TRUCK SPEED STUDY

Evaluation of Hill-
Climbing Ability of
Motor Trucks

TSD-G-183-71

TRAFFIC and SAFETY DIVISION

DEPARTMENT OF STATE HIGHWAYS
STATE OF MICHIGAN

MICHIGAN DEPARTMENT OF STATE HIGHWAYS

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by

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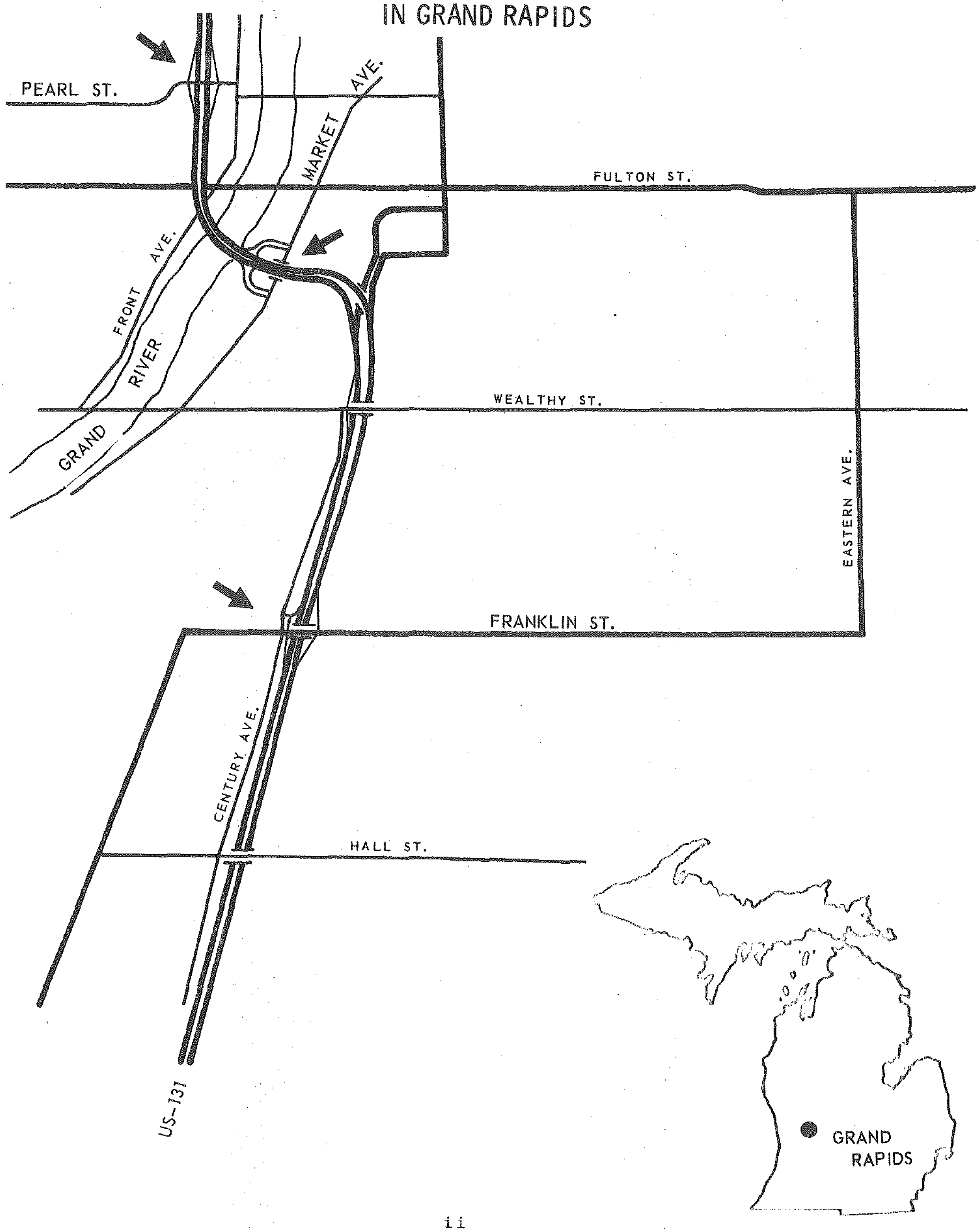
TRUCK STUDY LOCATIONS IN GRAND RAPIDS



EVALUATION OF HILL-CLIMBING ABILITY OF MOTOR TRUCKS

INTRODUCTION

Since most on-ramps to elevated freeways originate from a signalized crossroad at a lower elevation than the freeway, the ascending grade of the ramp significantly reduces the acceleration capability of trucks. Consequently, a traffic congestion problem will generally result when a truck or other vehicle enters the freeway at a speed well below that of vehicles on the mainline. This study evaluates the effect that ramp grades had on truck speed at five ramps in Grand Rapids.

PURPOSE OF THE STUDY

The purpose of this study is to evaluate the hill-climbing ability of large trucks. To accomplish this purpose, the study is divided into two distinct but closely related parts: (1) actual grade driving tests, using a truck with known engine performance and gross weight and (2) a mathematical model of the test runs.

CONCLUSION

The performance of the truck in the test runs correlated, with a very small discrepancy, to the performance predicted by the model, which was designed to simulate the same circumstances. In most instances the difference in speed did not exceed three miles per hour.

The results of this study will: (1) assist the designing engineer in determining grades that will not cause trucks to unreasonably hinder traffic flow and (2) provide for restrictions in the usage of certain ramps by vehicles whose weight-horsepower ratio exceeds a certain allowable limit that will not permit reasonable acceleration.

RECOMMENDATIONS

Based upon the close resemblance of the actual grade test and the established method for determining the gradability of motor trucks, this study makes three recommendations:

1. The result of this study should be used as a basis for the design criteria for truck climbing lanes.
2. With the absence of a definite design criteria, a legal weight-to-horsepower ratio of 400:1 for motor trucks is proposed.
3. Since values pertaining to the capacity of a roadway were not included, a follow-up study to determine how capacity is affected by inadequate acceleration on ramps should follow.

TRUCK PERFORMANCE ON GRADES

The maximum gross vehicle weight that a truck can pull up a given grade at a certain speed depends on the performance of the engine. Low performance (high weight-to-horsepower ratio) and related low speed when associated with high volume freeways is certain to cause intolerable congestion. This is particularly true when a low performance engined vehicle starts from a stop condition and proceeds on an ascending ramp prior to entering a freeway. Truck performance on the Grand Rapids Freeway System is representative of this condition. Although the study was conducted on US-131, most of I-196 and I-296 is also elevated. The elevated freeway system necessitates ascending on-ramps and descending off-ramps which do not enhance smooth flow of traffic. The irregularity in traffic flow encouraged gathering information for evaluating truck speeds on grades and also preparation of a truck-climbing lane standard guide since present design criteria is rather vague.

Two basic geometric and operational criteria were necessary for effective evaluation: (1) the ramp had to originate at a signalized crossroad and (2) the approach to the freeway had to be on a grade.

To obtain a fair degree of accuracy of the truck performance, markings with spray paint at intervals of 100 ft were made along the pre-selected ramps. These markings started at the origin of the ramp at the crossroad and continued at least one-half mile onto the freeway.*

A truck weighing 87,700 lb (weight-to-horsepower ratio of 515) and an experienced driver were supplied by a local trucking company. The truck was followed by a Department of State Highways vehicle equipped with a vehicle event recorder, which recorded the speed at each marked interval and the time required to travel from one interval to the next.

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* On future studies where markings on the pavement or its appurtenances are required, the use of tape is recommended for ease of removal when the study is completed.

For the safety of men and equipment, a police escort was provided. This escort also permitted completion of several uninterrupted test runs through all five pre-selected ramps and their elongation. Figures 1 through 5 show the result of this motor gradability test. With the exception of the Franklin Street ramp (Figure 5), which starts on a significant downhill grade, all test runs originated with an uphill grade.

Although accidents related to slow moving vehicles were not evaluated, it was observed that vehicle platoons formed when a truck entered the through lanes at a speed below the posted minimum speed.

A comparison of the results of this study with theoretical calculations[1] indicated a high degree of correlation between calculated and actual data, Consequently, it is feasible to compute speeds by utilizing various horsepower ratios. Figures 6 through 10 illustrate the change in speed when the horsepower ratio is altered. Each family of curves shows the increase of speed when the weight-horsepower ratio is decreased from a high of 515:1 to a low of 100:1. A horsepower ratio of 100 to 1 is considered the lower limit for motor trucks. Evaluation of truck performance on grades has to be viewed under two conditions: First, where a truck starts from a standstill and secondly, when a truck changes speed from its running speed. The first case is applicable to arrive at a minimum lower speed, or crawl speed. The running speed of the second case is established by the overall performance of motor trucks on flat grades.

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[1] See Appendix for the equations.

For the mathematical model, a lower limit of 12 mph and an upper limit of 47 mph were used.

Figure 11 shows the speeds of a motor vehicle as it accelerates from an initial speed of 12 mph. The speeds shown are purely theoretical: no truck driver would accelerate his vehicle on a 7 percent downgrade to the speed shown. Yet it is still considered correct to compute the speed on this downgrade, provided the increment is small or physical geometrics allow a driver to accelerate.

Figure 12 shows the speeds of a motor vehicle as it decelerates from an initial speed of 47 mph. No increase of speeds is shown on downgrades. Both figures show a close resemblance to those as given in AASHO's "A Policy on Geometric Design of Rural Highways", 1965 (1) p 197.

FIGURES

FIGURE 1
TRUCK SPEED CHART - SB US-131 (PEARL ST.) ON-RAMP A

FIGURE 2
TRUCK SPEED CHART - NB US-131 (PEARL ST.) ON-RAMP D

FIGURE 3
TRUCK SPEED CHART - SB US-131 (MARKET ST.) ON-RAMP

FIGURE 4
TRUCK SPEED CHART - NB US-131 (MARKET ST.) ON-RAMP D

FIGURE 5
TRUCK SPEED CHART - NB US-131 (FRANKLIN ST.) ON-RAMP B

FIGURE 6
VARIABLE SPEED CHART - SB US-131 (PEARL ST.) ON-RAMP A

FIGURE 7
VARIABLE SPEED CHART - NB US-131 (PEARL ST.) ON-RAMP D

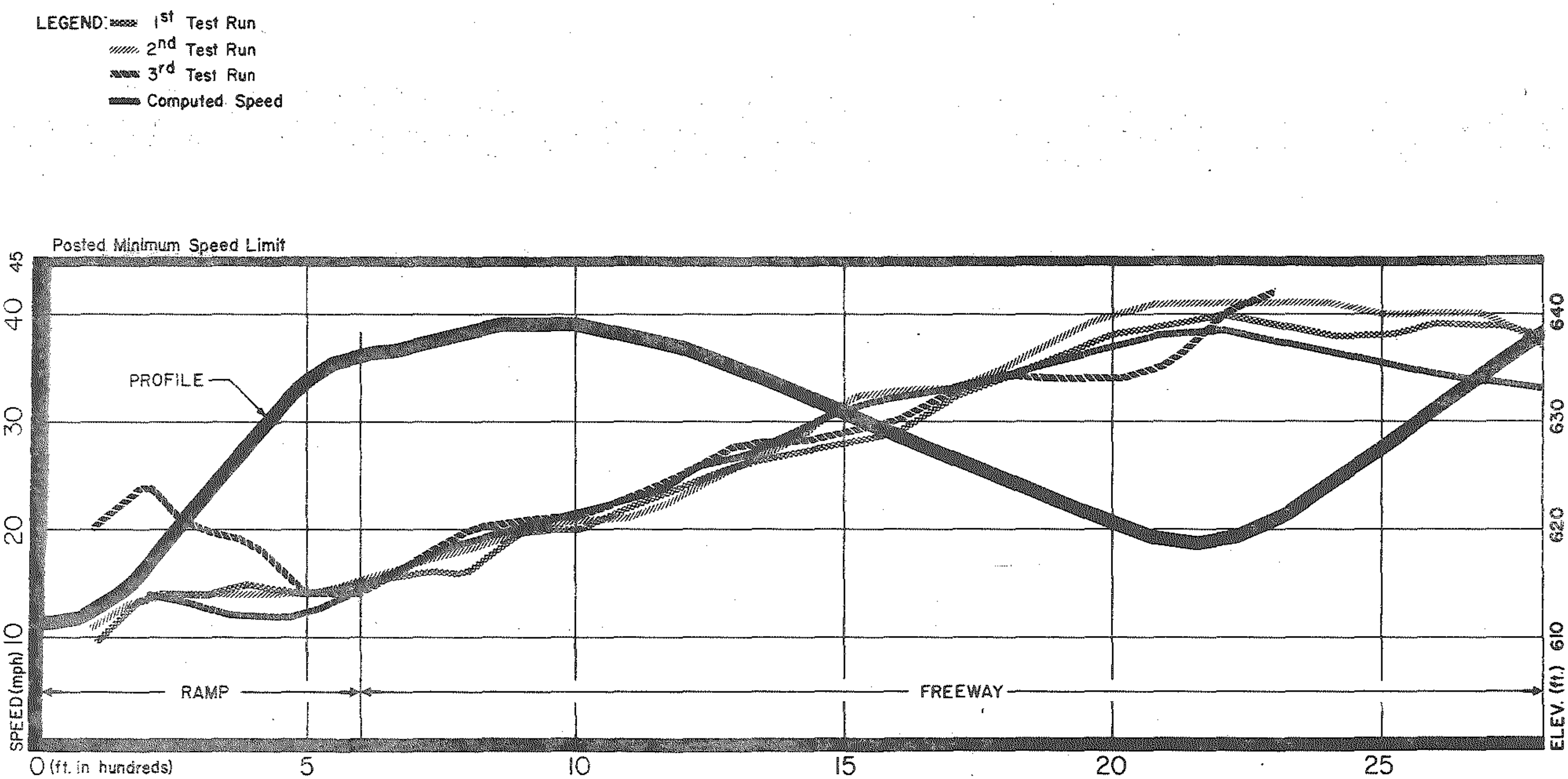
FIGURE 8
VARIABLE SPEED CHART - SB US-131 (MARKET ST.) ON-RAMP

FIGURE 9
VARIABLE SPEED CHART - NB US-131 (MARKET ST.) ON-RAMP D

FIGURE 10
VARIABLE SPEED CHART - NB US-131 (FRANKLIN ST.) ON-RAMP B

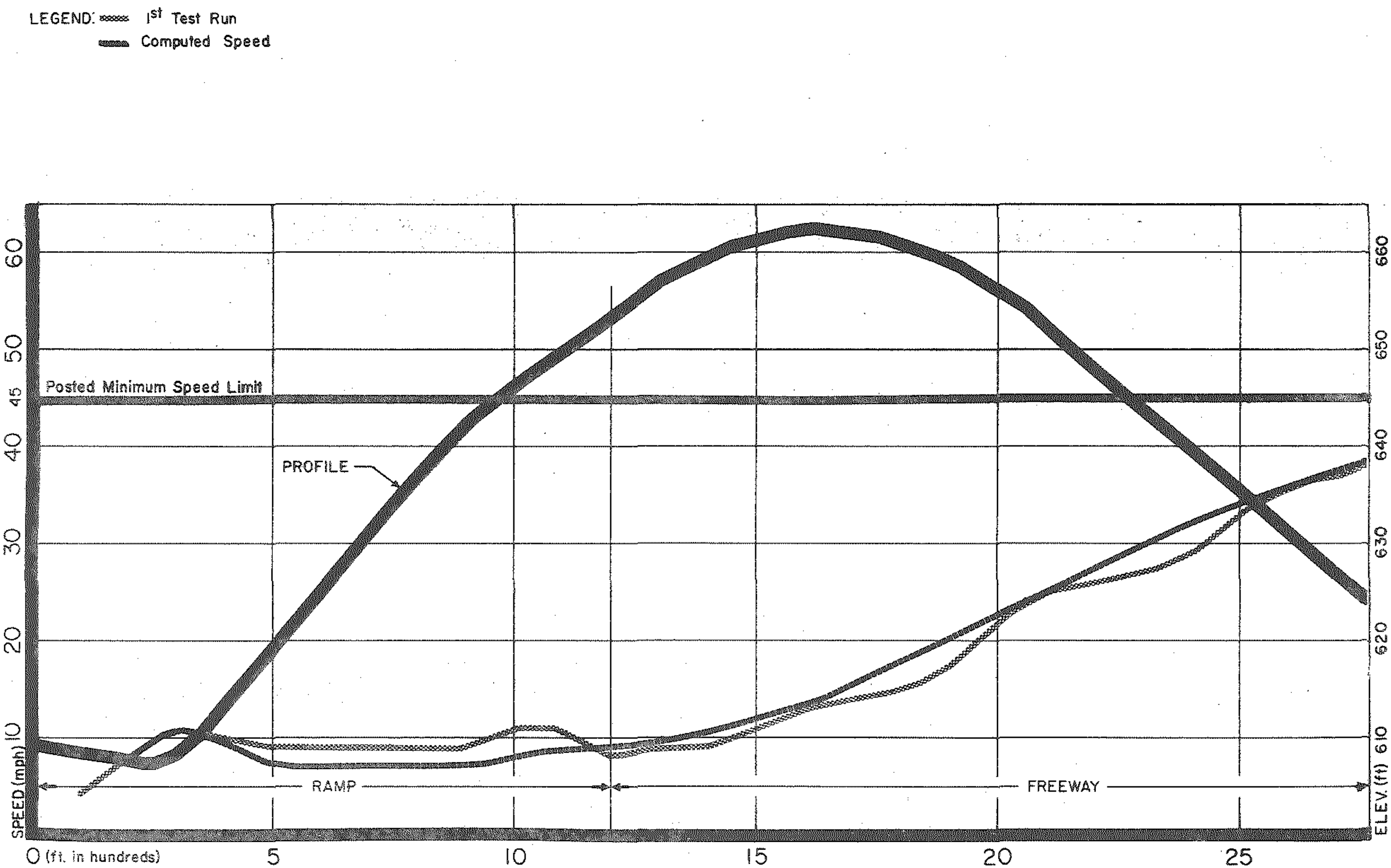
FIGURE 11
TRUCK SPEED CHART - ACCELERATION ON UPGRADE ✓ AND DOWNGRADE

FIGURE 12
TRUCK SPEED CHART - DECELERATION ON UPGRADES



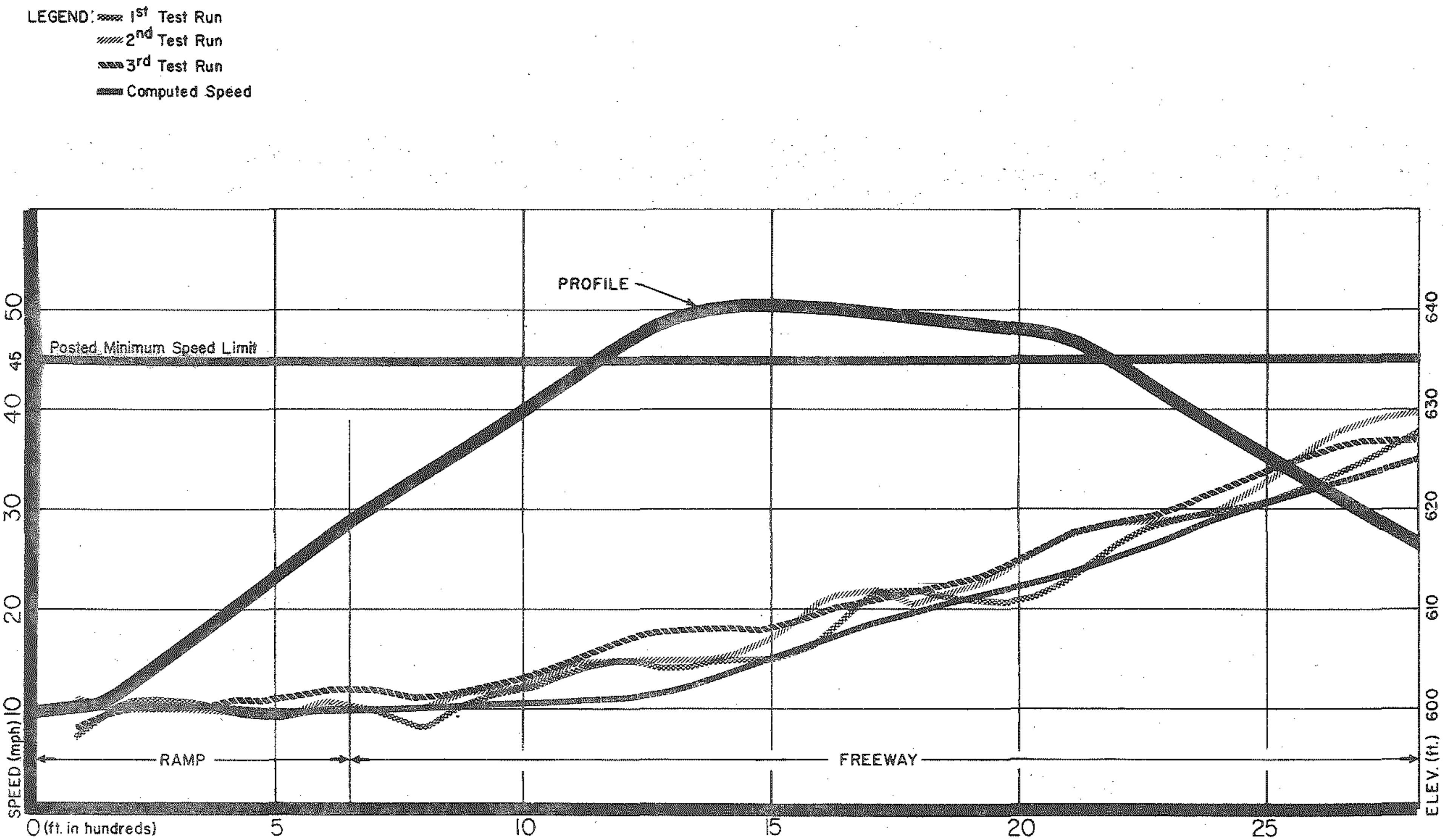
TRUCK SPEED CHART
S.B. US 131 (Pearl St.) ON RAMP A

FIGURE 1



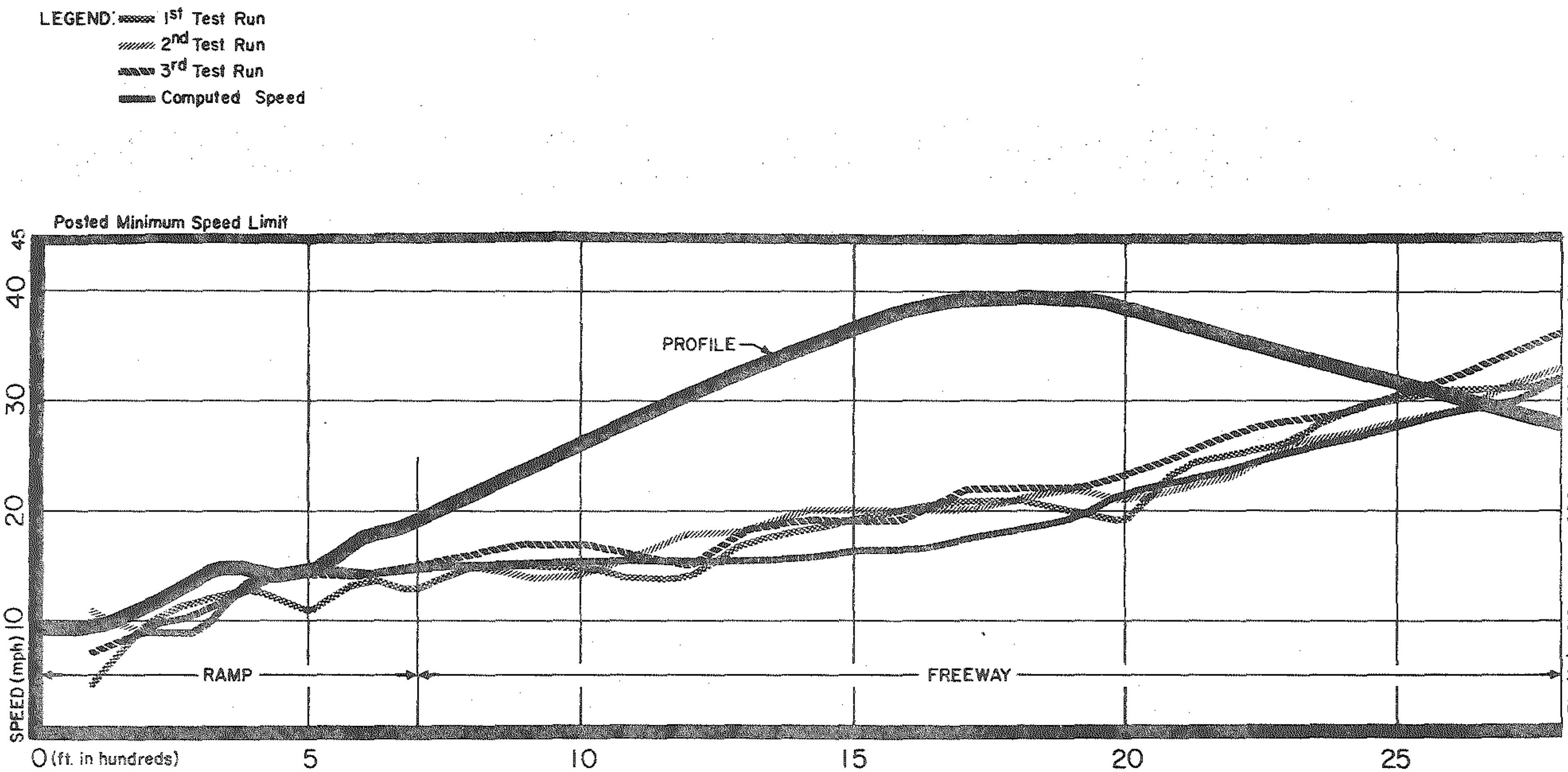
TRUCK SPEED CHART
N.B. US 131 (Pearl St.) ON RAMP D

FIGURE 2



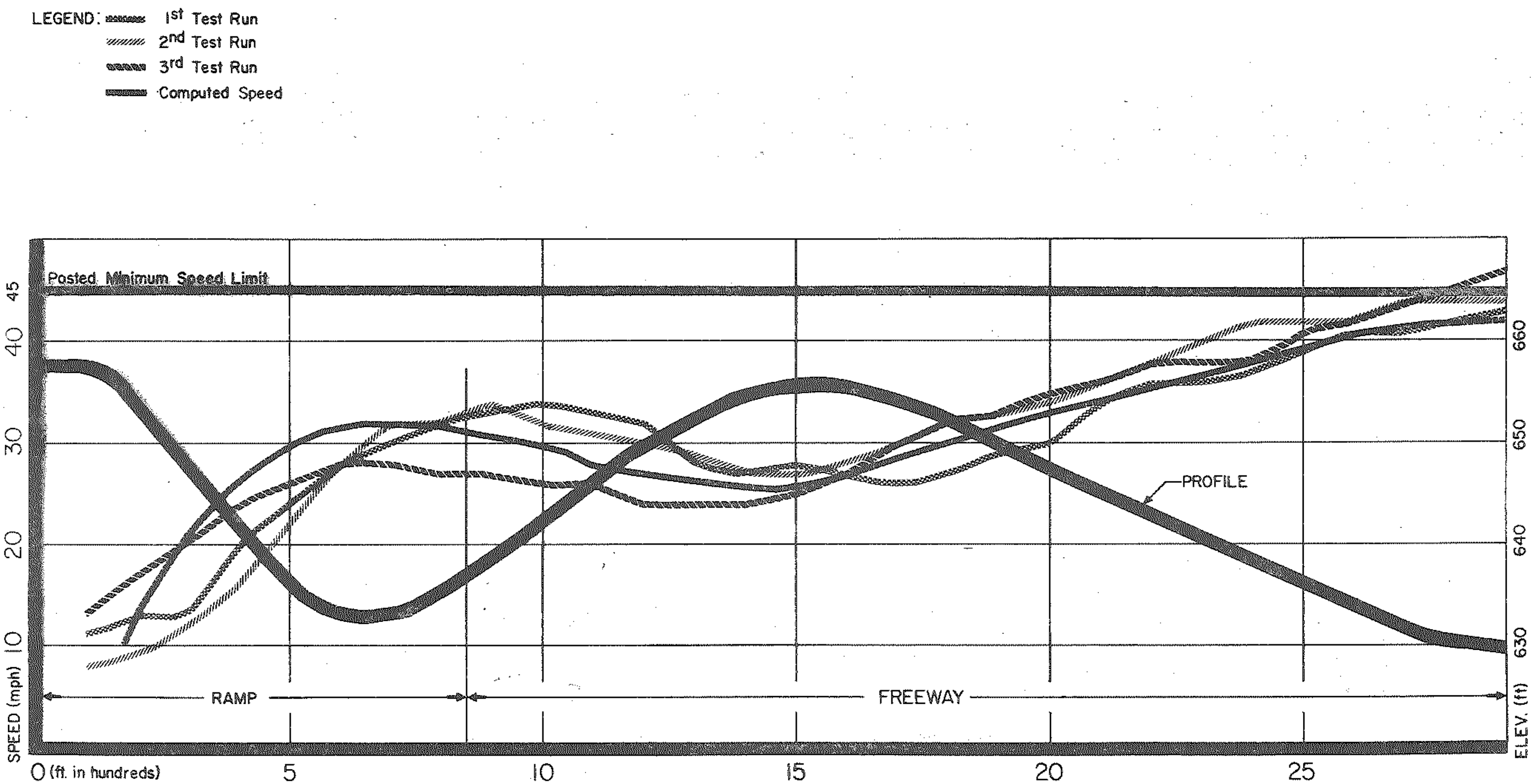
TRUCK SPEED CHART
S.B. US 131 (Market St.) ON RAMP

FIGURE 3



TRUCK SPEED CHART
N.B. US 131 (Market St.) ON RAMP D

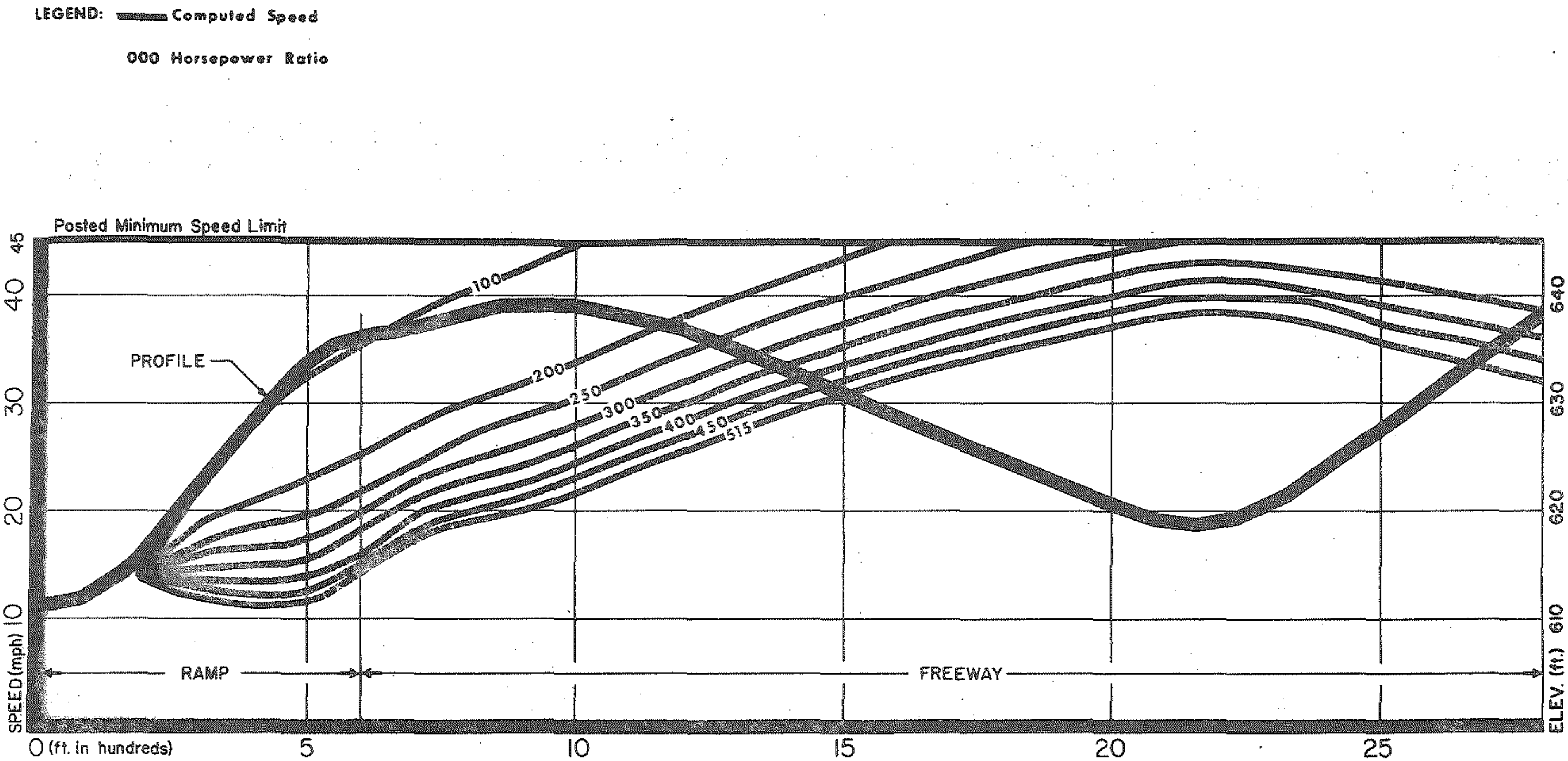
FIGURE 4



TRUCK SPEED CHART

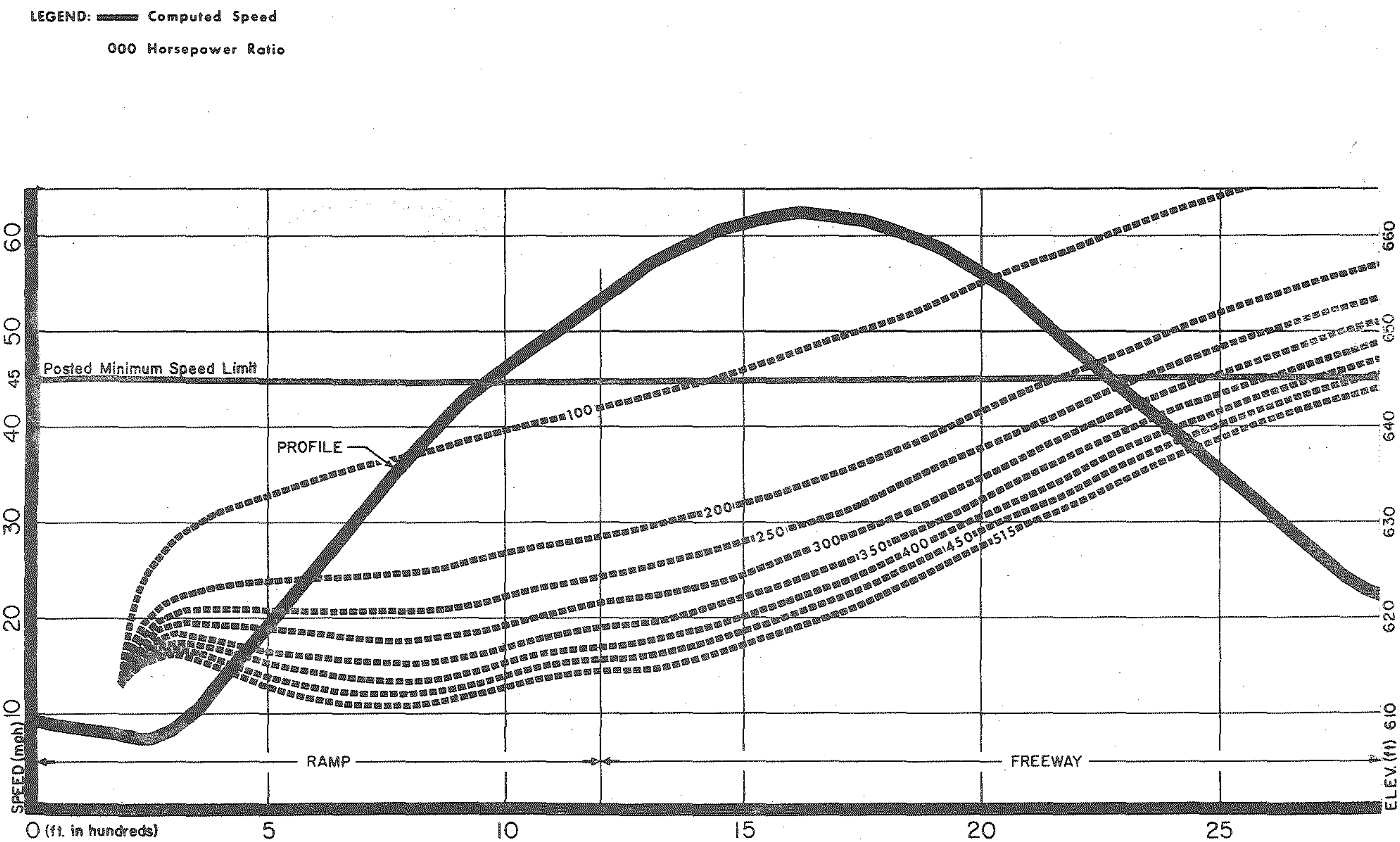
N. B. US 131 (Franklin St.) ON RAMP B

FIGURE 5



VARIABLE SPEED CHART
S.B. US 131 (Pearl St.) ON RAMP A

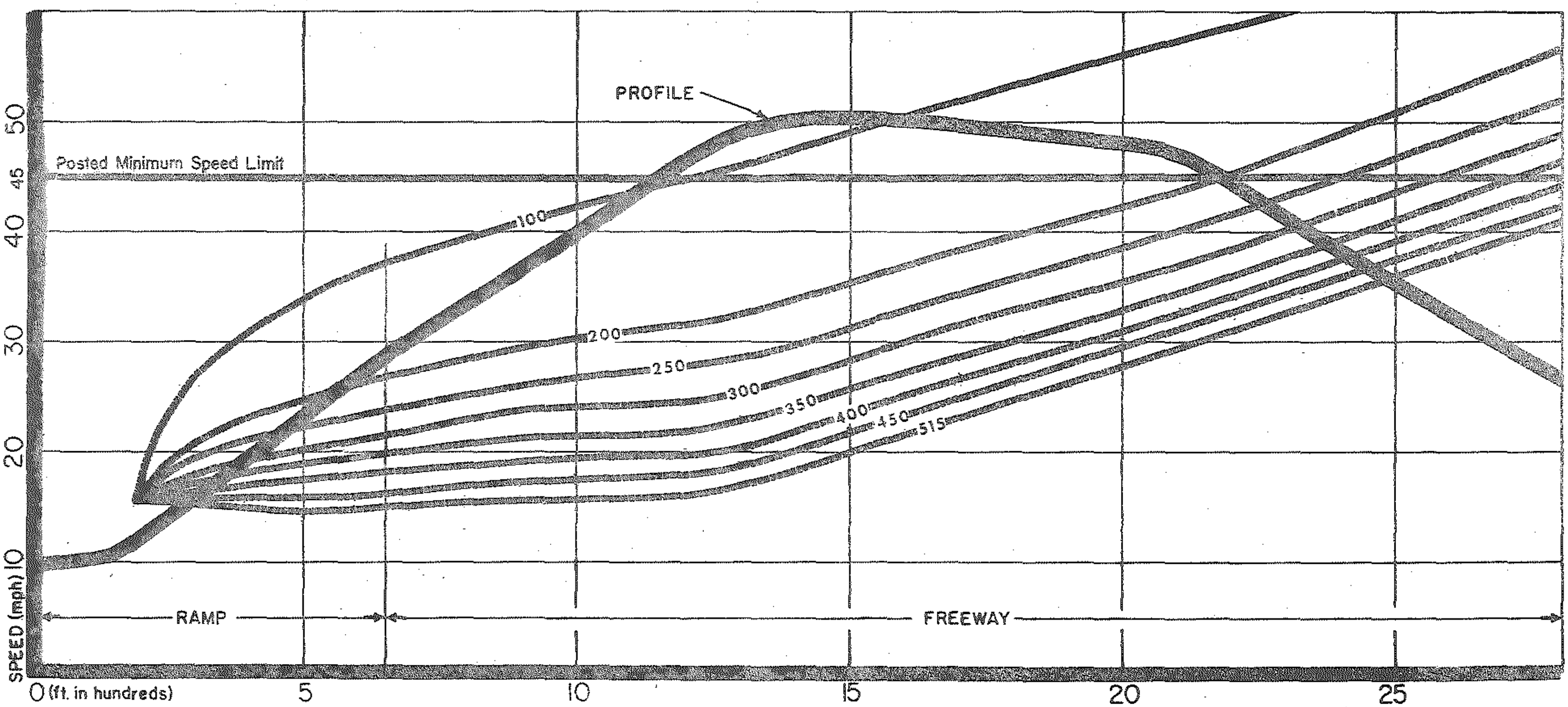
FIGURE 6



VARIABLE SPEED CHART
N.B. US 131 (Pearl St.) ON RAMP D

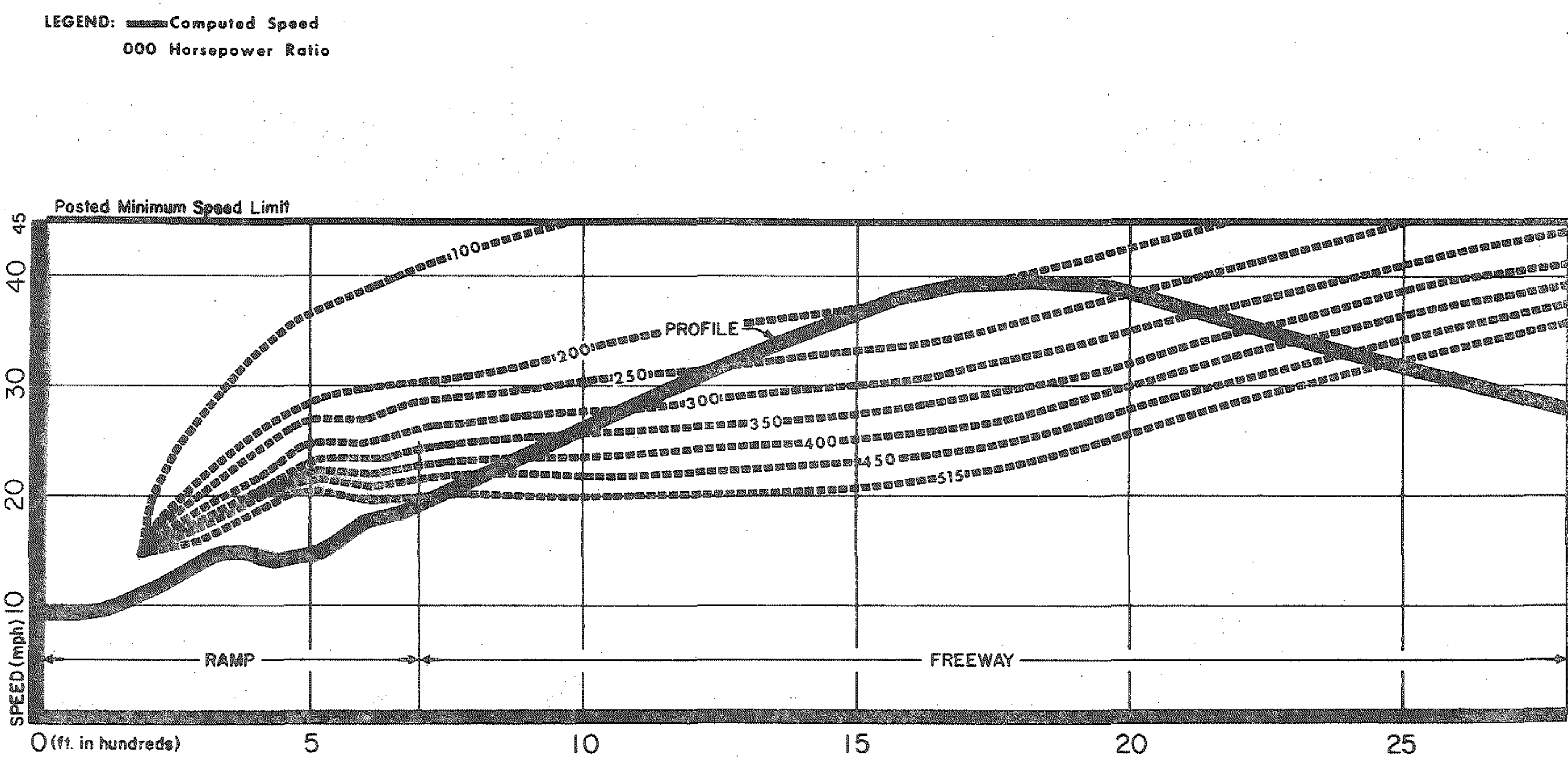
FIGURE 7

LEGEND: ▬▬ **Computed Speed**
000 Horsepower Ratio



VARIABLE SPEED CHART
S.B. US 131 (Market St.) ON RAMP

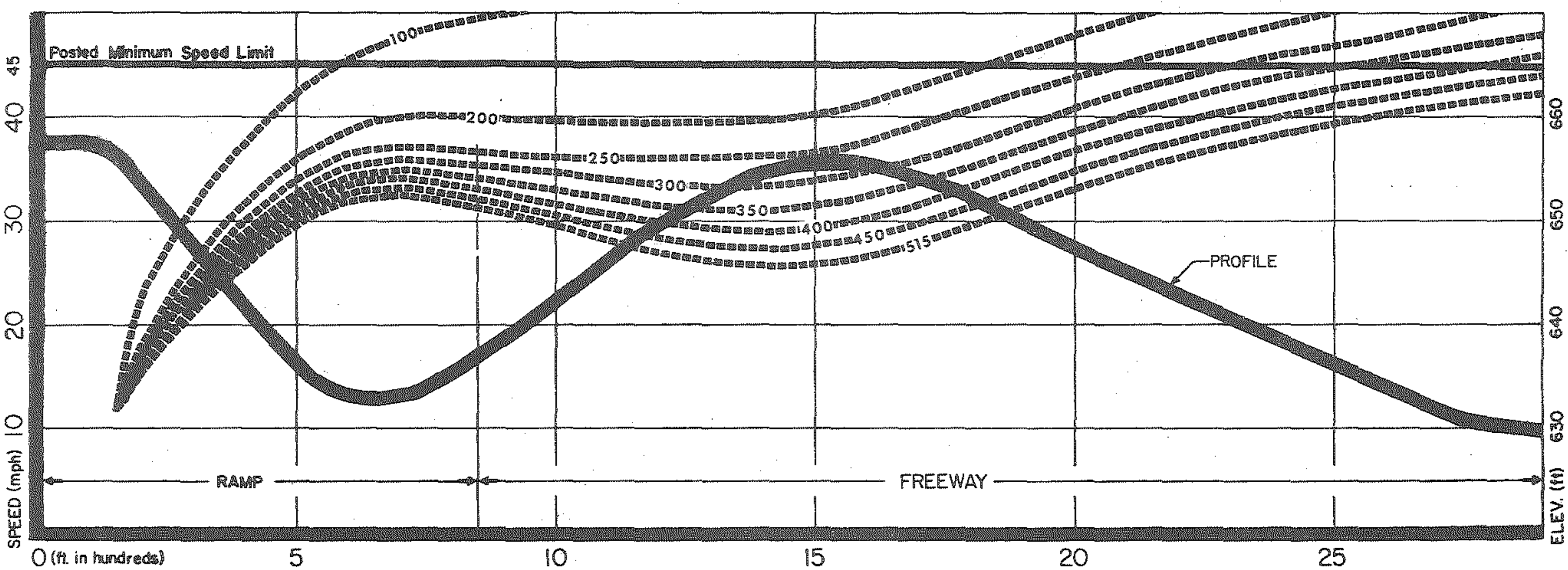
FIGURE 8



VARIABLE SPEED CHART
N.B. US 131 (Market St.) ON RAMP D

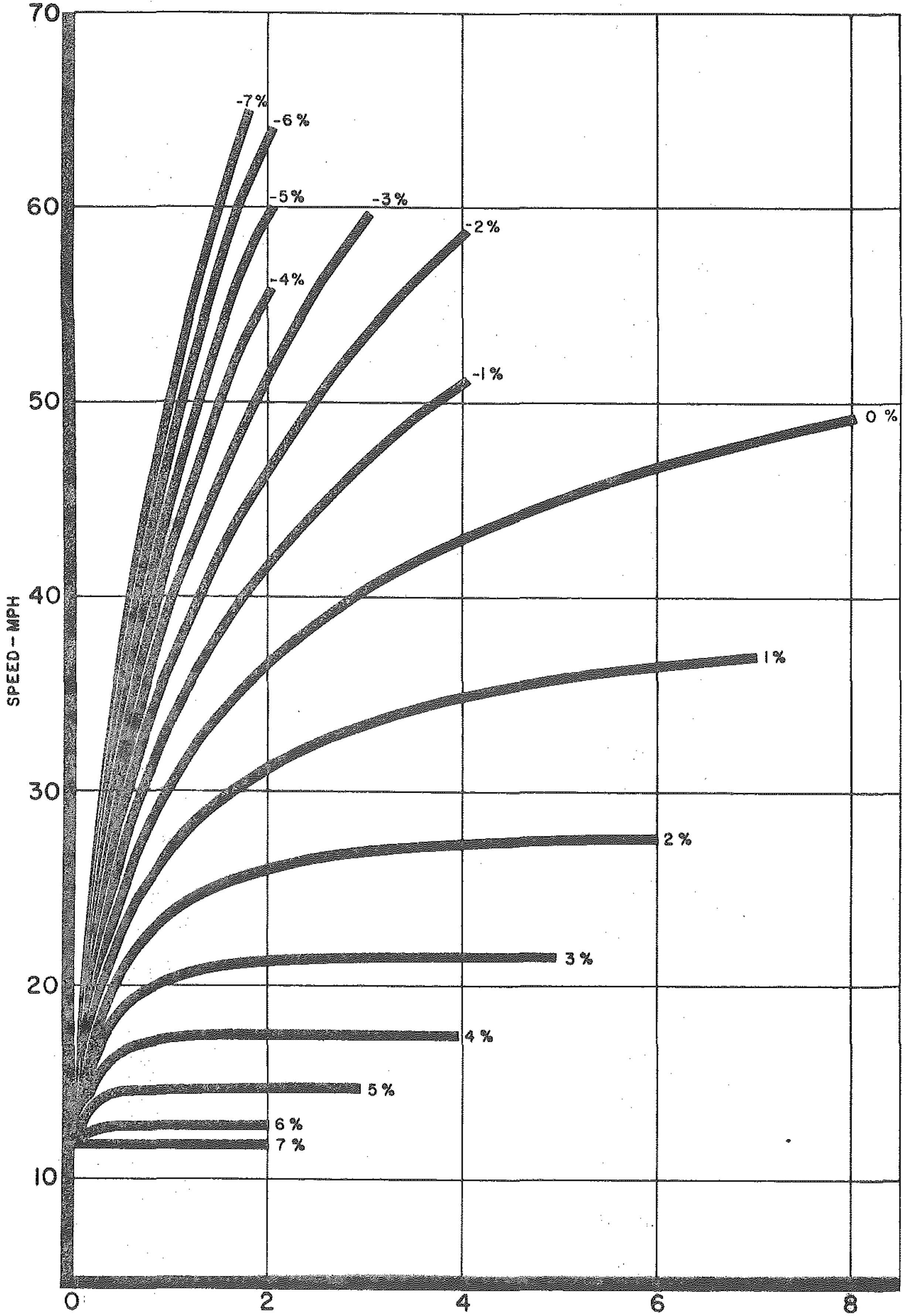
FIGURE 9

LEGEND: ▬▬ Computed Speed
000 Horsepower Ratio



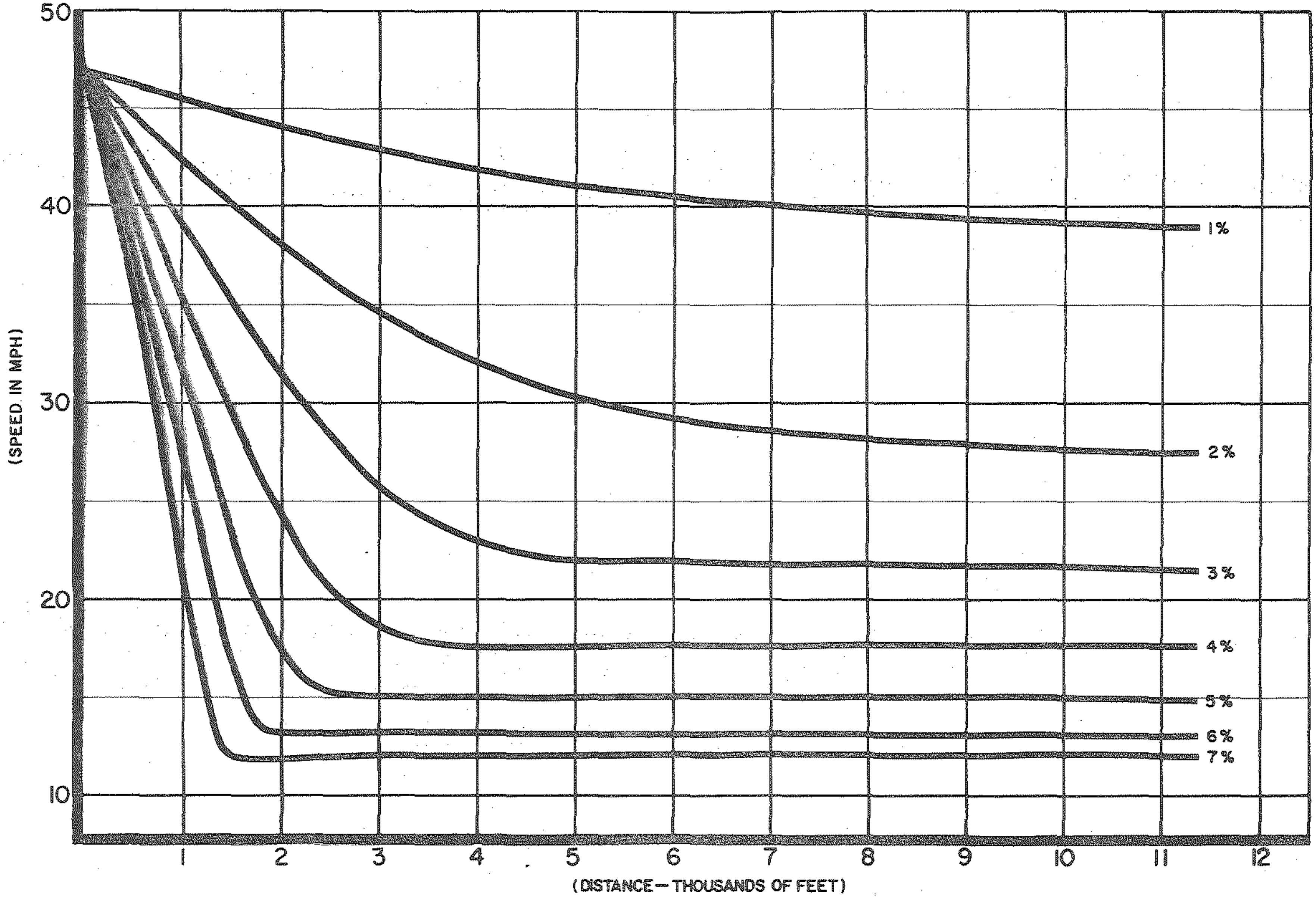
VARIABLE SPEED CHART
N. B. US 131 (Franklin St.) ON RAMP B

FIGURE 10



(DISTANCE — THOUSANDS OF FEET)
TRUCK SPEED CHART
ACCELERATION ON UPGRADE AND DOWNGRADE
INITIAL SPEED — 12 MPH

FIGURE 11



TRUCK SPEED CHART
DECELERATION ON UPGRADES
INITIAL SPEED — 47 MPH

FIGURE 12

APPENDIX

Theoretical Acceleration Capabilities

(source: Matson, Smith and Hurd (2) pp 26-31)

A moving vehicle needs a continuous energy input to overcome rolling resistance, air resistance, and the effect of gravity, if the vertical alignment is not level. The energy required, in horsepower, required to overcome each of these resistances is:

$$HP_{roll} = \frac{1.47\ V \times W \times R_r}{550} \qquad (1)$$

where HP_{roll} = energy to overcome rolling resistance (horsepower)

V = instantaneous vehicle speed (mph)

W = weight of vehicle (ton)

R_r = rolling resistance (lb per ton)

1.47 = conversion factor: mph to ft per sec.

550 = conversion factor: ft lb/sec to horsepower

$$HP_{air} = \frac{0.0017\ AV^2 \times 1.47\ V}{550} \qquad (2)$$

where HP_{air} = energy to overcome air resistance (horsepower)

A = frontal area of vehicle (ft^2)

0.0017 = empirical constant for air resistance, with no streamlining

$$HP_{grade} = \frac{1.47\ V \times W \times 2000 \times 0.01G}{550} \quad (3)$$

where HP_{grade} = energy to overcome effect of gravity (horsepower)

G = vertical grade (percent)

2000 = conversion factor: ton to lb

0.01 = conversion factor: percent to decimal

Summing equations 1, 2, and 3 yields the total energy required to overcome resistance:

$$HP_{resist} = HP_{roll} + HP_{air} + HP_{grade} \quad (4)$$

$$= \frac{W \times V\ (R_r + 20G) + 0.0017AV^3}{375}$$

where HP_{resist} = the energy required to overcome resistance (horsepower)

The horsepower available for acceleration is:

$$HP_{avail} = HP_{total} - HP_{resist} \quad (5)$$

where HP_{avail} = energy available for acceleration

HP_{total} = energy delivered from engine

The acceleration can then be computed as:

$$a = \frac{550\ HP_{avail}}{\frac{W_1}{32.2} \times 1.47\ V} \quad (6)$$

where a = acceleration (ft/sec^2)

W_1 = vehicle weight (lb)

32.2 = acceleration of gravity (ft/sec^2)

In determining the computed data for this study, the following assumptions were used:

R_r = 25 lb per ton of truck weight

A = 30 ft^2

The truck was not streamlined

The theoretical truck speeds were determined by the Department's computer program 16295.

REFERENCES

1. American Association of State Highway Officials, Washington, D. C., _A Policy on Geometric Design of Rural Highways_ (1965).

2. Matson, Smith and Hurd, McGraw-Hill, New York (1955), _Traffic Engineering_.