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16. Abstract

A truck-mounted portable maintenance barrier is described in this report. The barrier is designed to provide a reasonable degree of positive protection in short duration work zones where it is not practical to use conventional barriers. The barrier consists of a steel barrier section which is supported between two maintenance trucks. The barrier section is towed to the work zone on a specially fabricated transport dolly. On-site deployment can be accomplished by a crew of two men in 15 minutes or less. The barrier is highly maneuverable in the deployed configuration so that it can be easily repositioned as the work progresses. Three full-scale tests were conducted to demonstrate the impact performance of the barrier.

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DEVELOPMENT OF A TRUCK-MOUNTED PORTABLE MAINTENANCE BARRIER

by

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Research Report 262-5
on
Research Study No. 2-18-79-262
Safety Devices for Highway Work Zones

Sponsored by
State Department of Highways and Public Transportation

in cooperation with
U.S. Department of Transportation
Federal Highway Administration

April 1984

Texas Transportation Institute
The Texas A&M University System
College Station, Tx

DISCLAIMER

KEY WORDS

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DEVELOPMENT OF A TRUCK-MOUNTED
PORTABLE MAINTENANCE BARRIER

ABSTRACT

A truck-mounted portable maintenance barrier is described in this report. The barrier is designed to provide a reasonable degree of positive protection in short duration work zones where it is not practical to use conventional barriers. The barrier consists of a steel barrier section which is supported between two maintenance trucks. The barrier section is towed to the work zone on a specially fabricated transport dolly. On-site deployment can be accomplished by a crew of two men in 15 minutes or less. The barrier is highly maneuverable in the deployed configuration so that it can be easily repositioned as the work progresses. Three full-scale crash tests were conducted to demonstrate the impact performance of the barrier.

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DEVELOPMENT OF A TRUCK-MOUNTED PORTABLE MAINTENANCE BARRIER

INTRODUCTION

There is an increasing number of high volume, multilane expressways where it is not practical to stop traffic across all lanes during maintenance operations. The current approach to this problem is to close only those lanes which are under repair and redirect traffic into adjacent lanes. The problem with this approach is that the work zone is adjacent to a traffic lane thus exposing the workers to the risk of being struck by an errant vehicle. This situation is particularly hazardous during times of heavy traffic flow when the loss of even one lane of traffic can create severe local traffic congestion. There is an urgent need to increase the protection of workers in this situation.

In some instances, the nature of the maintenance operation is such that the work zone is occupied for weeks or months. In such cases, it is possible to install portable concrete barriers (1). In other instances, the time required to acomplish the maintenance is only a few hours. In the latter case, it takes substantially more time to deploy portable concrete barriers than it does to perform the maintenance. In addition, the widths of the portable concrete barriers are such that they encroach into either the work zone or the adjacent traffic lane.

Research presented in this paper was directed toward development of a truck-mounted portable maintenance barrier for use in short-term highway maintenance operations. The portable maintenance barrier developed provides a reasonable degree of protection for the workers; it can be easily deployed; and once deployed, it remains highly maneuverable so that it can be easily repositioned in the work zone. This report presents a discussion of the concept of the portable maintenance barrier, a discussion of the performance criteria, a discussion of the design approach, and results of both strength and maneuverability tests.

CONCEPT

It is common practice in highway maintenance to station supply trucks and other maintenance vehicles in the work zone lane immediately upstream and downstream of the work zone. This is done to provide ready access to maintenance supplies and to prevent unnecessary blockage of additional traffic lanes. A side benefit of this practice is that the maintenance vehicles afford the workers protection from in-lane impacts. The purpose of the research reported herein is to develop a barrier system which enhances the protection afforded by in-lane maintenance vehicles without introducing new hazards to impacting vehicles. The portable maintenance barrier developed is intended for use in short-term, less than one day, maintenance operations such as guardrail replacement, pothole repair, etc. Major emphasis was placed on developing a barrier that is easily transported and deployed.

The truck-mounted, portable maintenance barrier developed consists of a steel barrier section which is supported between two support trucks as shown in Figure 1. Figure 2 shows planned deployments of the portable maintenance barrier in a work zone. The support trucks provide protection against in-lane impacts, while the barrier section provides protection against lateral impacts. The major components of the portable maintenance barrier are: the support trucks, the hitch assemblies, the support members, the barrier section, and the transport dolly (ref. Fig. 3). Each of these components is discussed below.

The support trucks used in the prototype are standard 5 cubic yard State Department of Highways and Public Transportation (SDHPT) dump trucks. The trucks were obtained from the SDHPT surplus property department. The major modification to the trucks consisted of the installation of a frame

metal plate

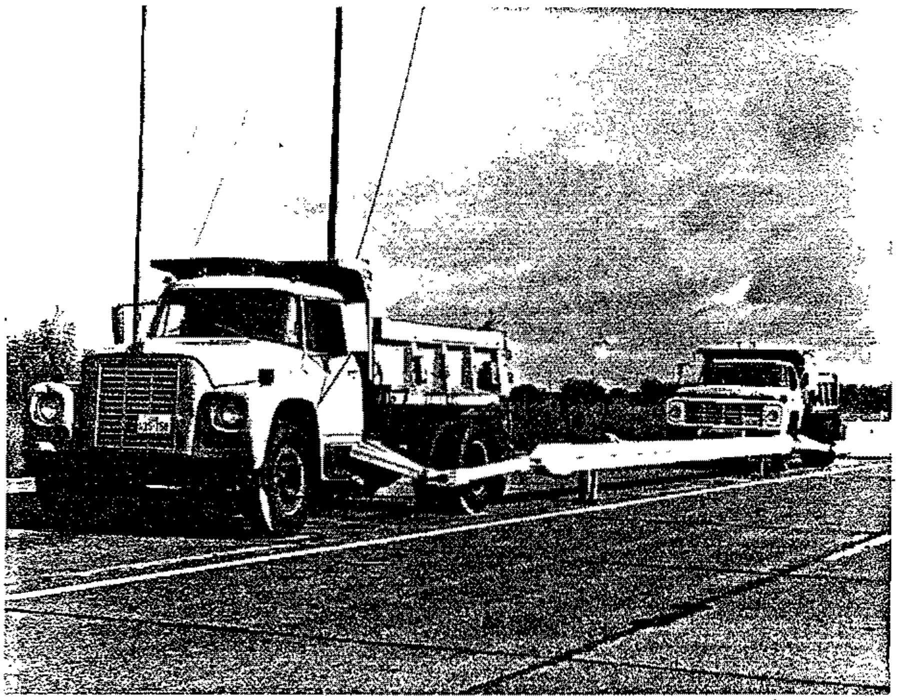
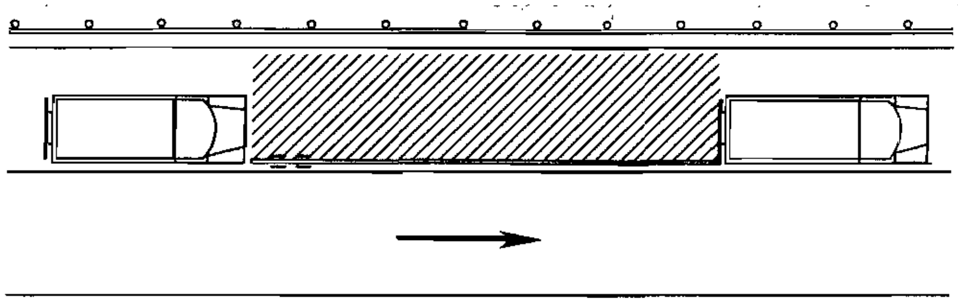
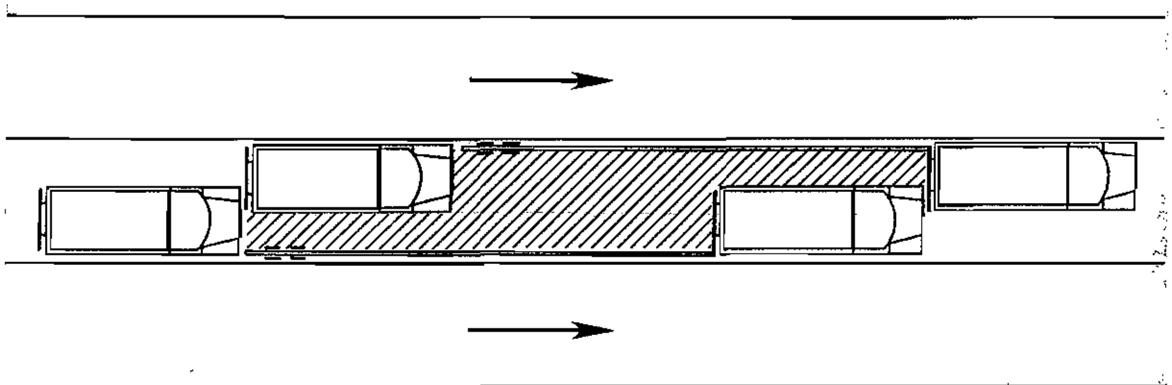


Figure 1. Truck-Mounted Portable Maintenance Barrier



EXTERIOR LANE WORK ZONE



INTERIOR LANE WORK ZONE

Figure 2. Single Lane Barrier Deployments

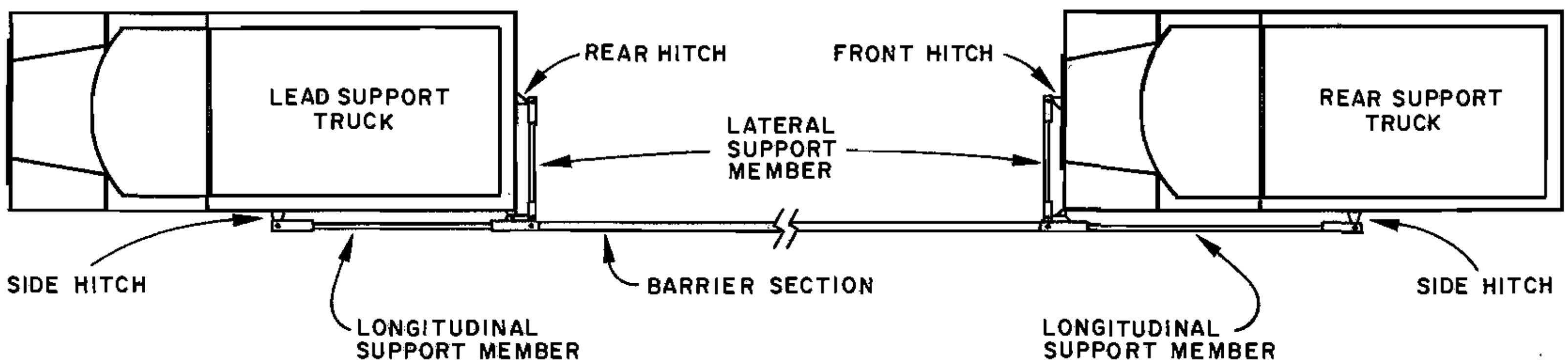


Figure 3. Barrier Components

plate to increase the in-plane stiffness of the truck frames. The purpose of stiffening the truck frames is to assure that the support trucks can survive the design impact with no damage. The frame plate consists of a 1/2 in. (1.27 cm) steel thick plate which is mounted between the frame members of the truck and the dump bed in a horizontal plane. The plate was welded in place in the prototype. However, it will probably be necessary to attach the plate with bolts on newer trucks with high-strength frames. Installation of the frame plate does not interfere with the dump mechanism.

Two different types of hitch assemblies were developed to attach the support members to the trucks: a front/rear hitch and a side hitch. The front/rear hitches were welded to the truck frames on the prototype. As before, it may be necessary to bolt these hitches onto newer trucks with high-strength frames. The side hitches were bolted to the truck frame with twelve 1 in. (2.54 cm) diameter bolts for each hitch. Fabrication details of the hitches are presented in Figures 4 and 5. The lead support truck is equipped with a rear and side hitch, while the rear support truck is equipped with a front and side hitch. The support members attach to the hitches with pins and bolts.

Two types of support members were developed to attach the barrier section to the hitch assemblies: longitudinal support members and lateral support members. The purpose of the support members is to transfer the impact forces from the ends of the barrier section to the hitches mounted on the support trucks. The longitudinal support members connect the side hitches to the ends of the barrier section. The lateral support members connect the barrier ends of the longitudinal support members to the rear and front hitches of the front and rear support trucks, respectively. Fabrication details of the support members are presented in Figures 6 and 7.

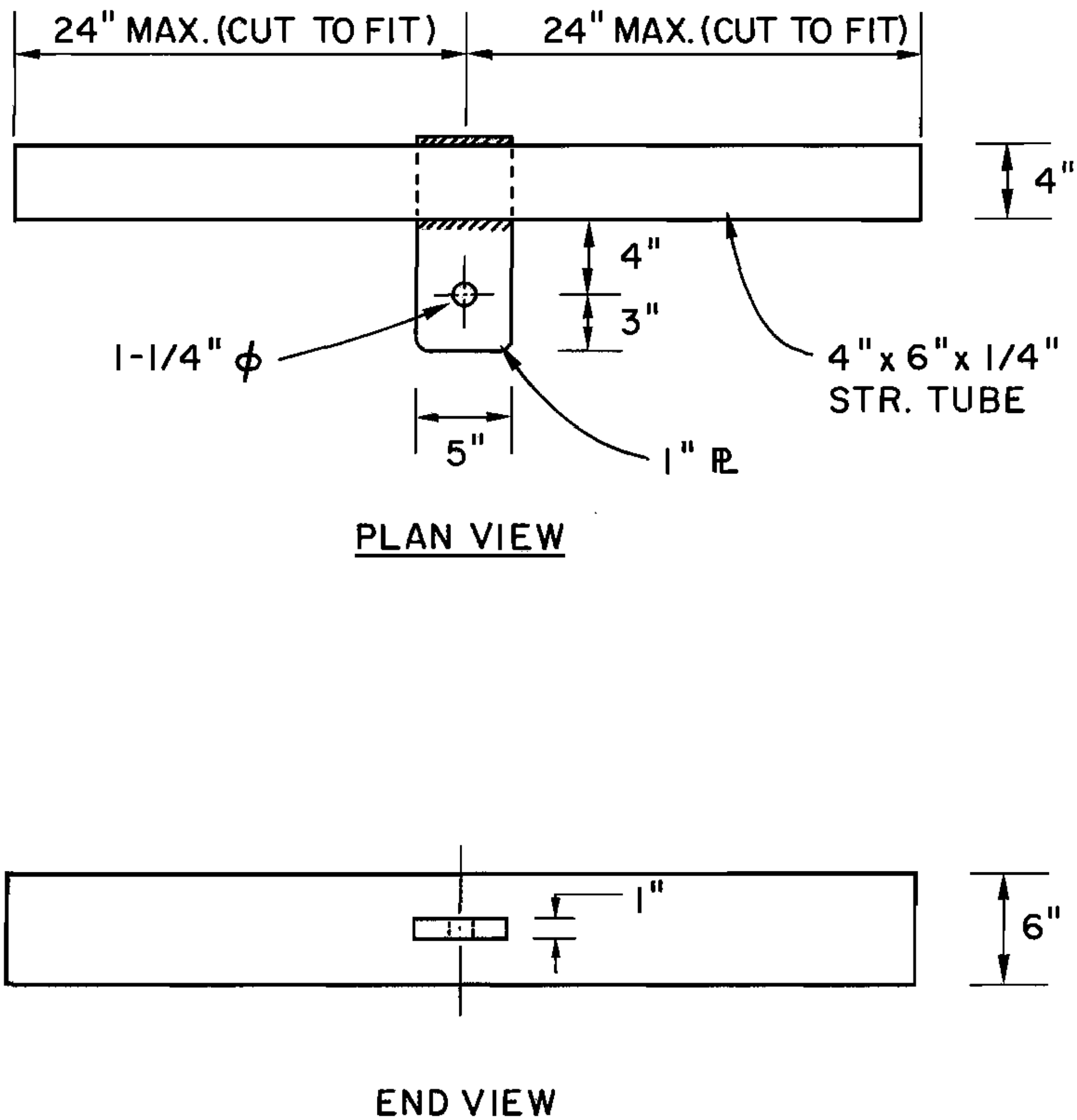
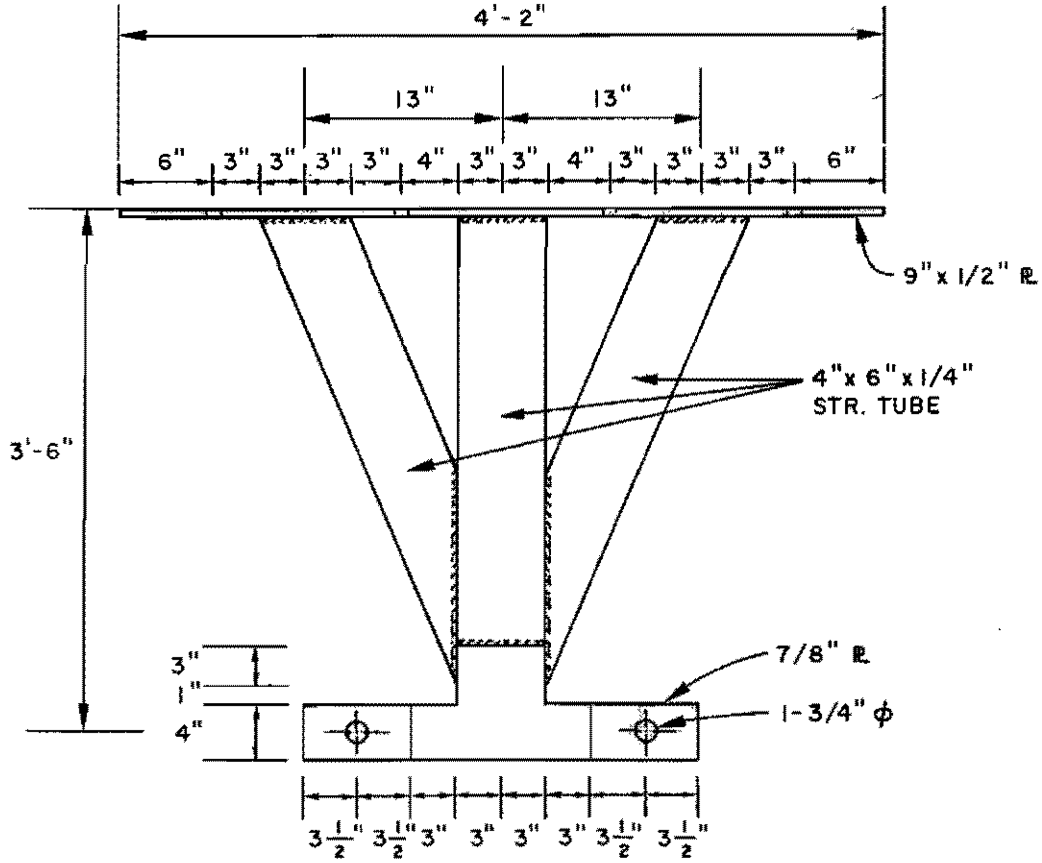
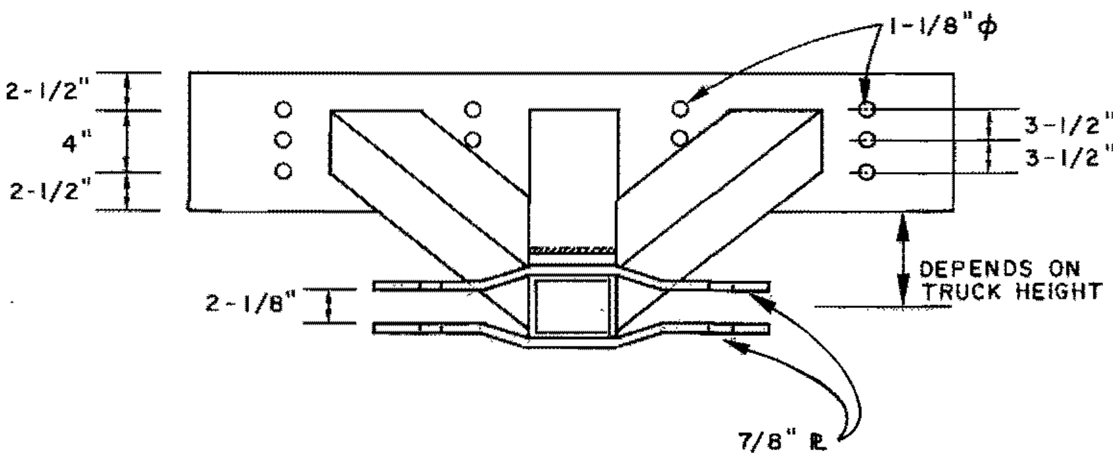


Figure 4. Fabrication Details of Front and Rear Hitches



PLAN VIEW



ELEVATION

Figure 5. Fabrication Details of Side Hitches

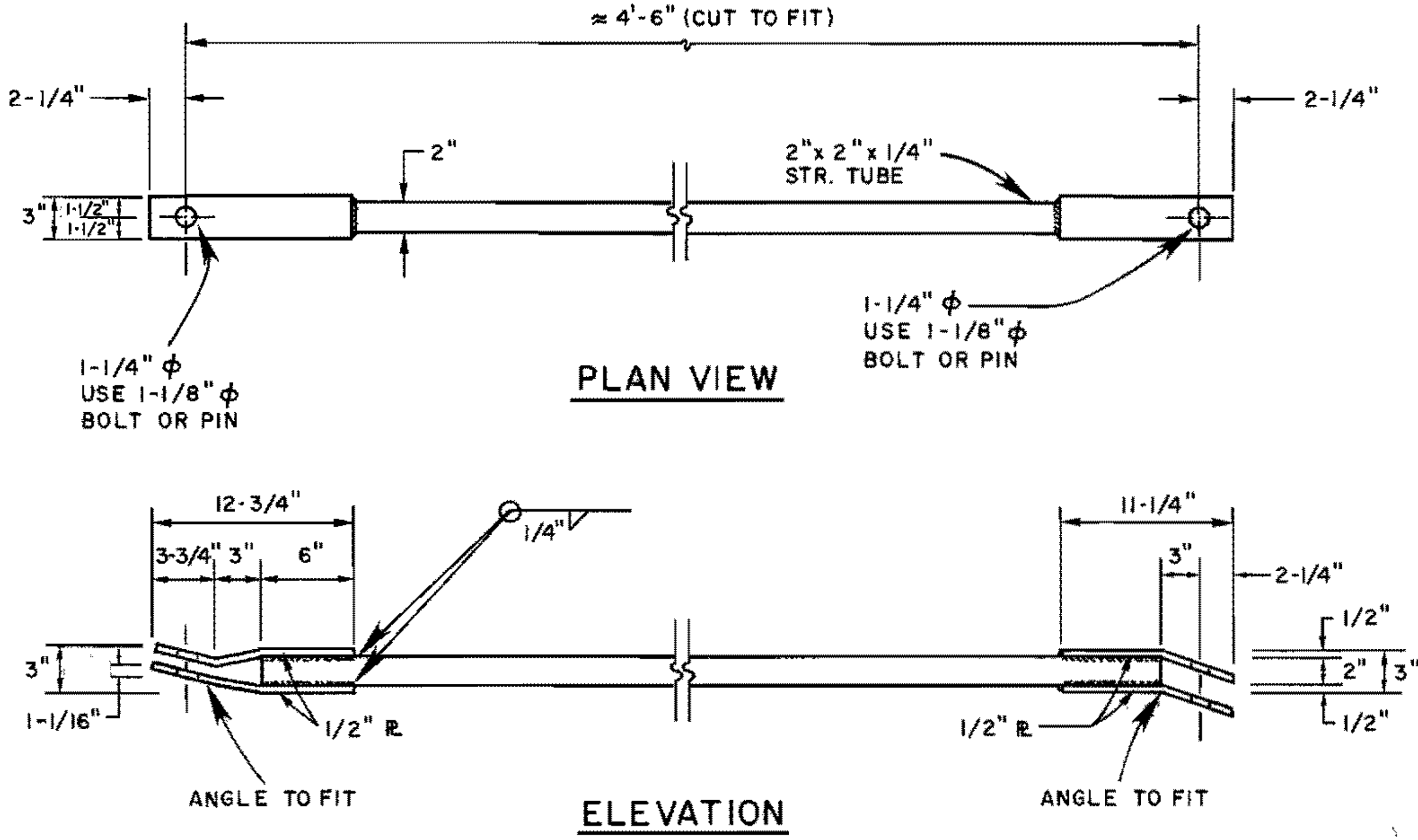


Figure 6. Fabrication Details of Lateral Support Members

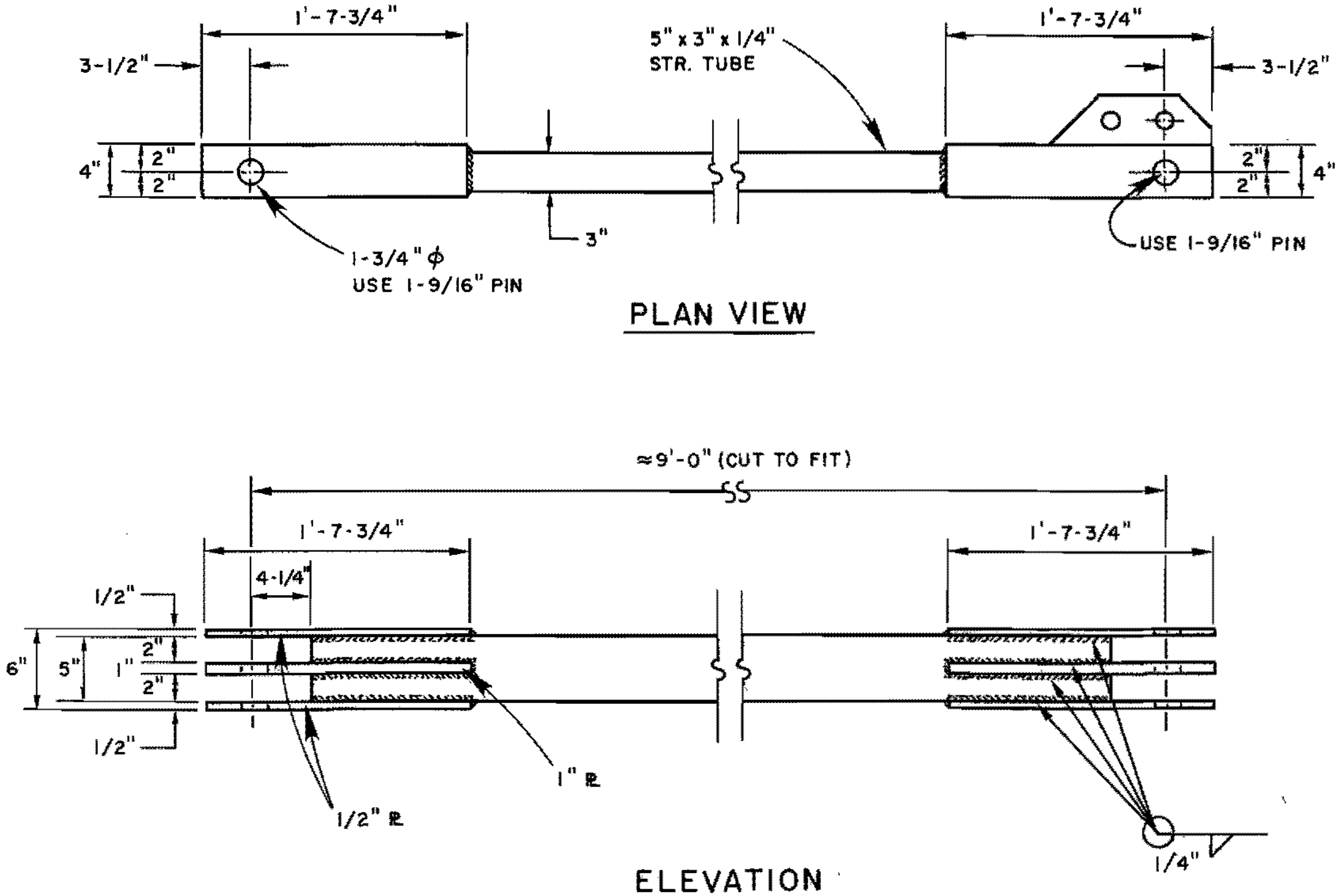


Figure 7. Fabrication Details of Longitudinal Support Members

The barrier section is fabricated using two parallel sections of 6 x 6 x 1/4 in. (15.24 x 15.24 x .64 cm) structural steel tubes welded together as shown in Figure 8. The weight of the barrier section is supported by two swivel casters which are permanently mounted on the underside of the barrier section as shown in Figure 9. In addition, two screw jacks are permanently mounted on the barrier section to aid in handling. The ends of the barrier sections are equipped with single pin connections that mate with the ends of the longitudinal support members. These connections are designed to allow 180 degrees of yaw and nominal amounts of pitch and roll between the barrier section and the support trucks. The combined effects of these features result in a highly maneuverable barrier which can be easily moved through short distances in the work zone.

The barrier section is towed to and from the work zone using a detachable transport dolly (ref. Fig. 10). Fabrication details of the transport dolly frame are presented in Figure 11. The barrier section is loaded and unloaded onto the transport dolly by alternately using the two barrier section screw jacks. An experienced crew of two men can load or unload the barrier section in a period of 15 minutes or less. Complete details for the loading and unloading operations are presented in Appendix A. When not in use, the transport dolly is connected to an auxiliary hitch point located on the rear of the front truck.

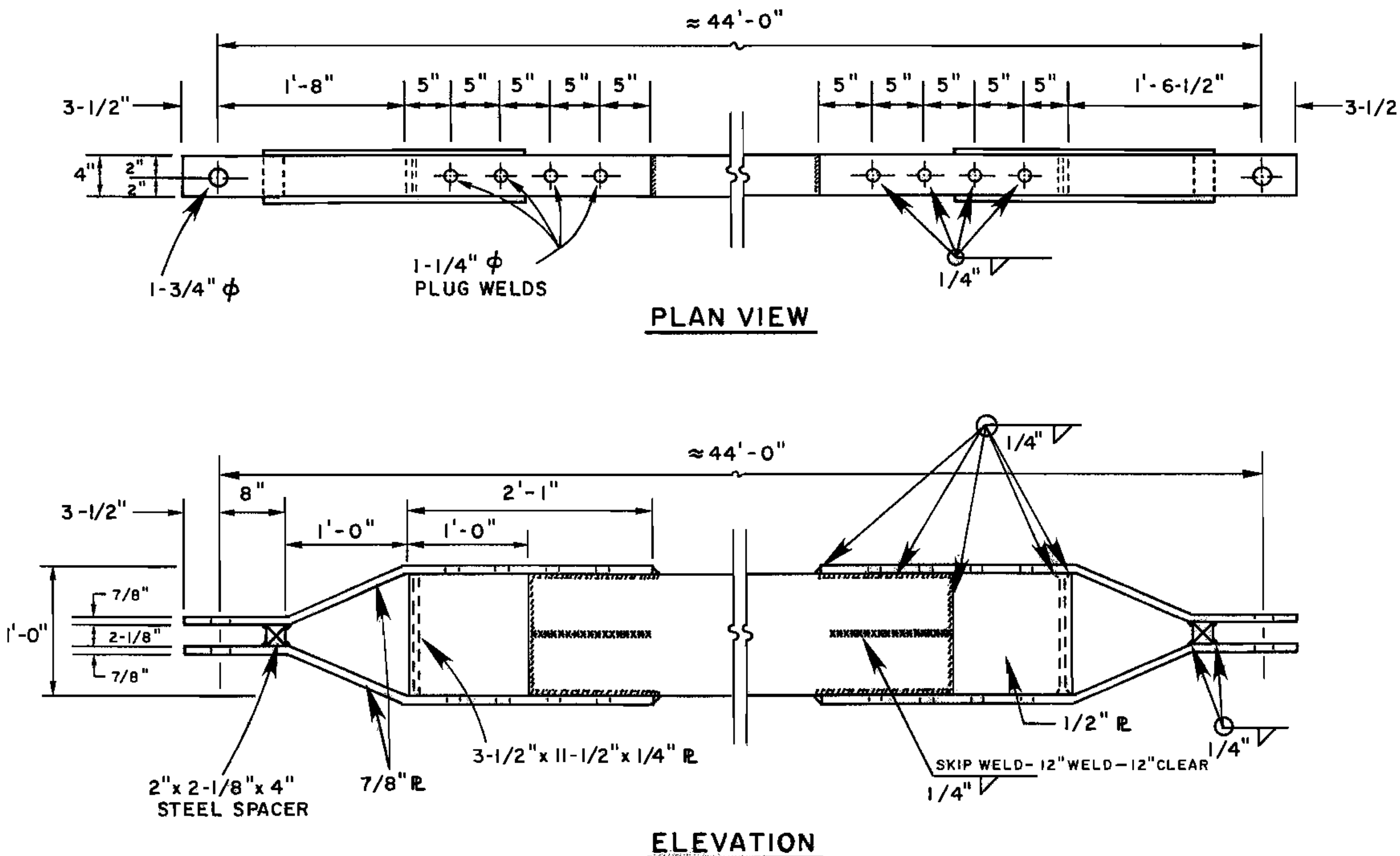


Figure 8. Fabrication Details of Barrier Section

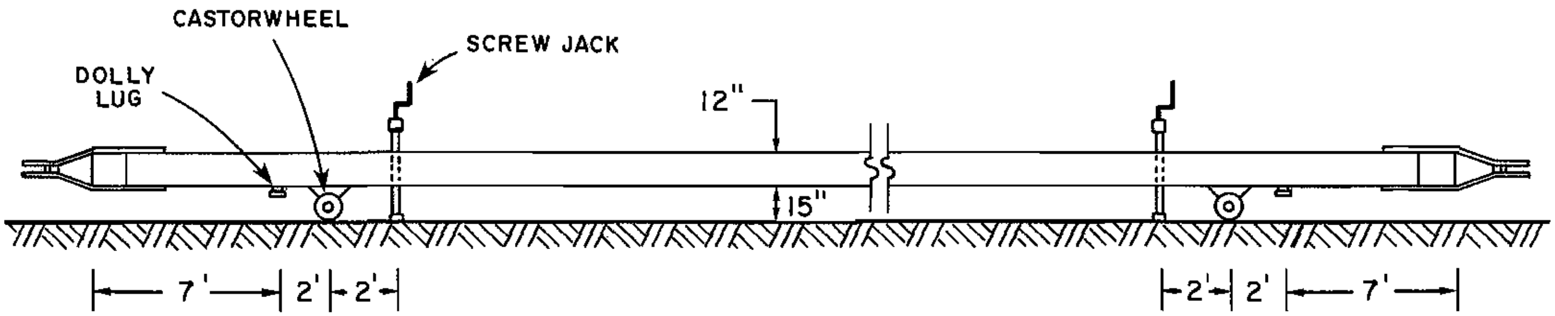


Figure 9. Side View of Barrier Section

metal plate

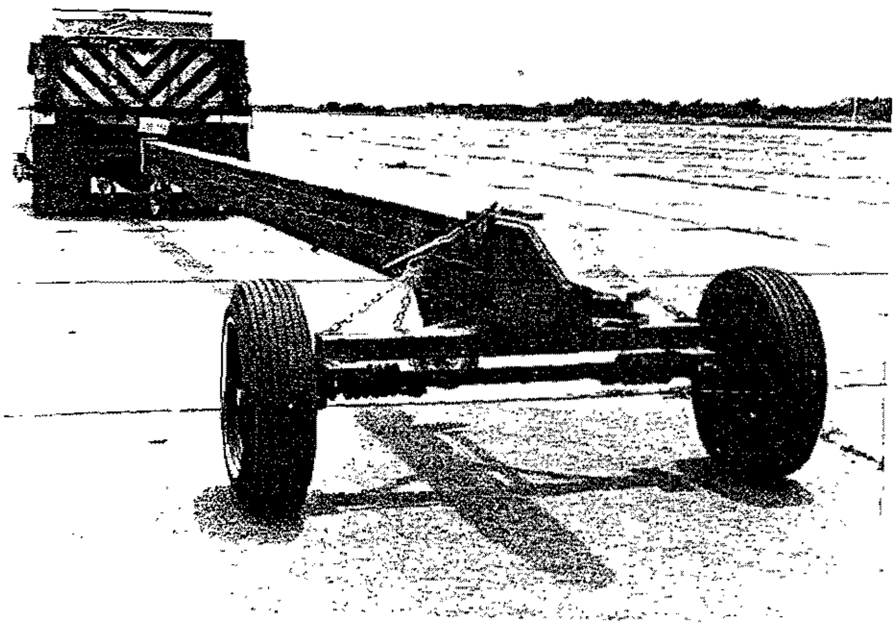
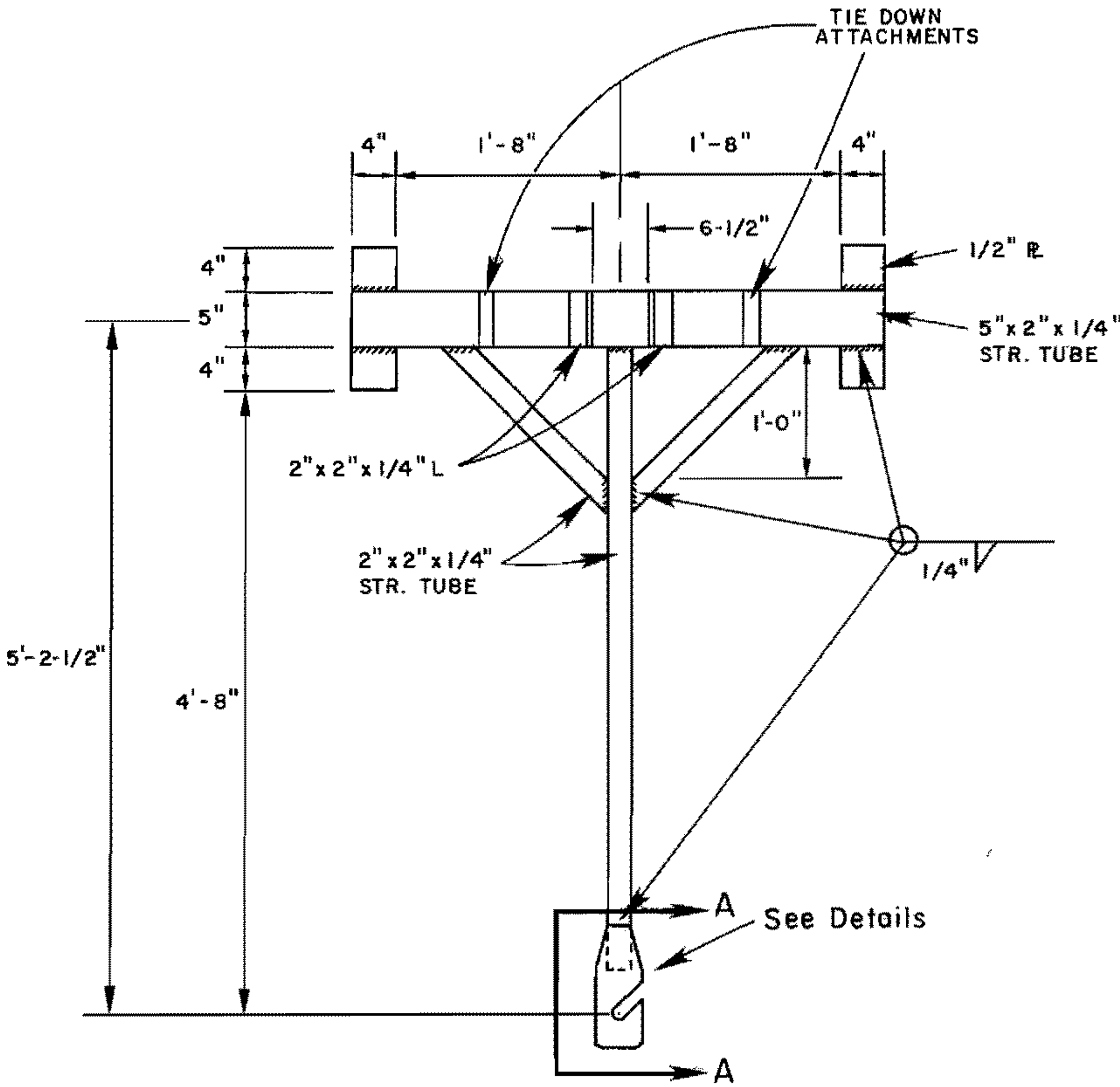
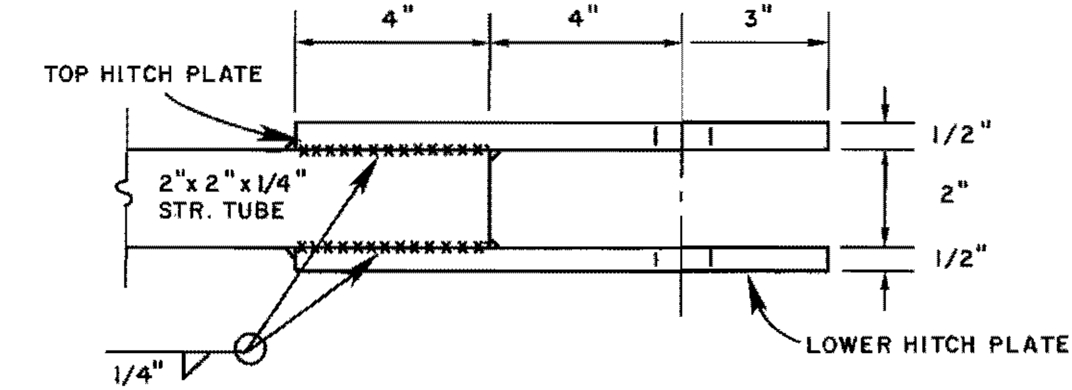


Figure 10. Barrier Section on Transport Dolly

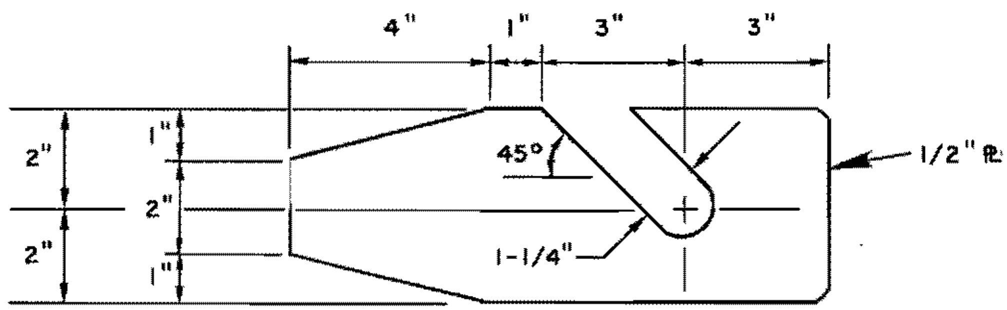


PLAN VIEW

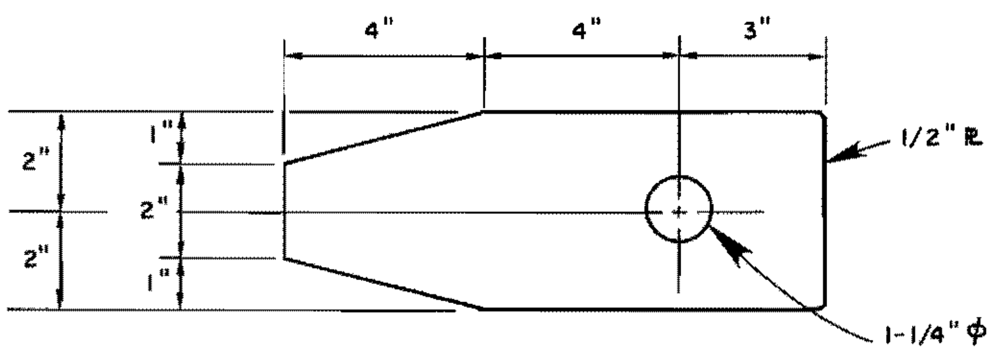
Figure 11. Fabrication Details of Transport Dolly



SECTION "A-A"



TOP HITCH PLATE



LOWER HITCH PLATE

Figure 11. Fabrication Details of Transport Dolly (continued)

PERFORMANCE CRITERIA

Performance criteria for guardrails, traffic barriers, and other types of highway appurtenances are presented in NCHRP Report 230 (2). The criteria presented in this report are the result of a consensus process involving interested experts and professionals. While it is not explicitly stated in the report, the primary use of NCHRP Report 230 has been to establish performance criteria for permanent appurtenances.

The proposed portable maintenance barrier is not intended to be permanently deployed. Therefore it is not exposed to the continual risk associated with a permanent barrier or semipermanent portable barrier. Further, it must be recognized that the maintenance workers are currently working with a limited amount of protection. These factors combine to suggest that it is reasonable to employ design criteria which are less stringent than performance criteria presented in NCHRP Report 230 (2).

The criteria for permanent guardrail installations presented in NCHRP Report 230 is intended to evaluate the following three principal performance factors: structural adequacy, occupant risk, and vehicle after-collision trajectory (2). Permanent guardrail installations must be designed to safely redirect a 4500 lb (2043 kg) automobile traveling at 60 mph (96.6 km/h) and impacting at an angle of 25 degrees. In addition, permanent guardrail installations should be able to smoothly redirect compact automobiles (2250 and 1800 lb) (1022 kg and 812 kg) traveling at 60 mph (96.6 km/h) and impacting at an angle of 15 degrees. The first criterion establishes the required strength of the barrier and evaluates the occupant risk factors. The second criterion evaluates the barrier's potential for destabilizing errant automobiles.

Based upon input received through discussions held with SDHPT engineers and researchers, coupled with the judgment of researchers at TTI, the following performance criteria was established for the truck-mounted portable maintenance barrier. The portable barrier was designed to redirect a 4500 lb (2043 kg) automobile with a velocity of 50 mph (80.5 km/h) and an impact angle of 15 degrees. The destabilizing potential of the portable maintenance barrier was evaluated using an 1800 lb (812 kg) automobile traveling at 50 mph (80.5 km/h) and impacting at an angle of 15 degrees. It was the consensus of all professionals contacted that these are reasonable performance criteria for the truck-mounted portable maintenance barrier presented herein.

BARRIER ANALYSIS AND DESIGN

The structural design of the portable maintenance barrier was accomplished in two stages. First, a simplified analysis was used to determine the relative effects of varying barrier length, stiffness, and mass. Results of this preliminary study were then used to develop a preliminary portable maintenance barrier design. The performance of the preliminary design was further examined using a computer simulation, Barrier VII (3). Based upon results from the computer simulation, a refined barrier design was advanced. The refined design was reviewed by SDHPT engineers, and suggested changes were incorporated. This section presents pertinent details of the design of the portable maintenance barrier.

PRELIMINARY ANALYSIS

To simplify analysis of the portable maintenance barrier, the following idealized impact is assumed. First it was assumed that the support trucks do not slide laterally during the impact. This assumption leads to consideration of the barrier section as a simply supported beam between the support trucks. Further, it is assumed that the automobile is a point mass impacting the barrier section with a velocity, V_i, and with an angle of impact, θ (ref. Fig. 12). The impact is considered to be perfectly plastic so that the automobile is redirected parallel to the barrier face. Finally, it is assumed that the force between the barrier and the automobile acts normal to the barrier section and is the result of the flexural stiffness of the barrier. Other forces such as friction and intertia forces are ignored.

Using the principle of impulse and momentum, the exit velocity, V_f, of the automobile is calculated as follows:

$$V_f = V_i \cos \theta \qquad (1)$$

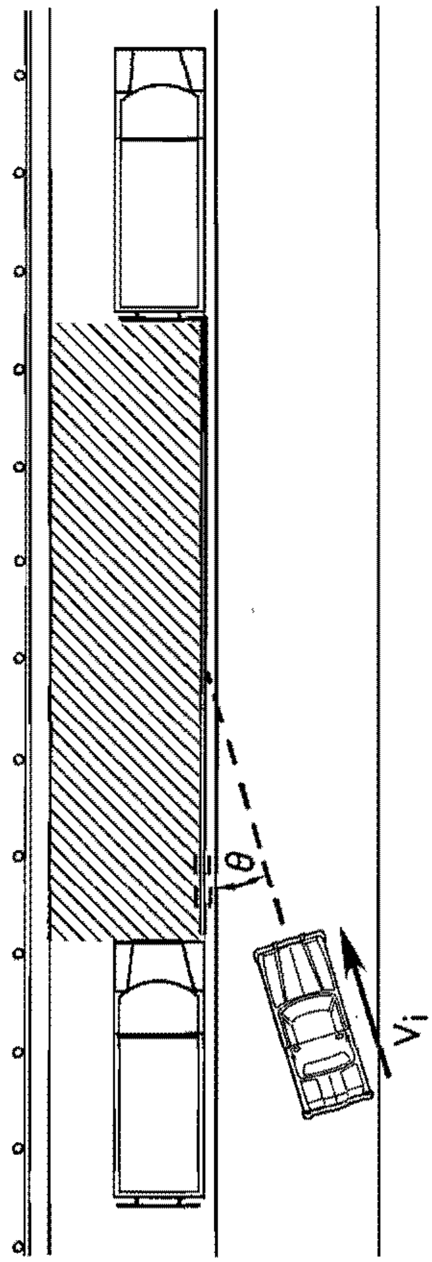


Figure 12. Idealized Impact

The change in kinetic energy of the automobile during this idealized impact is referred to as the impact severity, IS, in NCHRP Report 230 (2). The IS energy is calculated as follows:

$$IS = 1/2\ m\ V_i^2 \sin^2 \theta \tag{2}$$

where V_i is the impact velocity and m is the mass of the automobile.

When the automobile impacts the barrier section, a force develops between the barrier and the impacting automobile and energy is absorbed through several different mechanisms including: deformation of the automobile, deformation of the barrier, friction, etc. In the preliminary analysis, it is assumed that the barrier absorbs a percentage, β, of the IS energy in an elasto-plastic flexural response.

Figure 13 presents the idealized elasto-plastic force displacement relationship between the automobile and the barrier. The total amount of energy, U_t, absorbed by the barrier is given as follows:

$$U_t = 1/2\ P_y\ \delta_y + P_y\ \delta_p \tag{3}$$

where P_y and δ_y are the force and displacment corresponding to the elastic limit of the barrier, and δ_p is the plastic deformation of the barrier. The first term in equation (3) is the elastic response, and the second term is the plastic response.

The ratio of the plastic deformation, δ_p, to the elastic deflection, δ_y, is the ductility ratio and is a measure of the barrier's capacity for plastic deformation. A maximum allowable value of 5 was assumed for the ductility ratio in the preliminary analysis. Substitution of this value into equaton (4) results in the following expression for the total amount of energy that a given barrier section can absorb:

$$V_t = \frac{11}{2} P_y\ \delta_y \tag{4}$$

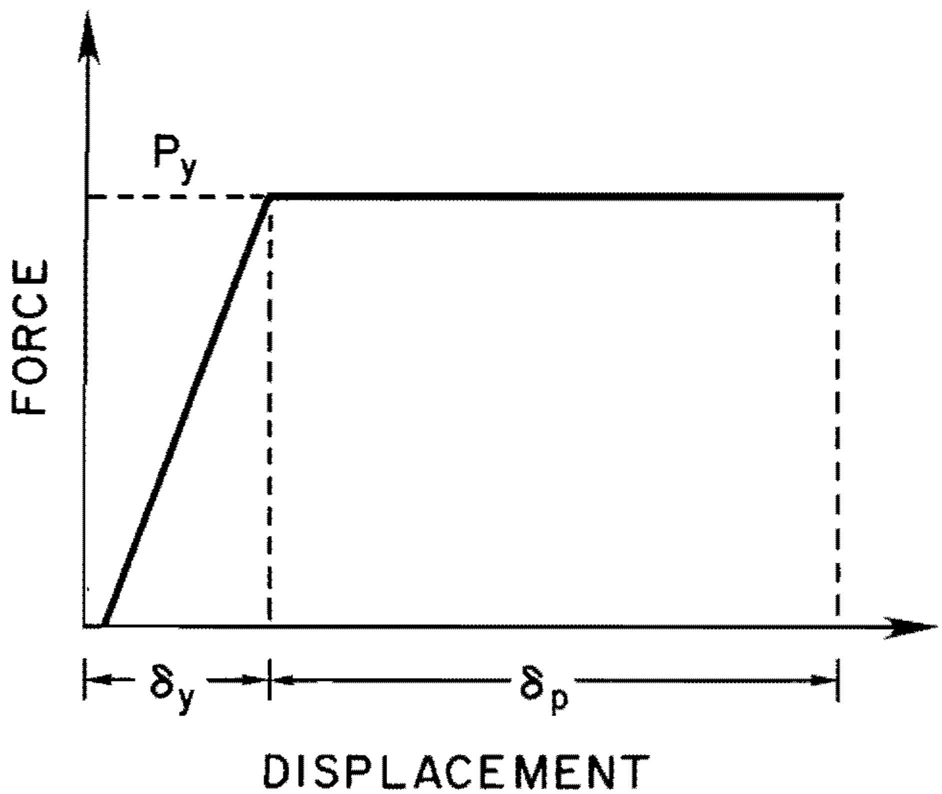


Figure 13. Idealized Barrier Force Deformation Relationship

Using elementary concepts of mechanics of materials and equation (4), the following expression for the total amount of energy that can be absorbed by the barrier section is developed:

$$V_t = \frac{11}{6} \left(\frac{\sigma_y^2 \, I\ell}{c^2 E}\right) \tag{5}$$

where I is the moment of inertia of the barrier section, ℓ is the barrier section length, σ_y is the yield strength of the barrier section, c is the distance from the neutral axis to the extreme fibers of the barrier section, and E is the modulus of elasticity of the barrier section.

The optimum use of material results when the energy absorption capacity of the barrier section is set equal to the percentage of energy that must be absorbed by the barrier as follows:

$$\frac{11}{6} \left(\frac{\sigma_y^2 \, I\ell}{c^2 E}\right) = \beta(IS) \tag{6}$$

Equation (6) can be rearranged so that the cross-section properties of the barrier section appear on the left side of the equation while the automobile characteristics, the barrier section length, and the properties of the barrier section material appear on the right side of the equation as follows:

$$\frac{I}{c^2} \geq \frac{6}{11} \frac{\beta E(IS)}{\sigma_y^2 \ell} \tag{7}$$

Equation (7) was used to perform feasibility studies and the preliminary barrier design. During the preliminary studies a wide range of values of β were assumed. Subsequent experience in the testing phase of the project suggests that values of β ranging from .30 to .40 are reasonable for analysis of this type of barrier.

FINAL ANALYSIS AND DESIGN

The preliminary analysis presented above was used to establish the feasibility of the proposed portable maintenance barrier and to develop preliminary barrier designs. The preliminary designs were then examined using a crash simulation program, Barrier VII (3). Modifications to the barrier design were made based on information generated using the computer analysis.

Because of the complexities and uncertainties associated with the problem, a simplified model of the barrier was used in the computer study (ref. Fig. 14). In the simplified computer model, the support member attachment points (hitch points) are assumed to be immovable. In the real situation, the support trucks allow the hitch points to translate as a result of sliding of the trucks and truck suspension deflections. It is the opinion of the writers that the assumed model provides conservative estimates of the impact forces. Major points of the design are discussed below.

The portable maintenance barrier was designed to withstand the impact of a 4500 lb (2043 kg) automobile traveling at a velocity of 50 mph (80.5 kg/h) and impacting at an angle of 15 degrees. The barrier section was designed to experience plastic deformation when exposed to the design impact, while the support trucks, support members, and hitches were designed to remain elastic. The barrier section should be repaired or replaced after a design hit, while the rest of the barrier can be reused.

An approximate analysis of the truck frame using the impact forces determined from the computer analysis suggests that the unreinforced truck frame would be subject to plastic deformation at the design impact. Therefore, the stiffness of the frame was increased by coupling the primary frame

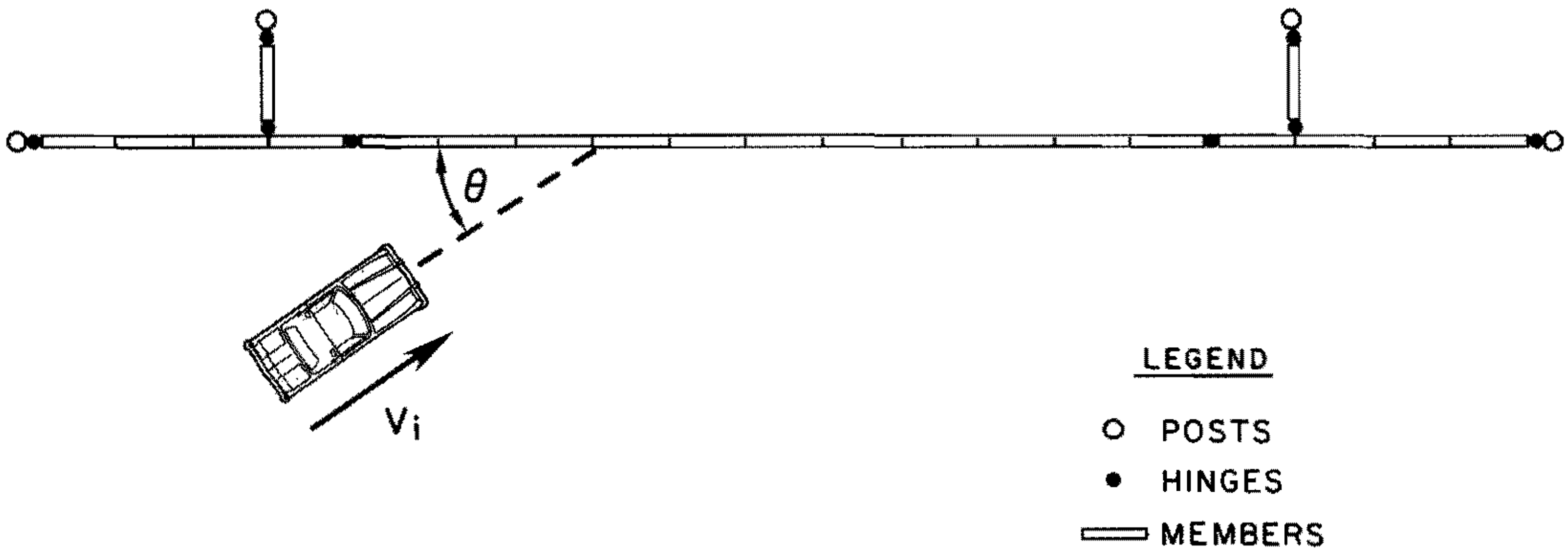


Figure 14. Computer Model of Barrier

members together using a horizontal frame plate. The effect of the frame plate is to transform the truck frame into a horizontal plate girder with the frame plate serving as the plate girder web and the truck frame members serving as the plate girder flanges. The frame plate modification adds sufficient stiffness to the truck frame to prevent permanent deformation of the truck frame.

The support members and hitch configurations were designed so that the longitudinal and the lateral support members are two-force members. As stated earlier, the support members and the hitches were designed to remain elastic during impact. Results of the computer analysis show that the lateral support members experience compression during impact, while the longitudinal members experience tension. In addition to the tension force, the longitudinal members were designed to withstand a direct impact from the automobile.

Of primary concern with the design of the barrier section was lateral torsional stability. An approximate analysis of different proposed barrier sections suggested that barrier sections with open cross sections such as wide flanges, I beams, etc., would be susceptible to lateral torsional buckling. The torsional rigidity of closed sections such as the one used in the prototype is sufficient to prevent lateral torsional buckling. An additional concern with the design of the barrier section was local buckling of the barrier section sidewall. It is the opinion of the writers that a barrier section made of a single rectangular tube would have a tendency for local buckling of the sidewall at the point of impact. Therefore a double structural tube section was selected to reduce the propensity for local buckling.

Major emphasis was placed on specifying commonly available materials for construction of the portable maintenance barrier. Two types of structural steel were used in the design of the portable maintenance barrier: structural tubes and flat steel. Structural tubes are most commonly available with a mimimum yield strength of 46 ksi. All structural tubes are of this type. The most commonly available structural steel used for bars and plates has a minimum yield strength of 36 ksi. All flat steel used in the barrier was designed on this basis. The bolts and pins used in the portable barrier were sized using minimum available strengths. This should preclude problems if field substitutions are made.

TEST RESULTS

Three full-scale crash tests were conducted on the truck-mounted portable maintenance barrier. The purpose of the tests was to establish the redirective capabilities of the barrier and to determine its destabilizing effect on compact cars. The impact point in all of the tests was located one third of the length of the barrier section ahead of the rear support truck. This impact point was selected to maximize the flexural loading on the barrier section. It is recognized by the writers that direct impact into the supporting trucks would be much more serious for the errant vehicle. However, there is no reason to think that such an impact would be more serious than an impact with a free standing maintenance vehicle. It is recommended that one of several different types of rear crash cushions be towed behind the rear support truck to reduce the consequences of a vehicle impact at that point.

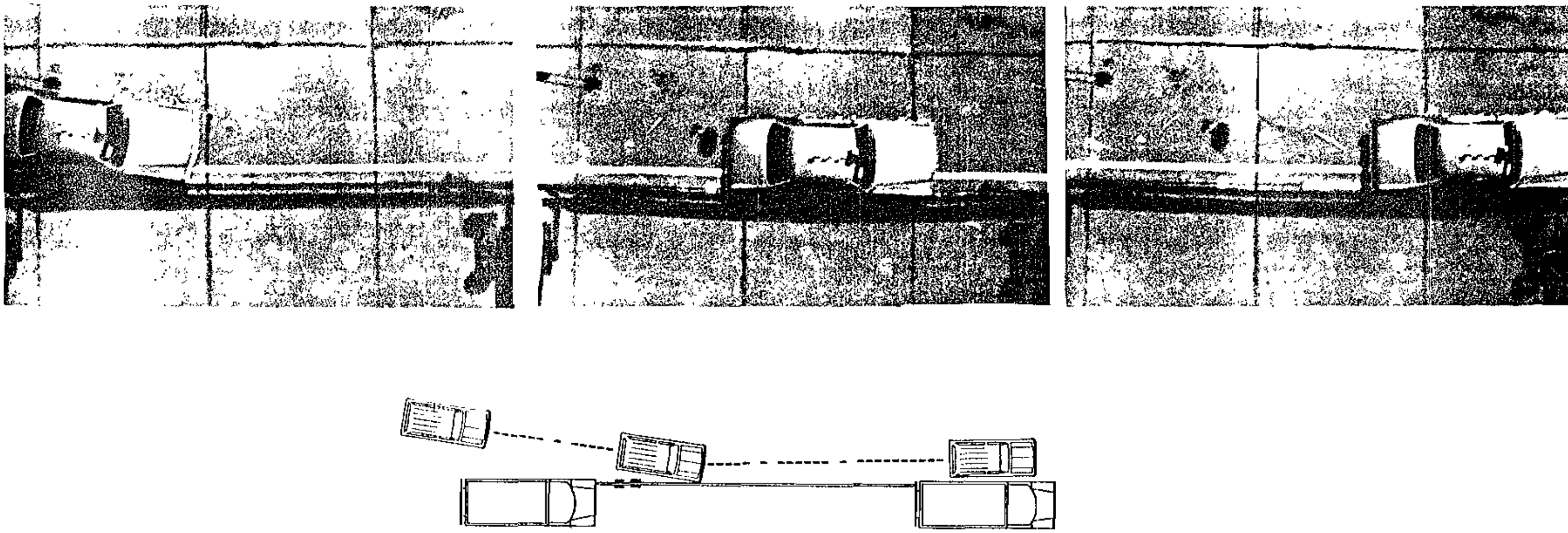
Table 1 presents a summary of pertinent test statistics. The tests were conducted in order of increasing severity. Sequential photos of the tests are presented in Appendix B. Appendix C presents accelerometer traces and plots of roll, pitch, and yaw angles. In addition, tests were conducted to evaluate the maneuverability of the barrier. Short discussions of both the strength and maneuverability tests are presented below. Results presented in this report are a part of an ongoing research. The three crash tests are the 9th through 11th tests of this series.

TEST 9

In this test, a 4500 lb (2043 kg) vehicle impacted the barrier at 50.9 mph (81.95 km/h) with an angle of impact of 7.3 deg. The automobile was smoothly redirected with relatively minor damage. Figure 15 presents a

TABLE 1. CRASH TEST SUMMARIES

Test	9	10	11
Vehicle Weight, lb (kg)	4500 (2043)	1765 (801)	4500 (2043)
Impact Speed, mph (km/h)	50.9 (81.95)	50.9 (81.95)	49.7 (80.02)
Impact Angle, deg.	7.3	14.0	15.0
Exit Angle, deg.	.5	1.3	1.0
Barrier Displacement, in. (cm)	11.2 (28.45)	13.0 (33.02)	24.0 (60.96)
Occupant Impact Velocity f/s (m/s)			
Longitudinal	6.7	11.3	10.0
Lateral	0	0	0
Occupant Ridedown Accel., g's			
Longitudinal	.87	1.58	1.34
Lateral	0	0	0
Vehicle Damage Classification			
TAD	2-RFQ-1	2-RFQ-2	2-RFQ-2
VDI	02RFMW5	02RFMW6	02RFMW9



Test No.	2262-9
Date	8/22/83
Installation	
Drawing Nos.	2262-5(3-9,11)
Length-ft (m)	88 (26.8)
Beam Rail	
Member	2 6x6x1/4 in. Stl. Tubes
Length of Segment-ft (m)	44 (13.4)
Maximum Deflections	
Dynamic - in. (cm)	11.2 (28.3)
Permanent - in. (cm)	.5 (1.3)
Vehicle	
Model	1977 Plymouth Gran Fury
Mass-lb (kg)	4500 (2045)

Speed-mph (kph)	
Impact	50.9 (81.9)
Exit	46.2 (74.4)
Angle - deg	
Impact	7.3
Exit	.5
Occupant Impact Velocity - fps (m/s)	
Forward	6.69 (2.04)
Lateral	N/A
Occupant Ridedown Accelerations - g's	
Forward	.87
Lateral	N/A
Vehicle Damage*	
TAD	2RFQ-1
VDI	02RFMW5

Figure 15. Summary of Test 9

summary of the results of this test. All measured occupant risk values and vehicle trajectory characteristics are well below the values recommended by NCHRP 230 (2).

Figure 16 presents photographs of the barrier and the automobile prior to impact. Figure 17 presents photographs of the barrier and the automobile after impact. The barrier section sustained 1/2 in. (1.27 cm) of permanent lateral deflection. The support trucks, hitches, and support members were not damaged. Most of the damage to the right front of the automobile visible in Figure 17 occurred when remotely controlled safety brakes failed to stop after impact. As a result, the automobile crashed into a concrete median barrier downstream from the barrier. The primary damage to the automobile as a result of contact with the portable barrier occurred when the right front tire and rim struck the barrier section support caster as the autombile slid along the barrier section. This occurred because the caster pivoted outward as the steel barrier section underwent lateral deformation. Similar damage occurred in all three tests. Failure of the tire and rim did not destabilize the impacting vehicle. The damage ratios presented in Figure 15 reflect the damage before the secondary impact.

TEST 10

In this test, a 1765 lb (801 kg) vehicle impacted the barrier with a velocity of 50.9 mph (81.95 km/h) with an angle of 14.0 deg. The same barrier section used in the first test was reused in this test. The previous 1/2 in. (1.27 cm) of permanent deformation was not removed. Figure 18 presents a summary of the results of this test. Again the vehicle was smoothly redirected. The measured occupant risk values and the vehicle trajectory characteristics were well below the values recommended by NCHRP 230 (2).

metal plate

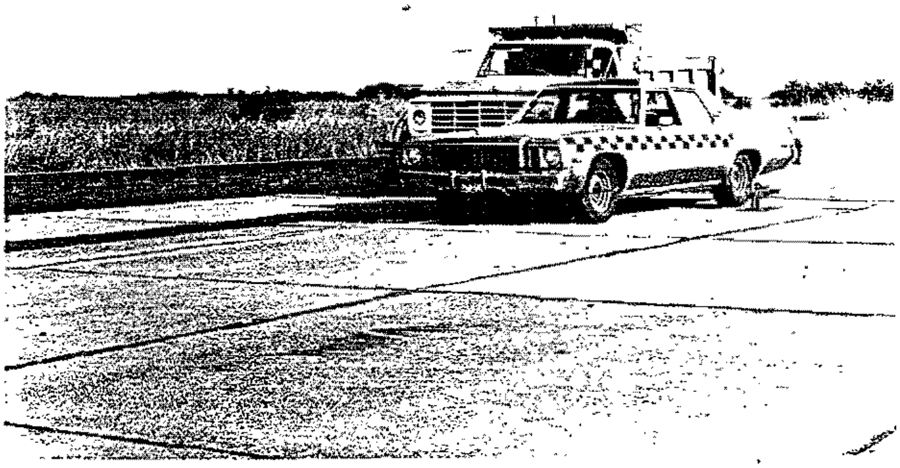


Figure 16. Barrier and Automobile
Prior to Test 9

metal plate

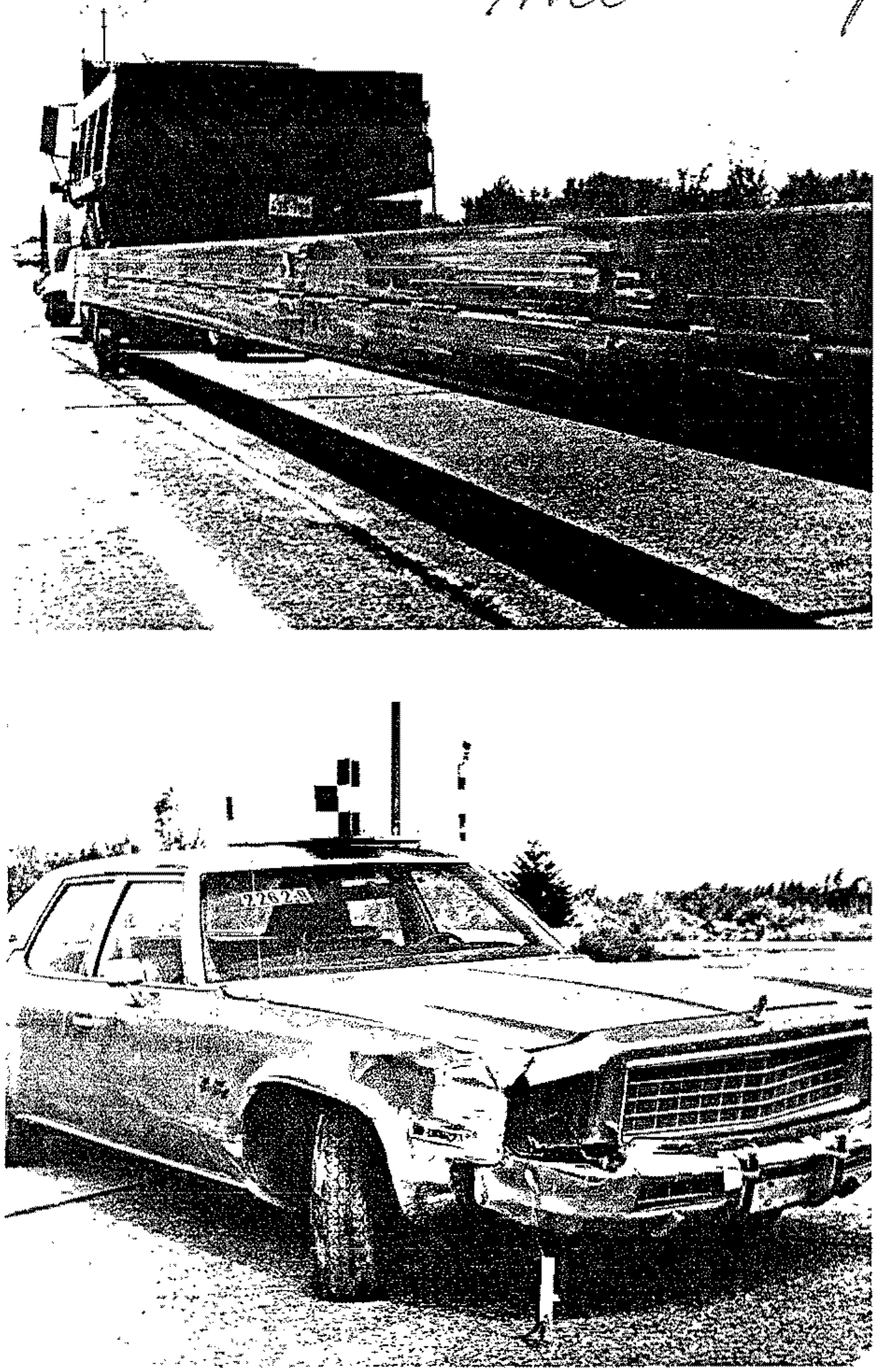
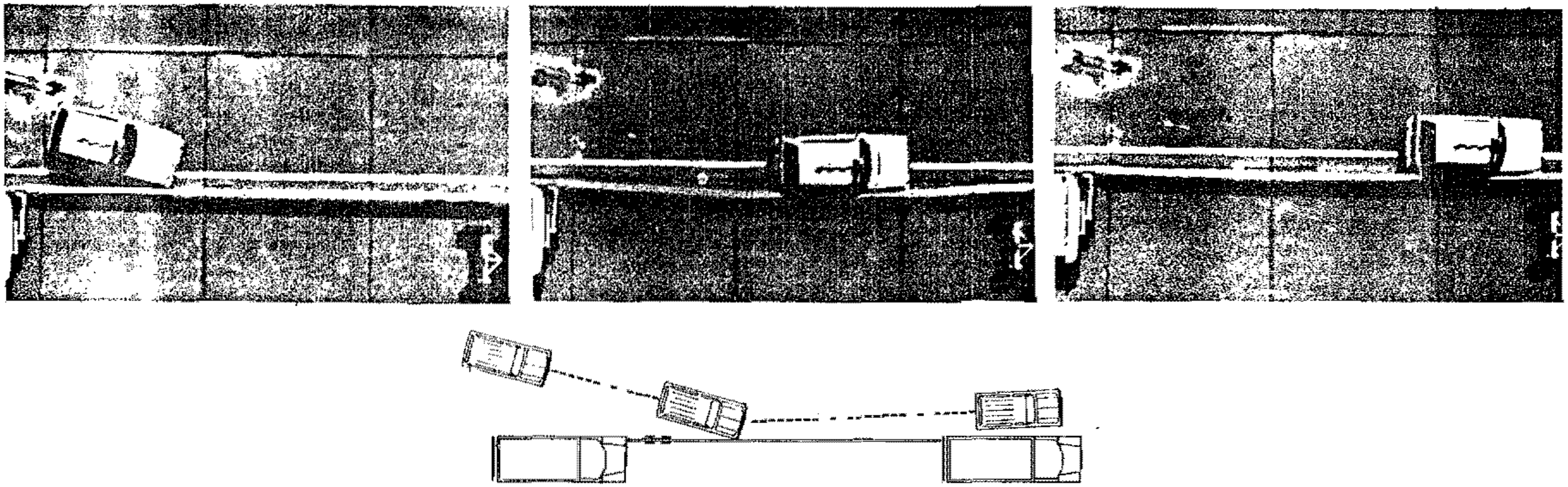


Figure 17. Barrier and Automobile After Test 9



Test No.	2262-10
Date	8/24/83
Installation	
Drawing Nos.	2262-5(3-9, 11)
Length-ft (m)	88 (26.8)
Beam Rail	
Member.	2 6x6x1/4 in. Stl. Tubes
Length of Segment-ft (m). .	44' (13.4)
Maximum Deflections	
Dynamic - in. (cm). . . .	13.0 (32.9)
Permanent - in. (cm). . .	.5 (1.3)
Vehicle	
Model	1979 Honda Civic
Mass-lb (kg).	1765 (801)

Speed-mph (kph)	
Impact.	50.9 (81.9)
Exit.	42.6 (68.6)
Angle - deg	
Impact.	14.0
Exit.	1.3
Occupant Impact Velocity - fps (m/s)	
Forward	11.3 (3.5)
Lateral	N/A
Occupant Ridedown Accelerations - g's	
Forward	1.58
Lateral	N/A
Vehicle Damage	
TAD	2RFQ-2
VDI	02RFMW6

Figure 18. Summary of Test 10

Figure 19 presents photographs of the barrier and the automobile prior to impact. Figure 20 presents photographs of the barrier and the automobile after impact. The barrier section experienced another 1/2 in. (1.27 cm) of permanent deflection during this test, resulting in a total of 1 in. (2.54 cm) permanent deformation. The support trucks, hitches, and support members experienced no damage. The automobile experienced damage to the right front fender and scratches down the right side, damage to the right front tire and rim, and the right front headlight.

TEST 11

In this test, a 4500 (2043 kg) vehicle impacted the barrier with a velocity of 49.7 mph (80.02 km/h) and an angle of 15.0 deg. Again, the same barrier sections used in the previous two tests were reused in this test. The accumulated 1 in. (2.54 cm) of lateral deflection was not removed. Figure 21 presents a summary of the results of this test. The vehicle was smoothly redirected. The measured occupant risk values and the vehicle trajectory characteristics were well below recommended values.

Figure 22 presents photographs of the barrier and the automobile prior to the impact. Figure 23 presents photographs of the barrier after the impact. The barrier section experienced another 3 in. (7.62 cm) of permanent deformation during this test. The support trucks, hitches, and support members experienced no damage. The automobile experienced damage to the right front fender and bumper, scratches down the right side, and damage to the right front tire and rim. Following the crash test, the spare tire was mounted on the right front of the car and the automobile was able to operate at low speeds under its own power.

MANEUVERABILITY TESTS

In addition to the three full-scale crash tests discussed above, maneuverability tests were conducted using the truck-mounted portable maintenance

metal plate

Figure 19. Barrier and Automobile Prior to Test 10

metal plate

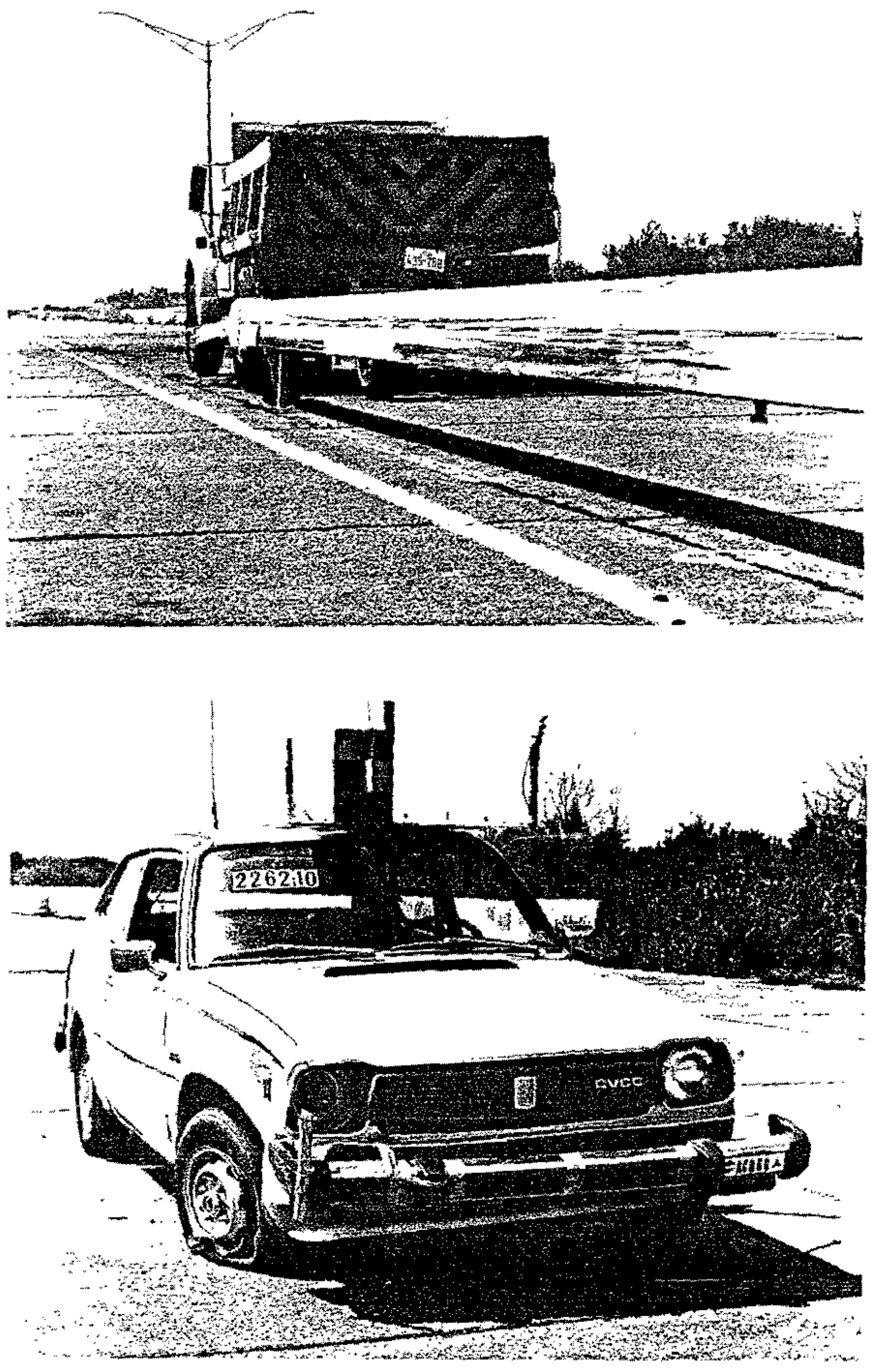
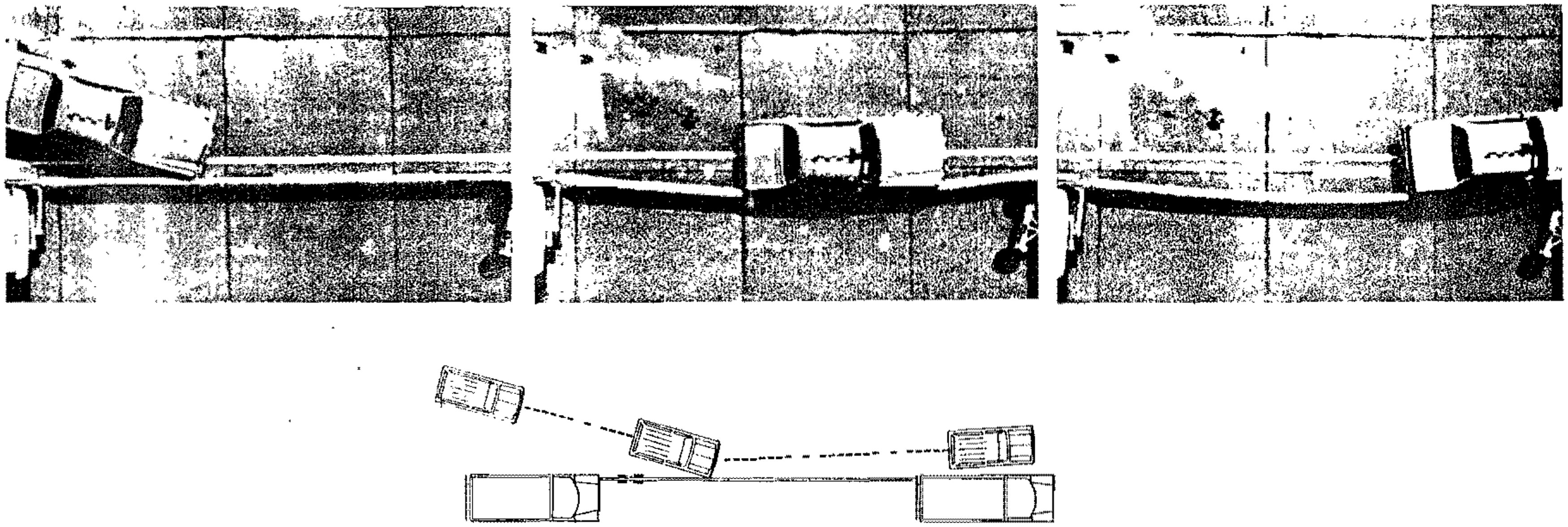


Figure 20. Barrier and Automobile
After Test 10



Test No.	2262-11
Date	8/26/83
Installation	
Drawing Nos.	2262-5(3-9, 11)
Length - ft (m)	88 (26.8)
Beam Rail	
Member	2 6x6x1/4 in. Stl. Tubes
Length of Segment-ft (m)	44 (13.4)
Maximum Deflections	
Dynamic - in. (cm)	24 (61.0)
Permanent - in. (cm)	3 (7.62)
Vehicle	
Model	1978 Plymouth Salon
Mass - lb (kg)	4500 (2045)

Speed-mph (kph)	
Impact	49.7 (80.0)
Exit	40.6 (65.4)
Angle - deg	
Impact	15.0
Exit	1.0
Occupant Impact Velocity - fps (m/s)	
Forward	9.96 (3.0)
Lateral	N/A
Occupant Ridedown Accelerations - g's	
Forward	1.34
Lateral	N/A
Vehicle Damage	
TAD	2RFQ-2
VDI	02RFMW9

Figure 21. Summary of Test 11

metal plate

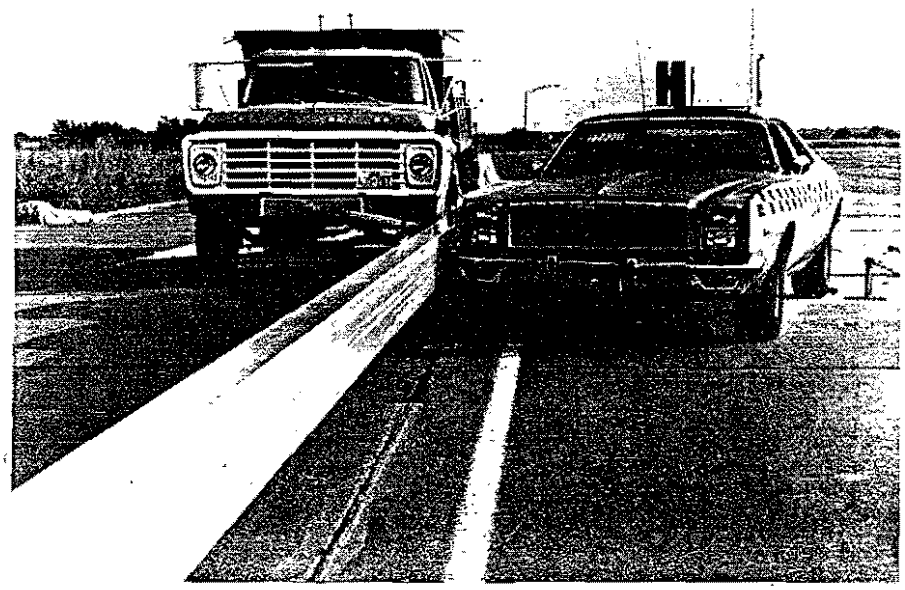


Figure 22. Barrier and Automobile Prior to Test 11 .

Figure 23. Barrier and Automobile
After Test 11

barrier using professional truck drivers employed by TTI. It was found that the barrier section mounted on the transport dolly and hitched to the center of the lead truck for highway transport had handling characteristics similar to a tractor-trailer rig of similar length. There were no special problems noted by the drivers in maneuvering the system set up in this fashion.

The fully deployed system (ref. Fig. 1) consisting of both trucks, the barrier section, and two drivers had a surprising amount of maneuverability with forward speeds up to 15 mph (24.15 km/h). When deployed in this fashion the lead truck provides the power. The forward thrust is transferred through the barrier section to the rear truck whose transmission is in neutral. The driver in the lead truck is responsible for controlling the application of power and braking. The responsibility of the driver in the rear truck is simply to guide the rear truck along the desired path. Because the barrier is supported on pivotal casters, the barrier offers no restraint to the maneuverability of the rear truck. The only constraint on maneuverability is that the trucks are forced to remain a constant distance apart. The drivers reported no special problems with the system.

In addition to the general maneuverability tests discussed above, the following test was conducted to simulate an actual maintenance operation. A 30 ft (9.15 m) long section of pavement was marked off between the trucks to simulate an area of pavement under repair as shown in Figure 24. The purpose of the test was to demonstrate that upon completion of the maintenance in the 30 ft (9.15 m) zone it is possible to move the portable maintenance barrier forward without encroaching into the repair zone. The objective was accomplished by moving the lead truck forward while the rear truck was steered around the repair zone. The maneuverability of the portable maintenance barrier around such objects is hindered only by the base-line maneuverability of the rear truck.

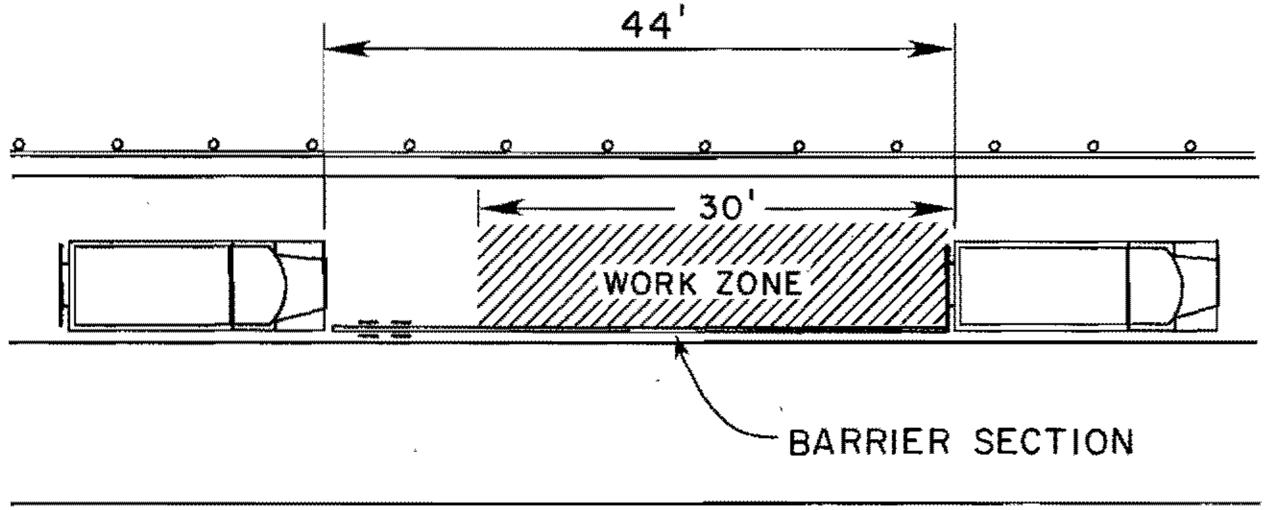


Figure 24. Barrier Configuration for Maneuverability Test

CONCLUSIONS

Recent experiences with injuries and fatalities among SDHPT maintenance personnel suggest that there is a need for increased personnel protection in short-term work zones. One way to reduce the risks is to use portable maintenance barriers. The problem is that most portable maintenance barriers that are available require too much setup time or too much work zone space. A new truck-mounted portable maintenance barrier design that overcomes both of these difficulties is presented in this report.

The truck-mounted portable maintenance barrier consists of a steel barrier section which is supported between two support trucks. The barrier section was designed to smoothly redirect a 4500 lb (2043 kg) automobile impacting at a velocity of 50 mph (80.5 km/h) with an angle of 15 degrees. This design criteria reflects a consensus among SDHPT and TTI engineers on a reasonable design criteria for the portable maintenance barrier. Results of three crash tests conducted on the prototype substantiated that the barrier section can successfully redirect the design impact. It is clear that if an errant vehicle directly impacted either of the support trucks the outcome would not be as favorable as the impact with the barrier section. However, it is the contention of the writers that such an impact would be no more severe than an impact with any other maintenance vehicle. It is recommended that normal procedures involving the use of towed crash cushions and proper delineation of the work zone hazard be used with the truck-mounted portable maintenance barrier.

Of equal importance with the redirective characteristics of the portable maintenance barrier is the time required for on-site deployment and the ease of handling. The barrier is towed to the work zone on a specially fabricated transport dolly. Experience with the system shows that the barrier can be deployed by an experienced team of two men in less than 15 minutes. Approximately the same amount of time is required to transfer the system back to the transport dolly. In addition, tests show that the deployed portable maintenance barrier can be easily maneuvered around simulated obstacles that might be encountered in a work zone.

The approximate cost of the barrier system exclusive of the cost of the trucks, which can be multipurpose vehicles, is $8,000 for a 44 ft (13.42 m) barrier section. This translates to an approximate cost of $182 per ft. A substantial portion of the fabrication cost is involved in the construction and installation of hitches, support members, and the truck frame-plate. However, in the event of a design impact, only the barrier section will have to be replaced or repaired. Therefore, the economics of the system seem to be favorable.

It is therefore concluded that a workable, affordable portable maintenance barrier for use in short-term work zones has been successfully developed. The portable maintenance barrier is capable of providing a reasonable degree of protection for maintenance personnel, it can be conveniently transported to the work zone, easily deployed, and once deployed it can be easily maneuvered in the work zone.

A second version of the portable maintenance barrier has been constructed and delivered to the Houston area SDHPT office which plans to put it into service shortly. Hopefully the system can be easily integrated into routine operations and help to reduce maintenance personnel injuries and fatalities.

APPENDIX A

BARRIER DEPLOYMENT

BARRIER DEPLOYMENT

There are two basic configurations for the portable maintenance barrier presented in this report: the transport configuration and the deployed configuration. This appendix presents the steps necessary to transfer the portable maintenance barrier from the transport configuration to the deployed configuration, and vice versa.

In the transport configuration, the transport dolly is placed under one end of the barrier section, and it is secured to the barrier section with a post tension chain assembly. The other end of the barrier section is attached to the main rear hitch point on the lead truck as shown in Figure 10. The front lateral support member is connected to an auxiliary rear hitch point. The front longitudinal support member is connnected to the side hitch and lateral support beam. This entire assembly is supported by a turnbuckle support. The support members on the rear truck are attached to the front hitch and side hitch and supported by a turnbuckle support. The trucks are driven to the work zone independently.

Once at the work zone, the following steps are necessary to transfer the barrier from the transport configuration to the deployed configuration.

1. The lead truck is positioned ahead of the rear truck.
2. The front barrier section jack is engaged and the barrier section is detached from the lead truck. The lead truck is moved forward a few feet, and the lateral support member is transferred to the main rear hitch.
3. The front barrier section jack is then disengaged and the barrier is allowed to rest on the front caster wheel and the transport dolly.

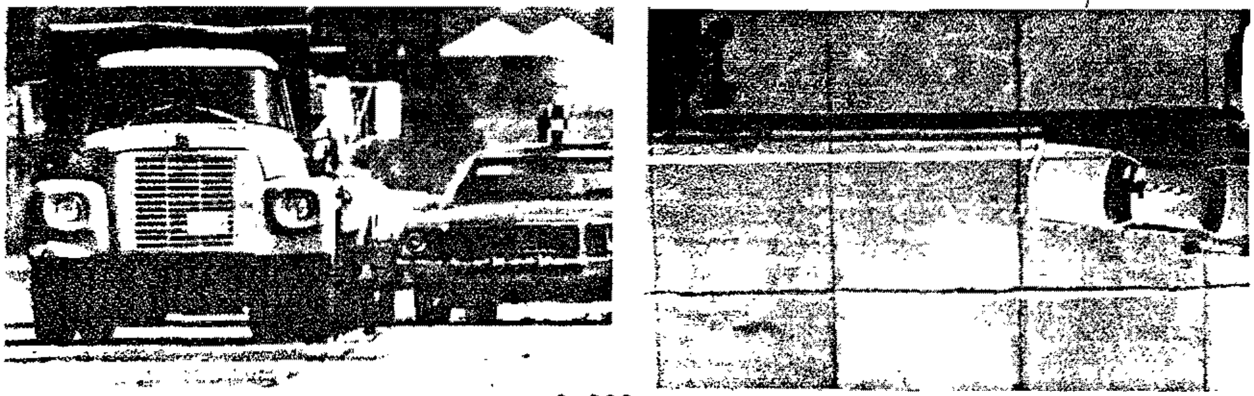
4. Next, the barrier section is manually pushed into line with the hitch point provided by the longitudinal support member on the lead truck. The lead truck is then backed into position, and the connection pin is put into place. Vertical adjustments of the longitudinal support member during this hitching operation are made using the turnbuckle support.
5. With the connection to the lead truck completed, the tie-down apparatus on the transport dolly is released, the barrier section is lifted from the transport dolly with the rear barrier section jack, and the dolly is removed.
6. The rear jack is then disengaged, allowing the rear caster wheel to contact the pavement. The weight of the barrier section is now completely supported by the caster wheels. Stability is afforded by the front lateral support member.
7. The transport dolly is then moved to an auxiliary hitch point on the lead truck.
8. Finally, the rear truck is pulled forward and the barrier section is connected to the hitch point on the rear longitudinal support member. During this operation the barrier section end can be manually pivoted laterally, and/or the vertical height of the longitudinal support member attached to the rear truck can be adjusted using the turnbuckle support.

A reverse procedure is followed to transfer the barrier from the deployed configuration back to the transport configuration.

The connections between the longitudinal members and the side hitches, and between the barrier section ends and the longitudinal members, are made using 1 9/16 in. (3.97 cm) diameter steel pins. The connections between the longitudinal and lateral support members are made with 1 1/8 in. (2.86 cm) diameter steel bolts. This connection should be kept tightened. Finally, the connections between the lateral support members and the rear and front hitches are made with 1 1/8 in. (2.86 cm) diameter steel pins. It is not necessary to use high strength bolts or pins.

APPENDIX B

SEQUENTIAL PHOTOGRAPHS



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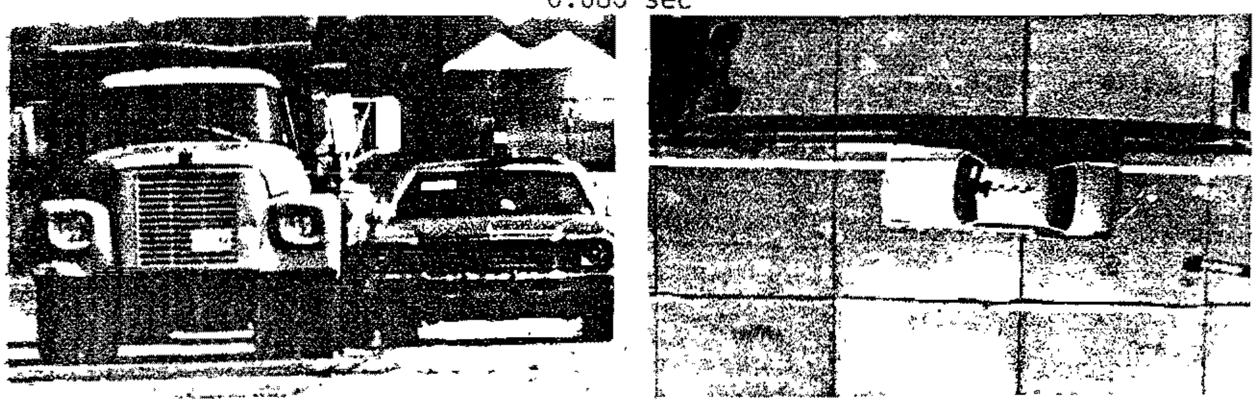

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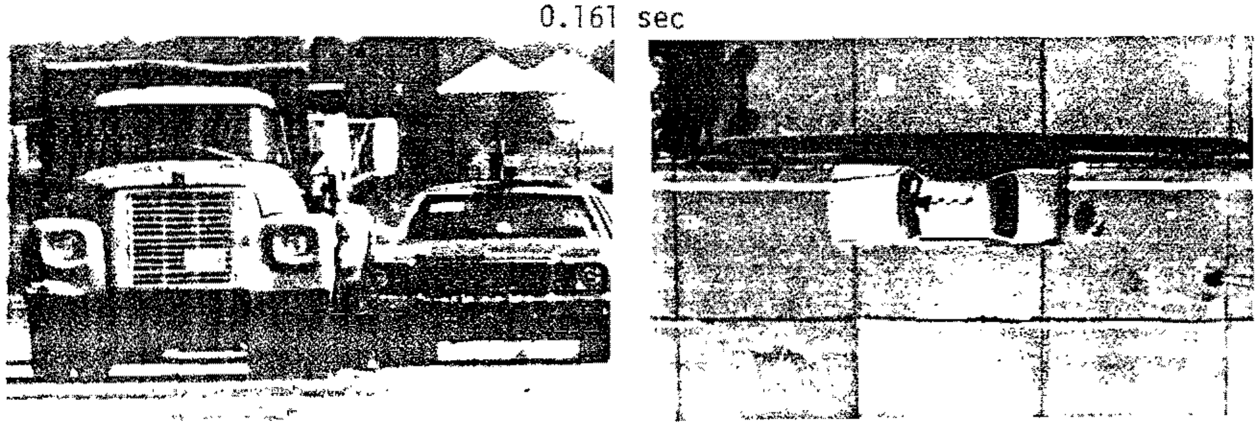

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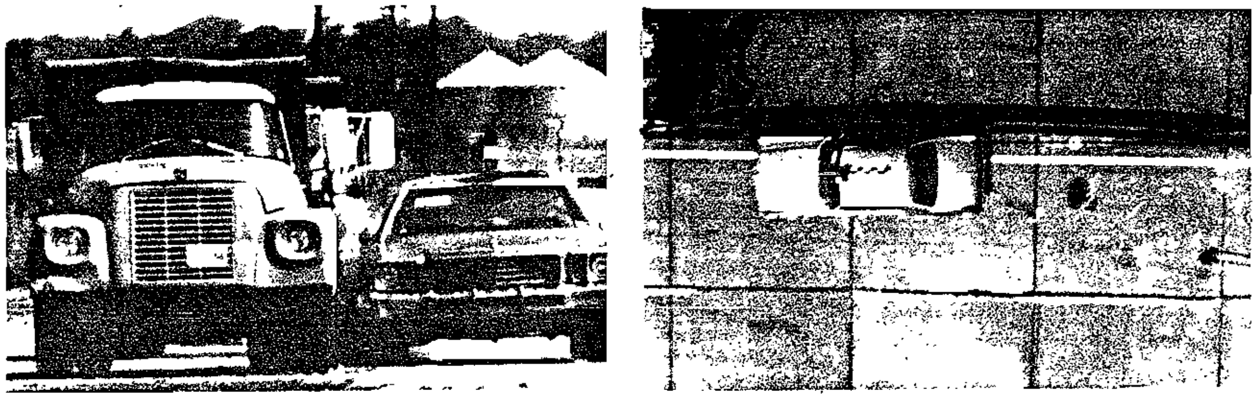
Figure 25. Sequential Photographs for Test 9



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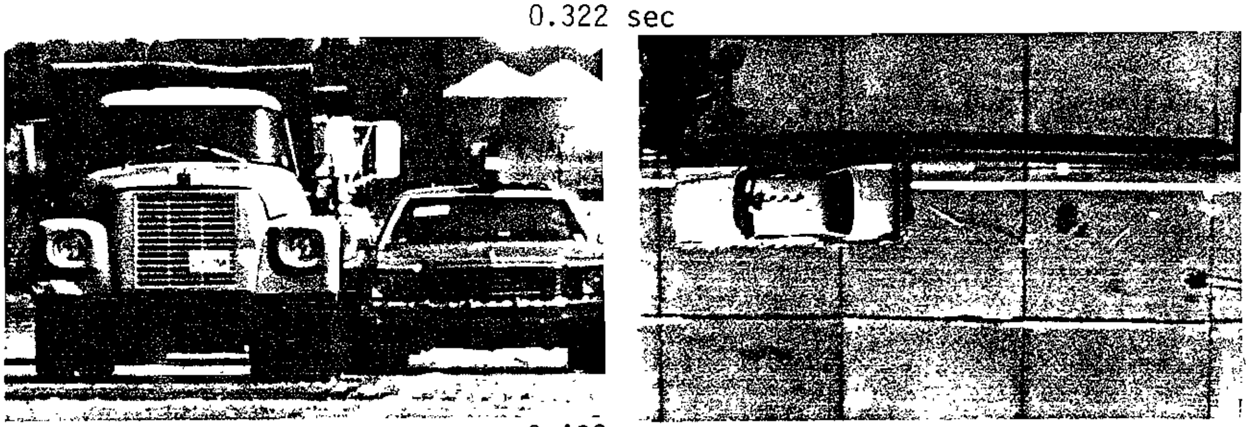

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0.483 sec

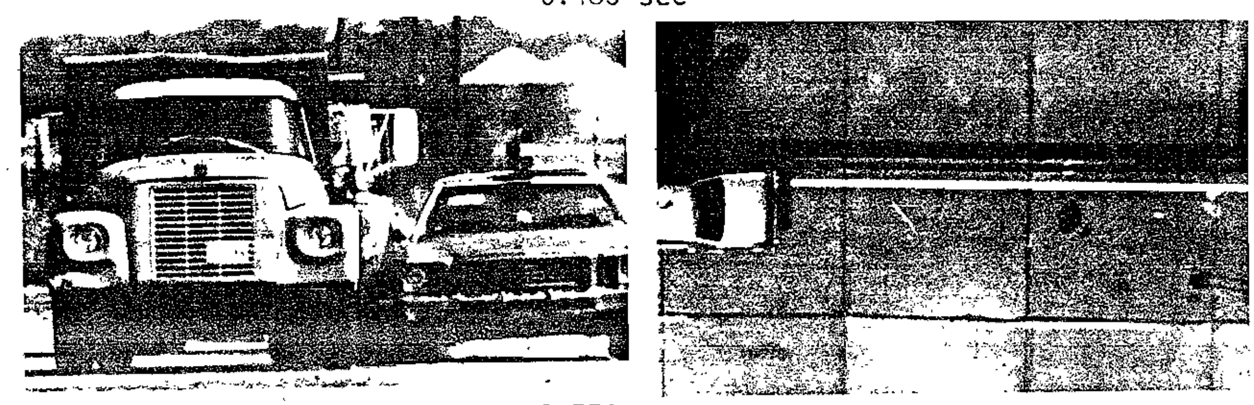

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Figure 25. Sequential Photographs for Test 9 (continued)

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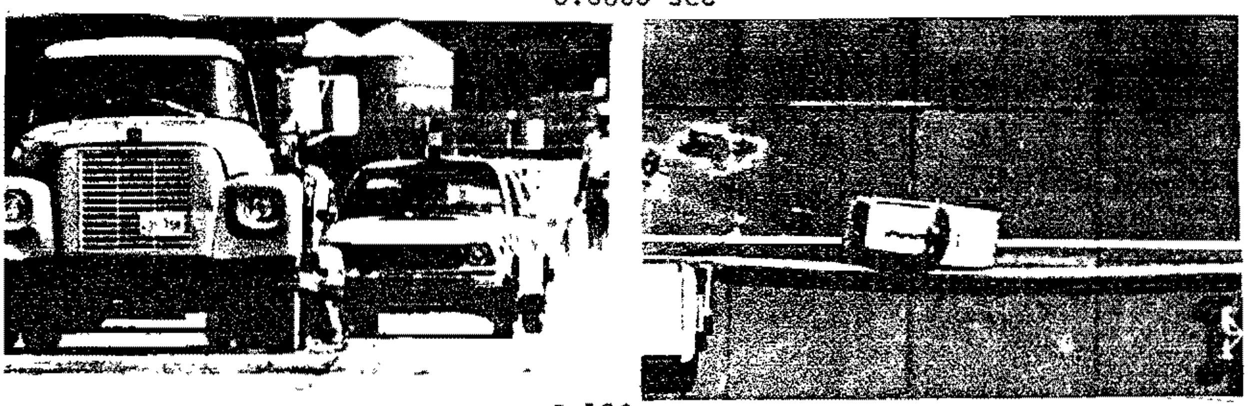

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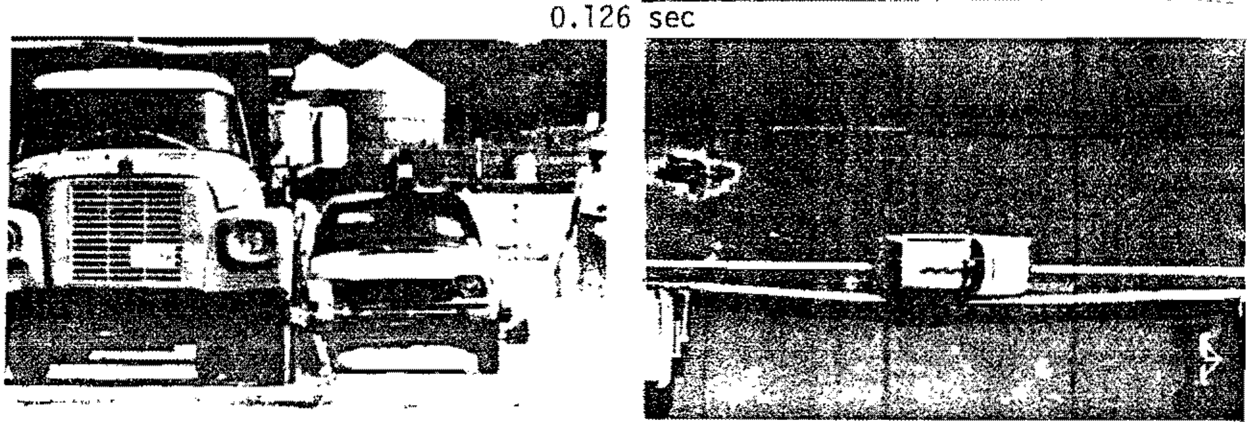

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Figure 26. Sequential Photographs for Test 10

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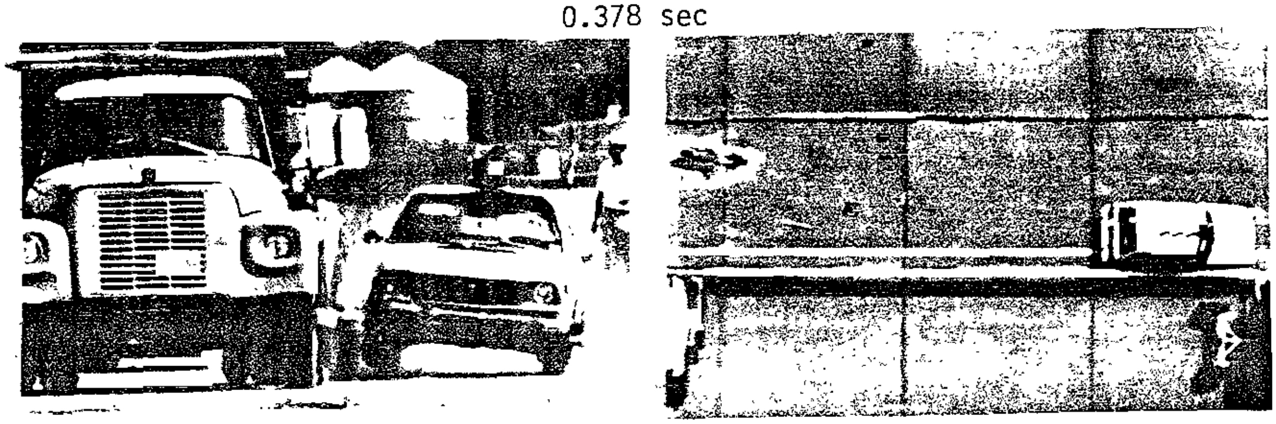

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Figure 26. Sequential Photographs for Test 10 (continued)

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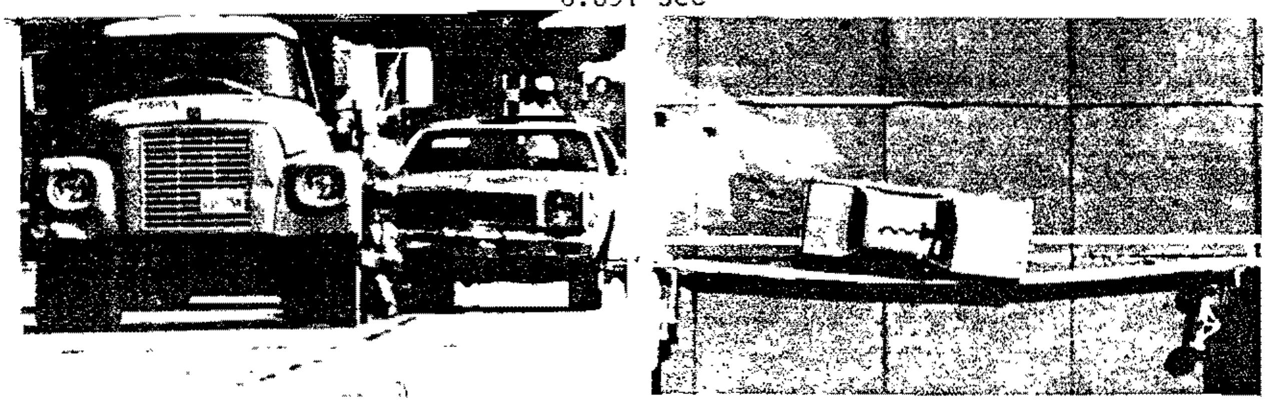

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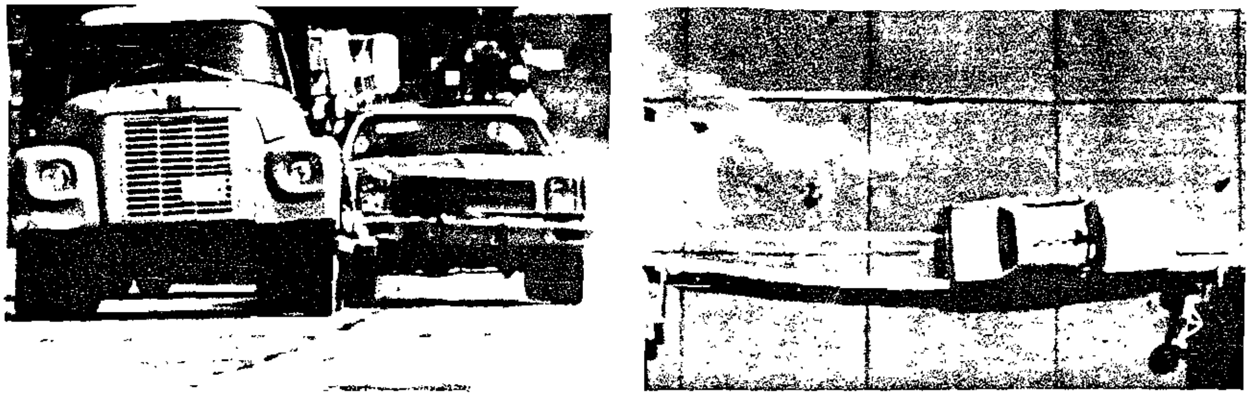
Figure 27. Sequential Photographs for Test 11



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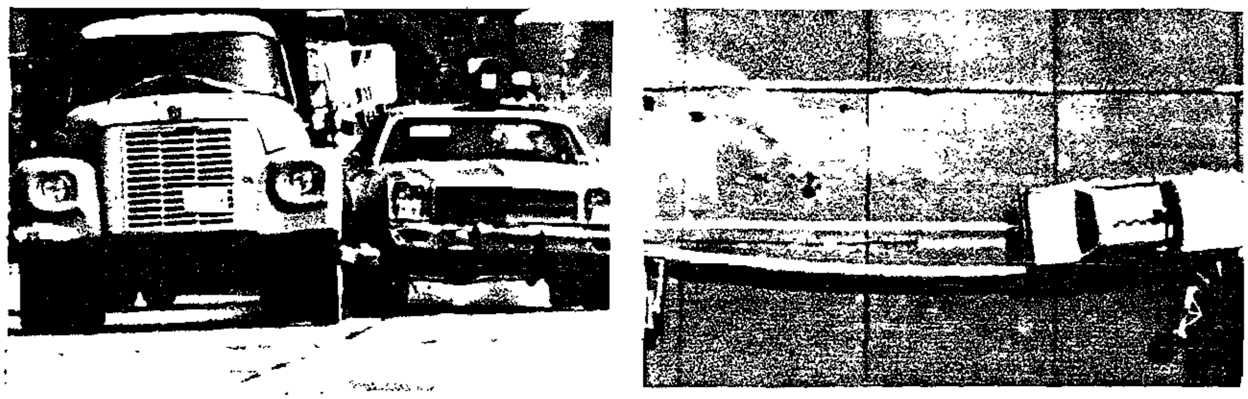

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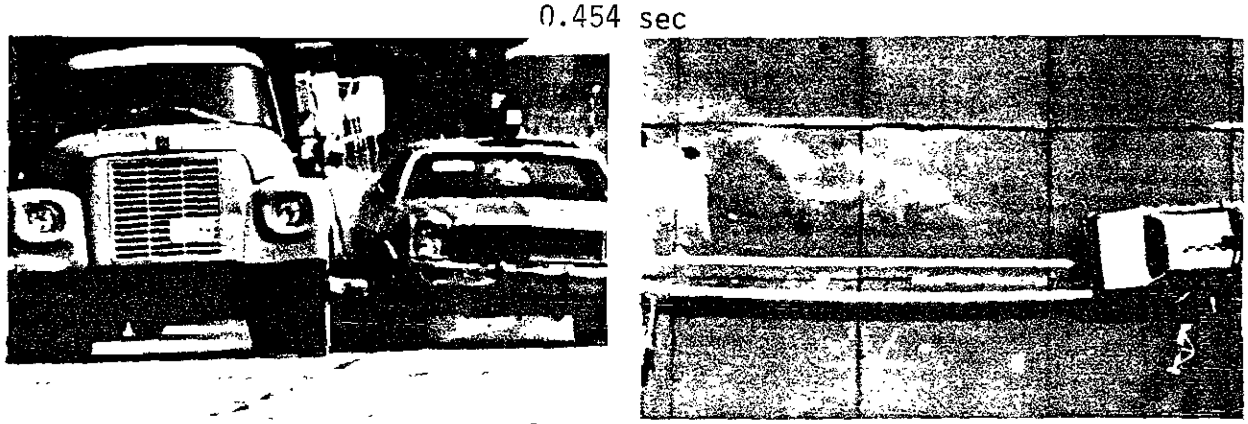

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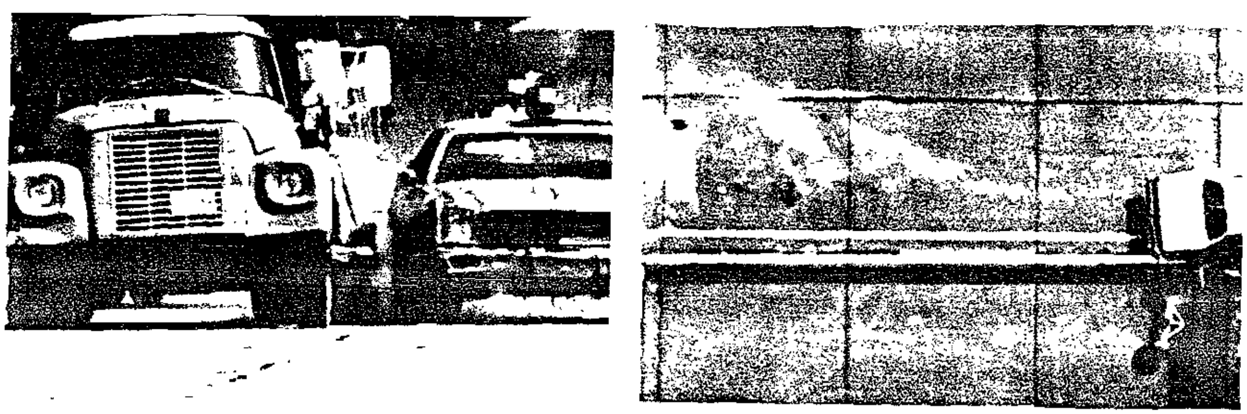

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Figure 27. Sequential Photographs for Test 11 (continued)

APPENDIX C

ACCELEROMETER TRACES AND PLOTS OF ROLL, PITCH, AND YAW

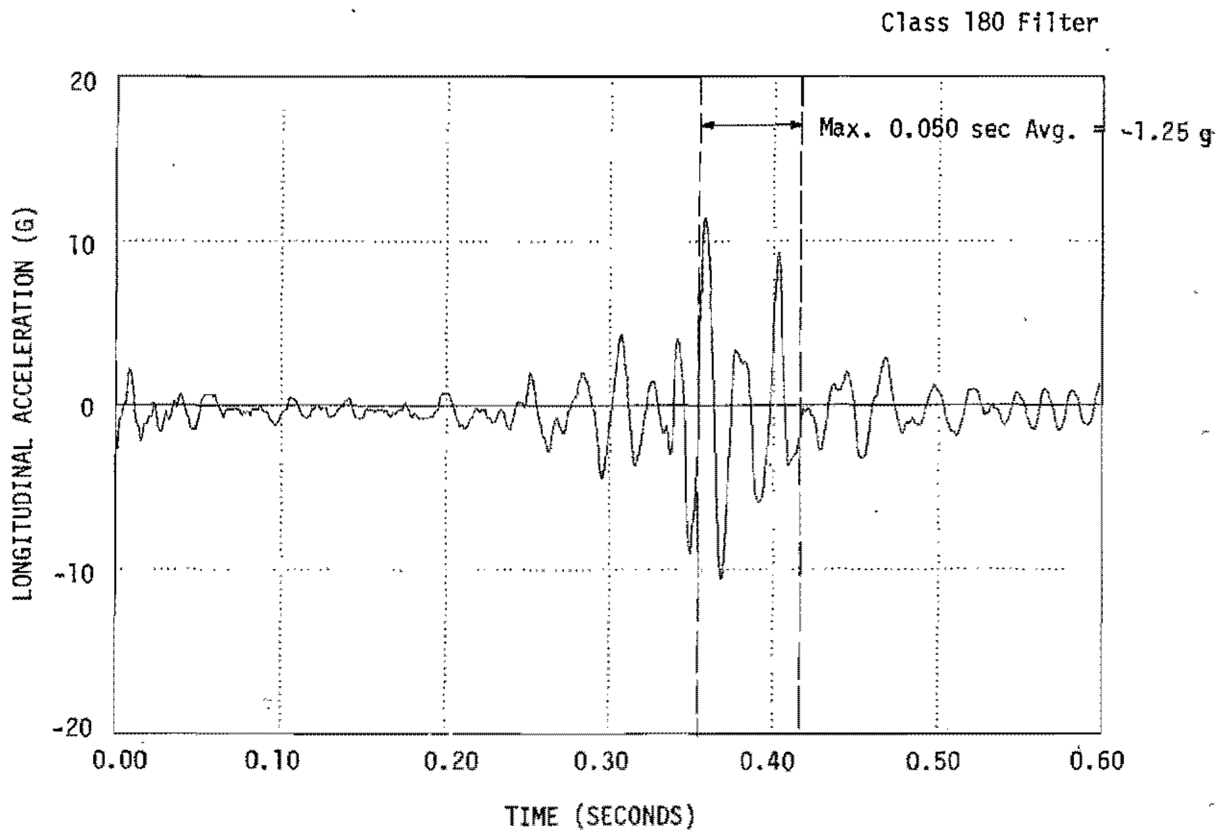


Figure 28. Vehicle Longitudinal Accelerometer Trace for Test 9

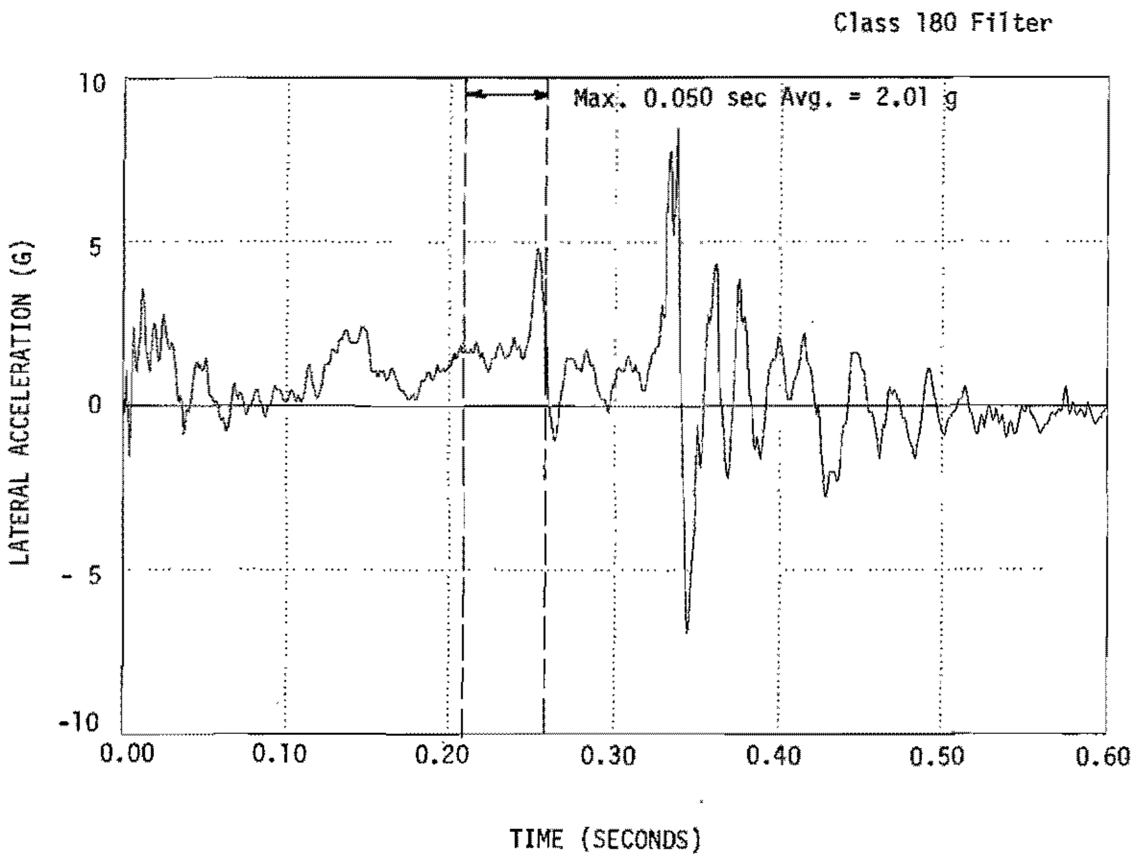


Figure 29. Vehicle Lateral Accelerometer Trace for Test 9

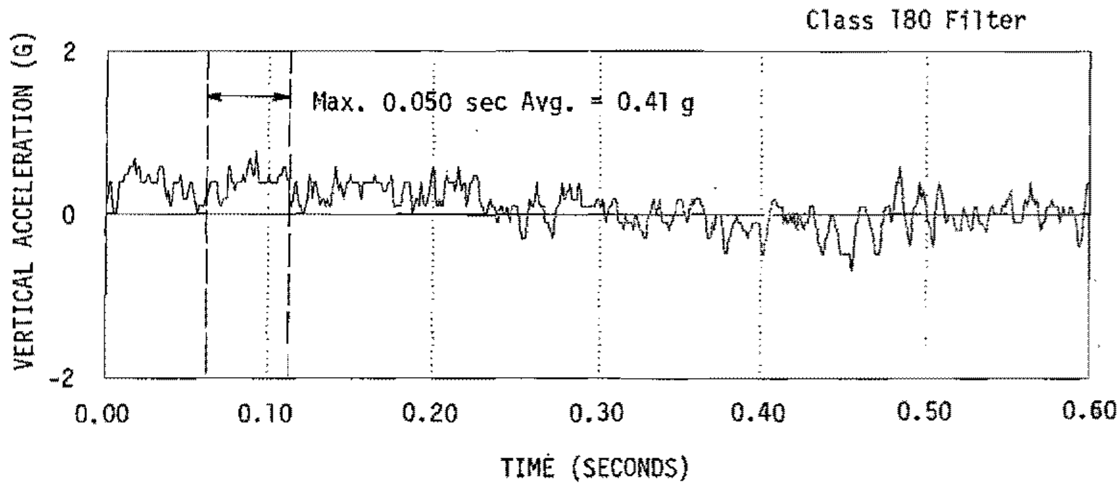


Figure 30. Vehicle Vertical Accelerometer Trace for Test 9

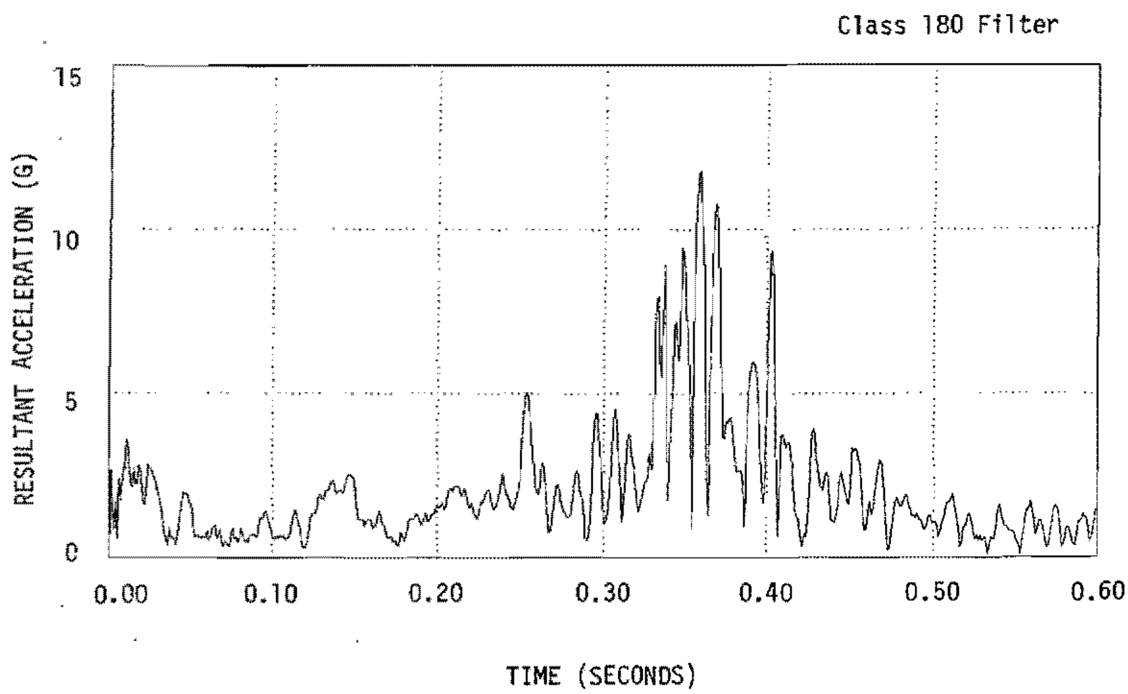
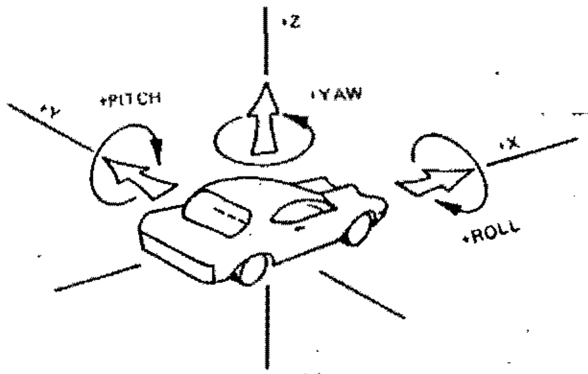


Figure 31. Vehicle Resultant Accelerometer Trace for Test 9



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

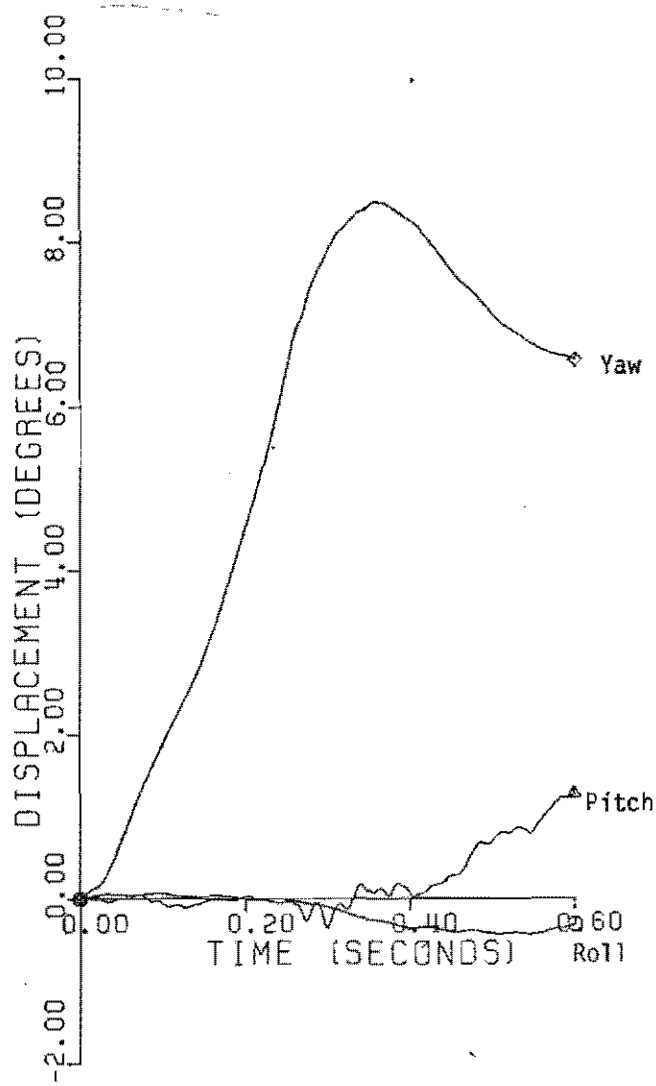


Figure 32. Vehicle Angular Displacements for Test 9

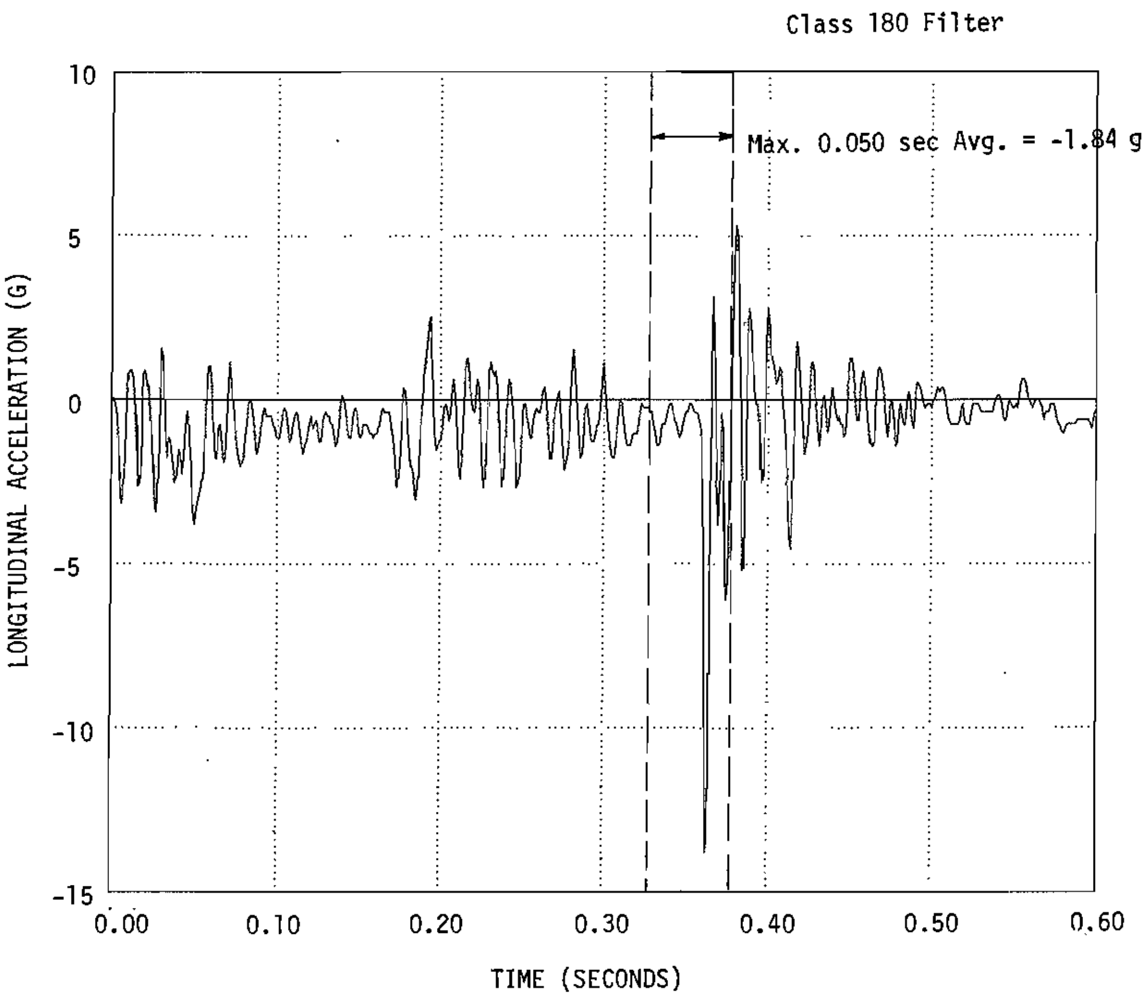


Figure 33. Vehicle Longitudinal Accelerometer Trace for Test 10

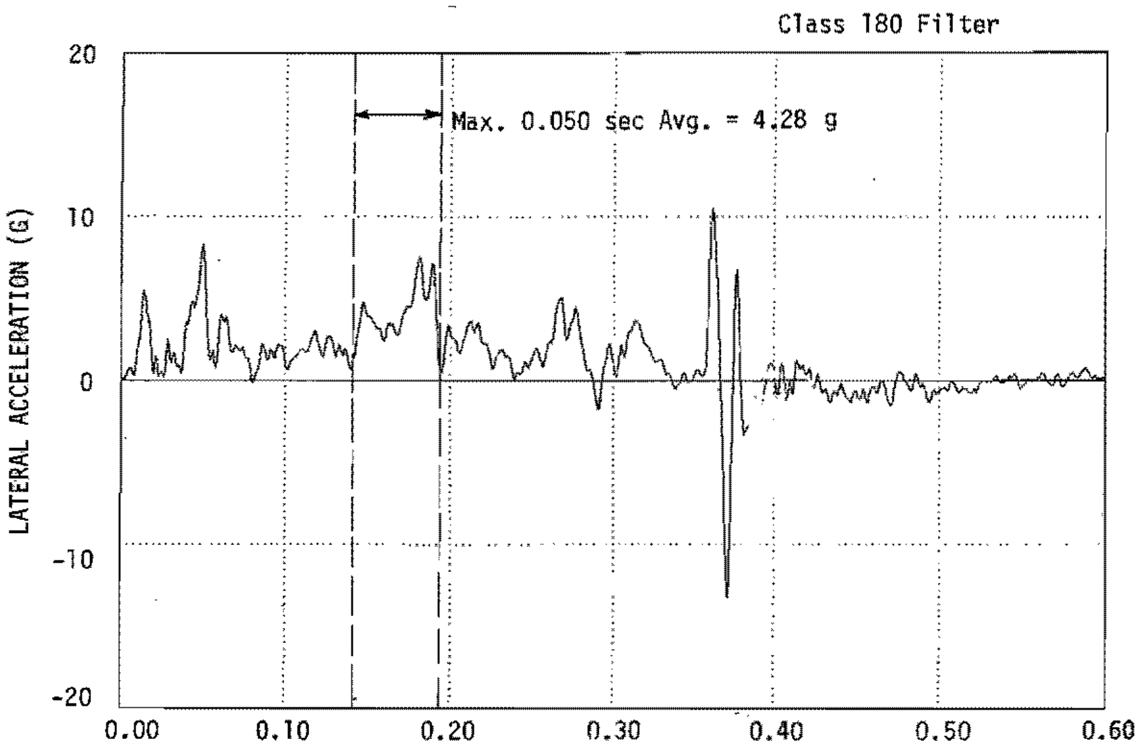


Figure 34. Vehicle Lateral Accelerometer Trace for Test 10

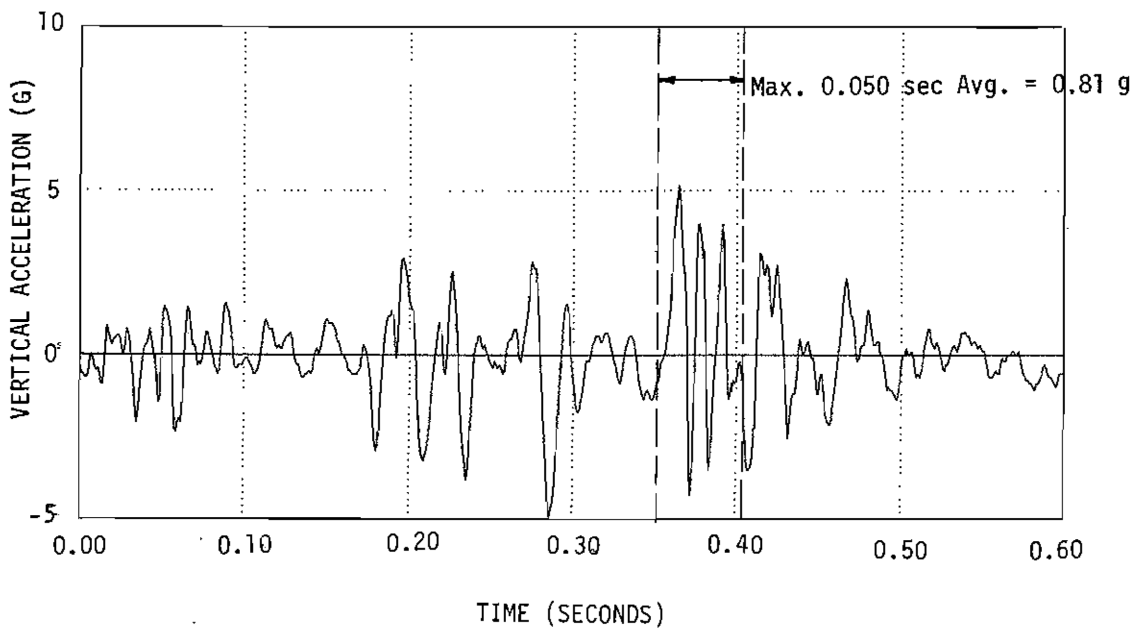


Figure 35. Vehicle Vertical Accelerometer Trace for Test 10

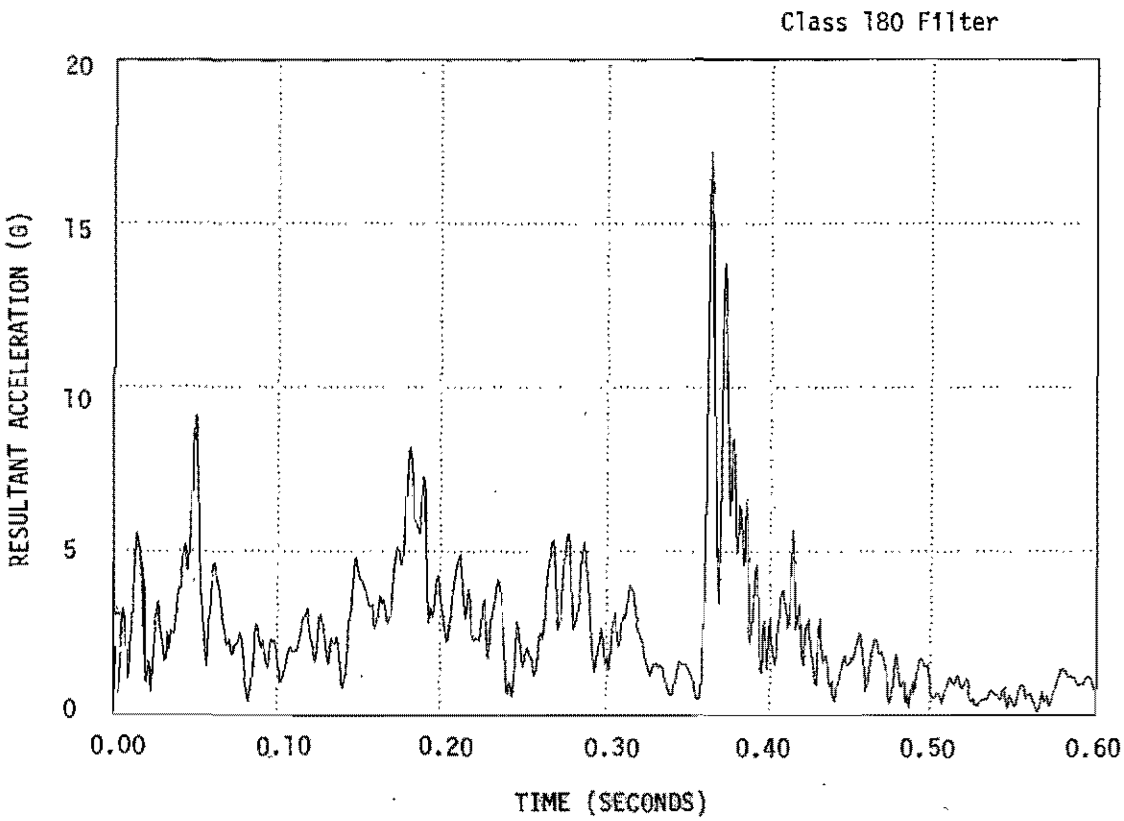
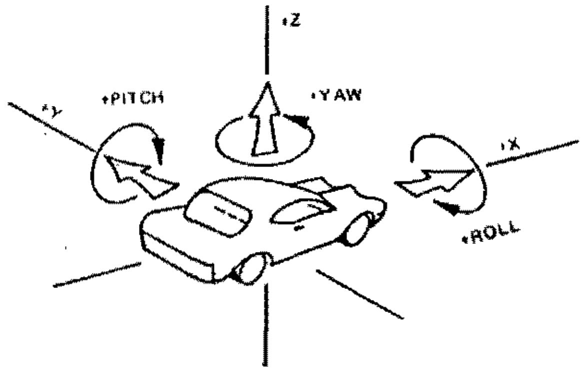


Figure 36. Vehicle Resultant Accelerometer Trace for Test 10



Axes are vehicle fixed.
Sequence for determining
orientation is:

1. Yaw
2. Pitch
3. Roll

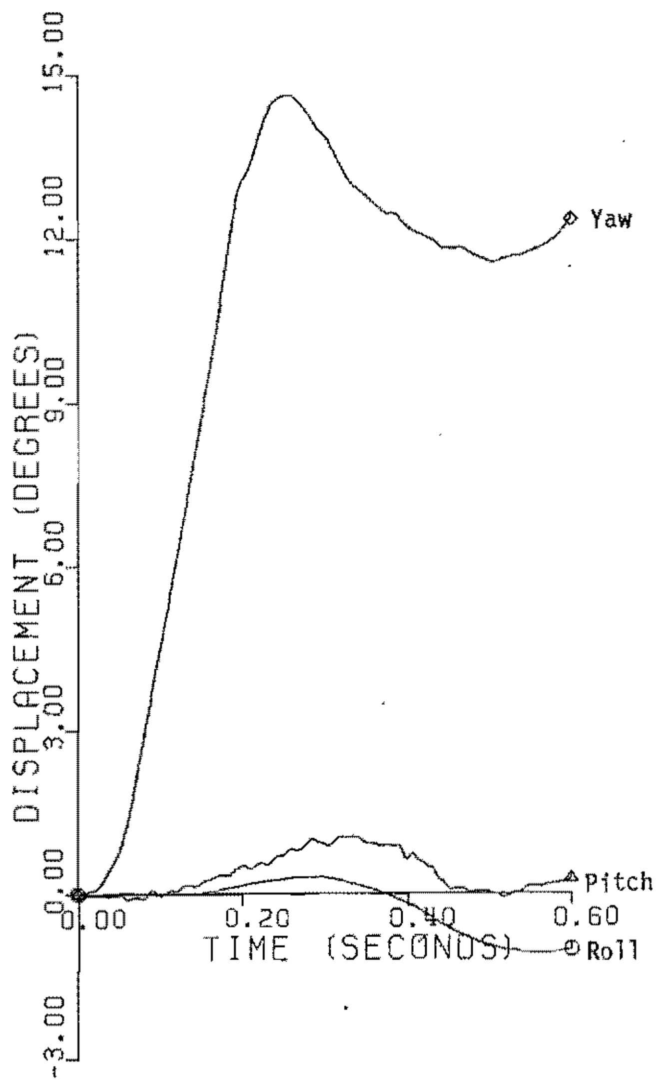


Figure 37. Vehicle Angular Displacements for Test 10

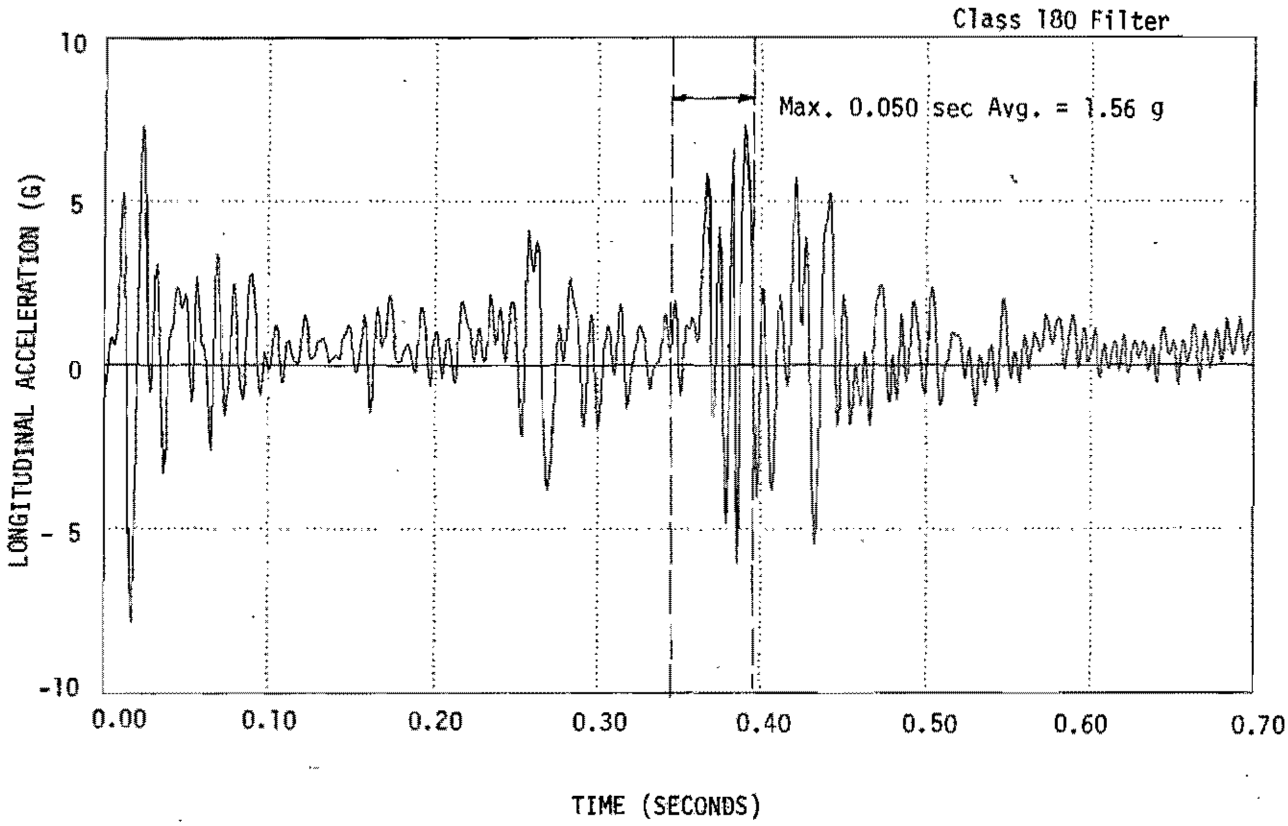


Figure 38. Vehicle Longitudinal Accelerometer Trace for Test 11

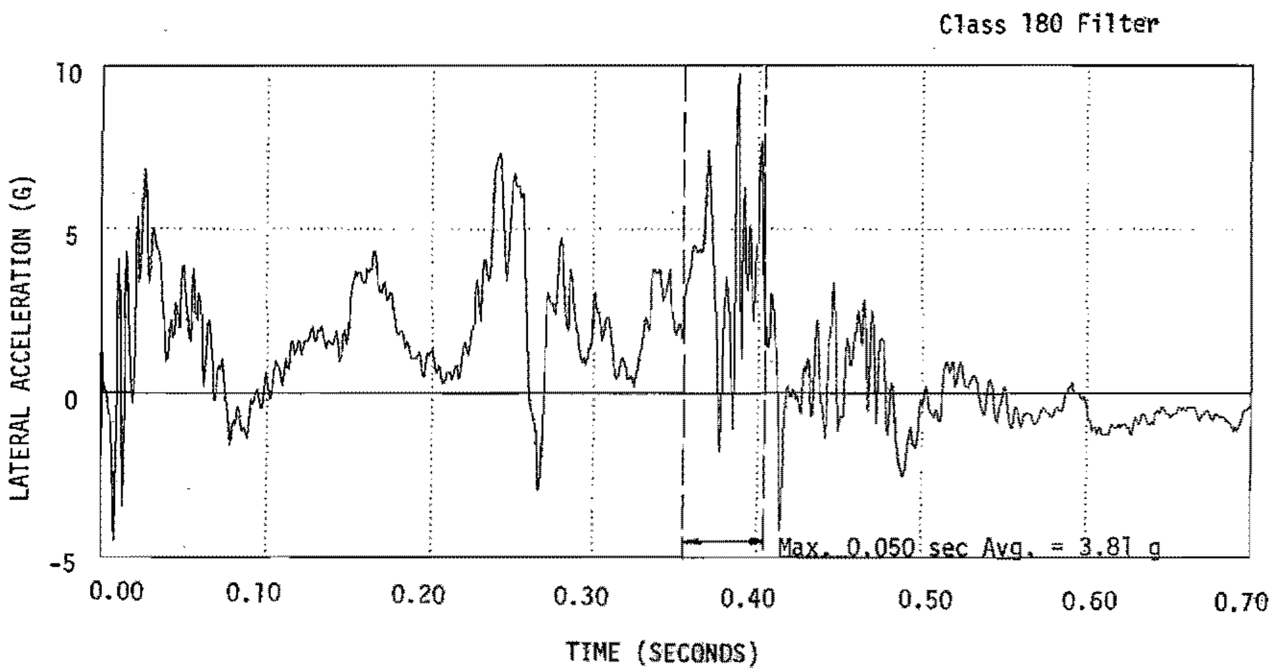


Figure 39. Vehicle Lateral Accelerometer Trace for Test 11

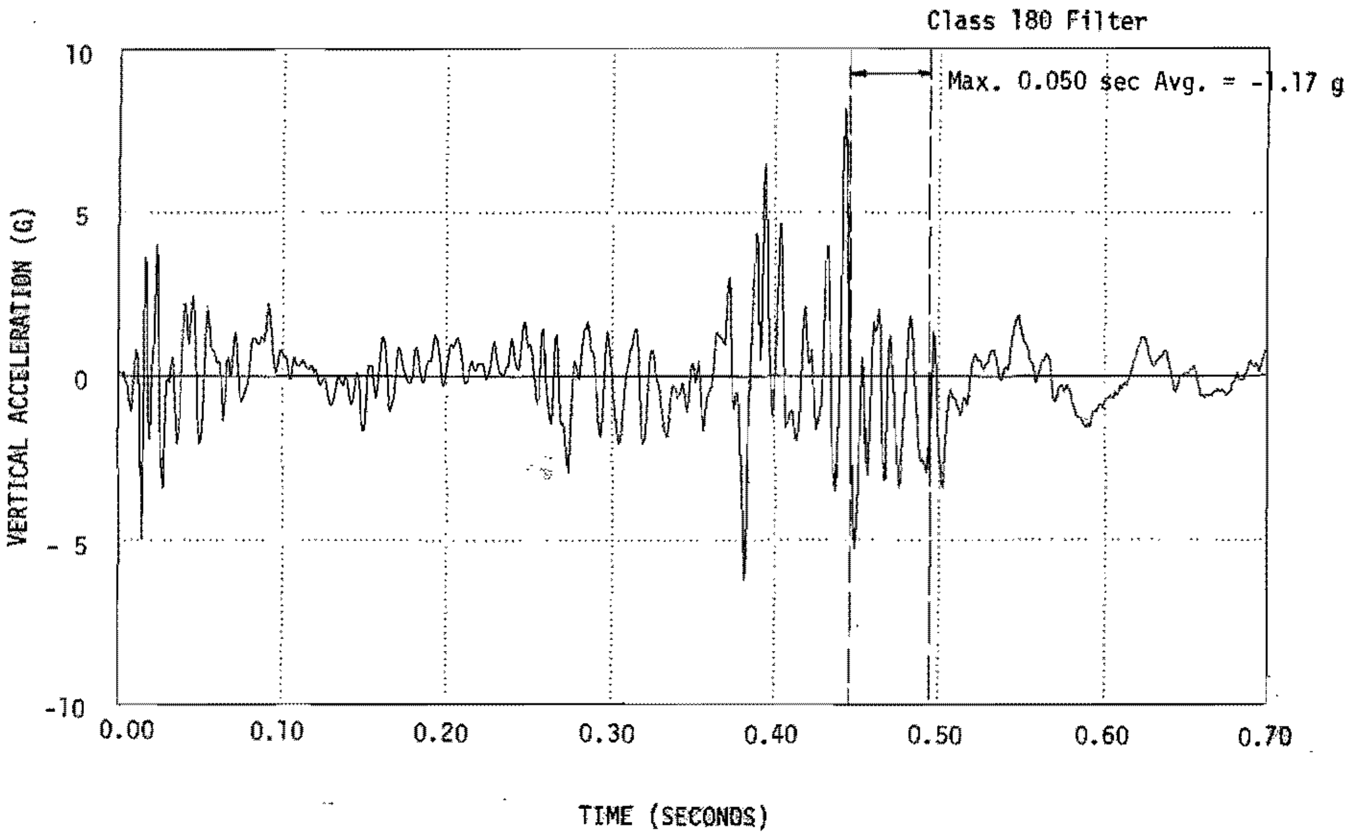


Figure 40. Vehicle Vertical Accelerometer Trace for Test 11

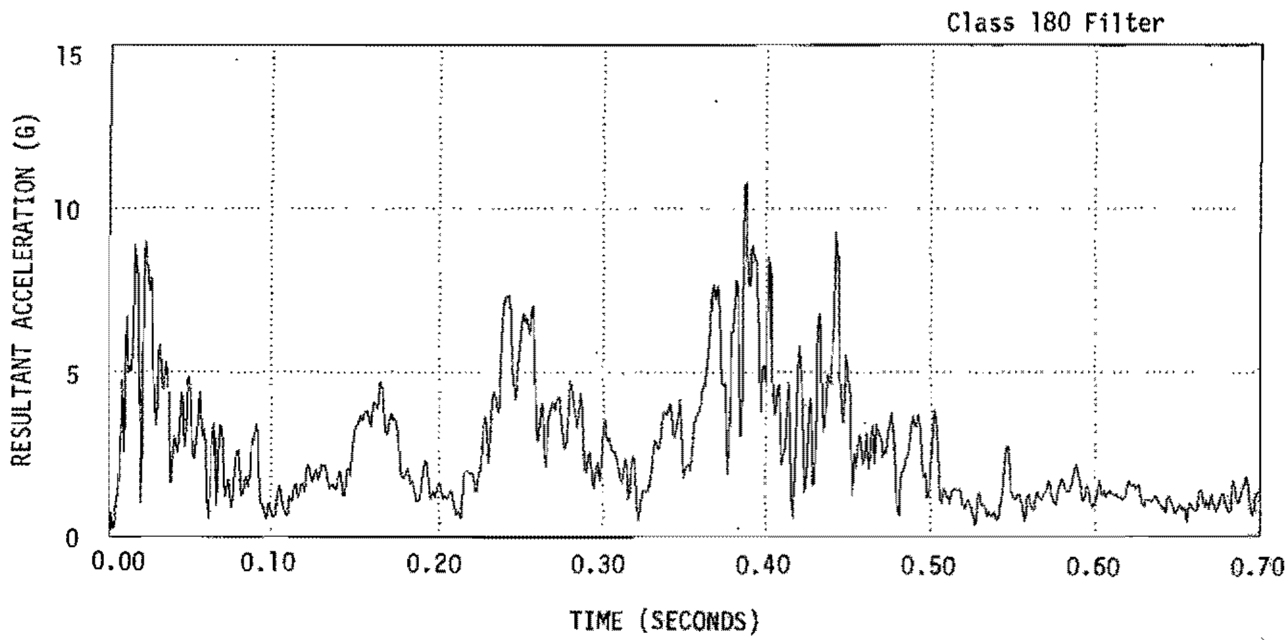
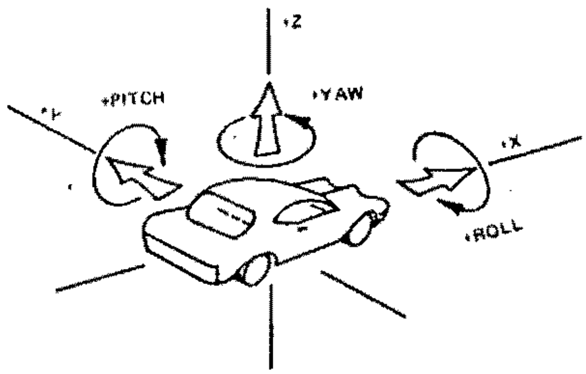


Figure 41. Vehicle Resultant Accelerometer Trace for Test 11



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

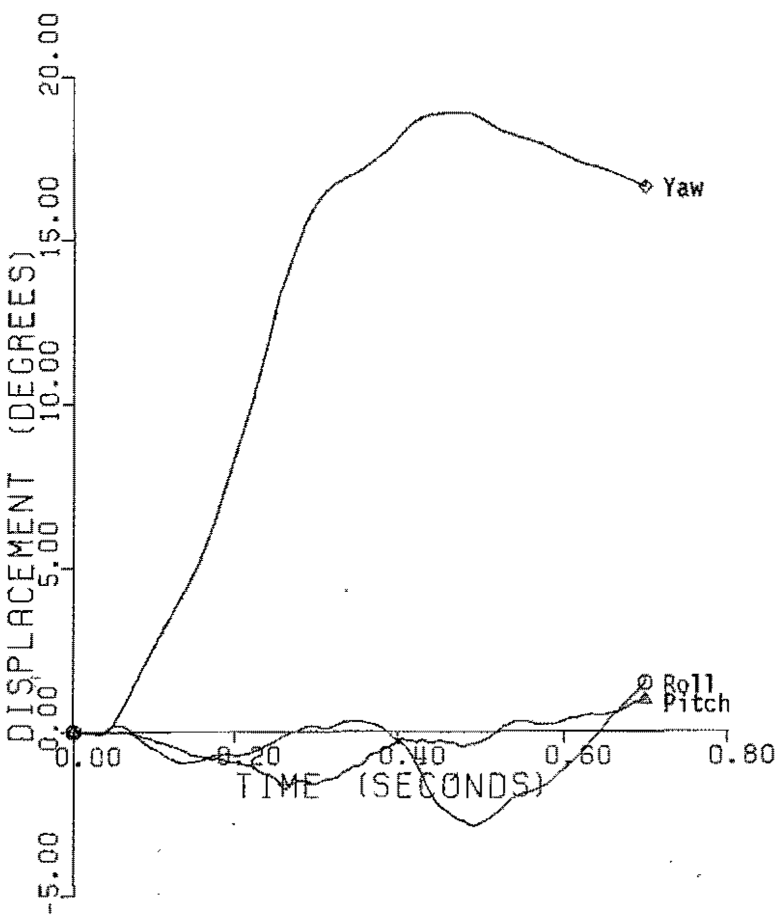


Figure 42. Vehicle Angular Displacements for Test 11

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2. Michie, Jarvis D., "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," NCHRP Report 230, March 1981.

3. Powell, G. H., "Barrier VII: A Computer Program for Evaluation of Automobile Barrier Systems," FHWA-RD-73-51, Federal Highway Administration, Office of Research and Development, Washington, D.C., April 1973.