Designation: E 1364 – 95 (Reapproved 2000)

Standard Test Method for Measuring Road Roughness by Static Level Method[1]

This standard is issued under the fixed designation E 1364; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the measurement of a longitudinal profile of a travelled surface using a static level for the purpose of obtaining a road roughness index. This test method is suitable for all surface types that are travelled by conventional ground vehicles, including paved and unpaved roads.

1.2 This test method is labor-intensive with respect to other means for measuring longitudinal profile, and is used mainly for (*1*) validating other profile-measuring methods and (*2*) calibrating response-type roughness-measuring systems.

NOTE 1—When measuring road roughness with a static level for the purposes of validating other profile-measuring methods or calibrating response-type roughness-measuring systems, the static level measurement process should be evaluated to ensure the measurements are within the resolution required in Table 1. It is recommended that several locations be marked at various distances from the level and these locations be measured in sequence several times to establish if the readings stay within the resolution required. Wind, distance between the rod and the level, surface texture, and positioning of the rod all have significant impact on the repeatability of the elevation measurements. Any variation from the true elevations will primarily affect the bias as explained in 10.2. To determine the effect of random variations, random variations can be added to an existing profile and the IRI recalculated to determine the impact of the variations.

1.3 This test method describes the computation required for one particular type of roughness index, the vehicle simulation used in the International Roughness Index (IRI). Additionally, the profile obtained with this test method can be processed to obtain other roughness measures.

1.4 This test method includes two levels of accuracy that can be chosen according to need. The more accurate, designated as Class 1, reduces the measurement error of the roughness index to less than 2 % of the true value of the index. The second, designated as Class 2, involves errors less than 5 %.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 950 Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Established Inertial Profiling Reference[2]

E 1082 Test Method for Measurement of Vehicular Response to Traveled Surface Roughness[2]

E 1170 Practices for Simulating Vehicular Response to Longitudinal Profiles of Traveled Surfaces[2]

E 1215 Specification for Trailers Used for Measuring Vehicular Response to Road Roughness[2]

3. Summary of Test Method

3.1 Measures of surface elevation are obtained at constant intervals along a line on a travelled surface to define a longitudinal profile. The line used for the profile is called a *wheeltrack*, a path followed by the tire of a road vehicle. The measured numbers are recorded and entered into a computer for graphical display and analysis. The profile points are used as input to a computational algorithm that produces a summary roughness index.

3.2 This test method describes the use of conventional survey equipment comprising an optical level and graduated rod, but it may also be applied to automated techniques (for example, laser-based systems) with appropriate adjustments. At a minimum, two persons are required; one to locate and hold the rod (the rod-man), and a second to read relative heights through the leveling instrument and record the readings. For better efficiency, it is recommended that a third person record the readings to allow the instrument operator to concentrate on adjusting and reading the instrument. When maximum measuring speed is desired, a fourth crew member is recommended to act as relief.

4. Significance and Use

4.1 This test method provides a means for obtaining a standard roughness index using generic equipment. This particular test method is simple but labor-intensive, and is most

[1] This test method is under the jurisdiction of ASTM Committee E17 on Vehicle-Pavement Systems, and is the direct responsibility of Subcommittee E17.31 on Methods for Measuring Profile and Roughness.

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[2] *Annual Book of ASTM Standards*, Vol 04.03.

TABLE 1 Resolution Requirements

IRI Roughness Range, in./mile (m/km)	Required Resolution, in. (mm)	
	Class 1	Class 2
0 (0) ≤ IRI < 30 (.5)	0.005 (0.125)	0.01 (0.25)
30 (.5) ≤ IRI < 63 (1)	0.01 (0.25)	0.02 (0.5)
63 (1) ≤ IRI < 190 (3)	0.02 (0.5)	0.04 (1.0)
190 (3)≤ IRI < 317 (5)	0.04 (1.0)	0.08 (2.0)
317 (5) ≤ IRI < 444 (7)	0.06 (1.5)	0.12 (3.0)
444 (7) ≤ IRI	0.08 (2.0)	0.16 (4.0)

appropriate for establishing reference roughness levels for a limited number of test sites.

4.2 Test sites whose roughness is measured with this test method can be used to calibrate response-type measuring systems (see Test Method E 1082).

4.3 Such sites can also be used to verify proper operation of other profile measuring systems, and to establish accuracy levels for other profile measuring systems (see Test Method E 950).

5. Apparatus

5.1 *Tape*—A surveyor's tape is used to locate the elevation measures at constant intervals. The tape accuracy must be within 0.2 % of its total length. It is helpful to mark the locations at which the measures will occur if they are not clearly visible when the tape is laying on the ground (for example, mark 1-ft intervals with bright paint).

5.2 *Level*—The level must be designed to provide height readings with the required resolution. The resolution requirements are more stringent for smooth roads, and are summarized in Table 1 based on IRI roughness levels. Table 1 requires resolutions that are beyond the capabilities of most levels used in routine surveying and road construction. Precision leveling instruments used for extremely accurate control work or construction layout are required for measuring the roughness of most paved roads, which is typically in the range of 30 to 317 in./mile (0.5 to 5 m/km) IRI. With most precision instrumentation of this nature, the level and rod (see 5.3) are calibrated together. Typically, the level includes a micrometer to interpolate between marks on the rod. Metric leveling instruments are available with a resolution of 0.1 mm, which is sufficient for any pavement. Class 1 precision is preferred when validating inertial profiling systems (see 8.3). Class 2 precision is considered adequate for calibrating response-type systems.

NOTE 2—Survey equipment is available for measuring surface elevation using a laser beam as a horizontal reference in lieu of a level. Such equipment may be used in accordance with the manufacturers recommendations, as long as the resolution requirements from Table 1 are met.

5.3 *Rod*—The rod must be marked such that changes in elevation between adjacent profile points can be discerned with the required precision. With most precision levels, the markings on the rod correspond to an interval built into a micrometer in the level (for example, 10 mm values are obtained visually from the rod, and 0.1 mm values are obtained from the micrometer).

NOTE 3—If a laser-based level is used, a suitable rod shall be used in accordance with the manufacturer's specifications. If the instrument does not require visible marks on the rod, such markings are not required. However, for any equipment used, the total system (instrument and rod) must have the resolution specified in 5.2.

5.3.1 The base of the rod should be designed to allow easily repeatable measures. On smooth-textured surfaces almost any type of base is suitable. For use on textured surfaces, a circular pad with a diameter of at least 0.8 in. (20 mm) is suggested to reduce sensitivity of the measurement to small variations in the rod placement.

NOTE 4—In limited work performed to date, pads with diameters of 20 mm (0.8 in.) and 100 mm (4 in.) have been used successfully.

5.3.2 The absolute distance between the bottom of the rod and the markings is not relevant for roughness measurement. Therefore, temperature-correction is not required. Also, modifications to the base of the rod are permitted (see 5.3.1) to improve repeatability on textured surfaces.

5.3.3 A bubble level attached to the rod is recommended to aid in keeping the rod vertical.

5.4 *Computer*—Due to the potential for human error with the large amount of data obtained with this test method, all calculations shall be performed automatically by computer. The computer should have the capability to: (*1*) store all of the raw data values on a permanent medium (floppy disk, hard disk, magnetic tape, etc.), (*2*) run programs that perform the calculations described in 8.2 and 8.3, and (*3*) graphically display the computed profile.

NOTE 5—Virtually all popular desktop and home computers have these capabilities.

NOTE 6—Virtually any computer language can be used to implement these tasks. Common choices are Fortran, BASIC, Pascal, and C. Also, spreadsheets and general-purpose numerical analysis programs can be used.

NOTE 7—Several computers can be employed for different tasks. For example, the profile computations could be performed on computer A, and displayed using computer B.

5.5 *Data Recording*— Instrument readings are typically recorded by writing the numbers on paper (field notes). Due to the large number of individual measurements involved in this test method, it is critical to eliminate as many sources of human error as possible. Standardized field forms should be used with longitudinal distances printed. The field forms should complement the display of the computer screen when the numbers are typed into the computer.

6. Procedure

6.1 Select each wheeltrack to be profiled based on criteria of length, roughness level, and surface type depending on the use to be made of the measurement.

NOTE 8—When calibrating one or more two-track response-type systems, it is necessary to measure two parallel wheeltracks in the same travelled lane. The distance between the wheeltracks should approximately match the track widths of the response-type systems being calibrated.

6.2 Clearly mark the line defining the wheeltrack with chalk, paint, or other appropriate method to identify the starting point, the stopping point, and the transverse position of the line at regular intervals along the length. These intervals shall be no further apart than 50 ft (15 m). Mark the endpoints of the tape for each setup. These markings are needed for the rod and level measurement and also for use by other roughness measuring equipment being calibrated or validated, to ensure that measurements made by different methods cover exactly the same wheeltrack.

6.3 Place the tape on the wheeltrack. Initially, the zero position on the tape is placed at the start of the wheeltrack. Secure the tape with weights or adhesive tape. Take readings at intervals along the length of the tape. When this is completed, move the tape such that the new zero point coincides with the old end point.

6.4 Place the leveling instrument at a location that allows focusing on the rod at the start of the tape and over as much of the tape as possible. It is recommended that the tripod for the level be located in line with the wheeltrack, so the repeated readings along the tape can be taken with minimal viewing adjustment. Follow the manufacturer's instructions to properly set up the instrument. When possible, set the tripod that supports the instrument low to the ground, to minimize errors associated with leaning of the rod (see 7.4).

6.5 At intervals along the tape, measure and record the distance between the ground and an arbitrary height associated with the level.

6.5.1 The maximum interval between measurements is 1.0 ft (305 mm) for Class 1 resolution, and 2.0 ft (610 mm) for class 2 resolution. Shorter intervals are permitted.

6.5.1.1 The requirements of 6.5.1 are valid for all types of road surfaces except those cases in which roughness is extremely localized and would be missed by using the above sample intervals (for example, small patches, tar strips, etc.). Due to the enormous effort involved in reducing the sample interval sufficiently to *capture* such features, it is recommended that sites with *localized roughness* not be measured with this test method.

6.5.2 The rod-man places the rod on the zero marker of the tape and aligns the rod vertically, using the bubble level as a reference. When the rod is properly placed and aligned, the rod-man signals the instrument operator.

6.5.3 The instrument operator reads the height according to the instructions of the equipment manufacturer. Typically, the first one or two digits are obtained from the markings on the rod, and the third and fourth digits are obtained using a micrometer in the level. The reading is recorded by the note-taker. When the reading is made, the note-taker calls out to the rod-man to signal that the rod can be moved to the next position.

6.5.4 Repeat 6.5.2 until the end of the tape is reached or the elevation under the rod puts the rod out of range.

6.6 Relocate the level when either its horizontal range is exceeded (that is, the distance between the level and rod is too short or too long to focus properly) or the vertical range is exceeded (the markings on the rod are "off scale" due to the slope of the road). The level can be relocated at any time, regardless of the position of the rod. However, it is necessary to account for the change in height of the instrument.

6.6.1 Before moving the level, identify the last measurement in the field notes. Also, carefully note and mark the location of the rod on the pavement if necessary. This point on the pavement is the *pivot point* for the change in instrument height that occurs with the new setup.

6.6.2 Repeat the first measurement shot with the level at its current position and compare with the first reading. If the difference between the two readings is greater than the required resolution (see 5.2), then all measurements taken from the current level setup must be repeated.

6.6.3 Move the level to a new location and set up as described in 6.4.

6.6.4 Take a new measurement with the rod located at the pivot point. The field notes should indicate that this is a repeated measurement, and that the instrument was moved.

6.7 With an experienced crew of three, the positioning of the rod by the rod-man, the reading of the level by the instrument operator, and the recording of the measurements by the note-taker can be synchronized such that the time required for each elevation measurement is less than 10 s. With several days experience, a team of three can measure profile at 1.0 ft intervals for a distance of 0.4 mile/day, with a resolution of 0.1 mm. More time is needed when measuring on a hill, due to the need for frequent changes in the leveling instrument.

7. Error Sources

7.1 As with any measurement practice, errors are introduced if the equipment is faulty, or operated incorrectly. Beyond these obvious sources of error, there are several less obvious sources of error in this test method that must be avoided.

7.2 *Data Recording and Entry*—The source of error that is the most difficult to eliminate is in the recording of the individual level measurements. A typical profile measurement involves at least 265 individual readings (1/10th mile, Class 2 measurement), and possibly thousands. These must be written in the field notes and later typed into a computer. One number that is badly in error has the same effect on the roughness computation as a large bump in the profile. Therefore, the survey crew must be aware of this significance. (The calculation methods (8.1, 8.2) include several checks to identify errors of this sort.)

7.3 *Improper Positioning of the Level*—The leveling instrument must provide a true horizontal datum. Also, the support (for example, tripod) cannot move during or between measurements. If the instrument is bumped, a new pivot point must be used to establish the new instrument height. The new pivot point should be the last location on the profile which is marked well enough to allow a repeat measurement to be made on exactly the same point (see 6.6.2).

7.4 *Deviation of the Rod from True Vertical*—The height of a mark on the rod above a point on the ground is:

$$h = R\cos\theta \quad (1)$$

where:

R = reading (the distance from the bottom of the rod to the mark seen through the level),

θ = angular deviation of the rod from vertical, and

h = height above the point at which the rod contacts the ground.

The error is the difference between the reading (R) and the true height (h) (for example, if the angle is 5° and R is 60 in., then h is 59.772 in., for an error of 60.000 − 59.772 = 0.228

in.). This error is controlled by: (*1*) keeping θ close to zero by using a bubble level attached to the rod, and (*2*) keeping *R* small by setting up the level instrument low (2 to 3 ft from the ground surface), so that mainly the bottom range of the rod is used.

7.5 *Absolute Elevation Error*—The absolute elevation does not contribute to roughness, and therefore the true elevation is irrelevant for this test method. Calibration and control methods designed to limit this type of error are not required. For example, the true distance from the markings on the rod to its base are not relevant. (Only the relative distances between markings must be accurate.)

7.6 *Cumulative Error*— The IRI roughness analysis applied to the profile emphasizes changes in elevation that occur within 50 ft (15 m). Accumulated changes in elevation over 200 ft (61 m) typically contribute less than 0.2 % of the IRI. Thus, the cumulative error that builds with every setup of the leveling instrument is generally not a problem when the IRI analysis is used. For other applications (for example, validating an inertial profiling device) the cumulative error may require more stringent control.

8. Calculation

8.1 *Data Entry*—Due to the potential for human error with the large amount of data obtained, all calculations shall be performed automatically by computer. The procedure used to enter the measurements into a computer should be designed to minimize the potential of human error. If possible, the display on the computer screen should correspond to the field form, to minimize the burden on the typist and to facilitate quick verification that the numbers entered match those from the field notes. The numbers entered into the computer should be the *raw* measurements from the field. In past projects, the computer has been programmed to beep when the difference between consecutive entries exceeds a threshold, to flag potential typing errors.

8.2 *Profile Elevation*—The individual readings from the level are the distances that the corresponding profile points lie below an arbitrary horizontal datum established by the leveling instrument, called the *instrument height* (IH). The elevation of each point is calculated by subtracting the reading from the IH. That is,

$$p_i = IH - R_i \tag{2}$$

where:

p_i = i^{th} profile elevation (i = 1, 2, ...),
IH = height of the instrument, and
R_i = rod reading at the i^{th} point.

8.2.1 In conventional leveling work, the absolute height of the instrument is carefully determined. However, for roughness work, only changes in elevation are of interest, and the absolute height of the instrument is of no concern. The height of the instrument is arbitrarily assigned to a convenient value (for example, IH = 10 000 mm) for the first setup. Although the initial height is arbitrary, all measures taken for a single profile must be correctly referenced to that height.

8.2.2 When the leveling instrument is moved, the new height is calculated from repeated readings of a pivot point, obtained as described in 6.5. The new instrument height is:

$$IH_{new} = IH_{old} + R_{new} - R_{old} \tag{3}$$

where:

IH_{new} and IH_{old} = new and old instrument heights, respectively, and
R_{new} and R_{old} = new and old rod readings for the pivot point.

8.2.3 *Profile Plots*— A plot shall be prepared showing profile elevation as a function of longitudinal distance. The purpose of the plot is to identify any points that were measured or read incorrectly and which introduce a fictitious bump or hole into the profile. The plot should be scaled so that elevation errors of 0.1 in. (2.5 mm) are visible. A hardcopy of this plot is recommended for reporting purposes, but a screen display is adequate for verifying the data integrity.

8.3 *Roughness Computation*—The elevation profile obtained in 8.2 is used as input to an algorithm that reduces the hundreds or thousands of elevation values to a single roughness index. The choice of roughness index should be made in accordance with the intended use of the data.

8.3.1 *Calibration of Response-Type Systems*—If the roughness index is to be used as a calibration reference for a response-type system, the IRI is suggested. The IRI is obtained by simulating a quarter-car vehicle model traversing the profile, using standardized vehicle parameter values and a simulated travel speed of 50 miles/h (80 km/h). Details for computing IRI and verifying the computer program are provided in World Bank Technical Paper Number 46, pages 31 through 43.[3] Fig. X1.1 in Appendix X1 provides an example program in the BASIC computer language, which can be modified as needed. The vehicle parameter values for the IRI are the same ones presented in Table 1 of Practice E 1170, for the *Ride Meter-Vehicle Mounted* quarter-car simulation.

8.3.2 *Validation of Profiling Systems*—If the roughness index is used to validate a profiling system (for example, Test Method E 950), then the same analyses used to process the measurements of the profiling system should be applied to the profiles obtained by rod and level. When comparing profiles from rod and level to those obtained with an inertial profiling system, simple plots of profile are not meaningful because the inertial systems do not include the longest wavelengths. Plots of profile can be compared only after the profiles from both sources are *filtered* identically. FHWA Report No. FHWA/RD-86/100[4] describes several methods for validating profiling systems through comparison with rod and level measurements, and shows example comparisons for ten inertial profiling systems.

[3] "Guidelines for Conducting and Calibrating Road Roughness Measurements," World Bank Technical Paper Number 46.

[4] "The Ann Arbor Road Profilometer Meeting," FHWA Report Number FHWA/RD—86/100, Federal Highway Administration.

9. Report

9.1 *Field Notes*— The field notes should include the following information:

9.1.1 The date on which the measurements were made,

9.1.2 The names of the members of the survey team,

9.1.3 A description of the wheeltrack that is sufficient to locate the wheeltrack for repeated measurements (for example, lane, transverse distance between wheeltrack and edge of lane, starting point, etc.),

9.1.4 All rod readings taken along the wheeltrack,

9.1.5 Pivot points, at which the leveling instrument was reset, and

9.1.6 Repeated rod readings at the pivot points.

9.2 *Computer Data Storage*—The computer software used to enter data shall store the *raw* numbers in a permanent medium, such as a floppy disk, hard disk, tape, etc. Through its organization or another method, the computer file must contain all of the information needed to reconstruct the numerical data contained in the field notes. As a minimum, it must associate each rod reading with a longitudinal position and an instrument height. It is recommended that the computer files also store all comments and descriptive information from the field notes.

9.3 *Graphs*—It is recommended (but not mandatory) that a plot of elevation versus longitudinal distance be prepared for each profile (see 8.2.3).

9.4 *Roughness*—Report the following information:

9.4.1 The date on which the measurements were made,

9.4.2 The names of the members of the survey team,

9.4.3 A description of the wheeltrack that is sufficient to locate the wheeltrack for repeated measurements,

9.4.4 The type of roughness analysis performed (for example, IRI), and

9.4.5 The numerical value of the roughness index.

10. Precision and Bias

10.1 *Precision*—Limited available data[5] indicate that the specifications for Class 1 measurements result in a repeatability precision for the IRI roughness of a profile 528 ft (160 m) long that is within 2 % of the mean value of repeated measurements. For a Class 2 measurement the precision is 5 % of the IRI value for a 528 ft (160 m) profile. Better precision is obtained for longer profile lengths.

10.2 *Bias*—Almost any form of measurement error causes an upward bias in the roughness index obtained with this test method. For example, if conventional surveying equipment is used with a vertical resolution of 0.01 ft (0.12 in. = 3 mm), the IRI computed from the profile can be high by 20 in./mile (0.3 m/km), which is excessive for smooth pavements. On the other hand, increasing the sample interval to more than 1 ft allowed for a Class 1 measurement causes a downward bias. For a Class 2 measurement, the bias error is less than 2 % of the IRI value obtained with a Class 1 measurement. The bias for a Class 1 measurement has not yet been determined.

[5] "The International Road Roughness Experiment: Establishing Correlation and Calibration Standard for Measurements," World Bank Technical Paper Number 45, and unpublished data from the research described in that report.

APPENDIX

(Nonmandatory Information)

X1. COMPUTATION OF IRI

X1.1 Fig. X1.1, a BASIC program adapted from the one in World Bank Technical Paper #46,[3] computes IRI when profile points are spaced at 1-ft intervals. This program is provided to illustrate the computation method. For simplicity, it does not interact with files on the computer (it requires the profile elevation points to be typed in manually). To make the program suitable for routine use, commands specific to a particular computer are needed to open a file (before line 1160) containing profile data. Lines 1160, 1170, 1270, and 1290 should be modified to read from the file.

X1.2 The following changes should be made if the program output is preferred with units of elevation per meter: Line 1060 should read "K = INT (0.25/DX + .5) + 1"; Line 1160 should read "11 m" instead of "36 ft"; Line 1180 should read "Z1(1) = (Y(K) − Y(1))/11"; and line 1510 should read "DATA 0.3048."

X1.3 If a sample interval other than 1 ft is used, lines 1520 through 1550 must be replaced as described in World Bank Technical Paper #46.[3]

```
1000  REM  This program demonstrates the IRI computation. It is
1010  REM  described in pp. 31 - 43 of World Bank Technical Paper #46.
1020  REM  The sample interval is 1.0 ft.  IRI output has units of
1021  REM  elevation / ft.
1030  REM  --------------------------------------  Initialize constants
1040       DIM Y(26),Z(4),Z1(4),ST(4,4),PR(4)
1050       READ DX
1060       K = INT (1. / DX + .5) + 1
1070       IF K < 2 THEN K = 2
1080       BL = (K - 1) * DX
1090       FOR I = 1 TO 4
1100           FOR J = 1 TO 4
1110               READ ST(I,J)
1120           NEXT J
1130           READ PR(I)
1140       NEXT I
1150  REM  -------------------------------------  Initialize variables.
1160       INPUT "profile elevation 36 ft from start:", Y(K)
1170       INPUT "X = 0. Elevation = ",Y(1)
1180       Z1(1) = (Y(K) - Y(1)) / 36.
1190       Z1(2) = 0
1200       Z1(3) = Z1(1)
1210       Z1(4) = 0
1220       RS = 0
1230       IX = 1
1240       I = 0
1250  REM  -------------  Loop to input profile and Calculate Roughness
1260       I = I + 1
1270       PRINT "X = ";IX * DX,
1280       IX = IX + 1
1290       INPUT "Elev. = "; Y(K)
1300  REM -----------------------------------------  Compute slope input
1310       IF IX < K THEN Y(IX) = Y(K)
1320       IF IX < K THEN GOTO 1270
1330           YP = (Y(K) - Y(1)) / BL
1340           FOR J = 2 TO K
1350               Y(J-1) = Y(J)
1360           NEXT J
1370  REM  ---------------------------------  Simulate vehicle response
1380       FOR J = 1 TO 4
1390           Z(J) = PR(J) * YP
1400           FOR JJ = 1 TO 4
1410               Z(J) = Z(J) + ST(J,JJ) * Z1(JJ)
1420           NEXT JJ
1430       NEXT J
1440       FOR J = 1 TO 4
1450           Z1(J) = Z(J)
1460       NEXT J
1470       RS = RS +  ABS (Z(1) - Z(3))
1480       PRINT "disp = ";RS * DX, "IRI = ";RS / I
1490       GOTO 1260
1500  END
1510  DATA 1.
1520  DATA .9951219, 1.323022E-02, -4.721649E-03, 4.516408E-04, 9.599989E-03
1530  DATA -.6468806, .9338062, -1.319262, 5.659404E-02, 1.966143
1540  DATA 3.018876E-02, 3.010939E-03, .6487856, 9.129263E-03, .3210257
1550  DATA 3.661957, .3772937, -43.40468, .3016807, 39.74273
```

FIG. X1.1 Sample BASIC Program