NEW CONCEPTS FOR
TRAFFIC BARRIER SYSTEMS

FINAL REPORT

Project RF 3253
Contract No. DOT-FH-11-8796

by

E. L. Marquis

&

T. J. Hirsch

Sponsored by

U.S. Department of Transportation
Federal Highway Administration
Washington, D.C.

Sept. 1978

Texas Transportation Institute
Texas A&M University

Technical Report Documentation Page

1. Report No.
FHWA-RD-79-65

2. Government Accession No.

3. Recipient's Catalog No.
PB80 187636

4. Title and Subtitle
NEW CONCEPTS FOR TRAFFIC BARRIER SYSTEMS

5. Report Date
Sept. 1978

6. Performing Organization Code

7. Author(s)
E. L. Marquis & T. J. Hirsch

8. Performing Organization Report No.
Research Report RF 3253

9. Performing Organization Name and Address
Texas Transportation Institute
Texas A&M University
College Station, Tx 77840

10. Work Unit No. (TRAIS)
FCP 31T3-012

11. Contract or Grant No.
DOT-FH-11-8796

12. Sponsoring Agency Name and Address
Structures and Applied Mechanics Division
Office of Research
Federal Highway Administration
Washington, D.C. 20590

13. Type of Report and Period Covered
June 1975
Final Sept. 1978

14. Sponsoring Agency Code
S0974

15. Supplementary Notes
FHWA Contract Managers: D. B. Chisholm and C. F. McDevitt

16. Abstract

This report examines the development of two roadside barrier-median barrier systems by computer simulation. The systems are designated as the Concrete Barrier with Blockedout W Rail and the Thrie T Barrier (TTB). Both systems are designed for impacts by vehicles ranging from 2250 lb (1020 kgm) to 40,000 lb (18,140 kgm). In addition, the concrete barrier with a blockedout W rail was investigated for impacts by vehicles in the 1650 lb (750 kgm) category. Both barriers are sufficiently developed for full-scale testing.

The concrete barrier with a blockedout W rail was designed as a rail attached to a vertical wall blocked out with a reusable unit which acts as a one-way spring. The rail was also designed to be attached to a safety shape. The simulation results indicate that the rollover probability of a lightweight narrow wheelbase vehicle impacting a safety shape with a blockedout W rail is significantly reduced when compared to impacts of the same vehicle with a plain safety shape. The TTB was developed by strengthening the European Neher-SWOV barrier. The TTB is a multiple stage barrier utilizing two thrie beam ribbons rigidly separated by a spacer and attached to a post to form a T. Both barriers appear to be capable of redirecting lightweight vehicle impacts at an intensity reduced from existing systems, and both systems appear to be capable of retaining intercity buses.

17. Key Words
Guardrail, Highway Safety, Traffic Barriers, Median Barriers, Concrete Safety Shape, Barrier VII, GUARD

18. Distribution Statement
No Restrictions: This document is available to the public through the National Technical Information Service, Springfield, Va., 22161

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
107

22. Price

TABLE OF CONTENTS

TABLE OF CONTENTS (continued

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF TABLES

I. INTRODUCTION

Purpose of Research

The purpose of this research has been to develop new concepts of traffic railings which are capable of safely redirecting and containing articulated and nonarticulated heavy vehicles while safely redirecting passenger vehicles. Specifically, the heavy vehicles were to be of the 40,000 lb (18,140 kgm) class, and the passenger vehicles were to be of the 2250 lb (1020 kgm) and 4500 lb (2040 kgm) classes. The barriers or railings could be completely new concepts or they could be strengthened or revised versions of systems in use or previously proposed.

Research Approach

The research has included a literature search and preparation of an annotated bibliography of barrier research performed and reported up to 1975. There were many foreign reports contained in the reference list. The data were studied and the research reviewed for systems or components which could be included in a heavy duty guardrail or median barrier. TTI personnel who had experience in barrier design development and use were assembled for a brainstorming session to suggest new or improved concepts of barriers.

As a result of the review of past research, the brainstorming and ideas of the researchers, several systems were discussed with and proposed to the contract technical manager. Those finally formally presented for more detailed study were:

1. The Modified NCHRP Attenuation Barrier System BRR3 (16)* which was varied by changing the spacing of the attenuator posts and changing the rail to a steel thrie beam (see Figure A-5).
2. The Dual System which was composed of a standard steel W rail attached to a post 21 in. (533 mm) above the ground and a steel thrie beam rail attached to the post 54 in. (1370 mm) above the ground. The W rail was blocked out from the post with an elastic material to act as an attenuator for automobile impacts. The thrie beam rail was rigidly attached to the post (see Figure A-1).
3. The NEHER-SWOV concept which in its modified and strengthened version was renamed the Thrie T Barrier. The barrier height was increased, and the W beam was replaced with a stronger thrie beam.
4. A Blocked Out W Section on a Concrete Barrier which could take the shape of the New Jersey safety shape or be a vertical concrete wall of the same height. The addition of the W section would reduce lateral accelerations and reduce rollover for lightweight passenger vehicles.

Cost analyses were made on the preliminary designs of the five systems. The Modified NCHRP Attenuation Barrier was found to be much more expensive than the others and was eliminated from further study. The Dual System was more expensive than the Thrie-T concept or the Concrete Barrier with the blocked out W section but in the general price range. These three barriers were studied in detail by computer analysis using HVOSM, BARRIER VII, or GUARD as appropriate.

---

*Numbers in parentheses, thus (16), refer to corresponding items in the Reference List.

Shortly after the more detailed analysis program was initiated, it became apparent that the cost of the Dual System would be considerable, and this Dual System was therefore abandoned. These two abandoned barriers are discussed briefly in Appendix A.

II. CONCRETE BARRIER WITH BLOCKED OUT W RAIL

The Concrete Median Barrier (CMB) with the New Jersey safety shape is considered by many experts in the highway safety field to be one of the most effective safety barriers in current use. Thirty-six transportation agencies employed a concrete safety shape to some extent in 1971 (1,2). Its effectiveness in safely redirecting vehicles is evidenced by the many tire marks riding upon the barrier face, with most of these encounters never reported to authorities as accidents. Some safety problems with the CMB do exist, however.

When impacted by subcompact automobiles at 60 mph (96 km/h) and 15 to 20 degree angles there is a tendency for the vehicle to roll over. British tests (4) using lighter weight automobiles (1650 lb - 750 kgm) with narrow wheel bases show that rollover tendency is a chronic problem at 20 degree impacts with such vehicles.

A second problem area is the high deceleration values inflicted on automobiles when they impact the CMB at 60 mph (96 km/h) and 15 degrees. Transportation Research Circular 191 (3) states that the maximum acceptable lateral acceleration is 5 g's based on a 50 msec average and measured near the center of mass of the impacting vehicle. Most automobile impacts exceed this value, as can be seen in Table 1, with some subcompacts exceeding 8 g's on the 50 msec average.

The third problem area according to one review of SwRI tests (2) is a secondary impact from the rear of an intercity bus after the initial front impact. In one test the CMB was cracked and weakened on the initial front impact, and when the rear end of the bus impacted the CMB at

TABLE 1. ACCELERATION VALUES FOR AUTOMOBILES IMPACTING THE CMB.

Vehicle	Trans. Res. Circular 191 Max.	(5) 1963 Chevrolet	(5) 1963 Ford	(2) Vega
Vehicle Weight	2250 lb 4500 lb	4210 lb	4500 lb	2250 lb
Impact Speed	60 mph	59.6 mph	60.0 mph	57.1 mph
Impact Angle	15^o	15^o	15^o	16.5^o
Lateral Acceleration, g's	5	6.8	7.2	8.3
Longitudinal Acceleration, g's	10	4.3	4.5	5.3
Total Acceleration, g's	12	8.0	8.5	9.8

Multiply lb by 0.454 to obtain kgm

mph by 1.609 to obtain km/h

approximately the same location, the barrier seemed to explode leaving a badly damaged segment. The bus was badly damaged but was redirected.

Bronstad, et al., (2) made numerous computer parameter studies in an attempt to improve on the shape of the CMB and finally recommended the "F" shape (Figure 1). The "F" shape being the basic geometry of the New Jersey shape with the first vertical step reduced to 7 in. (175 mm) in depth and the horizontal part reduced a corresponding amount so that the slopes of the faces remained the same. The probability of subcompact vehicle rollover is reduced in using the "F" shape but the average acceleration values and superficial sheet metal damage to the vehicles is increased.

It was felt that a second type modification should be investigated, such as that of adding a metal rail supported by a series of discreet energy absorbing cushions or blockouts as shown in Figure 2a. This type of design should reduce the acceleration values for all angles of impact and hold down or reduce the roll angles for automobiles, thus reducing vehicle rollover tendency. The rail would be the first part of the system to be impacted and would help spread the impact load over a larger area of the wall. The total impact load would be reduced, and damage to the barrier would also be reduced. A massive reinforced concrete barrier can be designed which will withstand the large impact forces from intercity buses and 40,000 lb (18,100 kgm) trucks. Figure 2a indicates how existing CMB's could be retrofitted, and Figure 2b indicates new concrete barriers could be simply constructed with vertical walls if desired.

NOTE

MULTIPLY INCHES x 25.4 TO OBTAIN mm.

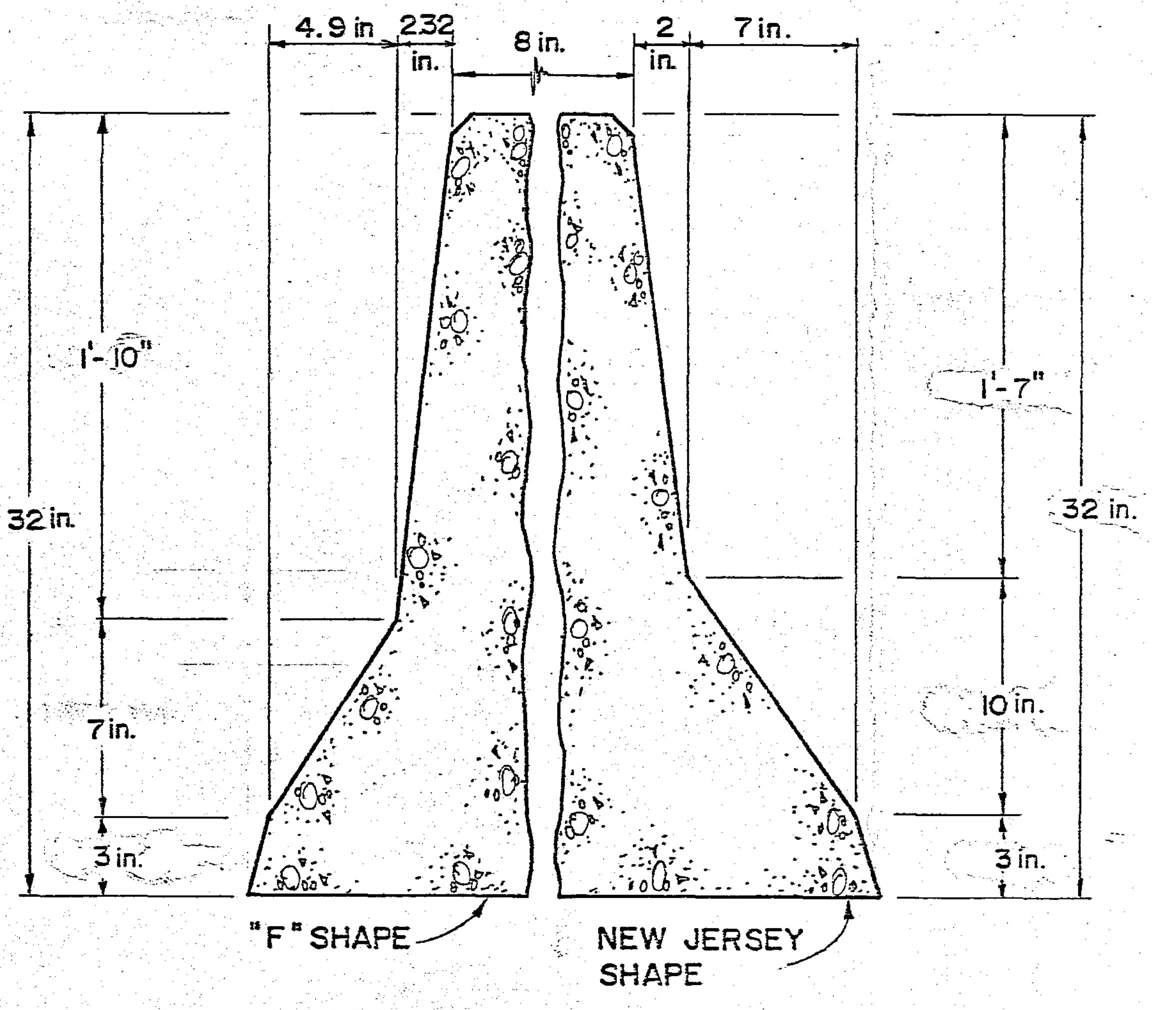
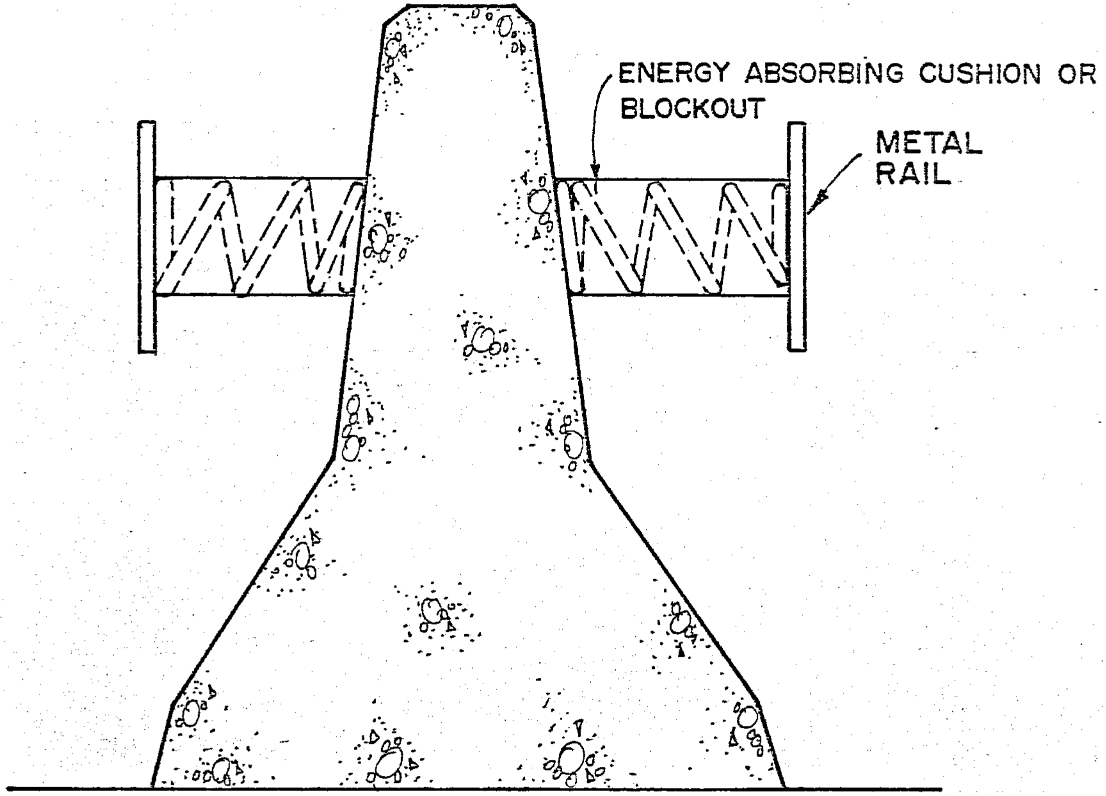
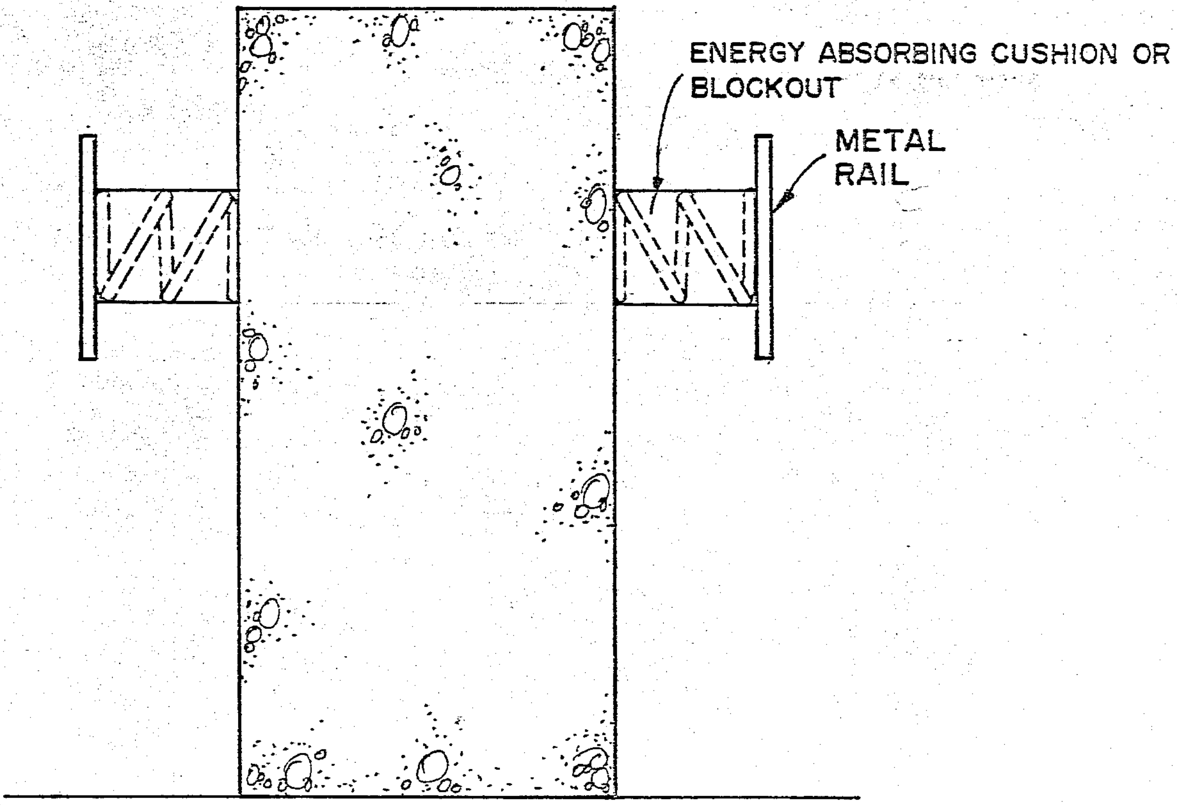


Figure 1. Concrete Median Barrier — Comparing The New Jersey Shape To The "F" Shape.



a) RETRO- FIT CMB NEW JERSEY SHAPE



b) NEW VERTICAL FACED CONCRETE RAIL

Figure 2. Concrete Barriers With Blocked Out Rail (Concept)

Simulation Techniques

There were three candidate models for computer simulation of vehicle impacts with these barriers. These were HVOSM, a three-dimensional model very adequate for determining vehicle behavior when all surfaces being impacted are rigid, i.e., rail elements cannot be allowed to deflect on impact. Young (5) and Bronstad (2) have used HVOSM with success in predicting the behavior of vehicles impacting a CMB. The model does not work for a flexible rail.

The second candidate model available was BARRIER VII, a two-dimensional simulation. When the barrier and the vehicle will act in one plane the model has proved to be reasonably accurate (6). A rigid barrier such as a concrete barrier may be approximated by inputting a series of rails one on top of the other up to the wall height. This composite rail may be made rigid by using very large moment of inertia and modulus of elasticity values to describe the rail elements. Vehicle roll angles and rollover tendencies were important aspects in this study of rigid barriers. Since this model is only two-dimensional it cannot determine vehicle roll behavior. Consequently BARRIER VII was not used to study the concrete barrier.

Bruce and Hahn (7) developed a three-dimensional model named GUARD to study the vehicle/vehicle-bumper/guardrail dynamic impact. The input for this simulation calls for terrain data which could be used to simulate the CMB safety shape. The program was very difficult to use, however, and some of the techniques required are discussed in Appendix A. In order to verify the validity of the GUARD program, three baseline cases were investigated comparing full-scale crash test data, HVOSM simulations and

GUARD simulations (Table 2). During the simulation the GUARD program terminated due to numerical instability after the impacting vehicle had started to redirect from the wall. It appears, however, that good results were obtained during the early significant portion of the impact event since relatively close correlations were obtained with the test data. The GUARD program was used in the parameter study.

Material Selection

Metal Railing. A metal which is ductile, tough and able to absorb large amounts of impact energy is desirable for a traffic rail. Consequently steel was chosen for the metal rail. Readily available materials are also desirable, therefore existing traffic railing shapes were investigated. These were the 10 and 12 ga W sections and the 6 x 6 steel rectangular tube sections.

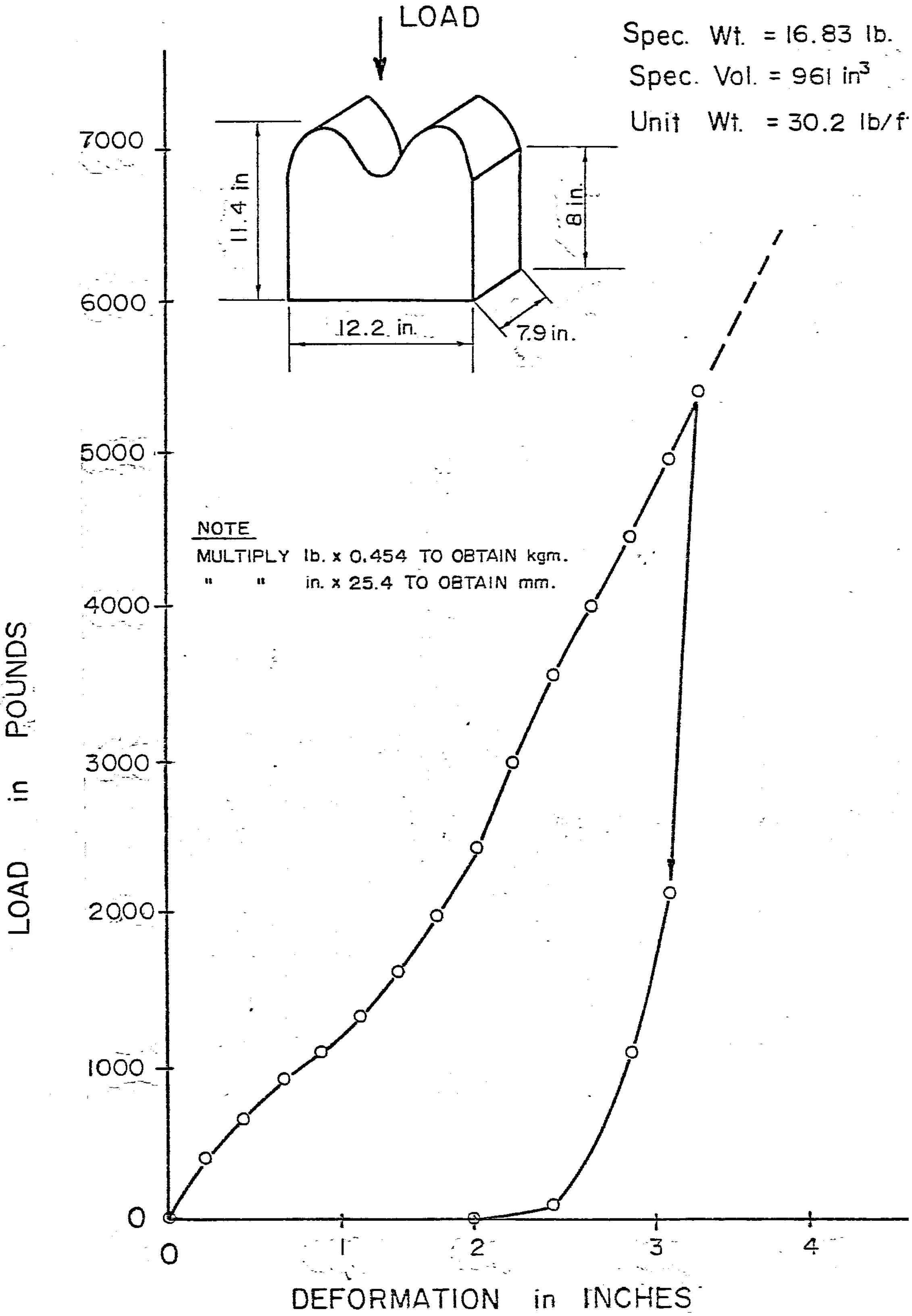
Energy Absorbing Cushion or Blockout. An effective blockout unit would be able to deflect horizontally under vehicle impact load but should not deflect or creep downward under the weight of the rail. When the lateral impact load is terminated the blockout should return to its original shape.

The blockout should be capable of deforming and absorbing impact energy with little or no elastic rebound during impact. A spring that would ultimately regain its original shape would be advantageous. A steel spring restrained from quickly returning to its original shape by a dash pot or shock absorber is one possibility. Another possibility is to use rebonded neoprene as a blockout element. Static tests on this material indicate that its force-deformation properties appear ideal for guardrail blockout purposes. Figure 3 indicates that during loading the

TABLE 2. COMPARISON OF HVOSM & GUARD SIMULATIONS TO CRASH TEST DATA FOR CMB IMPACT.

VEHICLE	VEHICLE WEIGHT lb	IMPACT ANGLE	IMPACT SPEED mph	TEST DATA (5) 50 msec ACCELERATIONS		HVOSM SIMULATIONS 50 msec DECELERATIONS		GUARD SIMULATIONS 50 msec DECELERATIONS	
				LATERAL	LONGITUDINAL	LATERAL	LONGITUDINAL	LATERAL	LONGITUDINAL
1963 Plymouth	4000	25^{o}	63.0	9.3	7.5	9.1	7.3	9.0	7.3
1963 Chevy	4210	15^{o}	59.6	6.8	4.3	6.0	4.2	6.4	4.0
1963 Chevy	4210	7^{o}	61.9	5.6	3.2	4.2	1.5	4.7	1.4

Multiply mph x 1.609 to obtain kph
lb x 0.454 to obtain kgm



Spec. Wt. = 16.83 lb.
Spec. Vol. = 961 in^3
Unit Wt. = 30.2 lb/f

NOTE
MULTIPLY lb. x 0.454 TO OBTAIN kgm.
" " in. x 25.4 TO OBTAIN mm.

Figure 3. Static Force vs Deformation Properties of Proposed Rubber Traffic Rail Block Out Element.

force vs. deformation is almost linear. When loaded suddenly, little instantaneous rebound is observed, yet the specimen eventually recovers its initial dimensions (within 2%) in several minutes. In several hours the compressed length will return to 99%+ of the original length. The material is a petroleum based polymer and currently a surplus item. American National Rubber Company currently has over 2 million pounds (907,184 kg) stockpiled with little means of disposal. Three other companies are restrained from normal disposal techniques (burning and burying) and need recycling outlets.

The spring constant of this size and shape specimen was about 9.4 kips/ft (137 KN/m) A more general material property would be the modulus of elasticity which is about 93 psi (640 KPa). This value has been developed in "static" tests by placing a full-scale guardrail blockout specimen in a universal testing machine, covering it with a short piece of 12 ga W beam and determining the force-deformation characteristics as shown in Figure 3. This curve is a composite of four tests on two specimens all at ambient (80^{o}F) (26.7^{o}C) temperature. The specimens were then soaked in a container of water for seven days, quick frozen in a -20^{o}F (-29^{o}C) cold room, covered with an airtight plastic bag for three days, then tested again. There was essentially no difference in measured properties for the wet, frozen specimen. Next the specimens were heated to 150^{o}F (65.6^{o}C) then tested. Again the same results were obtained.

A series of static tests were conducted with varying base restraints such as placing the base of the specimen in a tray which just fits the bottom and testing and finally applying a silicone lubricant (grease) to the bottom and testing. The result of all of these tests yielded essentially the same properties.

One negative feature of this material is the nature of the bonding material and its reaction when exposed to ultraviolet light (sunlight). The base material (neoprene) is quite stable in ultraviolet light but the manufacturers are concerned about the bonding media used. The manufacturers therefore are recommending that a coating of hypalon be used as a shield to sunlight. The chief concern is that after about three years of continuous exposure to weather without the coating there might be noticeable deterioration of the surfaces exposed to the sun's rays. A substantial (10 mil) coating of hypalon is expected to eliminate that concern.

Vertical deflection and creep are also concerns. In order to test this a block of rebonded neoprene the size shown in Figure 3 was attached to a vertical wall, and a 75 lb (34 kgm) weight attached to the end of the specimen. The specimen deflected 1/4 in. (6 mm) immediately, then after approximately one year the deflection was checked and found to be 7/16 in. (11 mm), indicating there would be about 3/16 in. (5 mm) creep in the first year. The weight was removed and after 24 hours the specimen had returned to an overall downward deflection of 1/8 in. (3 mm). This amount of downward creep should be negligible for highway use.

The Concrete Median Barrier New Jersey Safety Shape (CMB(NJ)) with Blocked Out Rails

The first rail to be studied was the CMB(NJ). The study was done by computer simulation using the GUARD model as the primary program with verification by HVOSM and comparing to full-scale crash test results where possible. A simulation matrix was developed for a parameter study to select rail type, spring spacing, and spring constant. Then the

TABLE 3. SUMMARY OF GUARD PARAMETER STUDY RESULTS FOR ENERGY ABSORBING BLOCKOUTS USED WITH GUARDRAIL. (Vehicle impacts at 60 mph and 15°.)

RAIL TYPE	VEHICLE WEIGHT lb	BLOCKOUT SPRING CONSTANT lb/in.	BLOCKOUT SPACING													
			4 ft		6 ft		7 ft		8 ft		9 ft		10 ft		12 ft	
			MAX. DEFL. in.	G_{AVG}*	MAX. DEFL. in.	G_{AVG}*	MAX. DEFL. in.	G_{AVG}*	MAX. DEFL. in.	G_{AVG}*	MAX. DEFL. in.	G_{AVG}*	MAX. DEFL. in.	G_{AVG}*	MAX. DEFL. in.	G_{AVG}*
12 ga W	2250	500	6.2	6.0	14.0	5.1	15.1	4.8	18.2	4.7						
		1000	4.5	7.8	6.8	5.5	7.9	5.3	9.9	5.2						
		1500			5.0	7.4	5.9	7.2	8.0	7.1						
	4500	500	8.3	5.3	16.2	2.9	18.1	2.9	21.4	2.8						
		1000	7.0	5.6	10.0	3.0	12.0	3.0	15.1	3.0						
		1500			9.0	4.1	10.0	3.9	11.2	3.6						
10 ga W	2250	500			11.8	5.2	12.2	4.9	14.8	4.8	16.3	4.6				
		1000			5.9	5.5	6.1	5.9	8.9	5.4	10.1	5.5				
		1500			5.7	7.8	6.2	7.6	7.0	7.0	8.2	6.3				
	4500	500			15.0	3.2	17.2	3.2	20.1	3.1	24.0	3.1				
		1000			8.5	3.9	9.4	3.5	12.2	3.8	16.1	3.2				
		1500			6.8	4.2	7.2	3.6	9.1	4.0	11.2	3.5				
TS 6"x6"x.1875"	4500	500							4.2	9.2	4.2	8.3	4.4	7.8	6.1	7.5
		1000							4.0	9.1	3.9	8.5	4.0	8.1	5.7	7.5
		1500							3.4	9.4	3.5	9.0	3.7	8.2	5.6	7.9

*G_{avg} = Deceleration averaged over 50 msec.

Multiply lb x 0.454 to obtain kgm.
in. x 25.4 to obtain mm
lb/in. x 175 to obtain N/m

composite rail was studied with respect to vehicle rollover and vehicle accelerations. These were then compared to the CMB(NJ) with a W section and the benefits and tradeoffs determined.

Simulation Matrix for the CMB(NJ) with Blocked Out Rails. The investigation was conducted using the GUARD program. The simulation matrix included a study of the following significant variables:

1. three rail sections --
    a. 12 ga W section,
    b. 10 ga W section,
    c. 6 x 6 steel tube;
2. one-way spring blockout spacings ranging from 4 ft to 12 ft in one-foot increments (1.2 m to 3.6 m in 0.3 m increments);
3. blockout spring constants ranging from 500 lb/in. to 1500 lb/in. (87.6 kN/m to 262.7 kN/m);
4. the vehicle weights were 2250 lb and 4500 lb (1020 kgm and 2040 kgm);
5. impact conditions were 60 mph (97 km/h) and 15 degrees.

Table 3 presents a summary of the parameter study results. The maximum rail deflection in inches (millimetres) and the maximum average 50 msec deceleration of the impacting vehicle are presented.

Rail Selection. The development of plastic hinges near the point of impact and at the supports ahead or behind the impact point was used to indicate the maximum strength limitations of the rail and when significant damage was beginning to occur. It was determined that plastic hinges formed in the 12 ga rail when the spring blockouts were spaced at more than 6 ft (1.8 m) apart when impacted by the 2250 lb (1020 kgm) vehicle. Plastic hinges formed in the 10 ga rail when the blockouts were spaced at more than 8 ft apart (2.4 m). The 6 in. x 6 in. (152 mm x 152 mm) tube proved to be very stiff and strong, and no plastic hinges were observed in this study.

The W section is fabricated in 12 ft-6 in. (3.8 m) and 25 ft (7.6 m) lengths with allowance for splicing. In the interest of economics it is better to use standard lengths which would be shelf items. If a 25 ft (7.6 m) section is considered, blockout spacings could be conveniently located at 12 ft 6 in. (3.8 m); 8 ft 4 in. (2.5 m); 6 ft 3 in. (1.9 m); or 5 ft (1.5 m). In view of these results, the 10 or 12 ga W section with blockouts spaced at the usual 6 ft 3 in. (1.9 m) appears adequate. The sample blockout previously tested had a stiffness of about 800 lb/in. (140 kNm). From Table 3 it can be seen that if the blockouts were used with a 10 or 12 ga W section with a 6 ft-3 in. (1.9 m) spacing, lateral deflections of from 7 to 9 in. (.18 to .23 m) would be obtained from a 2250 lb (1020 kgm) vehicle. The deflection would be 11 to 12 in. (0.31 m) with a 4500 lb (2040 kgm) vehicle.

Blockout Design. From Table 3 it can be seen that the 500 lb/in. (88 kNm) blockout spring constant produces large rail deflection on the order of 12 in. to 16 in. (.30 m to .40 m) with a 6 ft (1.83 m) spacing. These large deflections would be difficult to accommodate with a reasonable size blockout. Consequently, it appears that a stiffer blockout is desirable. A stiffness on the order of 750 lb/in. (131 kN/m) or greater appears desirable.

Additional simulations were made using the 12 ga rail with blockouts at 6 ft 3 in. (1.9 m) spacing. A spring constant of 800 lb/in. (140 kN/m) was used since this was the approximate stiffness of the previously tested sample.

The rail deflection was 11 in. (280 mm) when impacted by a 4500 lb (2040 kgm) vehicle at 60 mph (97 km/h) and 15°. The blockout had an average thickness of approximately 12-5/8 in. (see Figure 4), the required height to fit a W section of 12-1/4 in. (310 mm), and a width of 8.0 in. (203 mm).

Verification of the Design by Simulation. Using this design, additional computer simulations were then made for the following vehicles impacting the rail at 60 mph (97 km/h) and 15°:

a. 1650 lb car (750 kgm)

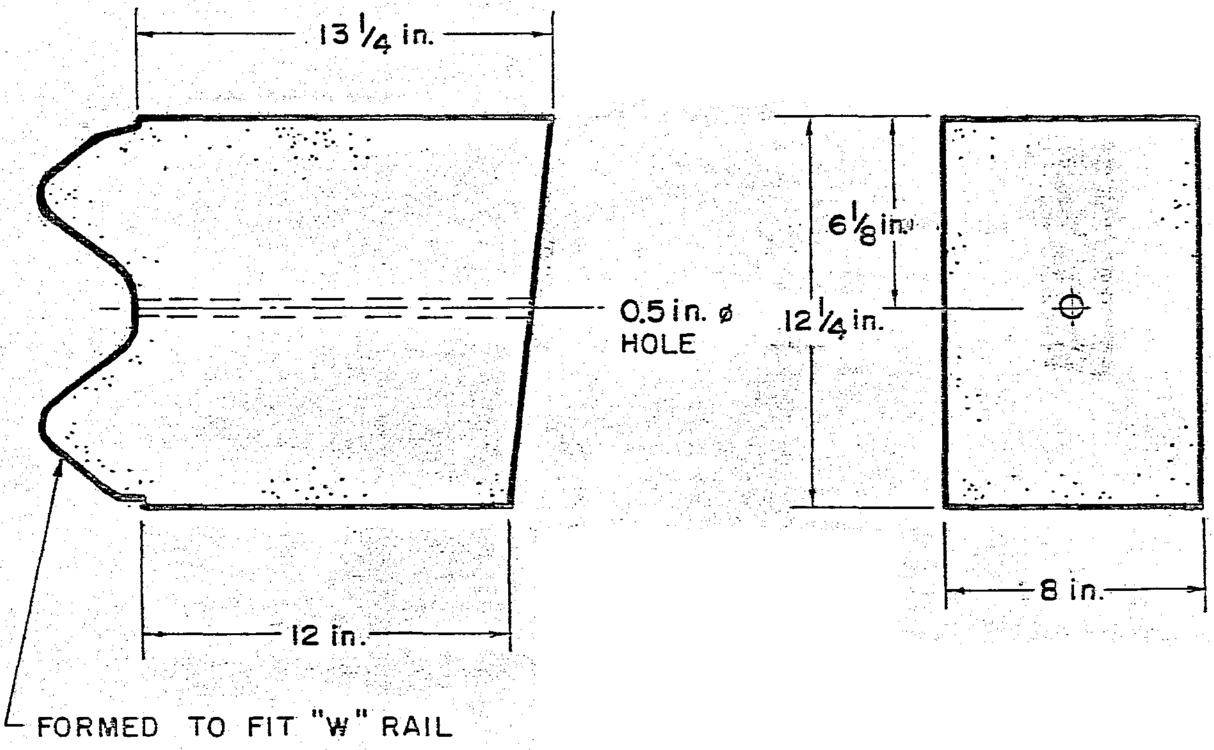
b. 2250 lb car (1020 kgm)

c. 4500 lb car (2040 kgm)

d. 20,000 lb school bus (9070 kgm)

e. 40,000 lb intercity bus and truck (18,140 kgm)

In order to establish a baseline for comparison, simulations were made for a concrete barrier without a rail and a barrier with energy absorbing blockouts and a W section rail. Where possible these results were compared with crash test data. The results are found in Table 4. It should be noted that rollover was predicted by both HVOSM and GUARD for the Simca and Vega impacting the CMB. GUARD also predicts that the addition of the blocked out W section will hold the roll angle to reasonable levels for these two vehicles and significantly reduce the roll angle for other subcompact automobiles, standard size automobiles, and school buses. The maximum roll angle of the intercity bus (52°±) seems to be unaffected by the addition of the rail. Also, GUARD simulations predict that there will be reductions in the acceleration levels experienced by the vehicles



NOTE: MULTIPLY in. x 25.4 TO OBTAIN mm

Figure 4. ENERGY ABSORBING BLOCKOUT DIMENSIONS FOR W SECTION.

TABLE 4. SUMMARY OF GUARD VEHICLE IMPACT SIMULATION RESULTS FOR A CONCRETE MEDIAN BARRIER (CMB) AND A CONCRETE BARRIER WITH ENERGY ABSORBING BLOCKOUTS. (All vehicle impacts at 60 mph and 15°.)

VEHICLE MAKE	VEHICLE WEIGHT lb	C.G. HEIGHT in.	WHEEL TRACK ft	CMB(NJ)				CONCRETE BARRIER WITH BLOCKED OUT RAIL	
				GUARD		TEST DATA			
				MAX. ROLL ANGLE degrees	G_{AVG}*	MAX. ROLL ANGLE degrees	G_{AVG}*	MAX. ROLL ANGLE degrees	G_{AVG}*
Simca	1650	19	4.0	Rollover	NA	Rollover ( )	NA	23	7.7
Vega	2250	20	4.5	Rollover	NA	Rollover ( )	NA	12	7.3
Pinto	2250	20	4.5	21	8.1	--	--	12	7.2
Ford	4500	21	5.0	35	7.2	25 ( )	6.0	2.5	3.5
S. Bus	20000	38	7.5	46	2.1	--	--	20	2.2
Intercity Bus	40000	63	7.5	52	1.7	45 (2)	1.4 (2)	53	1.7

*G_{avg} = deceleration averaged over 50 msec

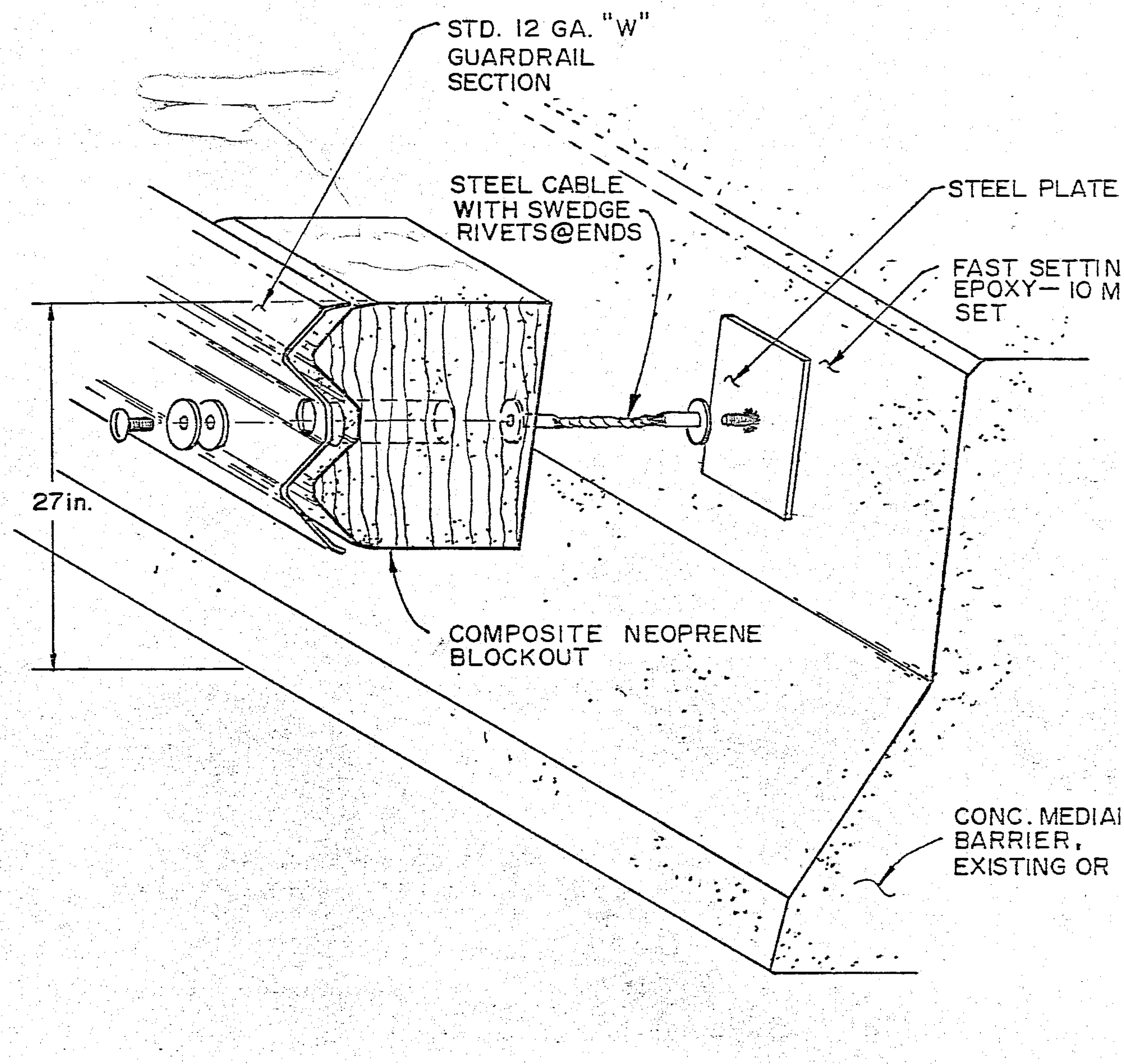
Multiply mph x 1.609 to obtain km/h
lb x 0.454 to obtain kgm
in. x 25.4 to obtain mm
ft x 0.3048 to obtain m

impacting the CMB with the blocked out guardrail. The acceleration level for the subcompact automobile was reduced 11% to 7.2 g's. This is in excess of the 5 g recommendation contained in Circular 191. The predicted acceleration level for the standard weight (4500 lb - 2040 kgm) automobile was reduced 51% down to 3.5 g's, well below the maximum recommended level. There are no significant variations in the deceleration levels in the bus category.

The results in Table 4 show that the addition of the energy absorbing blockout and rail to the concrete barrier did eliminate the rollover behavior for the compact and subcompact automobile impacts. The energy absorbing blockouts and rail will also reduce the maximum decelerations by 11 to 51% for automobiles.

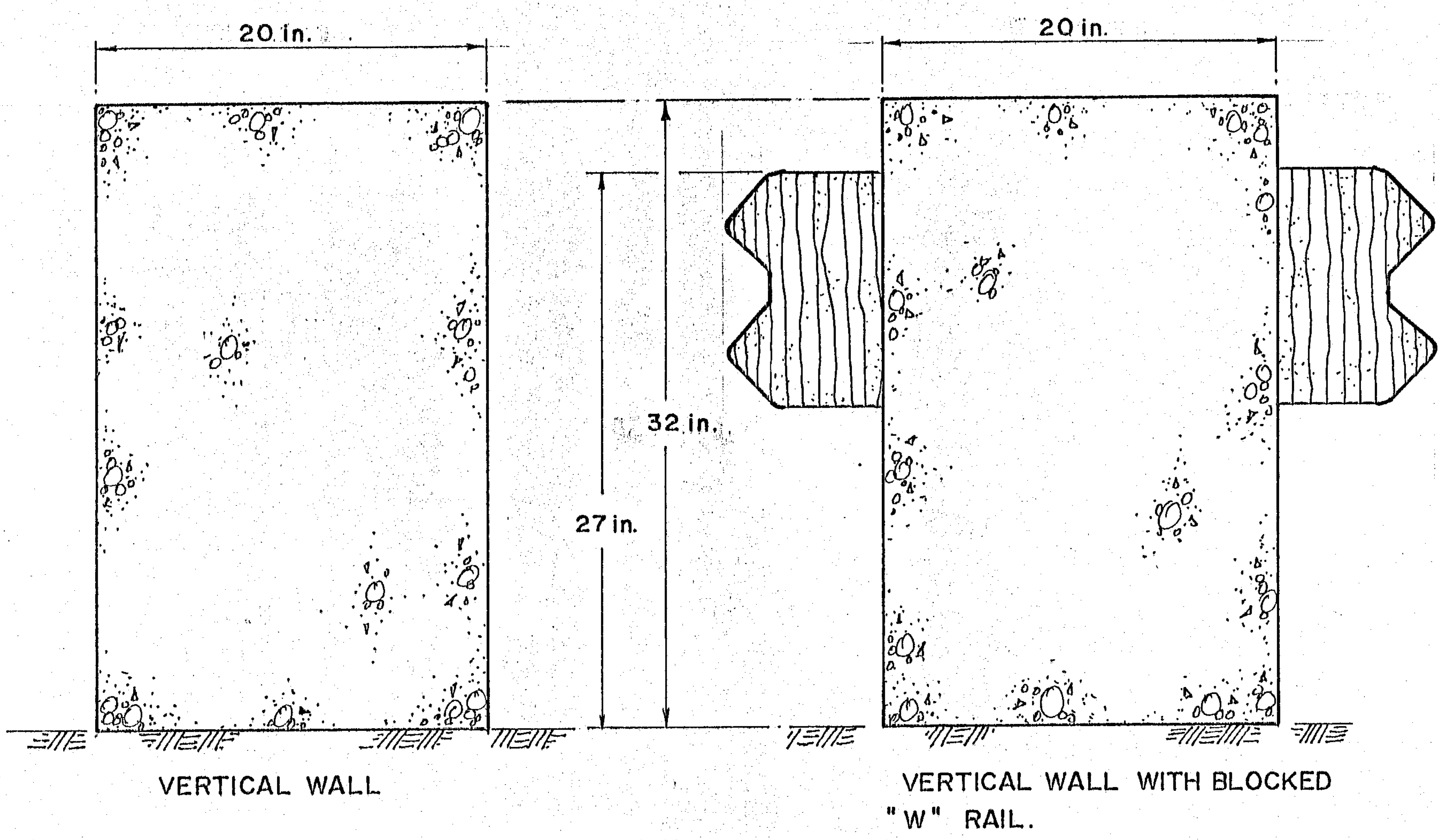
The Vertical Faced Concrete Barrier with Blocked Out Rails

The addition of a blocked out rail on the CMB to a large extent eliminates the effectiveness of the safety shape; but if the population of compact and subcompact cars continues to increase and the frequency of rollover accidents increases, these barriers can be retrofitted with a blocked out rail such as this. For new installation a simple vertical concrete wall could be used to support the energy absorbing blockouts and rail. The vertical wall, Figure 6, was studied both with and without the blocked out rail so that a comparison could be made. The barriers were studied by impacting them with vehicles ranging from 1650 lb (780 kgm) to 40,000 lb (18,140 kgm). The results are given in Table 5. The addition of the blockouts to the vertical wall appears to have no significant effect on roll angles. The addition of the energy absorbing blockouts and rail has a significant effect on impact decelerations of the automobiles.



NOTE: MULTIPLY in. x 25.4 TO OBTAIN mm

Figure 5. Exploded View Of Fastener And Blockout To Attach "W" Beam Rail To CMB.



NOTE: MULTIPLY in. x 25.4 TO OBTAIN mm

Figure 6. Vertical Walls Simulated.

TABLE 5. SUMMARY OF GUARD SIMULATION RESULTS FOR VEHICLE IMPACTS INTO A VERTICAL CONCRETE WALL AND ENERGY ABSORBING BLOCKOUTS AND RAIL BARRIER. (All impacts at 60 mph (97 kph) & 15°.)

VEHICLE MAKE	VEHICLE WEIGHT lb	C.G. HEIGHT in.	WHEEL TRACK ft	VERTICAL WALL		ENERGY ABSORBING BLOCKOUTS AND RAIL	
				MAX. ROLL ANGLE degrees	G_{AVG}*	MAX. ROLL ANGLE degrees	G_{AVG}*
Simca	1650	19	4.0	1.1	10.0	2.0	5.8
Vega	2250	20	4.5	1.8	9.3	1.7	5.2
Ford	4500	21	5.0	2.7	8.5	2.9	3.2
S. Bus	20000	38	7.5	44	2.0	24	2.6
Intercity Bus	40000	63	7.5	53	1.8	52	1.8

*G_{avg} = deceleration averaged over 50 msec

Multiply lb x 0.454 to obtain kgm
in. x 25.4 to obtain mm
ft x 0.3048 to obtain m

The CMB size and shape have proven to be stable with little sliding or overturning during impact by automobiles (2). A vertical wall concrete barrier should also be designed so that it will be stable during vehicle impact. This implies that the vertical concrete wall should be as heavy as the CMB and have a similar base width and height of center of gravity. The mass moment of the cross section of the wall should be the same as or greater than that of the CMB to have the same resistance to overturning. An impact force (Figure 7) will cause a barrier to rotate about point A at the ground surface. The overturning moment caused by a force P acting a distance of "h" from the surface is resisted by the weight of the barrier W acting through its center of gravity. For the CMB this is the same as

$$\text{CMB Stabilizing Moment} = \frac{461}{1728} \times \gamma_c \times \frac{27.5}{2} = \frac{44}{12}\gamma_c$$

where 461 is the cross-sectional area of the CMB in sq. in.

1728 is the conversion from in.^{3} to ft^3

γ_c is the unit weight of the concrete in lb per cu ft

27.5" is the width of the base of the CMB

Then for the vertical concrete wall (VCW)

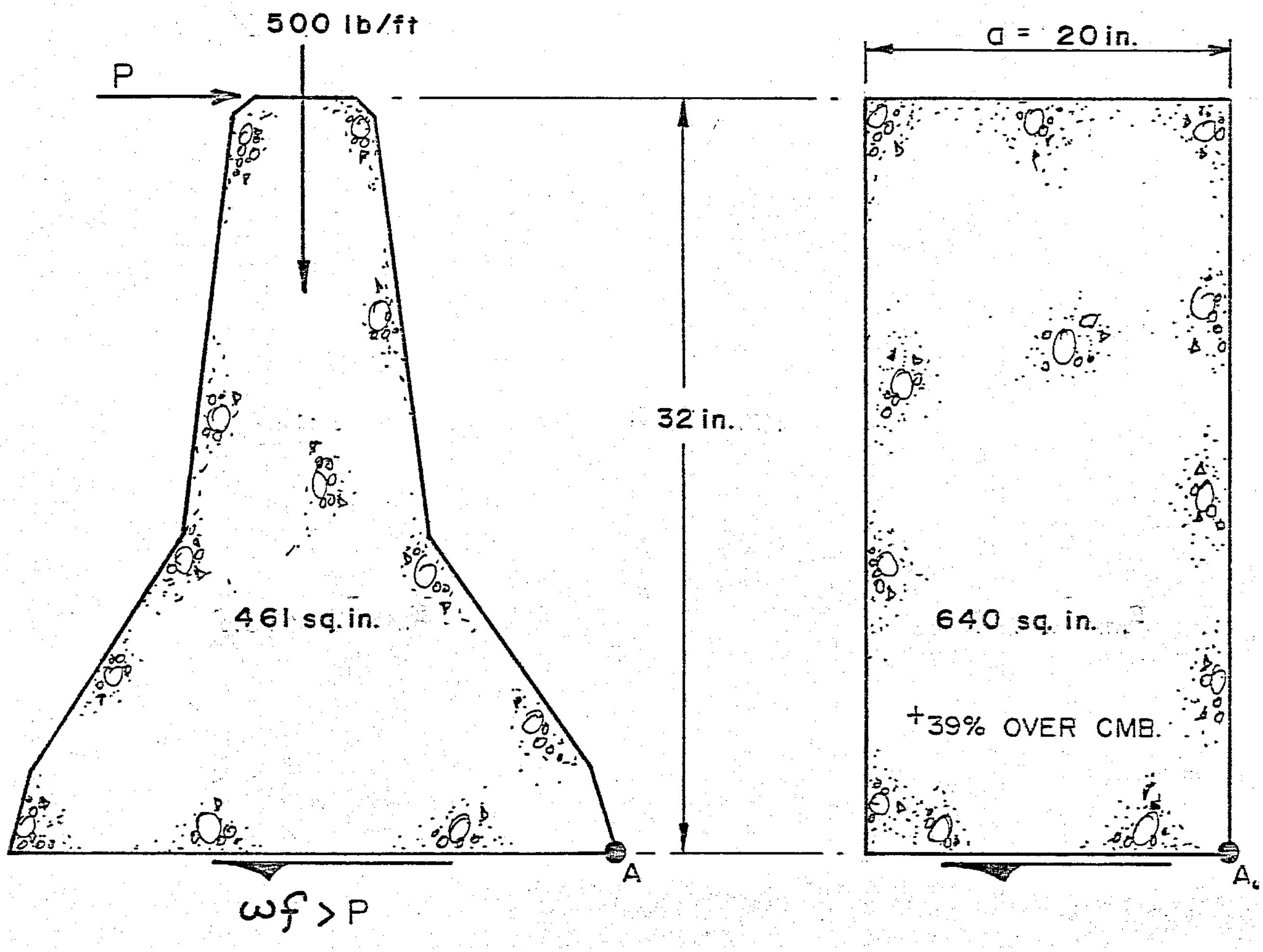
$$\text{VCW Stabilizing Moment} = \frac{32 \text{ x } a}{1728} \times \frac{a}{2} \times \gamma_c = \frac{a^2\gamma_c}{9 \times 12}$$

and this must equal the value of the CMB or

$$44\gamma_c = \frac{a^2\gamma_c}{9} \quad \text{or}$$

$$a^2 = 9 \times 44 = 396 \quad \text{and}$$

$$a = 19.9 \text{ in., say 20 in. (508 mm)}$$



NOTE: MULTIPLY in. x 25.4 TO OBTAIN mm

Figure 7. Comparison Of Sliding And Overturning Of CMB And Vertical Wall.

Therefore a vertical wall barrier would have to be 20 in. (508 mm) wide. This would be 39% heavier or contain 39% more concrete than the CMB, and sliding and overturning requirement would be satisfied.

The extra concrete in the wall would be approximately 1.25 sq. ft/ft (.117 sq. m/.305 m) of wall. The cost of the concrete would be partly offset by the reduced cost of forming and placing.

The design of the wall with the blocked out W beam is shown in Figure 7. All components would be the same as the blocked out CMB except that the polymer blockout material would be squared off at the junction of the blockout and wall.

III. THE THRIE "T" BARRIER

Engineers in West Germany and the Netherlands have developed a roadside barrier which has been called alternately the NEHER barrier or the SWOV barrier. Several reports have been written describing the more than 100 full-scale crash tests and computer simulations performed on this barrier in Europe (9,10,11,12). Vehicles used in testing ranged in weight from 1200 lb (545 kgm) to more than 30,000 lb (13,600 kgm). Speeds at impact varied from 35 mph to 70 mph (56 km/h to 115 km/h). Impact angles ranged from 7.5° to 30° with the majority of the crash tests being at about 20°.

The NEHER barrier (Figure 8) consisted of two 12 ga W rails spaced 739 mm (29.1 in.) back to back. The spacers are rigid and hold the rail on a 6° angle from the vertical. The spacers generally are supported by posts driven in the ground. For soft soil conditions encountered in Holland, the Dutch developed a concrete disc to be placed in the bottom of the drilled hole to hold the bottom of the post as a point of rotation during vehicle impact. For such soft soil conditions the backfill in the hole was tamped to at least the density of the surrounding ground.

Crash test data of the NEHER-SWOV concept including high-speed movie film indicated that the barrier concept had good potential for redirecting heavy vehicles with a high center of gravity because the rail height increases as the post rotates during impact. The maximum impact test condition conducted in Europe was for a 30,000 lb (13,600 kgm) truck impacting the barrier at 42 mph (67 km/h) at an angle of 20°. The impact conditions required on this project were for a 40,000 lb truck (18,160 kgm)

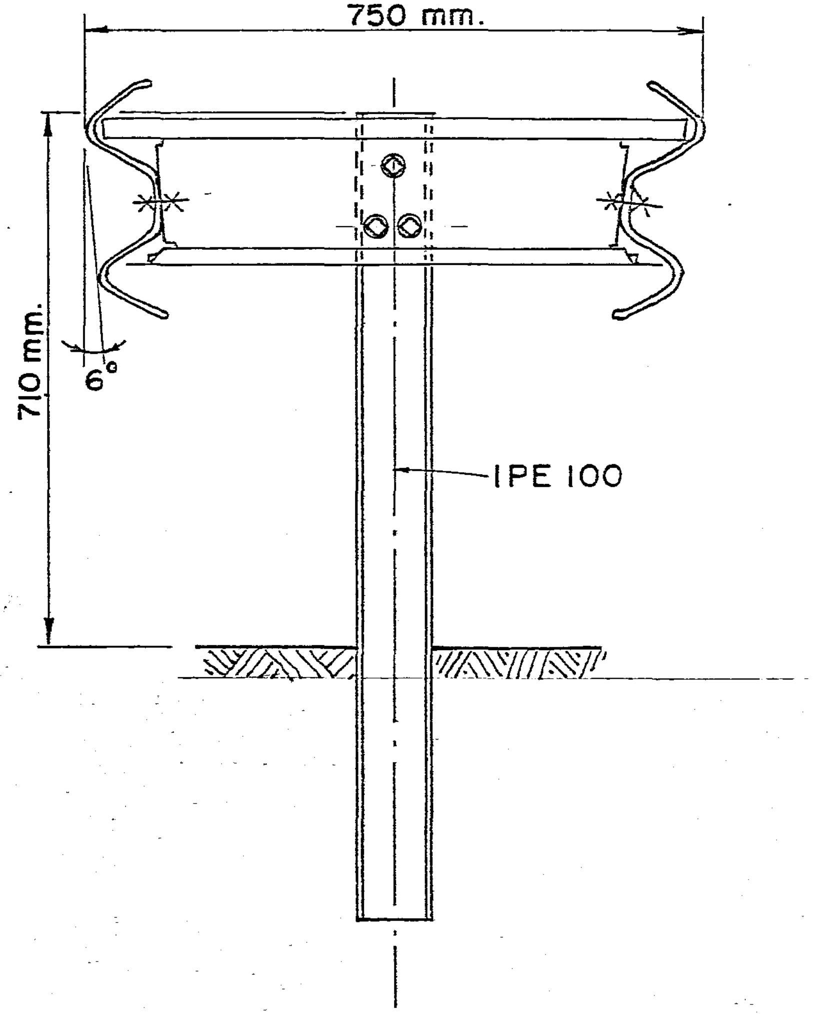


Figure 8. Neher Barrier

at 60 mph (97 kph) and 15^0. In order to compare these values it is necessary to compare in terms of kinetic energy a scaler value which in itself will not consider the impact angle. However, if we note that

$$KE = \frac{MV^2}{2} = \frac{WV^2}{2g}$$

where KE = kinetic energy

M = mass

W = weight

g = acceleration due to gravity

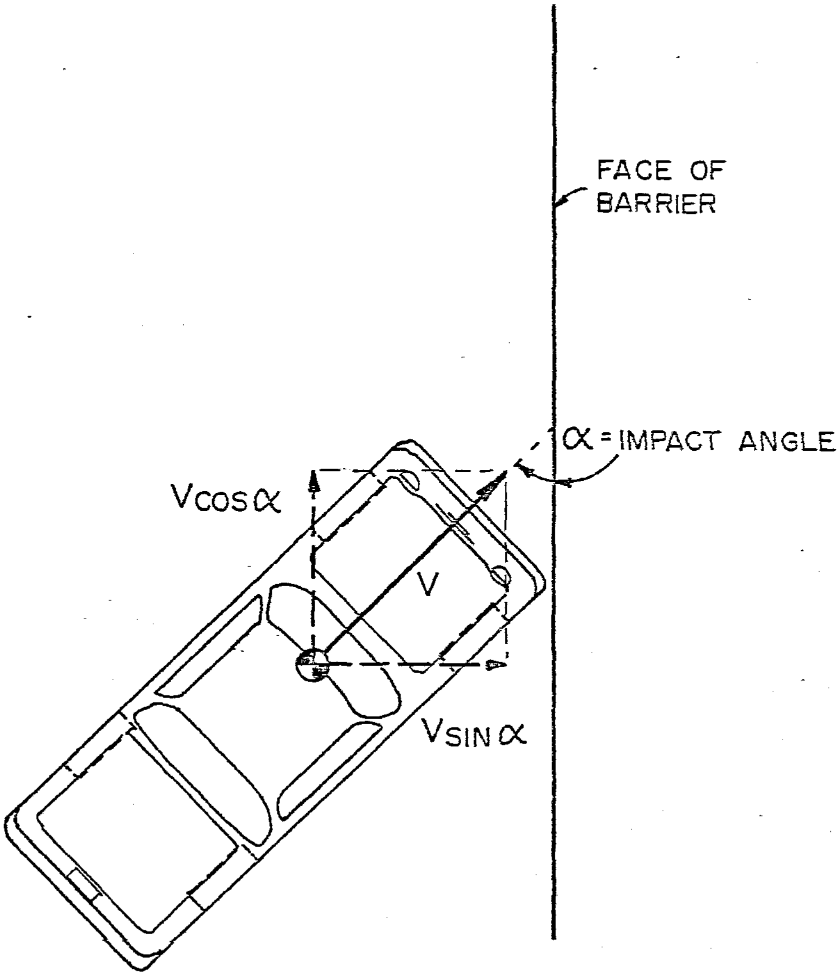
V = velocity

The velocity is a vector quantity and can be resolved into components perpendicular to and parallel to a barrier (Figure 9). By doing this we may rewrite the kinetic energy equation into components perpendicular to and also parallel to the barrier as follows:

$$KE = \frac{W(V\sin\alpha)^2}{2g} + \frac{W(V\cos\alpha)^2}{2g} = \frac{WV^2}{2g}$$

Where α is the impact angle. The term $\frac{W(V\sin\alpha)^2}{2g}$ is the component of kinetic energy perpendicular to the traffic barrier. The longitudinal traffic barrier must be capable of absorbing this perpendicular component of kinetic energy if vehicle redirection is to be achieved.

The lateral velocity component of kinetic energy for the severest European test was 207,000 ft-lb (280,000 N-m) whereas the rails developed on this project must withstand a lateral velocity component of kinetic energy of 332,700 ft-lb (437,300 N-m). This is an increase of about 56%,



$$K.E. = \frac{WV^2}{2g}, \text{ ALSO}$$

$$K.E. = \frac{W(V\sin\alpha)^2}{2g} + \frac{W(V\cos\alpha)^2}{2g}$$

Figure 9. VELOCITY COMPONENTS OF VEHICLE IMPACTING A BARRIER.

a considerable amount for a barrier that appeared to be performing at its maximum capability in the European tests. To redirect heavy vehicles the traffic rail needs to be strengthened and raised in height in order to accommodate high center of gravity of trucks or buses. The thrie beam (13) appeared to be a logical initial choice to investigate since it is both stronger and wider, permitting higher mounting heights without danger of smaller vehicles underrunning the rail.

The barrier using a thrie beam (Figure 10a) is identified as the Thrie-T Barrier, or TTB.

Simulation Techniques

The GUARD model (7) was developed to study barriers of similar characteristics as the TTB and was therefore selected to study the behavior of various TTB designs. In order to validate or test the accuracy of the GUARD program for the NEHER or TTB type barrier, four problems were run in order to compare with crash test results. These comparisons were made on the basis of German tests (11) since their soil strength conditions were similar to those contained in the GUARD subroutine SOIL. The results of these comparisons are shown in Table 6. The GUARD results are seen to compare favorably with the crash test data. These early European crash tests reported only dynamic and static barrier deflections which could be used to indicate impact severity. Therefore no vehicle deceleration levels could be compared.

Numerical instability with the GUARD computer program occurred frequently when large impact angles and large lateral velocity energy components were used. The integration interval had to be reduced to

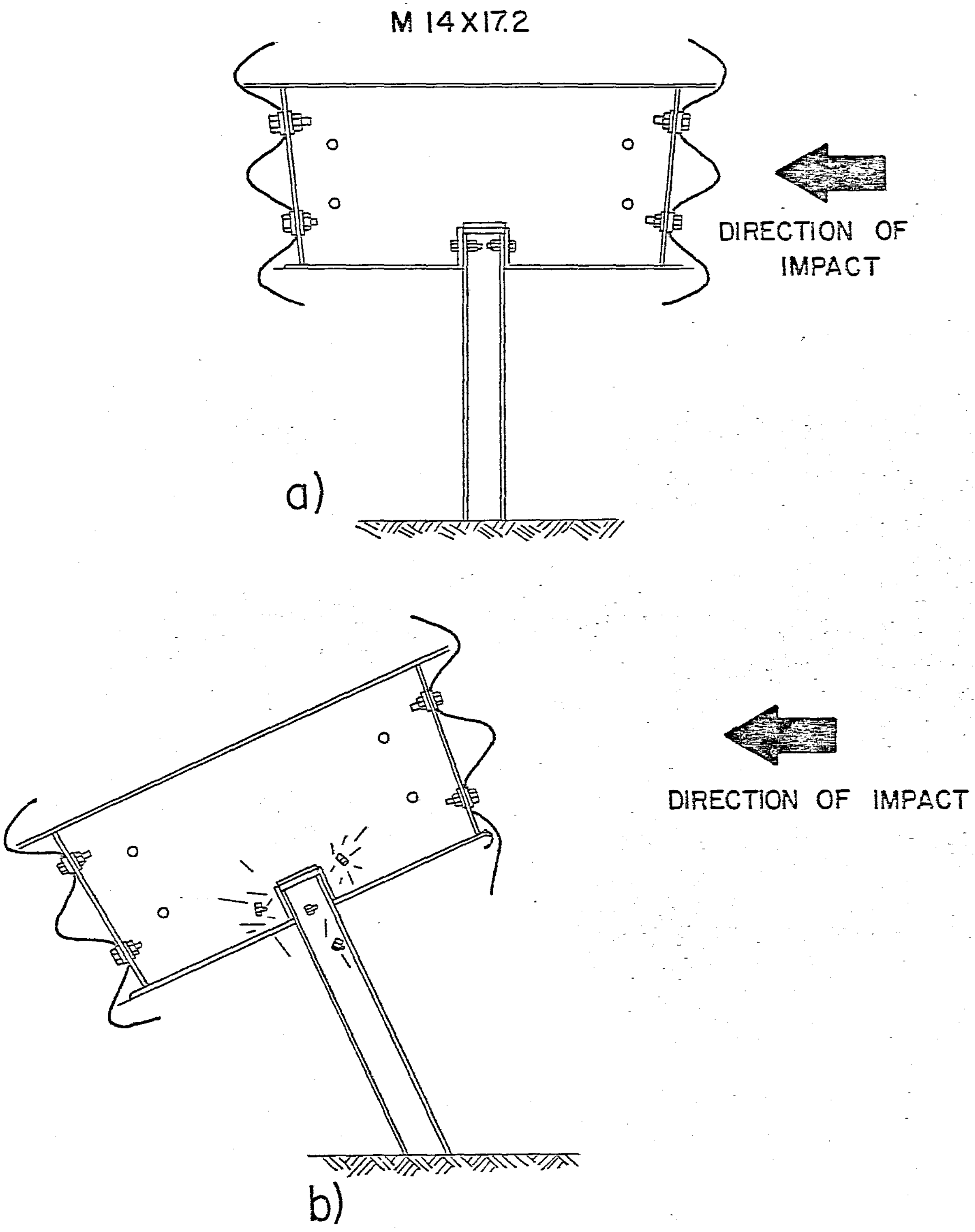


Figure 10. Cross-Section of Proposed Thrie "T" Barrier

TABLE 6. COMPARISON OF FULL-SCALE TESTS AND GUARD SIMULATION OF NEHER BARRIER.

Vehicle Weight	Vehicle Speed	Impact Angle	DYNAMIC DEFLECTION	
			Crash Test	Guard Simulation
540 kgm 1190 lb	80 km/h 50 mph	20°	40 cm 16 in.	46 cm 18 in.
1220 kgm 2680 lb	97 km/h 60 mph	20°	90 cm 35 in.	79 cm 31 in.
2630 kgm 5790 lb	66 km/h 41 mph	20°	90 cm 35 in.	73 cm 33 in.
3500 kgm 7700 lb	72 km/h 45 mph	20°	140 cm 55 in.	162 cm 64 in.

0.5 msec before a passenger car would start to exit from the barrier before numerical instability disrupted computations. The computer time required was 500 cpu seconds. For heavier buses the interval had to be reduced to 0.1 msec, and the computer time was 800 cpu seconds. GUARD proved to be a very expensive computer model to run. The GUARD results were considered valid if the vehicle's lateral velocity was reduced to zero and movement started in the opposite direction (as soon as the vehicle started to exit from the barrier) before numerical instability set in and stopped the computations. This problem eliminated the possibility of comparing exit angles and exit velocities in most cases. Even with these difficulties GUARD was producing reasonable results considering the limitations previously described.

Simulation Matrix for the Thrie-T Barrier (TTB)

The TTB was developed by considering the following matrix of variables:

1. Two post sizes
   a. S3 x 5.7
   b. W6 x 8.5
2. Two thrie beam rails
   a. 12 ga
   b. 10 ga
3. The longitudinal distance between spacers was varied from 4 ft to 8 ft in 1 ft increments (1.2 m and 2.4 m in 0.3 m increments).
4. Two post spacings were used -- posts on alternative spacers and posts on each spacer.
5. Three vertical rail angles
   a. vertical
   b. bottom of the rail sloped 6° toward the post
   c. bottom of the rail sloped 15° toward the post

6. Two back-to-back rail spacings
    a. 18 in. (457 mm)
    b. 30 in. (762 mm)
7. Two rail heights of
    a. 2 ft-2 in. to centroid (for a 36 in. high top rail edge) (0.66 m (for a 0.91 m high top rail edge))
    b. 1 ft-11 in. to centroid (for a 33 in. high top rail edge) (0.59 m (for a 0.81 m high top rail edge))
8. Three vehicles
    a. 2500 lb car (1020 kgm)
    b. 4500 lb car (2040 kgm)
    c. 40,000 lb bus (18,160 kgm)

All simulations were at 60 mph (97 kph) and 15°.

A summary of the GUARD computer simulation results is presented in Table 7.

Post Size

Two post sizes were investigated. The S3 x 5.7 post and the W6 x 8.5 were used with the 10 ga rail, a 1 ft 11 in. (0.59 m) centerline mounting height and a 30 in. (762 mm) back-to-back rail spacing. For post spacings of 4 ft (1.2 m), 5 ft (1.5 m), and 6 ft (1.8 m), it can be seen from Table 7 that the maximum lateral deflection of the rail is almost identical with either post size. The minimum rail deflection was 9 in. with the 2250 lb (1020 kgm) vehicle and the maximum rail deflection was 73 in. (1854 mm) with the 40,000 lb (18,140 kgm) vehicle, each post size giving the same deflection. Therefore the smaller S3 x 5.7 post was thus selected for use in the other cases investigated.

TABLE 7. SUMMARY OF GUARD VEHICLE IMPACT RESULTS
WITH THE THRIE-T BARRIER.

(All vehicle impacts were at 60 mph (97 kph) and 15° angle.)

Rail Height 1 ft-11 in. to Centerline, Rail Spacing 30 in. Back-to-Back, Rail Slope 6° to Vertical. Post at each Spacer.

			DISTANCE BETWEEN SPACERS														
			4 ft			5 ft			6 ft			7 ft			8 ft		
RAIL SIZE	VEHICLE WEIGHT lb	POST TYPE	Max. Defl. in.	Max. Roll)°	G_{Avg}*	Max. Defl. in.	Max. Roll)°	G_{Avg}*	Max. Defl. in.	Max. Roll)°	G_{Avg}*	Max. Defl. in.	Max. Roll)°	G_{avg}*	Max. Defl. in.	Max. Roll)°	G_{Avg}*
12 Ga	2250	S3 x 5.7	10	1.1	5.9	11	1.6	5.4	14	0.5	4.1						
	4500	S3 x 5.7	14	1.9	4.2	16	1.6	3.5	21	1.5	2.8						
	40,000	S3 x 5.7	68	52	1.1	76	45	1.0	90	40	1.0	98	30	0.8	111	25	0.7
10 Ga	2250	S3 x 5.7	9	1.1	6.1	11	0.9	5.0	13	0.7	4.2	18	0.5	4.0	26	0.5	3.9
		W6 x 8.5	9	1.1	6.1	11	0.9	5.0	13	0.6	4.2						
	4500	S3 x 5.7	13	2.5	4.2	15	2.1	3.7	19	2.0	2.8	25	1.5	2.7	31	1.0	2.7
		W6 x 8.5	12	2.5	4.2	16	2.1	3.8	19	2.0	2.9						
	40,000	S3 x 5.7	65	53	1.3	68	51	1.2	73	53	1.0	79	40	0.9	102	31	0.9
		W6 x 8.5	65	53	1.3	69	51	1.3	73	53	1.0						

Rail Height 1 ft-11 in. to Centerline, Rail Spacing 30 in. Back-to-Back, Rail Slope 6° to Vertical, Post at Alternate Spacers.

RAIL SIZE	VEHICLE WEIGHT lb	POST TYPE	4 ft Max. Defl. in.	4 ft Max. Roll)°	4 ft G_{Avg}*	5 ft Max. Defl. in.	5 ft Max. Roll)°	5 ft G_{Avg}*	6 ft Max. Defl. in.	6 ft Max. Roll)°	6 ft G_{Avg}*
10 Ga	2250	S3 x 5.7	13	1.2	4.2	26	1.2	3.7			
	4500	S3 x 5.7	19	0.7	2	36	0.5	2.3			
	40,000	S3 x 5.7	76	42	1.0	102	31	1.0			

Rail Height 1 ft-11 in. to Centerline, Rail Spacing 30 in. Back-to-Back, Rail Slope Vertical, Post at each Spacer.

RAIL SIZE	VEHICLE WEIGHT lb	POST TYPE	4 ft Max. Defl. in.	4 ft Max. Roll)°	4 ft G_{Avg}*	5 ft Max. Defl. in.	5 ft Max. Roll)°	5 ft G_{Avg}*	6 ft Max. Defl. in.	6 ft Max. Roll)°	6 ft G_{Avg}*
10 Ga	2250	S3 x 5.7							13	22.3	4.2
	4500	S3 x 5.7							19	12.5	2.8
	40,000	S3 x 5.7							73	53	1.0

Rail Height 1 ft-11 in. to Centerline, Rail Spacing 30 in. Back-to-Back, Rail Slope 15° to Vertical, Post at each Spacer.

RAIL SIZE	VEHICLE WEIGHT lb	POST TYPE	4 ft Max. Defl. in.	4 ft Max. Roll)°	4 ft G_{Avg}*	5 ft Max. Defl. in.	5 ft Max. Roll)°	5 ft G_{Avg}*	6 ft Max. Defl. in.	6 ft Max. Roll)°	6 ft G_{Avg}*
10 Ga	2250	S3 x 5.7							13	0.7	4.1
	4500	S3 x 5.7							19	2.0	2.8
	40,000	S3 x 5.7							73	53	1.1

Rail Height 2 ft-2 in. to Centerline, Rail Spacing 30 in. Back-to-Back, Rail Slope 6° to Vertical, Post at each Spacer.

RAIL SIZE	VEHICLE WEIGHT lb	POST TYPE	4 ft Max. Defl. in.	4 ft Max. Roll)°	4 ft G_{Avg}*	5 ft Max. Defl. in.	5 ft Max. Roll)°	5 ft G_{Avg}*	6 ft Max. Defl. in.	6 ft Max. Roll)°	6 ft G_{Avg}*
10 Ga	2250	S3 x 5.7							12	0.5	4.2
	4500	S3 x 5.7							19	1.8	2.8
	40,000	S3 x 5.7							73	46	1.0

Rail Height 1 ft-11 in. to Centerline, Rail Spacing 18 in. Back-to-Back, Rail Slope 6° to Vertical, Post at each Spacer.

RAIL SIZE	VEHICLE WEIGHT lb	POST TYPE	4 ft Max. Defl. in.	4 ft Max. Roll)°	4 ft G_{Avg}*	5 ft Max. Defl. in.	5 ft Max. Roll)°	5 ft G_{Avg}*	6 ft Max. Defl. in.	6 ft Max. Roll)°	6 ft G_{Avg}*
10 Ga	2250	S3 x 5.7	11	1.0	6.0	11	1.2	5.3	15	1.0	4.0
	4500	S3 x 5.7	15	0.8	3.2	18	0.7	2.9	27	0.7	2.0
	40,000	S3 x 5.7	22	50*	1.0	86	63*	0.9	101	83*	0.9

*Vehicle still rolling when program stopped.
Multiply lb x 0.454 to obtain kgm
Multiply in x 25.4 to obtain mm
Multiply ft x 0.3048 to obtain m

Rail Size

The 12 ga and 10 ga thrie beam rail sizes were investigated with the 1 ft 11 in. (0.59 m) centerline height and 30 in. (762 mm) back-to-back spacing. The S3 x 5.7 post with 4 ft, 5 ft, and 6 ft (1.2 m, 1.5 m, and 1.8 m) spacing was used. It can be seen from data in Table 7 that for passenger car impacts (2250 lb and 4500 lb) (1020 kgm and 2040 kgm) little difference in the maximum lateral rail deflection was observed. For example the maximum rail deflection changed from 21 in. (533 mm) to 19 in. (482 mm) when going from the 12 ga rail to the heavier 10 ga rail with 6 ft (1.8 m) post spacing.

For the case of the heavy 40,000 lb (18,140 kgm) vehicle impact with posts spaced at the usual 6 ft (1.8 m) center, the maximum lateral rail deflection was reduced from 90 in. (2286 mm) to 73 in. (1854 mm) by using the heavier 10 ga rail. This amounts to approximately a 20% reduction in rail deflection. Consequently the 10 ga rail was selected for use in the other case studies.

Spacer and Post Location

Guardrail W beams and the thrie beams are normally fabricated in 25 ft (7.62 m) lengths in this country. Consequently, post or spacer locations are usually located at distances of 12.5 ft (3.8 m), 8.33 ft (2.54 m), 6.25 ft (1.91 m), 5 ft (1.52 m), or 4.17 ft (1.27 m). In the early development of the SWOV and NEHER barriers, a post was usually located at each spacer location. In later versions of these barriers the posts have been located at alternate or every other spacer location.

In the Guard computer simulations shown in Table 7 posts were located at each spacer and at alternate spacers. With the large distance between spacers (8 ft (2.44 m) or more) and the post located at alternate spacers the maximum barrier displacement becomes quite large, 102 in. (260 cm) or more when impacted by the 40,000 lb (18,144 kg) vehicle. Consequently, it is recommended that posts be placed at each spacer when trying to redirect heavy trucks and buses. Also from Table 7 it can be seen that at the usual 6 ft 3 in. (1.91 m) post spacing, the maximum barrier deflection is about 73 in. (1854 mm) when impacted by the 40,000 lb (18,144 kg) vehicle. This appears reasonable so the 6 ft 3 in. (1.91 m) post spacing seems adequate.

It is recommended that the post be installed by driving into natural soil approximately 40 in. (1016 mm). The Europeans use an IPE 100 post which has a strong axis section modulus approximately 50% greater than the S3 x 5.7 while the weak axis section modulus of the S3 x 5.7 is about 20% greater than the IPE 100. These values appear to be sufficiently close so that the barrier reactions will not be materially affected. The S3 x 5.7 is strong enough to allow the 3/8 in. (9.5 mm) bolts at the spacer to shear and weak enough to bend out of the way when run over by an automobile or bus.

Spacer. The spacer recommended is fabricated from a length of a standard M14 x 17.2 shape. (See the detail on Figure 10.) The web has been cut back and a tab welded or bent to hold the railing at a 6° angle with the vertical. The flanges extend beyond this tab into the top and bottom corrugations to stabilize the thrie beam against rotation (Figure 10) and to transfer the lateral load component due to vehicle impact to the spacers. The top lip has been made rigid while the bottom lip was reduced in thickness so that it will bend or buckle as the barrier rotates thereby allowing the impacted rail to remain more vertical while in contact with the vehicle (Figure 10).

Eight inch deep spacers such as the NEHER spacer or one fabricated from an M8 x 6.5 section were considered. The concept, shown in Figure 11, was to allow the lower corrugation to bend down and protect the spacers from the vehicle wheels. The idea stemmed from a previous TTI test in which several spacers were snagged by the vehicle and were torn out during impact. An impact would first rotate and twist the barrier as shown in Figure 11. Under severe impacts the barrier would be twisted as shown in Figure 11 with the spacers and beams attaining a nearly vertical position. The top rail would be deformed around the edge of the spacer and reduce the space for wheel penetration and contact with the spacer and reduce the possibility of the wheel snagging on the spacers. It appears that the lower rail in Figure 11 would act as a track forcing the wheel to the spacers. If the spacer held, then the force of the vehicle against the top rail could cause the barrier to rotate past center (more than 90^o). The shallow spacer concept was abandoned in favor of modifications which would stiffen the barrier and be more likely to keep the barrier from rotating to the vertical position.

Rail Element Angle with the Vertical

The rail element on the European barriers has a 6^o sloped with the vertical (see Figure 8). According to the literature and films of crash tests, they studied two conditions: vertical and a 6^o slope. The slope was such that the impacting vehicle contacted the top corrugation on impact then as the barrier deflected and rotated away from the vehicle the lower corrugation contacted the vehicle, rotating upward causing that side of the vehicle to raise and roll away from the barrier. Crash

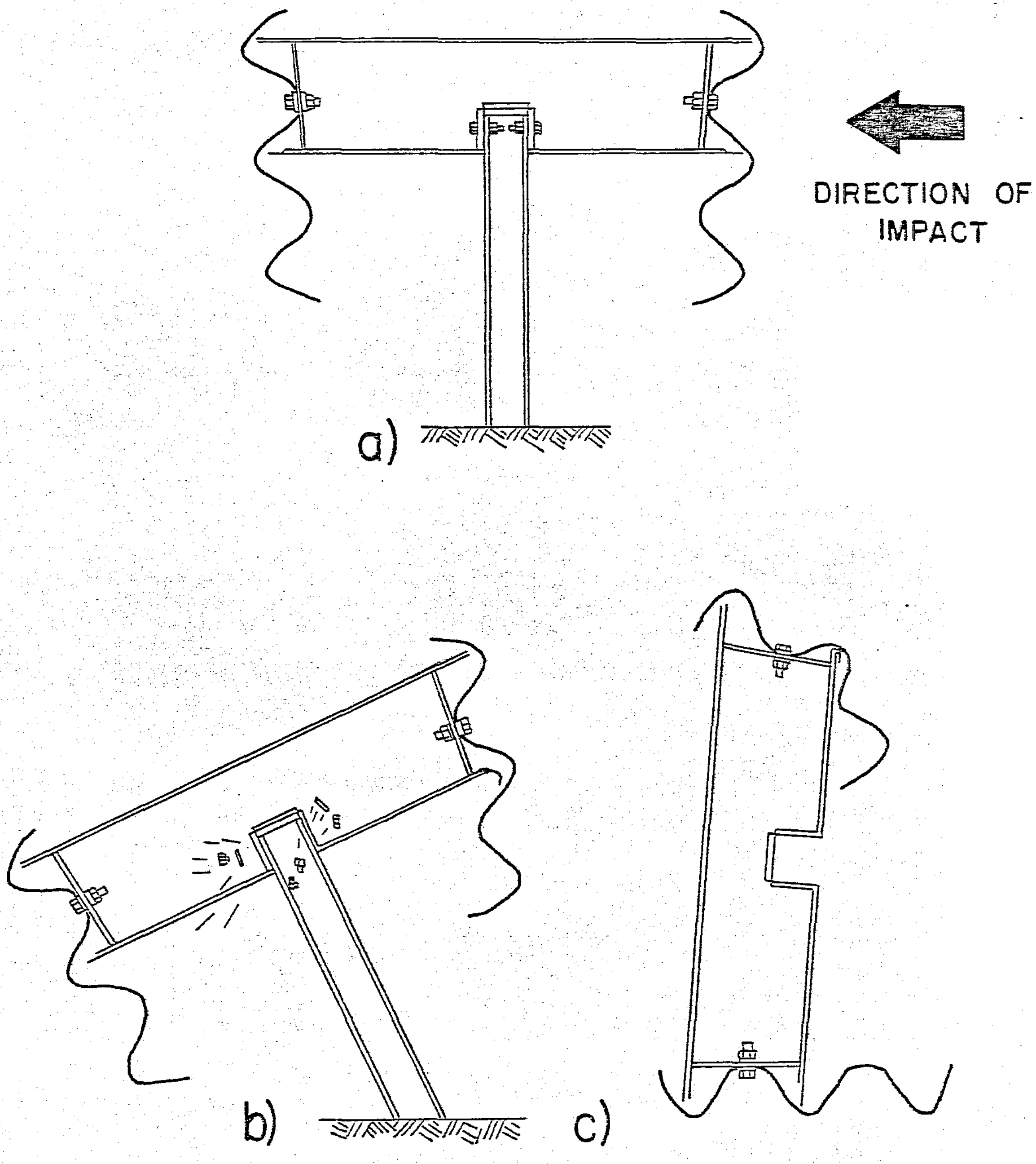


Figure 11. 8 in. (203mm) Spacer With Thrie Beam.

test results have confirmed this behavior. Three different rail slopes were investigated using the GUARD simulation: vertical, the bottom sloping 6^o toward the post and the bottom sloping 15^o toward the post. According to the simulation results shown in Table 7, a 2250 lb (1020 kgm) vehicle will roll 22.3^o toward the barrier if the rail is vertical and 0.7^o if the rail element is sloped 6^o or 15^o toward the post. This is a very dramatic reduction in the vehicle roll angle. A similar reduction is predicted for the 4500 lb (2040 kgm) vehicle. The roll angle of 12.5^o for the vertical rail was reduced to 2^o for the 6^o and 15^o slopes. There was no reduction in roll angle for the bus. In view of these results, the 6^o slope was chosen.

Barrier Width

The out-to-out barrier width for the median barrier was selected as 38 in. (0.97 m). This width is consistent with the ratios used with the NEHER system. Also, this provides approximately a 30 in. (762 mm) back-to-back spacing at the vertical center of the rail element. Since there is usually a critical space restriction for roadside median barriers, an 18 in. (457 mm) space was also investigated. The simulation data in Table 7 indicates that the bus would roll over the narrow 18 in. (457 mm) back-to-back barrier. An out-to-out width of 38 in. (965 mm) or 30 in. (762 mm) back-to-back was thus selected.

Rail Height

There were minor differences between the acceleration levels and roll angles for the 33 in. (838 mm) and 36 in. (914 mm) high barriers for automobiles. The 36 in. (914 mm) rail did reduce the bus roll angle from 53^o to 46^o for the case of 6 ft (1.83 m) spacer distance.

The rail height selected for the TTB barrier is 36 in. (0.91 m) to the top of the rail in order to minimize potential vehicle rollover. This is 6.5 in. (165 m) higher than the NEHER or SWOV barriers and 9 in. (230 mm) higher than AASHTO barriers G4 and MB4. The bottom of the thrie beam is 16 in. (400 mm) above the ground or 1-1/2 in. (38 mm) lower than the NEHER or SWOV barriers but 3 in. (76 mm) higher than the AASHTO barriers. According to Bloom, et al., (14), an impacting bus or truck at 60 mph (97 km/h) and 15^o should not roll over. The potential bus-truck rollover-vaulting ratio for the 36 in. (914 mm) height barrier is less than 0.6 for a 45,000 lb (20,650 kgm) truck, c.g. 55 in. (1400 mm), impacting a flexible barrier at 60 mph (97 km/h) and 15^o. A ratio of less than 1 is supposed to indicate that the vehicle will not roll over.

Simulation of Final Design

The final Thrie T Barrier design was verified by simulating impacts with a (1) 1650 lb (750 kgm) car; (2) 2250 lb (1020 kgm) car; (3) 4500 lb (2040 kgm) car; (4) 20,000 lb (9080 kgm) bus; and (5) 40,000 lb (18,160 kgm) bus. The results of these simulations are presented in Table 8.

The Thrie-T Barrier acceleration values are just slightly greater than the NEHER values, and the maximum roll angles are less than 2^o for all automobiles. The 50 msec acceleration values are predicted to be less than the maximum recommended by Circular 191 (3). The 73 in. (1.85 m) maximum deflection does not accurately reflect the encroachment of the barrier into the opposing traffic lane of a median. The angle of twist of

TABLE 8. SIMULATION RESULTS OF NEHER AND THRIE T BARRIERS

Vehicle Weight lb	C.G. Height in.	Wheel Track	NEHER BARRIER			THRIE T BARRIER		
			Max. Roll Angle degrees	Lateral G avg.	Rail Deflection in.	Max. Roll Angle degrees	Lateral G avg.	Rail Deflection in.
1650	19	4'-0"	1.7	2.3	14	1.2	3.5	11
2250	20	4'-6"	0.6	3.8	19	0.7	4.2	12
4500	21	5'-0"	0.8	2.1	28	1.9	2.4	18
20,000	38	7'-6"				28	2.1	57
40,000	63	7'-6"				53	1.0	73

Average G's taken over 50 msec.

All simulations at 60 mph (97 km/h) and 15^{0}.

Multiply lb x 0.454 to obtain kgm
in. x 25.4 to obtain mm

the spacer-rail system reduces the deflection of the offside of the rail to about 50 in. (1.27 m).

Diagonal Braces. In the final design, diagonal braces have been included between the transverse spacers in order to stiffen the barrier and reduce its lateral displacement and rotation during heavy vehicle impact. Previous crash tests have shown that if the barrier displaces and rotates 90° or more it has little chance of redirecting a heavy bus or truck. These diagonals have been sized as 1 in. (25 mm) diameter rods of 60 ksi (415 MPa) yield steel in order to match the shear strength of the two 5/8 in. (15.9 mm) A490 bolts (40 kips) (180 N).

Design Details

Connection details of the barrier are as important as the basic size of the major components. Particular attention is directed to the spacer design, the rail-to-spacer connection, and the spacer-to-post connection. The design details are shown on Figures 12 and 13.

Spacer Design. The upper lip of the spacer (Figure 13) should be stiff to allow the rail to start to pivot. The lower lip of the spacer is designed to bend or buckle out of the way as is shown. Depending on the energy imparted to the rail, the rail may continue to rotate until the offside rail contacts the ground and the impacted rail is raised up.

Rail-to-Spacer Connection. The TTI crash test (15) on the anglicized NEHER barrier has been carefully analyzed. It was found that the bolts attaching the rail to the spacer pulled through the slotted hole on the W beam rail at and downstream from the point of impact. The next 10 spacers downstream of the impact point were snagged with the vehicle wheel and knocked out of the barrier. The bolt heads pulled out of the slotted holes in the rail. To minimize the chance of the spacers being knocked out, standard AASHTO-ARBA rectangular washers are used with the 5/8 in. (15.9 mm) bolts.

The use of two 5/8 in. (15.9 mm) high strength A490 bolts is recommended for attaching the thrie beam rail to the spacers. This will stiffen the barrier, making the two back-to-back thrie beams act more a composite beam. These two high strength bolts will develop an ultimate shear load of about 40 kips or 20 kips (180 kN or 90 kN). For the two thrie beams to act completely as a composite beam, a shear capacity of about 75 kips (333 kN) is required. It is recognized that the two high strength bolts used will develop only one-half the full beam capacity.

Post-to-Spacer Connection. The post-to-spacer connection consists of a shallow 3 in. (76 mm) pocket with two 3/8 in. (9.53 mm) bolts (ASTM A307). The mild steel bolts will shear after the barrier has rotated approximately 20° and the post and spacer will separate.

Summary

The SWOV and NEHER barriers have redirected 30,000 lb (13,620 kgm) trucks or buses at speeds of about 42 mph (68 km/h) and impact angles of about 20°. These vehicles had a total kinetic energy of about 1.7 million ft-lb (2.3 mN-m) and a lateral component of kinetic energy of 200 ft-kips (270 kMN). The maximum lateral deflection of the barrier was about 83 in. (2.1 m).

A 40,000 lb (18,160 kgm) bus at 60 mph (97 kph) and impacting at 15^0 has a total kinetic energy of about 4.8 million ft-lb (5.6 mN-m) and a lateral component of kinetic energy of about 322 ft-kips (436 kNM). The lateral component of kinetic energy is thus about 60% greater than that used in any European tests.

To handle this 60% plus increase in impact severity, we have strengthened the Thrie T Barrier as follows:

1. POST - twice as many but only 2/3 as strong, yielding a net increase in post strength of 33%.
2. BEAM - 10 ga thrie beam has cross-sectional area of 3.93 in.^{2} (2.53×10^{-3} m^2) to 1.99 in.^{2} (1.28×10^{-3} m^2) for 12 ga W beam, a net increase of about 100% in tensile and bending strength.
3. SPACER - about twice as strong.
4. BEAM-TO-SPACER CONNECTION - used two high strength 5/8 in. (15.9 mm) diameter A490 bolts instead of one; increased strength more than 100%.
5. SPACER-TO-POST CONNECTION - used two 3/8 in. (9.53 mm) diameter A307 bolts which increased strength by about 100%.
6. DIAGONAL BRACING - have used crossed tension bracing in every span instead of single tension; compression diagonal in every third span. It is hoped to reduce the 83 in. (2.1 m) maximum lateral barrier deflection obtained in Europe by a significant amount.

The end anchors detailed on sheet 1 of 2 (Figure 12) are extremely important for proper behavior of this barrier. These anchors have been designed to develop the tensile strength of the thrie beams and to simulate a continuous rail. The S3 x 5.7 is very weak about the weak axis, and a large number of posts (or considerable length of barrier) would have to be installed up and downstream from the impact point to properly anchor the rail otherwise. For field installation, a similar end anchor would have to be used at the rail ends. The end treatment could be a BCT, turned down rail, or other safe treatment.

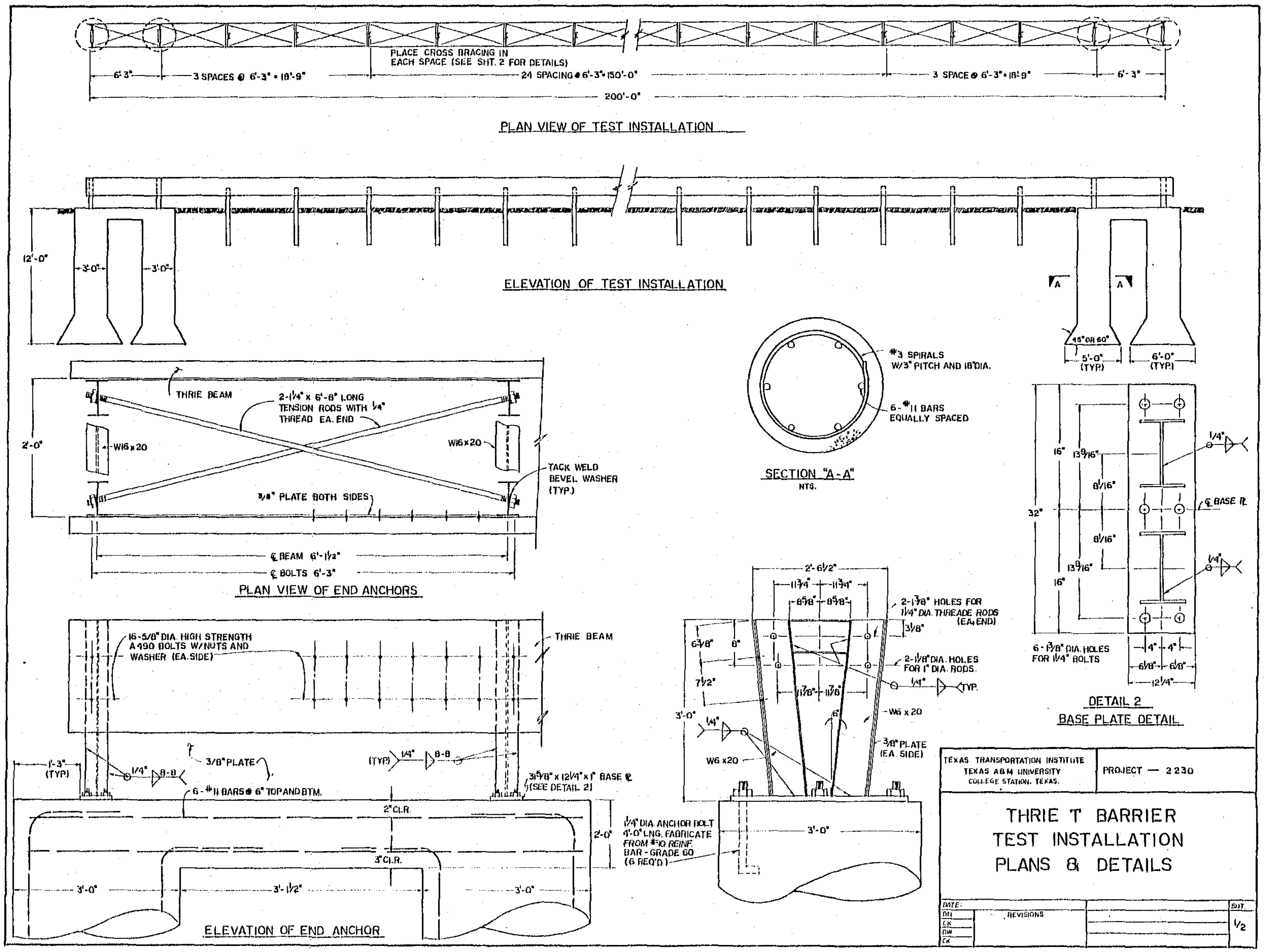


FIGURE 12. THRIE-T BARRIER TEST INSTALLATION PLANS & DETAILS.

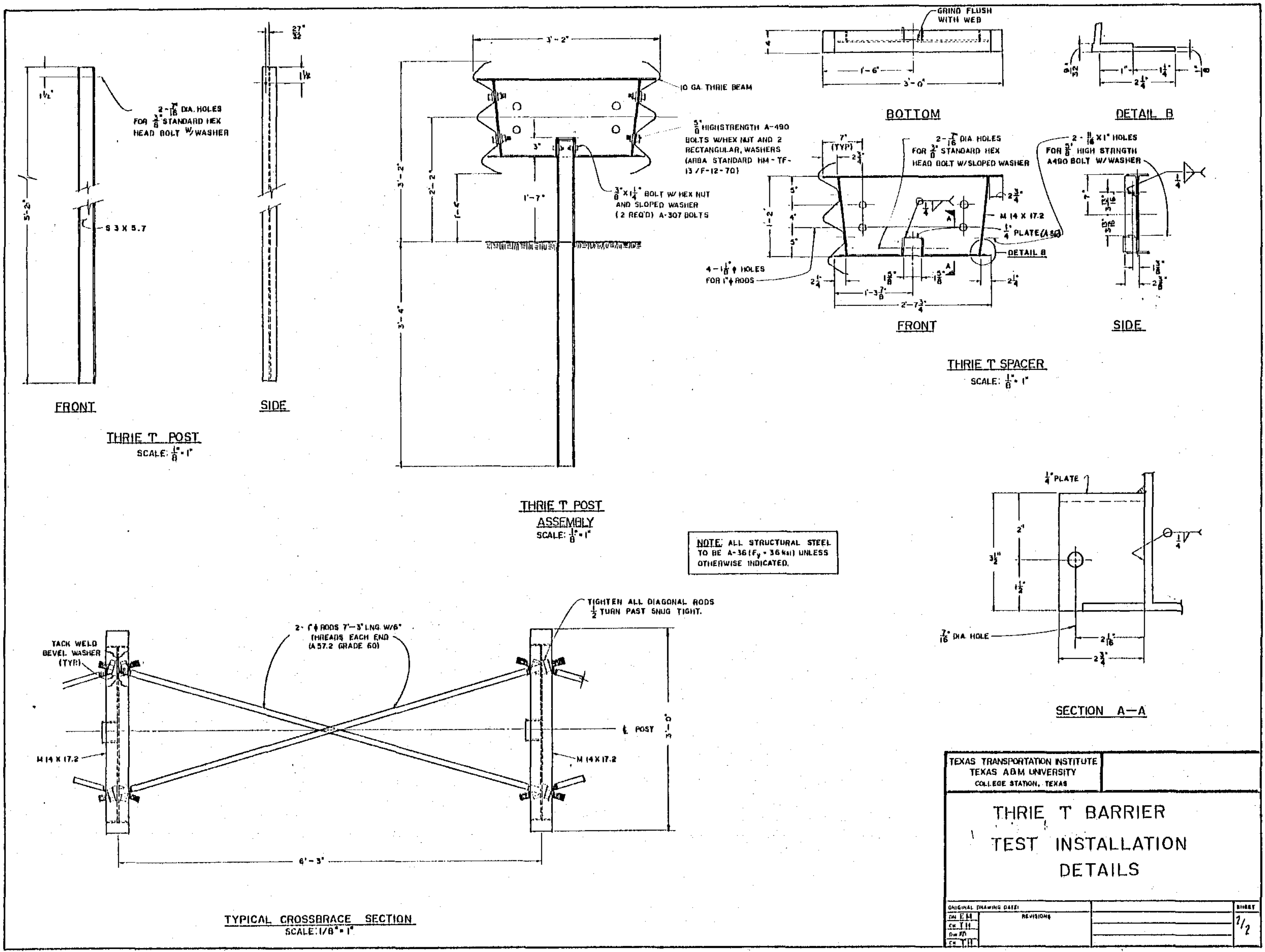


FIGURE 13. THRIE-T BARRIER TEST INSTALLATION DETAILS.
Multiply in. x 25.4 to obtain mm. Multiply ft x 0.3048 to obtain m

IV. CONCLUSIONS AND RECOMMENDATIONS

Concrete Barrier with Blocked Out W Rail

The results of the studies on concrete barriers described herein indicate that the impact severity of passenger cars with a concrete barrier can be reduced if a W rail is added to the barrier and blocked out with a suitable energy absorbing material. This is true for the maximum impact conditions of the CMB(NJ) and for all conditions of a vertical concrete wall type rail. When a blocked out rail is added to the CMB, accelerations appear to be reduced by 12% and roll angles reduced up to a maximum of 12^{o}. When the blocked W rail is added to a vertical concrete wall the predicted accelerations for passenger vehicles are all less than 6 g, including a 1650 lb (750 kgm) automobile. Roll angles are extremely small.

The reduction in roll angles and acceleration levels are significant since vehicles of the subcompact size and smaller have rolled over when impacting the CMB under test conditions. At 60 mph (97 km/h) and 15^{o}, accident reports (2) show that there have been rollovers on the highways as well. Smaller cars are becoming more popular with concern about the dwindling energy supply. With the increase in small cars there undoubtedly will be an increase in small car impacts with current CMB installations. There may also be an increase in severe accidents including rollover at critical locations. If this develops, a blocked out rail retrofit to existing CMB's may be an effective solution. The blocked out rail can be retrofitted to most CMB installations quite readily.

The vertical concrete wall barrier with a blocked out rail should be more economical to construct than the conventional CMB with or without a blocked out rail for new construction. The GUARD computer simulations have indicated the vertical concrete wall with energy absorbing blockouts will reduce impact severity when compared to the conventional CMB.

The material for the rail is a standard 12 ga W rail in standard use and stockpiled in many district and division yards of local and state transportation agencies.

The material for the recommended blockout is a rebonded neoprene. The bonding medium may deteriorate in sunlight, and therefore a thick (10 mil) coating of ultraviolet reflecting material such as hypalon is recommended. When the rebonded neoprene is coated and properly installed it should last for many years even when the rail it supports is impacted and deflected frequently and the blockout is deformed. The composite material has a very low coefficient of restitution and should not cause a vehicle to rebound into traffic. The material is a surplus item generated in the manufacture of petroleum products.

There is one significant disadvantage to modifying existing CMB's or using the vertical faced barrier in lieu of the CMB. The superficial sheet metal damage to cars that occurs in shallow angle or low energy impacts will be increased by contact with the W rail. There are instances in which a vehicle has contacted a CMB, left tire marks on the face of it and driven off without reporting the incident to authorities. By counting the tire marks on such barriers it could be concluded that many of these incidents occurred in which the impacting vehicle suffered little to no sheet metal damage.

The cost of an installation would include the cost of the concrete barrier and the following items:

$10.00 each for the blockouts	>	$2.16 per ft (0.305 m) at 6.25 ft (1.91 m) spacing
$ 3.50 each for the attaching system		
$ 3.00 per ft of W beam		

The cost for a concrete median barrier is approximately $20 per ft (0.305 m). The addition of a rail to each side will cost approximately $10 per ft (0.305 m) for the materials and $10 per ft (0.305 m) for installation, making the total cost approximately $40 per ft ($131 per m) of barrier. This appears to be a reasonable cost for a high performance barrier.

Thrie-T Barrier

The studies made on the Thrie T Barrier indicate that the barrier as designed and detailed will perform within the criteria recommended in Circular 191 (3). The maximum lateral acceleration predicted for a subcompact automobile was 4.2 g or less than the 5 g recommended value. The maximum rail deflection for a 40,000 lb intercity bus was 73 in. (1.85 m) when impacted at 60 mph (97 km/h) and 15°. This appears to be a reasonable value. The barrier as designed contains tension diagonals between each post and spacer to stiffen the barrier and provide truss action.

The weight of the post and diagonal materials per ft (0.305 m) of barrier by item are:

Spacers	8.25 lb	(3.75 kgm)
Posts	4.75 lb	(2.15 kgm)
Diagonals	7.50 lb	(3.40 kgm)
Total	20.5 lb	(9.30 kgm)

If the fabricated costs are conservatively estimated at $1 per lb (per 0.45 kgm) and the cost of two rails is estimated at $9 per ft (0.305 m), then the material cost of the barrier system would be less than $30 per ft ($98 per m). Installation costs are estimated at $20 per ft ($66 per m) for a total of $50 per ft ($164 per m). This appears to be a reasonable cost per ft (0.305 m) for a high performance barrier.

REFERENCES

1. U.S. Dept. of Transportation, Federal Highway Administration Notice EN-20, "Concrete Median Barriers and Parapets", March 1971.

2. Bronstad, M. E., Calcote, L. R., Kimball, C. E. Jr., "Concrete Median Barrier Research - Volume 2 Research Report", SwRI, FHWA-RD-77-4, March 1976.

3. Transportation Research Board, National Academy of Sciences, "Transportation Research Ciruclar No. 191", February 1978.

4. Correspondence from the Road Research Laboratory of England, July & August 1977.

5. Young, Ronald D., Post, Edward R., and Ross, Hayes E. Jr., "Simulation of Vehicle Impact with Texas Concrete Median Barrier: Test Comparisons and Parameter Study", Highway Research Record No. 460, pp. 61-72, 1973.

6. Kimball, C. E., Bronstad, M. E., Michie, J. D., Wentworth, J. A., and Viner, J. G., "Development of a Collapsing Ring Bridge Railing System", Report No. FHWA-RD-76-39, January 1976.

7. Bruce, Robert W., Hahn, Edward E., "Guardrail/Vehicle Dynamic Interaction", IIT Research Institute, IITRI Project J6346, Contract DOT-FH-11-8520, March 1976.

8. "A guide to Standardized Highway Barrier Rail Hardware", ARBA Technical Bulletin No. 268, May 1971.

9. Paar, H. G., "Crash Barrier Research and Applications in the Netherlands", Highway Research Record No. 460, pp. 40-48, 1973.

10. Giavotto, V., "Mathematical Model for Impact Tests on Crash Barriers", Highway Research Record No. 460, pp. 49-60, 1973.

11. Bohringer, A., Rosehmann, R., and Domban, M., "Anfahrversiche an Leitplanken", Innenministeriam Bedm-Württemberg, Stuttgart, 1969.

12. Tösswein K., "Anfahrversuche an Schutzleiplanken Mit Sigma-Pfosten", Herausgegeben von der Tludiengesellscheft für Slchllerplanken e.V, 1977.

13. Bronstad, M. E., Michie, J. D., Viner, J. G., and Behm, N. E., "Crash Test Evaluation of Thrie Beam Traffic Barriers", Transportation Research Record No. 488, pp. 34-44, 1974.

14. Bloom, J. A., Rudd, T. J., and Labra, J. J., "Establishment of Interim Guidelines for Bridge Rails Required to Contain Heavy Vehicles", Report No. FHWA-RD-75-45, Volume I, Statement of Criteria, November 1974.

15. Buth, C. E. et al., Unpublished data on crash tests performed under Contract DOT-FH-11-8509, 1977.

16. Guide for Selecting, Locating, and Designing Traffic Barriers, American Association of State Highway and Transportation Officials, System BRR

APPENDIX A

OTHER CONCEPTS

Two other traffic barrier concepts considered during this project deserve mentioning. These are (1) the dual system and (2) the modified NCHRP concept.

Dual System. The dual system, Figure 14, can be either a roadside barrier or median barrier. The lower rail's function is to redirect automobiles, and the upper rail in conjunction with the lower rail serves to redirect larger trucks and buses. The rail, according to the mathematical modeling, should work very well. It is huge and bulky, and general acceptance by the motoring public is questionable. All modeling for the dual system was done using BARRIER VII.

The lower beam is a standard 12 ga W section and is impacted first by the vehicle. The center of the beam is at 21 in. (533 mm) or approximately at the center of gravity of a passenger car. The energy absorbing blockout used was that as described in the discussion on the concrete barrier with blocked out rail. The impact severity, according to BARRIER VII simulation, is relatively low for passenger cars (see Table 14).

The upper beam is fabricated from two thrie beams on the median barrier, Figure 14. The beams are separated 22 in. (559 mm) as shown so that they act as cable members and a Vierendeel truss combination.

Evaluations of other barriers made by SwRI indicated that a breakaway base or slipbase may improve on the performance of barriers similar to this one. Therefore, in the dual systems proposed here, a slipbase has been incorporated in the design. Breakaway forces of 15 to 60 kips

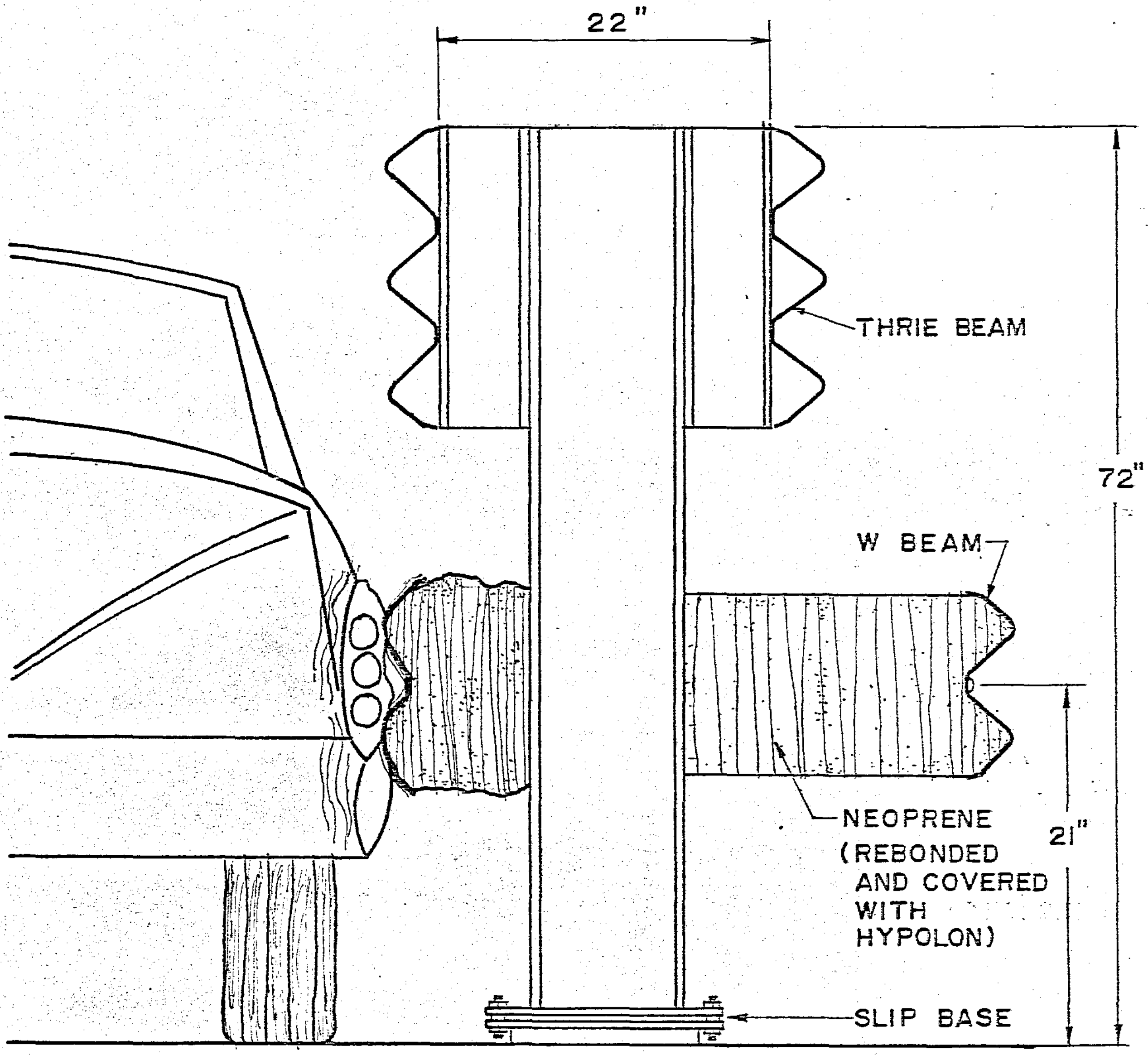


Figure 14. Dual System Impacted By Light Car.

Multiply in. x 25.4 to obtain mm

TABLE 9. SUMMARY OF BARRIER VII SIMULATION RESULTS FOR DUAL SYSTEM BARRIER

Vehicle Weight	Impact Speed (mph)	Impact Angle (degrees)	Rail Deflection (inches)	Passenger Compartment 50 msec (G's)	Peak Tension in Rail (kips)	Remarks
2250	60	15	8.5	5.6	2.3	All barriers
4500	60	15	16.0	4.5	7.5	All barriers
21,400	60	15	21.9	7.9*	36.1	Median barriers
45,200	60	15	46.0	7.1*	51.0	Median barriers
21,400	60	15	37.2	12.9*	80.0	Tubular Thrie beam top
45,200	60	15	63.4	8.2*	110.0	Tubular Thrie beam top

*Typically the lateral deceleration at the rear of the Truck is 6g (50 msec) or 85% of passenger compartment (driver).

Multiply mph x 1.609 to obtain km/h
Multiply in. x 25.4 to obtain mm
Multiply kips x 454 to obtain kgm

(67 kN to 267 kN) have been investigated. A range of 25 to 35 kips (111 kN to 155 kN) is preferable for proper operation of the barrier. This allows the 2250 lb (1020 kgm) vehicle impact at 60 mph (97 kph) and 15° to be redirected without a base activating (according to BARRIER VII). A stiff post is required to allow the base to activate with minimum rotation outward. According to computer simulation, a W10 x 33 appears to be a good selection for the post. The deformation mode of the rail impacted by a truck is shown in Figure 15.

The anhydrous ammonia truck accident in Houston in May 1976 showed the need to contain high center of gravity vehicles on selected routes in urban areas. According to one witness, the truck started to take a sharp curve to the left at a high rate of speed. The rig jackknifed and rolled over the curb-bridge rail combination. The c.g. of the trailer was estimated to be over 78 in. (2 m) high. It is possible that this high dual rail could have contained such a vehicle.

The Modified NCHRP Barrier. The posts for the NCHRP barrier (Figure 16) weighed approximately 100 lb (45.4 kgm) and cost some $200 each for cutting, forming, and heat treating. Several other shapes of posts were studied, and only a 10% savings was quoted by the fabricators for any basic design which would give similar load versus deflection properties to the original design. In addition, there are extra costs involved in shaping the concrete pavement or concrete shoulder at the posts (also Figure 16). This entails a continuous concrete support adjacent to a barrier. This alone would limit its potential use particularly when used as a roadside barrier. Using static load deflection curves

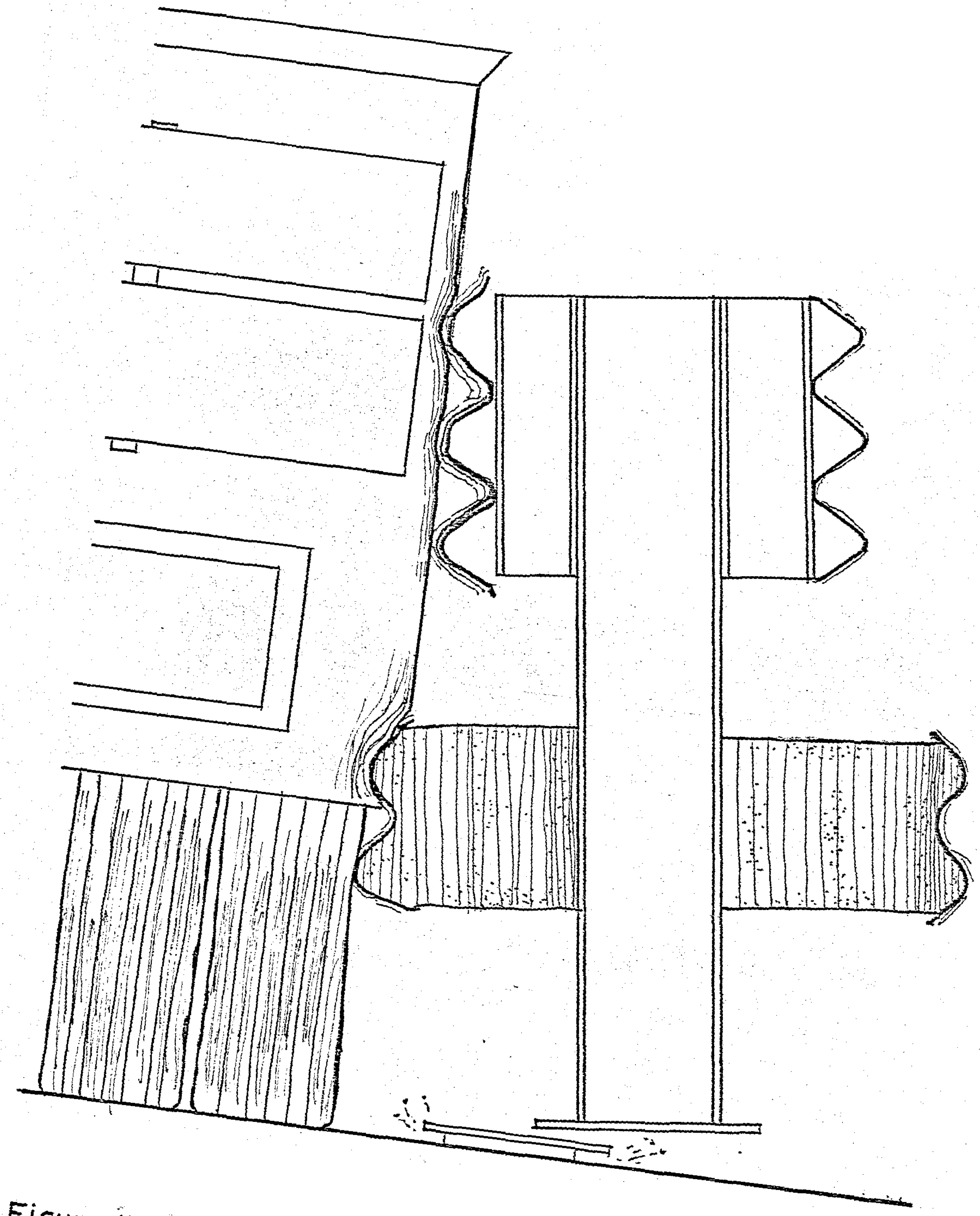


Figure 15. Dual System Impacted By Truck

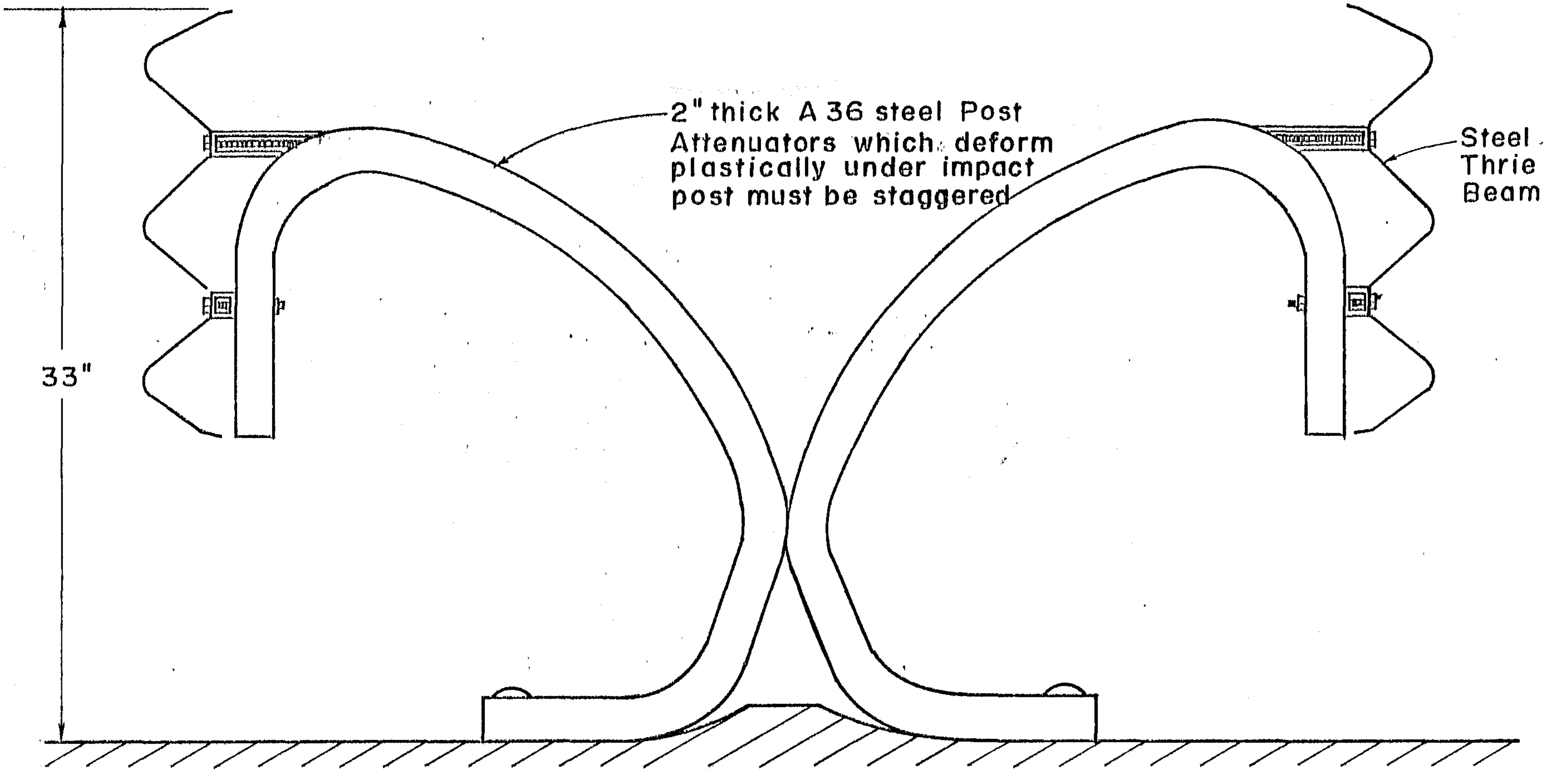


Figure 16. Modified NCHRP [illegible] Multiply in. x 25.4 to obtain mm

developed for these attenuator posts, a 6 ft-3 in. (1.9 m) spacing and a thrie beam rail, it appeared that a high performance barrier could result from this concept.

APPENDIX B

GUARD

General

GUARD is a computer program developed by the Illinois Institute of Technology Research Institute (IITRI) to mathematically model the interaction between an impacting vehicle and a longitudinal traffic barrier. The program was developed as the result of a research project sponsored by FHWA which had as a part of its objectives to (1):

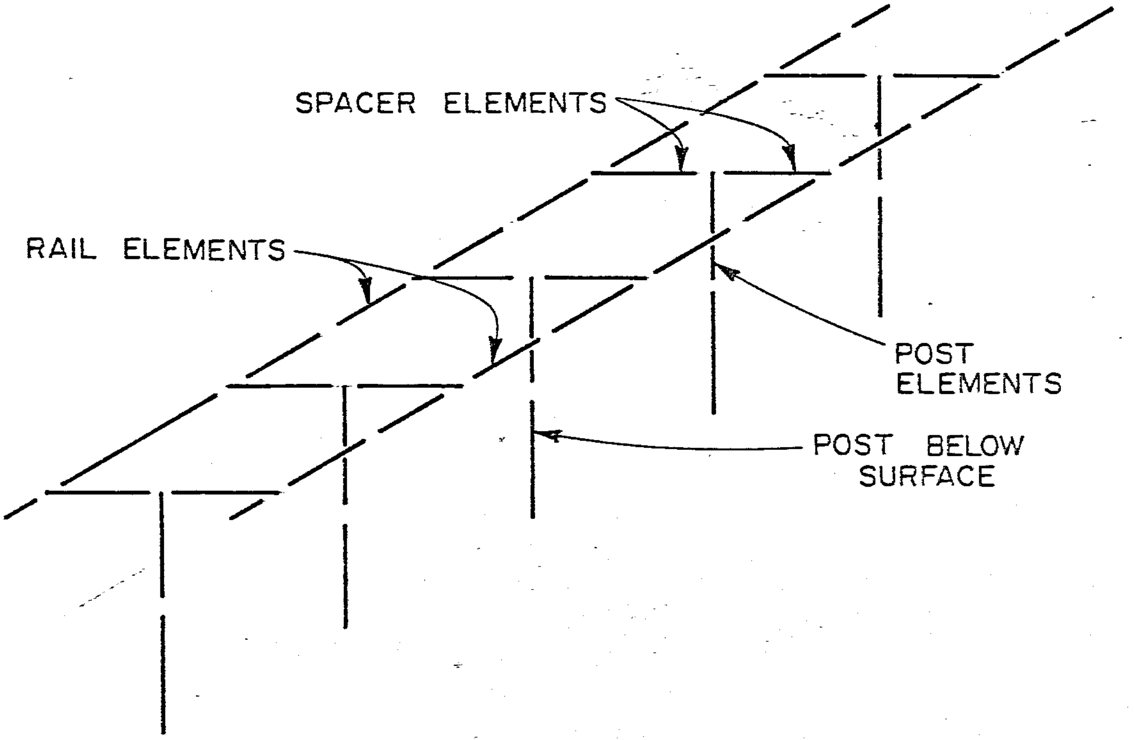
- "develop and implement a generalized simulation model capable of depicting the three-dimensional nonlinear dynamic response of guardrail/median barrier systems
- "develop and implement a three-dimensional vehicle model that accounts for the bumper modifications produced by FMVSS 215 (2) and is capable of three-dimensional interaction with the guardrail/median barrier simulation model ..."

(The reference to Federal Motor Vehicle Safety Standards (FMVSS) 215 (2) is related to that portion of the standards which require front and rear bumper impacts without damage to safety related components.)

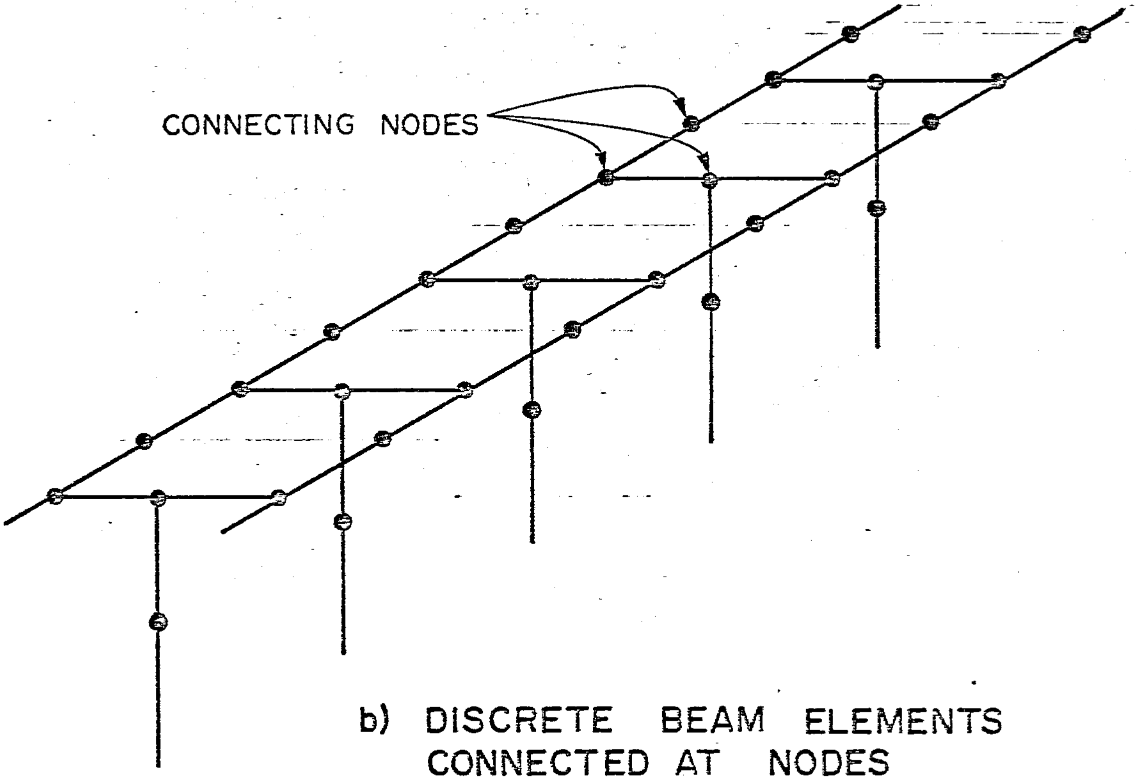
The model as it relates to the barrier systems is divided into three distinct parts: (1) the dynamic frame analysis, (2) the dynamic finite element rail analysis, and (3) the dynamic post-soil interaction analysis.

Frame Analysis

In order to analyze the frame, the barrier is divided into discrete beam elements as shown in Figure 17. There are six degrees of freedom at each end of the element as shown in Figure 18. The elements are



a) DISCRETE BEAM ELEMENTS



b) DISCRETE BEAM ELEMENTS CONNECTED AT NODES

Figure 17.

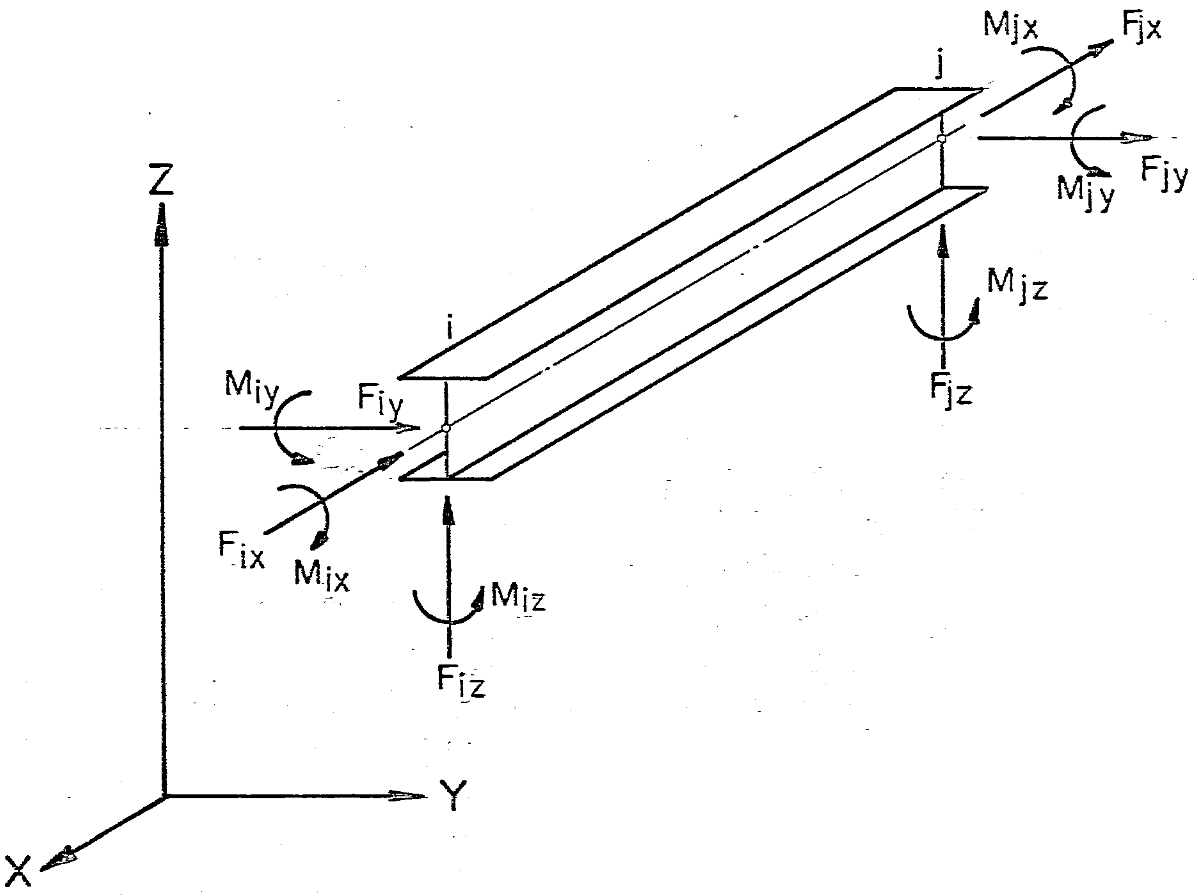
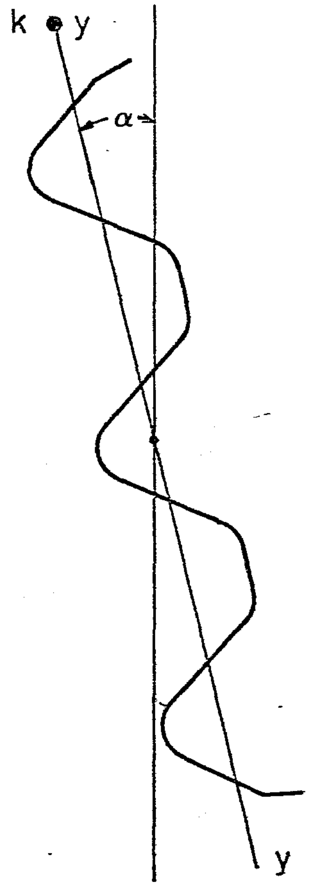


Figure 18. BEAM ELEMENT MEMBER FORCES (POSITIVE).

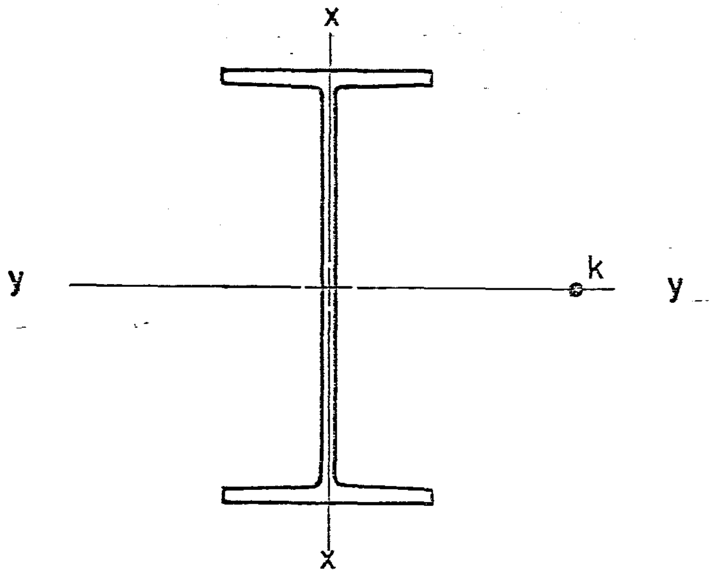
interconnected at nodes as shown in Figure 17. The theory provides for complete compatibility between all elements at the nodes. That is, the slopes of the elements and the deflections of the elements are the same at the intersecting node as long as the stresses in the elements are in the elastic range. The solution is so formulated so that any one or all members may have stresses in the plastic range under certain impact and deflection conditions. When this occurs a plastic hinge will occur at the node.

The nodes are defined by coordinates. Elements are defined by nodes or points at ends i and j. A third node, an axis orientation node (k), is used to define the y axis of the element as designated in the user input data (see Figure 19). One axis orientation node may be used in the definition of several elements such as those defining a rail in a straight line. In certain instances, such as a flexible spacer, a separate axis orientation node is required for each element.

The rail or longitudinal ribbon in many of the barrier systems is blocked out a considerable distance from the center of the post, i.e., the G4 or MB4. This blockout is rigid and would ordinarily require one element for each blockout (Figure 17). The programmers have incorporated a system using primary nodes and secondary nodes to define elements which will allow the study of a rail with stiff elements. This technique is shown in Figure 20. The mass for the elements, including the spacers, are lumped at the primary nodes. The secondary nodes translate and rotate with their designated primary nodes, Figure 21. Element stresses are then computed on the basis of the location of the secondary nodes. This technique was used to reduce the mass and element stiffness matrices and reduce the computer time.



RAIL



POST

Figure 19. AXIS ORIENTATION NODE.

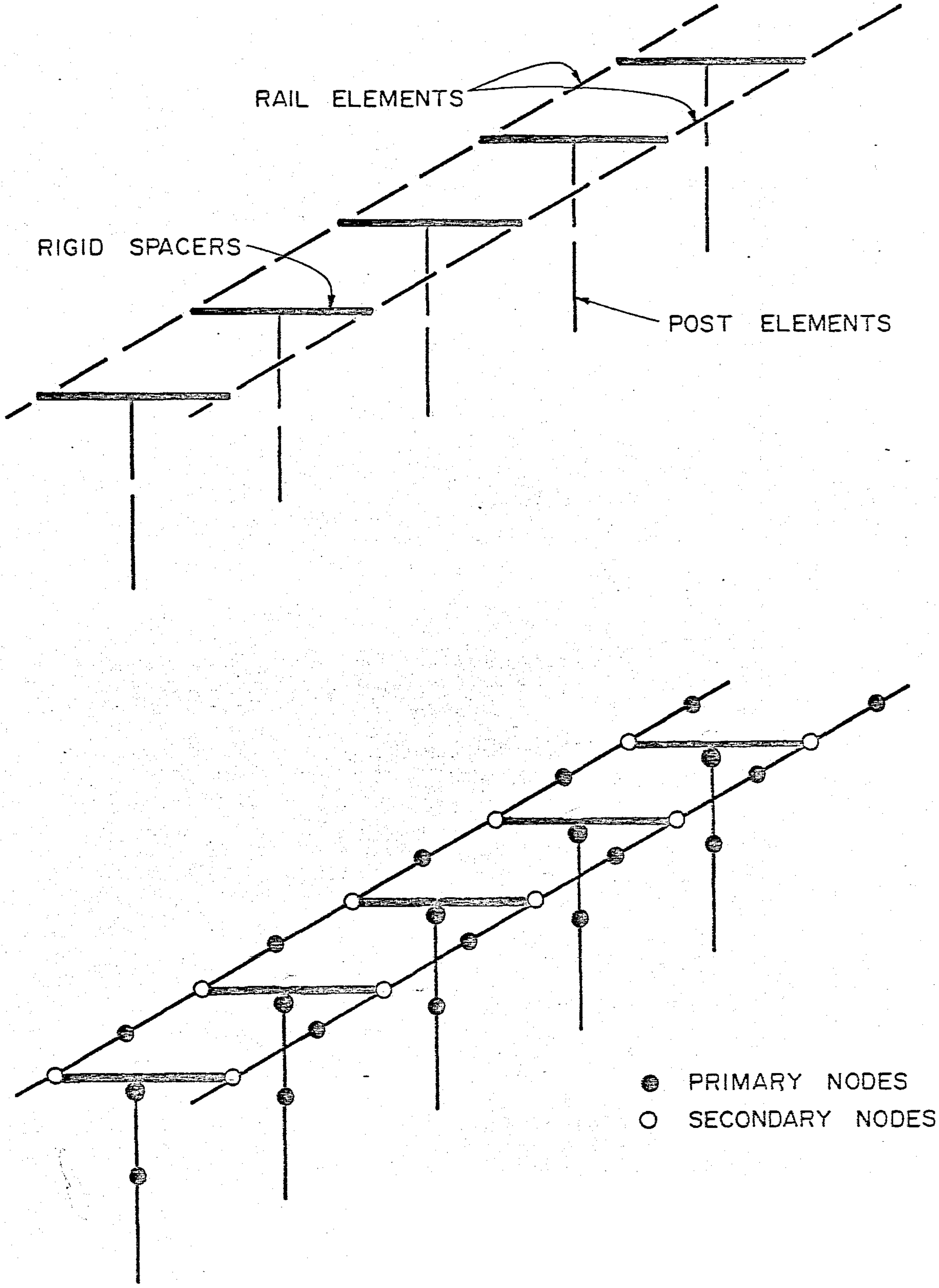
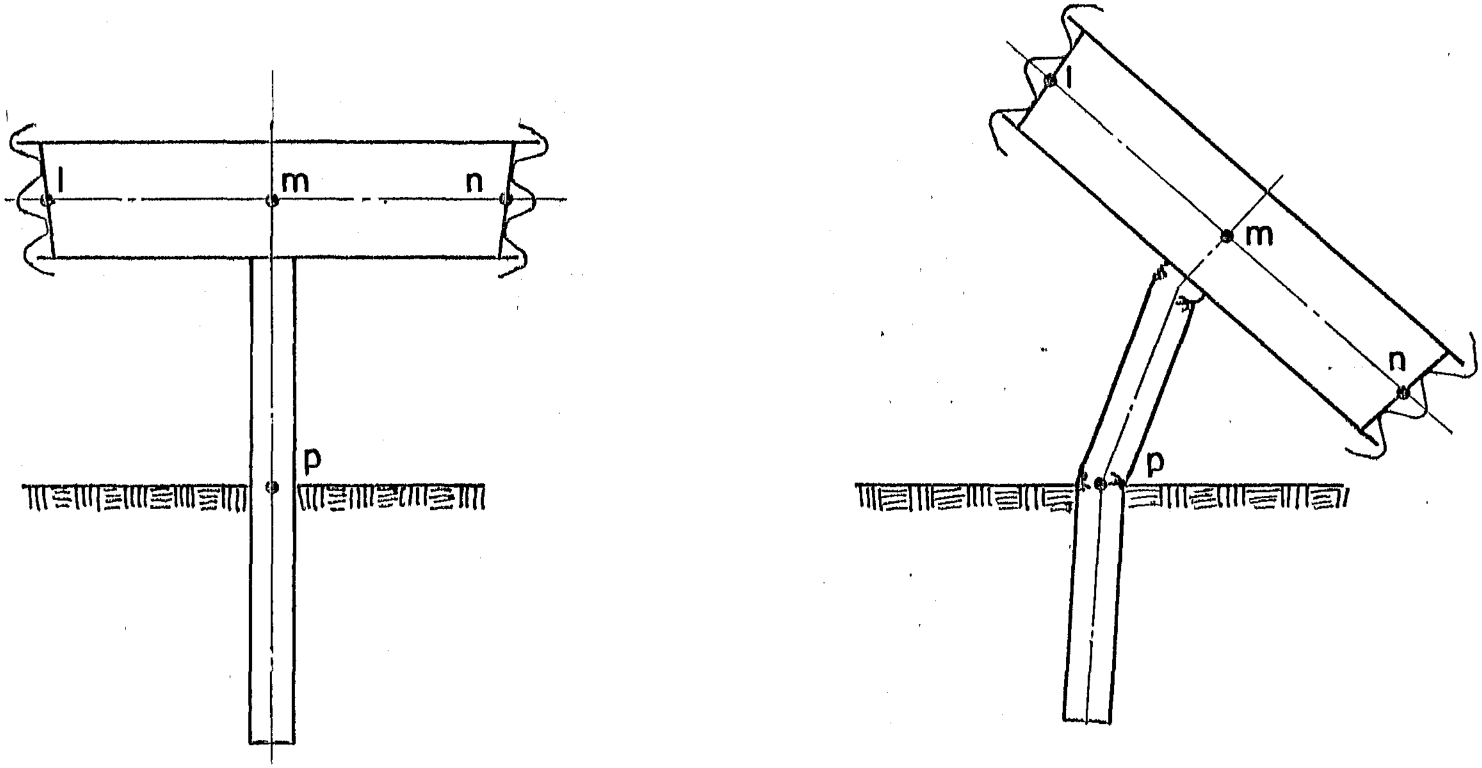


Figure 20. RIGID SPACER DETAIL.



NODE	COORDINATE	PRIMARY NODE	SECONDARY NODE
l	X_l Y_l Z_l	m	l
m	X_m Y_m Z_m	m	m
n	X_n Y_n Z_n	m	n
p	X_p Y_p Z_p	p	p

Figure 21. RELATIONSHIP BETWEEN PRIMARY AND SECONDARY NODES.

Rail Analysis

The dynamic finite element rail analysis portion models the vehicle-rail impact, the local effects on the vehicle and rail, and the loads or forcing functions imparted to the barrier system. The rail elements are rectangular strips extending along the rail section between nodes and discrete lengths of the rail in cross section as shown in Figure 22 for a "W" rail section. Figure 22b shows the rail in a slightly different configuration which is used for vehicle bumper contact test.

The original program contains five rail cross sections in its library. They are:

a. W Section

b. 6 x 6 x 0.180 in. (152.4 x 152.4 x 4.57 mm) Steel Tube

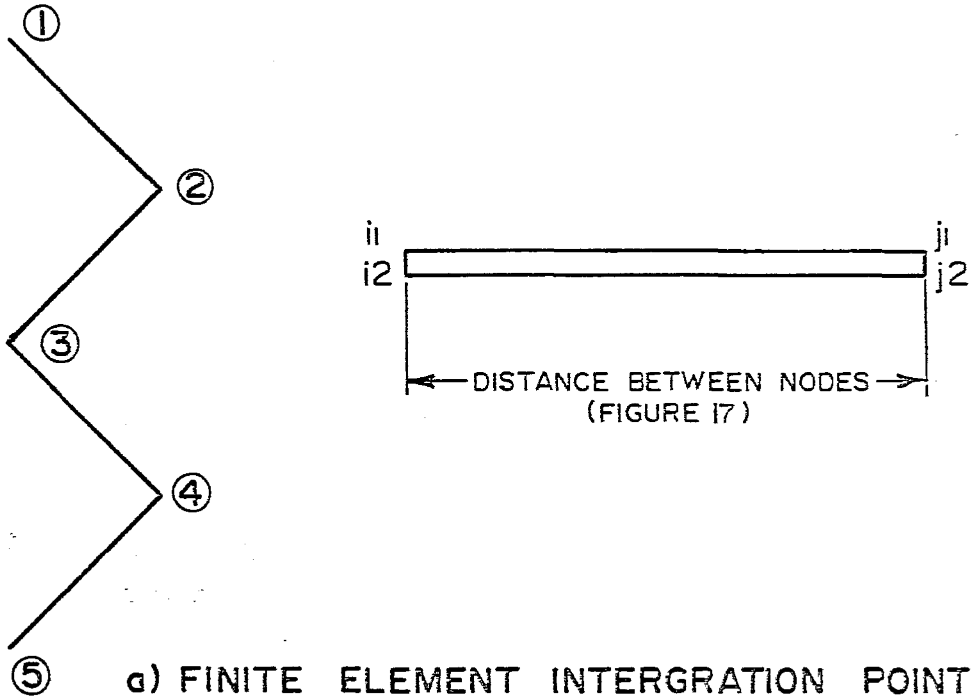
c. 8 x 6 x 0.250 in. (203.2 x 152.4 x 6.35 mm) Steel Tube

d. 0.75 in. (19.05 mm) dia. Steel Cable

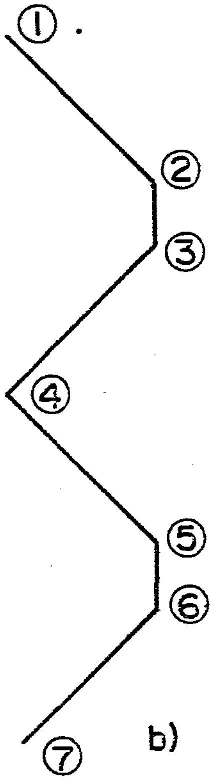
e. 6061-T6 Aluminum Extrusion

TTI has added the thrie beam rail to that library.

The program, in its current configuration, must have a rail member at the height to be contacted by the vehicle bumper. That is, the program will not simulate a vehicle transversing a roadway free of obstructions. Also, when an obstacle such as a concrete barrier is placed in the path of a moving vehicle, a rail must be placed in the barrier as shown in Figure 23 before the vehicle wheels will follow the contour of the barrier to allow the vehicle to acknowledge that the barrier is included in the terrain. When the rail is included as shown the results of the program simulation agree reasonably well with HVOSM simulations and test results. See Table 18 in the main body of the report.



a) FINITE ELEMENT INTERGRATION POINTS



b) BUMPER CONTACT POINTS

Figure 22. GUARD LIBRARY DESCRIPTION OF THE W-BEAM RAIL SECTION.

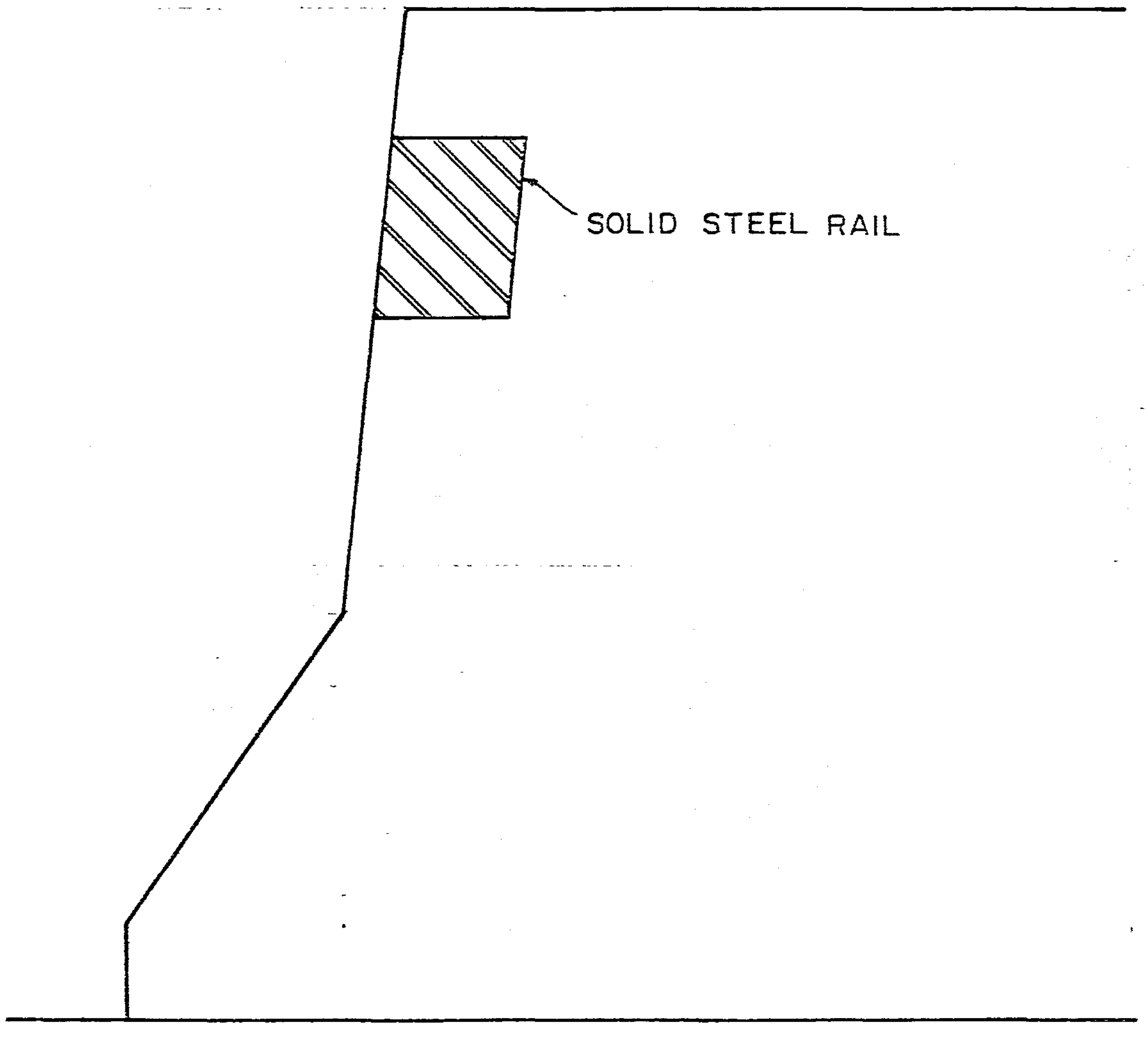


Figure 23. CONCRETE MEDIAN BARRIER AS SIMULATED BY GUARD.

Post Soil Analysis

The program contains a library of four posts. They are:

a. S3 x 5.7

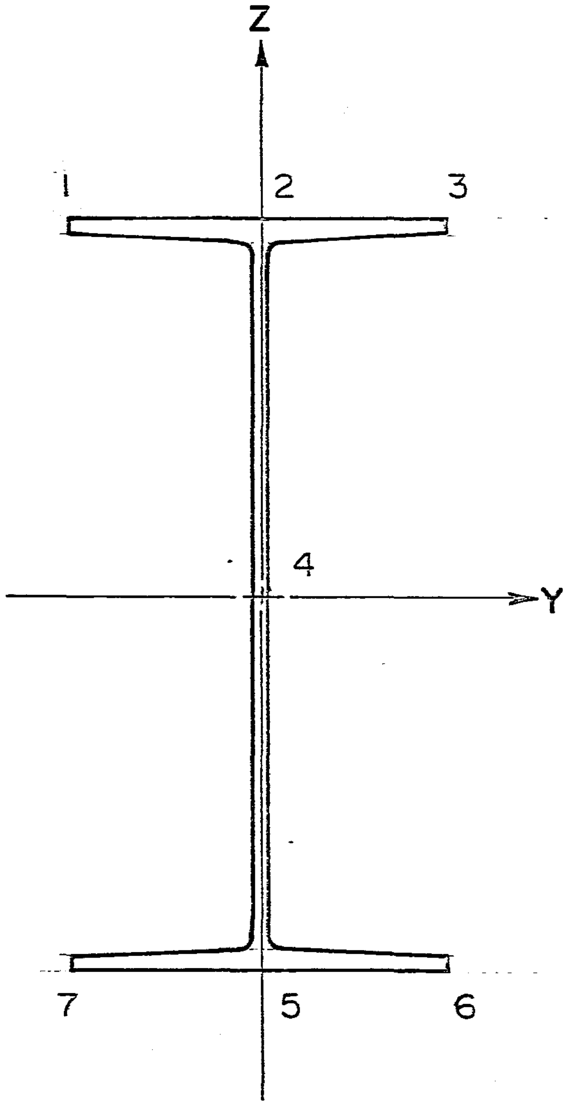
b. W6 x 8.5

c. Aluminum 5.5 x 7.5 H Section

d. 8 in. x 8 in. (203.2 x 203.2 mm) Douglas Fir

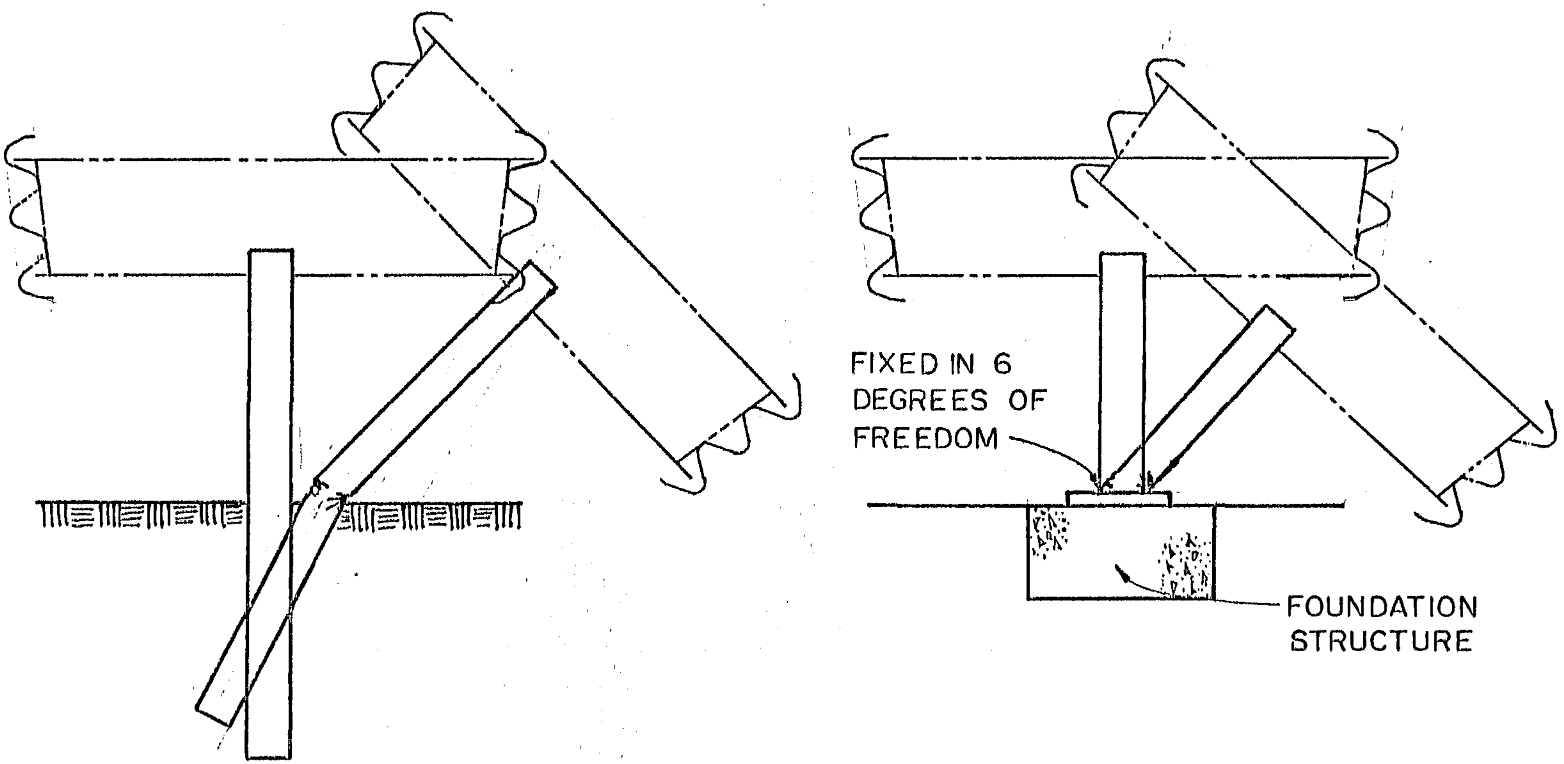
The data for the metal posts contained in the library are strictly geometrical. Figure 24 shows the points used to describe the post cross section. Structural characteristics, yield stresses, ultimate stresses, modulus of elasticity, moments of inertia, etc., of the various members are input into the program by the user. If the cross-sectional geometry of a post, not in the library, is reasonably close to one of the above four then these may be used simply by inputting the correct structural characteristics. For instance, an oak post could be used in lieu of Douglas fir, an S3 x 7.5 could be used in lieu of the standard S3 x 5.7, and the new W6 x 9 post could be used in lieu of the W6 x 8.5 simply by using the correct input data. Should it be necessary to study the European IPE100, then it would be necessary to add its geometry to the library.

By definition of the program a post is a member which penetrates into the soil and reacts with the soil as shown in Figure 25. The post may rotate, usually about some point below the ground line, and it may translate through the soil. A plastic hinge may be formed at the ground or at the top of the post. The situation of the post attached to a massive foundation structure, Figure 25, can be simulated by applying boundary



NUMBERS REPRESENT INTERGRATION POINTS

Figure 24. GUARD LIBRARY DESCRIPTION OF ROLLED SECTION POSTS.



a) POST AS GENERALLY DEFINED BY GUARD

b) POST ATTACHED TO A MASSIVE FOUNDATION STRUCTURE

Figure 25. GUARD POST SIMULATORS.

conditions to the node at the groundline which restrict all six degrees of freedom at that point. That is, slopes and translations in all three directions are set equal to zero.

The soil reactions on a post are computed as a total force and a moment in each plane of the post. They are based on the amount of translation of the post at groundline and soil data developed from tests conducted in the state of New York (3,4). In these tests, W6 x 8.5 steel and 8 in. x 6 in. (203.2 x 152.4 mm) wood posts were driven in either glacial till or fine sand and were impacted by automobiles. Force-deflection curves were developed from these tests. The data for glacial till were used in the soil routine of the program (1).

GUARD VEHICLE

The GUARD vehicle is a six degree of freedom mass and enters the equations of motion as such. The vehicle is further described by adding special features such as:

1. the capability for describing the safety bumpers as required by FMVSS 215 (2), see also Figure 26;
2. contact surfaces on the impact side of the vehicle; and
3. wheel position for four wheels.

The vehicle applies loads or forcing function to a rail or the surface through these special features. Rail contact by the bumper is required by the program. Thus if it is desired to investigate vehicle reaction with the concrete barrier it is necessary to place a rail at a position to be contacted by the vehicle bumper. This rail may be infinitely rigid such as shown in Figure 23.

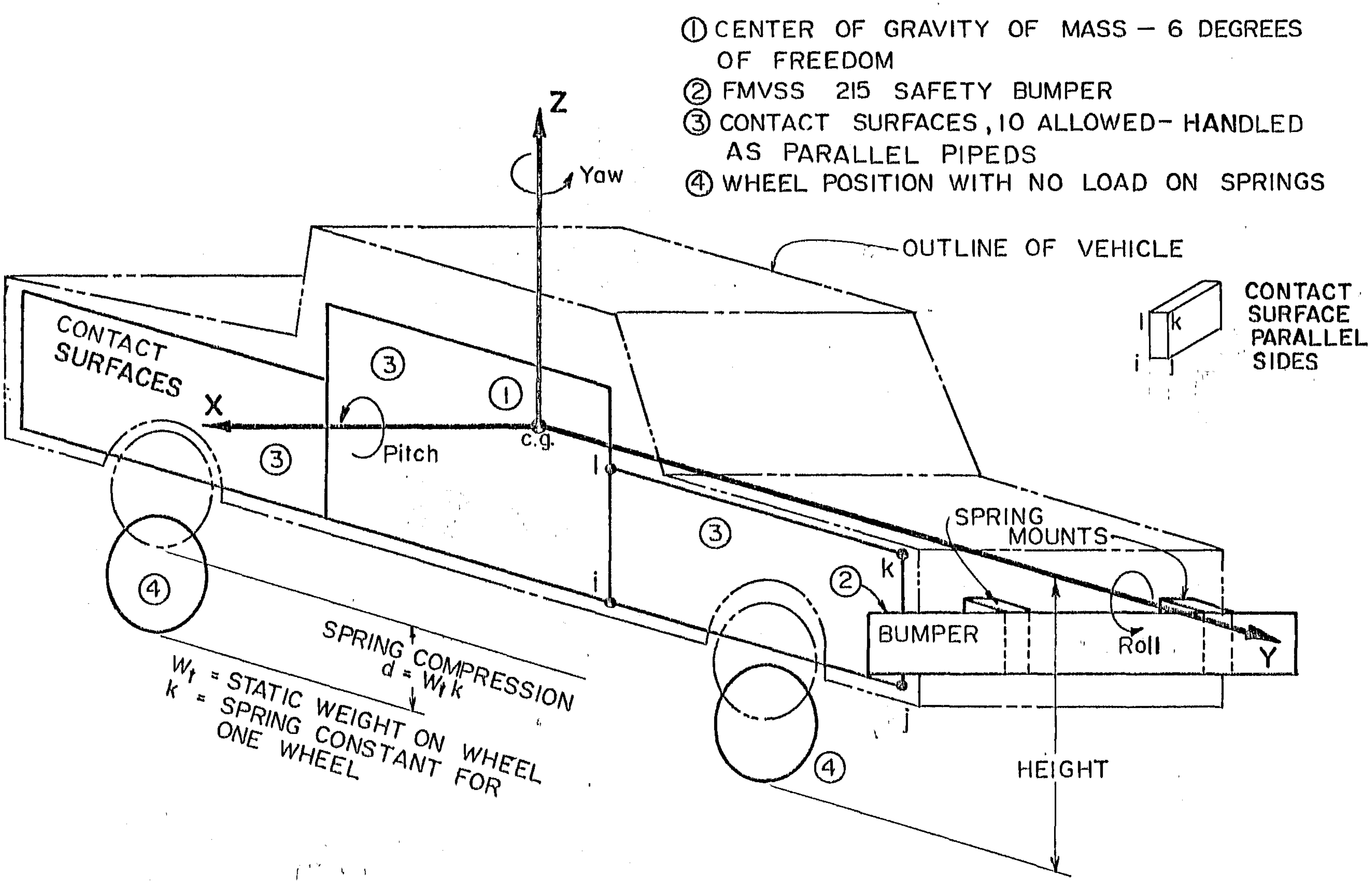


Figure 26. DESCRIPTION OF GUARD VEHICLE.

Professor Newmark (5) is of the opinion that a variation of Beta is advisable for the conditions encountered in the possible solutions of the equations of motion. Specific values of Beta represent a variation of the acceleration as shown in Figure 27. A value of Beta = 1/4 produces an average deceleration between a_n and a_{n+1} and is the solution described by Timoshenko. Using the equation of Newmark and a value of Beta = 1/4 is easier to program than taking the actual average of the decelerations. A value of Beta = 1/6 is equivalent to a uniform variation across the time interval and Beta = 1/8 is equivalent to a step function.

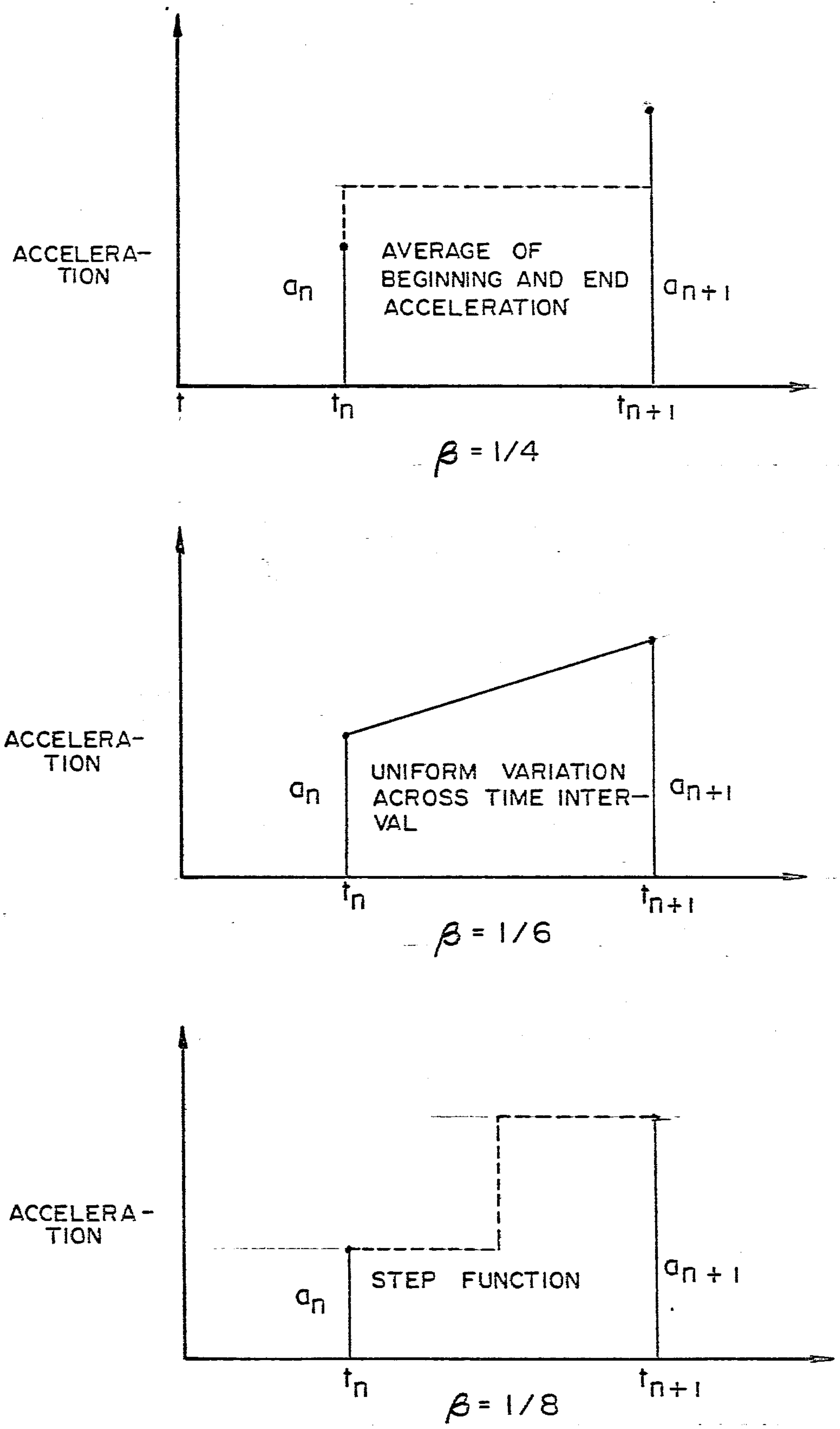


Figure 27. VARIATION OF ACCELERATION WITH FUNCTIONS OF β.

Safety Bumper

The safety bumper feature of the program is one of the primary reasons for its development (1). This feature takes into consideration the FMVSS 215 safety bumper by using the effects of the spring loaded mounting assembly which in many instances is a simple hydraulic shock absorber. The bumper supports are located by the vehicle coordinate system (Figure 26) and may be preloaded. The height and length of the bumper are given along with the stiffness and the value of the plastic moment. It is necessary that there be a rail which can be impacted for the program to function. The top of the bumper must also be above the bottom of the rail under initial conditions. Under impact conditions the bumper creates a force on the barrier through the rail. An equal but opposite force is applied to the vehicle mass. There is no bumper stop; and as the spring is compressed one of the parallel pipeds, created by a contact surface of the side panels, will take precedence over the bumper.

Contact Surfaces

The contact surfaces are defined by points i, j, k, and ℓ (Figure 26). These extend through the vehicle as parallel pipeds and are defined on the impact side of the vehicle. The surface stiffness, coefficient of friction between the surface and the rail, and the maximum force the particular piped can withstand, are among the input variables. As with the safety bumper, the force applied to the rail by these surfaces is applied in reverse to the vehicle mass. The combination of force and stiffness applied to each parallel piped produce an integrated deflection of the vehicle side. In the more severe impacts the program has predicted vehicle deformations which went past the center of gravity of the vehicle. The location of the vehicle center of gravity remains constant during this time. This is more extreme than occurs in actual practice, and it is felt that deflection limitations (hard points) would be appropriate as a program modification.

Wheel Position

The wheel input data differs from most other vehicle models in that the wheel location is described under zero load conditions. Longitudinal and lateral positions (x and y coordinates) are fixed. The vertical wheel coordinates are variable. They are determined as functions of the static load on the wheels and the spring constant.

SOLUTION METHOD

The dynamic solution is based on a system developed by Professor N. M. Newmark (5) and frequently referred to as the Newmark-Beta method. The equations of motion are relatively simple and standard based on Timoshenko's original equations except that a value Beta has been added such as:

$$x_{n+1} = x_n + V_n h + (\tfrac{1}{2} - \beta) a_n h^2 + \beta a_{n+1} h^2$$

and

$$V_{n+1} = V_n + a_n \, h/2 + a_{n+1} \, h/2 \qquad \text{where}$$

h = the time interval

a = the acceleration

x = the deflection

V = the velocity

The subroutine SOLVE which is the Newmark-Beta solution sets the value of Beta at 0.25. The researchers believe that the value of Beta should be selected by the user and a description of the possible values be provided.

REFERENCES FOR APPENDIX B

1. Bruce, R. W. and Hahn, E. E., "Guardrail/Vehicle Dynamic Interaction", Summary Final Report IIT Research Institute Contract DOT-FH-11-8520, March 1976,

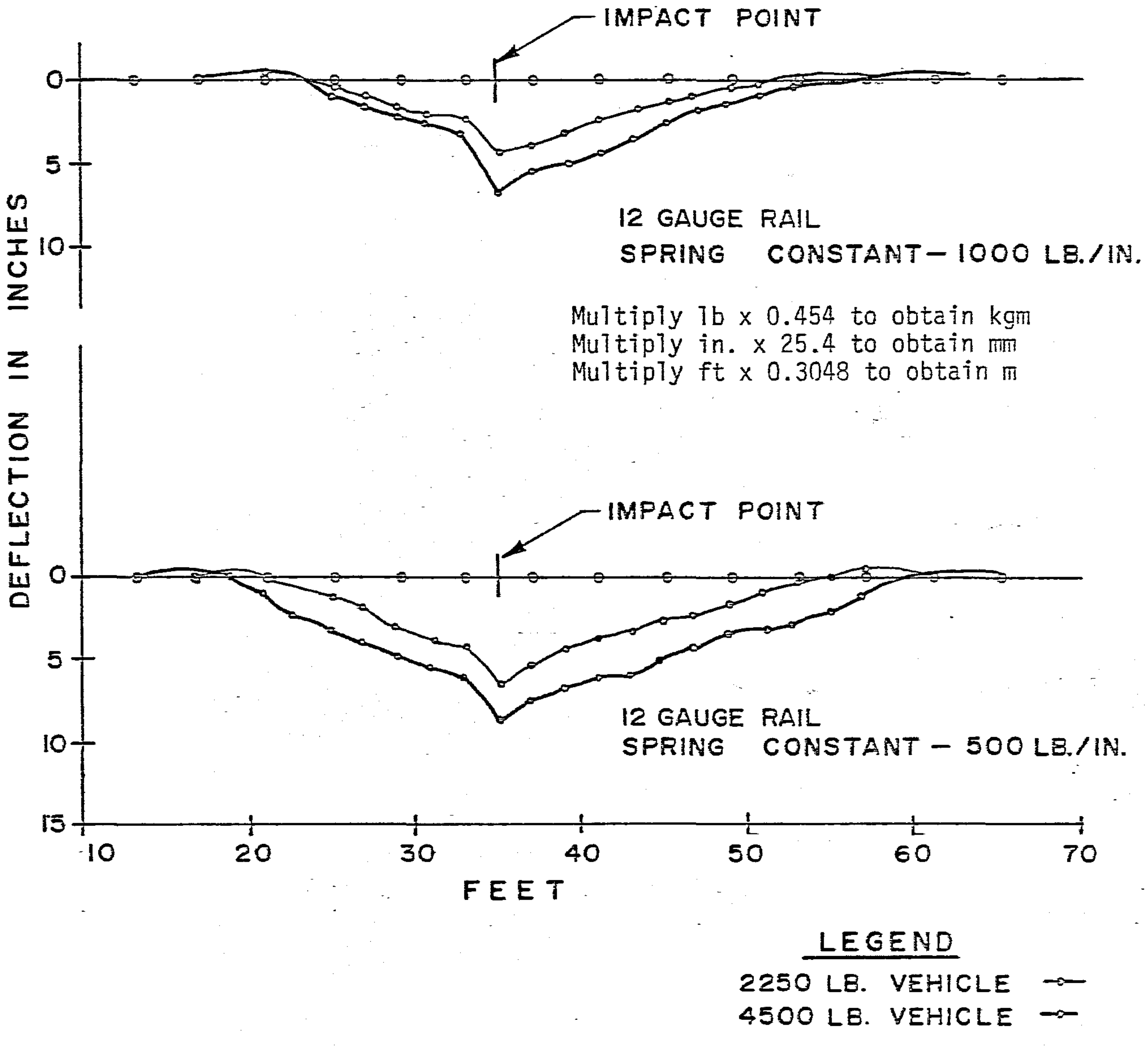
2. Federal Motor Vehicle Safety Standards and Regulations, Section 215, August 1972.

3. Deleys, Norman J. and McHenry, Raymond R., "Highway Guardrails - A Review of Current Practice", NCHRP Report 36, 1967.

4. Michie, Jarvis D., Calcote, Lee R. and Bronstad, Maurice E., "Guardrail Performance and Design", NCHRP Report 115, 1971.

5. Newmark, Nathan M., "A Method of Computation for Structural Dynamics", Transactions of the American Society of Civil Engineers, Vol. 127, Part 1, 1962, pp. 1406-1435.

VEHICLE SPEED 60 MPH (97 km/h)
IMPACT ANGLE 15°



Multiply lb x 0.454 to obtain kgm
Multiply in. x 25.4 to obtain mm
Multiply ft x 0.3048 to obtain m

FIGURE 28. MAXIMUM DYNAMIC DEFLECTION OF BLOCKED OUT RAIL ON CMB FROM PARAMETER STUDY-BLOCKOUT SPACING 4 FT (1.2 m).

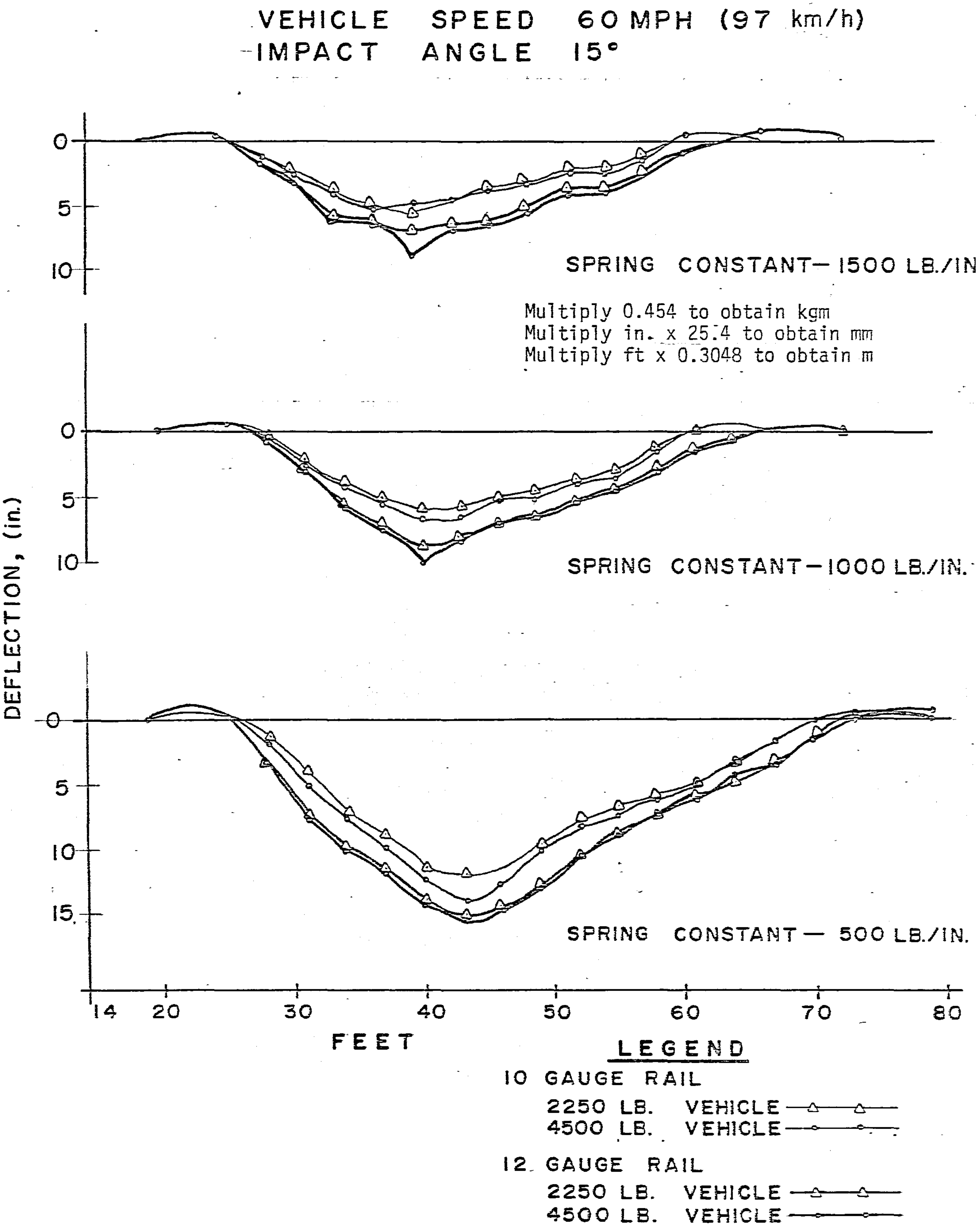


FIGURE 29. MAXIMUM DYNAMIC DEFLECTION OF BLOCKED OUT RAIL ON CMB FROM PARAMETER STUDY-BLOCKOUT SPACING 6 FT (1.8m).

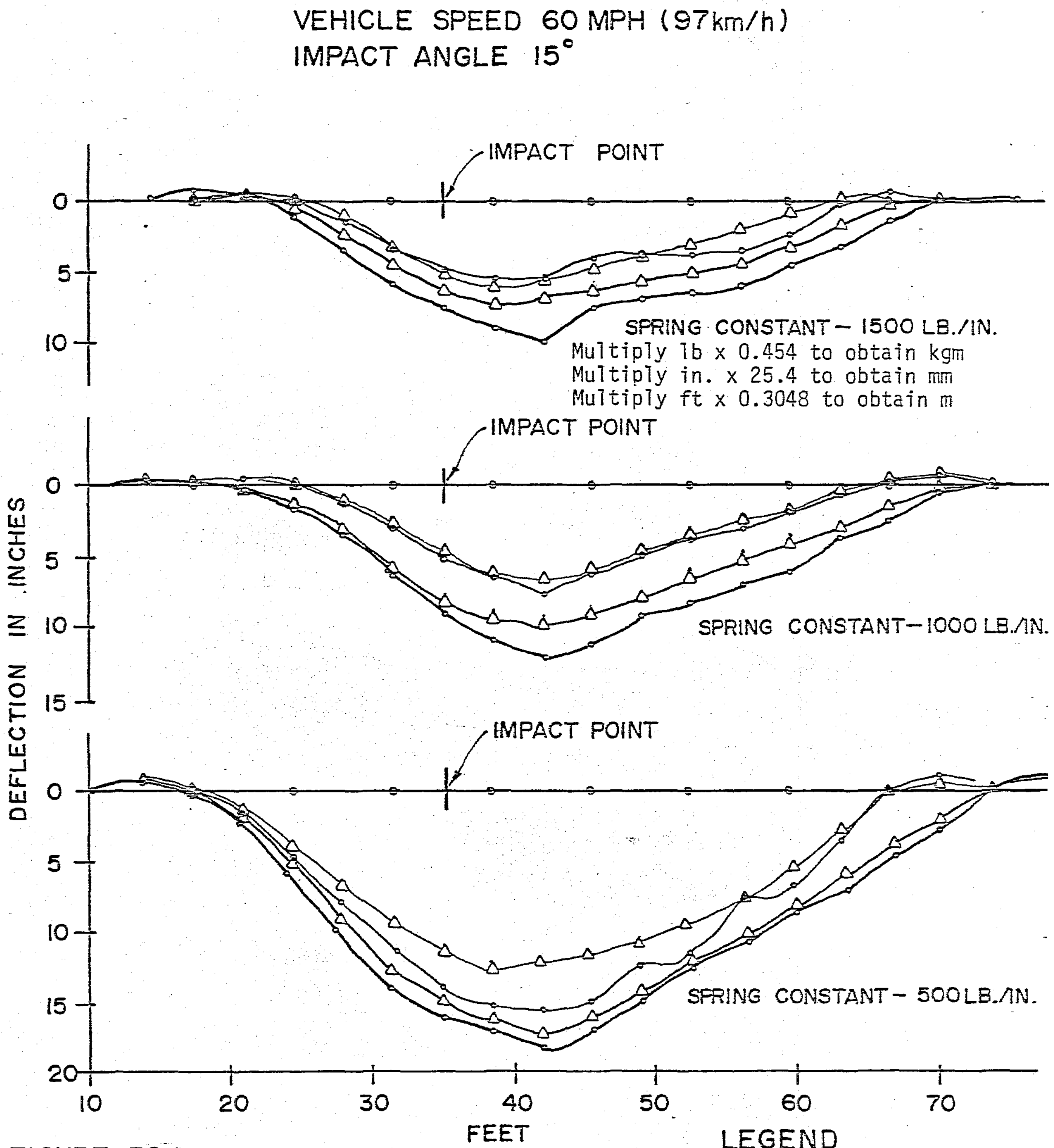
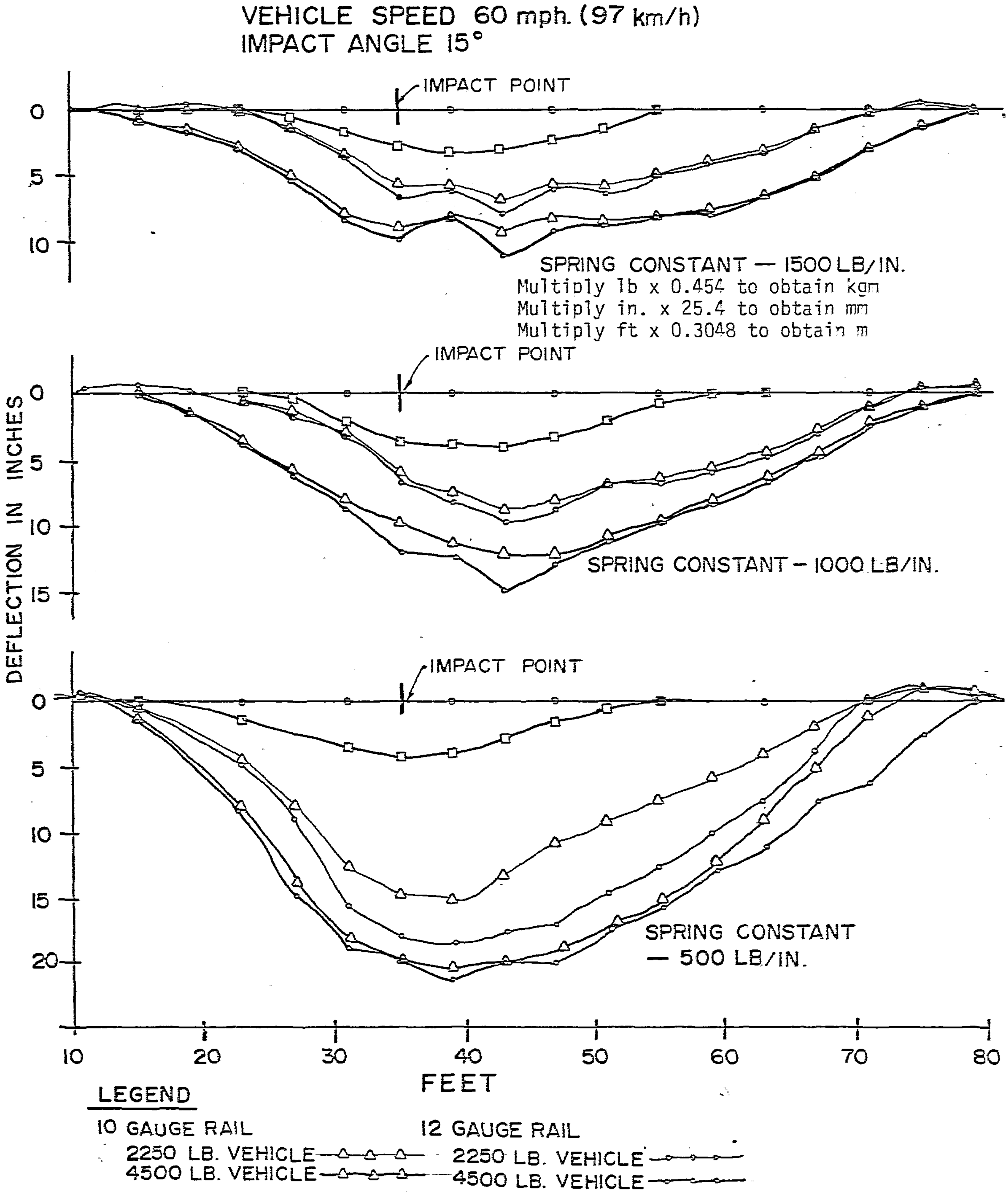


FIGURE 30. MAXIMUM DYNAMIC DEFLECTION OF BLOCKED OUT RAIL ON CMB FROM PARAMETER STUDY — BLOCKOUT SPACING 7 FT (2.1m).



Multiply lb x 0.454 to obtain kgm
Multiply in. x 25.4 to obtain mm
Multiply ft x 0.3048 to obtain m

FIGURE 31. MAXIMUM DYNAMIC DEFLECTION OF BLOCKED OUT RAIL ON CMB FROM PARAMETER STUDY — BLOCKOUT SPACING 8 FT (2.4 m).

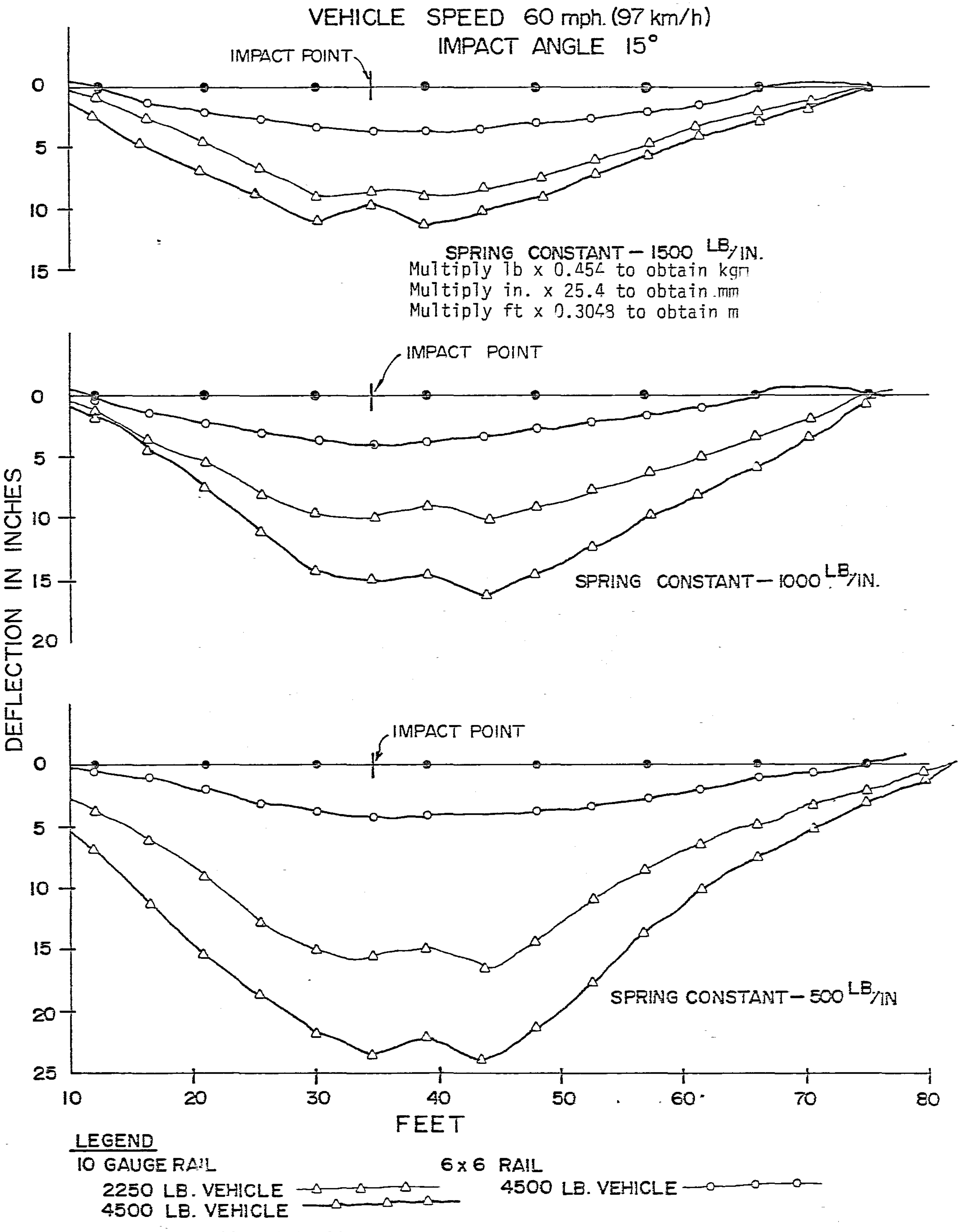
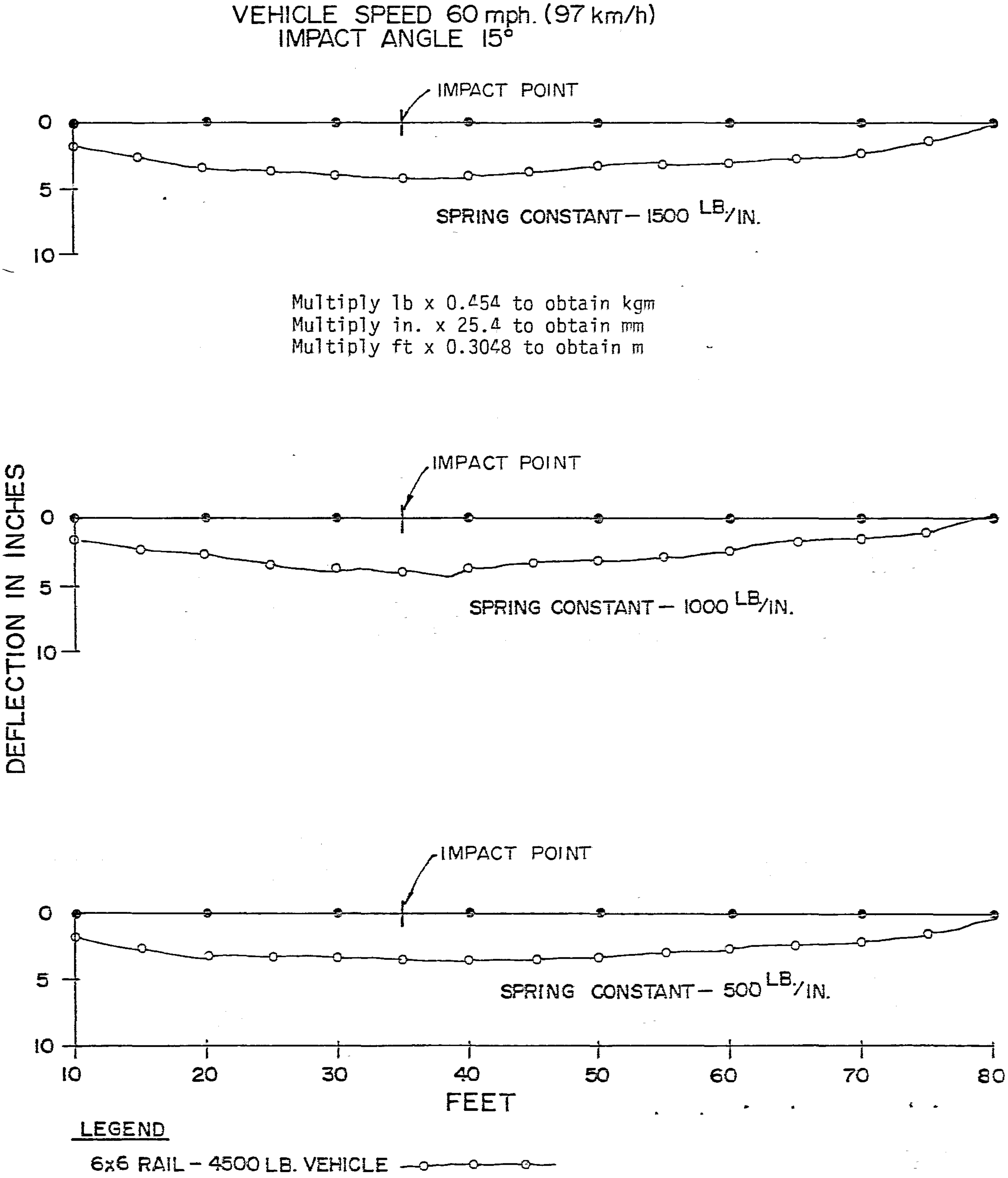
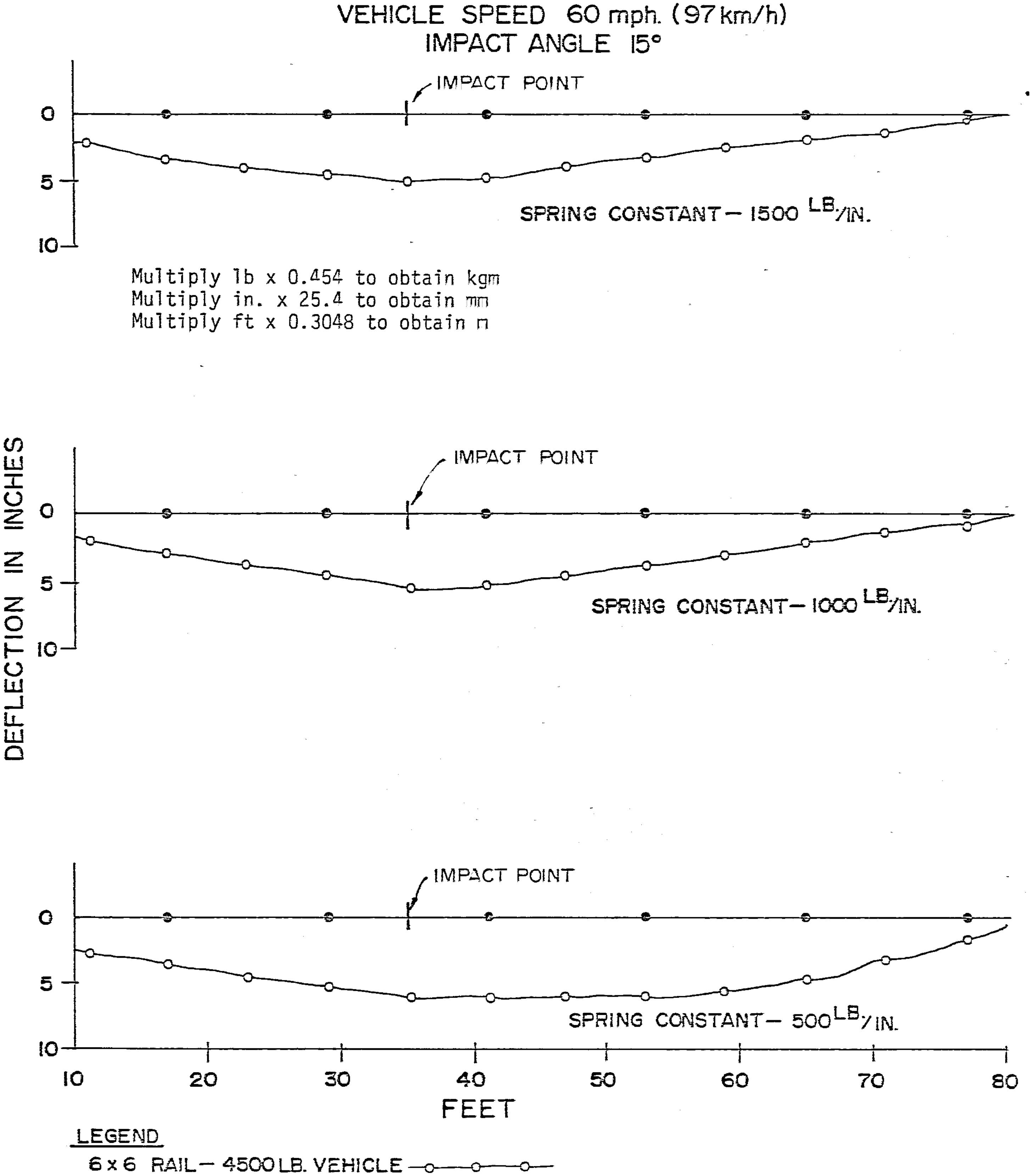


FIGURE 32. MAXIMUM DYNAMIC DEFLECTION OF BLOCKED OUT RAIL ON CMB FROM PARAMETER STUDY – BLOCKOUT SPACING 9 FT (2.7m).



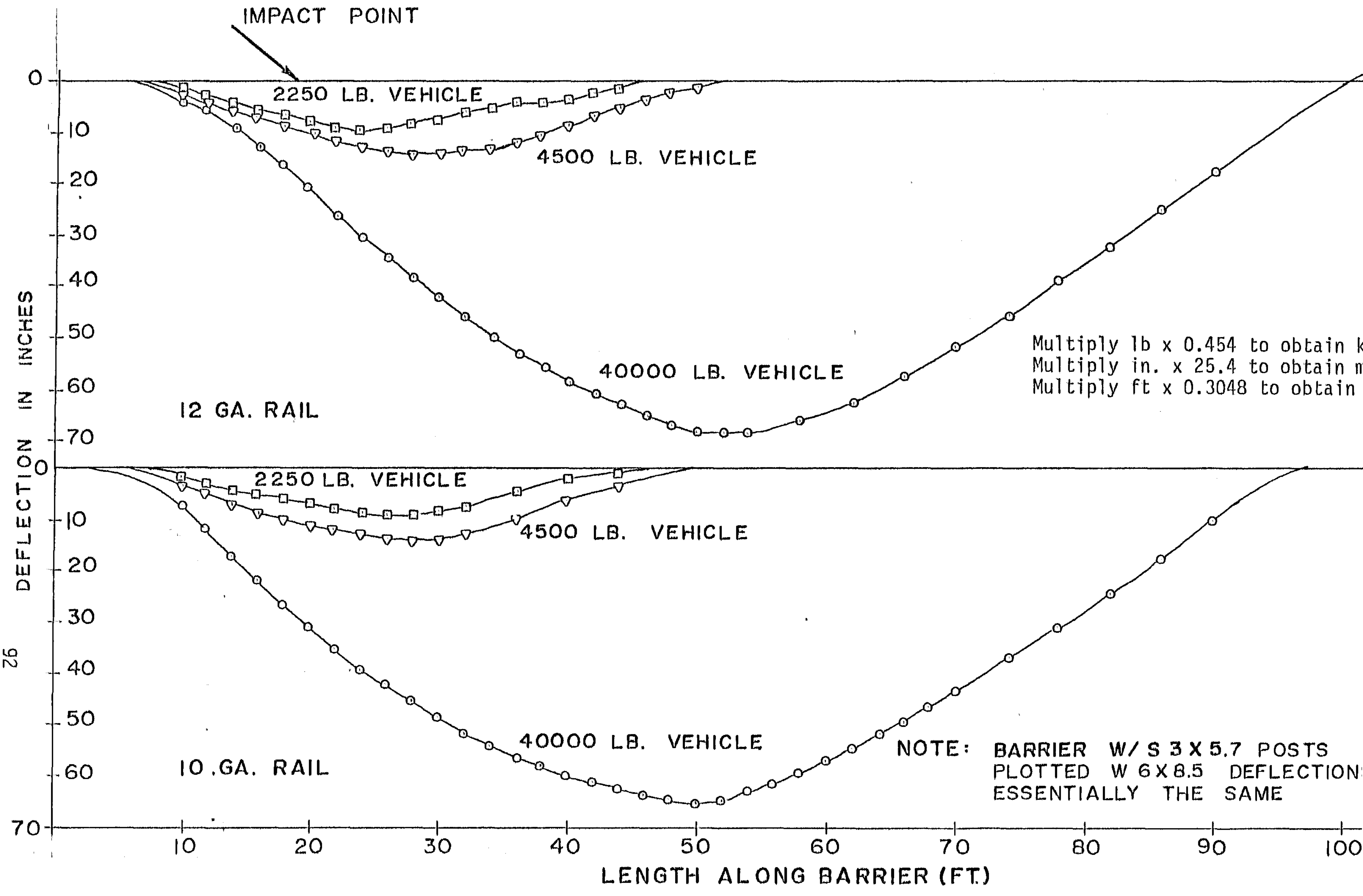
Multiply lb x 0.454 to obtain kgm
Multiply in. x 25.4 to obtain mm
Multiply ft x 0.3048 to obtain m

FIGURE 33. MAXIMUM DYNAMIC DEFLECTION OF BLOCKED OUT RAIL ON CMB FROM PARAMETER STUDY.
BLOCKOUT SPACING 10 FT (3m).



Multiply lb x 0.454 to obtain kgm
Multiply in. x 25.4 to obtain mm
Multiply ft x 0.3048 to obtain m

FIGURE 34. MAXIMUM DYNAMIC DEFLECTIONS OF BLOCKED OUT RAIL ON CMB FROM PARAMETER STUDY. BLOCKOUT SPACING 12 FT (3.7m).



Multiply lb x 0.454 to obtain k
Multiply in. x 25.4 to obtain m
Multiply ft x 0.3048 to obtain

NOTE: BARRIER W/ S 3 X 5.7 POSTS
PLOTTED W 6 X 8.5 DEFLECTION
ESSENTIALLY THE SAME

FIGURE 35. MAXIMUM DYNAMIC DEFLECTIONS FROM PARAMETER STUDY
THRIE T-BARRIER: POST SPACING 4 FT (1.2m).

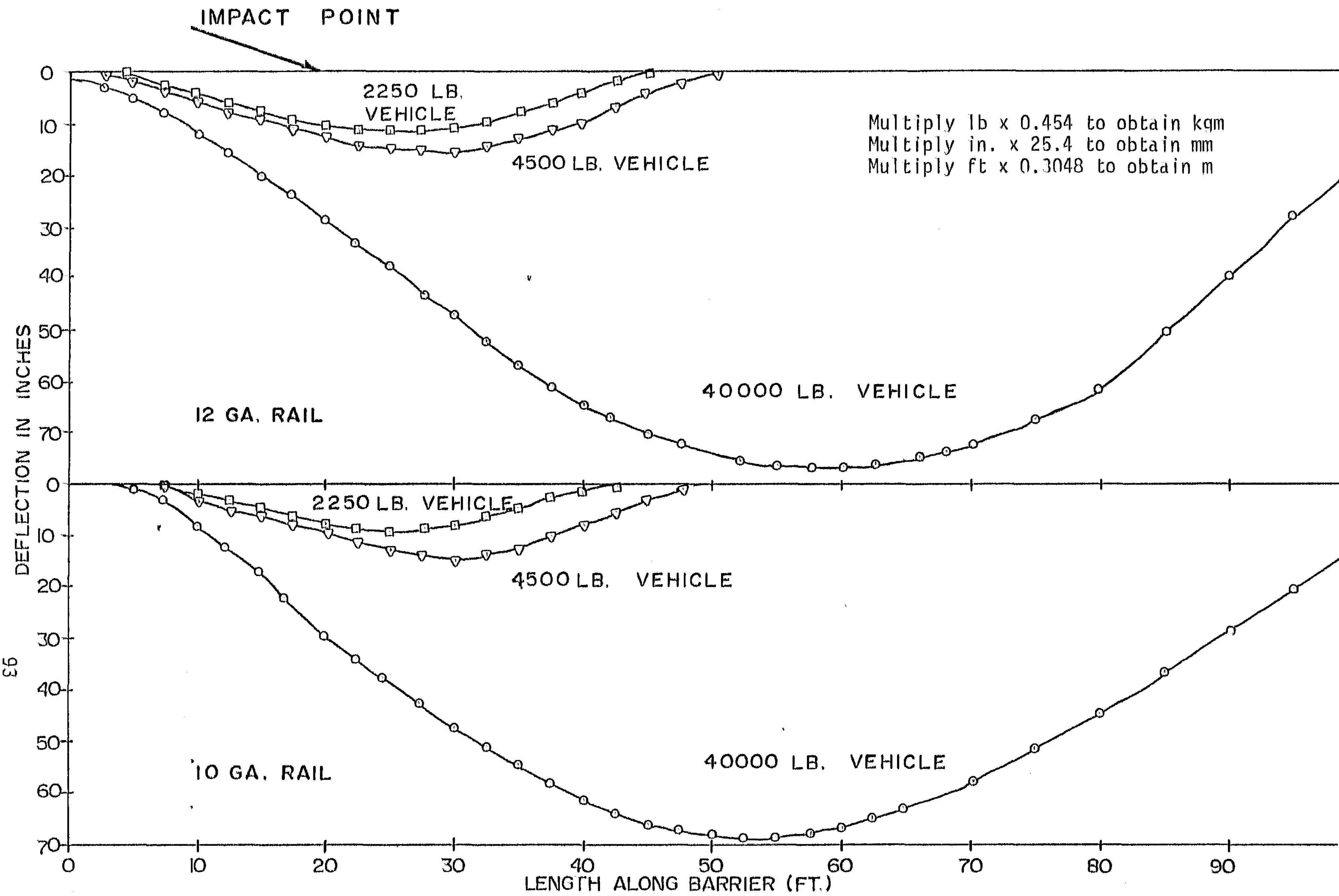


FIGURE 36. MAXIMUM DYNAMIC DEFLECTIONS FROM PARAMETER STUDY THRIE T-BARRIER, POST SPACING 5 FT (1.5m).

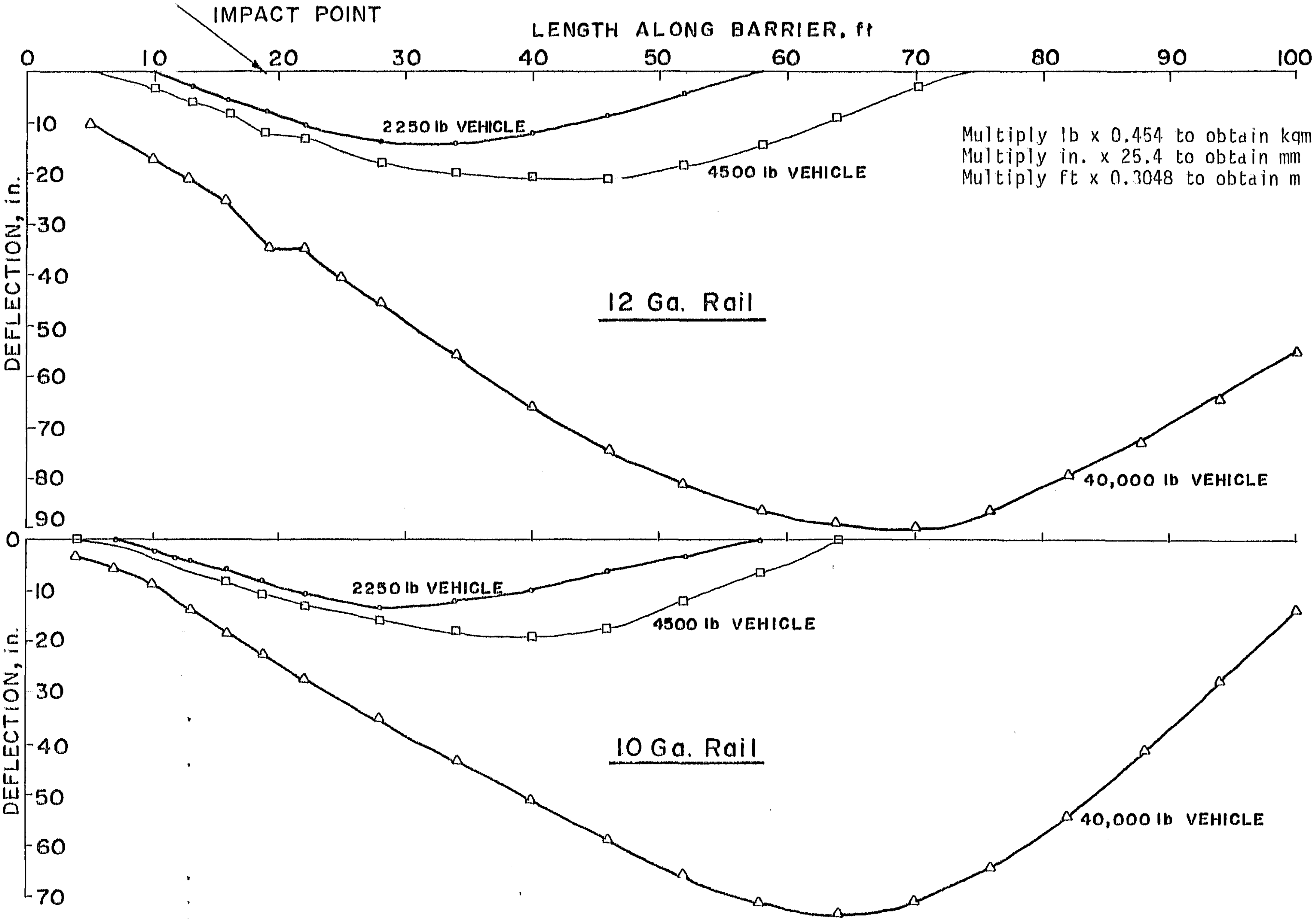
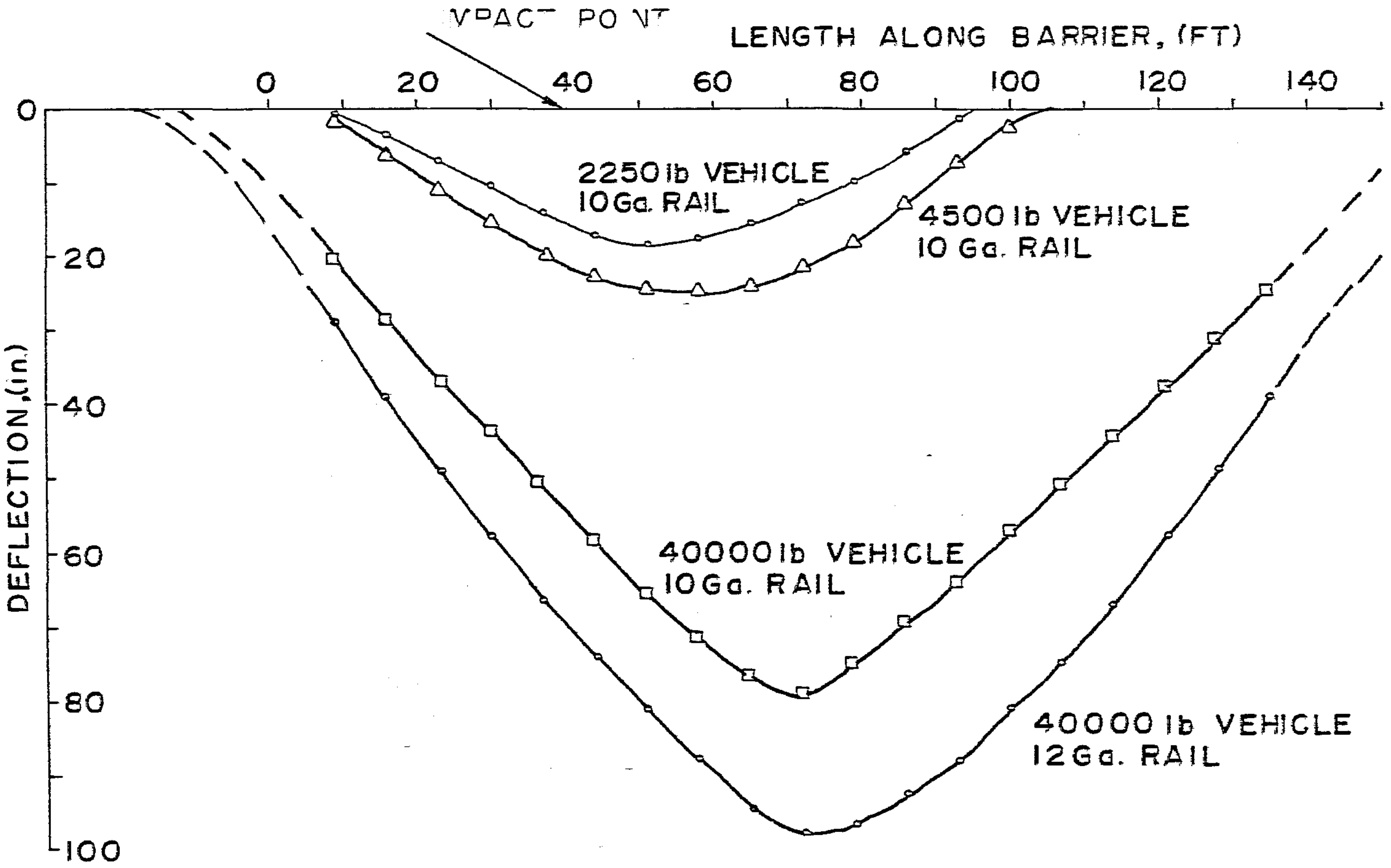


Fig. 37. Maximum Dynamic Deflections From Parameter Study Thrie T-Barrier.
Post Spacing = 6 ft (1.8 m)



Multiply lb x 0.454 to obtain kg
Multiply in. x 25.4 to obtain mm
Multiply ft x 0.3048 to obtain m

FIGURE 38. MAXIMUM DYNAMIC DEFLECTIONS FROM PARAMETER STUDY THRIE T-BARRIER POST SPACING 7 FT (2.1 m).

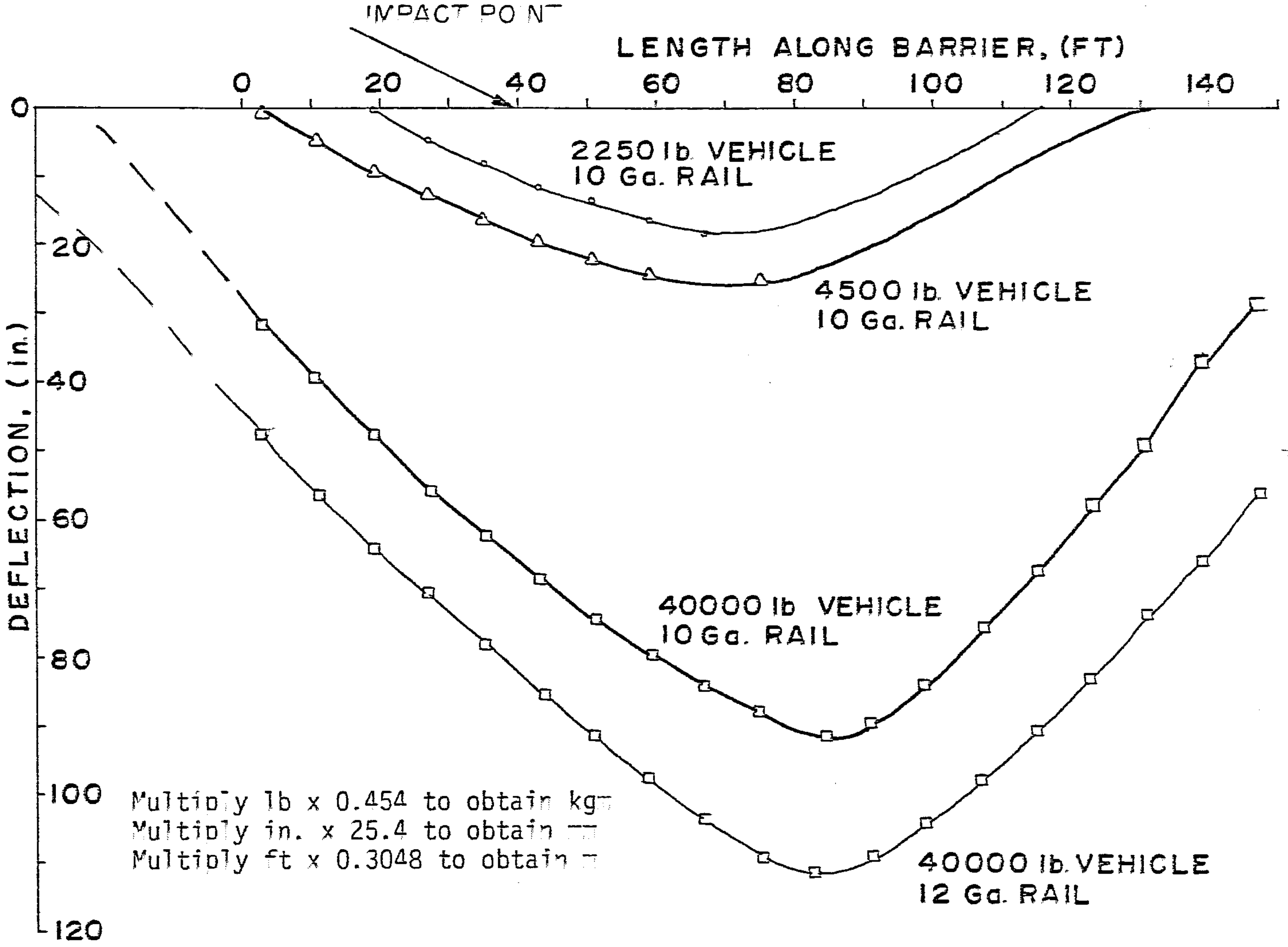


FIGURE 39. MAXIMUM DYNAMIC DEFLECTIONS FROM PARAMETER STUDY THRIE T-BARRIER POST SPACING 8 FT (2.4m).

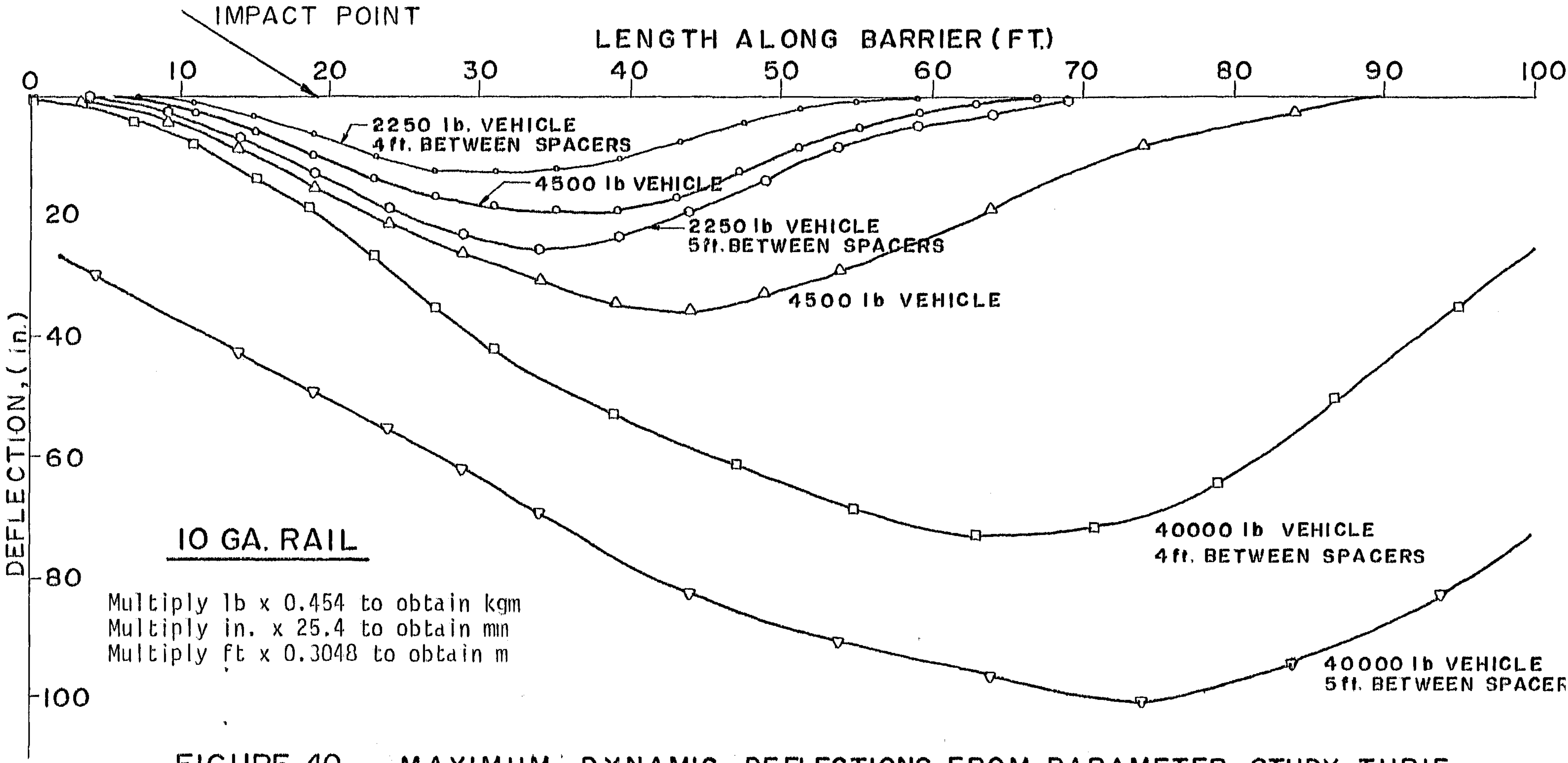
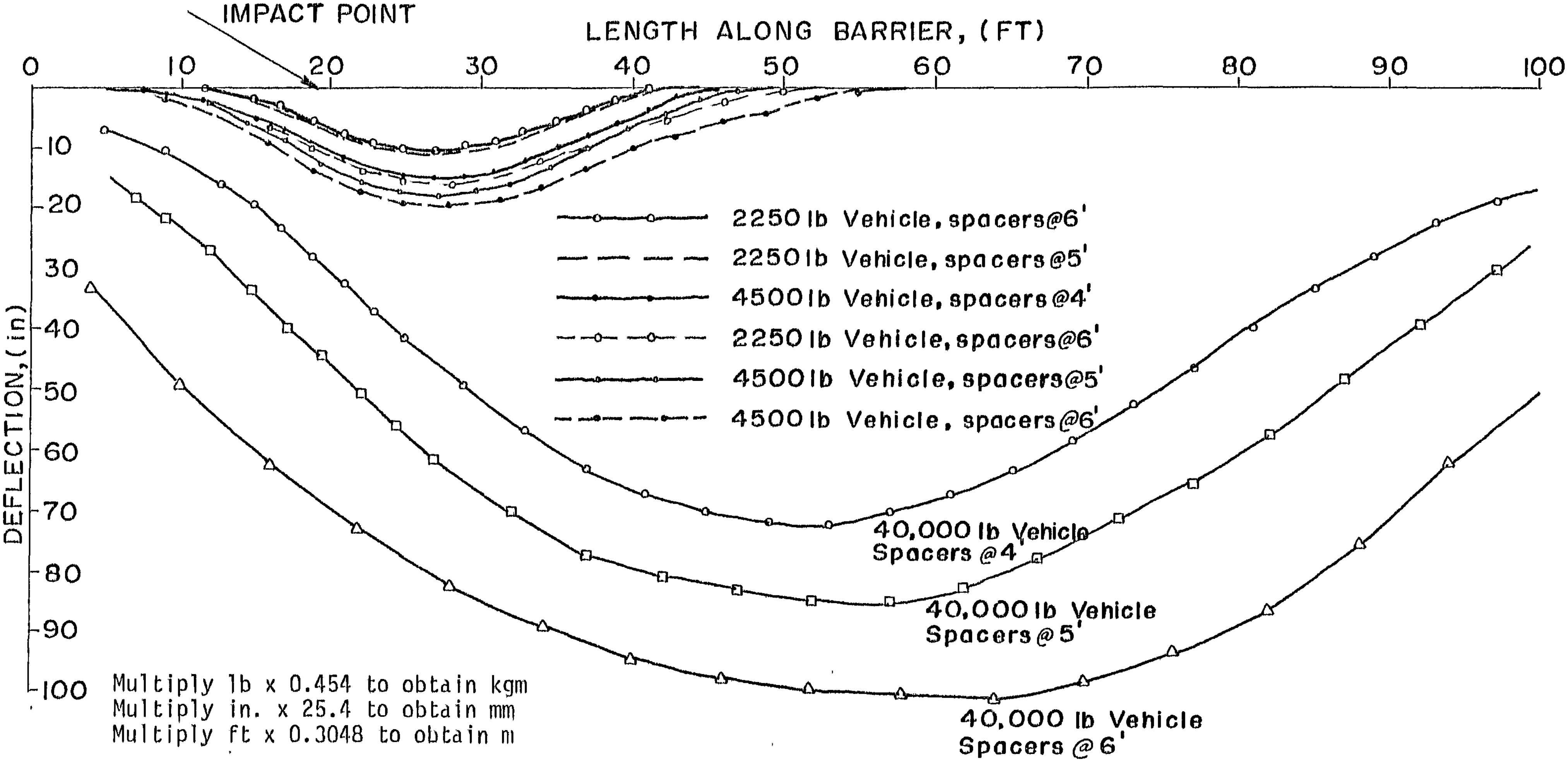


FIGURE 40. MAXIMUM DYNAMIC DEFLECTIONS FROM PARAMETER STUDY THRIE T-BARRIER. POSTS AT ALTERNATE SPACERS.



Multiply lb x 0.454 to obtain kgm
Multiply in. x 25.4 to obtain mm
Multiply ft x 0.3048 to obtain m

FIGURE 41. MAXIMUM DYNAMIC DEFLECTIONS FROM PARAMETER STUDY THRIE T-BARRIER. VARIABLE POST SPACING 18"(457mm) BETWEEN RAILS.