# A CALCULATOR PROGRAM TO
# ESTIMATE TRUCK COASTING
# SPEEDS FOR DESIGNING
# GRAVEL ARRESTER BEDS

Research Project 94

A. F. Stanley, P. E.
Associate Materials Engineer I

November 1978

Idaho Transportation Department
Boise, Idaho

## Acknowledgment

This project was initiated by James W. Hill, P. E., Research Supervisor of the Idaho Transportation Department. His advice and support are appreciated. The gravel bed stopping distance data furnished by the Oregon State Highway Division were a valuable contribution to the project. Special thanks to Gordon Beecroft and W. J. Quinn for providing this information.

Typed by Linda S. Brown

## Introduction

This project was undertaken to provide an improved method for selecting the locations, lengths, and grades of gravel beds for stopping runaway trucks safely. A convenient program has been developed for use on desk calculators having program storage of about 250 steps or more. It can be used to predict the speed of a coasting truck as it travels along a grade of varying steepness. Surface drag can be chosen to represent either pavement or a bed of loose gravel.

## Program Usage and Limiting Assumptions

During the design process, the program may first be used in the pavement mode to determine the speed a runaway truck might reach at various points as it coasts down a paved highway grade. Following this, the gravel bed mode can be used to check any desired combinations of entry speed, grade, and length for escape ramps. Thus, escape ramp configurations and locations can easily be chosen to match the terrain and the expected truck speed at any point along the highway.

Several simplifications were required to keep the program short enough for desk calculator use. First, vertical curves are approximated by chords. Second, horizontal curvature has been ignored altogether. Therefore, the energy loss due to sideways friction in curves isn't considered. This means the speed prediction for a runaway truck may be slightly high in some cases. Another result of ignoring horizontal curvature is that the speed estimation is independent of safe cornering speed. The user must check the speed predictions against horizontal alignment to determine whether or not a truck can negotiate a given curve at the predicted speed. Finally, the truck is assumed to be out of gear. This corresponds to a situation where the driver has tried to downshift to increase the engine braking effect, but has missed the shift.

## Program Description

The theoretical basis of the program is energy summation followed by computation of the speed corresponding to a given kinetic energy. The energy summation has the following form:

$$\begin{bmatrix}\text{Final}\\ \text{kinetic}\\ \text{energy}\end{bmatrix} = \begin{bmatrix}\text{Initial}\\ \text{kinetic}\\ \text{energy}\end{bmatrix} + \begin{bmatrix}\text{Energy change}\\ \text{due to ele-}\\ \text{vation change}\end{bmatrix} - \begin{bmatrix}\text{Energy loss}\\ \text{due to road}\\ \text{friction}\end{bmatrix} - \begin{bmatrix}\text{Mechanical}\\ \text{loss within}\\ \text{the truck}\end{bmatrix} - \begin{bmatrix}\text{Air drag}\\ \text{energy}\\ \text{loss}\end{bmatrix}$$

Mathematical expressions for road, mechanical, and air drag losses appear in references (1) and (3). Reference (2) indicates the air drag and mechanical loss expressions given in (1) are unrealistically high, and suggests that they be multiplied by 0.72 and 0.22, respectively. These factors were used in the Idaho Transportation Department program, and a further change was made as a result of field testing. The detailed energy summation, after solving for speed is:

$$V = 5.469\ (.03343\ V_o^2 - H - KL - .000016\ V_m L - .0012\ FLV_n^2/W)^{1/2}$$

Where $V$ = speed (mph) at the end of distance L

$V_o$ = speed (mph) at the beginning of distance L

$H$ = vertical distance (ft) corresponding to distance L

$K$ = constant incorporating surface friction and speed-independent portion of mechanical loss: .01675 for pavement and .26175 for gravel bed

$L$ = grade distance (ft) computed from stationing and decimal fraction grade

$V_m$ = average of $V_o$ and $V$

$F$ = frontal area of truck ($ft^2$)

$V_n^2$ = average of $V_o^2$ and $V^2$

$W$ = truck weight (lb)

The fact that $V_m$ and $V_n^2$ are both functions of V complicates the determination of V. An iterative technique was chosen because it is relatively easy to program. A first estimate for V is obtained by assuming the potential energy available, as weight W moves through vertical distance H, is all converted to kinetic energy. First estimates for $V_m$ and $V_n^2$ are then computed and inserted into the right side of the expression. The right side is next evaluated, giving an improved estimate of V. The process is repeated until successive approximations differ by less than 0.1 mph.

Program structure is outlined in Figure 1. Note that input data is called for in two places. Initial input includes information about the truck. Input at a grade change requires only data about the length and steepness of the new grade. The original truck data and the speed at the end of the previous grade are retained in memory and need not be reentered.

## Field Verification

A series of downhill coasting runs was made on an Idaho highway, using a Department tractor and lowboy semitrailer loaded with a motor grader. As indicated earlier, a change was made in a program constant as a result of the field work. This adjustment yielded a speed prediction error of two mph or less, up to 64 mph for the combination of vehicle and grade under which the testing was done. No testing was done above 64 mph, nor was any other truck-trailer combination readily available for testing. The appendix contains a more detailed discussion of the field work.

# FLOW CHART FOR TRUCK COASTING SPEED PROGRAM

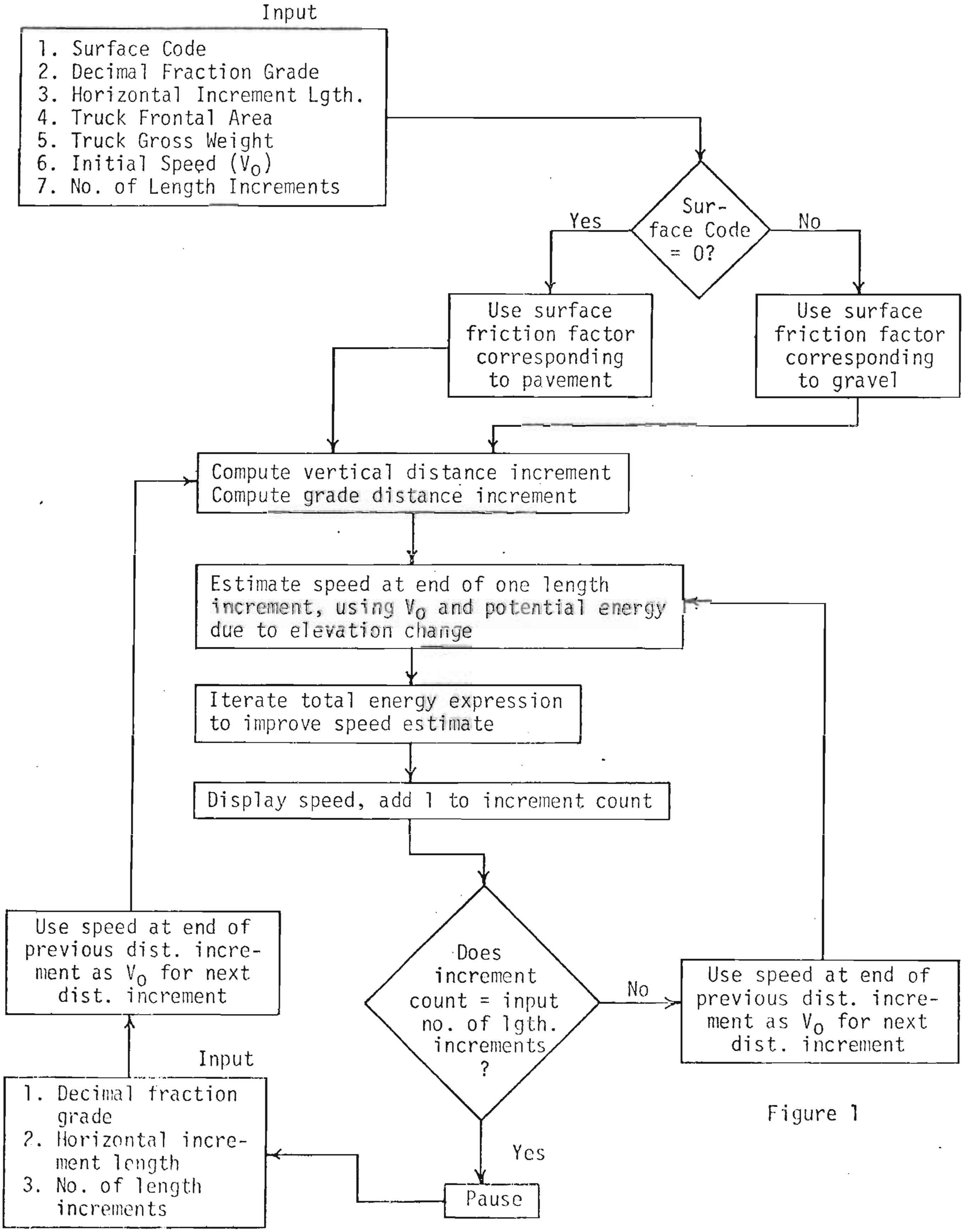

Figure 1

Field verification of the gravel bed mode of program operation is based on a series of runs made in 1977 by the Oregon State Highway Division. A loaded tractor-flatbed trailer was coasted at speeds up to 55 mph into a gravel bed having a grade of -5.5%. The gravel was 18 inches deep, and met the following gradation specification:

| Sieve Size | % Passing |
|---|---|
| 1 Inch | 100 |
| 3/4 Inch | 85-100 |
| 3/8 Inch | 0-15 |

The gravel coefficient in the calculator program was adjusted to give a stopping distance at 80 mph, which is 20 feet greater than indicated by extrapolation of the Oregon field data. Further details are presented in the appendix.

# References

1. Truck Ability Prediction Procedure SAE-J688, Society of Automotive Engineers, 1975.

2. Grade Effects on Traffic Flow Stability and Capacity, NCHRP Report 185, Transportation Research Board, 1978.

3. 1977 Chevrolet Truck Data Book, Chevrolet Motor Division.

4. Preliminary Results - Truck Escape Ramp - internal report, Oregon State Highway Division, by W. J. Quinn, dated 12-29-77.

# APPENDIX

## Downhill Coasting Runs on Pavement

A series of field runs was made September 22, 1978, on I-80N, between mileposts 108 and 109. Highway grade varies from -4.0% to -4.3%. The vehicle used was a forward-engine tractor towing a lowboy semi-trailer loaded with a motor grader. Gross weight was 61,200 lb., and overall frontal area, including grader cab, was 82 ft$^2$. All runs were made with the transmission out of gear.

Typical distance-speed data from the field runs are given in Table A-1. Speedometer observations were made as the truck passed roadside delineator posts. Tabulated speeds include correction for speedometer error. These corrections were obtained from a speedometer calibration check performed the same day as the coasting runs.

Table A-1 also lists estimated speeds given by the calculator program, incorporating a modification made as a result of the field runs. This change involves the speed-independent mechanical loss term of the energy balance. Reference (3) gives a resistance value of 6.75 lb. per 1000 lb. of truck weight, but 4 lb. per 1000 lb. was found to give better speed prediction under the conditions of these field runs. Computed results also include the effect of an altitude correction factor of .94 applied to air resistance.

Figure A-1 is a graphical presentation of the speed data in Table A-1.

## TABLE A-1

| Delineator Number | Negative Grade % | Dist. Ft. | Cumulative Dist. Ft. | Truck Speed MPH | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Speed-ometer | Program | Speed-ometer | Program | Speed-ometer | Program |
| 1 | | | 0 | 15 | 15 | 25 | 25 | 34 | 34 |
| | 4.0 | 505 | | | | | | | |
| 2 | | | 505 | 24 | 23.7 | 32 | 30.8 | 38 | 38.3 |
| | 4.0 | 475 | | | | | | | |
| 3 | | | 980 | 31 | 29.5 | 36 | 35.3 | 42 | 41.8 |
| | 4.0 | 480 | | | | | | | |
| 4 | | | 1460 | 35 | 34.2 | 40 | 39.2 | 46 | 45.1 |
| | 4.0 | 200 | | | | | | | |
| PI VC | | | 1660 | | 36.0 | | 40.7 | | 46.3 |
| | 4.3 | 375 | | | | | | | |
| 5 | | | 2035 | 40 | 39.5 | 45 | 43.8 | 49 | 48.9 |
| | 4.3 | 500 | | | | | | | |
| 6 | | | 2535 | 44 | 43.6 | 48 | 47.4 | 52 | 52.0 |
| | 4.3 | 550 | | | | | | | |
| 7 | | | 3085 | 48 | 47.6 | 52 | 51.0 | 55 | 55.2 |
| | 4.3 | 550 | | | | | | | |
| 8 | | | 3635 | 51 | 51.2 | 54 | 54.3 | 58 | 58.2 |
| | 4.3 | 620 | | | | | | | |
| 9 | | | 4255 | 54 | 54.8 | 58 | 57.6 | 61 | 61.2 |
| | 4.3 | 310 | | | | | | | |
| 10 | | | 4565 | 55 | 56.5 | 59 | 59.2 | 63 | 62.6 |
| | 4.3 | 285 | | | | | | | |
| 11 | | | 4850 | 56 | 58.0 | 61 | 60.6 | 64 | 63.9 |

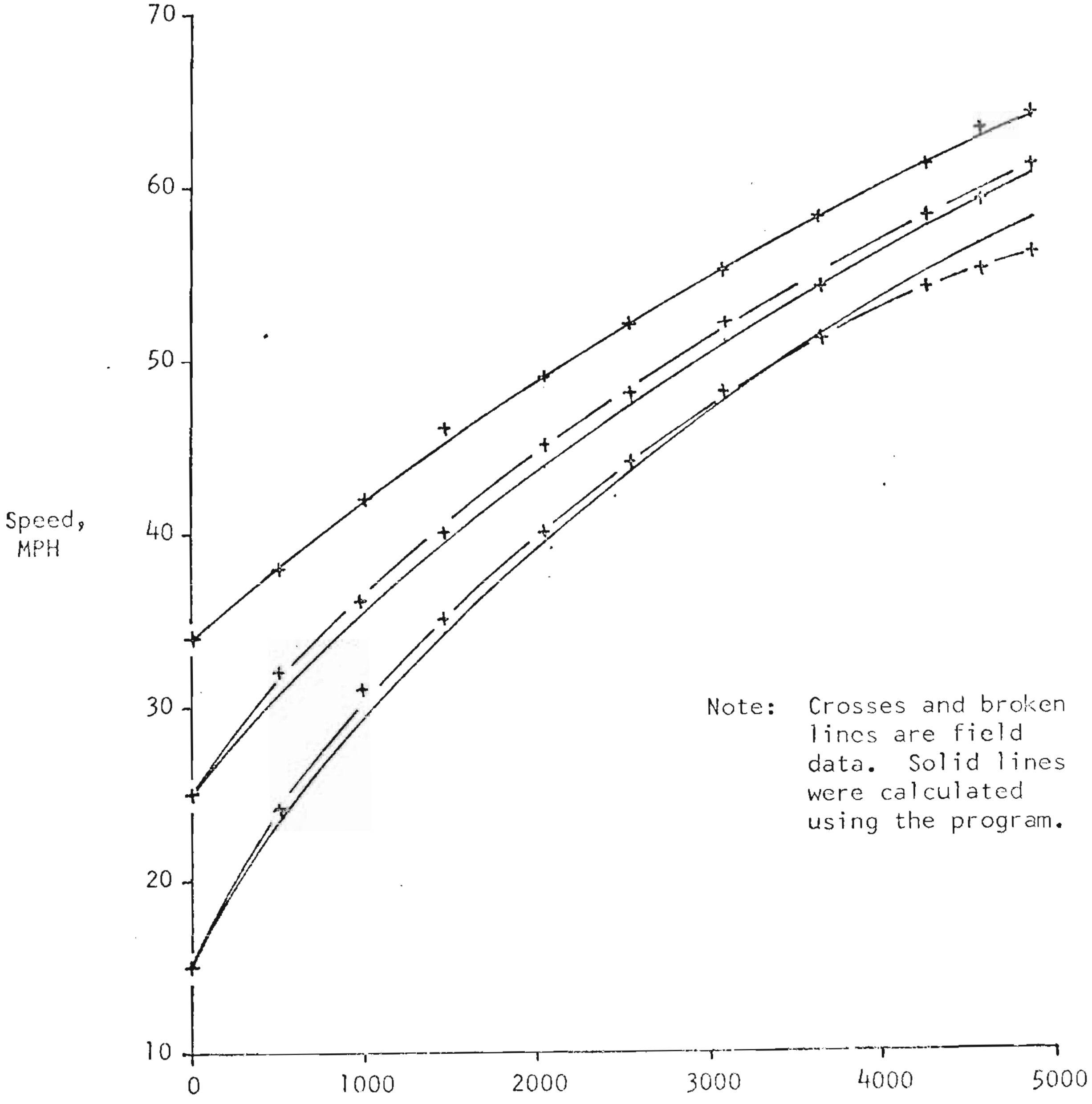
70
60
50
40
30
20
10
Speed, MPH
0
1000
2000
3000
4000
5000
Distance, Ft.
Note: Crosses and broken lines are field data. Solid lines were calculated using the program.

Figure A-1

## Gravel Bed Data from Oregon

The gravel resistance factor used in the program is based on a series of field runs made by the Oregon State Highway Division in December of 1977. The arrester bed was described in the body of this report. Several runs were made with a 5-axle tractor semi-trailer combination, both loaded and empty. Empty weight was 28,800 lb., and loaded weight was 49,200 lb. All runs were made with the transmission out of gear.

Entry speeds and stopping distances furnished by Oregon are listed below. Radar was used to measure the entry speeds.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Entry Speed V, mph. | 28.5 | 28.5 | 39.5 | 40 | 48 | 55 | 28 | 27 | 41 | 40 | 53 |
| Stopping Dist. to Front Axle D, ft. | 123 | 132 | 246 | 259 | 359 | 484 | 129 | 113.5 | 253 | 236 | 433.5 |
| Loaded or Empty | E | E | E | E | E | E | L | L | L | L | L |

Using a least squares technique, the following regression expression was obtained based on the Oregon data:

$$\log V = .5039 \log D + .3938 \quad (V = \text{speed, mph and } D = \text{distance, ft.})$$

The foregoing regression equation was used to extrapolate the Oregon data to a speed of 80 mph, giving a stopping distance of 990 ft. The gravel resistance term in the calculator program was then adjusted to give a comparable stopping distance for the conditions of the Oregon runs. The value selected is 255 lb. resistance per 1000 lb. of truck weight, giving a stopping distance of 1010 ft. This slight conservatism was incorporated into the program to help compensate for uncertainties in the original data and to provide a slight margin of safety in design.