NOAA Technical Report NOS 68 NGS 4

Test Results of First-Order Class III Leveling

Rockville, Md.
November 1976

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Survey

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U.S. DEPARTMENT OF COMMERCE
Elliot L. Richardson, Secretary

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Robert M. White, Administrator

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Allen L. Powell, Director

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TEST RESULTS OF FIRST-ORDER, CLASS III LEVELING*

Charles T. Whalen and Emery I. Balazs
National Geodetic Survey
National Ocean Survey, NOAA
Rockville, Maryland

ABSTRACT. The National Geodetic Survey has programmed for a partial releveling of the first-order, National vertical control net and for readjustment of the entire first- and second-order net during 1977 through 1985. In the past, first-order, class I or II, double-run leveling was used exclusively to establish and relevel the first-order net. Programmed funds permit releveling and replacing destroyed marks on approximately half of the National first-order net by double-run leveling, or on essentially the entire net by new first-order, class III, single-run leveling. The new specifications, based on an analysis of leveling errors, were field-tested on a level line from Waldorf to Baltimore, Md. between December 1975 and April 1976. Test results indicate that first-order, class III leveling can provide a viable alternative to first-order, class I leveling for releveling the first-order, National vertical control net.

INTRODUCTION

The National Geodetic Survey (NGS) of the National Ocean Survey is faced with the task of reobserving a portion of the National first-order level net in the 1977-1985 period in preparation for a general readjustment. The preparations will include transferring all the archival leveling observations and descriptions from paper records to computer files in the NGS data base during the same period. The purposes of the releveling are to strengthen the net, to determine where crustal motion has occurred, and to replace missing bench marks. New observations will be combined with selected old observations in a weighted block adjustment to obtain the best possible set of elevations for the National net. If double-run procedures are used, only the portion of the National net shown by heavy black lines in figure 1 could be releveled with programmed funds. If single-run procedures are used, that portion of the National net shown by heavy black lines in figure 2 (basic net A) could be run with the same programmed funds. The loops in figure 2 are about one-fourth the size of the loops in figure 1. Basic net A includes 116,000 kilometers of first-order level lines, plus 4,000 kilometers of second-order lines, to reduce the size of some large first-order loops.

*Reprinted in Surveying and Mapping, 37, March 1977.

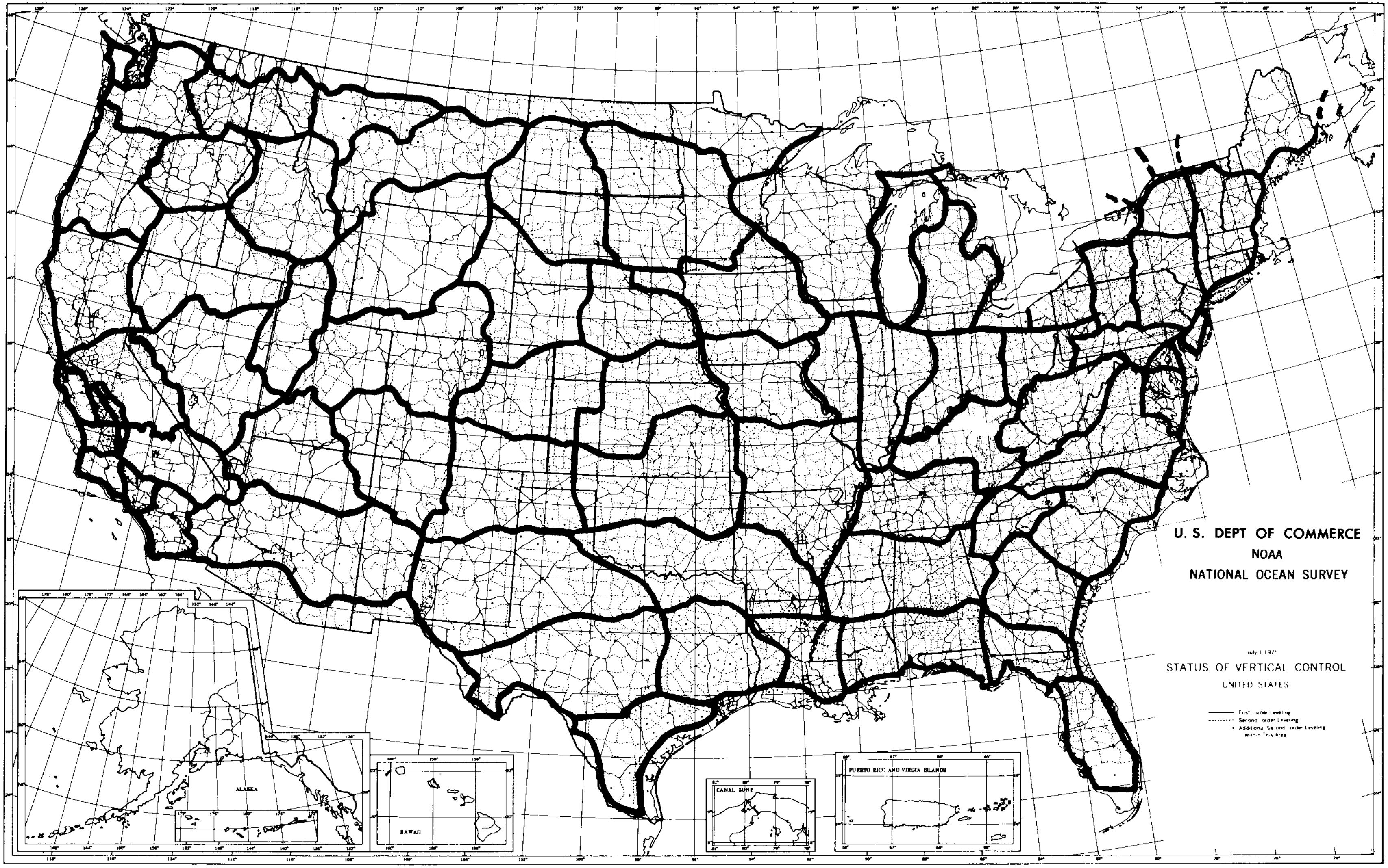

Figure 1.--Planned releveling, first-order,class I double-run procedures.

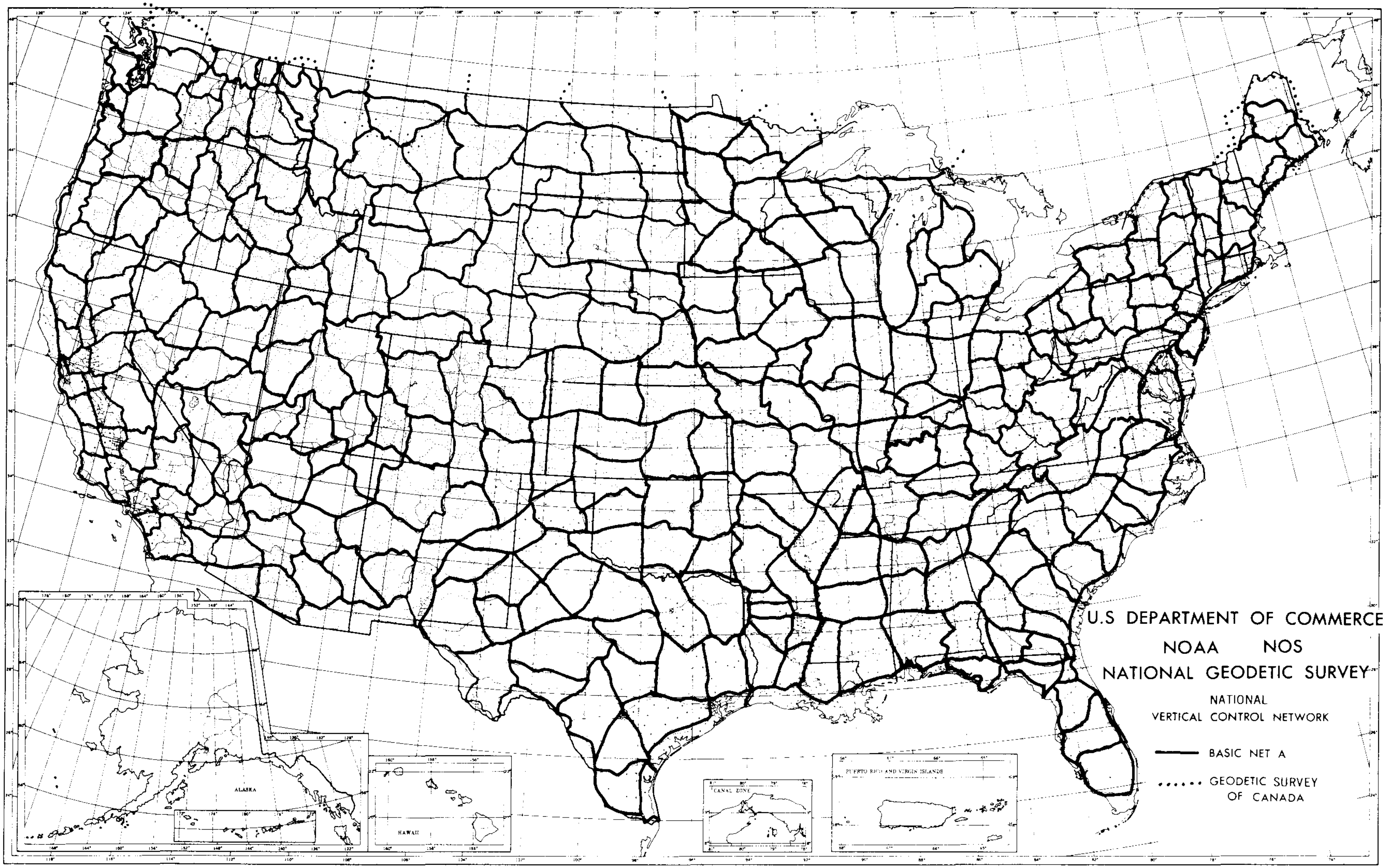

Figure 2.--Planned basic net A releveling, first-order, class III single-run procedures.

Double-run leveling has been specified in the past for the first-order primary net. The double-run procedures permitted detection of blunders and application of tolerance limits as leveling was extended into unsurveyed areas of the country. Meaning of backward and forward levelings of each section reduced certain small systematic errors and decreased the standard error of elevation difference by a factor of $1/\sqrt{2}$. The advantages of single-run (fig. 2) over double-run leveling (fig. 1) are: (1) the entire primary first-order net would be updated with new observations, and missing bench marks would be replaced; (2) loop misclosures would be much more meaningful because loops would have smaller circumferences; and (3) a better picture of the crustal motion would be obtained because of the increased density of the releveling.

The historic disadvantages of single-run versus double-run leveling are: (1) the increase in the standard error of elevations for bench marks, (2) the increase in the standard errors of elevation differences between bench marks, (3) the increased difficulty of detecting significant blunders in the observations, and (4) the accumulation of small systematic errors with distance.

The first disadvantage does not apply to the single-run leveling of basic net A (fig. 2,) because twice the density of leveling would result in essentially the same standard error of bench mark elevations as the double-run net of figure 1. As stated in this report, the standard error of the mean of a backward and forward leveling between bench marks for modern first-order, class I leveling is $\pm 0.7\sqrt{k}$ mm, where k is the section length in kilometers. If that section were leveled only once using the same equipment and observing sequence, the standard error of the elevation difference would increase, by a factor of $\sqrt{2}$, to $\pm 1.0\sqrt{k}$ mm. The increase of $\pm 0.3\sqrt{k}$ mm in the standard error cannot be considered significant on a mark-to-mark basis for the National releveling project, so the second disadvantage does not apply. The standard errors of bench mark elevations and of elevation differences between bench marks will be further reduced by combining new leveling with old in the readjustment of the National net where crustal motion has been insignificant or modelable.

The purpose of the testing described herein was to determine if significant blunders could be detected and if the accumulation of small systematic errors could be controlled in one-way leveling, so that the procedure could be used to relevel basic net A and thus restore the entire primary first-order National vertical control net.

LEVELING ERROR SOURCES

It was necessary to make an analysis of leveling errors and prepare specifications for high precision single-run leveling. Field tests and evaluations were required before a decision could be reached on whether to use single- or double-run leveling for the releveling program. The new high precision single-run leveling has tentatively been labeled first-order, class III.

Figure 3 shows a matrix of leveling error sources and procedures used to detect and control them. Errors are categorized as random, systematic, or blunders. Procedures used to detect and control (minimize or eliminate) leveling errors are divided into standard NGS practices used in the field, first-order class III procedures to strengthen one-way leveling, and current office corrections or computational procedures. For detailed discussions of leveling error sources, see Entin (1959) and Karren (1964). In figure 3, under "Field, standard NGS practices used," "leap-frog rods" refer to the practice of having the forward rod remain on the pin while the rear rod is moved ahead to become the forward rod of the next setup. Under "Field, first-order class III procedures," the rod observing sequence of rod A left scale (A_L), rod A stadia (A_S), rod B left scale (B_L), rod B stadia (B_S), rod B right scale (B_R) and rod A right scale (A_R) minimizes errors caused by refraction changes due to changing temperature and permits detection of vertical tripod or rod support motion during a setup. Starting and ending each section with rod A on the bench marks, coupled with leap-frogging the rods between setups, cancels the rod index error. Leveling the instrument while pointing at rod A will tend to cancel errors caused by over or under compensation. Reversing the direction of running levels on alternate work days helps to minimize the accumulation of small systematic errors caused by the forward rod support which tends to settle or rise while the rear rod and instrument are being moved forward for the next setup and by the tripod settling or rising during observations. Such errors tend to cancel when double-run measurements are meaned, but they can accumulate in single-run leveling if the running direction is not alternated. Left scale (Δh_L) and right scale (Δh_R) elevation differences are used to compute the check quantity (Δh_L-Δh_R) at each setup. Restricting this quantity to ±0.25 mm encourages the observer to shorten sight distances when short-period scintillation and pointing errors become excessive. When used with the above observing sequence, it will also result in a reobservation of all rod scales for a setup if either the tripod or rod supports move excessively during an initial set of observations. Using double-scale rods with different scale offsets permits on-site detection and correction of transpositions of backsight and foresight rod readings. Twice the scale offset difference of a

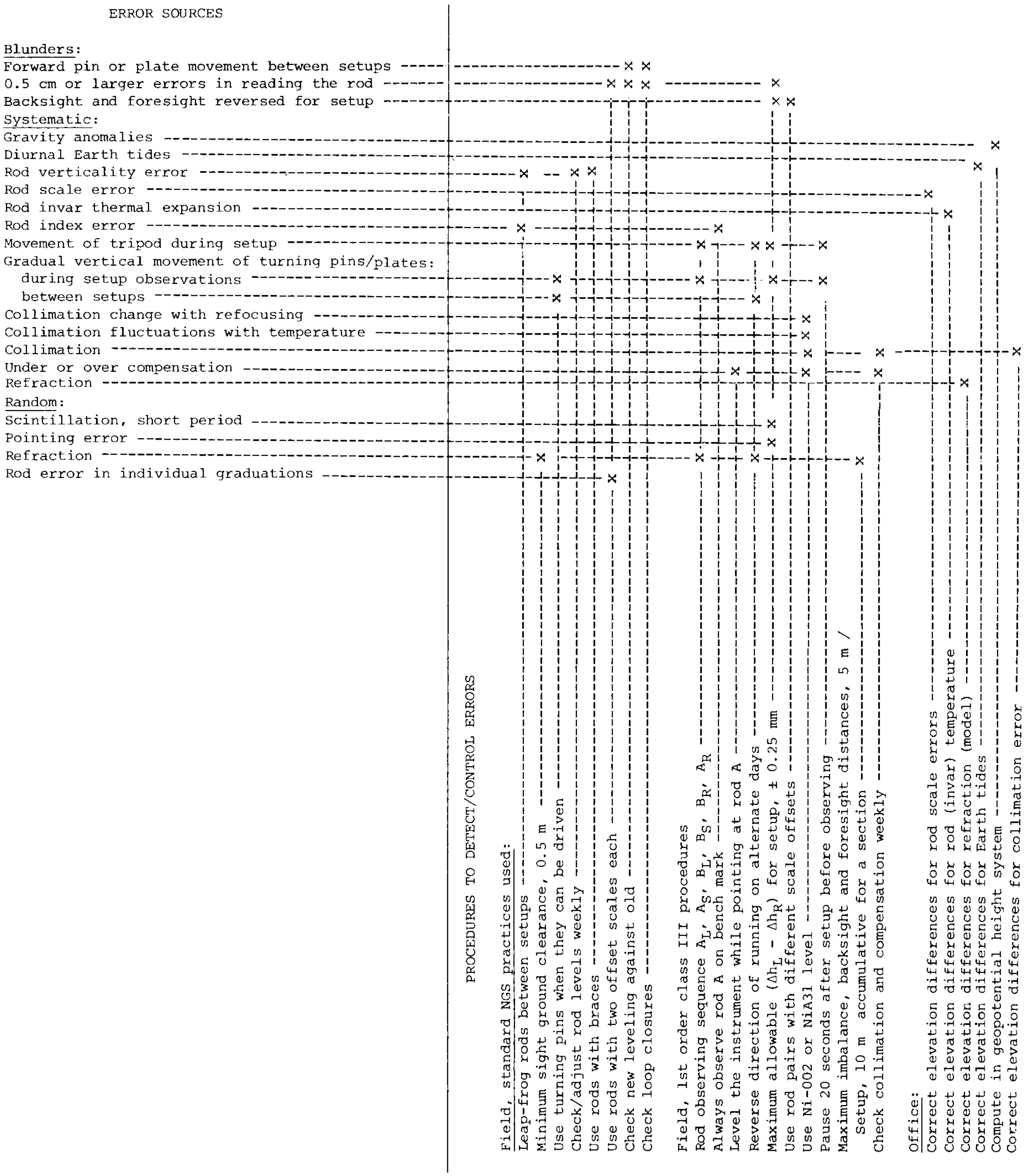

Figure 3.--Leveling error sources and procedures employed for detection and control.

rod pair shows up in the check quantity ($\Delta h_L - \Delta h_R$) when a transposition occurs.

The Zeiss-Jena Ni 002 and Magyar Optikai Muvek (MOM) Ni A 31 level designs minimize compensation and collimation problems. Pausing for 20 seconds after setting up the instrument and the forward rod allows time for them to stabilize before starting observations on the rods. A larger imbalance is permitted in backsight and foresight distances if the Ni 002 or Ni A 31 are used. The Ni 002 has a reversible compensator; therefore, the collimation error of one position cancels the error in the other position. The collimation error of the Ni A 31 is not affected by refocusing the instrument. The collimation and compensation of Ni 002 and Ni A 31 levels should be checked weekly to ensure that the instruments are functioning properly. At NGS, the office corrections (fig. 3) are made by the computer for all first-order and second-order leveling surveys.

SPECIFICATIONS FOR FIRST-ORDER, CLASS III LEVELING

A tentative set of specifications for first-order, class III leveling was prepared after careful consideration of the error sources in leveling and the procedures used to minimize them (listed in fig. 3). These specifications are given in appendix I.

Field Test

The tentative specifications were field tested on a 100-km line between Waldorf and Baltimore, Maryland, (fig. 4) between December 1975 and April 1976. The first and second single-run levelings were made with Ni 002 automatic levels and the third and fourth with an Ni A 31 automatic level.

Leveling Equipment

Figure 5 shows an Ni 002 level used in the test. The instrument has a swivel eyepiece (which permits the observer to make observations without walking around the tripod), control knobs on both sides of the instrument, and a reversible compensator. Collimation and compensation errors can be canceled by reversing the compensator between left and right scale readings and meaning the left and right scale elevation differences for each instrument station. The instrument has a rather large profile which can cause problems in winds. The eyepiece at the top of the instrument results in relatively low setups which can increase refraction problems in conventional leveling. The instrument was designed for use on a high tripod in motorized leveling to reduce refraction problems in this mode of operation.

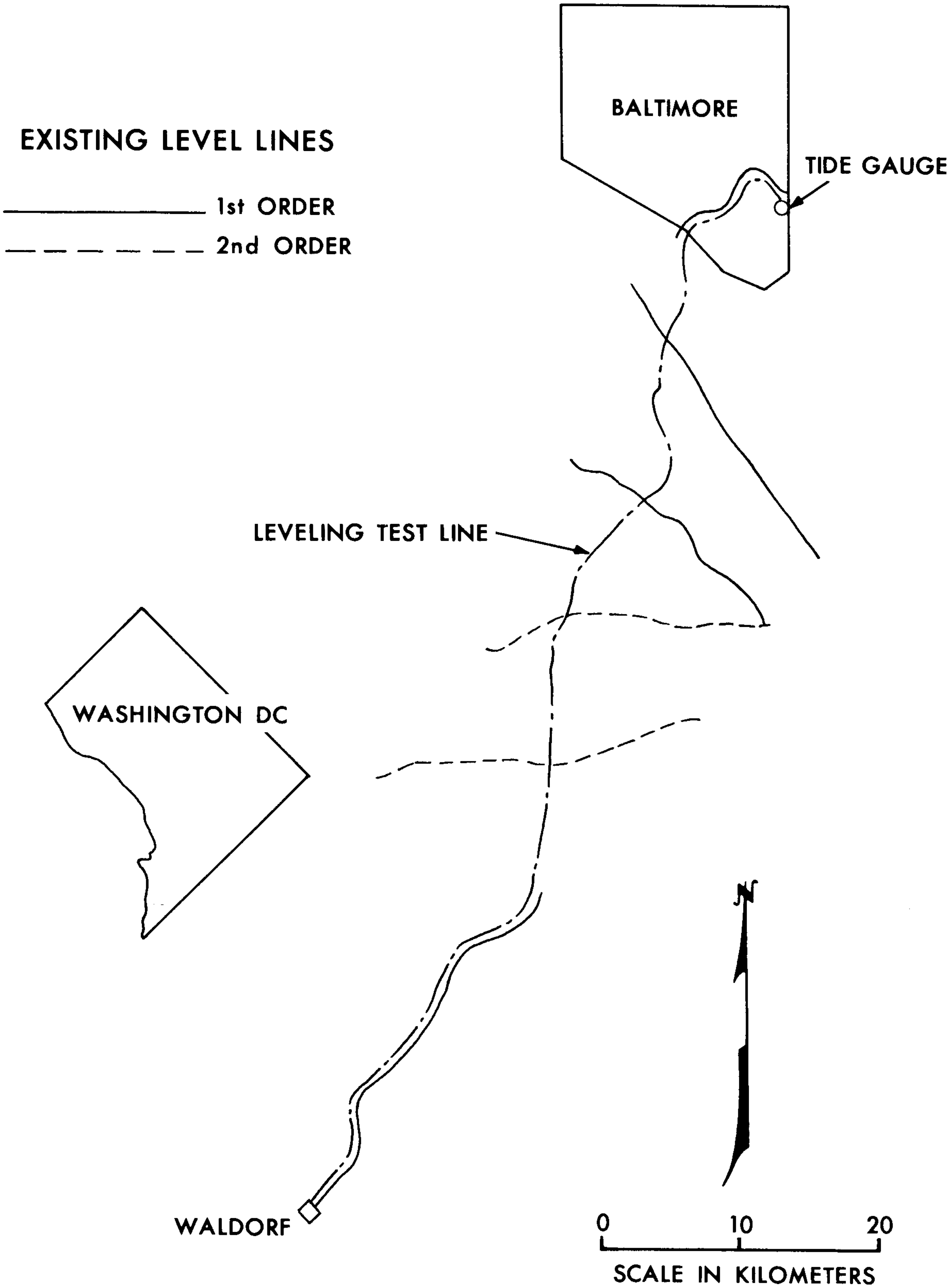

Figure 4.--Leveling test line, Waldorf-Baltimore, Maryland.

Figure 5.--An Ni 002 level in operation.

Figure 6 shows the Ni A 31 level used in the test. The Ni A 31 is designed so refocusing does not change the collimation. Changes in temperature had very little effect on the collimation error which remained nearly constant throughout the test. Location of the eyepiece under the instrument permits relatively high setups, thereby reducing refraction problems. The instrument is equipped with a tripod that dampens the effects of ground vibrations and wind. The micrometer knob is mounted on an energy absorbing spring, so the effects of shaky fingers are dampened before reaching the micrometer. The instrument has the minor drawbacks of not having an endless horizontal motion screw, and the "V" used to center the rod graduations for observations has a larger angle than our observers are accustomed to.

A rod pair consisted of one Zeiss Jena and one Kern rod with 1/2-cm graduations and different constants between left and right scales (fig. 7). The different constants were used to detect transpositions of backsight and foresight rod readings which could cause serious problems in one-way leveling.

Recording Equipment and Procedures

New procedures were devised to encode, check, and compute leveling observations on a small programmable Monroe calculator and to record them on a Monroe cassette recorder. The programmable calculator was used to control the observing sequence and quality at each instrument station. Observations were stored on cassette until they could be transferred to a central computer for recomputation, additional analysis, and abstracting.

Figure 8 shows the programmable calculator and cassette recorder. The calculator has 12 storage registers and can accept up to 160 program steps. The cassette recorder can store 12 registers in a block, 14 blocks in a file, and 12 files on each side of the 30-minute cassette. This permits recording about 28 km of single-run leveling per cassette.

Figure 9 shows procedures, effective near the end of the test, for recording Ni 002 leveling observations on the Monroe system. Procedures used earlier in the test were more complicated and required more human intervention. To start recording the rod readings for a section, the recorder clears data registers, then keys JUMP START START.

The calculator displays flag 1 to indicate rod A must be at the backsight position. The observing and recording sequence for each instrument station is always the following: rod A left scale with rod A stadia, rod B left scale with rod B stadia. At this point the calculator computes and displays the difference ΔS between the backsight and foresight stadia distances. If the absolute value of ΔS is greater than 5 meters,

Figure 6.--A Magyar Optikai Muvek (MOM) Ni A 31 level in operation.

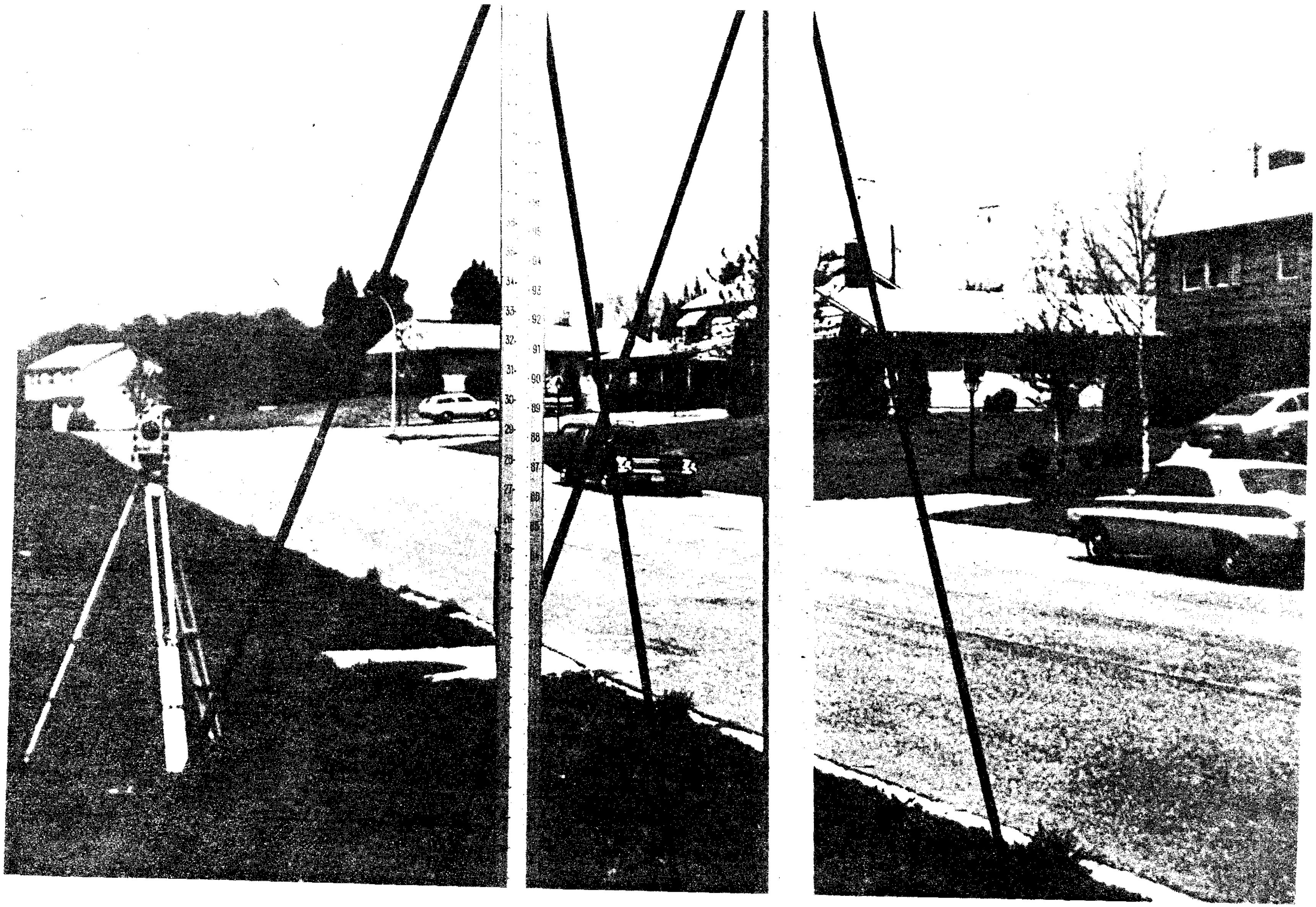

Figure 7.--Zeiss-Jena and Kern leveling rods.

Figure 8.--Programmable Monroe 326 calculator with model 392 cassette recorder.

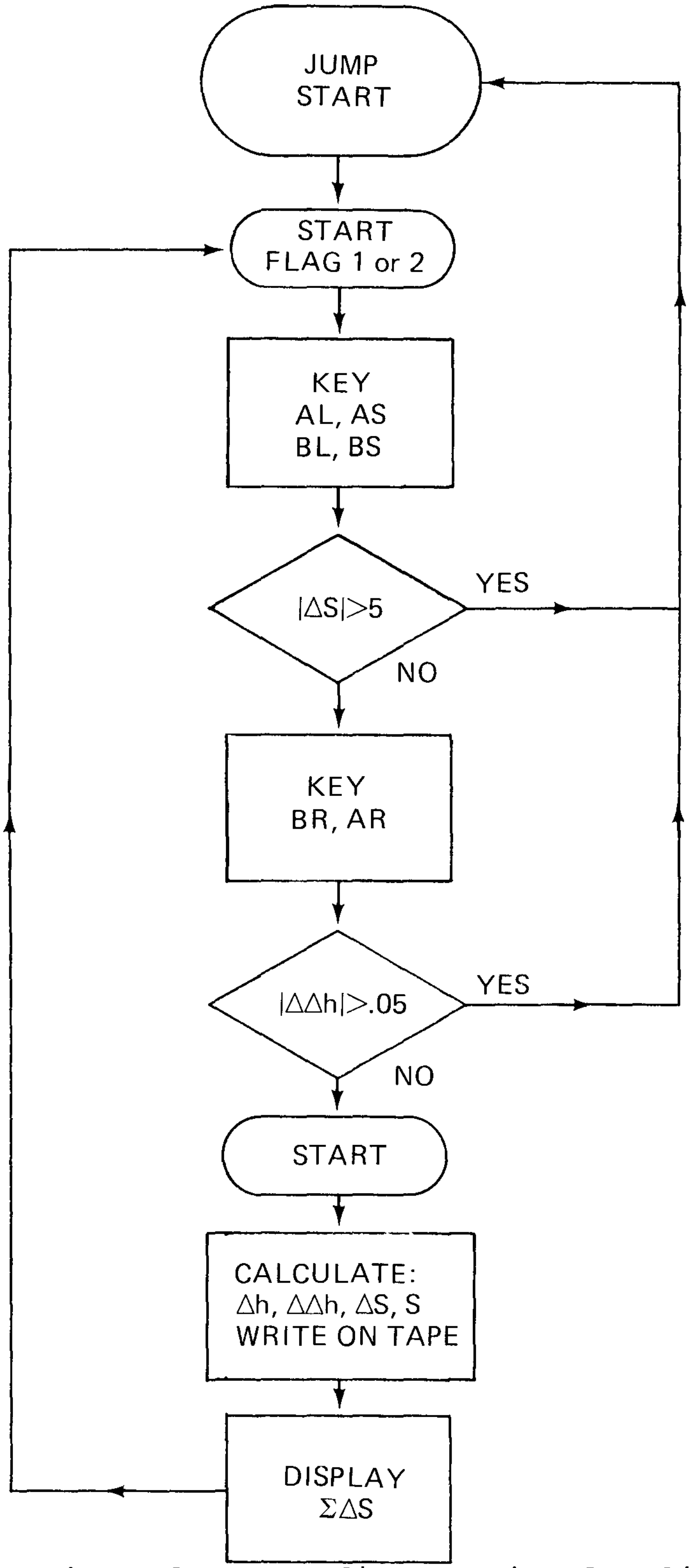

Figure 9.--Flow chart for recording precise leveling observations for Ni 002.

the recorder alerts the observer to balance the stadia distances by moving the instrument or the forward rod, then keys JUMP START START to reinitiate recording of the rod readings. If the difference is less than or equal to 5 meters, the compensator of the Ni 002 is reversed, and rod B and rod A right scale readings are observed and recorded. The calculator then computes and displays the difference between left and right scale elevation differences, which has been corrected for collimation for the instrument station, $\Delta\Delta h$. If the absolute value of $\Delta\Delta h$ exceeds 0.05 of one half-centimeter unit (0.25 mm), the recorder advises the observer to reobserve the rod readings for the instrument station. If $\Delta\Delta h$ is about equal to twice the difference between the rod constants, the observer is advised that the readings have been transposed, e.g., that the observing sequence did not start on rod A. The recorder then keys JUMP START START to reinitiate the program. If $\Delta\Delta h$ is less than or equal to 0.05, the recorder keys START and the 326 updates the registers, records the readings on the cassette and displays the sum of the stadia distance imbalance ($\Sigma\Delta S$) from the start of the section. The recorder informs the rear rod person if a correction is needed for the next setup to reduce $\Sigma\Delta S$, as the rod person moves forward. The recorder keys START at the next instrument station and the calculator displays flag 2 for rod A in the foresight position. The above procedures are repeated until the section observations are completed at the next bench mark.

Figure 10 shows the recording procedures used for the Ni A 31 at the end of the test. The Ni A 31 does not have a reversible compensator; consequently, the $\Delta\Delta h$ check value does not have to be corrected for collimation. As a result, there are more program steps available in the Ni A 31 program. These programs steps were used so the calculator would make the YES/NO decisions shown on the flow chart. The calculator decisions eliminated chances of human error when the Ni A 31 was used. All other Ni A 31 recording procedures are the same as those for the Ni 002.

The calculator reads the recorded data from the cassette and sends them through a Monroe 395 interface unit to a Texas Instrument (TI) Silent 700 Series terminal (fig. 11), where they are listed on a printer and stored on a cassette in the field office. The field office terminal is used to transmit leveling observations and bench mark descriptions to a central computer for recomputation, analysis, abstracting, and storage for the NGS data base, using programs developed as a result of the test.

Table 1 is a listing of observations with error codes for one section of levels from the central computer. The last four columns contain the $\Delta h_L - \Delta h_R$ reading check, the sum of the

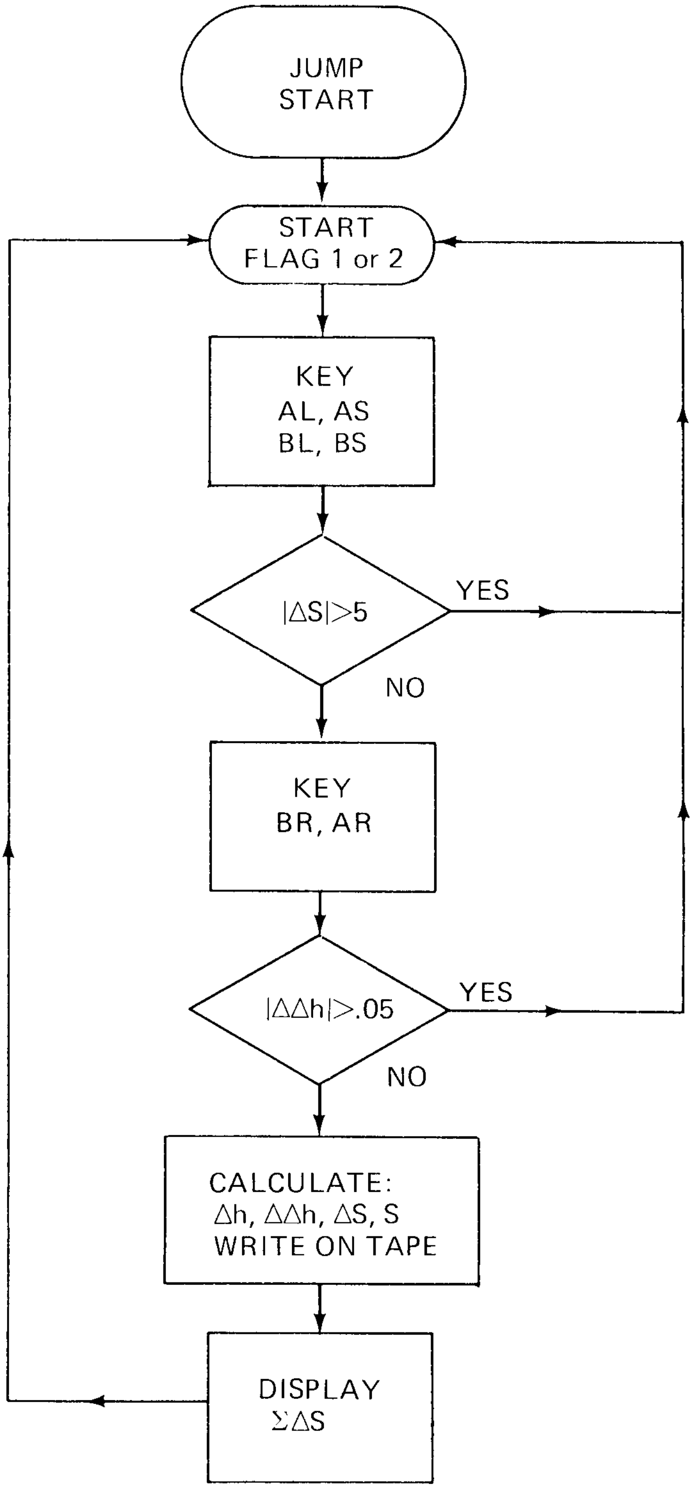

Figure 10.--Flow chart for recording precise leveling observations for Ni A 31.

Figure 11.--A Texas Instrument Silent 700 series terminal.

Table 1.--Leveling observations, as shown on sample computer printout.

```
     LEVELING OBSERVATIONS FOR *X7*  HG L24114   PAS    PAGE  47
                                                        ERROR CODES

CARD            TIME      LEVEL     ROD NO. 1  ROD NO. 2
CODE   DATE     ZONE   TYPE-S.N.  TYPE-S.N.  TYPE-S.N.
   OBSERVER      HOUR-MIN    LEVEL CCNST.    TEMP. SCALE

40.    760916     T      231   90823 316  87851 316  87813
        D B         9    0       -0.0380            F

CARD   START    END     TIME     AIR    WIND   SUN
CODE   B.M.     B.M.    HR-MN   TEMP.   CODE   CCDE    DATE

50.     589     590     9 20     79      1      1    760916

       - - - - - - 1/2 CM - - - - - - -  - - - METER - - -
SET    STADIA   LEFT     RIGHT   D.D.H.     S.C.S.     Q
 UP        BACKSIGHT
           FORESIGHT                      S.S.D.     S.D.H.M.

 1.    222.5   262.22   854.72    0.03        -1.5
       248.0   289.81   892.34           80.5      -0.13803
 2.    220.0   267.27   869.76    0.04        -2.4
       205.1   253.70   846.23          175.4      -0.07028
 3.    170.1   219.43   811.93    0.02        -0.7
       277.8   325.27   927.79          271.5      -0.59953
 4.    243.1   291.29   893.81   -0.05        -1.9
       274.9   324.31   916.78          368.5      -0.76450
 5.    238.1   285.72   878.24    0.01        -0.5
       266.5   312.83   915.36          460.9      -0.90008
 6.    224.1   275.91   878.43    0.01         0.4
       268.0   318.72   911.25          561.8      -1.11415
 7.    244.2   286.73   879.25   -0.03         1.1
       280.9   322.28   924.77          644.7      -1.29183
 8.    259.0   287.34   889.85    0.01        -0.9
       291.0   321.93   914.45          702.7      -1.46480

CARD   TIME     AIR     WIND    SUN
CODE   HR-MN   TEMP.    CODE    CODE

50.     9 32     83       1       1


              STANDARD ERRORS (MM.)                     SIGHT DISTANCE (M.)
 100 M SET   1 KM LEV   SECTION    POINTING                MEAN     MAXIMUM
  0.07533    C.23821    0.19968    0.05326                 43.92     50.90
```

stadia distance, the accumulative stadia imbalance, and the sum of the delta height means at each instrument station. Standard error estimates, based on the $\Delta\Delta h$ values, are given in millimeters and the mean and maximum sight distances are given in meters at the bottom of the table. The pointing error is normalized to a 50 sight distance. These error terms are based on precision only, so they are smaller than corresponding error terms computed from forward and backward running differences for sections. The pointing error can be used as an indicator of observer proficiency.

TEST RESULTS

Section elevation differences for each first-order, class III leveling of the test line were corrected for rod scale, invar temperature, refraction, and collimation errors. Elevations were computed for each bench mark at the NGS headquarters in Rockville, Md. Differences between bench mark elevations for each single-run leveling and mean bench mark elevations for the other three single-run levelings were computed and plotted against distance in kilometers (figs. 12 and 13). Curves of one-half the allowable loop misclosure $2\sqrt{2k}$ for first-order class I leveling (Federal Geodetic Control Committee 1974) are also shown on the figures. In all cases, the single-run elevation agrees with the mean elevation of three other single runs well within one-half the allowable first-order, class I limits. This quality of agreement on loop misclosures indicates that small systematic errors that tend to accumulate on one-way leveling surveys are adequately controlled by using the tentative first-order, class III specifications and the office corrections described earlier. The plotted differences for the Ni 002 are generally smaller than the plotted differences for the Ni A 31. The rms deviations were ±3.1 mm for the Ni 002 and ±4.5 mm for the Ni A 31. Although the loop closures are well within acceptable limits for both instruments, the Ni 002 results appear to be better than the Ni A 31 results. This could be attributed to the reversible compensator on the Ni 002 which effectively eliminates collimation and compensation errors at each instrument station.

Table 2 presents the first-order, class I and III leveling statistics. The Ni 004 and Breithaupt spirit levels were used by NGS from 1968 to 1972, and the Ni 1 since 1971. The Ni 002 was used on an operational survey in 1975 and on the test line with the Ni A 31. No direct limit is applied to the length of sight for first-order, class III leveling. The average and maximum sight distances on the test line were 37 m and 87 m for the Ni 002, and 40 m and 85 m for the Ni A 31. The number of level lines used to compute a standard error of one kilometer of double-run leveling is shown in the third column from the right. The standard errors are all 0.7 mm per kilometer. The equation used to compute the standard error was

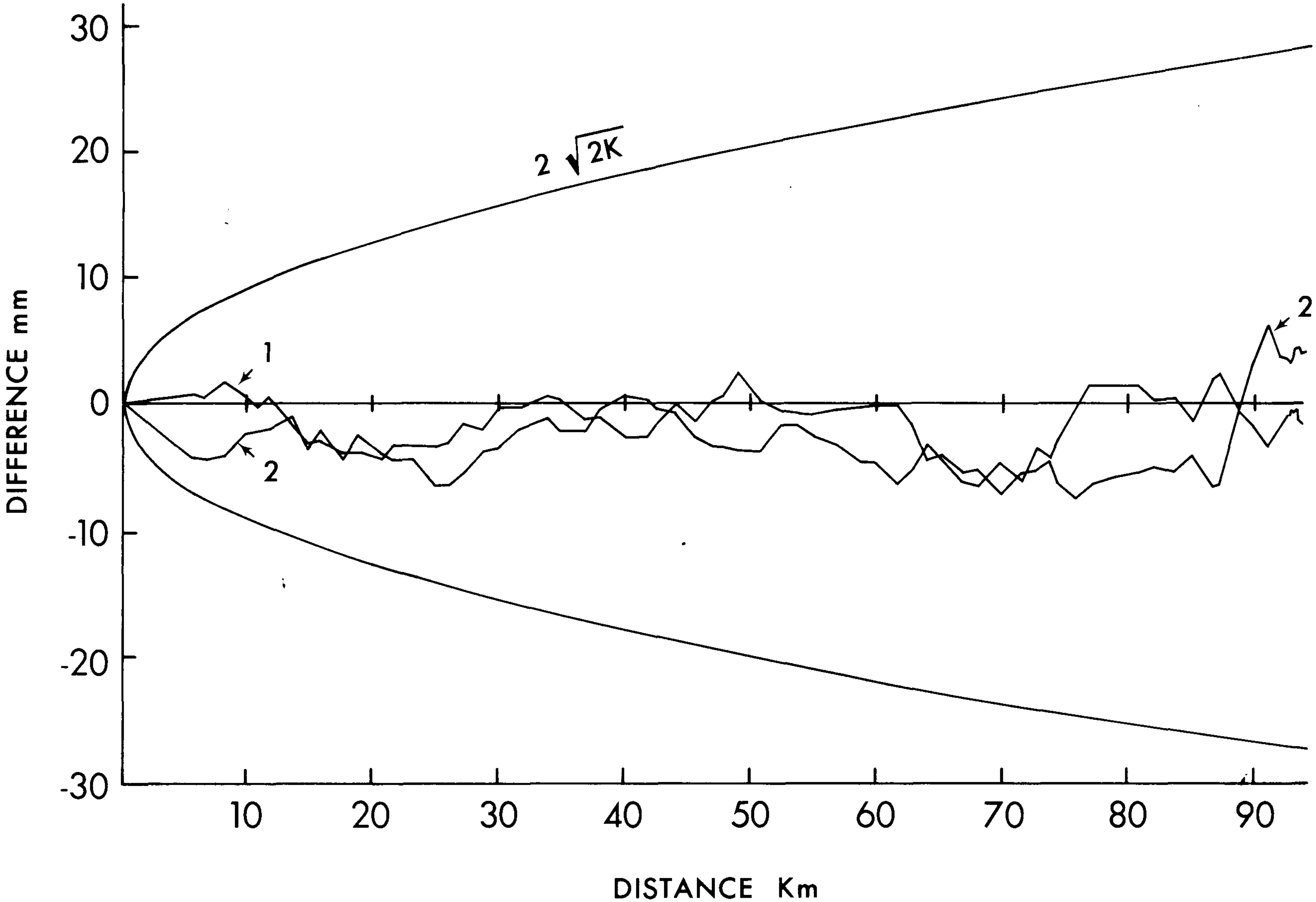

Figure 12.--Comparison of Ni 002 single-run elevations with mean elevations from three other single runs.

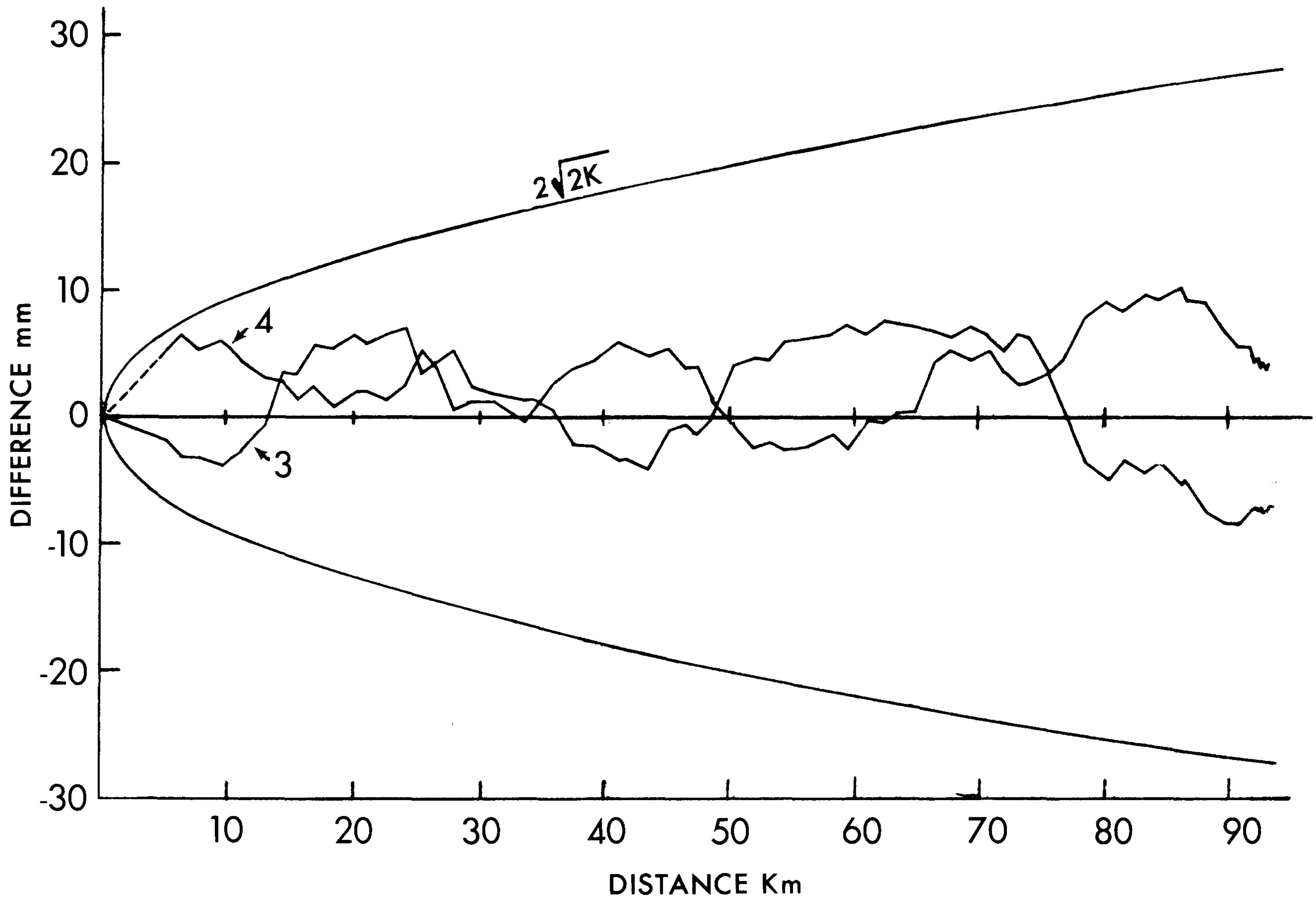

Figure 13.--Comparison of Ni A 31 single-run elevations with mean elevations from three other single runs.

Table 2.--First-order class I and III leveling statistics.

Instrument	Type	Order	Class	Tolerance limit used $mm\sqrt{k}$	Maximum sight (meters)	Number of lines	Standard error 1 km double-run (mm)	Degrees of freedom
Ni 004 and Breithaupt	spirit	1	I	3	65	10	0.7	3259
Ni 1	automatic	1	I	3	50	10	0.7	2142
Ni 002	automatic	1	III	3	none	1	0.7	84
Ni A 31	automatic	1	III	3	none	1	0.7	68

$\hat{\sigma} = \frac{1}{2}\sqrt{[\Sigma(d^2/k)]/n}$, where d is the difference between the backward and forward measurements of a section, k is the section distance in kilometers, and n is the total number of sections considered or degrees of freedom.

Table 3 shows the types of errors and problems encountered on the test line surveys. The first three items are problems with the recording system which were corrected by improving the calculator programs. The next five items are observer-recorder errors. Of the five items, the first two were corrected by changing the calculator program to eliminate possibilities for human error, the second two were corrected in the office and called to the recorder's attention, and the fifth item was called to the observer's attention. The last item on table 3 was a 13-mm error in the Ni 002 leveling, even though the two one-way runs for the section checked within 1 mm. The section was releveled with the Ni 002, but the cause for the error has not been determined to date.

Table 4 shows reruns determined with several different criteria. Column 2, 3, and 4 reruns are based on applying tolerance limits to disagreement between backward and forward runnings of each section. The $3\sqrt{k}$ mm criterion is used in first-order, class I leveling. For the first-order class III leveling of the test line, disagreements exceeding $3\sqrt{k}$ mm can be broken into two categories: errors attributable to a combination of factors--(1) observers, instruments, and observing conditions, and (2) blunders attributable to the many opportunities for recorder errors in the first versions of the Monroe 326 recording program. In table 4, the first category of errors was assumed to be in those sections with disagreements in the range $3\sqrt{k}$ to $10\sqrt{k}$ mm and the blunders were assumed to be in those sections where disagreements exceeded $10\sqrt{k}$ mm. Columns 5 and 6

Table 3.--Test line leveling errors/problems, detection and control.

Type errors/problems	How detected	Corrective action taken, 1976
Backsights and foresights transposed for an entire section.	Observer noted imbalance worsened instead of improved after correction and section elevation difference had wrong sign.	Program changed on January 29 to provide only one starting point. Specifications were changed to start and end each section with rod A on the bench marks.
Setup computed but not written on tape.	Setup numbers not sequential on tape listing.	Program changed on March 19 to automatically record data after accumulation in the computer registers.
Double recording of setup data on tape.	Double recording noted on tape listing.	" " "
Program was recorded on tape instead of data.	No data on tape listing.	Program revised on March 19 to record data automatically after accumulation in computer registers, regardless of PROGRAM/REGISTER switch position.
Reading checks greater than ± 0.05 half-cm (± 0.25 mm).	Noted on tape listing.	Changed programs on March 19 to: (1) correct Ni 002 reading checks for collimation error; (2) automatically reject Ni A 31 rod readings when check exceeded ± 0.05 half-cm.
Stadia distance imbalance exceeded ± 5 m for setup.	Noted on tape listing.	Changed Ni A 31 program on March 19 to reject automatically rod readings when imbalance exceeded ± 5 m.
Registers not cleared before starting section.	First setup number was not 1 on tape listing.	Corrected data for section. Called problem to recorder's attention.
Section information incomplete or not recorded on tape.	Noted on tape listing.	Corrected data from hand-recorded (backup) section sheet. Called problem to recorder's attention.
Readings below 0.5 m on rod.	Error flag on tape listing.	Called problem to observer's attention.
13-mm blunder, one section F-B < 1 mm.	Ni 002 did not check Ni A 31 or old leveling.	Releveled section with Ni 002.

Table 4.--First-order class III reruns (values shown in percent).

Instrument	Determined from $3\sqrt{k}$ mm	Determined from $3\text{-}10\sqrt{k}$ mm	Determined from $10\sqrt{k}$ mm	Determined from tape listings First run	Second run	Determined from previous leveling First run	Second run
Ni 002	16.8	2.4	14.4	15	18	68	72
Ni A31	4.0	2.7	1.3	10	10	0	8

reruns are based on an analysis of errors in the Monroe tape listing. Many of these errors disappeared when the data were recomputed on the central computer because the recorded rod readings were correct. Reruns for the last two columns were determined from comparisons of newly observed elevation differences with previously observed or adjusted elevation differences. When the closure exceeded the allowable loop closure of $5\sqrt{k}$ mm, a rerun was indicated. When the $5\sqrt{k}$ mm limit was exceeded between the level line which crossed the test line (fig. 4), the assumption was made that the entire segment between the cross level lines would have to be rerun to locate the error.

Using the error categories of table 4, the Ni 002 has a large percentage of reruns (16.8) determined from the $3\sqrt{k}$ mm tolerance limit, but most of these reruns (14.4) were attributable to blunders. The high percentages (68 and 72) of Ni 002 reruns determined from comparisons with previous levelings were caused by blunders occurring between the cross level line (fig. 4). The improvements in the calculator recording programs are reflected in the relatively low percentages of reruns for the Ni A 31 surveys run after the Ni 002 surveys. The percentages attributed to a combination of observer, instrument, and observation conditions in column 3 do not differ significantly for the two types of instruments. The drastic reduction in the blunder category (column 4) between the Ni 002 and Ni A 31 surveys can be attributed to elimination of opportunities for errors in the calculator recording program as can the lower percentages of reruns for the Ni A 31 in the last four columns of the table. In all cases, the requirement for reruns could be determined from single run data listings or from previous leveling available on parts of the test line.

SUMMARY

The National Geodetic Survey has programmed funds to level a portion of the National vertical control net, load all leveling from the archives in the data base, and combine old and new leveling in a weighted least-squares block adjustment to compute new elevations for the net. The releveling will strengthen the net, provide repeat leveling for modeling crustal motion in the readjustment, provide new stable bench marks at line junctions, and replace destroyed marks. If double-run leveling is used, only half of the primary first-order National net can be releveled with the programmed funds. If single-run leveling is used, the programmed funds would permit releveling the entire primary first-order net.

New single-run, first-order, class III specifications were prepared and tested with new hardware and software on a 100-km line between Waldorf and Baltimore, Md. The purpose of the test was to determine if single-run leveling would be suitable for the releveling program. The following test results were obtained:

1. First-order, class III instrumentation and observing procedures kept the accumulation of errors well within one-half the limit for first-order, class I leveling for four levelings of the test line.

2. Sections requiring reruns could be detected in all cases from computer listings or from comparisons with previously observed or adjusted elevation differences for the test line.

3. Blunders caused by transpositions of backsight and foresight rod readings were detected successfully using double-scale rods with different scale offsets, so rod readings could be reobserved in the correct order before the instrument was moved.

4. The Monroe 326/392 system was used successfully to encode, apply quality control checks, and record acceptable leveling data on tape cassettes under program control.

5. Cassette recorded field book data were successfully transferred through an interface unit and computer terminal in the field office to disk files on a large computer.

6. Computer programs were developed and used successfully to compute and edit the field book data, generate a field abstract, convert data to the NGS data base formats, and store results on disk or tape files.

7. Computer terminals were used successfully in the field offices to store data on cassettes, run the programs listed in 6, and list results for field use.

RECOMMENDATIONS

Programmed funds for the releveling program should be spent on single-run, first-order, class III releveling of basic net A, shown in figure 2, instead of the previously planned double-run, first-order, class I releveling, shown in figure 1.

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APPENDIX I. - FIRST-ORDER, CLASS III, LEVELING SPECIFICATIONS

Revision, November 1, 1976

1. Background: Double-run procedures have always been specified in the past for first-order leveling. The double-run procedure permitted detection of blunders and application of tolerance limits as the survey progressed. Meaning of backward and forward runs for each section canceled certain small systematic errors and slightly increased the precision of the difference in elevation. Since the double-run procedure was initiated, we have changed to compensator, micrometer instruments with improved optics and to double-scale rods. The compensator, micrometer, improved optics and double-scale invar rods have increased reading precision. The double-scale rods also permit detection of blunders in readings to a few tenths of a millimeter.

The following specifications for first-order, class III, single-run leveling are provided to take advantage of the improved instrumentation and procedures.

2. Principal Uses: The same as in first-order, class I and II -- basic framework of the National network and of metropolitan area control, extensive engineering projects, regional crustal movement investigations, determination of geopotential values. It is also particularly applicable when rerunning existing main scheme level lines for crustal motion studies and line restoration, when running new networks in self-checking loops, or when densifying within recent first-order, class I or II networks. First-order, class III leveling should not be used to run new lines that cannot be blunder checked with loop closures, against existing leveling, or by other methods providing reliable checks.

3. Recommended Spacing of Lines: National network, net A, 100 to 300 km; net B, 50 to 100 km. Metropolitan control, 2 to 8 km. Spacing of marks along lines, 1 to 3 km.

4. Instrument Standards: Micrometer levels of highest precision (Ni 1, Ni 002, Ni A31), invar double-scale rods with different constants between low and high scales for the two rods of a pair.

5. Field Procedures: Single-run where work can be blunder checked (above). Double-run where work cannot be blunder checked or when required by survey instructions.

Observing order, rod A low scale, rod A lower stadia, rod B low scale, rod B lower stadia, rod B high scale, rod A high scale, with rod A always observed first. This procedure minimizes effects of rod and tripod settlement during setups and errors caused by refraction changes with changing temperature. Rod A is the rod with the smaller constant between low and high scales.

Start and end each section with rod A on the bench mark (even number of setups). If this is not done, rod index errors from sections with an uneven number of setups can accumulate over long distances.

After a setup is completed, the instrument and back rod are moved forward "leap-frogging" to eliminate accumulation of systematic errors caused by index errors, refraction, etc.

Level the instrument with telescope pointing opposite directions at alternate instrument stations (that is, always pointed toward rod A) to prevent accumulation of small compensation errors on compensator levels, caused by hysteresis. This is not required on the Ni 002 when the compensator is reversed between left and right scale readings.

Maximum disagreement between left and right scale elevation differences is 5 micrometer units (0.25 mm) for each setup. The length of sight will be adjusted so setup observations will not have to be repeated frequently to meet this requirement. There are no other restrictions on length of sight, unless required by survey instructions.

The direction of running will be reversed on alternate work days to avoid accumulation of small systematic errors from refraction, movement of the forward turning pin while the instrument is moved to the next setup, etc.

Backward and forward stadia distances can differ by no more than 2 meters per setup and 4 meters accumulated along a section. For instruments designed so leveling results will not be affected by refocusing, (Ni 002, Ni A31) the above limits can be changed to 5 meters per setup and 10 meters accumulated along the section.

The line of sight between instrument and rod should always be higher than 0.5 meter (100 rod units for ½ cm rods) above the ground.

Maximum length of line between connections: net A, 300 km; net B, 100 km.

Maximum loop misclosure, 5 mm times the square root of the distance in kilometers if the entire loop was leveled by first-order, class III procedures. The maximum misclosure for loops made up of segments of different orders of leveling is the square root of the sum of the squares of the allowable misclosures for the segments.

Turning pins with driving cap will be used when they can be driven.

Turning pins will be driven vertically into the ground to provide a firm support for the rods. Tests show that the turning plate settles up to five times as much as the turning pin.

Allow 20 seconds for the tripod feet and turning pins (with rod on pin) to stabilize before making observations. Tests show that most of the displacement occurs during the first 20 seconds after the tripod and pin are forced into the ground.

The "C" factor will be checked daily on the Ni 1 and weekly on the Ni 002 and Ni A 31. Compensation will be checked weekly.

6. Data Checks: Transposition of sights at each setup will be checked by comparing the low and high rod scale elevation differences (see above). A disagreement of twice the size of the difference between scale constants of the rod pair plus or minus 0.25 mm will indicate a transposition of the backward and forward sights (rod A not observed first).

Reruns for double-run leveling will be determined from first-order, class I, misclosure limits. Reruns for single-run leveling will be determined from an analysis of data listings and error messages, new minus old comparisons, and loop misclosures.

Prepared by:

Charles T. Whalen
Chief
Vertical Network Branch
Control Networks Division
National Geodetic Survey

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