impact speed of 100 km/h (62.2 mi/h). The objective of this test is to evaluate vehicle and test article trajectory.

A total of three full-scale crash tests were conducted under this study. The first test was a low-speed test (test designation 3-60) with the original road closure gate design. This test failed to meet the evaluation criteria due to intrusion into the occupant compartment. After modifications to the support pole structure design, the low-speed crash test was re-run with successful results. The high-speed test (test designation number 3-61) was also conducted with the modified road closure gate design with satisfactory results.

The crash tests were conducted with the gate arm in the down position. This was considered a more critical test condition since the gate arm might affect the trajectory of the support pole structure after separating from the slip base assembly. The Federal Highway Administration (FHWA) was consulted and agreed with this test configuration. Brief descriptions of these three crash tests are presented below.

Low-Speed Crash Test

The first low-speed crash test was conducted on the original road closure gate design. As mentioned previously, the only difference between the original road closure gate design and the final design was the size and height of the support pole structure. Photographs of the test installation of the original road closure gate design are shown in Figure 6.

This test involved an 820-kg (1,808-lb) passenger car impacting head-on at a speed of 34.7 km/h (21.6 mi/h) with the left front quarter point of the vehicle aligned with the centerline of the support pole structure. The test weight of the vehicle was 896 kg (1,975 lb), including a restrained 50th percentile anthropomorphic dummy placed in the driver position.

Upon impact, the slip base activated as designed and the support pole structure rotated free of the slip-base assembly. As the vehicle continued traveling forward, the support pole structure rotated past the horizontal position and impacted the rear of the roof of the vehicle, breaking the glass in the rear hatchback and damaging the roof severely. The vehicle lost contact with the road closure gate traveling at 28.2 km/h (17.5 mi/h). Sequential photographs of the test are shown in Figure 7.

Damage to the road closure gate was minimal. The cast aluminum housing of the electric motor was fractured during the test and would require repair or replacement prior to reinstalling the road closure gate. Although the front of the test vehicle sustained only minor damage, the roof of the vehicle was severely crushed. The maximum recorded roof deformation was 160 mm (6.3 in) across the passenger compartment area and around the head of the anthropomorphic dummy which was positioned in the driver's seat. Damage to the test installation and test vehicle is shown in Figures 8 and 9, respectively.

The occupant risk factors were well within the limits set forth in NCHRP Report 350 as summarized in Table 1. However, this test was considered a failure due to intrusion into the occupant compartment resulting from the secondary impact of the separated support pole structure with the roof of the test vehicle. Analysis of the high-speed film indicated that the separated support pole structure had an angular velocity of approximately 180 deg/sec and was rotating about a point approximately 610 mm (2 ft) above the roof of the test vehicle. In comparison, a review of high-speed film from successful crash tests with slip-base luminaire supports indicated a much smaller angular velocity and higher point of rotation for the separated support pole structure.

An engineering analysis based on conservation of linear and angular momentum principles was used to study the impact performance and post-impact trajectory of the road closure gate system. Based on the results of the analysis, several options were explored with WYDOT, including lengthening or shortening of the pole structure. The option of shortening the pole structure was rejected over concern that: (a) the shorter pole structure may have the propensity to rotate into the windshield area of the impacting vehicle which could result in intrusion of the occupant compartment; and (b) the shorter pole structure would not provide any support for the long gate arm, which could result in damage to the gate arm under high wind conditions.

The option of lengthening the pole structure was therefore selected. The basic concept behind this option was to reduce the angular velocity and raise the point of rotation of the separated support pole structure by increasing the mass moment of inertia and center-of-gravity height, respectively. To accomplish this, several alternatives were evaluated, including different pole structure lengths and mast arm lengths.

After careful consideration, it was decided to replace the 5.5 m (18 ft) high pole structure with a standard 8.84 m (29 ft) high luminaire support to increase the mass moment of inertia and center-of-gravity height of the separated pole structure. In addition, a 2.44 m (8 ft) long mast arm and a light standard were incorporated into the design to further increase these properties and to provide better visibility. The taller support pole structure, with luminaire arm and luminaire, increased the weight of the road closure gate system by 54 kg (118 lb) from 198 kg (437 lb) to 252 kg (555 lb). The mass moment of inertia was increased by a factor of more than five, from 1.648×10^9 mm^4 (3960 in^4) to 8.460×10^9 mm^4 (20326 in^4), and the height of the center of gravity was raised from 2096 mm (82.5 in) to 3653 mm (143.8 in).

For the impact speed at which the first low-speed test was conducted, the predicted angular velocity of the separated pole structure was reduced from 180 to 95 deg/sec and the estimated rotation would be less than 90 degrees prior to re-contacting the vehicle or the ground (i.e., the separated pole structure would not reach a horizontal position above the vehicle). Although the predicted velocity change from impact with the modified road closure gate increased from 1.7 to 2.1 m/sec (5.5 to 7 ft/sec) due to the additional weight, this value is still well below the acceptable limit of 5 m/sec (16.4 ft/sec).

Second Low-Speed Crash Test

The low-speed crash test was repeated with the taller, modified support structure. Photographs of the test installation are shown in Figure 2. The vehicle impacted the modified road closure gate head-on at a speed of 31.8 km/h (19.7 mi/h) with the left front quarter point of the vehicle aligned with the centerline of the support pole. Upon impact, the road closure gate released from the slip base as designed and achieved an angular velocity of approximately 73 deg/sec. As the vehicle continued traveling forward, the support pole structure briefly contacted the left rear corner of the roof of the vehicle. The vehicle lost contact with the road closure gate traveling at 20.8 km/h (12.9 mi/h). Sequential photographs of the test are shown in Figure 10.

Damage to the road closure gate installation was relatively minor. The electric motor housing was again fractured and would require repair or replacement prior to reinstallation. Additionally, the luminaire was broken and would require replacement. The left front of the vehicle sustained light damage as did the left rear of the roof. The roof was deformed downward 10 mm (0.4 in) at the left rear corner, and there was no apparent intrusion into the passenger compartment area. Post-impact damage sustained by the vehicle and road closure gate is shown in Figure 11.

The occupant risk factors, summarized in Table 1, were well within the recommended limits set forth in NCHRP Report 350. The impact speed of 31.8 km/h (19.7 mi/h) was below the target impact speed of 35 km/h (21.7 mi/h). However, since a lower impact speed is generally considered to be more critical from the standpoint of activating the breakaway mechanism, the impact speed is not considered to be a problem.

High-Speed Crash Test

The vehicle used in the low-speed crash test was reused for this crash test. The vehicle impacted the road closure gate at an impact speed of 104.0 km/h (64.6 mi/h) with the right front quarter point of the vehicle aligned with the centerline of the support pole structure. Upon impact, the slip base activated as designed, allowing the support pole structure to rotate freely above the vehicle. The support pole eventually came to rest on the ground without contacting the vehicle. Sequential photographs of the test are shown in Figure 12.

Photographs of the test installation and vehicle after the test are shown in Figure 13. The road closure gate received extensive damage and the entire installation would need to be replaced. The vehicle sustained moderate damage to the right front. Maximum crush at the right quarter point of the bumper was 180 mm (7.1 in).

As summarized in Table 1, all occupant risk factors were well within the acceptable limits set forth in NCHRP Report 350. A small hole, measuring 10 mm (0.4 in) x 20 mm (0.8 in), was punched in the passenger side floor pan and the oil pan was also punctured. Upon further investigation, it appears that one of the slip bolts was first caught between the permanent lower slip base assembly and the undercarriage of the vehicle and then between the concrete pavement and the undercarriage of the vehicle, resulting in the damage. This behavior was indicated by gouge marks present on the top surface of the spacer plate of the permanent lower slip base assembly and on the concrete pavement.

CONCLUSIONS AND DISCUSSIONS

An existing road closure gate design used by the Wyoming Department of Transportation was analyzed and redesigned in this study. The modified road closure gate design was successfully crash tested in accordance with guidelines set forth in NCHRP Report 350 and the 1985 AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*. The road closure gate design has been adopted by the Wyoming Department of Transportation and accepted by the Federal Highway Administration for use on the National Highway System.[4]

Based on results of the crash tests and analytical studies, the following discussions are offered for consideration regarding field implementation of the road closure gate:

- A standard 8.8 m (29 ft) high luminaire support pole structure with an outside base diameter of 203 mm (8 in) and equipped with a 2.4-m (8-ft) mast arm and light standard was selected for use with the road closure gate design. If the mast arm and light standard are omitted from the design, a taller pole would be necessary to increase the mass moment of inertia and achieve comparable impact performance. For example, analysis indicates that WYDOT's next tallest standard luminaire pole, which is 11.4 m (37 ft-6 in) high and has an outside base diameter of 238 mm (9-3/8 in), would function similarly to the tested system. While other support pole options have not been tested, analysis indicates that a taller support pole structure would be an acceptable alternative.

- The height of the gate arm bracket was set at 5.5 m (18 ft) above the base of the support pole structure for the test installation. The mounting height of the gate arm bracket should be adjusted to accommodate the actual length of the gate arm in use. However, a minimum mounting height of 5.5 m (18 ft) is recommended. For locations where high wind poses a problem to proper retraction of the gate arm into the bracket, the length and/or the angle of the bracket can be increased to better accommodate the retraction of the gate arm. The increase in length and/or the angle of the bracket should not adversely affect the impact performance of the road closure gate.

- The road closure gate design, as tested, uses a four-bolt slip base for the breakaway mechanism. However, there is no reason to believe that the road closure gate design would not perform satisfactorily when used with other crash tested and approved breakaway bases, such as a three-bolt slip base, a frangible transformer base, or frangible couplings.

- The road closure gate design, as tested, uses an electric in-line linear actuator as the gate arm lift mechanism. Alternate lift mechanisms, such as a manual winch and pulley mechanism, should not adversely affect the impact performance and may be used provided that it does not significantly add to the weight or size of the design.

REFERENCES

1. H. E. Ross, Jr., D. L. Sicking, R. A., Zimmer, and J. D. Michie, "Recommended Procedures for the Safety Performance Evaluation of Highway Features," *NCHRP Report* 350, Transportation Research Board, Washington, D. C., 1993.

2. *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*, American Association of State Highway and Transportation Officials, Washington, D. C., 1985.

3. B. G. Pfeifer, J. C. Holloway, R. K. Faller, E. R. Post, and D. L. Christensen, "Full-Scale Crash Test on a Luminaire Support 4-Bolt Slipbase Design," *Transportation Research Record 1367*, Transportation Research Board, Washington, D. C., 1992, pp. 13-22.

4. Letter from Mr. Leonard G. Swanson, Wyoming Division, Federal Highway Administration to Mr. D. G. Diller, Director, Wyoming Department of Transportation, dated April 12, 1995.

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TABLE 1. Summary of crash test results.

Description		First Low-Speed Test	Second Low-Speed Test	High-Speed Test
Vehicle Weight		820 kg (1,808 lb)	820 kg (1,808 lb)	820 kg (1,808 lb)
Impact Speed		34.7 km/h (21.6 mph)	31.8 km/h (19.7 mph)	104.0 km/h (64.6 mph)
Exit Speed		28.2 km/h (17.5 mph)	20.8 km/h (12.9 mph)	88.0 km/h (54.7 mph)
Roof Deformation		160 mm (6.3 in)	10 mm (0.4 in)	None
Occupant Impact Velocity	Longitudinal	1.7 m/s (5.5 ft/s)	2.3 m/s (7.6 ft/s)	3.2 m/s (10.5 ft/s)
	Lateral	N/A	0.3 m/s (1.1 ft/s)	1.7 m/s (5.7 ft/s)
Ridedown Acceleration	Longitudinal	0.8 g	0.3 g	-0.9 g
	Lateral	N/A	1.6 g	1.1 g
Maximum 50-msec Average	Longitudinal	-3.6 g	-4.0 g	-6.5 g
	Lateral	-5.5 g	-0.52 g	0.8 g

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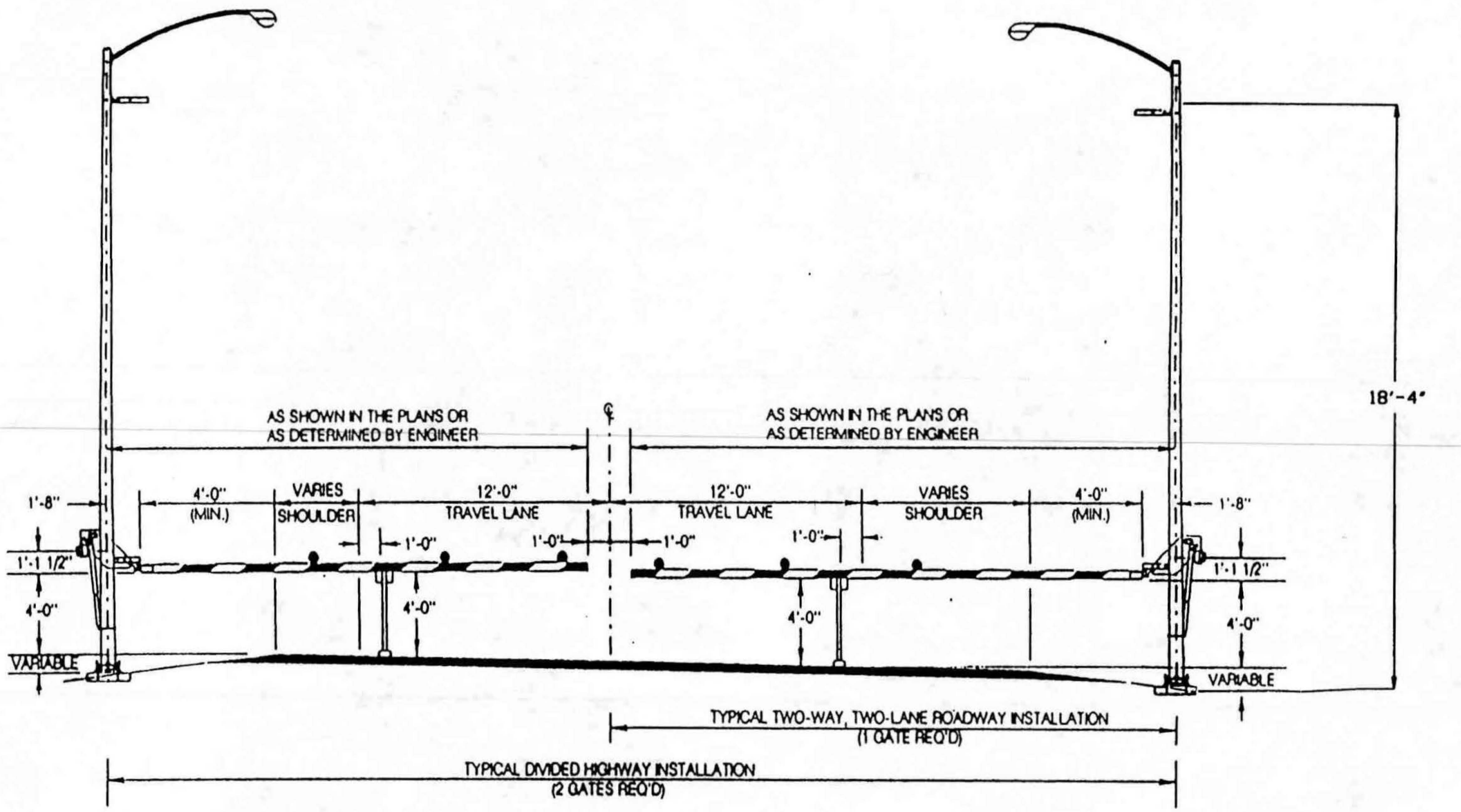


FIGURE 1. Schematic of road closure gate design.

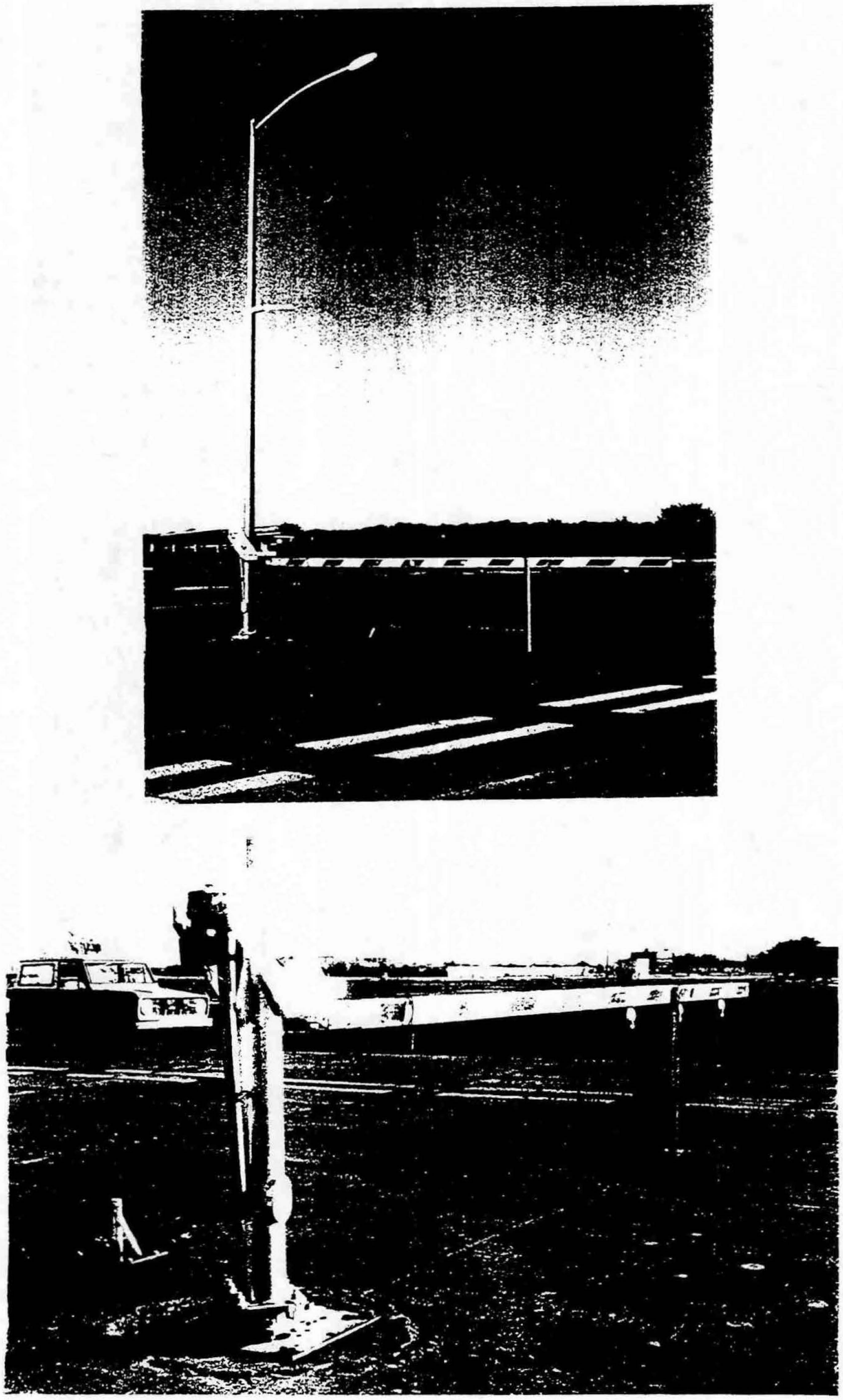


FIGURE 2. Photographs of road closure gate.

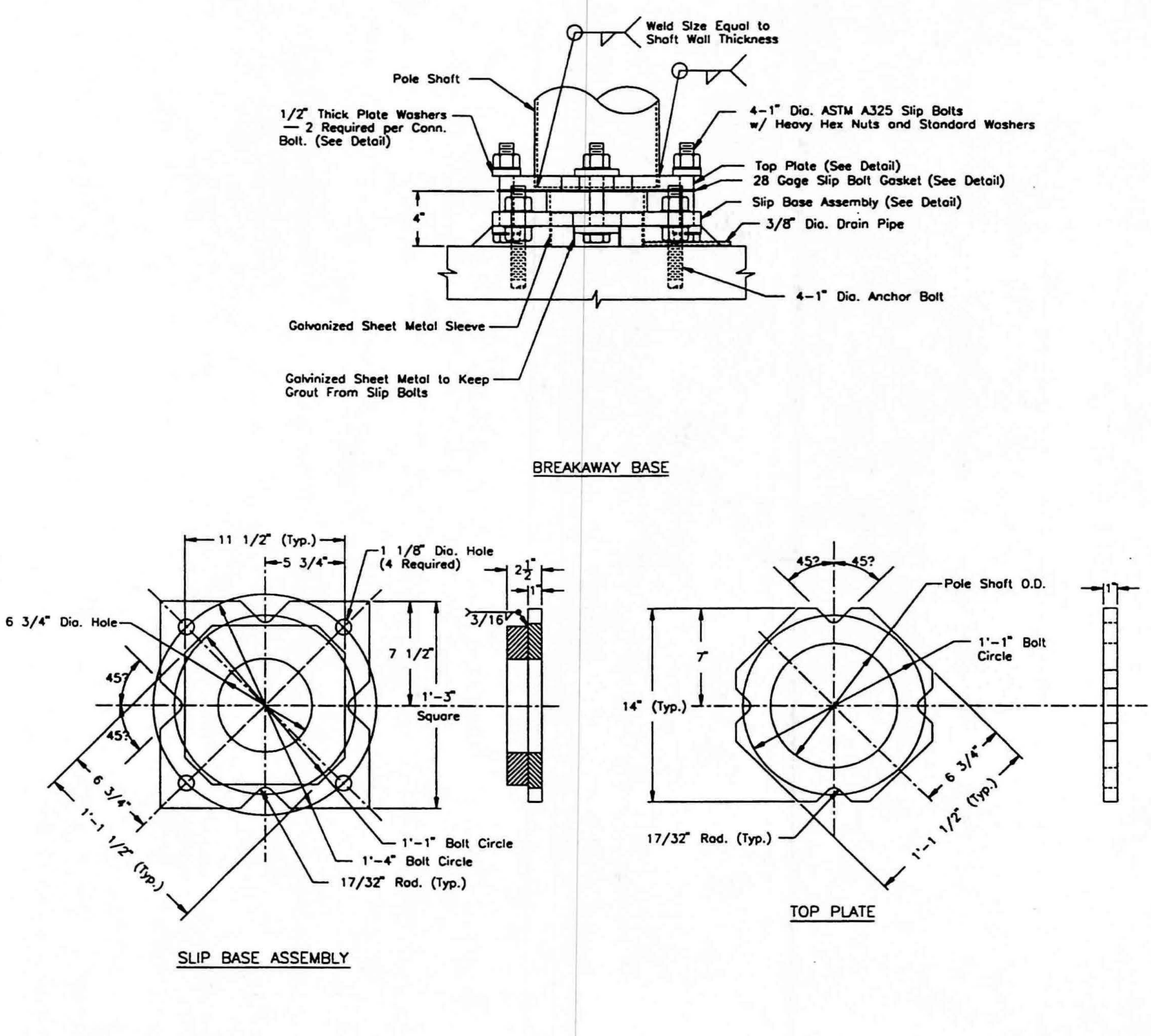


FIGURE 3. Schematic of 4-bolt slip base breakaway design.

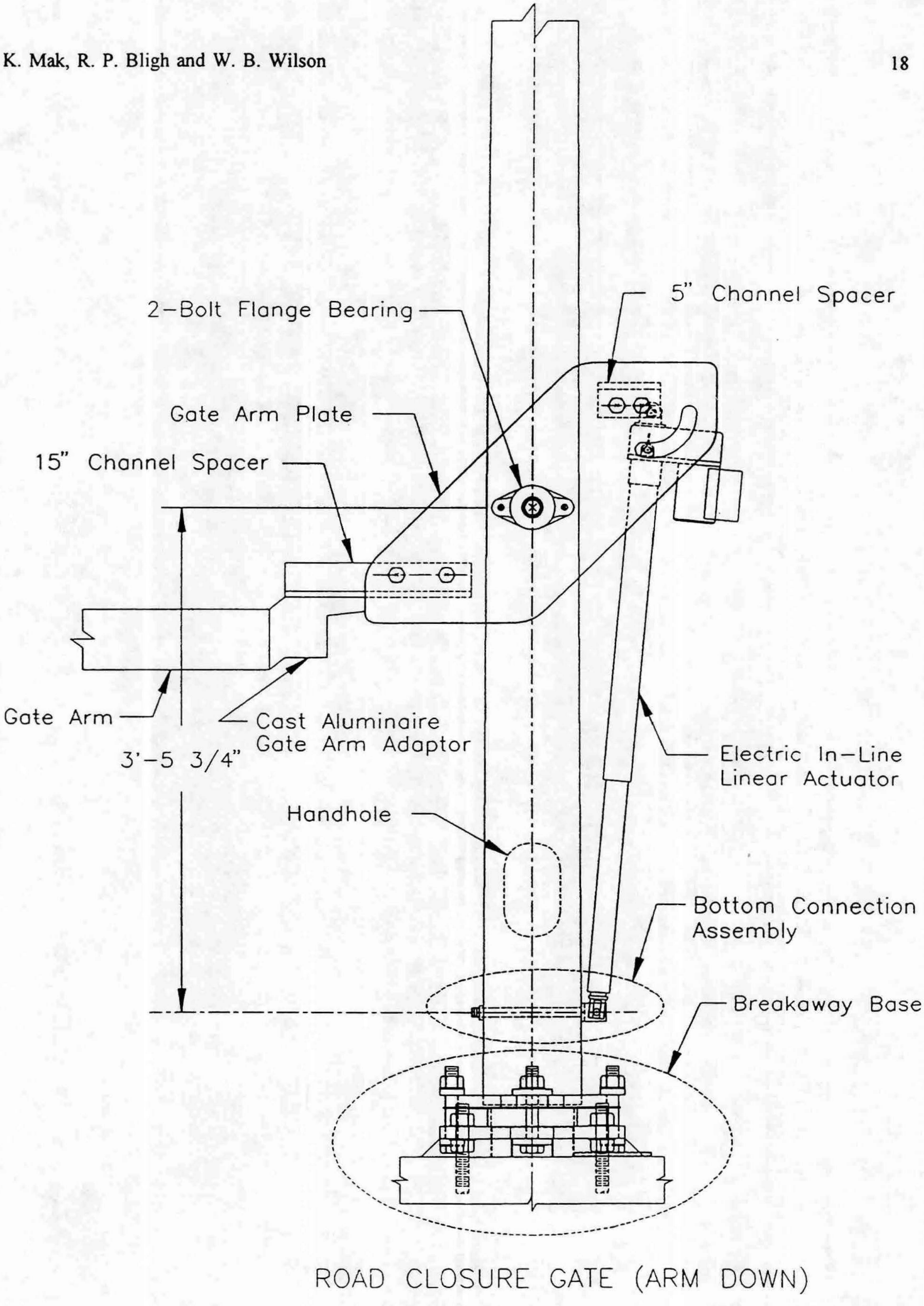


FIGURE 4. Schematic of gate arm attachment and lift mechanisms.

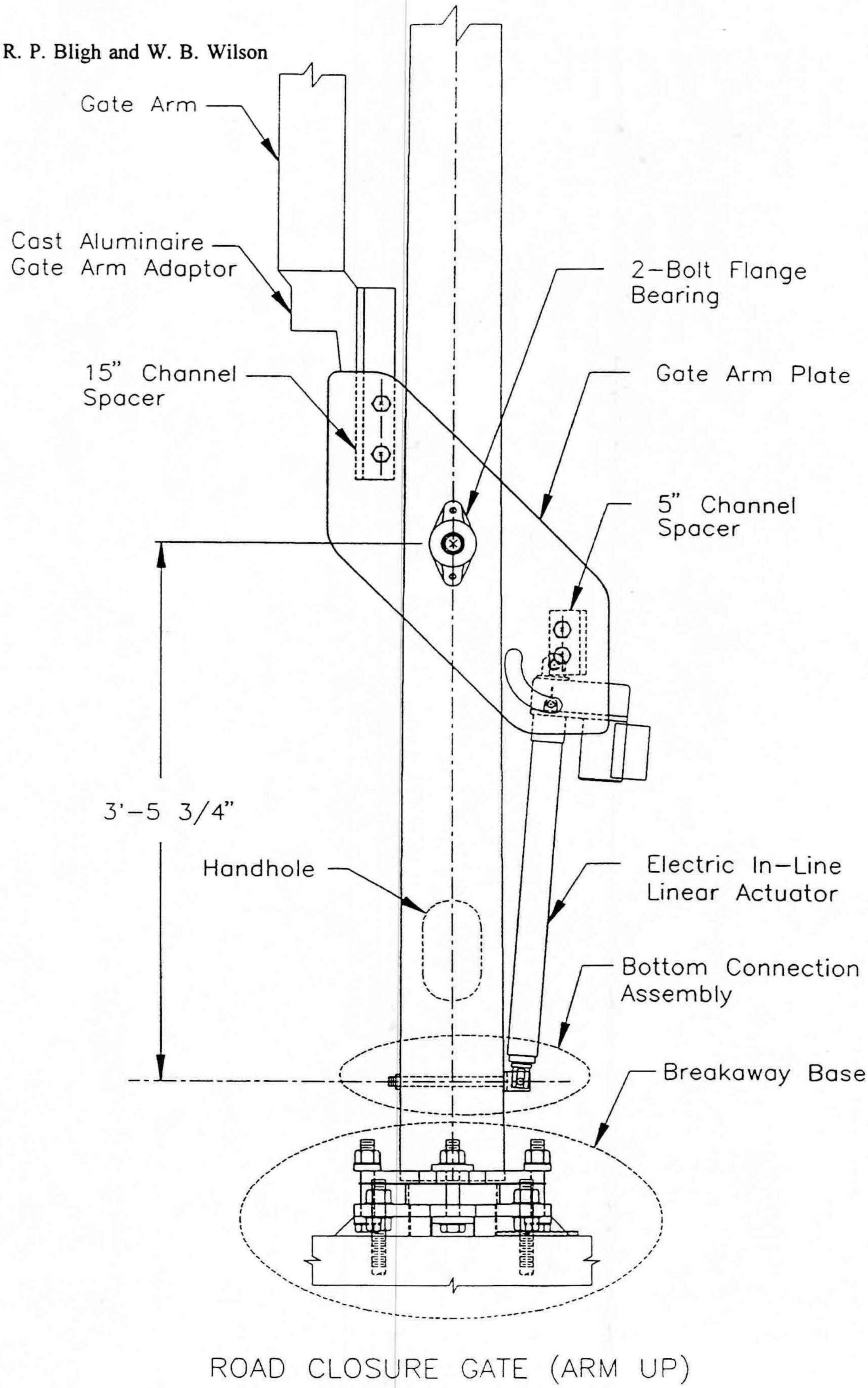
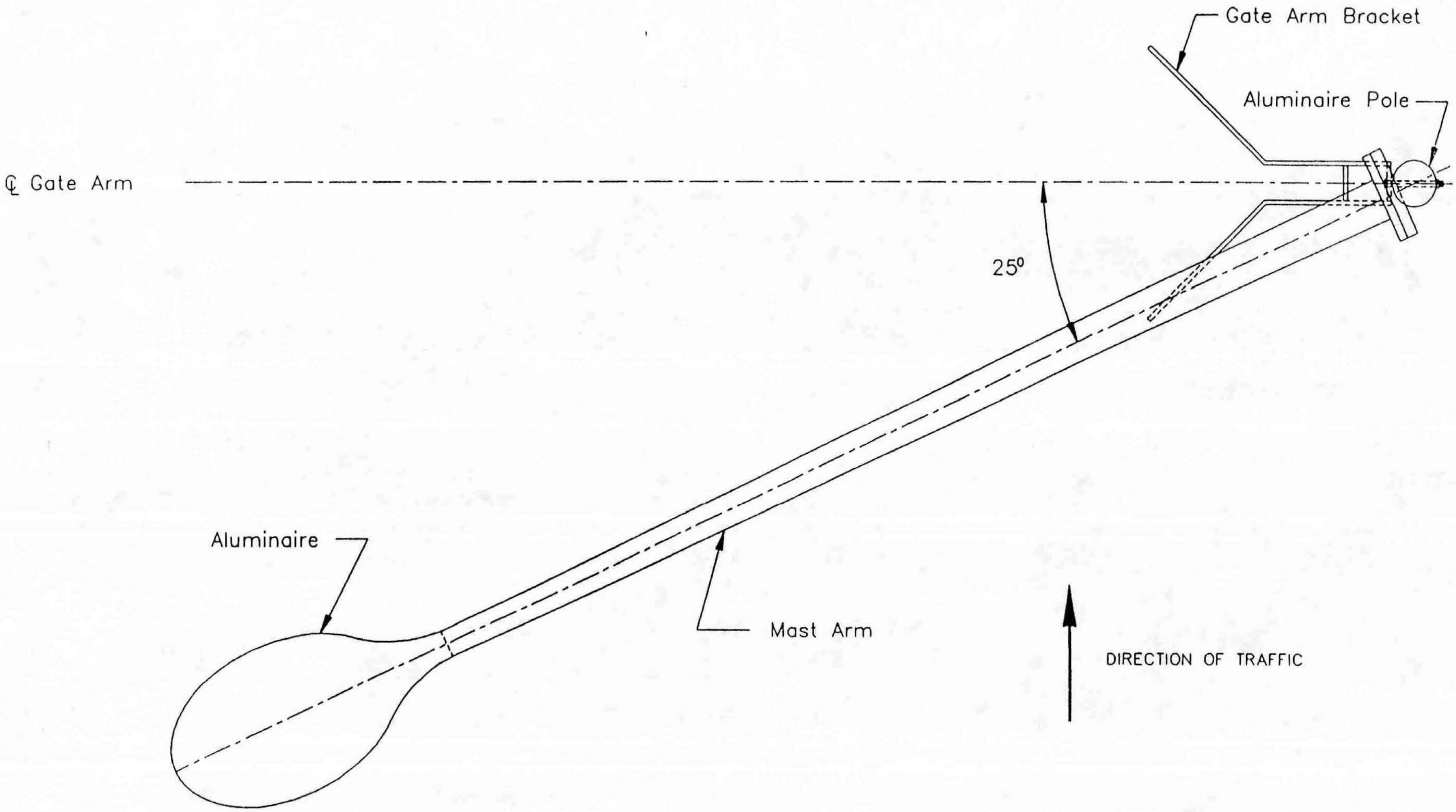
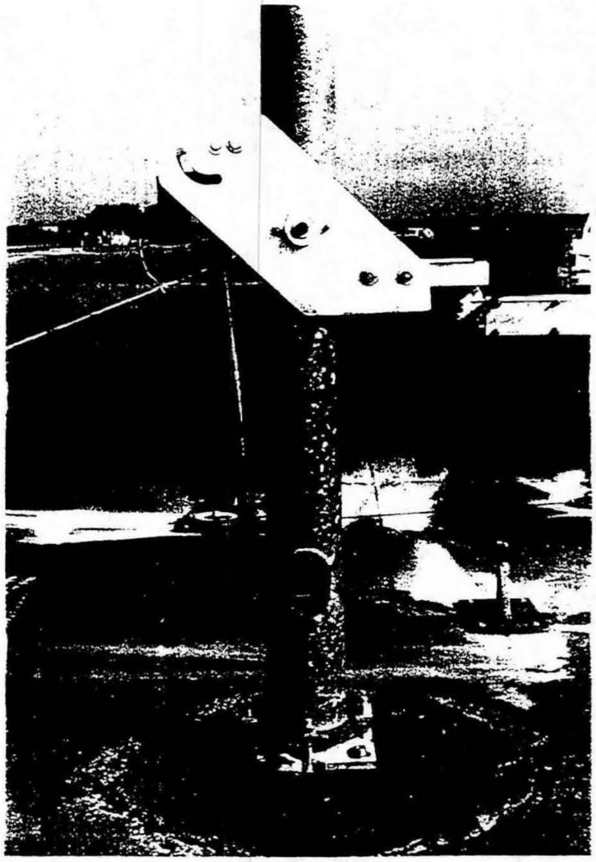


FIGURE 4. Schematic of gate arm attachment and lift mechanisms (continued).



PLAN VIEW OF ROAD CLOSURE GATE

FIGURE 5. Schematics of gate arm bracket.



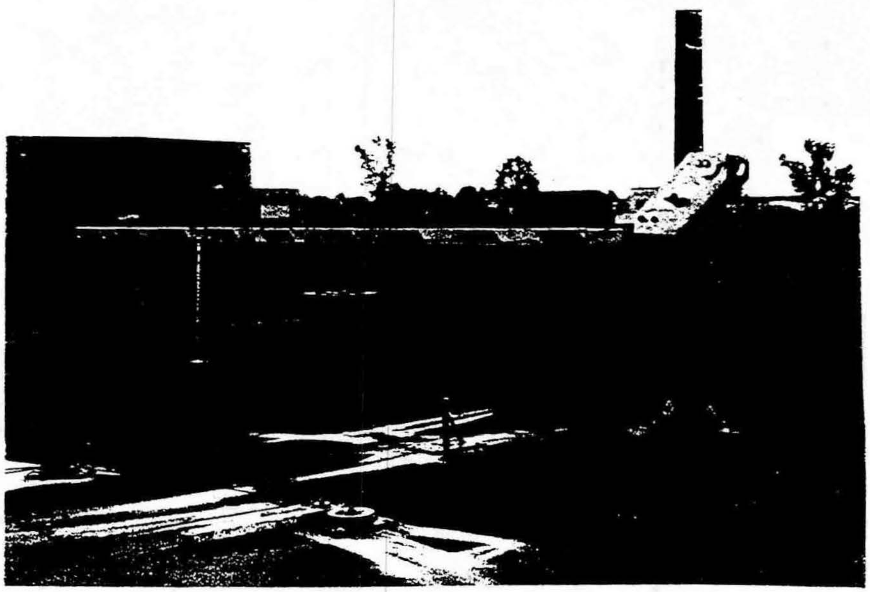


FIGURE 6. Photographs of test installation of existing road closure gate design.

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FIGURE 7. Sequential photographs of first low-speed crash test.

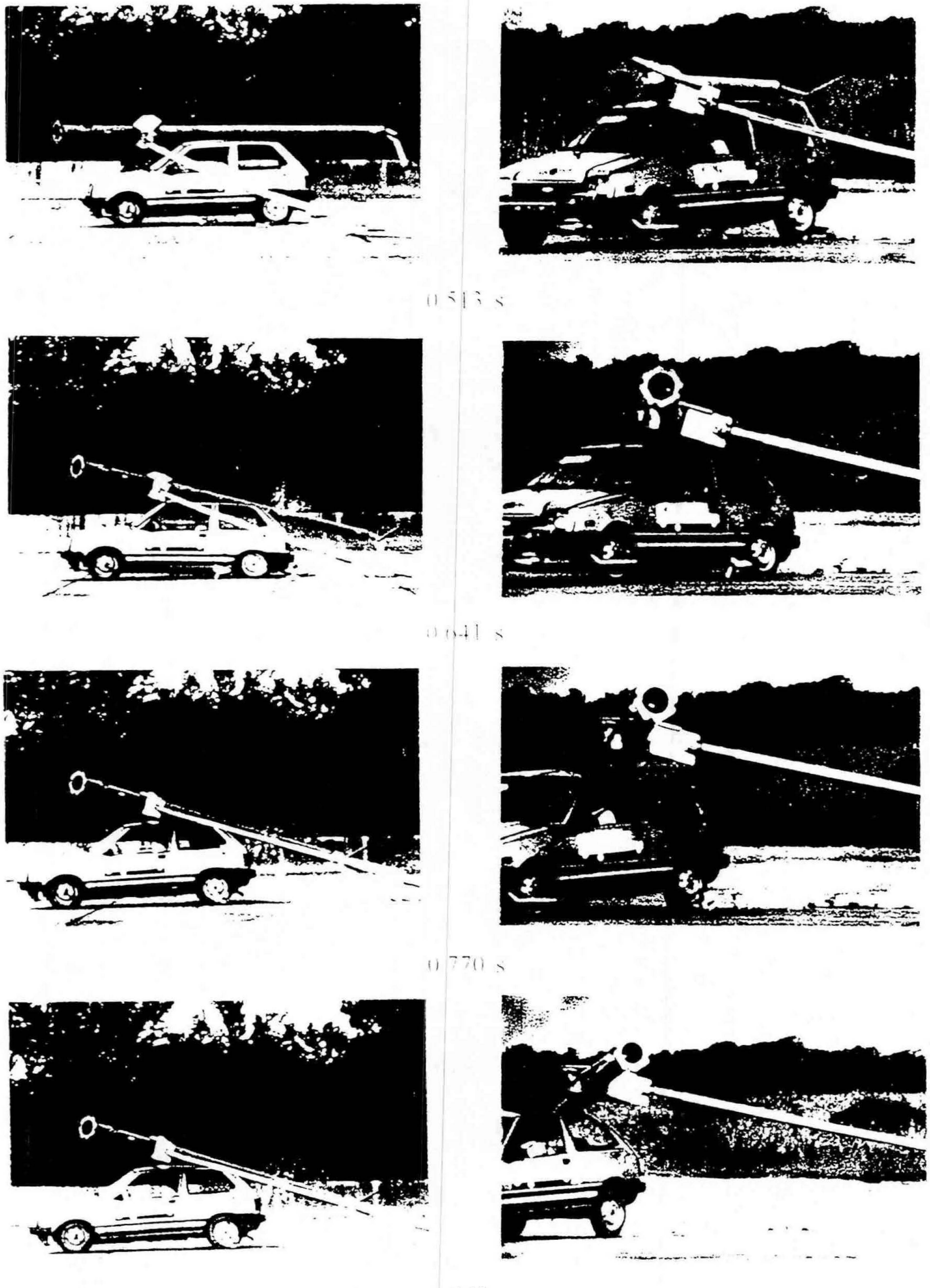

FIGURE 7. Sequential photographs of first low-speed crash test (continued).

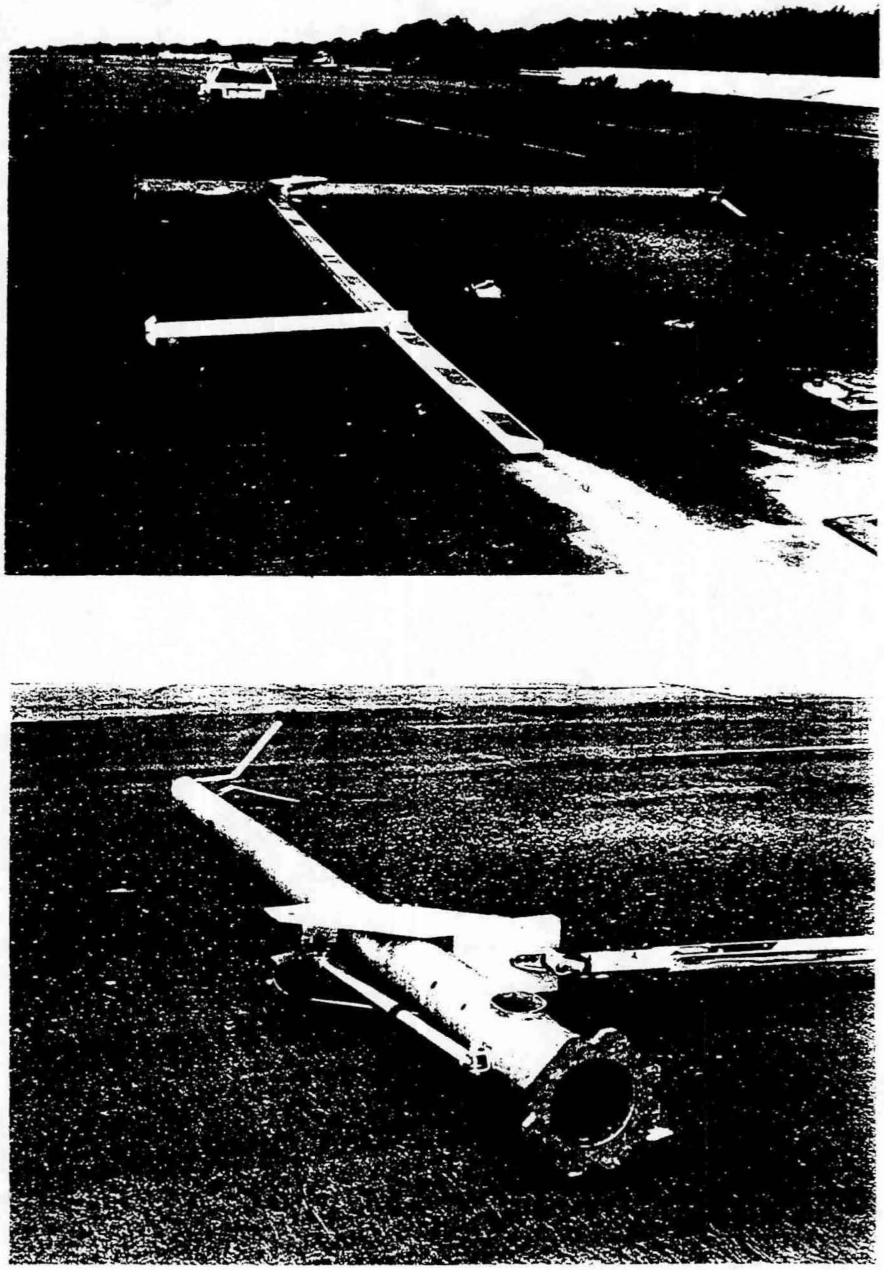

FIGURE 8. Damage sustained by test installation in first low-speed crash test.

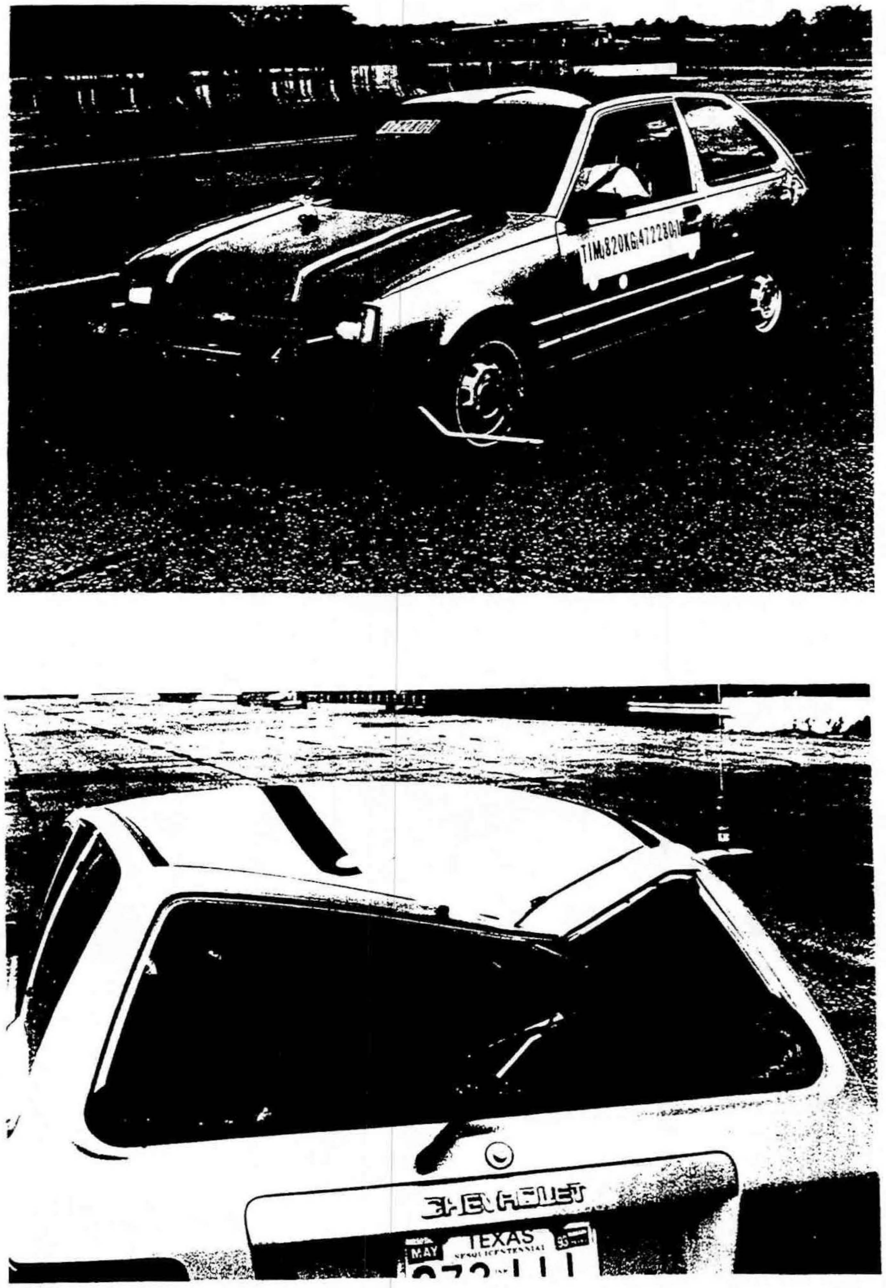

FIGURE 9. Damage sustained to vehicle in first low-speed crash test.

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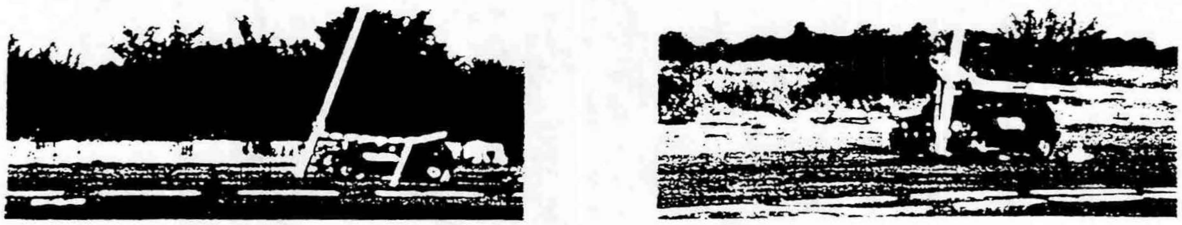

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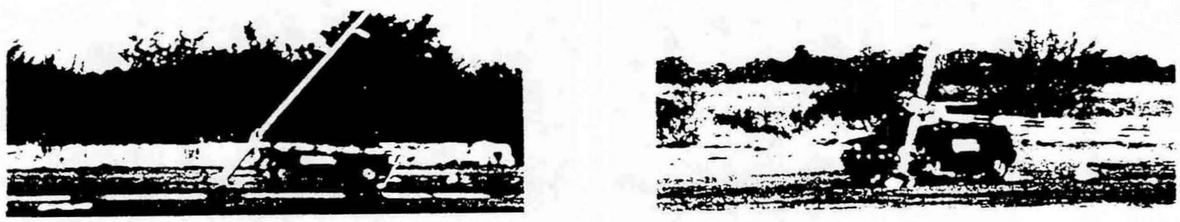

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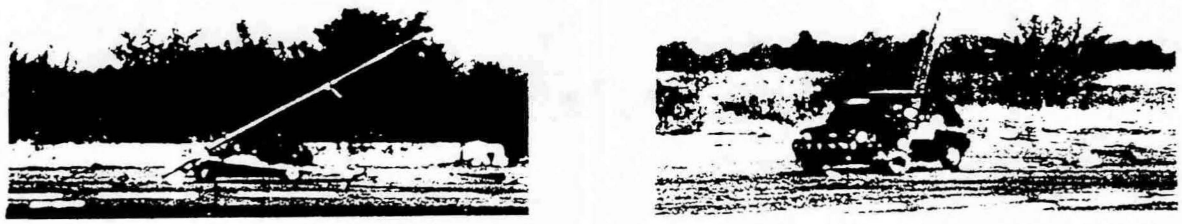

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FIGURE 10. Sequential photographs of second low-speed crash test.

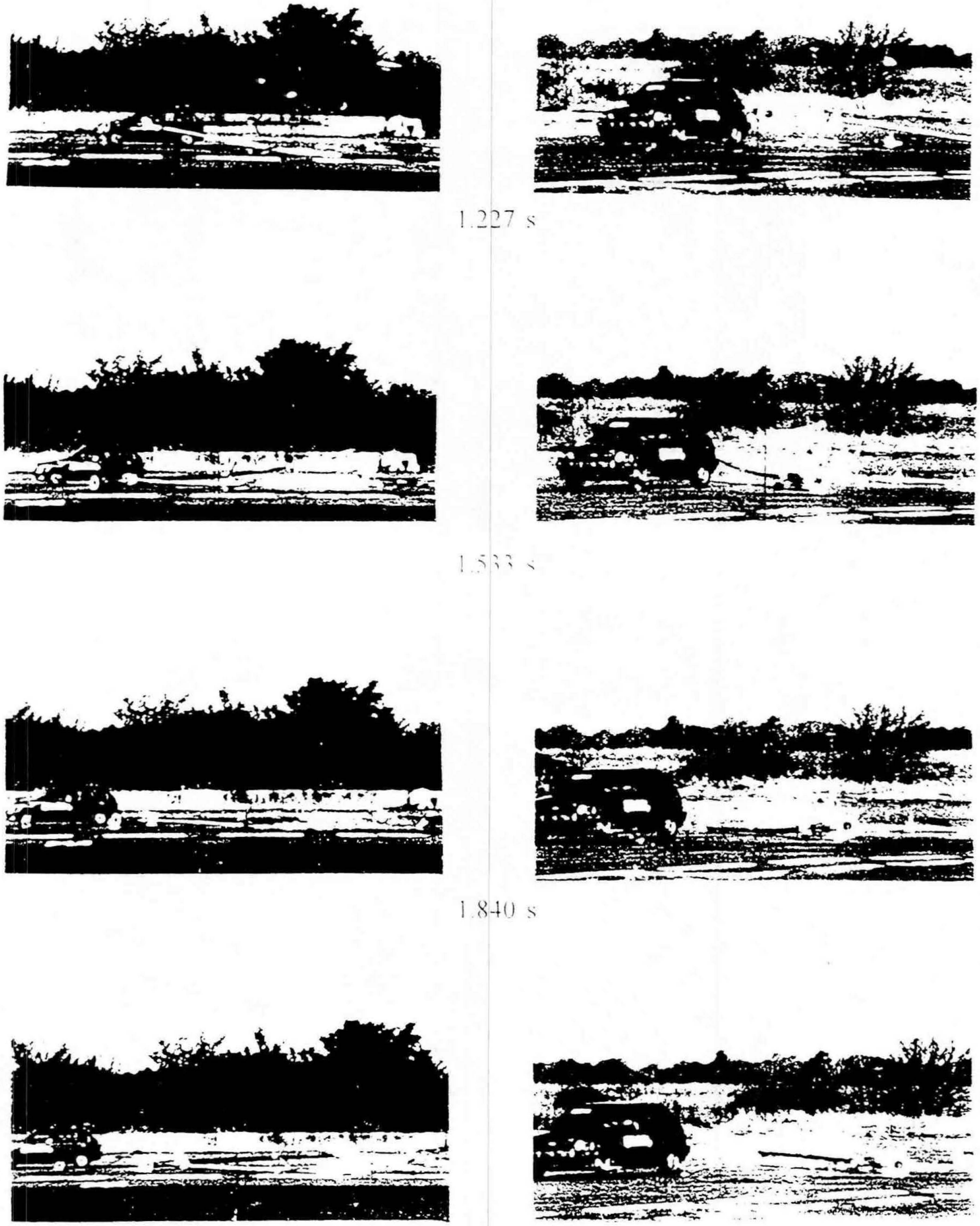

FIGURE 10. Sequential photographs of second low-speed crash test (continued).

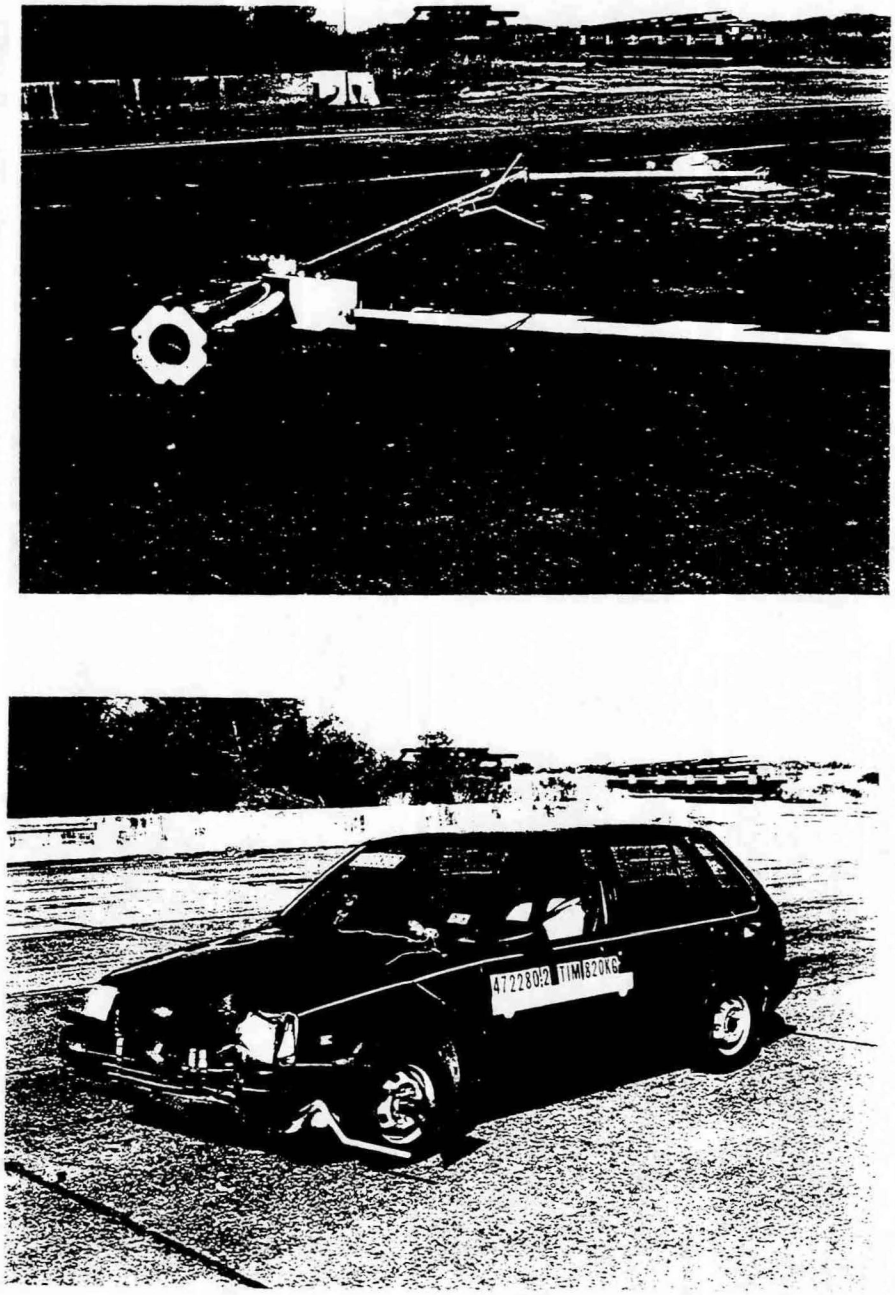

FIGURE 11. Damage sustained by test installation and vehicle in second low-speed crash test.

FIGURE 12. Sequential photographs of high-speed crash test.

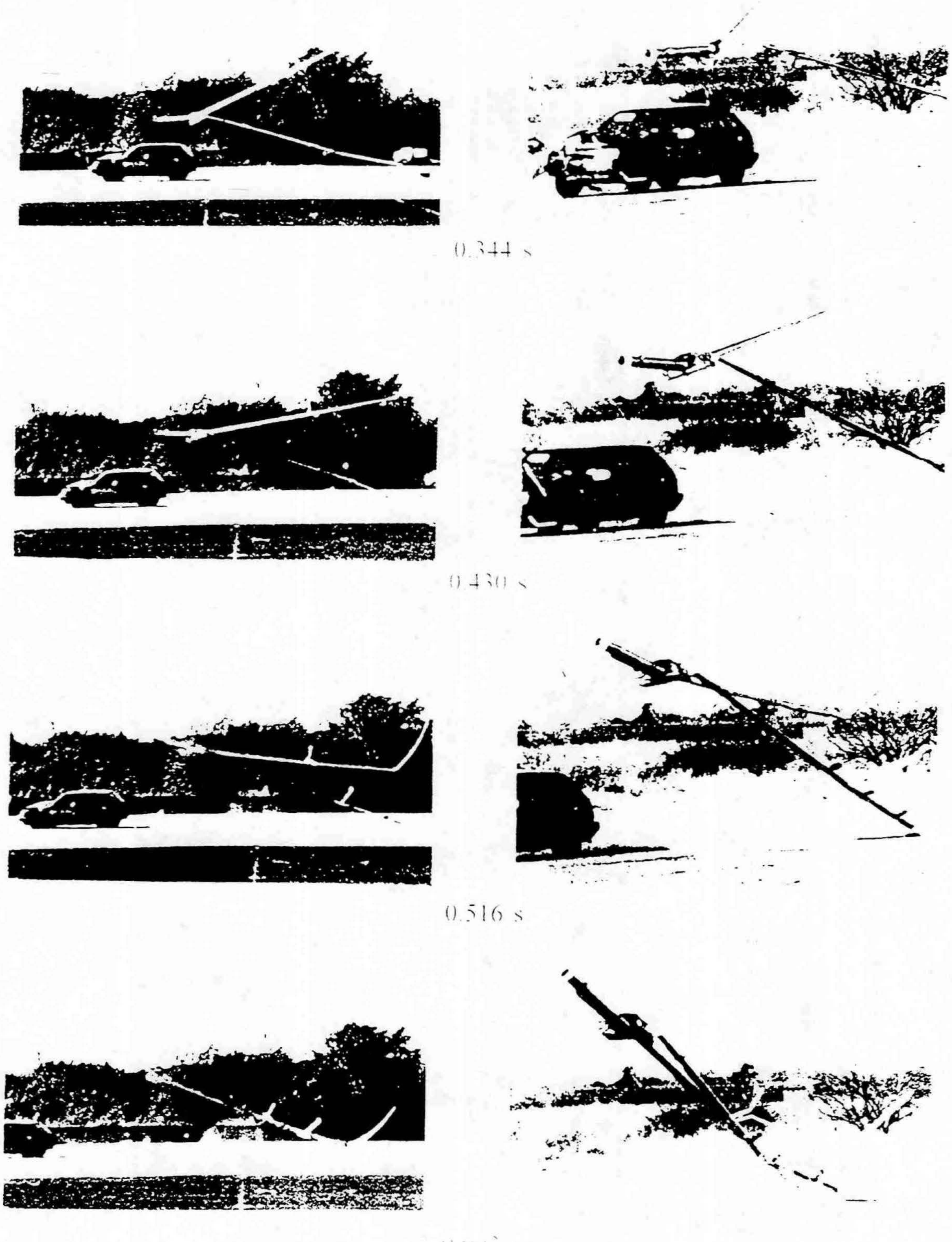

FIGURE 12. Sequential photographs of high-speed crash test (continued).

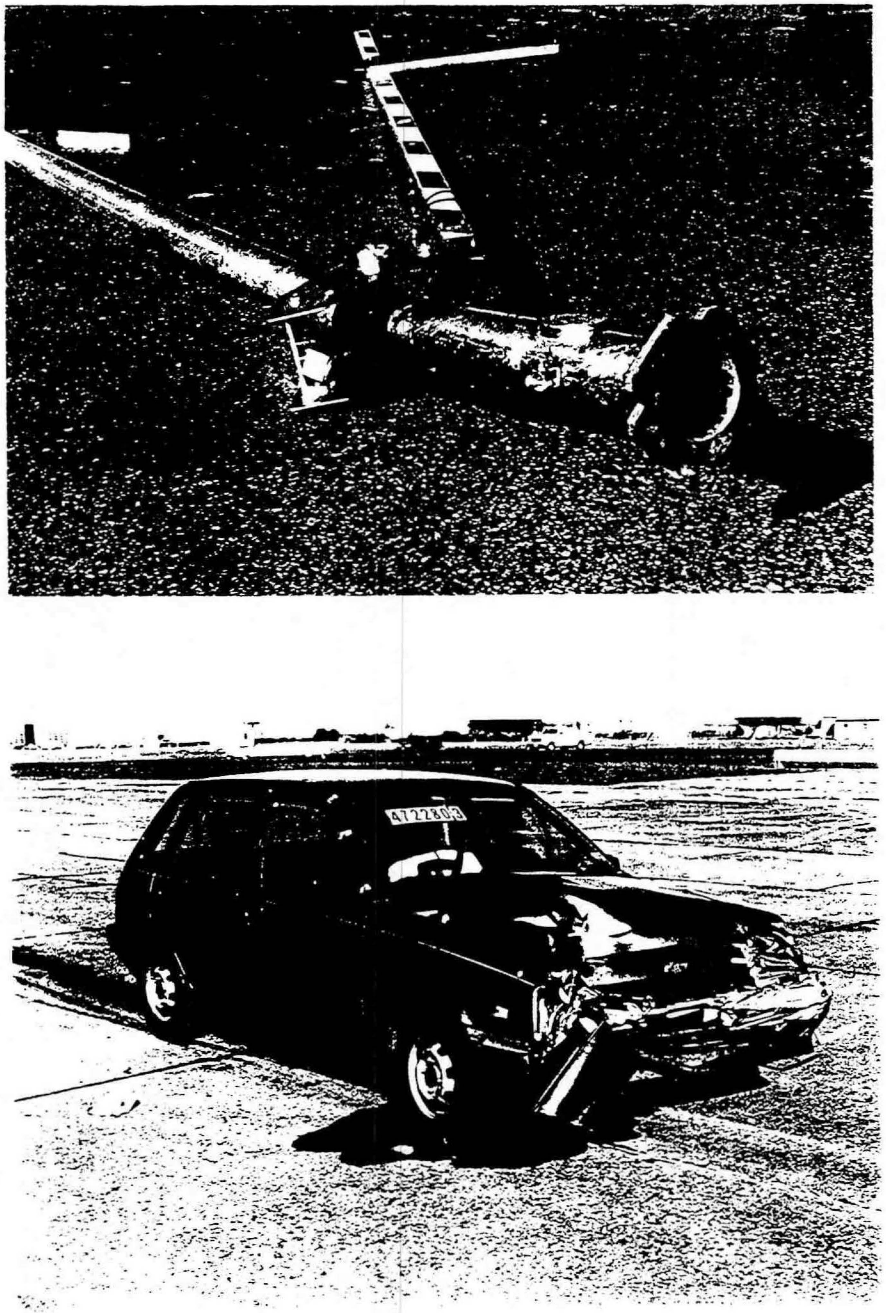

FIGURE 13. Damage sustained by test installation and vehicle in high-speed crash test.