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TRANSPORTATION
INSTITUTE

TEXAS
HIGHWAY
DEPARTMENT

COOPERATIVE
RESEARCH

DYNAMIC BEHAVIOR OF AN AUTOMOBILE
TRAVERSING SELECTED CURBS
AND MEDIANS

in cooperation with the
Department of Transportation
Federal Highway Administration

RESEARCH REPORT 140-6
STUDY 2-10-69-140
EVALUATION OF THE ROADWAY ENVIRONMENT

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| 16. Abstract <p>This study involved the determination of the behavior of an automobile as it traversed selected curb configurations and sloped medians. The objective of the study was to determine if a potential existed for the automobile to vault over a barrier placed behind each curb, or a barrier placed in each sloped median.</p> <p>Six-inch and eight-inch curb configurations were investigated. Medians having slopes of 1.1 inches per foot, 1.5 inches per foot, and 4.6 inches per foot were investigated.</p> <p>The Highway-Vehicle-Object-Simulation-Model (HVOSM) was used to make the investigation. The HVOSM is a computer model of an automobile and is used to simulate its dynamic response.</p> | | | | | |
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DYNAMIC BEHAVIOR OF AN
AUTOMOBILE TRAVERSING SELECTED CURBS
AND MEDIANS

by

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Research Report 140-6

Evaluation of the Roadway Environment by
Dynamic Analysis of the Interaction
Between the Vehicle, Passenger,
and the Roadway

Research Study No. 2-10-69-140

Sponsored by

The Texas Highway Department
in cooperation with the
U. S. Department of Transportation, Federal Highway Administration

January 1975

TEXAS TRANSPORTATION INSTITUTE
Texas A&M University
College Station, Texas

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

KEY WORDS

Medians, curbs, vehicle dynamics, median barriers, math simulation, guardrail.

METRIC CONVERSION FACTORS

The following English units were used in this report. Their equivalent metric units are also given.

| <u>UNIT</u> | <u>METRIC EQUIVALENT</u> |
|-------------|--------------------------|
| 1 inch | 0.0254 meters |
| 1 foot | 0.305 meters |
| 1 mile/hour | 1.609 kilometers/hour |

FOREWORD

The information contained herein was developed on Research Study 2-5-69-140 entitled "Evaluation of the Roadside Environment by Dynamic Analysis of the Interaction Between the Vehicle, Passenger, and Roadway." It is a cooperative research study sponsored jointly by the Texas Highway Department and the U. S. Department of Transportation, Federal Highway Administration.

The basic objective of the study is to develop criteria to aid in the design of a safe highway. This is being accomplished through the application of mathematical simulation techniques, verified by selected crash tests, to determine the dynamic behavior of automobiles and their occupants when in collision with roadside objects or when traversing highway geometric features such as ditches, sloping culvert grates, etc. The study began in September, 1968.

Several significant findings have resulted from the study and these are documented in the following reports:

1. "Documentation of Input for Single Vehicle Accident Computer Program", Young, R.D., et al., TTI Research Report 140-1, July 1969.
2. "A Three-Dimensional Mathematical Model of an Automobile Passenger", Young, R.D., TTI Research Report 140-2, August 1970.
3. "Criteria for the Design of Safe Sloping Culvert Grates", Ross H.E., Jr., and Post, E.R., TTI Research Report 140-3, August 1971.
4. "Criteria for Guardrail Need and Location on Embankments", Ross, H.E., Jr., and Post, E.R., TTI Research Report 140-4, April 1972.
5. "Simulation of Vehicle Impact with the Texas Concrete Median Barrier", Young, R.D., et al., TTI Research Report 140-5, June 1972.

6. "Comparison of Full-Scale Embankment Tests with Computer Simulations", Ross, H.E., Jr., and Post, E.R., TTI Research Report 140-7, December 1972.
7. "Impact Performance and a Selection Criterion for Texas Median Barriers", Ross, H.E., Jr., TTI Research Report 140-8, April 1974.
8. "HVOSM User's Manual", James, J.E., Jr., and Ross, H.E., Jr., TTI Research Report 140-9, August 1974.
9. "Evaluation of Roadway Safety Features by Computer Simulation--A Summary Report", Ross, H. E., Jr., TTI Research Report 140-10F, February, 1975.

SUMMARY

This study involved the determination of the behavior of an automobile as it traversed selected curb configurations and sloped medians. The objective of the study was to determine if a potential existed for the automobile to vault over a barrier placed behind each curb, or a barrier placed in each sloped median.

Six-inch and eight-inch curb configurations were investigated. Medians having slopes of 1.1 inches per foot, 1.5 inches per foot, and 4.6 inches per foot were investigated.

The Highway-Vehicle-Object-Simulation-Model (HVOSM) was used to make the investigation. The HVOSM is a computer model of an automobile and is used to simulate its dynamic response.

IMPLEMENTATION STATEMENT

The studies reported herein were conducted on request from several districts of the Texas Highway Department. The results were used by these districts in the evaluation of various design alternatives involving barriers on raised medians and on raised roadside areas.

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INTRODUCTION

At the request of several districts within the Texas Highway Department (THD), studies were conducted to determine the behavior of an automobile traversing selected curbs and sloped median configurations. The purpose of these studies was to determine if a potential existed for the automobile to vault a barrier placed near the curb or on the sloped medians.

The Highway-Vehicle-Object-Simulation-Model (HVOSM)(1) was used to determine the dynamic behavior of the automobile. A full-size automobile (weight of 4000 pounds) with a standard suspension system was simulated in each case. An extensive validation study has shown that the HVOSM can accurately predict vehicle behavior after traversing curbs (2).

STUDY A

Description of Problem

Cross sections of the two median configurations investigated in Study A are shown in Figures 1 and 2. They have been denoted Median Barrier 1A(MB1A) and Median Barrier 2A(MB2A) respectively.

In MB1A, the existing median consisted of a double flex beam barrier mounted on a 6-inch raised median, with a type C curb. Accidents had occurred in this median which resulted in vehicles going over the barrier. It was not known if the curb had been a factor in the vehicles vaulting the rail. Previous studies (2) had shown that the 6-inch type C curb introduced lift to an automobile that could potentially cause vaulting.

As a possible means of attenuating this lift, it was suggested that an asphalt "plug" be placed in the curb, as shown in Figure 1. HVOSM simulations were then made to determine an automobile's behavior for various encroachment angles into the plugged curb.

The investigation reported herein involves a determination of the automobile's behavior up to the time of impact with the barrier. Limitations of the Texas Transportation Institute's version of HVOSM precluded a simulation of the automobile's behavior after impact with the barrier.

HVOSM Simulations

Fourteen simulated traversals were made, eight for the MB1A plug and six for MB2A. Details of the runs are shown in Table 1. In all cases the automobile was assumed to be in a "free-wheeling" mode, i.e., no steer, power, or braking inputs were made. The automobile encroached to the right in each case, and first contact with the barrier would be with the right portion of the bumper.

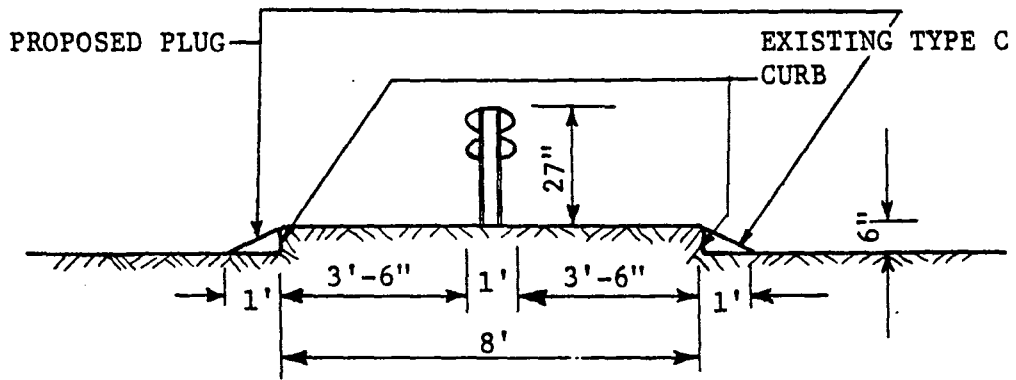


FIGURE 1. MEDIAN-BARRIER CONFIGURATION 1A(MB1A)

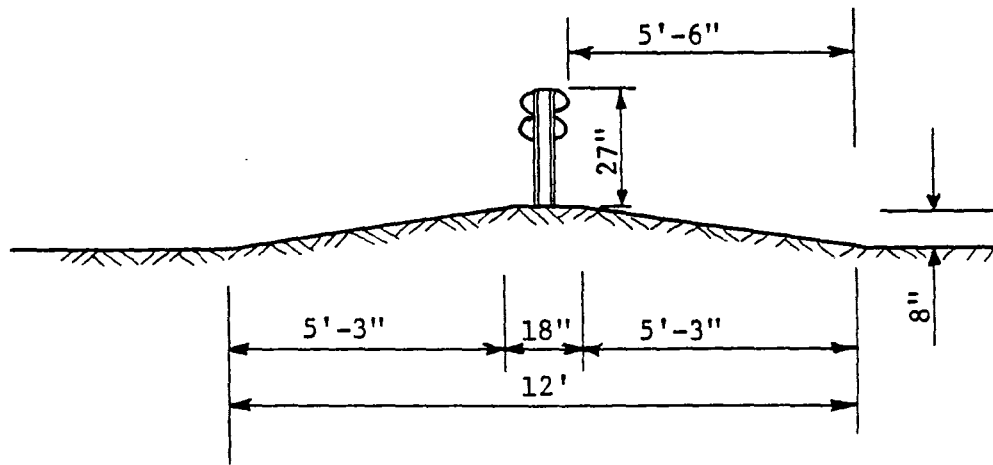


FIGURE 2. MEDIAN-BARRIER CONFIGURATION 2A(MB2A)

TABLE 1. STUDY "A" SIMULATIONS

| <u>MEDIAN BARRIER</u> | <u>RUN NO.</u> | <u>ENCROACHMENT ANGLE (DEG)</u> | <u>ENCROACHMENT SPEED (MPH)</u> | <u>TIRE-ROADWAY FRICTION COEFF., μ</u> |
|-----------------------|----------------|---------------------------------|---------------------------------|---|
| MB1A* | 1 | 15 | 50 | 0.8 |
| MB1A* | 2 | 15 | 60 | 0.8 |
| MB1A* | 3 | 15 | 70 | 0.8 |
| MB1A* | 4 | 15 | 60 | 0.5 |
| MB1A* | 5 | 7 | 50 | 0.8 |
| MB1A* | 6 | 7 | 60 | 0.8 |
| MB1A* | 7 | 7 | 70 | 0.8 |
| MB1A* | 8 | 7 | 60 | 0.5 |
| <hr/> | | | | |
| MB2A | 9 | 15 | 50 | 0.8 |
| MB2A | 10 | 15 | 60 | 0.8 |
| MB2A | 11 | 15 | 70 | 0.8 |
| MB2A | 12 | 7 | 50 | 0.8 |
| MB2A | 13 | 7 | 60 | 0.8 |
| MB2A | 14 | 7 | 70 | 0.8 |

*Plugged configuration.

Encroachment angles of 15 and 7 degrees were simulated for speeds of 50, 60, and 70 mph. Runs 4 and 8 were made to determine if the tire-pavement friction coefficient has any effect on the automobile's behavior.

Results

The results of each run are presented graphically in two figures. Figures 3 and 4 show the results of run number 1. Similar plots for the other 13 runs are given in Appendices A and B.

In the first figure, denoted as "Part 1", plots of bumper height, roll, and pitch are plotted versus the lateral distance off the roadway (perpendicular to roadway). In the second figure, denoted as "Part 2", plots of the lateral distance and vertical accelerations are plotted versus the distance along curb (parallel to roadway).

The solid line on the bumper height plots represents the path of the mid-height of the right most part of the bumper as determined from HVOSM. The mid-height of the bumper under a static equilibrium condition is approximately 16 inches above the ground. The bumper is approximately 12 inches in height. The dotted line is drawn 16 inches above the top of the flat median and where it intersects the barrier represents the height at which the mid-height of the bumper would "normally" contact the barrier.

The pitch angle is the rotation about the lateral axis of the automobile (left and right). It is a measure of the amount of rise of the front end of the automobile. A positive pitch angle means the front end is above its normal position. The roll angle is the rotation about the longitudinal axis of the automobile. A positive roll angle means the car's right side is lower than its normal position.

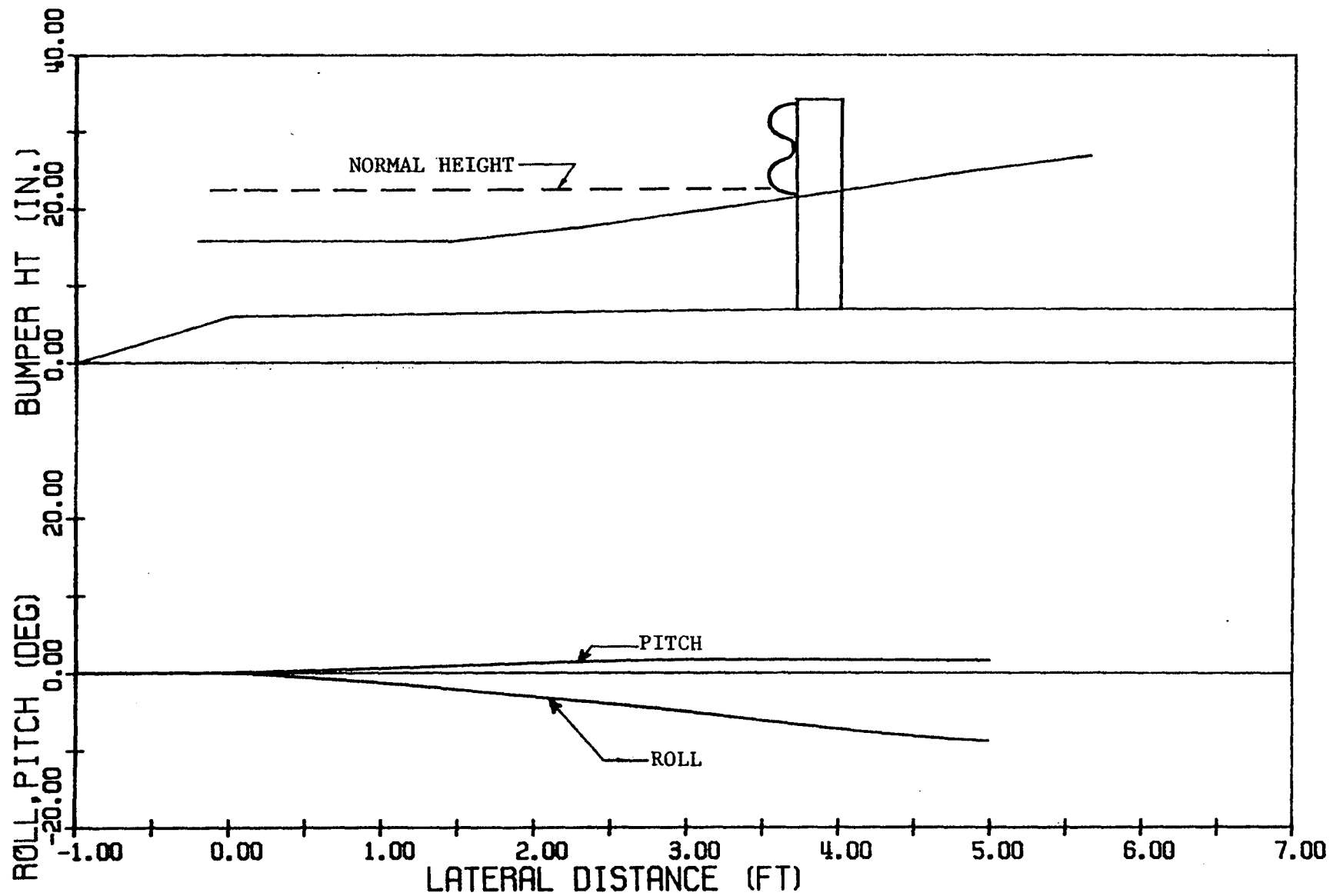


FIG. 3. VEHICLE BEHAVIOR, MEDIAN BARRIER 1A, 50 mph/15deg, $\mu=0.8$, PART 1

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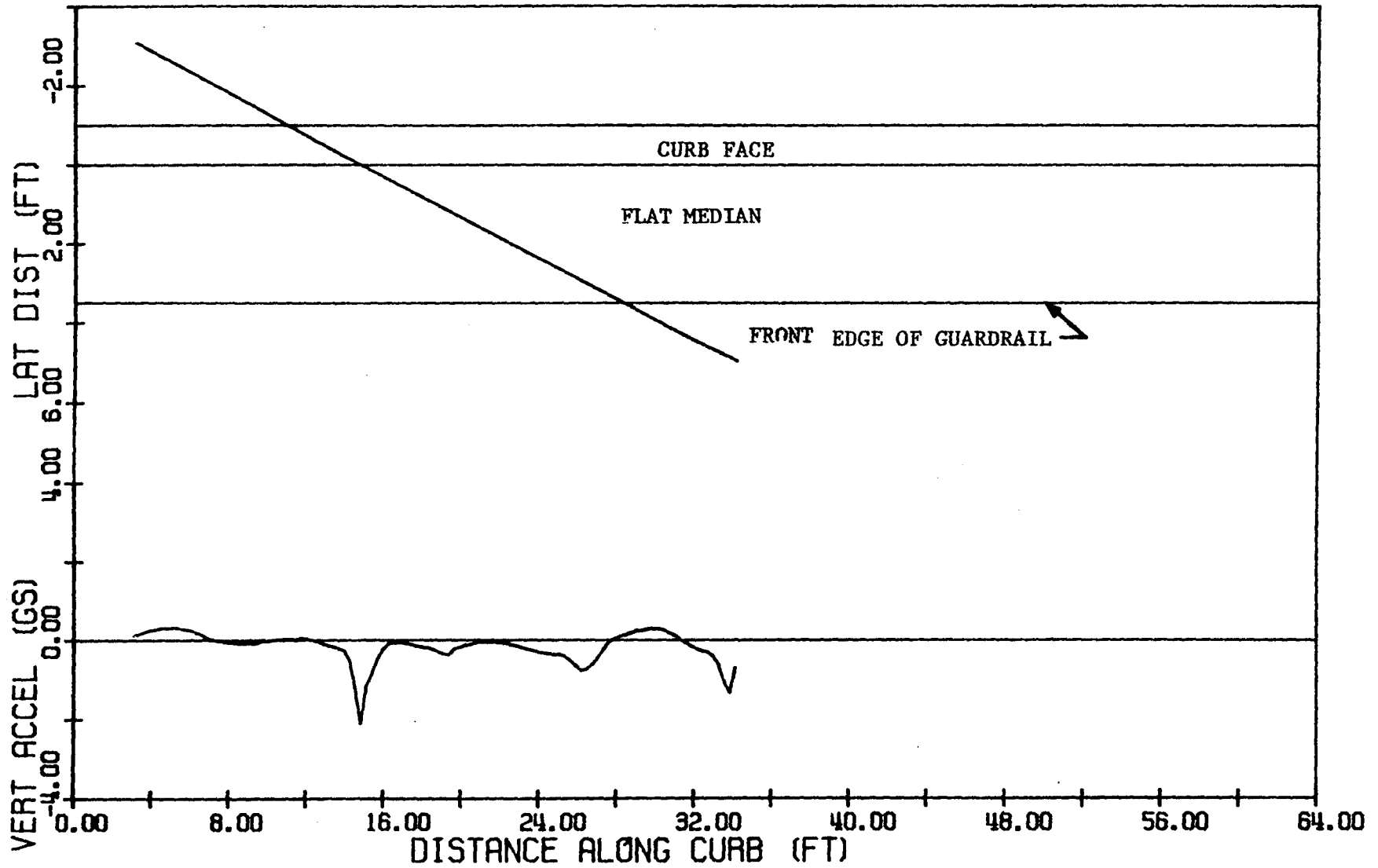


FIG. 4. VEHICLE BEHAVIOR, MEDIAN BARRIER 1A, 50mph/15 deg, $\mu=0.8$, PART 2

The lateral distance plots of part 2 represents the path of the center of gravity (C.G.) of the vehicle as it crosses the median. The vertical accelerations are those at the C. G. of the vehicle.

It can be seen by comparing Figures A5, A6, A13, and A14 with Figures A1, A2, A9, and A10 (figures are in Appendix) that the friction coefficient has no significant effect on the vehicle's behavior.

The bumper position relative to the barrier at impact is probably the most significant factor to consider in evaluation the potential for vaulting. Table 2 summarizes the bumper heights at impact.

For the MB1A plugged configuration, the 50 mph/7 degree encroachment condition resulted in a bumper height on impact of 6 inches above normal. Figure 5 shows the automobile's behavior up to the point of impact ($T=0.620$ SEC). Figure 6 shows an enlarged drawing of the automobile at impact. Also, at impact the roll angle is about 11.5 degrees (right side of auto above normal position). However, the roll angle is decreasing at impact. The pitch angle is small. From the above information, it appears doubtful that the automobile would go over the rail. There would be a distant possibility however that the roll angle of the auto would increase after impact with the barrier, i.e., the car could possibly roll over away from the barrier.

Other observations on the MB1A plug results are as follows:

(a) There was no appreciable redirection of the automobile upon contact with the plug for any of the 8 simulations.

(b) The accelerations would not cause serious injuries.

As shown in Table 2, the MB2A configuration did not cause any appreciable bumper height problem. In fact, bumper contact will in most cases occur below the normal height. In the 60 mph and 70 mph runs at 15 degrees,

TABLE 2. SUMMARY OF BUMPER HEIGHTS AT IMPACT

| ENCROACHMENT CONDITIONS | | BUMPER HEIGHT(IN) ¹ | |
|----------------------------|----------------|--------------------------------|------|
| SPEED (MPH) | ANGLE (DEG) | MB1A ² | MB2A |
| 50 | 7 | +6.0 | +0.5 |
| 60 | 7 | +4.0 | -0.5 |
| 70 | 7 | +2.5 | -2.0 |
| 50 | 15 | -2.0 | -4.5 |
| 60 | 15 | -2.5 | -6.0 |
| 70 | 15 | -3.5 | -6.0 |

¹ Measured with respect to normal impact height.
Positive values indicate the bumper is above its normal impact height and negative numbers indicate it is below.

² Plugged configuration.

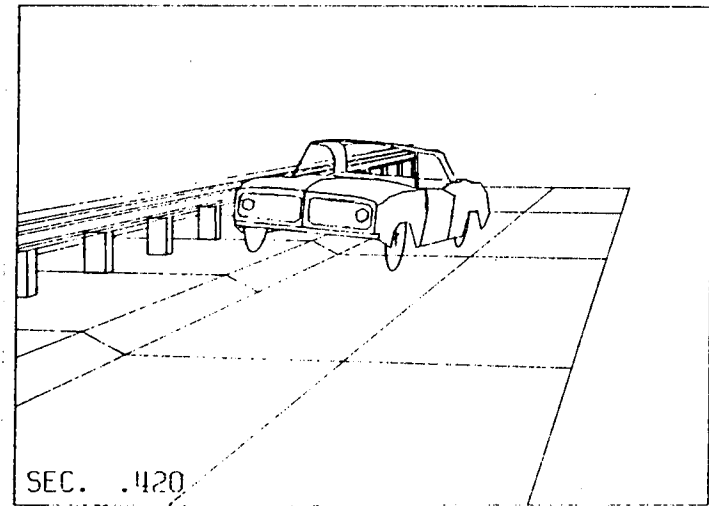
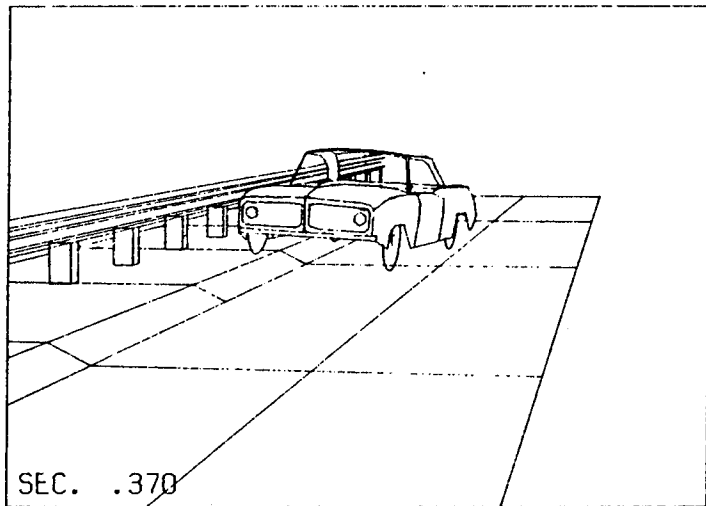
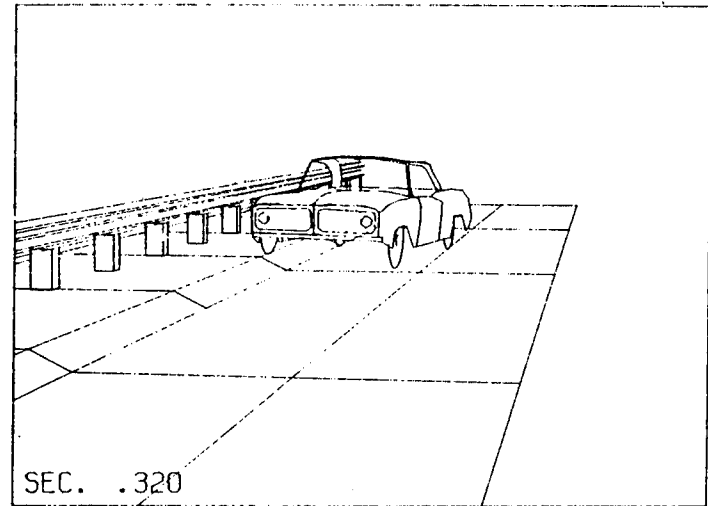
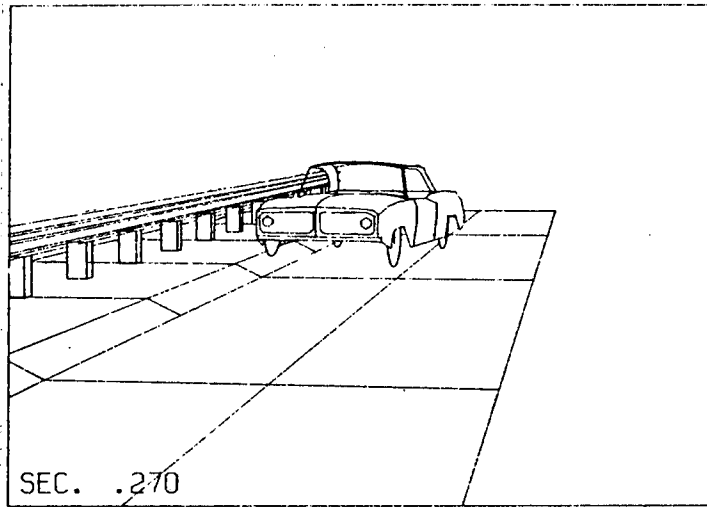


FIGURE 5. VEHICLE BEHAVIOR FOR 50 mph/7 deg ENCROACHMENT, MEDIAN BARRIER 1A PLUG

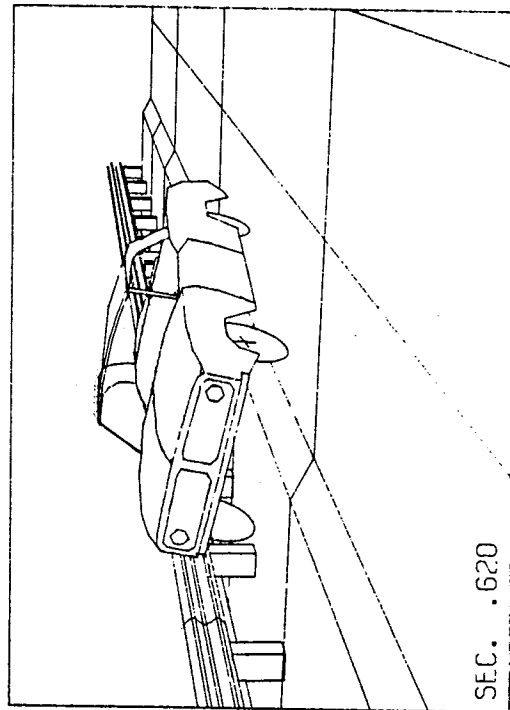
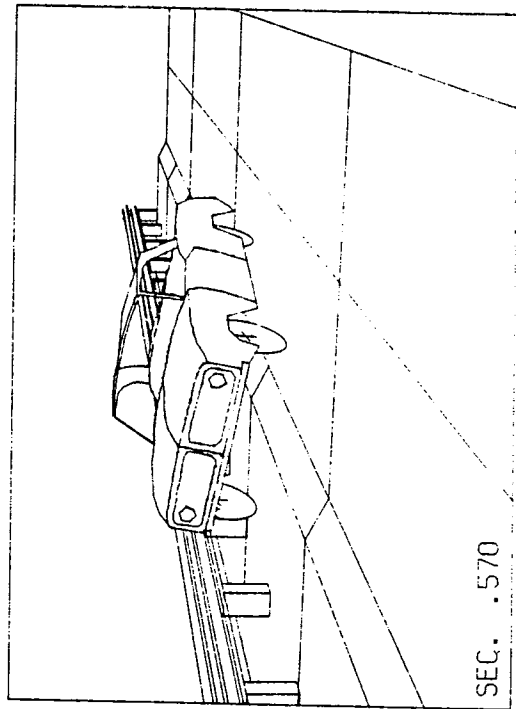
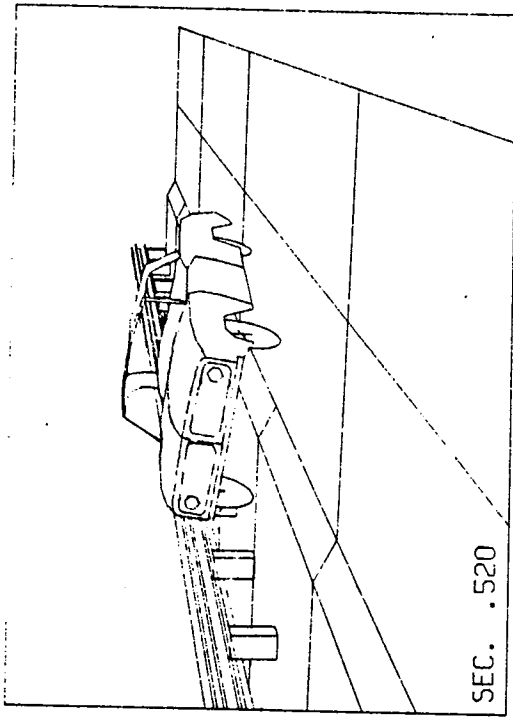
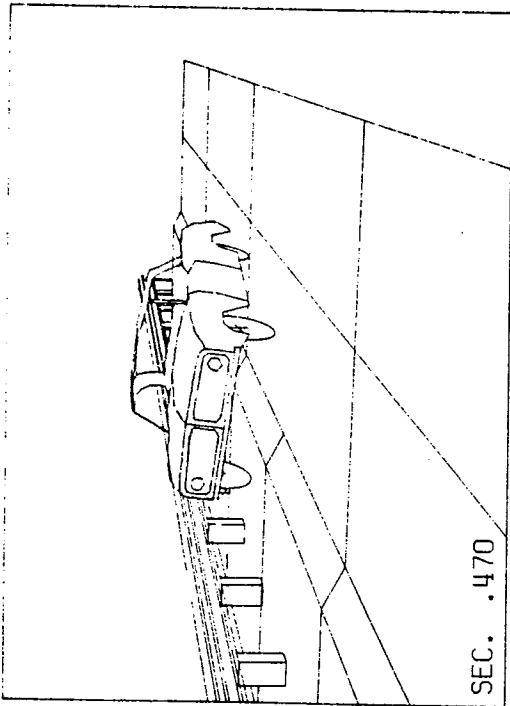


FIGURE 5. CONCLUDED

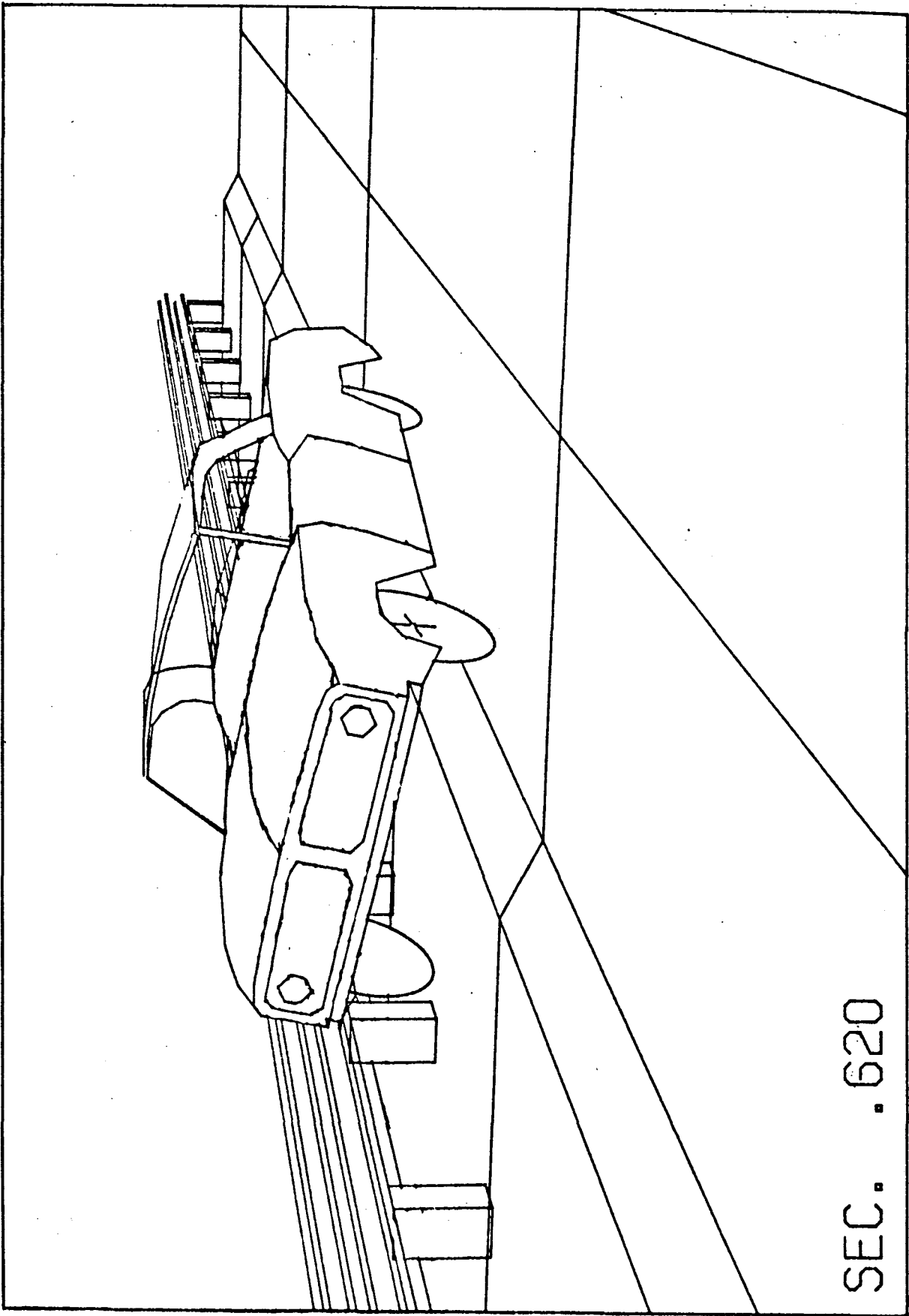


FIGURE 6. IMPACT AT 50 mph/7 deg, MEDIAN BARRIER 1A PLUG

the bumper will contact the barrier 6 inches below its normal contact height. Figure 7 shows the automobile's behavior during the 60 mph/15 degree encroachment and up to impact (T=0.310 SEC). Figure 8 shows an enlarged drawing of the automobile at impact. From an analysis of the MB2A results, it appears that the only problem which could occur would be snagging of the vehicle on the posts. However, a rub rail would eliminate this problem.

Other observations on the MB2A configuration are as follows:

(a) No appreciable redirection occurred prior to impact with the barrier in any of the 6 cases simulated.

(b) Accelerations were well below values which would cause serious injuries.

(c) Very little pitch or roll occurred.

Comparison of the Type C Curb with the Plug

Figures 9, 10, and 11 show a comparison of vehicle bumper height versus lateral distance for the 6 inch type C curb and the plug. Data on the C curb were obtained from another TTI study (2).

From Figure 9, it can be seen that the C curb causes about 5 inches more lift at impact than does the plug, for encroachments at 60 mph and 15 degrees. Figure 10 shows the comparison for a speed of 60 mph and an encroachment angle of 7 degrees. In this case the C curb redirects the vehicle before impact with the guardrail while the plug does not. At impact the plug causes the bumper to rise about 7 inches above its normal contact height. Although the C curb redirects the vehicle at 60 mph and 7 deg., it should be noted that the C curb causes the bumper to rise about 9 inches above the normal contact height and at that time the bumper is

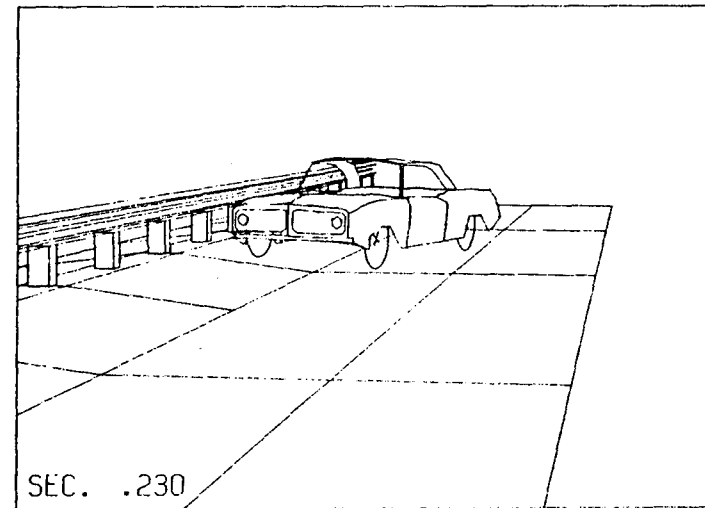
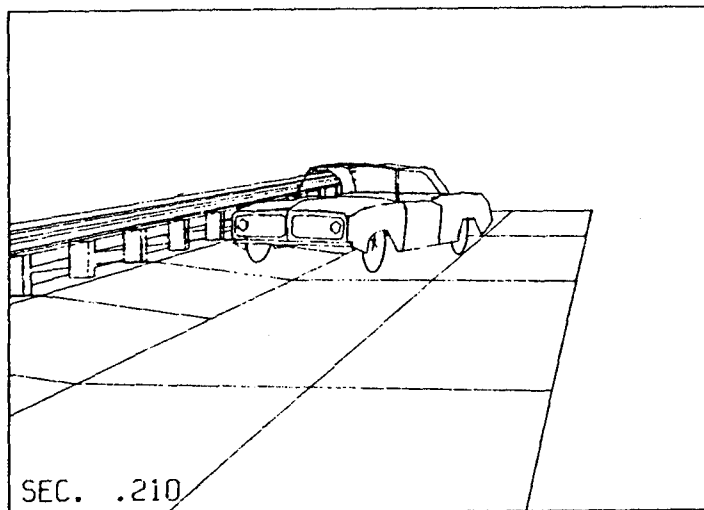
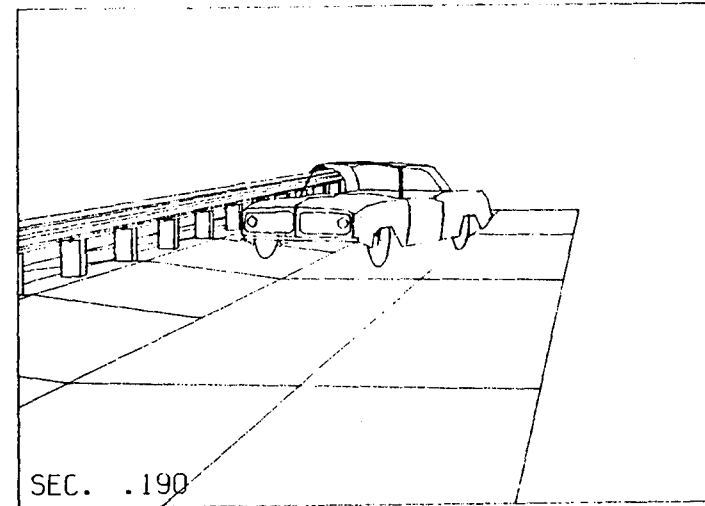
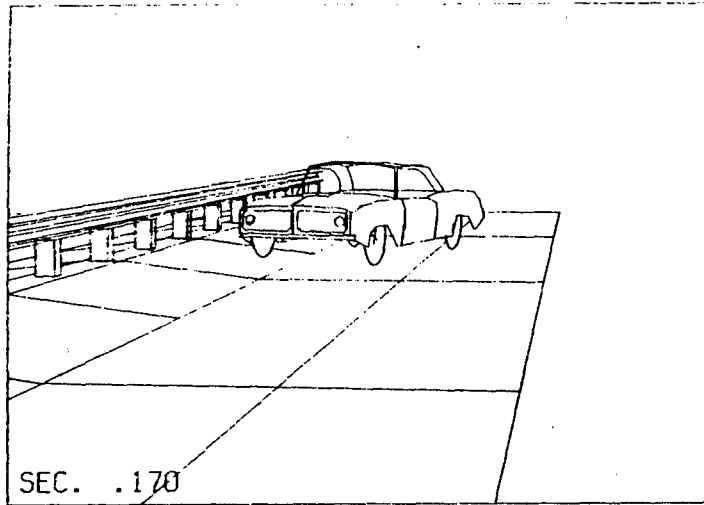


FIGURE 7. VEHICLE BEHAVIOR FOR 60 mph/15 deg ENCROACHMENT, MEDIAN BARRIER 2A

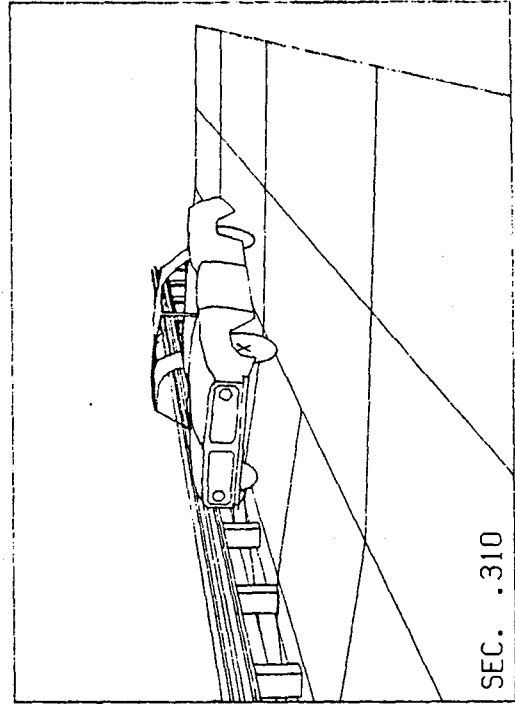
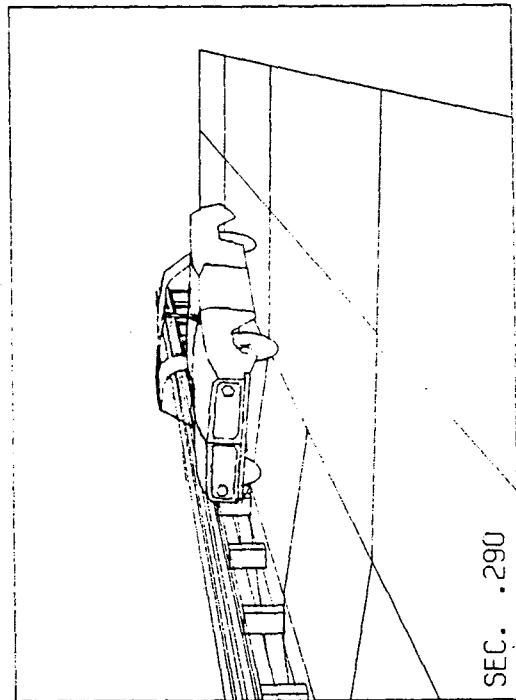
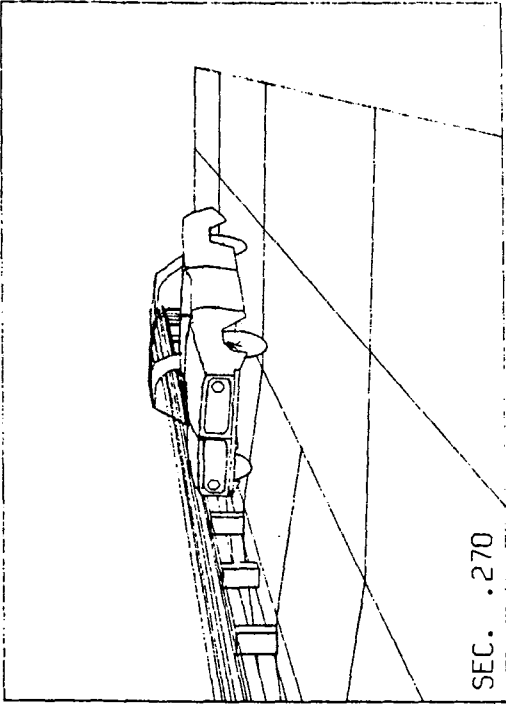
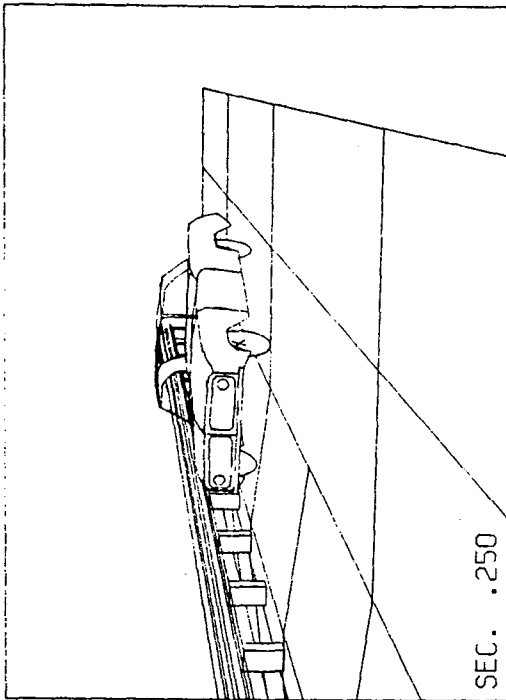


FIGURE 7. CONCLUDED

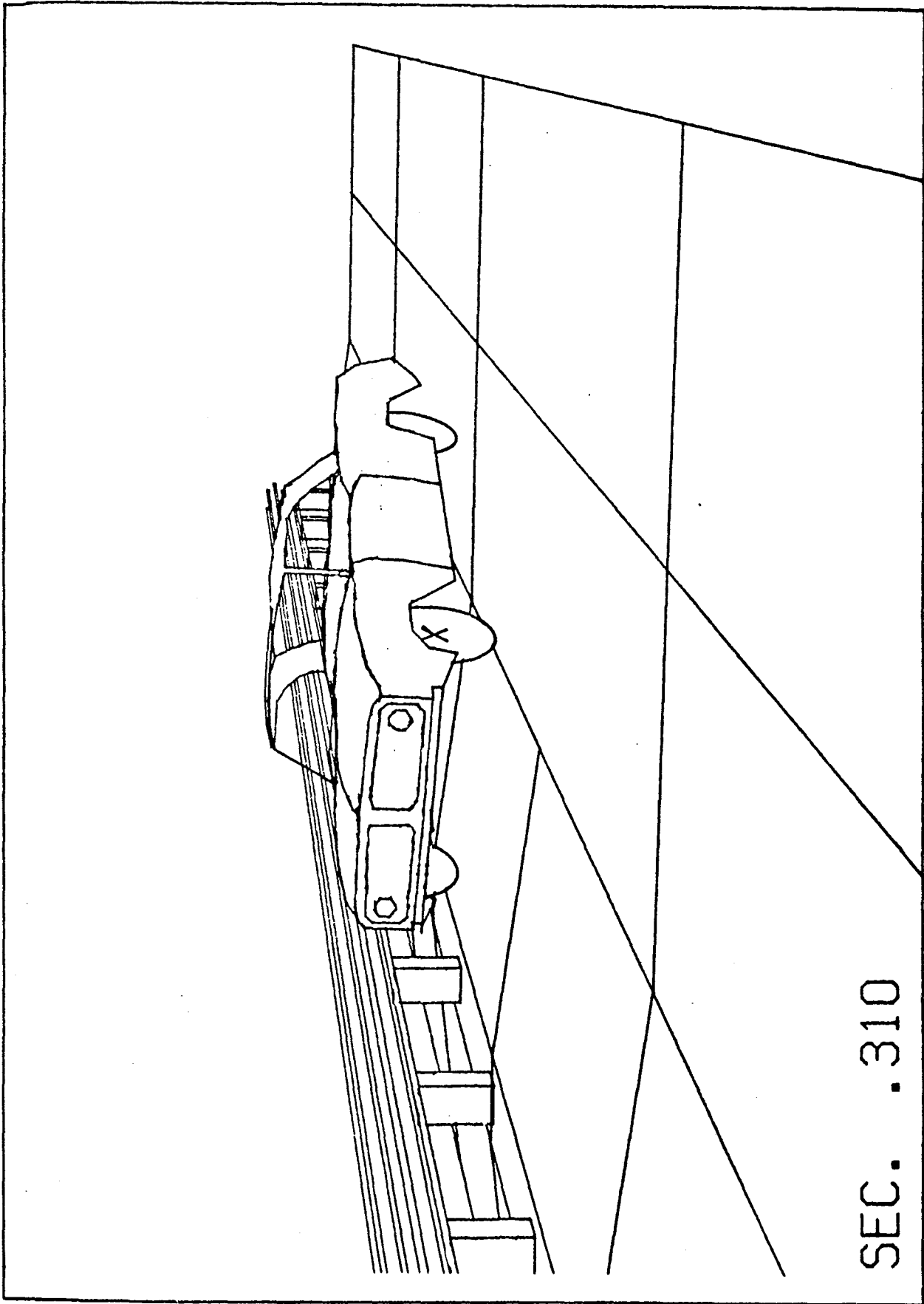


FIGURE 8. IMPACT AT 60 mph/15 deg, MEDIAN BARRIER 2A

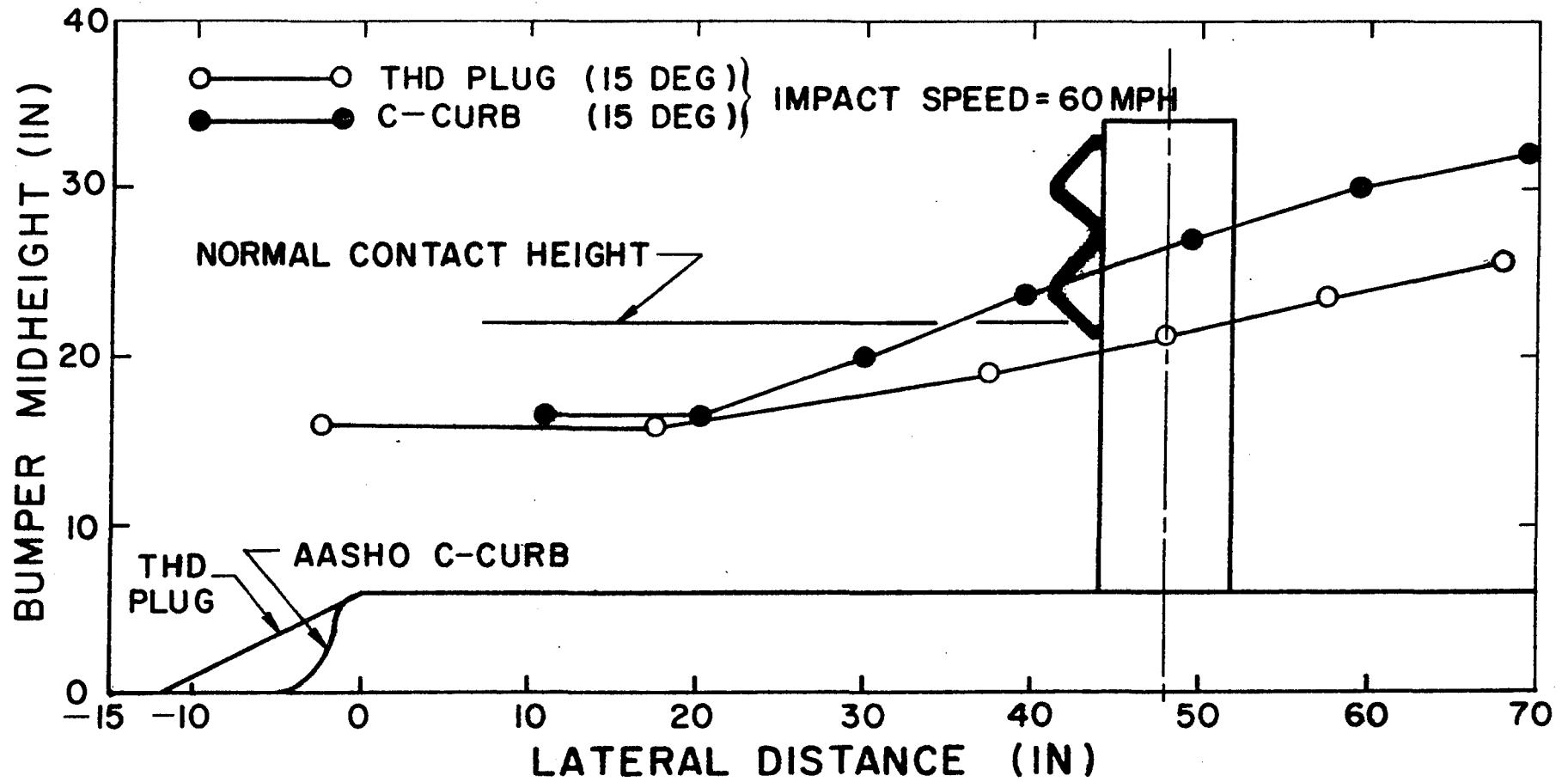


FIGURE 9. PLUG VERSUS C CURB, 60 mph/15 degrees

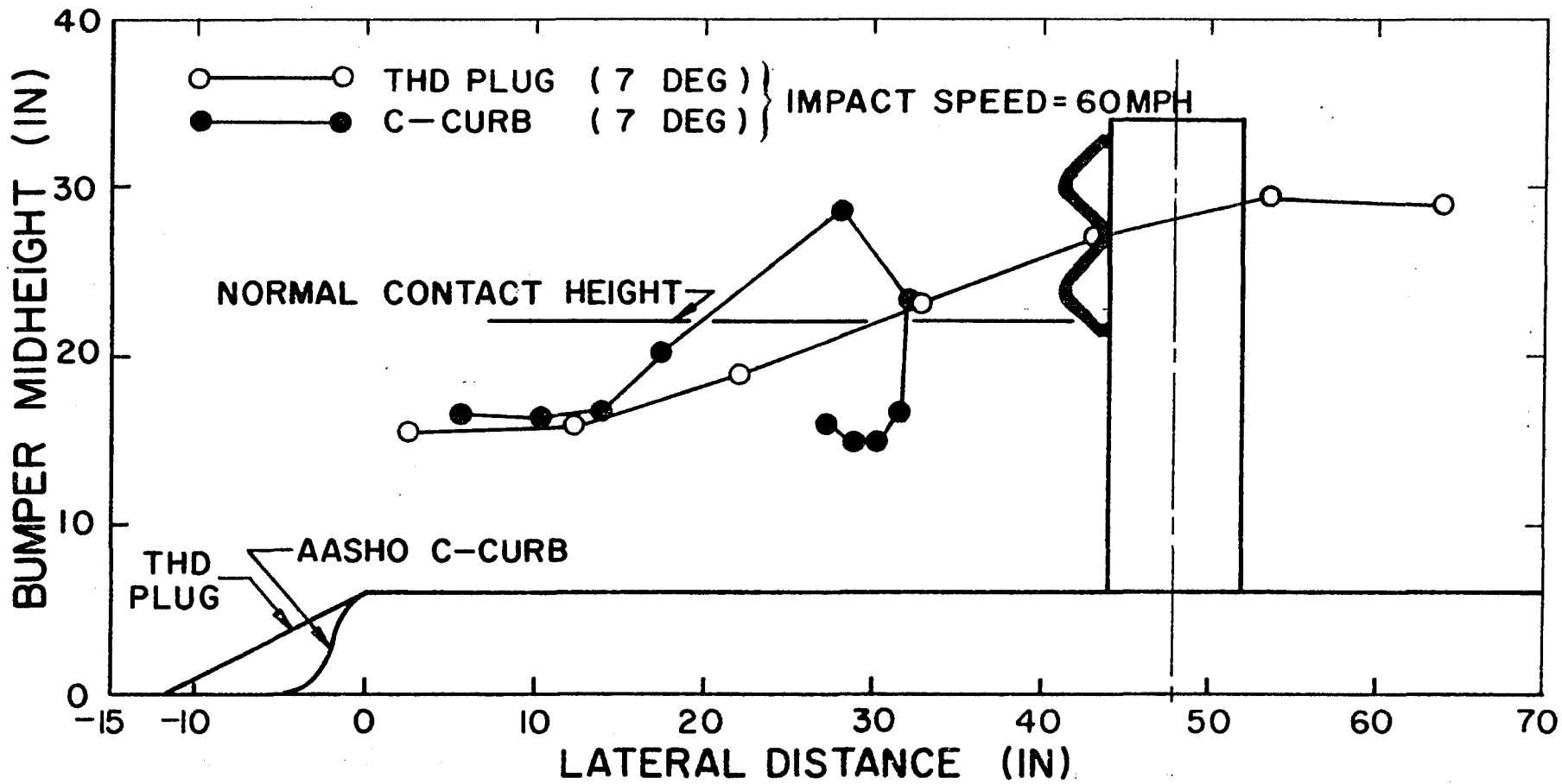


FIGURE 10. PLUG VERSUS C CURB, 60 mph/7 degrees

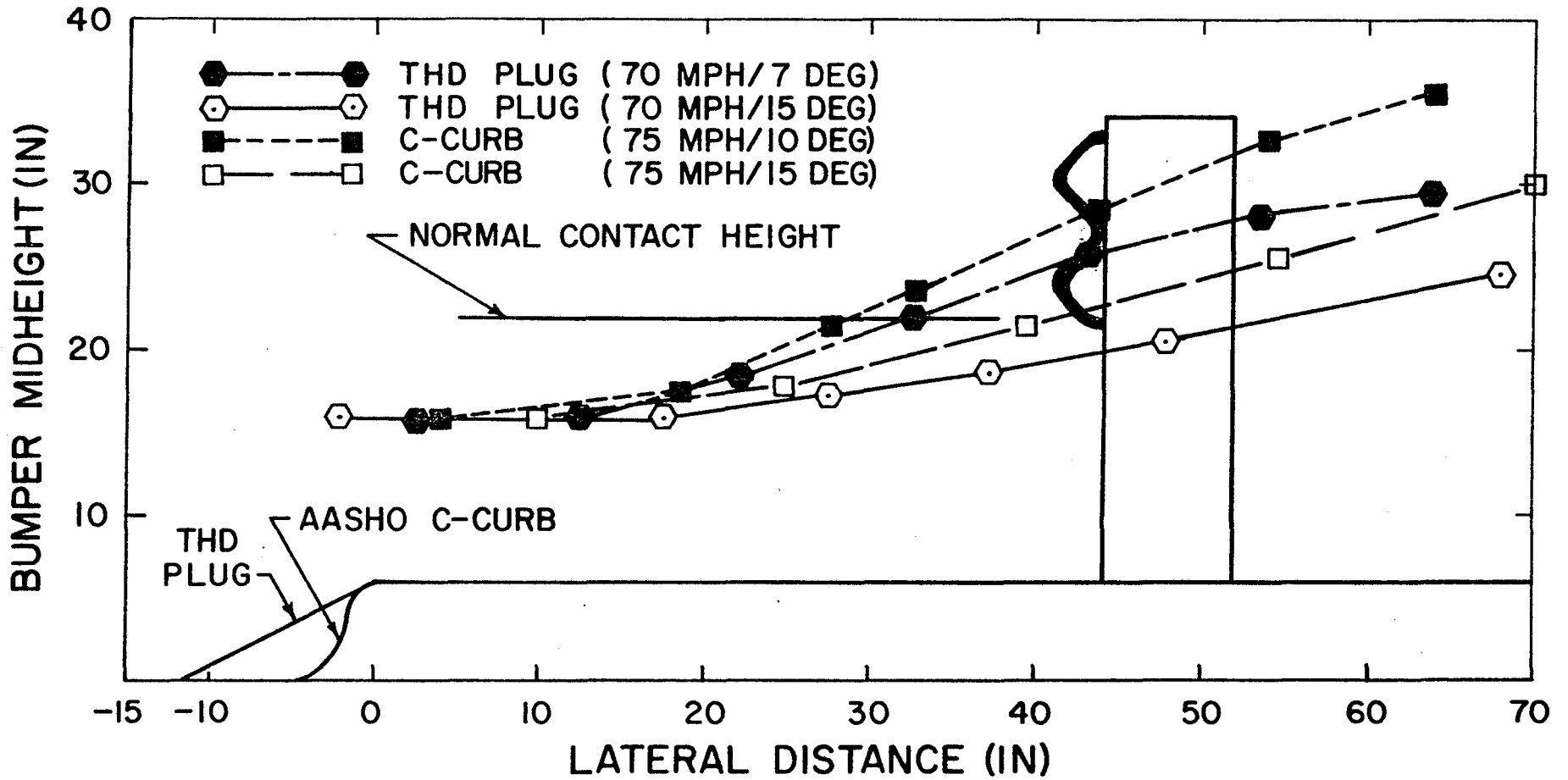


FIGURE 11. PLUG VERSUS C CURB, VARIOUS SPEEDS AND ANGLES

about 12 1/2 inches from the guardrail. Thus, for the C curb, a slight increase in the encroachment angle above 7 deg. would probably cause contact with the guardrail while the bumper was still considerably higher than its normal contact height.

Figure 11 shows the comparison for various speeds and angles. For these conditions, it appears that the C curb will cause higher bumper rise than the plug. However, since the encroachment conditions differed slightly, an exact comparison could not be made between the two configurations.

STUDY B

Description of Problem

Cross sections of the three median configurations investigated in Study B are shown in Figures 12 through 14. These have been denoted as MB1B, MB2B, and MB3B, respectively. Note that in MB1B and MB2B there is both an *existing* and a *proposed* configuration to consider. Figure 15 shows the cross section of the roadside configuration investigated, and it is denoted as RB.

As in Study A, the objective in this study was to determine the behavior of an automobile as it traversed these various median and roadside configurations. The potential for each of these configurations to cause an automobile to vault over the barrier could thus be determined. Limitations of the TTI version of HVOSM precluded a simulation of the automobile's behavior after impact with the barrier.

In MB1A, a barrier is placed at the center of a 16-foot median. In the *existing* configuration, an 8-inch curb is used, while the *proposed* configuration consists of a sloped median. The MB2A configuration is similar to MB1A except the median is 5-foot in width.

The MB3B configuration consists of a 4-foot raised median, with two different types of median barriers, the concrete median barrier (CMB) and the metal beam guard fence (MBGF). The RB configuration consists of a standard guardrail placed 3-foot 6-inches behind an 8-inch curb.

HVOSM Simulations

A total of 30 simulations were made in Study B. The matrix of simulated conditions is shown in Table 3. In all cases, the automobile was assumed to be in a "free-wheeling" mode, i.e. no steer inputs were made.

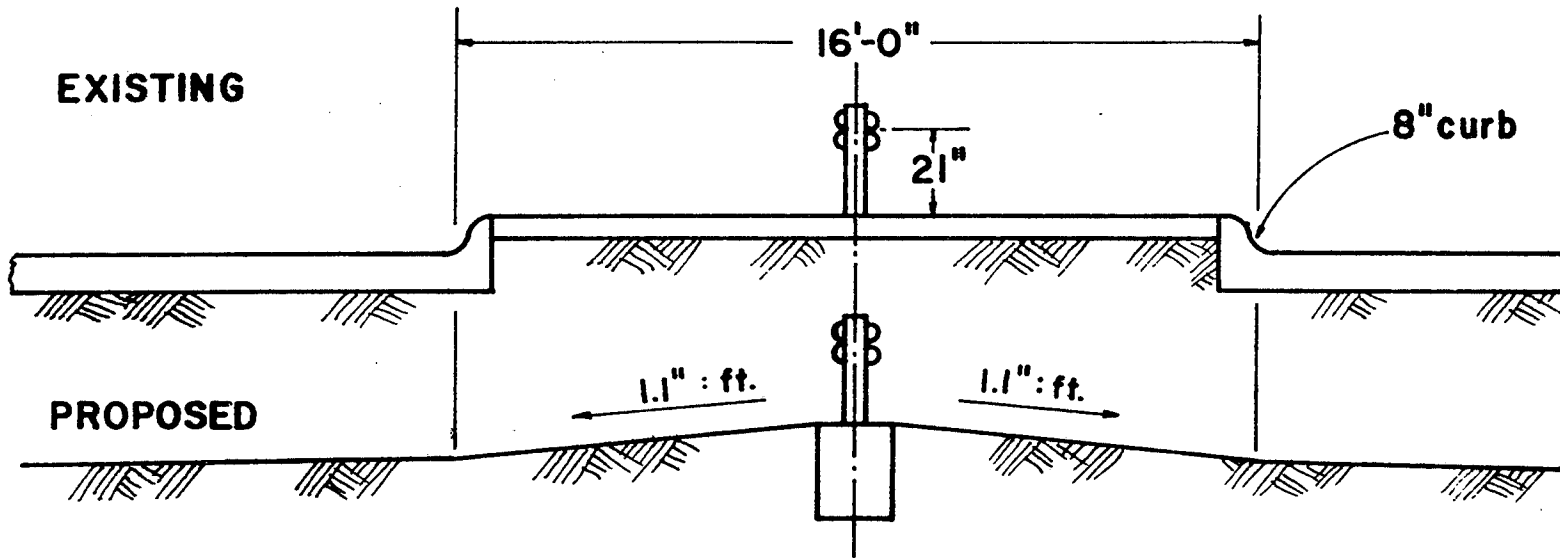
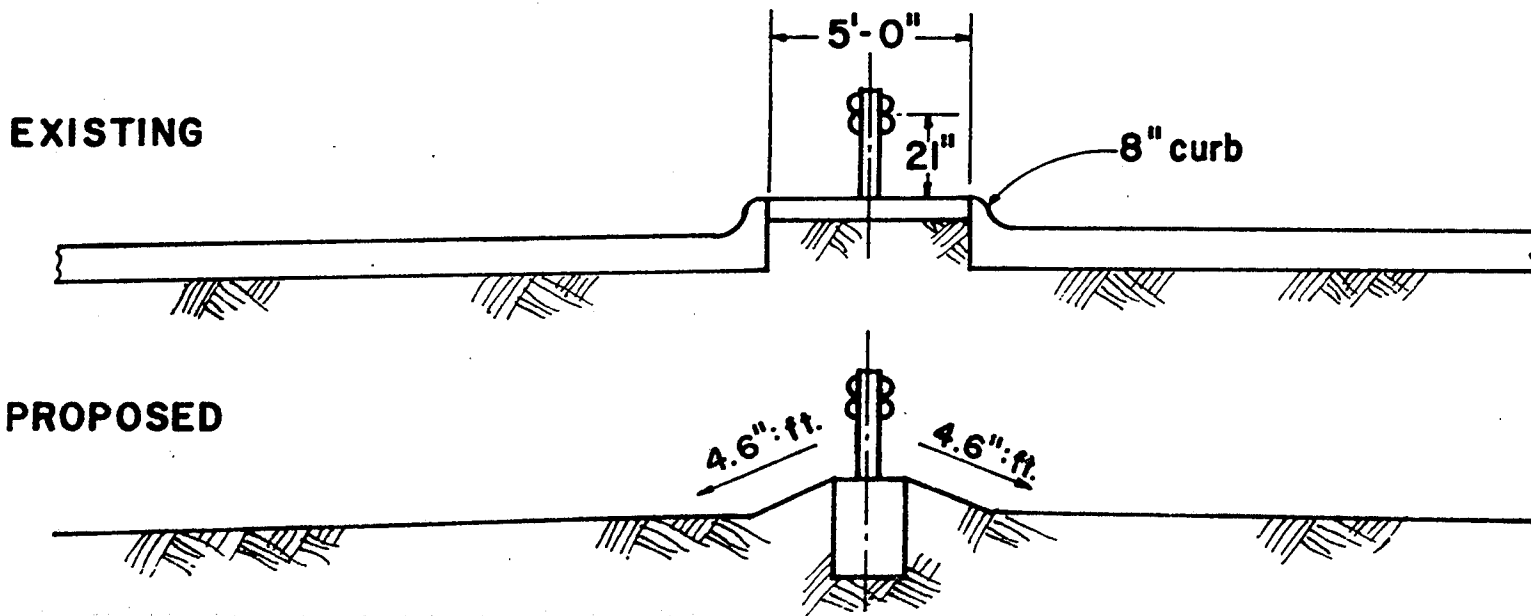
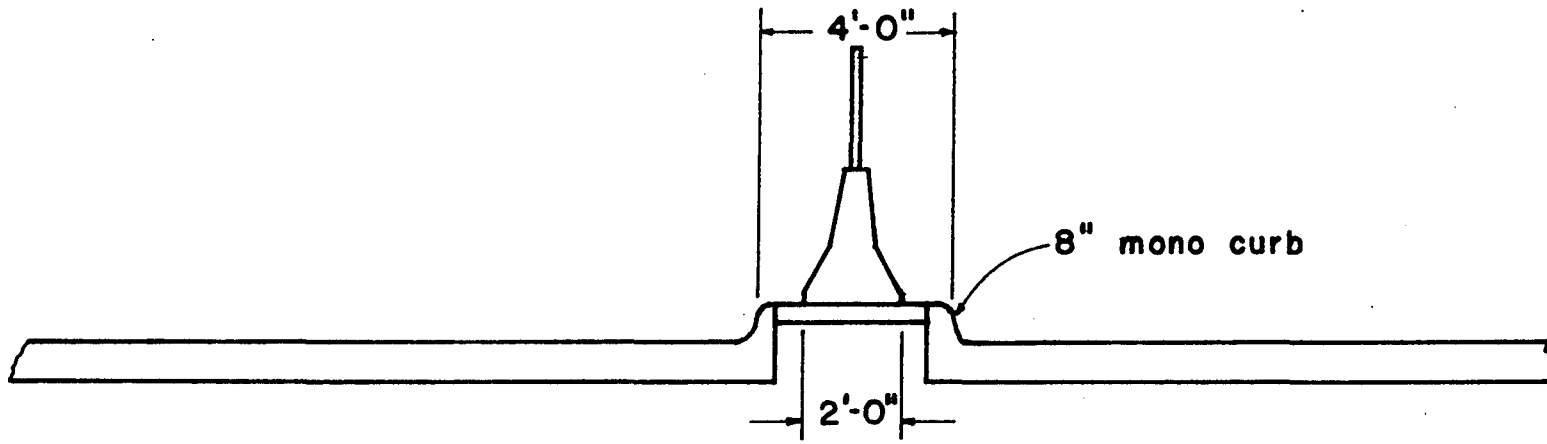
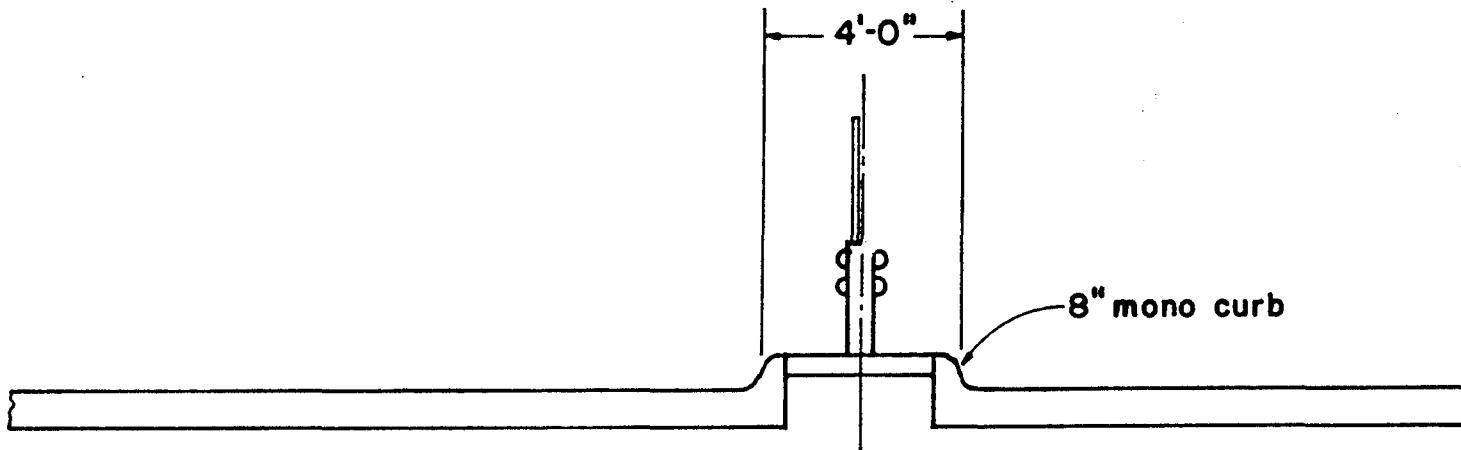


FIGURE 12. MEDIAN-BARRIER CONFIGURATION 1B(MB1B)





CONCRETE MEDIAN BARRIER (CMB)



METAL BEAM GUARD FENCE (MBGF)

FIGURE 14. MEDIAN-BARRIER CONFIGURATION 3B(MB3B)

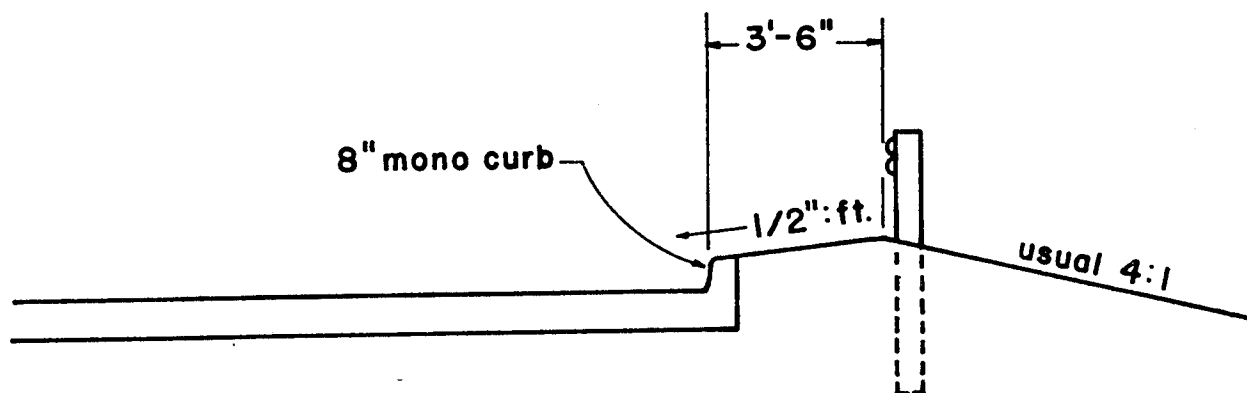


FIGURE 15. ROADSIDE-BARRIER CONFIGURATION (RB)

TABLE 3. MATRIX OF SIMULATIONS FOR STUDY B

| <u>CONFIGURATION</u> | <u>ENCROACHMENT CONDITIONS</u> | | | | | | | | |
|----------------------|--------------------------------|-----------|-----------|--------------------|-----------|-----------|--------------------|-----------|-----------|
| | <u>SPEED (MPH)</u> | | | | | | | | |
| | <u>40</u> | | | <u>50</u> | | | <u>60</u> | | |
| | <u>ANGLE (DEG)</u> | | | <u>ANGLE (DEG)</u> | | | <u>ANGLE (DEG)</u> | | |
| | <u>5</u> | <u>10</u> | <u>15</u> | <u>5</u> | <u>10</u> | <u>15</u> | <u>5</u> | <u>10</u> | <u>15</u> |
| MB1B EXISTING | | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ |
| MB1B PROPOSED | | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ |
| MB2B EXISTING | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| MB2B PROPOSED | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Simulations were not necessary for configurations MB3B and RB since the results of the other simulations could be used to evaluate these configurations.

Results

A discussion of the results for each respective configuration follows. The figures show the trajectory of the mid-height (16 inches above ground) of the right side of the front bumper. The "normal contact height" shown on each figure is 16 inches above the base of the barrier. This is the height at which the bumper would contact the rail if the barrier were on level ground.

MB1B (8-inch curb on a 16-foot median). The results of the runs on this configuration are shown in Figures 16 through 19. It is clear that the *proposed* configuration is the most desirable alternative in this case. For 15 degree encroachments, the trajectory of the vehicle is quite pronounced after crossing the *existing* curb, as shown in Figures 16, 17, and 18. At 60 mph and 15 degrees, (Figure 18), it appears that the vehicle would clear the barrier. The *proposed* median offers no such undesirable traits. However, a rub rail on the barrier would be desirable for the *proposed* median configuration since the bumper would contact the barrier in a lower than normal position in most cases. At 10 degree encroachment angles the *existing* curb redirected the vehicle. Figure 19 shows the 10 degree encroachment results for the *proposed* configuration. No 5 degree encroachments were simulated.

MB2B (8-inch curb on a 5-foot median) The results of the runs on this configuration are shown in Figures 20 through 23. In this case, it is not clear which of the two alternatives offers the most desirable configuration. It does not appear the vehicle will vault over the barrier in either

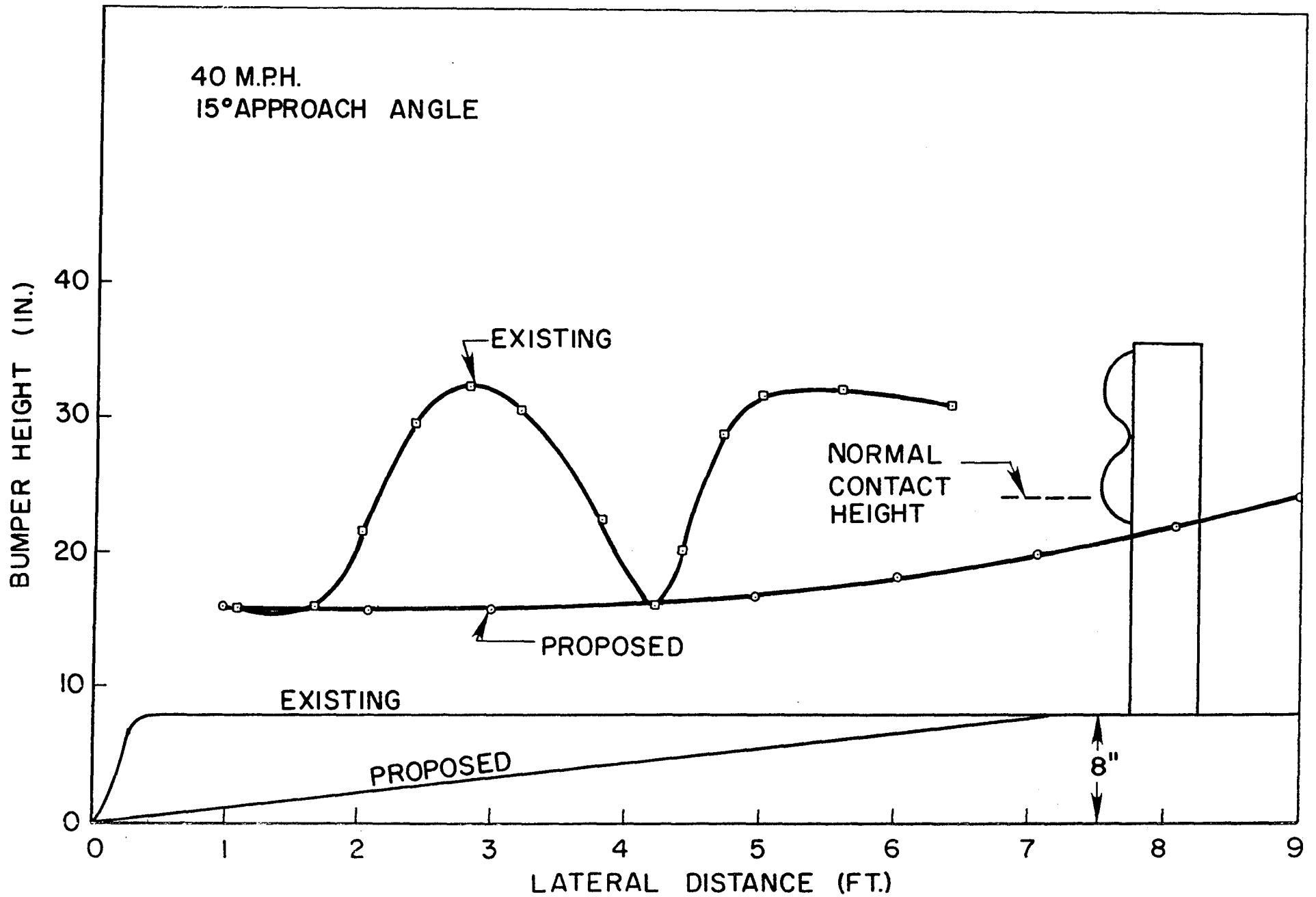
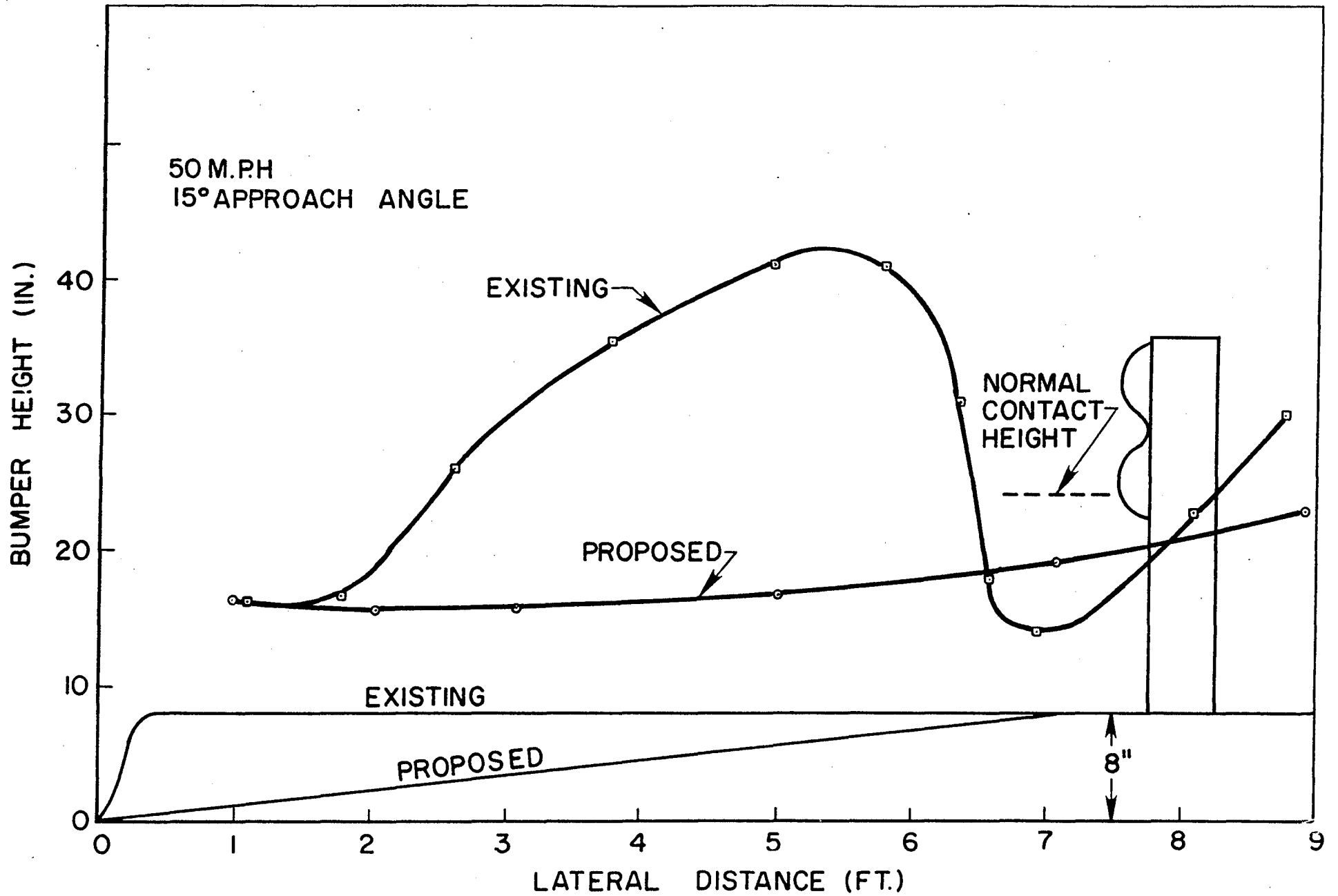


FIGURE 16. BUMPER HEIGHT VERSUS LATERAL DISTANCE, MB1B, 40 mph/15 deg



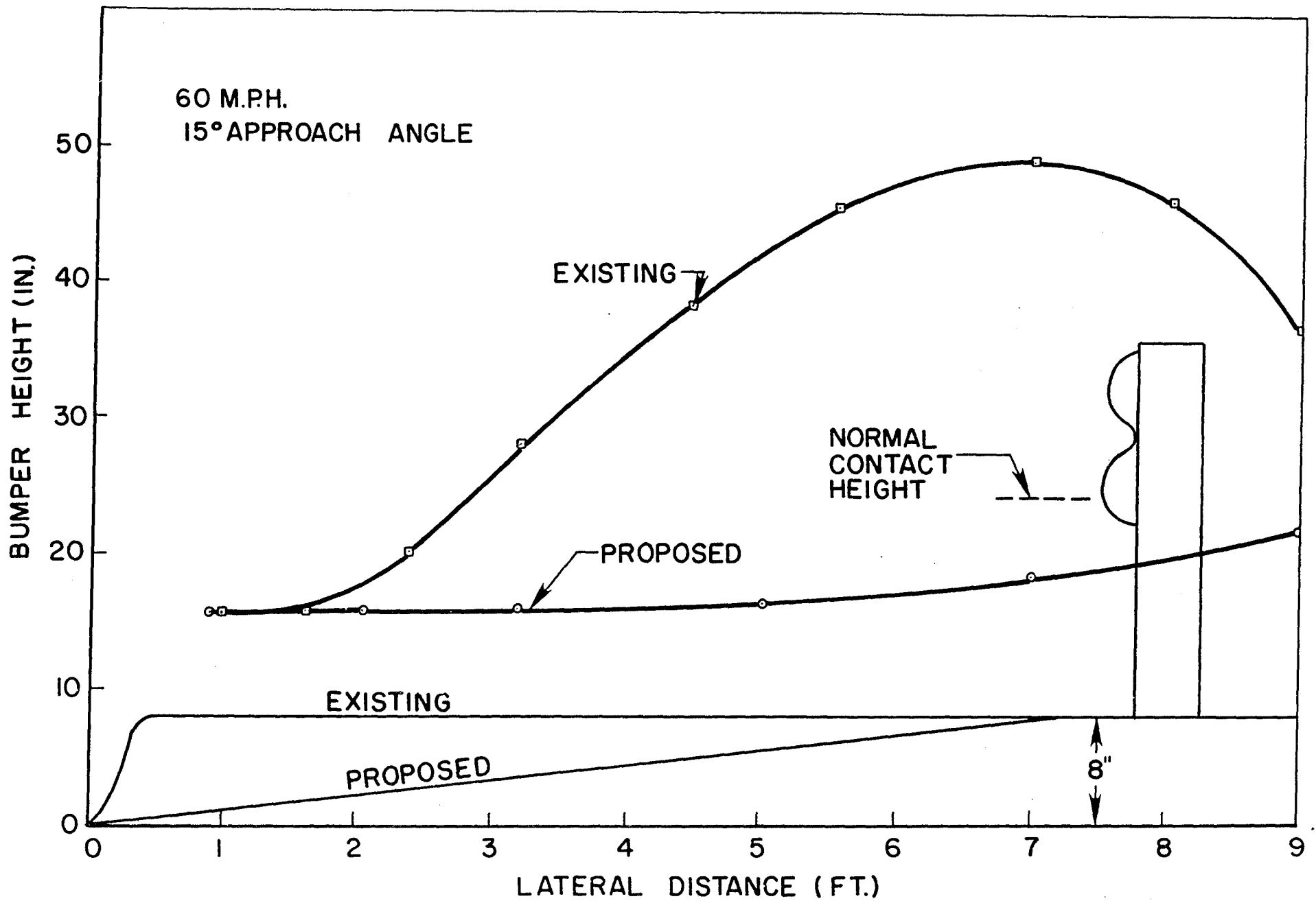


FIGURE 18. BUMPER HEIGHT VERSUS LATERAL DISTANCE, MB1B, 60 mph/15 deg

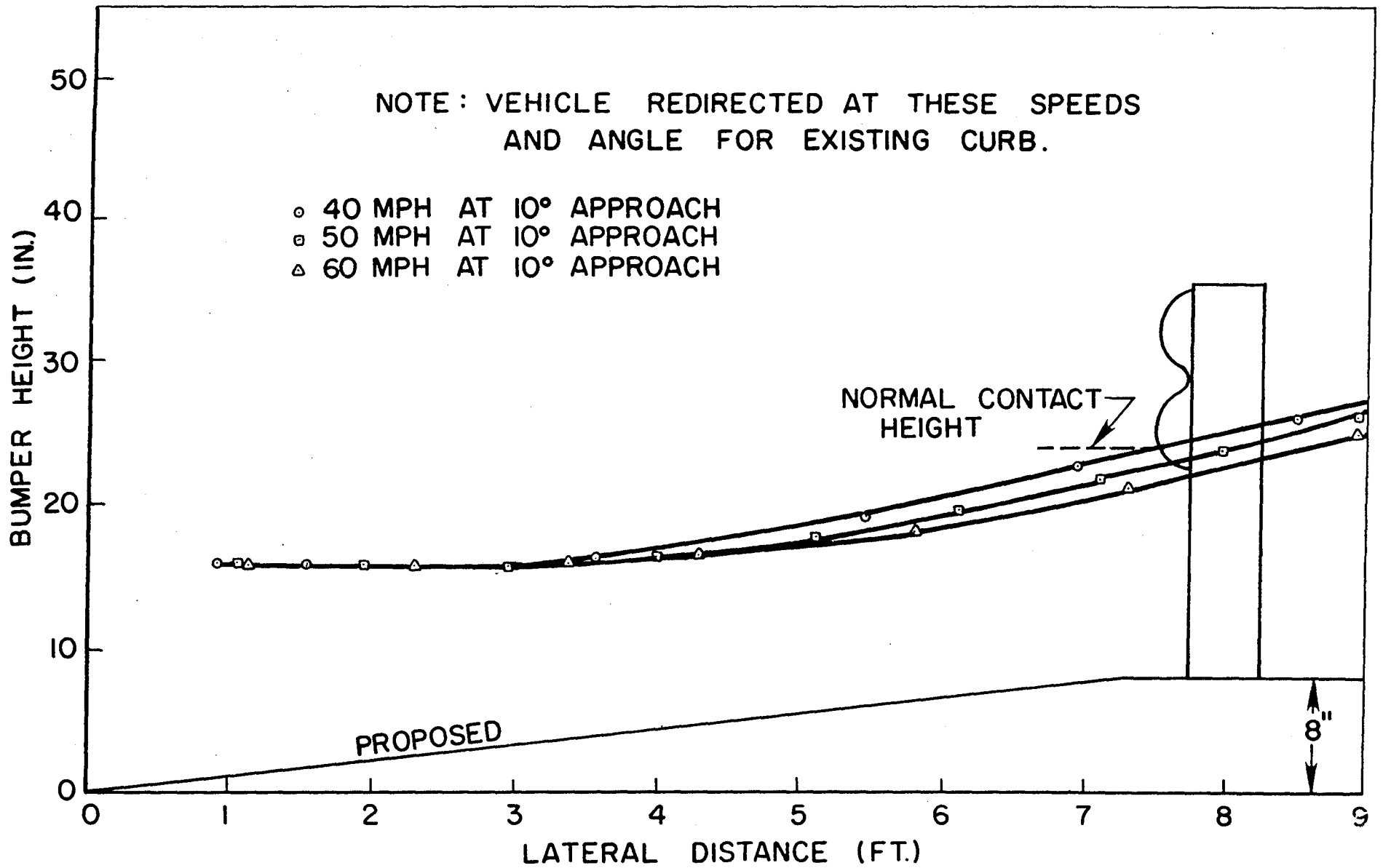


FIGURE 19. BUMPER HEIGHT VERSUS LATERAL DISTANCE, MB1B, 40 mph, 50 mph, 60 mph/10 deg

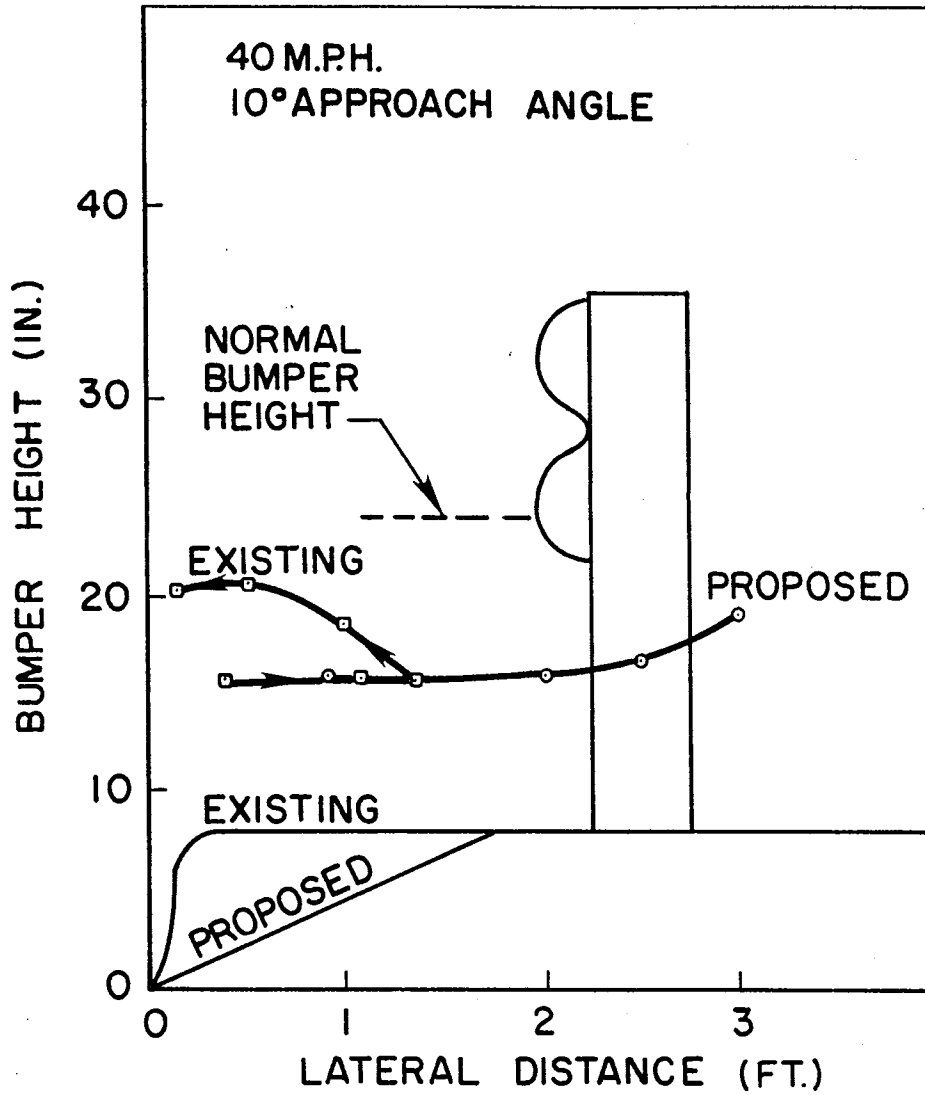


FIGURE 20. BUMPER HEIGHT VERSUS LATERAL DISTANCE, MB2B, 40 mph/10 deg

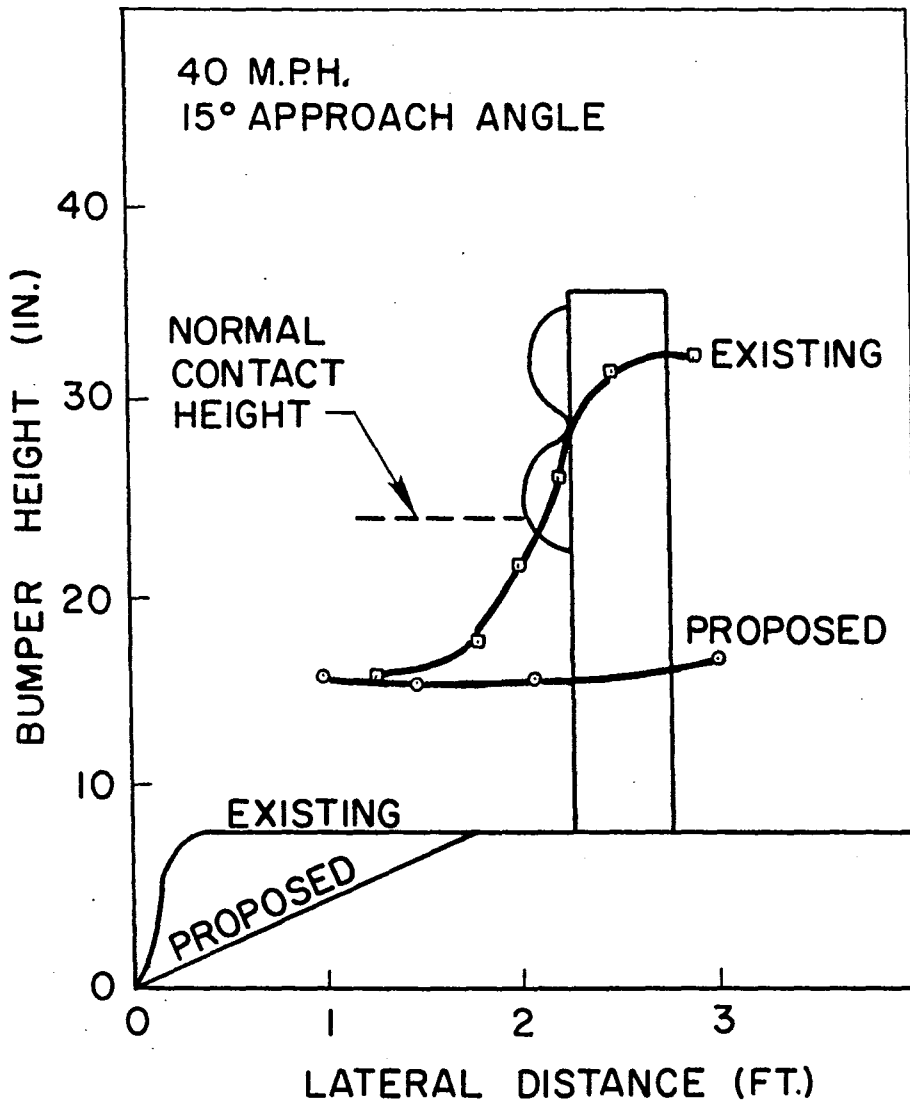


FIGURE 21. BUMPER HEIGHT VERSUS LATERAL DISTANCE, MB2B, 40 mph/15 deg

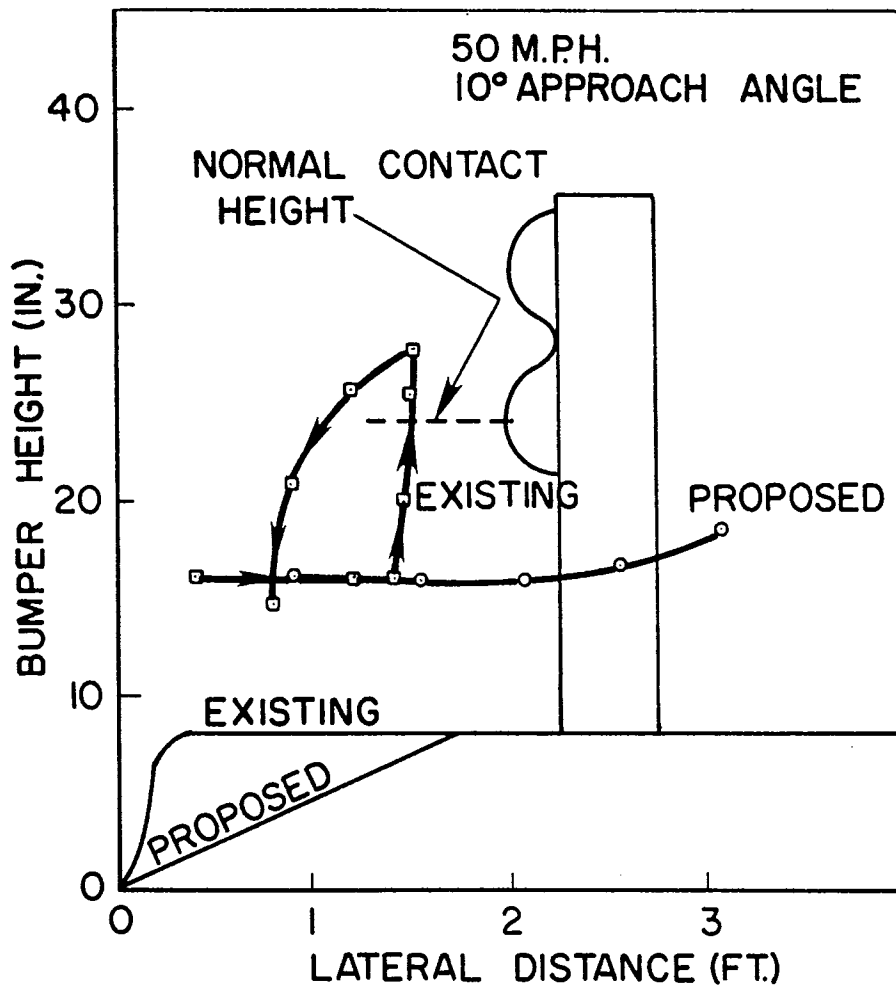


FIGURE 22. BUMPER HEIGHT VERSUS LATERAL DISTANCE, MB2B, 50 mph/10 deg

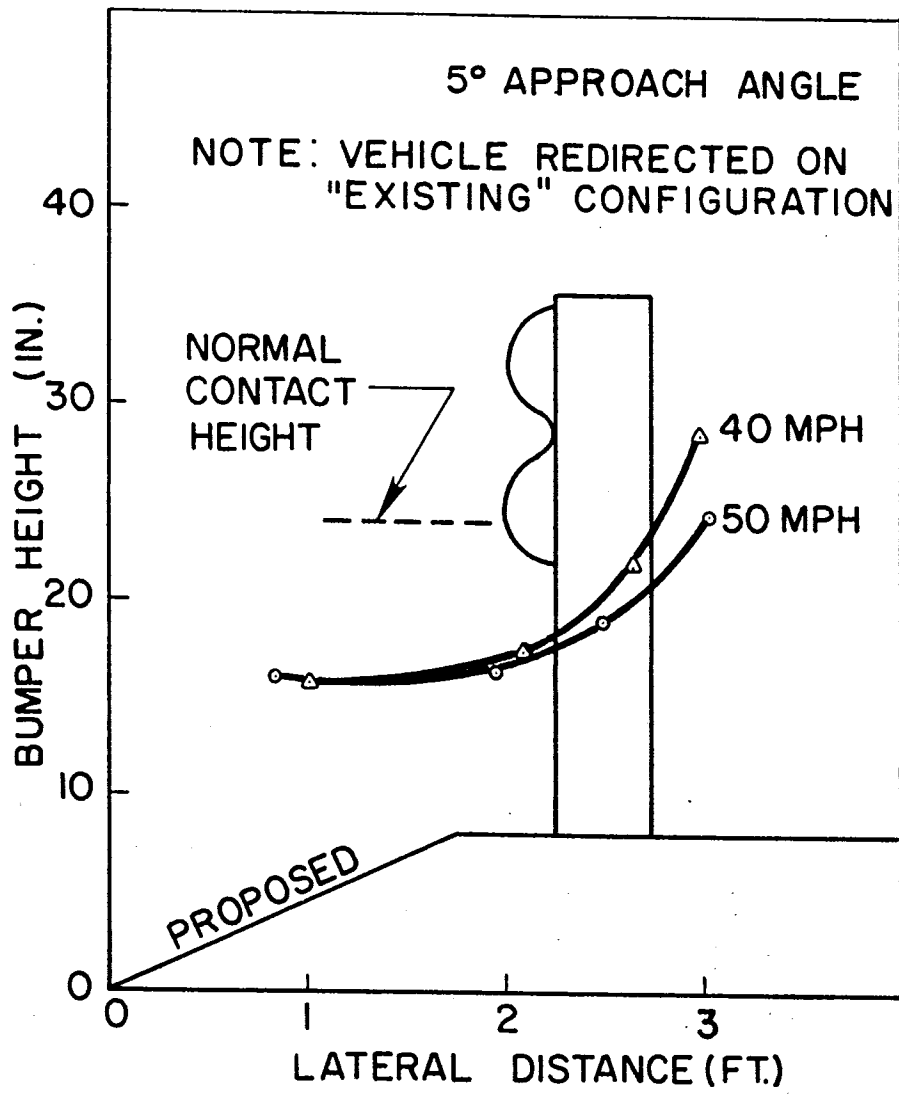


FIGURE 23. BUMPER HEIGHT VERSUS LATERAL DISTANCE, MB2B, 40 mph, 50 mph/5 deg

configuration, for speeds of 60 mph or less and encroachments angles of 15 degrees or less. The "critical" encroachment conditions for the *existing* curb are 40 mph and 15 degrees and as shown in Figure 21, the vehicle will strike the barrier at a lower than normal point. For encroachments of 10 degrees or less on the *existing* curb, the vehicle will be redirected before it contacts the barrier, at all speeds investigated. For the *proposed* configuration the vehicle contacted the barrier at a much lower than normal position for all the encroachment conditions investigated (5°, 10°, and 15° and 40 mph, 50 mph, and 60 mph). A rub rail would be desirable for the barrier.

MB3B (CMB and MBGF on an 8-inch curb on a 4 foot median) The results of this configuration are shown in Figures 24 and 25. Two basic configurations were analyzed in this case. Those were the MBGF on the 4-ft raised median and the CMB on the 4-ft raised median. As for the MBGF in the raised median, there appears to be no problems provided a rub rail is used. The observations made on the MB2B median with a MBGF apply here also. From the limited analysis performed, it appears that a CMB on a narrow raised median may prove to be undesirable. From Figures 24 and 25, it can be seen that the vehicle will contact the barrier at a much lower than normal position. The bumper will contact the lower sloped face and the possibility exists for a large lifting force to be exerted on the vehicle, larger than would exist had the vehicle contacted the barrier in a "normal" position. This lifting force, combined with that caused by the tires contacting the curb and the barrier could increase the potential for roll-over of the vehicle. It is suggested that before this configuration is adopted on a large scale, some full-scale tests should be conducted.

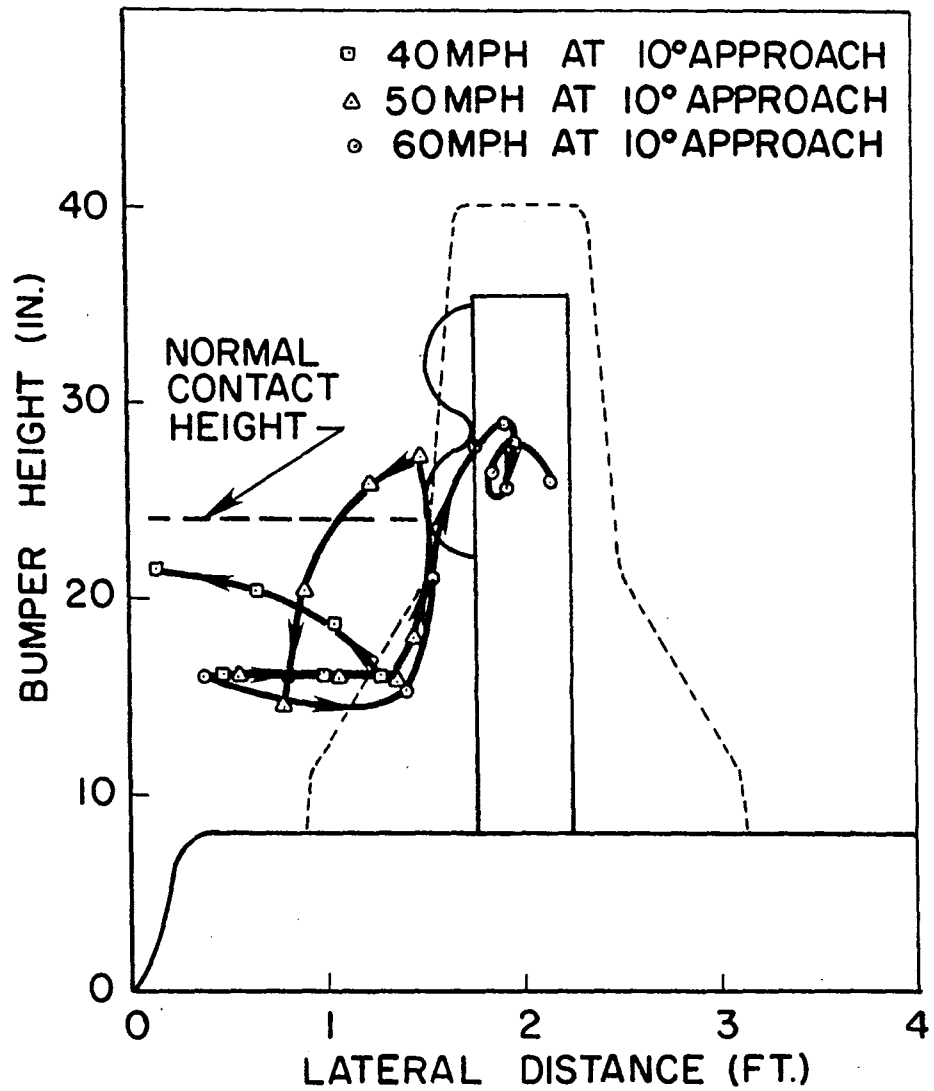


FIGURE 24. BUMPER HEIGHT VERSUS LATERAL DISTANCE, MB3B, 40 mph, 50 mph, 60 mph/10 deg

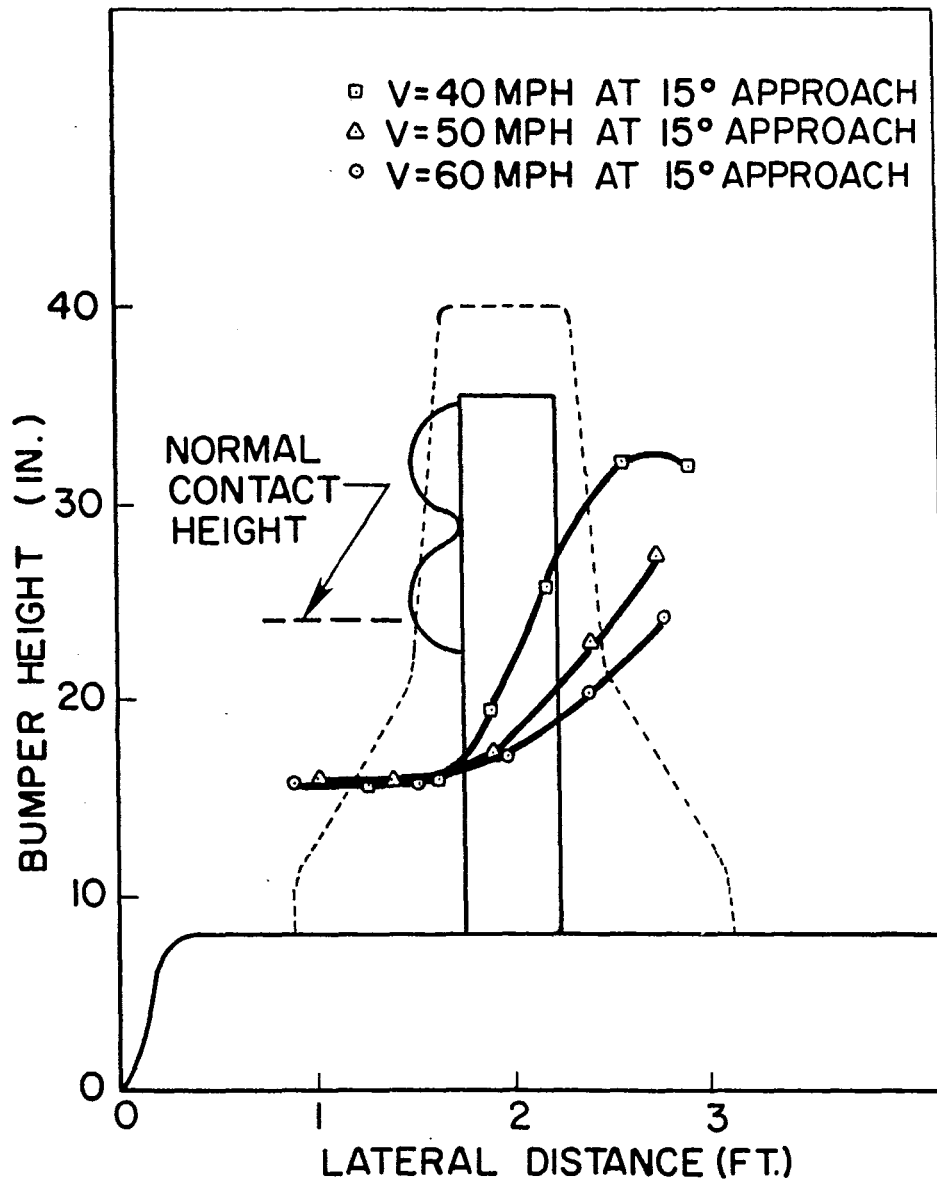


FIGURE 25. BUMPER HEIGHT VERSUS LATERAL DISTANCE, MB3B, 40 mph, 50 mph, 60 mph/15 deg

RB (8-inch curb on a roadside-barrier) The results of this configuration are shown in Figure 26. For 15 degree encroachments, it appears that the vehicle would go over the barrier, for speeds of 50 and 60 mph. As a consequence, this configuration is not desirable.

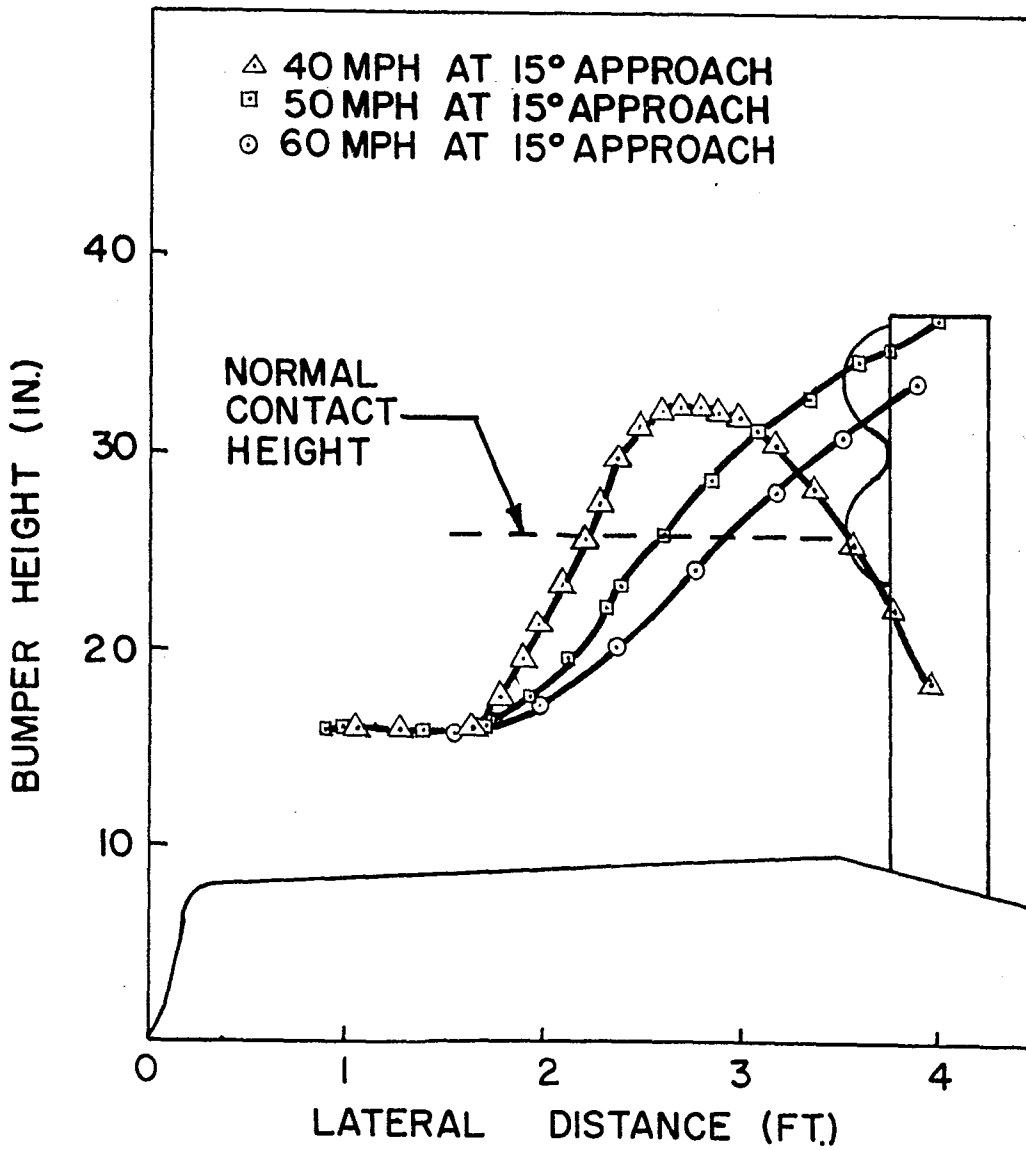


FIGURE 26. BUMPER HEIGHT VERSUS LATERAL DISTANCE, RB,
 40 mph, 50 mph, 60 mph/15 deg

CONCLUSIONS

From a safety standpoint, it is concluded that traffic barriers should not be placed near curbs. Curbs can potentially cause the vehicle to vault the barrier, or to impact it at a lower than normal position which can cause snagging of the vehicle. A flat approach area to the barrier appears to be the most desirable configuration.

Problems with barriers on raised curb-median or curb-roadside configurations can be reduced in certain cases by sloping the median or roadside up to the barrier.

Concrete median barriers placed on narrow raised medians should be avoided where possible.

REFERENCES

1. McHenry, R. R., and DeLeys, N. J., "Vehicle Dynamics in Single-Vehicle Accidents-Validation and Extension of a Computer Simulation" CALSPAN Report No. VI-2251-V-3, Dec. 1968.
2. Olson, R. M., Weaver, G. D., Ross, H. E., and Post, E. R., "Effect of Curb Geometry and Location on Vehicle Behavior", NCHRP Report 150, 1974.

APPENDIX A

MEDIAN BARRIER 1A

RESULTS

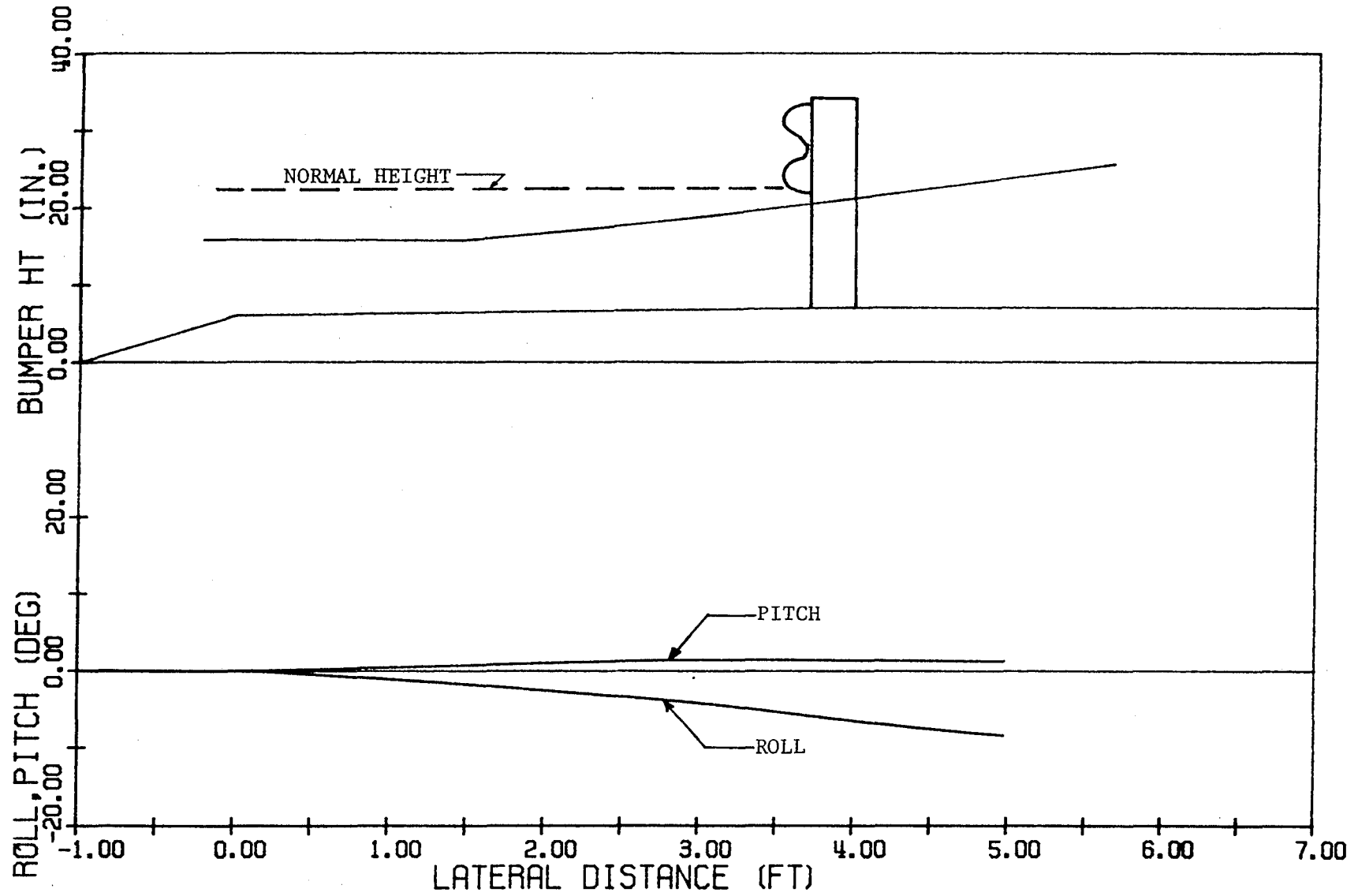


FIG. A1. VEHICLE BEHAVIOR, MEDIAN BARRIER 1A, 60 mph/15 deg, $\mu=0.8$, PART 1

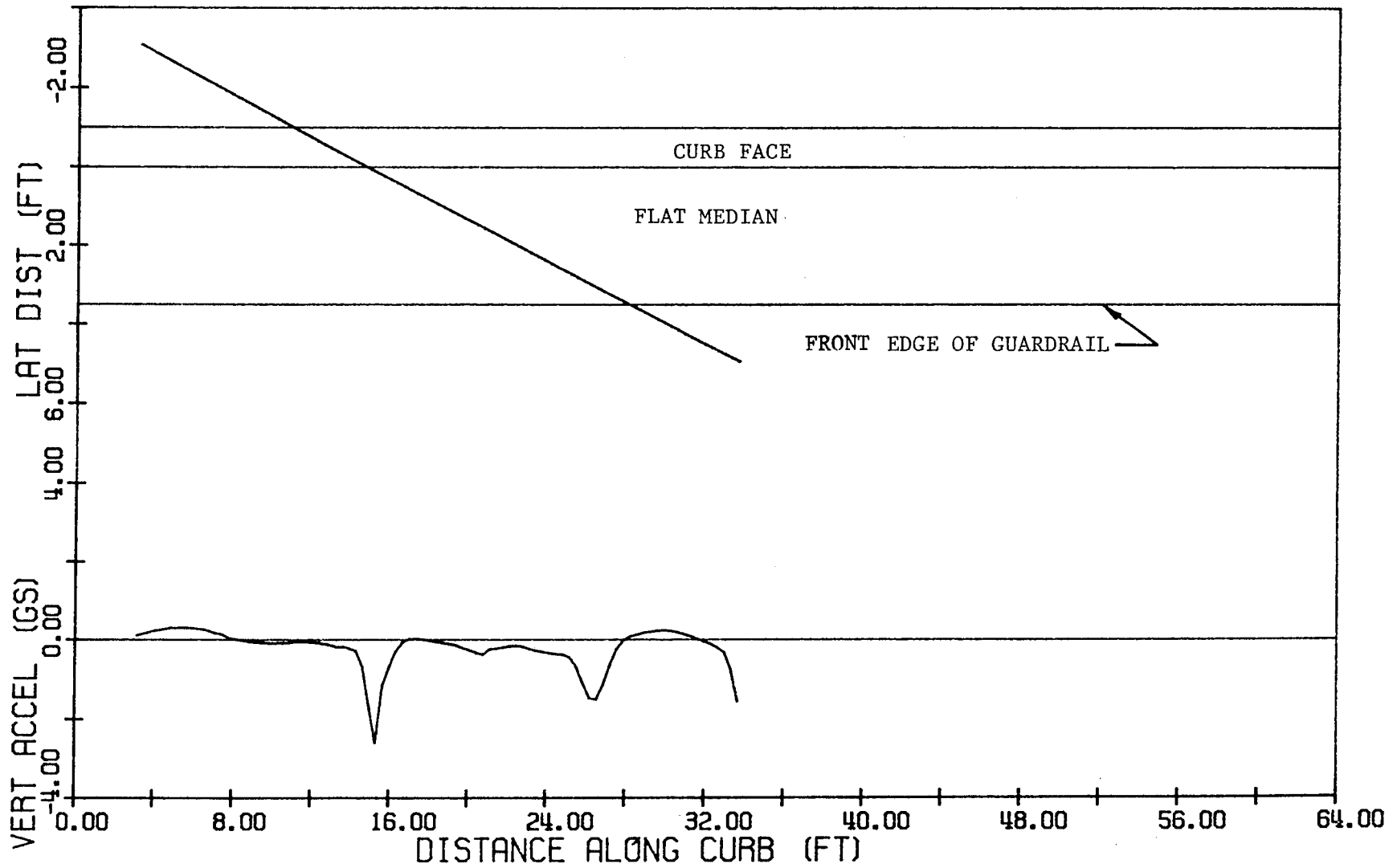


FIG. A2. VEHICLE BEHAVIOR, MEDIAN BARRIER 1A, 60 mph/15 deg, $\mu=0.8$, PART 2

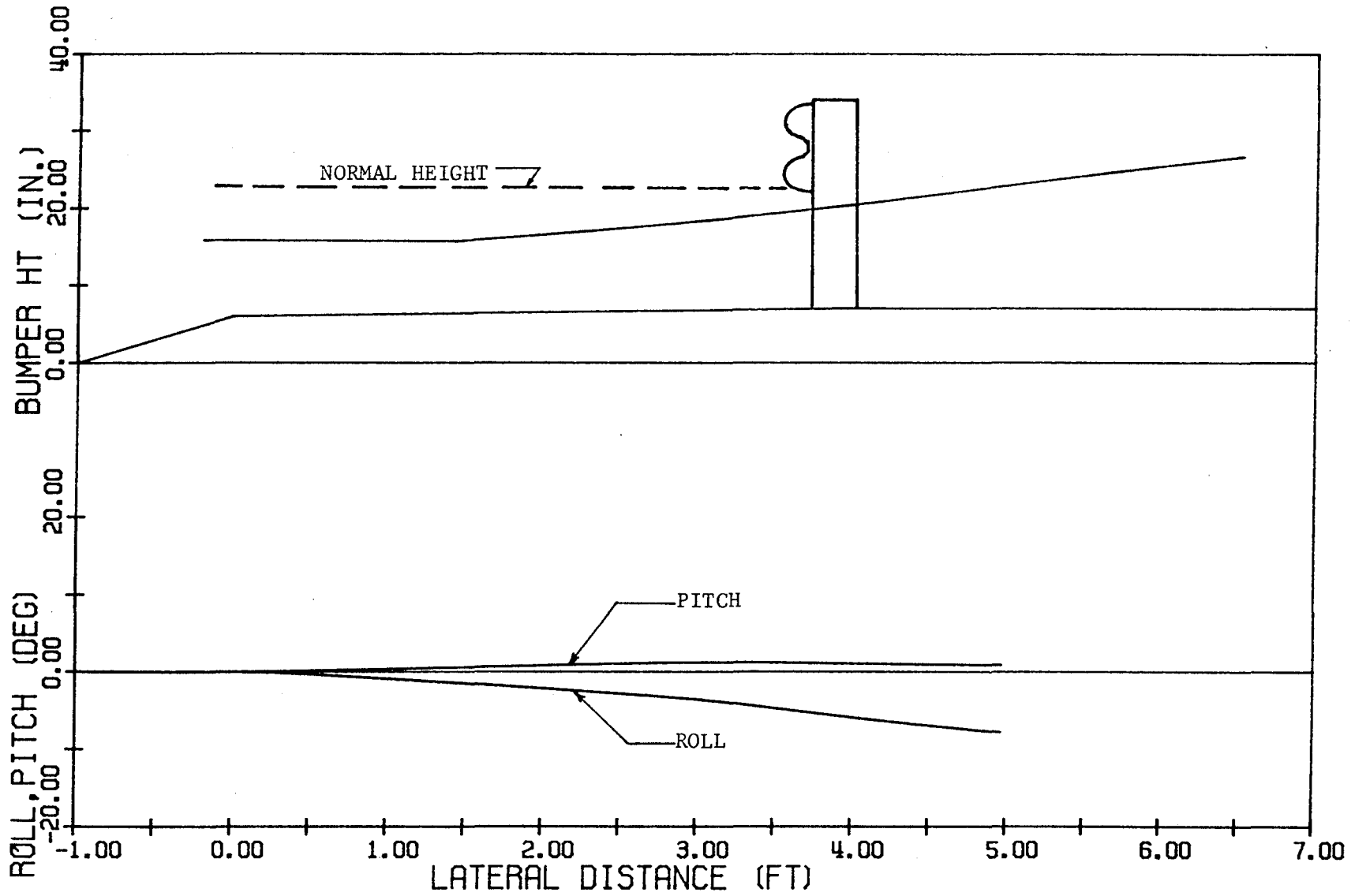


FIG. A3. VEHICLE BEHAVIOR, MEDIAN BARRIER 1A, 70 mph/15 deg, $\mu=0.8$, PART 1

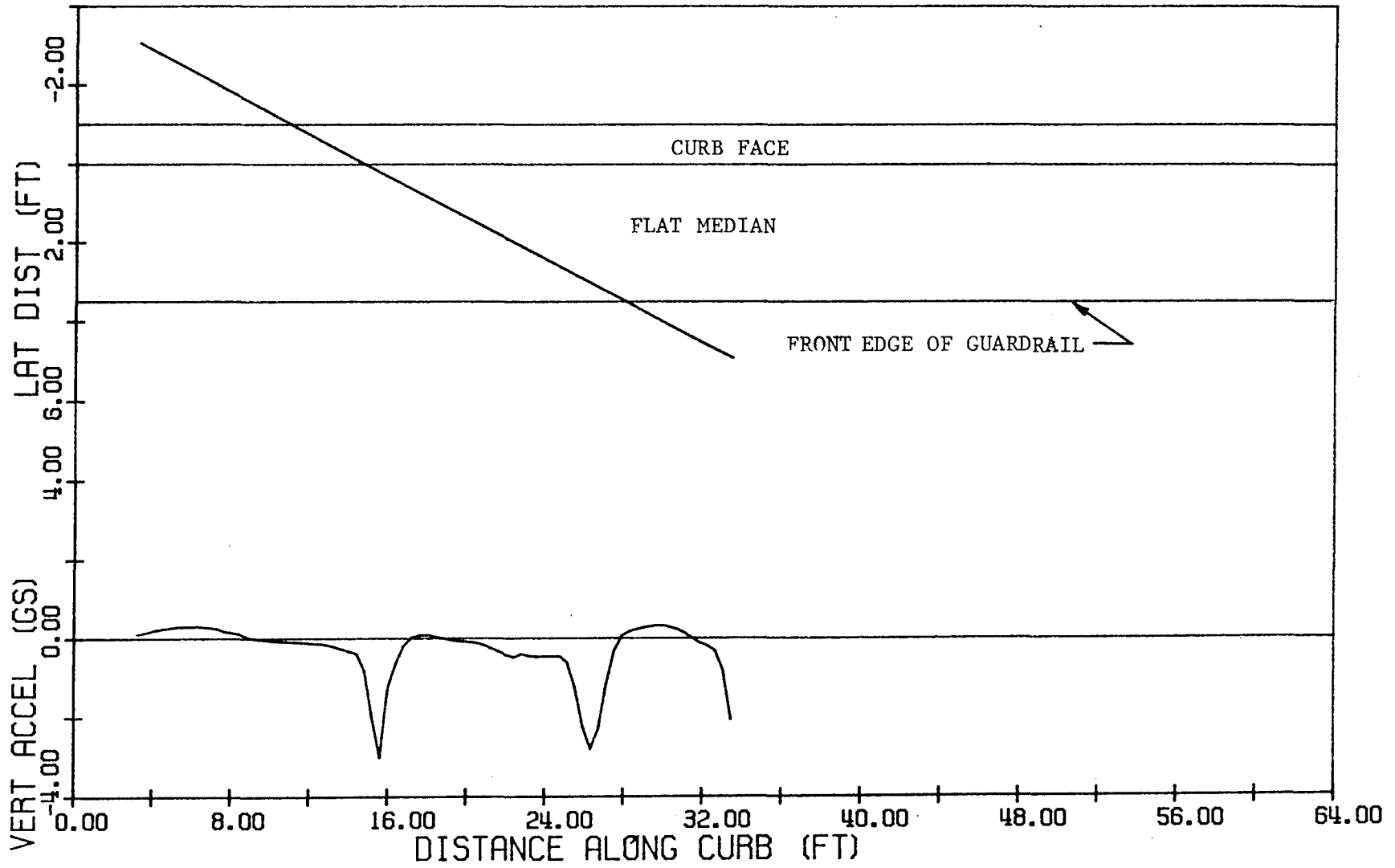


FIG. A4. VEHICLE BEHAVIOR, MEDIAN BARRIER 1A, 70 mph/15 deg, $\mu=0.8$, PART 2

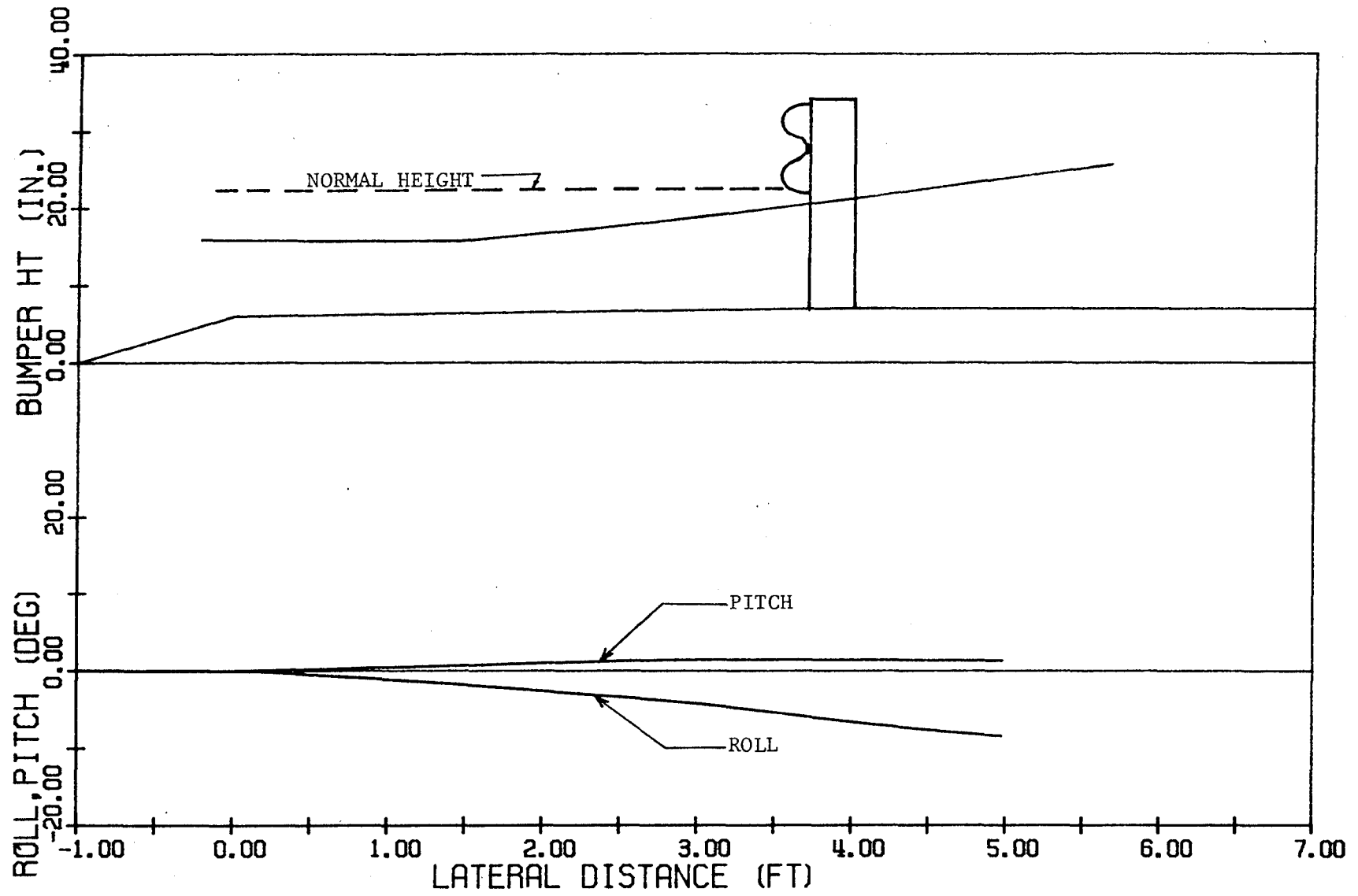


FIG. A5. VEHICLE BEHAVIOR, MEDIAN BARRIER 1A, 60 mph/15 deg, $\mu=0.5$, PART 1

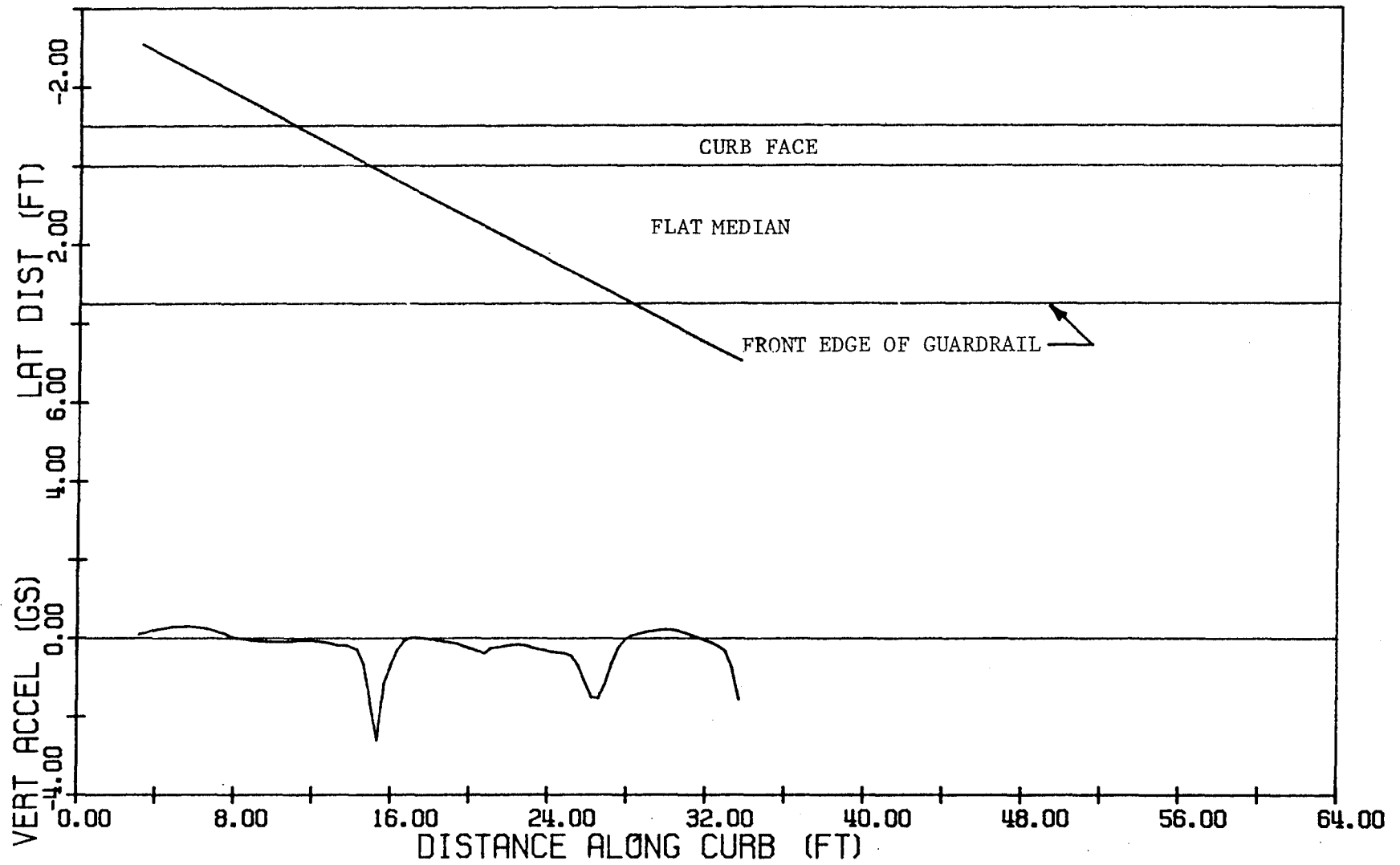


FIG. A6. VEHICLE BEHAVIOR, MEDIAN BARRIER 1A, 60 mph/15 deg, $\mu=0.5$, PART 2

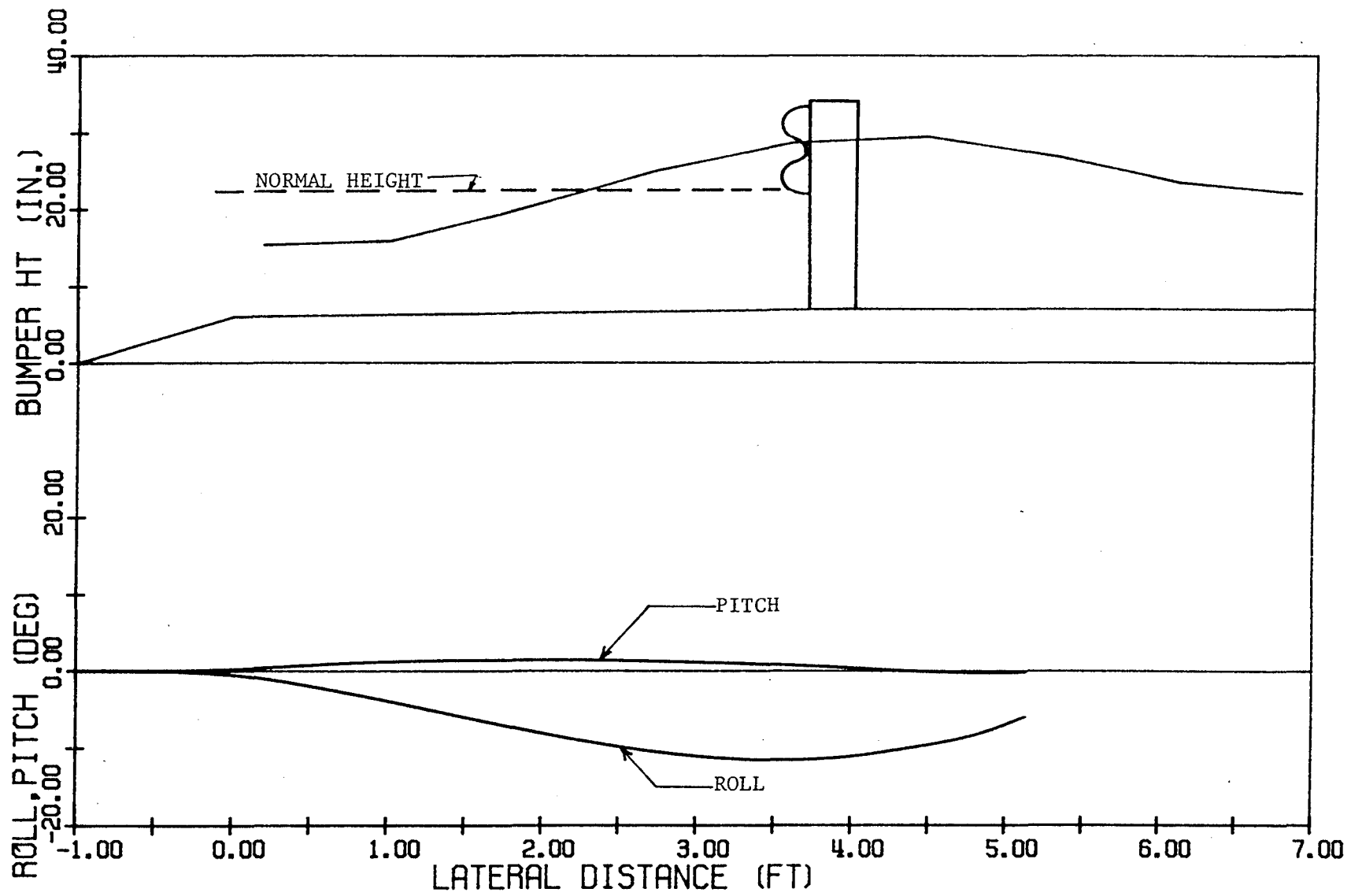
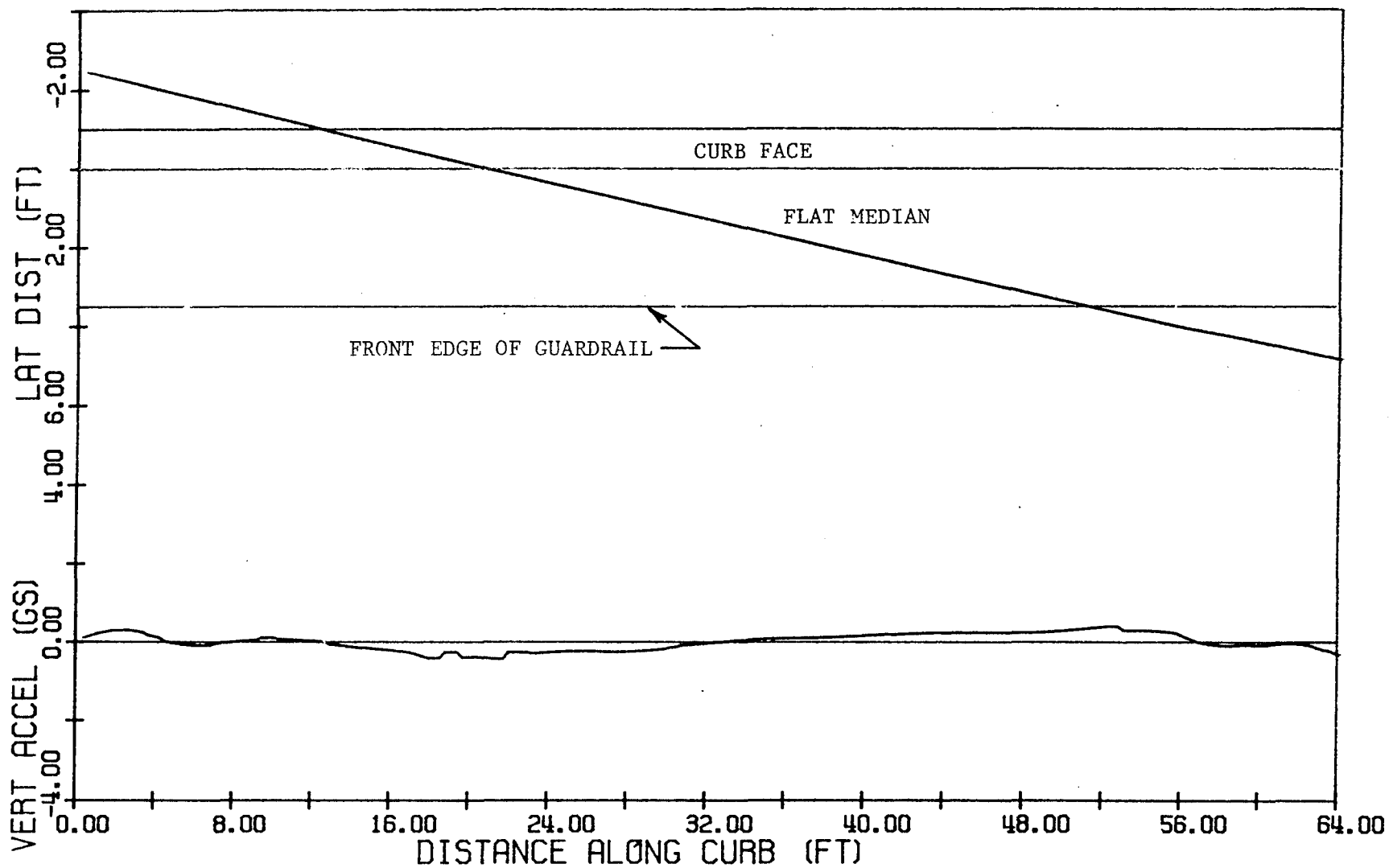


FIG. A7. VEHICLE BEHAVIOR, MEDIAN BARRIER 1A, 50 mph/7 deg, $\mu=0.8$, PART 1

FIG. A8. VEHICLE BEHAVIOR, MEDIAN BARRIER 1A, 50 mph/7 deg, $\mu=0.8$, PART 2

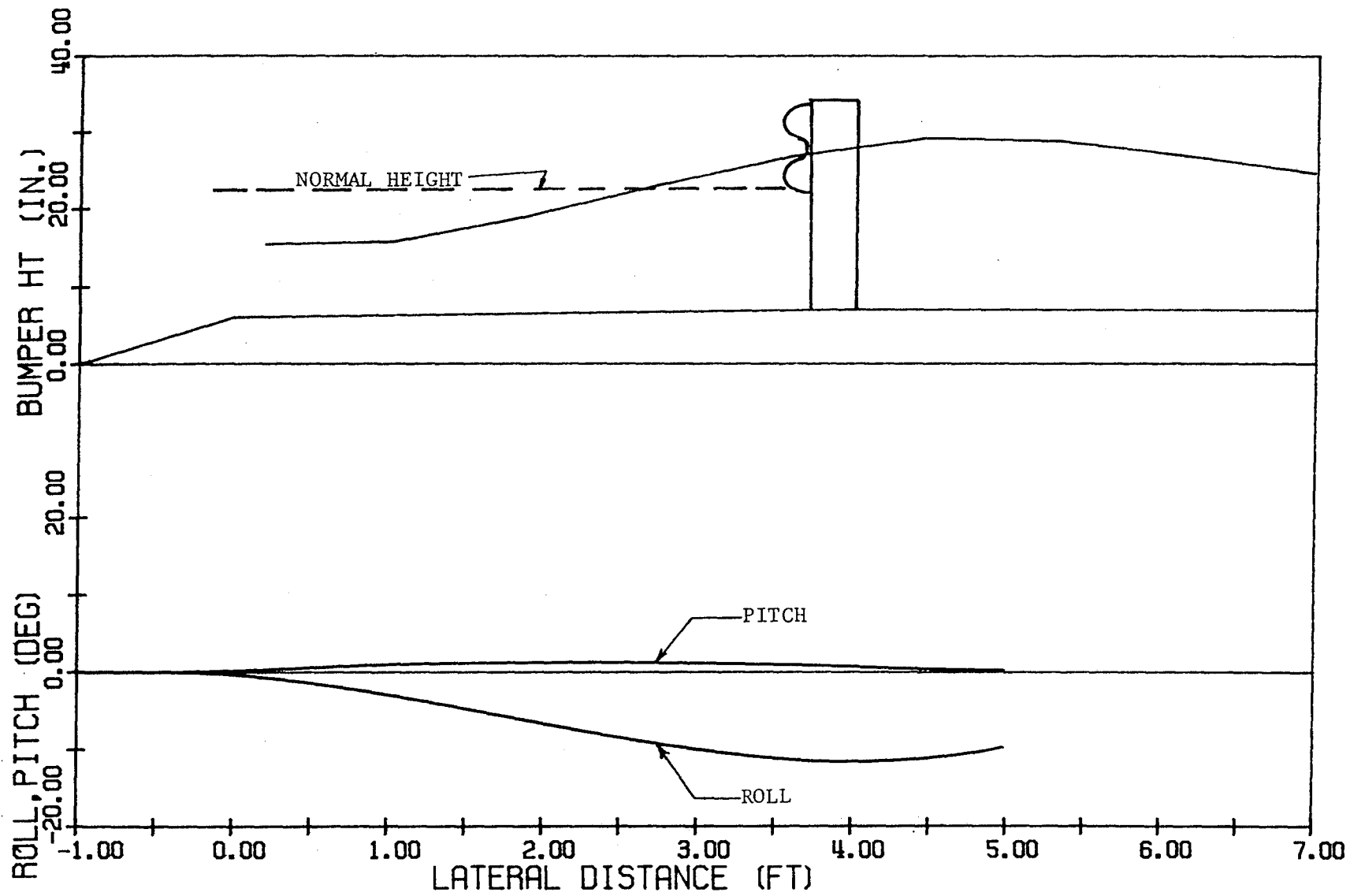
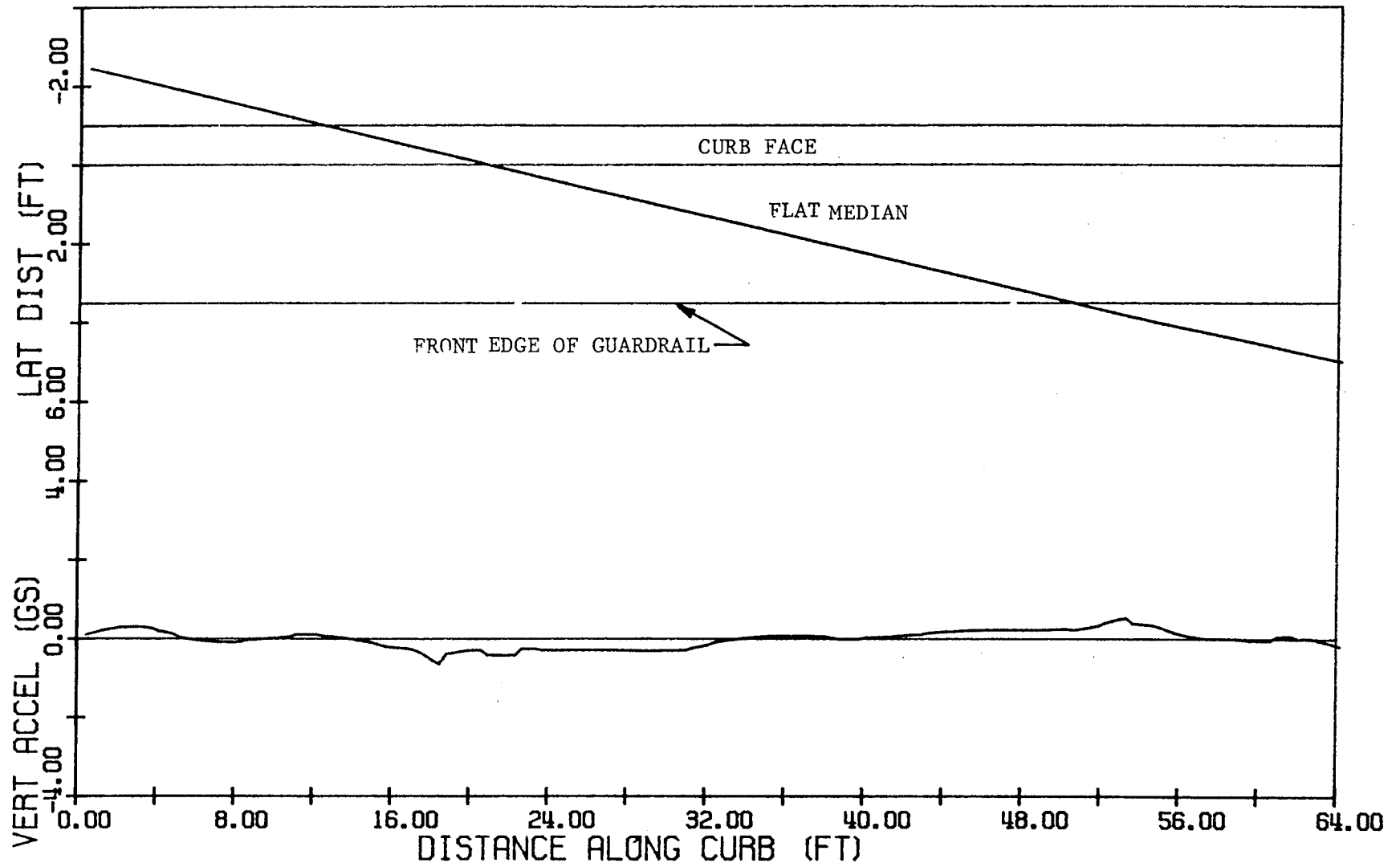


FIG. A9. VEHICLE BEHAVIOR, MEDIAN BARRIER 1A, 60 mph/7 deg, $\mu=0.8$, PART 1

FIG. A10. VEHICLE BEHAVIOR, MEDIAN BARRIER 1A, 60 mph/7 deg, $\mu=0.8$, PART 2

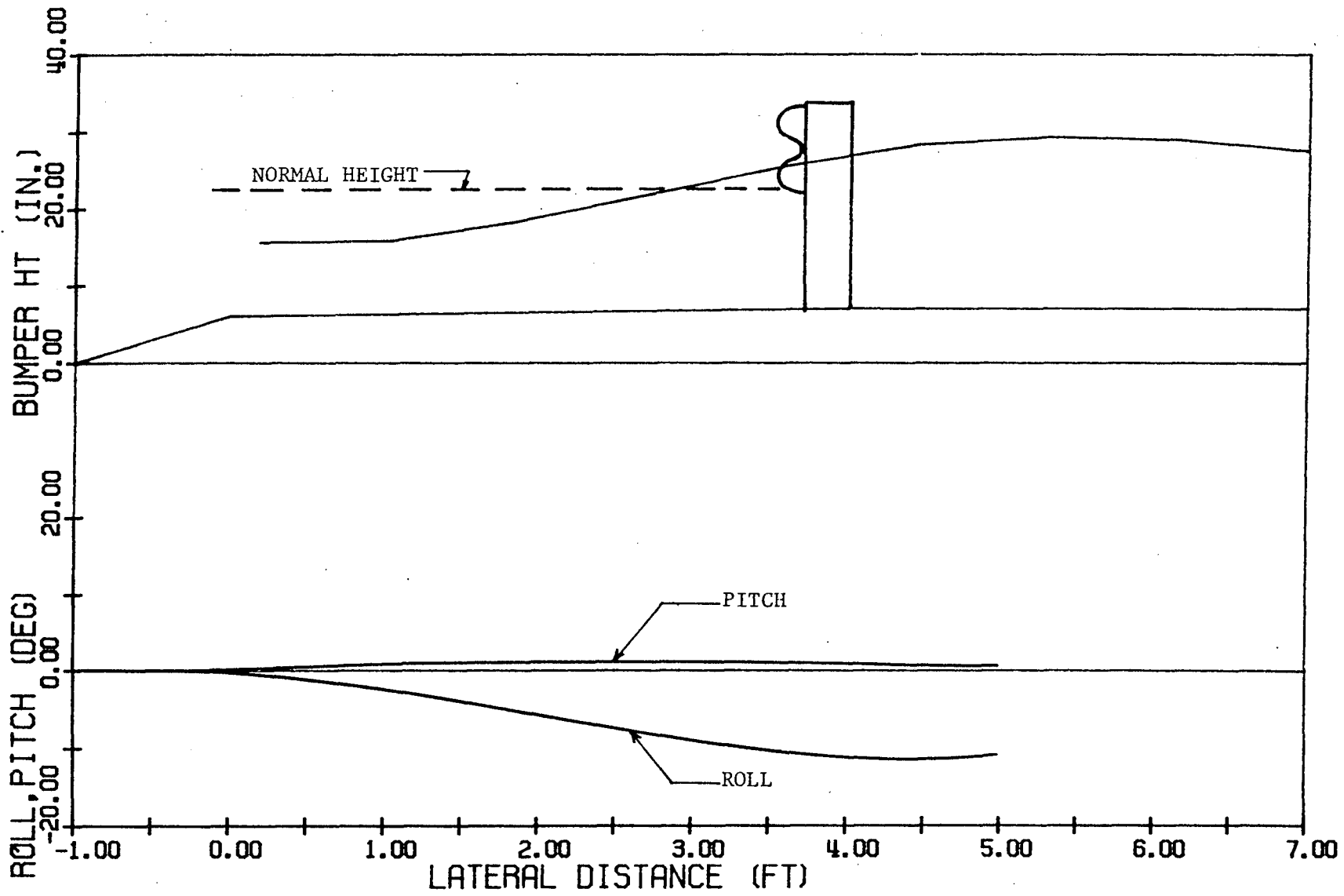


FIG. A11. VEHICLE BEHAVIOR, MEDIAN BARRIER 1A, 70 mph/7 deg, $\mu=0.8$, PART 1

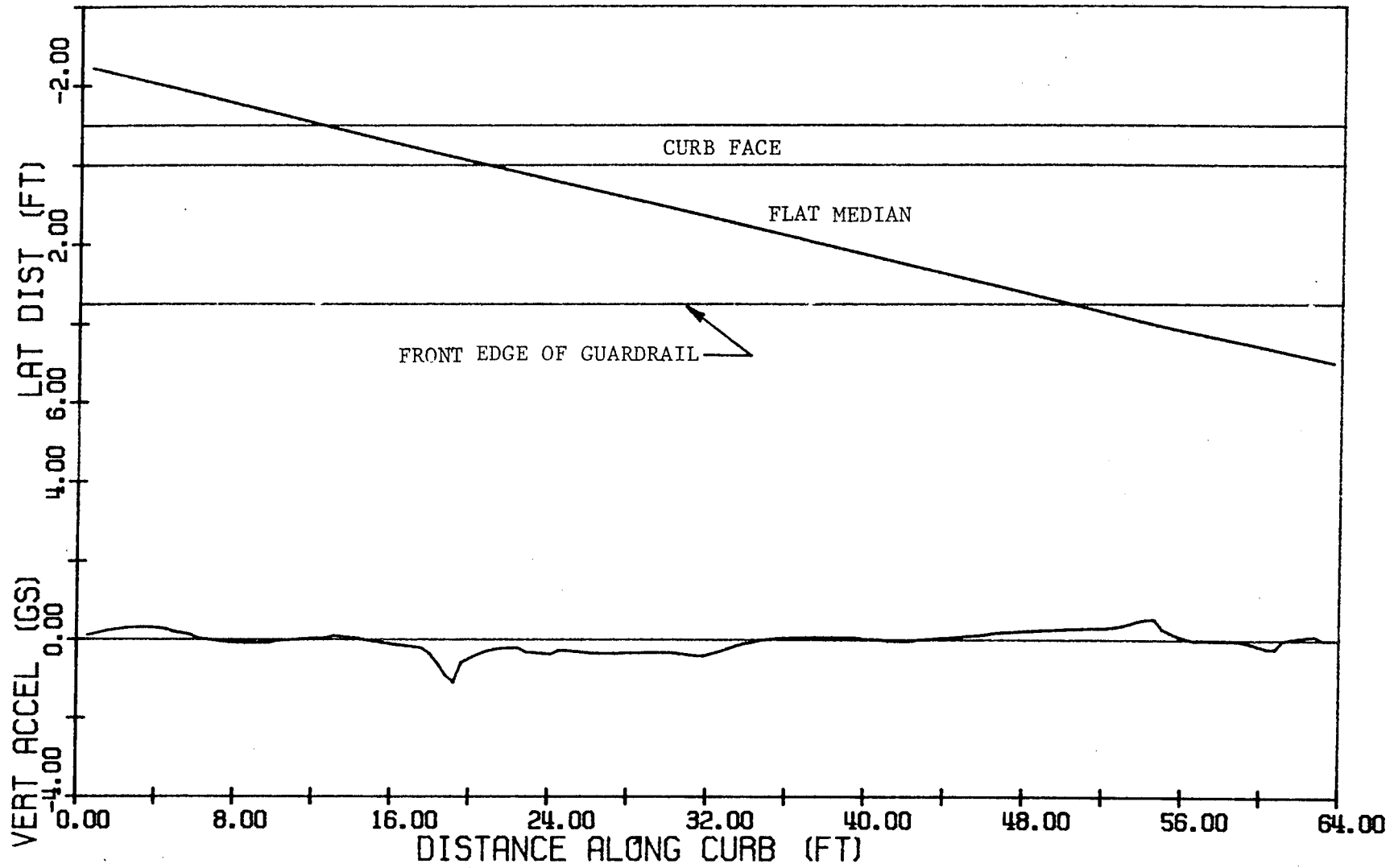


FIG. A12. VEHICLE BEHAVIOR, MEDIAN BARRIER 1A, 70 mph/7 deg, $\mu=0.8$, PART 2

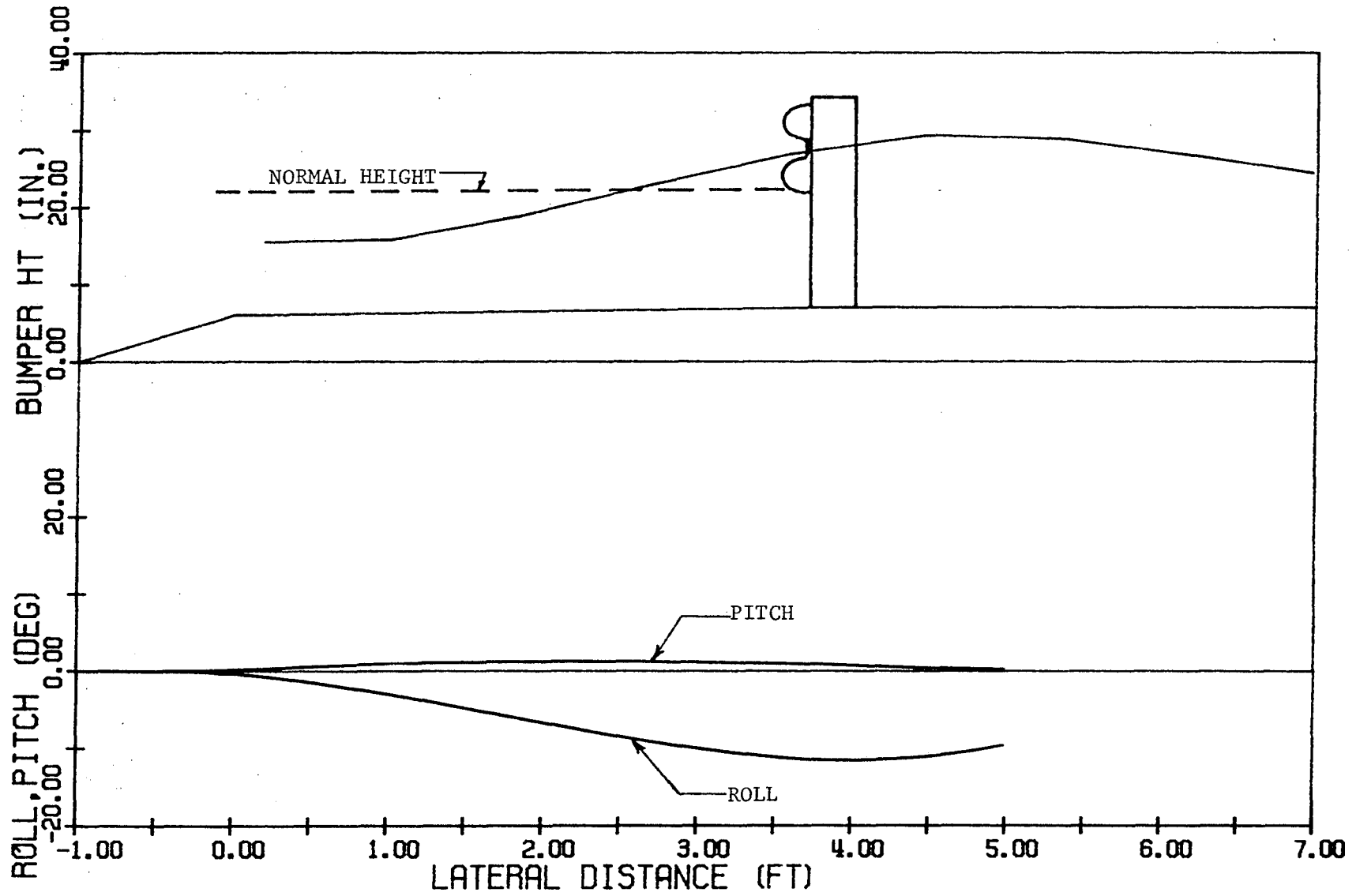


FIG. A13. VEHICLE BEHAVIOR, MEDIAN BARRIER 1A, 60 mph/7. deg, $\mu=0.5$, PART 1

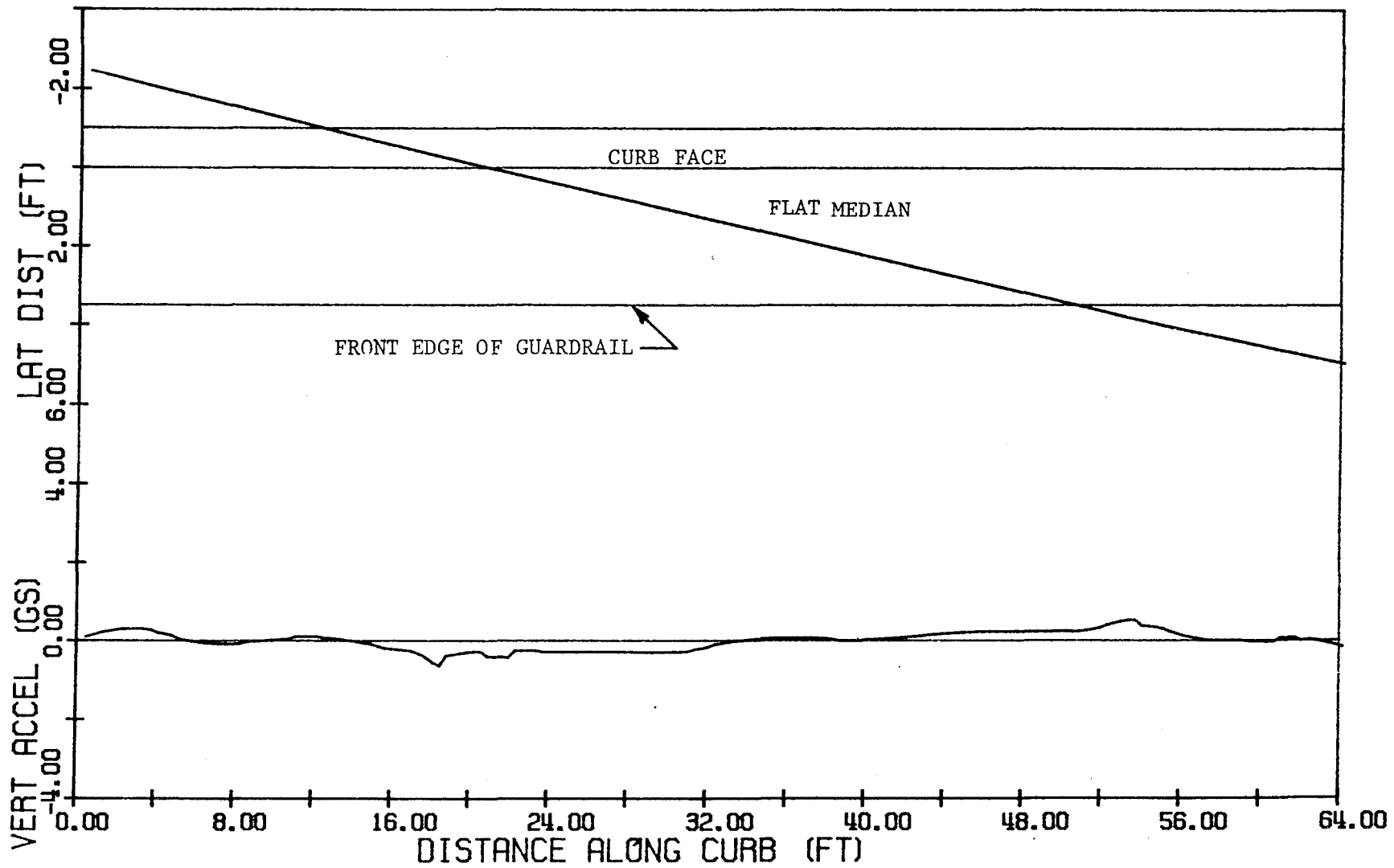


FIG. A14. VEHICLE BEHAVIOR, MEDIAN BARRIER 1A, 60 mph/7 deg, $\mu=0.5$, PART 2

APPENDIX B

MEDIAN BARRIER 2A

RESULTS

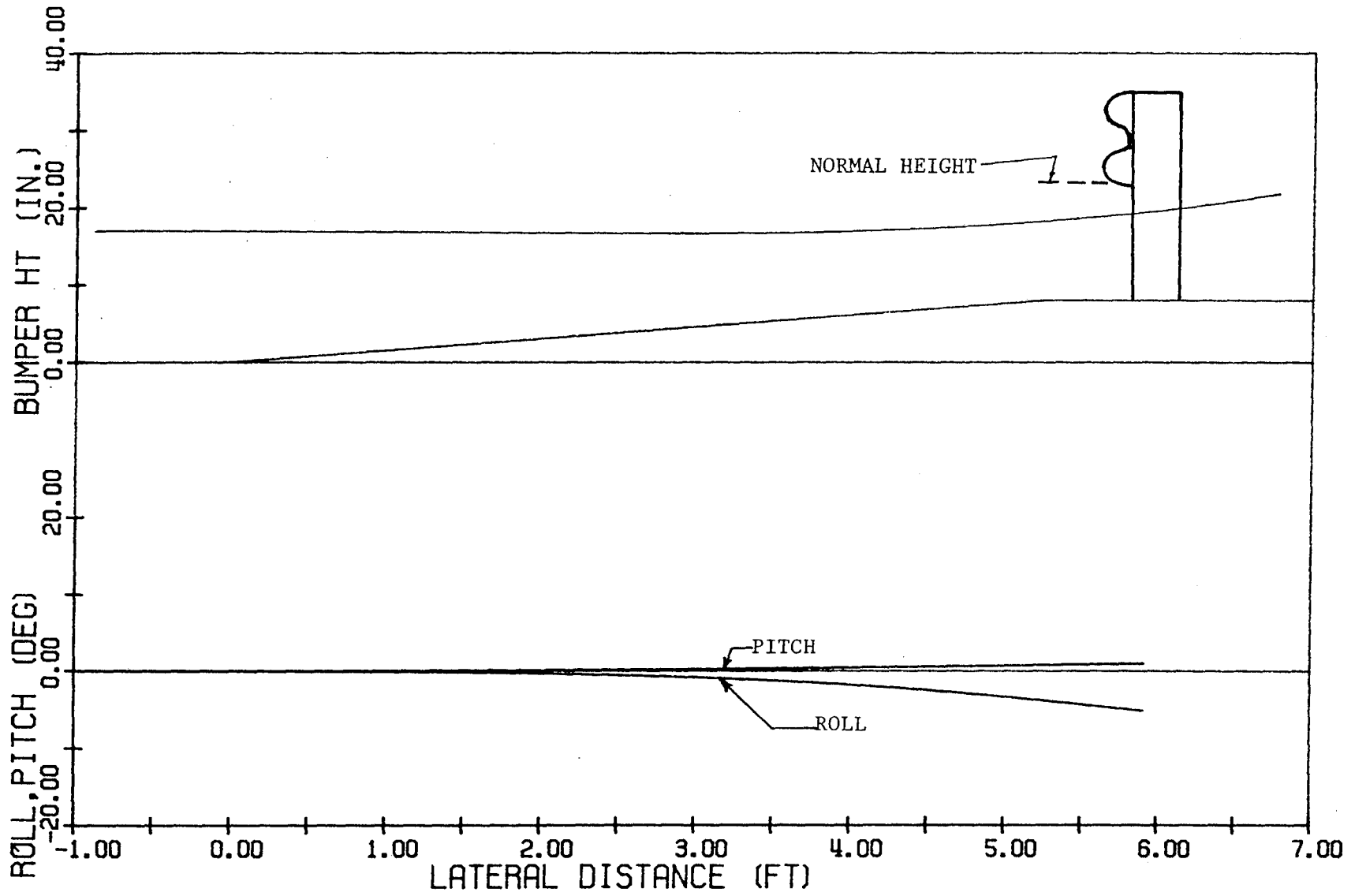


FIG. B1. VEHICLE BEHAVIOR, MEDIAN BARRIER 2A, 50 mph/15 deg, $\mu=0.8$, PART 1

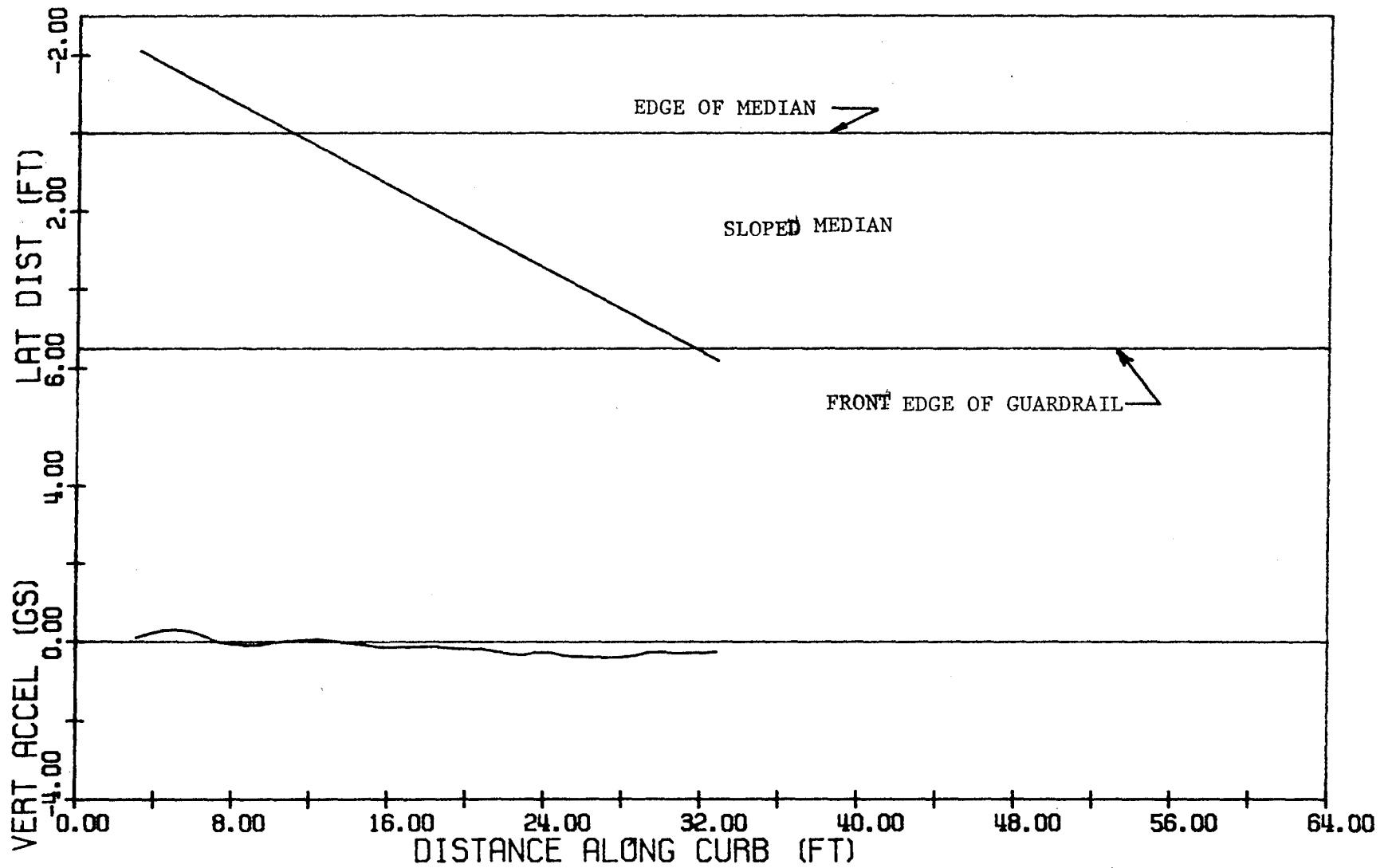


FIG. B2. VEHICLE BEHAVIOR, MEDIAN BARRIER 2A, 50 mph/15 deg, $\mu=0.8$, PART 2

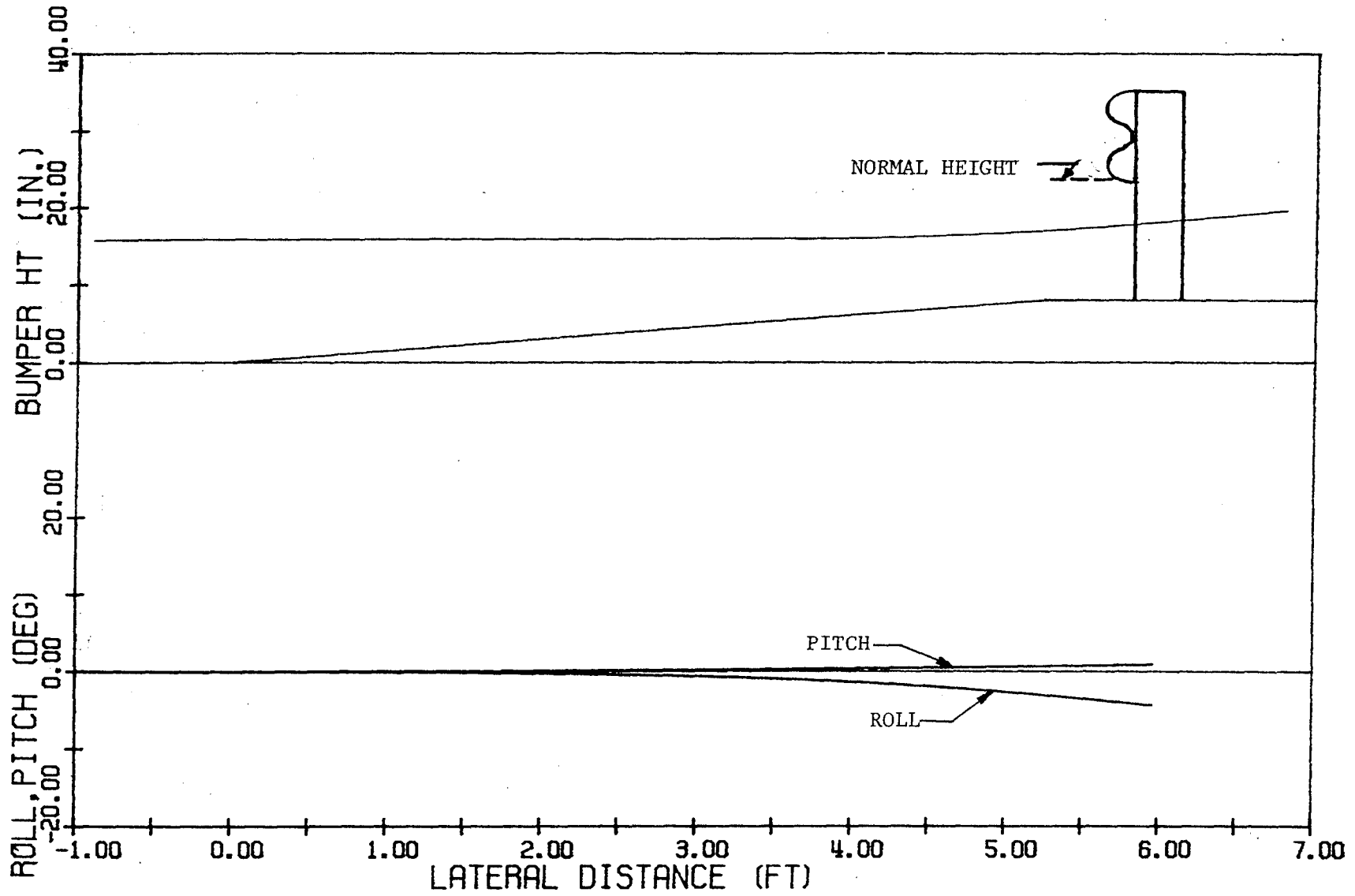


FIG. B3. VEHICLE BEHAVIOR, MEDIAN BARRIER 2A, 60 mph/15 deg, $\mu=0.8$, PART 1

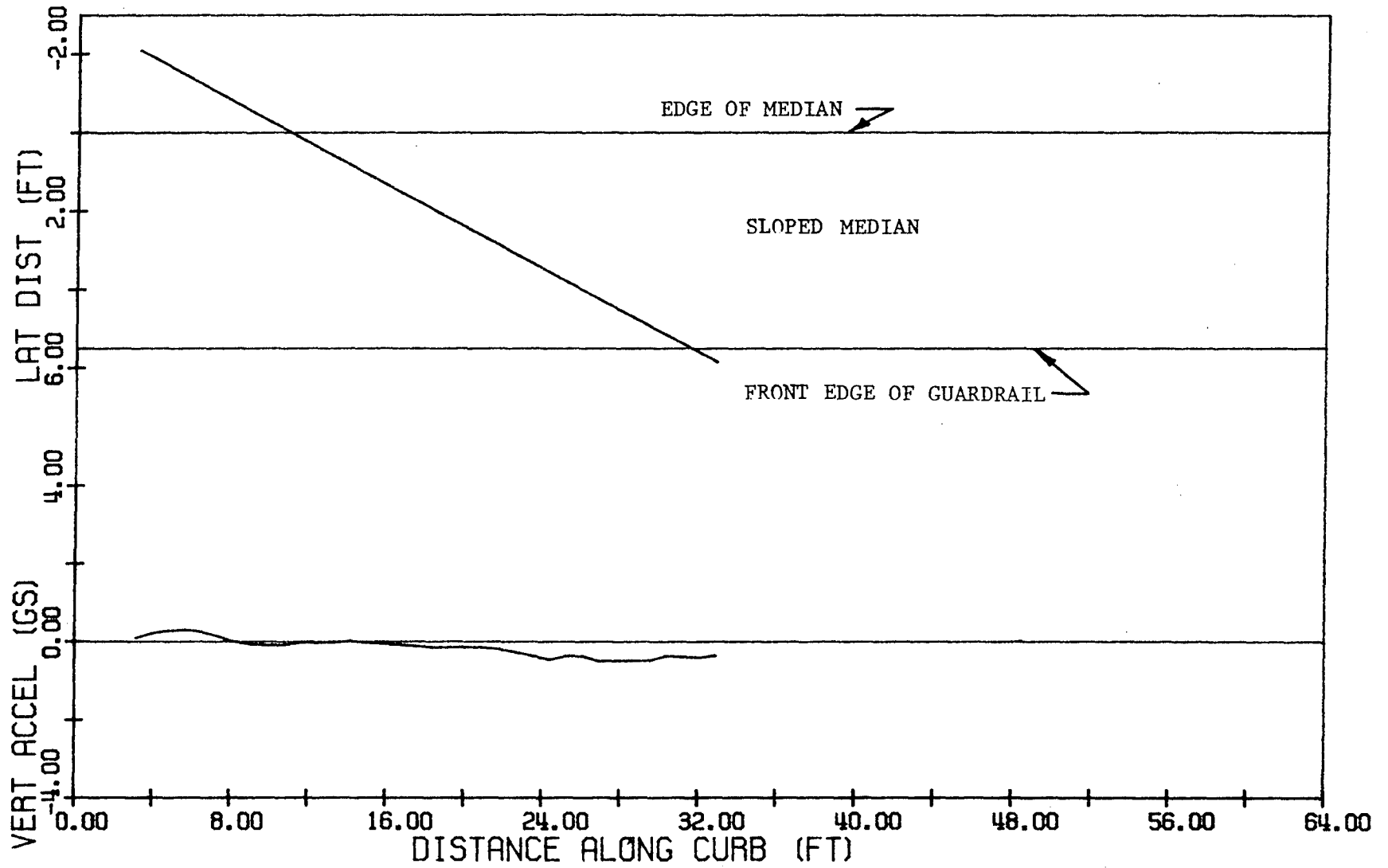


FIG. B4. VEHICLE BEHAVIOR, MEDIAN BARRIER 2A, 60 mph/15 deg, $\mu=0.8$, PART 2.

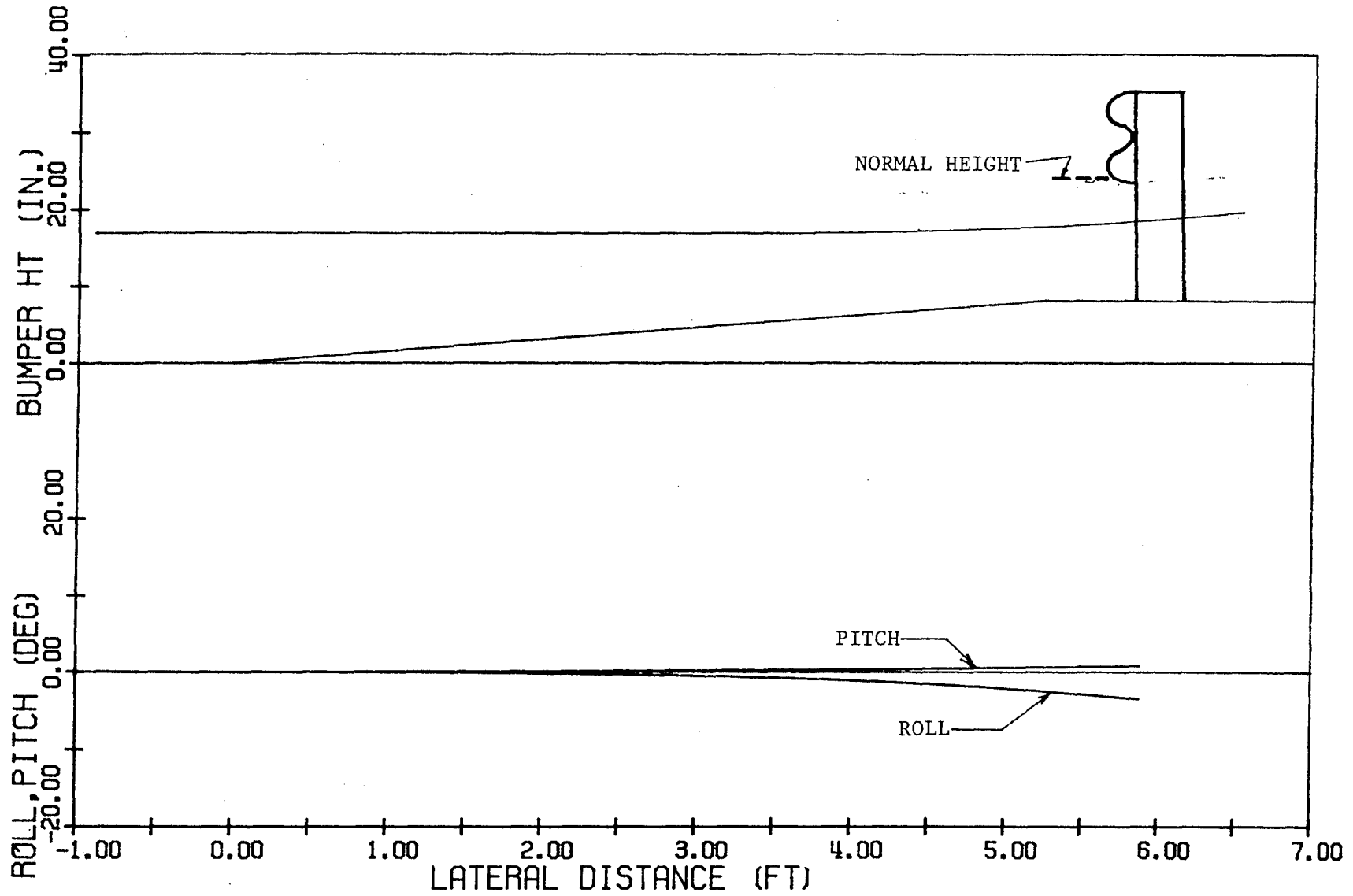


FIG. B5. VEHICLE BEHAVIOR, MEDIAN BARRIER 2A, 70 mph/15 deg, $\mu=0.8$, PART 1

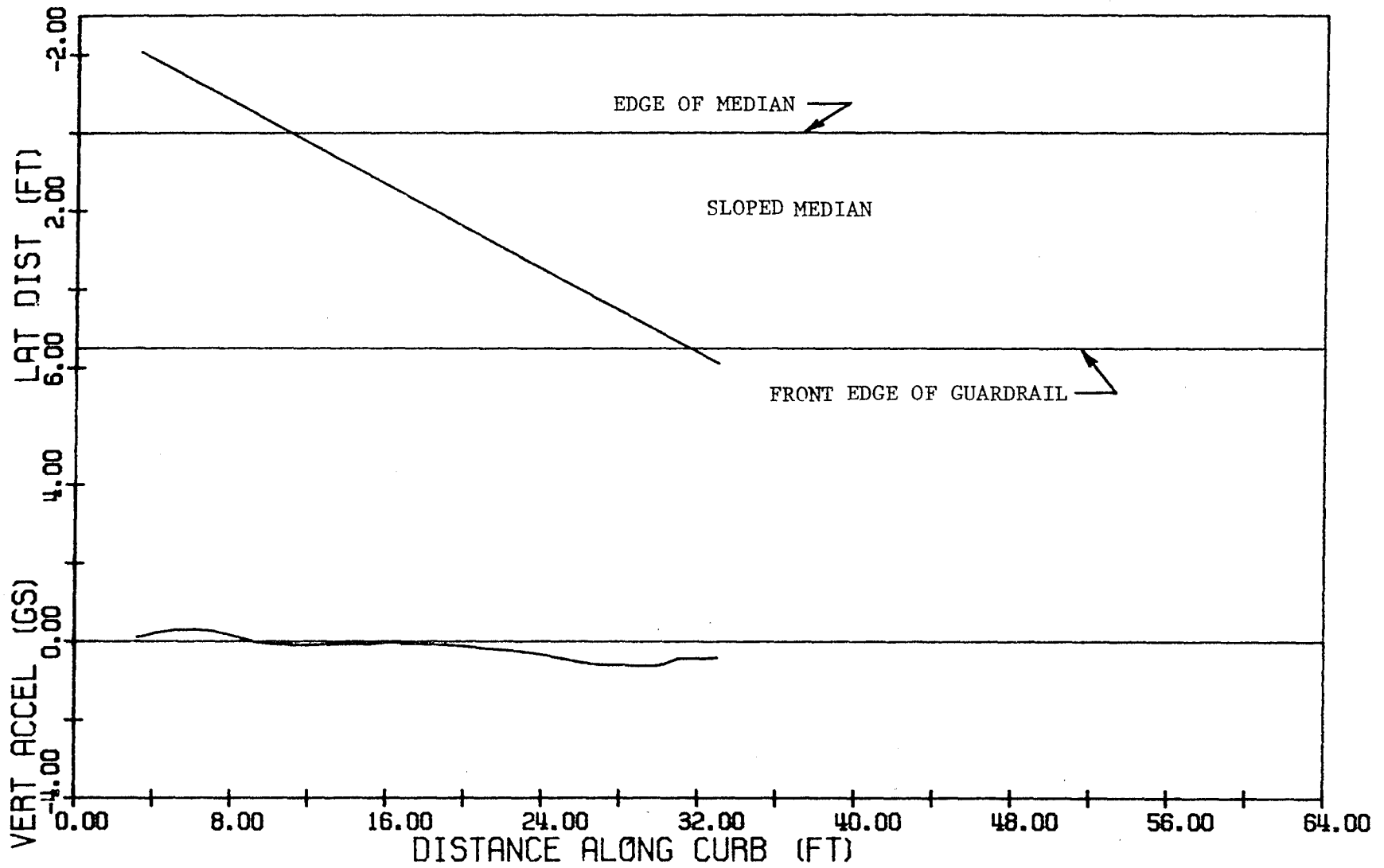


FIG. B6. VEHICLE BEHAVIOR, MEDIAN BARRIER 2A, 70 mph/15 deg, $\mu=0.8$, PART 2

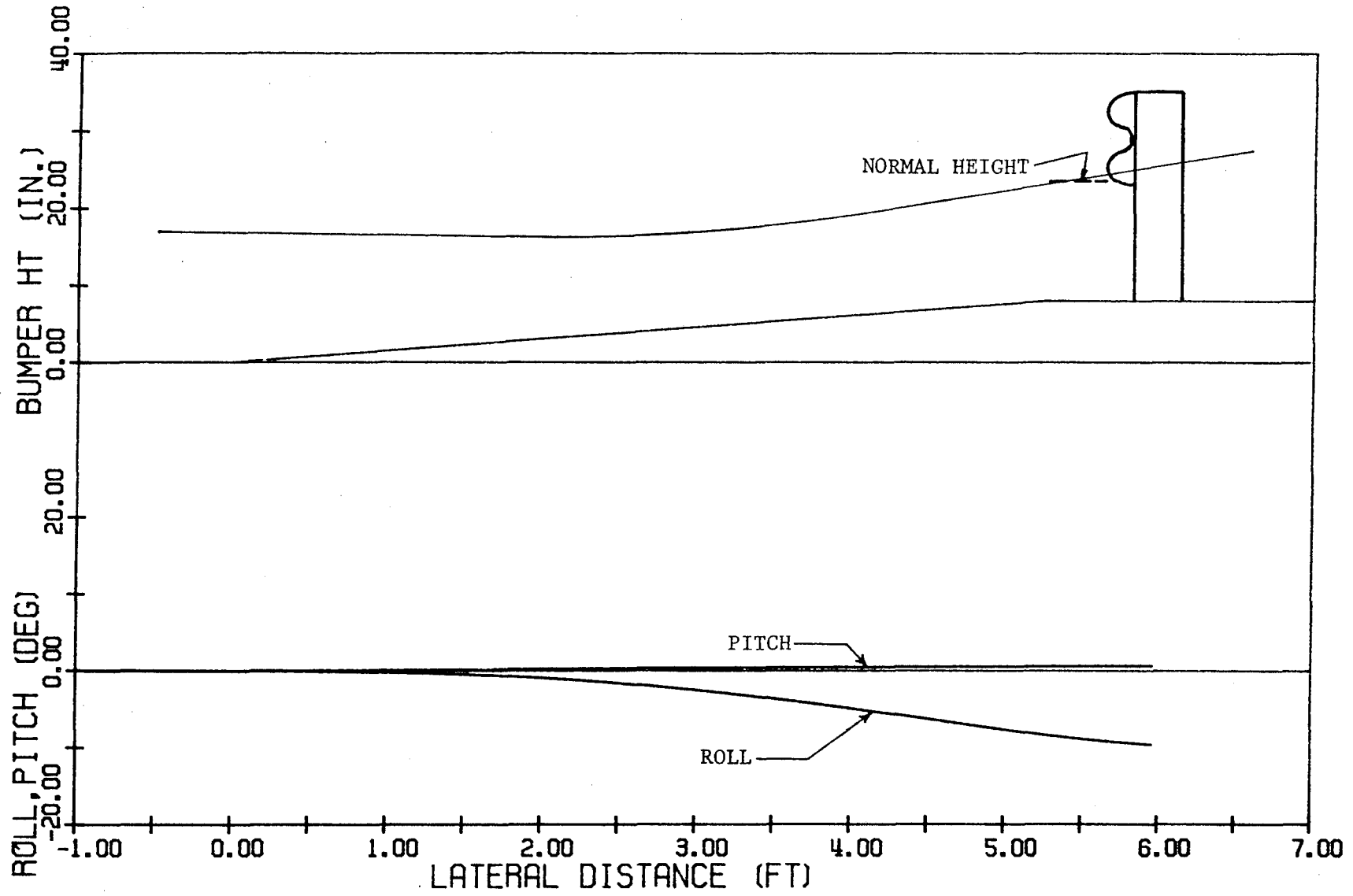


FIG. B7. VEHICLE BEHAVIOR, MEDIAN BARRIER 2A, 50 mph/7 deg, $\mu=0.8$, PART 1

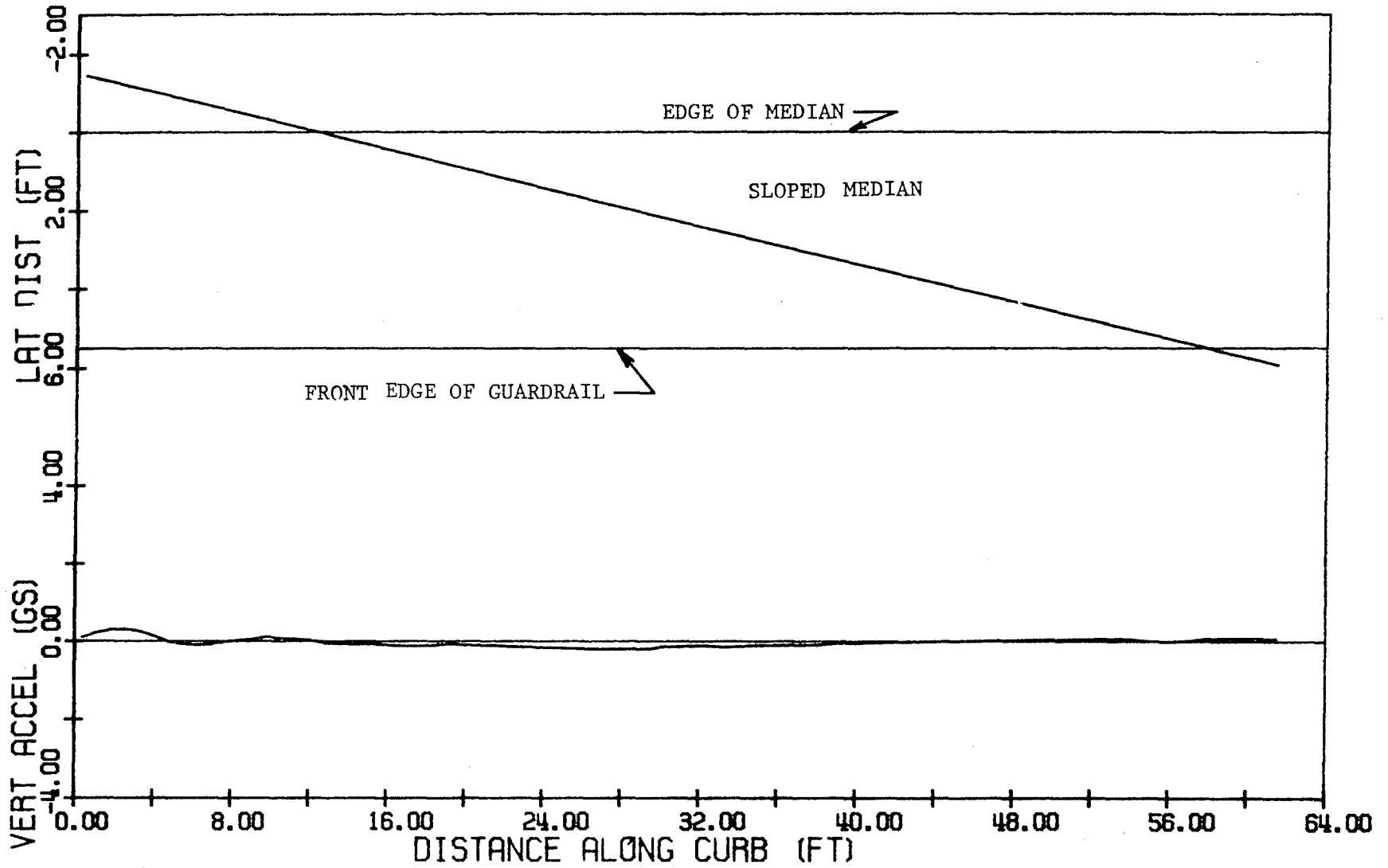


FIG. B8. VEHICLE BEHAVIOR, MEDIAN BARRIER 2A, 50 mph/ 7 deg, $\mu=0.8$, PART 2

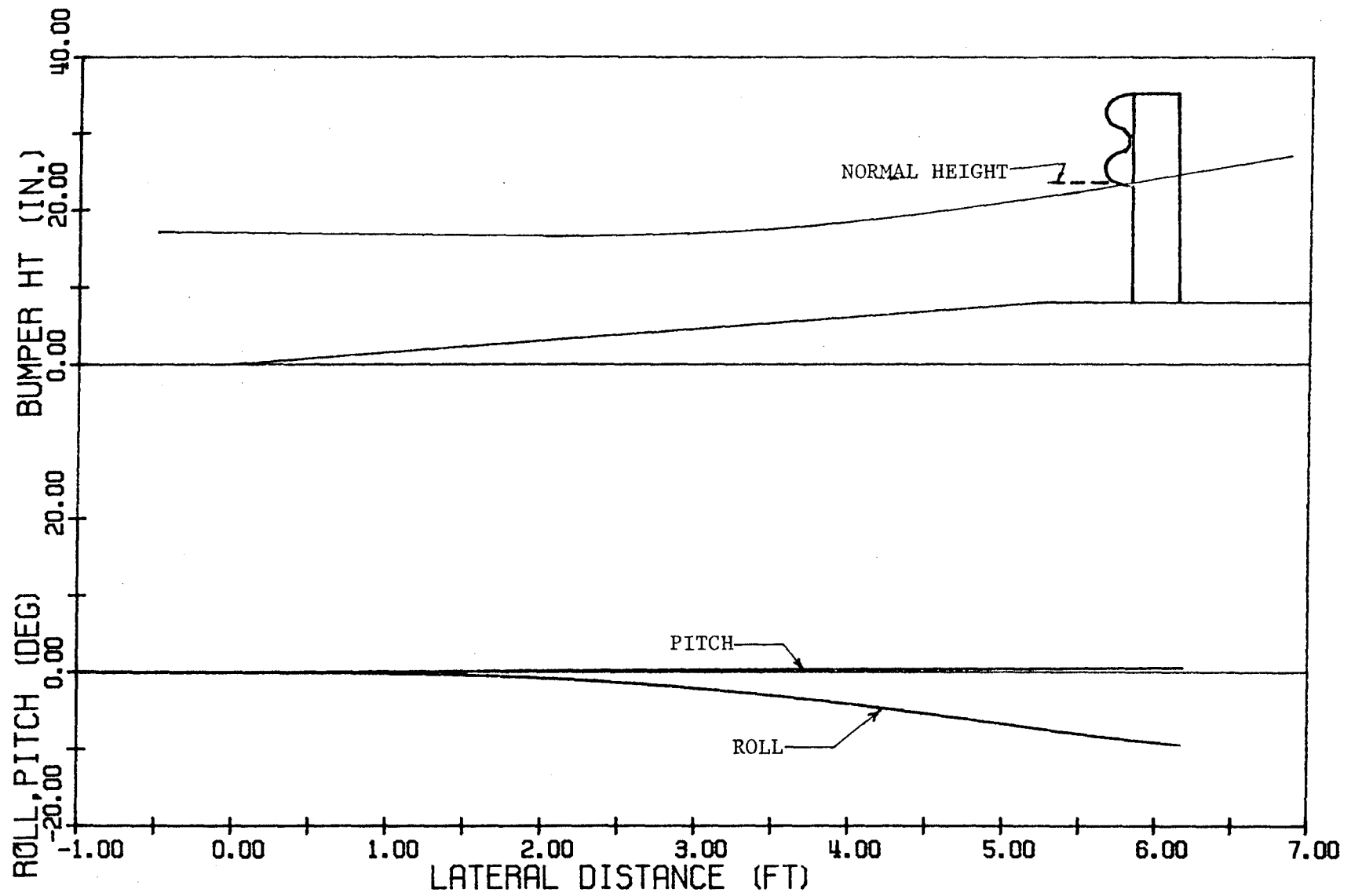


FIG. B9. VEHICLE BEHAVIOR, MEDIAN BARRIER 2A, 60 mph/7 deg, $\mu=0.8$, PART 1

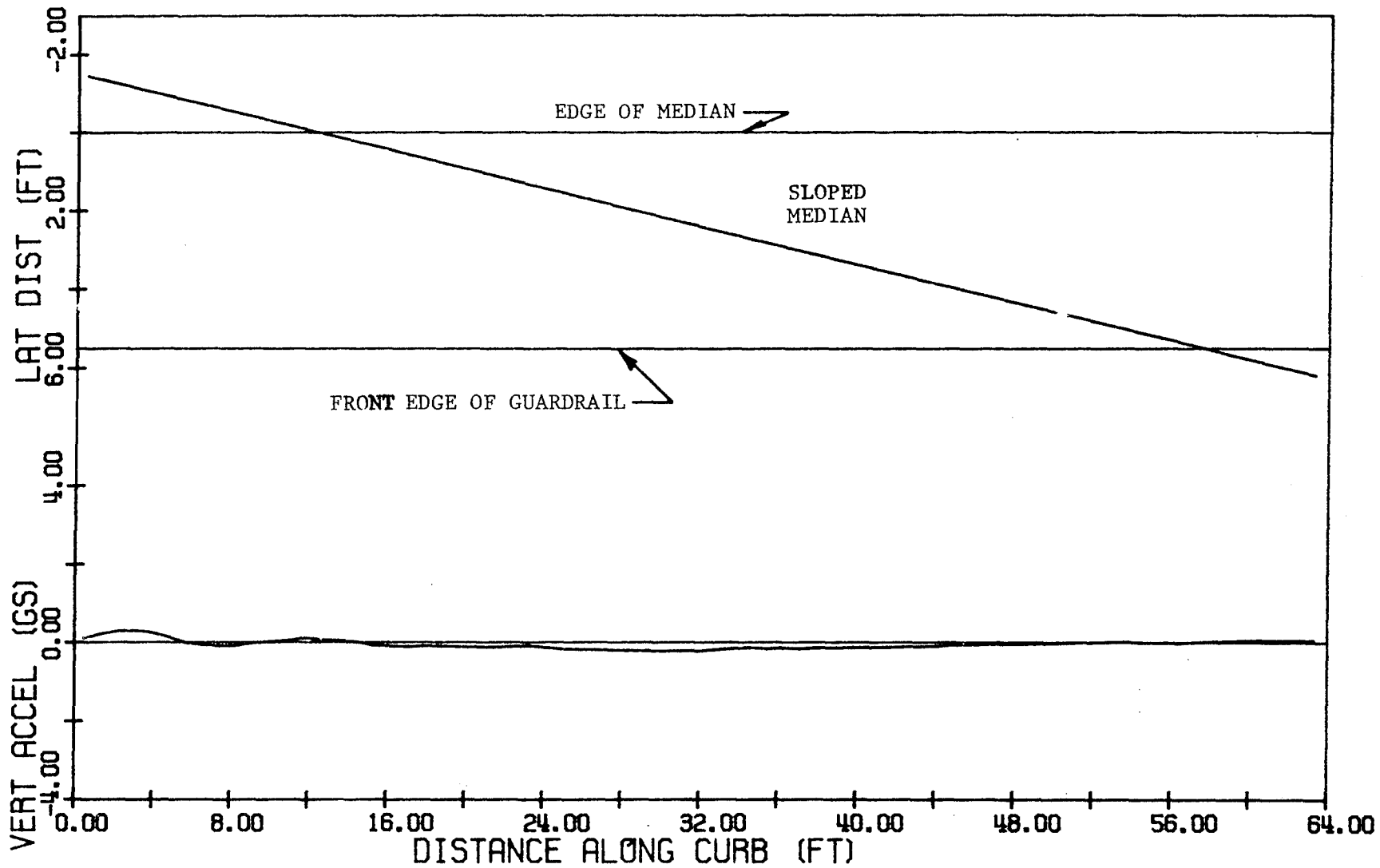


FIG. B10. VEHICLE BEHAVIOR, MEDIAN BARRIER 2A, 60 mph/7 deg, $\mu=0.8$, PART 2

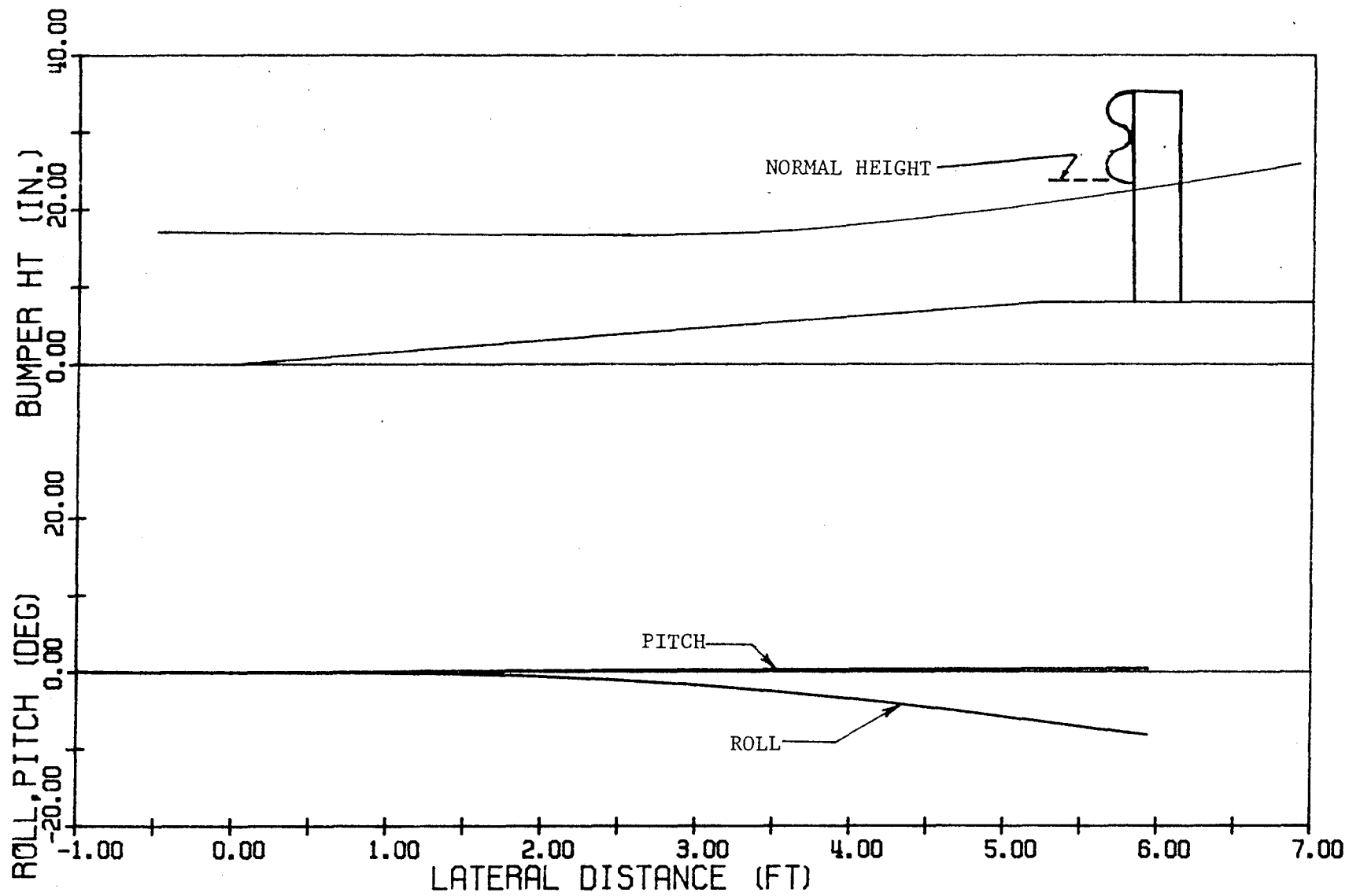


FIG. B11. VEHICLE BEHAVIOR, MEDIAN BARRIER 2A, 70 mph/7 deg, $\mu=0.8$, PART 1

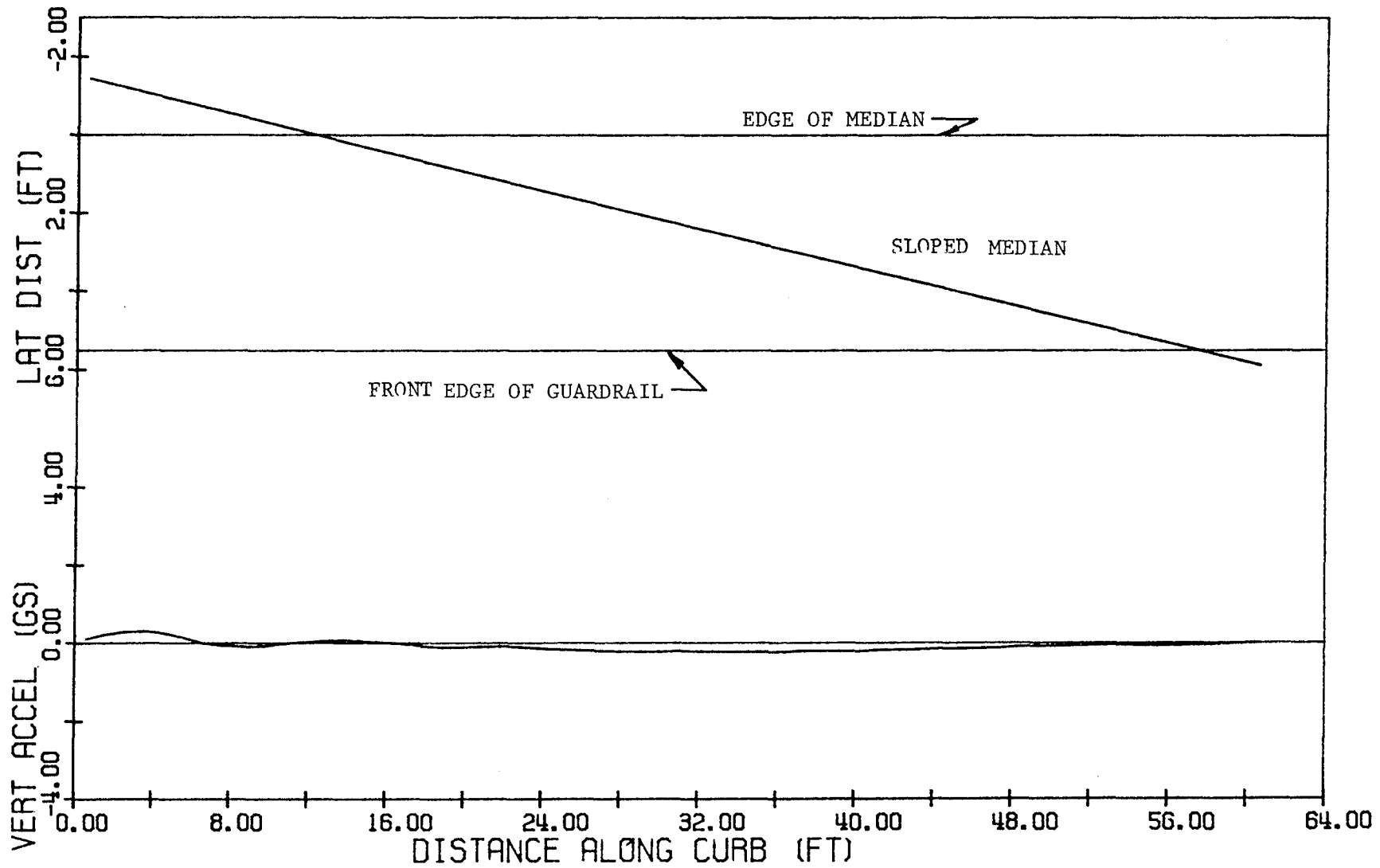


FIG. B12. VEHICLE BEHAVIOR, MEDIAN BARRIER 2A, 70 mph/7 deg, $\mu=0.8$, PART 2