MAKING, PLACING, AND PRECISE DETERMINATION OF ELEVATION OF BENCH MARKS ON MICHIGAN STATE COLLEGE FARM

Thesis for the Degree of B. S.

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THE MAKING, PLACING, AND PRECISE DETERMINATION OF ELEVATION OF BENCH MARKS ON MICHIGAN STATE COLLEGE FARM

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THESIS

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PREFACE

This thesis is a problem selected by us for the purpose of furthering our knowledge of Precise Leveling and Precise Leveling Methods.

The bench marks are of our own design and were built and placed by us previous to running the levels.

We have attempted to conform strictly to the method used by the U. S. Coast and Geodetic Survey both in our observations in the field, and in our computations and adjustment of the level net.

CONTENTS

PRECISE LEVELING

Precise spirit leveling is the means by which elevations, above mean sea level, of points on the earth's surface are determined with great precision. Its primary purpose is to furnish an accurate control for the elevations in a region. Precise leveling differs from ordinary leveling in the refinements introduced into the construction of the instruments and into the method used. All possible sources of error have been eliminated or redused to a minimum by the careful design and selection of the materials for the instruments and rods, and by the precautions taken in the method of observation.

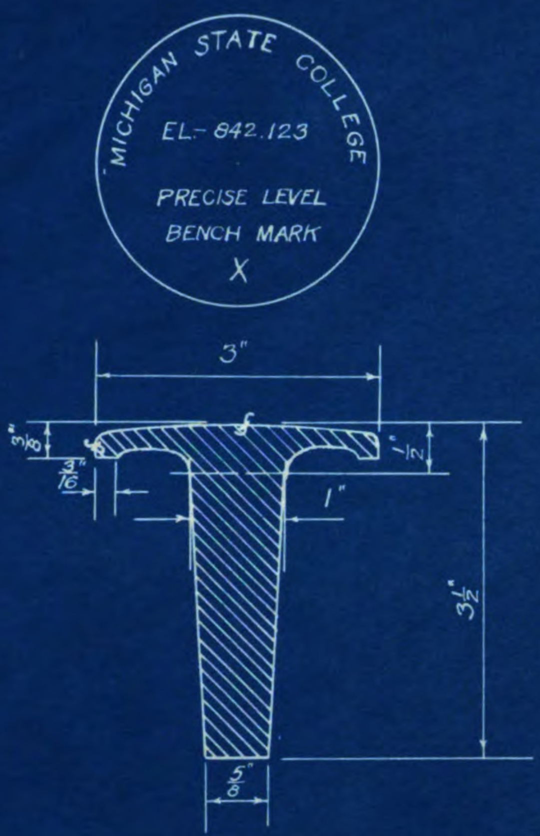
The elevations are referred to the mean sea level as a datum. This datum is obtained from a series of long-term gaugings which are carried on by means of automatic recording tide gauges. In the work of the U. S. COAST AND GEODETIC SuRVEY the elevation of mean sea level is taken the same for the Atlantic and Pacific Oceans and the Gulf of Mexico.

In the United States and its Possessions, the greater part of the precise leveling has been done by the U. S. COAST AND GEODETIC SURVEY and the U. S. GEOLOGICAL SURVEY. Lines of precise levels have been run and bench marks established along these lines covering all the United States, Panama and Alaska. The elevations and descriptions of these bench marks may be found in the published reports of the Superintendent of the COAST AND GEODETIC SURVEY.

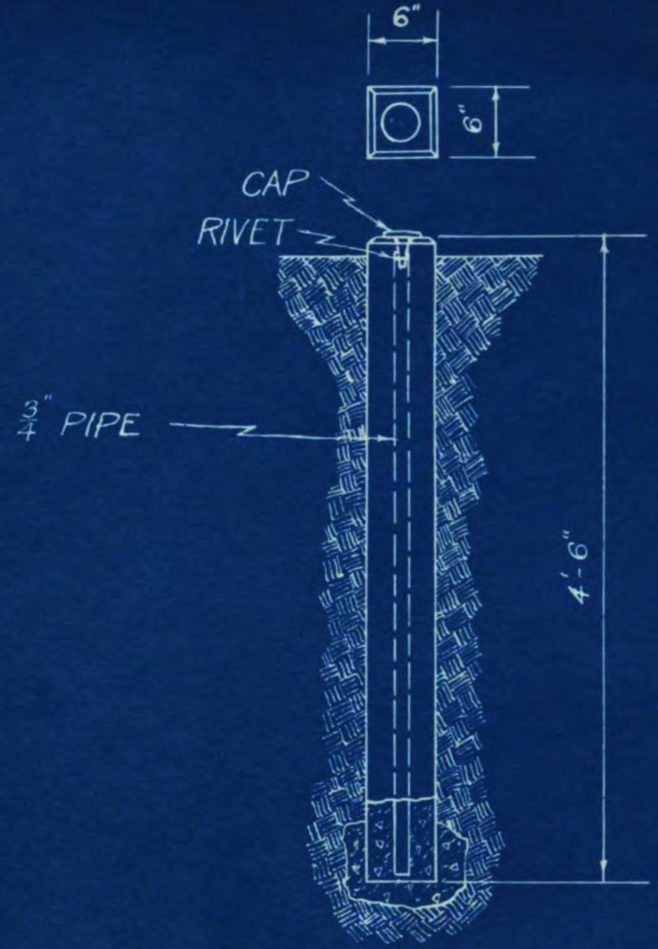
THE BENCH MARKS.

Inasmuch as it was desired that these bench marks be of a permanent nature, the following design was decided upon. The monument was to be of concrete, 6"x 6"x 4'-6". This length placed the base of the monument well below the frost depth found in this part of the country. Into the top of this was set a brass plate (for details, see Plate 1. fig. a.) which was securely riveted to a piece of $\frac{3}{4}$" water pipe extending lengthwise through the monument. Besides holding the cap in place, this pipe also acted as a reinforcement for the monument, preventing damaging cracks. A pattern was made for this brass cap, and the czp cast in the college foundry. The heads were later machined, and stamped as shown in Plate 1. fig.a. Fig. b. of Plate 1. shows the assembly of the monument.

In placing these monuments, wet concrete was placed in the bottom of each hole and the monument set in this. This gave a wide firm base preventing any possible heaving of the monuments due to the upward pressure of frost action. Some of the monuments wrre placed with the top flush with the surface of the ground, while others were left slightly projecting. The photographs on the following page show both the completed monuments out of the ground, and the same after being set.



CAP DETAIL
Fig. a



ASSEMBLED AND EMPLACED
MONUMENT
Fig. b

PLATE I

THE INSTRUMENT.

THE U. S. COAST AND GEODETIC SURVEY PRECISE LEVEL.

Commencing with the summer of 1900, a new type of precise level was put into use in the U. S. COAST AND GEODETIC SURVEY and a method of observation was adopted which has since then remained unchanged except in unimportant details. The justification for the adoption of the new instrument and method was later evidenced by the greatly increased accuracy, rapidity and cheapness of precise leveling since its introduction.

The present COAST SURVEY LEVEL is the result of a series of exhaustive tests and careful study in the attempt to design an instrument of great precision, with ease of operation and durability of construction.

The instrument developed is of the dumpy type with a three screw base. The distance between the level tube and the line of collimation is reduced to a minimum by placing the level tube in an opening cut in the telescope. This practically eliminates the effect of temperature changes on the parallelism of the axis of the bubble tube and the line of collimation. The telescope and the inserted bubble tube are placed within a tube-shaped support at one end of which are two pivot screws which support the telescope and provide a horizontal axis about which it can be rotated a small amount. This vertical motion is for the purpose of

making the line of collimation horizontal and is controlled by a micrometer screw mounted at the other end of the tubular support. The tubular support gives a strong and light form of support and also serves as a protection for the level mounted in it.

The binocular level-reading device is a decided improvement over the old striding level type in that it enables the observer to stand erect and observe the level bubble with one eye and the rod with the other. The level-reading device consists of a pair of prisms mounted in a tube at the left side of the telescope. The distance between the two prisms can be varied by means of an adjusting screw so that both ends of the level bubble can be made visivle to the observer. A small mirror is mounted on the tubular support, directly over the level vial and at such an angle that the image of the level bubble is reflected into the tube at the side of the telescope and thence through the prisms to the eye of the observer.

The telescope, the draw-tube, the tube incasing the level vial, the reticle and the tubular support are made of a nickel-cast iron alloy which has a coefficient of expansion of .000004 per degree centigrade.

The pointed screws pivoting the telescope, the screws holding the level tube in place, the screws holding and adjusting the reticle ring and the fine motion micrometer screw upon all of which is dependent the constancy of the relation between the line of sight and the plane tangent to the middle point of the level vial and which requires a harder metal than castings are made of a nickel-steel alloy with a coefficient of expansion of .000001 per degree centigrade.

The base of the instrument is of the three screw type and cast in a single piece of a hard, fine-grained cast-iron. In the legs at a radial distance of 9 cm. are threaded the foot screws. The ends of the legs are split and provided with milled-head screws for clamping the foot screws in place. The center of the base has an unusually long conical bore which affords a good bearing for the center which is made of the finest and hardest grade of tool steel. It is secured against being withdrawn by a small nut on the lower end and by screwing and riveting a hard cast-iron disc which forms a base for the supporting cylinder on the upper end.

The supporting cylinder is a nickel-iron casting which has two lugs at the front end for the screws which form the horizontal axis of the telescope and the nut in the rear which carries the fine-motion micrometer screw. At the top-center of the supporting cylinder is a rectangular opening fitted with a glass slide to protect it from dust and air currents. The level tube is readily accessible for adjustment through this opening by unclamping a hinged locking device and sliding the cover back.

The telescope tubes are made of nickel-iron castings bored and turned. The draw-tube is enlarged at the outer

end to carry the nickel-iron reticle ring which is held in place by four nickel-steel screws. The reticle ring carries one vertical and three horizontal spider threads. The upper and lower threads are equidistant from the center and intercept a space of 30 cm. at a distance of 100 meters. The objective lens is mounted in a nickel-iron shell, has a focal length of 41 cm. and a magnifying power of from 32--43 diameters. The draw tube is moved into focus by means of a rack and pinion.

The level vial is of the chambered type and has a division value of about 2" of arc. The rear end of the level tube is provided with a vertical adjustable motion for the purpose of keeping the level parallel to the line of collimation. This is the only adjustment that is required of the observer in the field.

The telescope, the supporting cylinder and the level tube are covered with a heavy coating of cloth dust of a bluish-gray color, giving a finish which has the appearance of a cloth of fine quality and also affords considerable protection against sudden and temporary changes of temperature.

The weight of the instrument alone is 5.2 kg. and with the tripod 12.4 kg.

The three main points in regard to the instrument are:

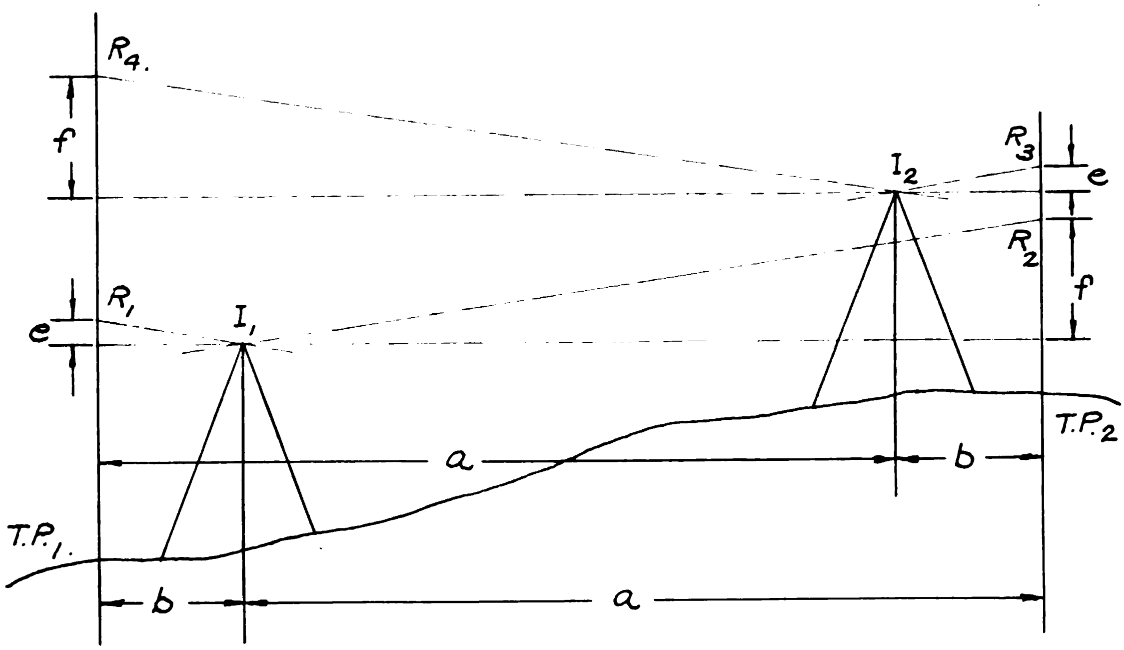
1.- The instrument is irreversible and as simple as possible. The telescope is supported directly on trunnions between the objective and the middle of the telescope and on the point of a micrometer screw near the eye end. The level vial is fixed relatively to the telescope except for the small range provided for adjustment.

2.- The device for reading the position of the bubble enables the observer to stand erect and to see the bubble and rod alternately by merely shifting the attention from one to the other.

3.- The design and materials used in the instrument greatly reduces errors in observation due to changes in the relative temperature of different parts of the instrument.

THE ADJUSTMENT OF THE COAST SURVEY LEVEL.

This is the only adjustment that is required of the observer in the field and consists of making the axis of the bubble tube parallel to the line of collimation. While this instrument is a dumpy level in which both the bubble tube and the line of collimation are usually adjusted, it is necessary to adjust only its bubble tube as the maker adjusts the line of collimation, and it is not disturbed, the adjusting screws are not accessible to the user of the instrument. The adjustment to make the axis of the bubble tube parallel to the line of collimation is done by the peg method and in accordance with section 21 of the general instructions. Fig. 2. shows the method followed.



Let the distance (b) be 1/10 of the distance between the turning points. The readings R_1 and R_2 are the near rod readings and R_2 and R_4 are the far rod readings. Let (e) be the error in the rod reading for the distance (b) and (f) be the error in the rod reading for the distance (a). Then

$$R_1-e-R_2-f = R_4-f-R_3-e$$

$$e = \frac{1}{9} f$$

$$R_1-R_3-(R_2-R_4) = -\frac{16}{9} f$$

$$f = -\frac{9}{16} (R_1-R_3-(R_2-R_4))$$

In testing and adjusting the instrument, the readings R_1 and R_2 are taken from the instrument set up at I_1 in accordance with the conditions of Fig. 2. Then the instrument is set up at I_2 and the readings R_3 and R_4 are taken. From all these readings (f) is determined. The rod reading R_4 is then changed by the amount (f), adding when the line of sight is below the horizontal and subtracting when the line of sight is above the horizonyal. To the amount thus obtained the correction for curvature and refraction in the distance (a) is added. The target on the rod is set at this computed reading and the rod is then held on T.P.$_1$. The middle thread of the instrument is made to coincide with the target by means of the leveling screws and the bubble is then brought to the middle of the tube by means of the adj. usting screws. The line of collimation is then horizontal as shown by Fig. 2, and the bubble being in the middle of its tube the axis of the bubble is horizontal and hence the line of collimation and the axis of the bubble tube are parallel.

In the work of the COAST AND GEODETIC SURVEY the error is found from

$$c = \frac{\text{Sum of near rod readings - Sum of far rod readings}}{\text{Sum of far intervals - Sum of near intervals}}$$

By Fig. 2, this gives

$$C = \frac{R_1 + R_3 - (R_2 + R_4)}{2a - 2b.} = \frac{-\frac{16}{9}f}{\frac{16}{9}a} = -\frac{f}{a}.$$

That is, c is the ratio of the error to the distance which gives the error.

If c is not greater than .01 it is not necessary to adjust the instrument.

It is necessary to determine the (reversing point) reading of the micrometer which makes the axis of the bubble tube perpendicular to the vertical axis of the instrument, because it is required that the micrometer shall not be moved more than one turn to bring the bubble to the middle of its tube. If a greater movement of the micrometer is necessary, the instrument is releveled by the leveling screws. To determine this reading the micrometer is set approximately at 0 and the instrument is leveled in each of two positions at right angles to each other, Then the instrument is revolved 180° about the vertical axis from one of these positions, and if the bubble remains in the middle of the tube, the reading of the micrometer is the one desired. If the bubble does not remain in the middle of the tube, the bubble is brought half-way back by the micrometer and the reading of the micrometer is then the one desired. This reading can be checked by another trial.

THE PRECISE LEVELING RODS.

The self-reading rod has been used exclusively in precise leveling for the past thirty years. These rods are non-extensible and in section are + shaped. They are made of high grade white pine and treated with paraffin to make them impervious to moisture. The rod is 3.2 meters in length and graduated in meters, decimeters and centimeters The meter graduations are marked with silver plugs. Due to the fact that the instrument has an inverting telescope the figures on the rod are upside down so that they may be seen erect when observed through the telescope. There is also attached to the rod a thermometer for reading the rod temperature and a level for plumbing the rod. The base of the rod is fitted with a brass shoe, the end of which is cylindrical in form and rounded on the very bottom to fit into the top of the foot plate or foot pin. The foot pin is used almost exclusively at the present time. The following are some of the pictures taken of the rid used.


GOODS
H. L. WILLSON

THE METHOD.

The following instructions are taken from Special Publication No. 18 of the COAST AND GEODETIC SURVEY and comprise the method of precise leveling that is carried on at the present time.

GENERAL INSTRUCTIONS FOR PRECISE LEVELING

1. Except when specific instructions are given to proceed otherwise, all lines are to be leveled independently in both the forward and backward directions.

2. The distance between successive permanent bench marks shall nowhere exceed 15 kilometers. There shall be no portion of the line 100 kilometers long in which there are not at least 20 permanent bench marks. No permanent bench mark is to be counted in considering these limits unless it is adequately described, nor shall both of two bench marks be counted if they are placed so near to one another and in such manner of exposure as to be likely to be destriyed at the same time. The above-stated limits are to be regarded as extreme lower limits. It is desired that the number of bench marks shall, in general, greatly exceed that just necessary to keep within the limits. It is desired, also, that the bench marks in each general locality shall belong, in part, to each of several classes such as bolts or other marks on buildings, squares cut or bolts or discs set in rzilroad masonry, such as bridge piers, water tanks, etc., stone posts, and iron-pipe bench marks.

3. The line of levels is to be broken by temporary bench marks into sections from 1 to 2 kilometers long, except where special conditions make shorter sections advisable.

4. Temporary bench marks should be established in places where they will be free from disturbance by the track hands working along the road or by materials unloaded from cars. This is especially important when the temporary bench mark is expected to hold the line for any considerable time.

5. At each city along the line, the leveling should be connected with at least two stable bench marks which are connected with the city datum. Connections should also be made with all stable bench marks of other organizations which may be found along the route.

6. In general, the top of rail of the railroad track should be used as the rod support. However, footpins should be carried along during the progress of the work and they should be used whenever a train is known to be approaching or when there are special reasons for supposing the rail not to be in sufficiently stable condition.

7. When elevztions and descriptions of bench marks established by a railroad (over which a line is to be run) are furnished to this office with a request by the officials of the road to have the precise leveling done by this survey connected with them, as many of the railroad bench marks will be incorporated in our line of levels as can be done

without greatly delaying its progress. The railroad bench marks which are of permanent nature are to be treated in the same manner as new permanent bench marks established by the precise leveling party. If the permanent bench marks of the railroad are chiefly of the same general type, they must not be given full weight in deciding whether there are enough bench marks in any section of the line. (See paragraph 2.) Bench marks of the railroad which are not of permanent character may be determined by extra foresights, as in the manner provided for determining the height of rail in front of a railroad station (See paragraph 10). It will not be necessary to connect the precise leveling with the railroad bench marks which are in places not easily accessible. It will not be necessary to connect with each railroad bench mark where they are less than one kilometer apart. The benifits derived from connecting a line of precise leveling with railroad bench marks are (a) that time is gained by having some permanent bench marks already established; (b) the elevations of the railroad bench marks resulting from the connection with precise leveling are of great value to the railroad concerned; and, (c) as the work progresses, a check is obtained on gross mistakes which might escape notice, by comparing the elevations furnished by the railroad with those by the precise leveling party.

8. All old bench marks are to be called by their old names or numbers and are to be described fully by quoting

The old description, if one is available, and by making additions or corrections to it.

9. All new bench marks are to be designated by capital leters with numerical subscripts after the alphabet has been exhausted in each state.

10. The elevation of the top of the railroad rail in front of each railroad station along the line of levels is to be determined with a check. This may be done by using the point on the rail as a rod support in either the forward or backward running of the line, or by taking extra foresight to it on both the backward and forward runnings or by taking extra foresights to it from two instrument stations near it in one of the runnings of the line.

11. When it is desirable to get the elevations by means of which to compare the line of levels with the profile of the railroad, such elevations may be gotten by single readings on the rod held on top of the rail opposite water tanks, and over bridges and culverts. Such structures are usually shown on the railroad profiles.

12. It is desirable that the backward measurement on each section should be made under different atmospheric conditions from those which cccur on the forward measurement. It is especially desirable to make the backward measurement in the afternoon if the forward measurement was made in the forenoon, and vice versa. The observer is to secure as much difference of conditions between the forward and backward measurements as is possible without

materially delaying the work for that purpose.

13. On all sections upon which the forward and backward measures differ in millimeters by more than $4\sqrt{K}$ (in which K is the distance in kilometers leveled between adjacent bench marks) both the forward and backward measures are to be repeated until the difference between two such measures falls within the limit. No one of the questioned measures is to be used with a new measure in order to get this agreement.

14. If any measure over a section gives a result differing by more than 6 millimeters from the mean of all the measures over that section, this measure shall be rejected. No rejection shall be made on account of a residual smaller than 6 millimeters unless there is some other good reason for suspecting an error in this particular measure, and in such cases the reason for rejection must be fully stated in the record.

15. Whenever a mistake, such as reading the wrong decimeter or meter, or an interchange of sights (the backsight being recorded as a foresight), is discovered in any measure after its completion and the necessary correction applied, such measure may be retained provided there are at least two other measures over the same section which are not subject to any such uncertainty. Provided, further, that when it is found that the mistake was made on the last instrument station of the second running of a section and it is corrected on the same day and before beginning work on

an adjacent section, such measure may be retained and no further measures of the secgion are to be required on account of the mistake.

16. The program of observation at each station is to be as follows: Set up and level the instrument. Read the three lines of the diaphragm as seen projected against the front (or rear) rod, each reading being taken to the nearest millimeter (estimated), and the bubble being held continuously in the mifdle of the tube (i.e., both ends reading the same). As soon as possible thereafter read the three lines of the diaphragm as seen projected against the rear (or front) rod, estimating to millimeters as before, and holding the bubble continuously in the middle of the tube.

17. At each rod station the thermometer in the rod is to be read to the nearest degree centigrade and the temperature recorded.

18. At stations of odd numbers the backsight is to be taken before the foresight, and at even stations the foresight is to be taken before the backsight. As the same rod is held on a rod station for both the fore- and backsights, the effect of this is that the same rod is read first at each set-up, it being the rod used for the backsight at the first instrument station.

19. The difference in length between a foresight and the corresponding backsight must not exceed 10 meters. The difference is to be made as small on each pair of sights

as is feasible by the use of good judgment without any expenditure of time for this particular purpose.

20. The recorder shall keep a record of the rod intervals subtended by the extreme lines of the disphragm on each backsight, together with their continuous sum between each two contiguous bench marks (temporary or permanent). A similar record shall be kept aor the foresights. The two continuous sums shall be kept as nearly equal as is feasible without the expenfiture of extra time for that purpose, by setting the instrument beyond (or short of) the middle point between the back and front rods. The two continuous sums for a section shall not be allowed to differ by more than a quantity corresponding to a distance of 20 meters.

21. Once during each day of observation the error of the level should be determined in the regular course of the leveling and recorded in a separate opening of the record book as follows: The ordinary observations at an instrument station being completed, transcribe the last forsight reading as part of the error determination, call up the back rod and have it placed about ten meters back from the instrument, read the rod, move the instrument to a position about ten meters behind the front rod, read the front rod and then the back rod. (The two instrument stations are between the two rod points.) The rod readings must be taken with the bubble in the middle of its tube. The required constant C to be determined, namely, the ratio of the erquired correction to any rod reading to the corresponding

subtended interval. is

$$C = \frac{\text{Sum of near rod readings-Sum of distant rod readings}}{\text{Sum of distant intervals-Sum of near intervals}}$$

The total correction for curvature and refraction must be applied to the sum of the distant rod readings before using it in this formula. The level should not be adjusted if C is less than 0.005. If C is between 0.005 and 0.010 the observer is advised not to adjust the level, but if C exceeds o.010 the adjustment must be made. If a new adjustment of the level is made, C should at once be redetermined. It is desirable to have the determination of level error made under the usual conditions as to length of sight, character of ground. elevation of line of sight above ground. etc. The adjustment of the instrument to reduce C must be made by moving the level vial not by moving the reticle.

22. Notes for future use in studying leveling errors shall be inserted in the record, indicating the time of beginning and ending the work af each section, the weather conditions, especially as to cloudiness and wind. and whether each section of the line is run toward or away from the sun. Such other notes should be made as promise to be of value in studying errors.

23. The instrument shall be shaded from the direct rays of the sun, both during the observatuon and when moving from station to station.

24. The maximum length of sight shall be 150 meters,

and the maximum is to be attained under the most favorable condutions.

25. At the beginning and end of the season, and at least twice each month during the progress of the leveling, the 3-meter interval between metallic plugs on the face of each level rod shall be measures carefully with a steel tape which shall be kept continuously with the party during the season for that purpose only. The temperatures shown by the thermometer inserted in the rod and by the thermometer attached to the tape at the time of each of these measures must be recorded. The purpose of these measures is to detect changes in the length of the rods and not to determine the absolute lengths. The absolute lengths are determined at the office between field seasons.

26. The tape furnished by the office for measurement of the rods os a piece of steel tape about 3.1 meters long, having near one end a fine line graduation and about three meters from it (at the other end of the tape) a series of fine millimeter graduations on a steel rule riveted to the tape. With this special form of tape the measurement of a rod should be made somewhat as follows: The rod should be supported at about the 0.85 meter and 2.45 meter points only (approximately quarter points) to get the least bending of the rod for any two-support system. In making the measurement the single line should be made to coincide with the fine line on the silver plug nearest the bottom of the rod and the reading should be made at the line on the sil-

ver plug at the top of the rod. It is possible to estimate the half-tenths of millimeters on the rule which is attached to the tape. The tape should be placed on the face of the rod in such a way that the edge of the tape from which the rule does not project, coincides with the edge of the face of the rod nearest the meter marks of the rod. Care must be taken that the two edges coincide closely in order that the tape may always assume exactly the same position. The end of the rod at the foot of the rod should be clamped firmly to the rod after the line on the tape and that on the plug have been made to coincide. The tape should then be smoothed down by hand to make it lie perfectly flat on the face of the rod. With the hand lifted and, consequently, no tension on the tape, the reading should be made from the rule attavhed to the tape near the upper or top end of the rod.

27. The field computations and abstracts are to br kept up as the work progresses. As soon as each book of the roiginal record is out of use it is to be sent to the office by registered mail. The corresponding abstracts must be retained until an acknowledgment of the receipt of the original record at the office has been received.

28. No duplicates of the original records are to be made except of the descriptions of bench marks. of which duplicates in the form of carbon copies are to be made. At least once during each month such carbon copies have accumulated are to be sent to the inspector of Geodetic

work.

29. At least once each month, during the progress of the leveling, a test must be made of the adjustment of the rod levels, and a statement should be inserted in the record showing the manner in which the test was made, whether the error was found to be outside the limit stated below , and whether an adjustment was made. With the bubble of the level rod held at the center. the deviation from the vertical of the plane intersecting the center of the face of the rod throughout its length and normal to the face of the rod. must be determined. The deviation from the vertical of the plane coinciding with the face of the rod. must also be determined. If the deviation from the vertical exceeds 10 millimeters on a 3-meter length of rod. the rod level must be adjusted.

30. On the left-hand page of the record the number of each instrument station at which the instrument is not set up in the railroad track is to be included in parentheses. Similarly. on the right-hand page of the record. the designating letter for the foresight rod (V,W,etc.) shall be inclosed in parentheses. if said rod is not supported on the railroad rail. If the length of any portion of the level line run off the railroad is 25 meters or more greater than the railroad distance between the points of departure from and return to the railroad. then the distance along the track between these two points must be shown in the record. The purpose of these requirements os to furnish the

office a means of detecting blunders in the leveling, by plotting the level line on the profile of the railroad.

31. When it is expected that the forward and backward runnings of the line are to be completed up to any one place, the elevation at that place should be held by two points, established at least one set-up of the instrument apart. When the leveling is continued from or to such a pair of points, the instrument should be set up between them and readings of the rod taken on each poinr. The same arrangement of points should be used at the completed end or ends of any detached portion of the line of levels. Either one of the two points may be used for carrying along the elevation, with the other used only as a check against mistakes in reading the rod, or a disturbance of one or both of them. The records should show clearly which one of the two points was used to carry the elevation, and it is believed that it is good policy to use the same point (backward or forward) in each case as far as may be practicable. It is believed that, by employing this method, no mistake of a meter or decimeter made in reading the rod, held on a bench mark, will escape detection.

v 32. As far as possible, all the permanrnt bench marks should be in the main line of levels and not on spur or branch lines. One of the exceptions to this rule is where the line runs several miles off the railroad to the mark of a triangulation station. In such a case the spur, or branch line, is the more economical way of doing the work and will be satisfactory. Whenever a permanent bench mark is established by means of a spur or branch line, which has only one set-up, the forward and backward lines, of the spur or branch should be run at different time of the day or on different days, if practicable. If it should be necessary to have the two runnings made one immediately after the other, the height of the instrument should be materially changed to make the second measure. This would help to prevent any mistake in the leveling.

33. Except in rare cases, the permenent bench marks should be established before or during the first running of the linr. It is believed to be inadvisable to delay the tying in of the permenent bench marks until after the line has been run, even in only one direction. When it is impracticable to establish a permanent bench mark before or dyring the first measurement of the line, an acceptable manner of tying in the permanent bench mark or including it in the main line of levels is to establish a temporary bench mark on each side of the proposed location of the permanent bench mark and to leave the distance between them unleveled until the permanent bench mark has been set. The arrengenent of the temporary bench marks established for this purpose should be similar to that described in the latter part of paragraph 31 of these instructions. This would provide fro two points, the difference in elevation between which are known, on each side of the permanent bench mark and the distance between the two pairs of points makes a section

in the main line of levels. A diagram showing the arrangement of the stakes and the permanent bench mark is shown below:

----O----X----O----X----B----X----O----X----O----

The positions of the instrument are shown by X, the positions of the temporary bench marks by O, and the position of the permanent bench mark by B.

34. Chiefs of party should keep the length of sight great enough to make it necessary to do a moderste amount of rerunning. If an observer is extremely cautious and confines all his observations to sights sufficiently short to insure easy reading of the rod, it is possible to work monrh after month with almost no rerunning, but the progress will be slow. On the other hand, it is certain that an attempt to take sights of the limiting length, 150 meters, at all times would lead to a very large amount of rerunning and the progress would not be rapid. It is believed that the maximum speed consistent with the required degree of accuracy will be secured by continually keeping the length of sight such that the amount of rerunning eill be from 5 to 15 per cent. An extremely small percentage of rerunning would indicate an excess of caution on the part of the observer. The occurrence of a moderate amount of rerunning is due largely to an attempt on the part of the observer to obtain maximum progress consistent with the required degree of accuracy and not to inability to secure such obser-

vations that little or no rerunning would be necessary. Observers have found a convenient rule in fixing the length of sight to be to shorten the sights whenever the upper and lower thread intervals subtend on the rod are found to differ frequently by more than a selected limit. Each observer should fix the limit from his own experience by noting the relation between such a provisional limit and the amount of rerunning found to be necessary while using it. Such a rule is based upon the idea that the additional errors which are encountered when the length of sight is increased are, in the main, those due to the increasing accidental errors in the reading the rods.

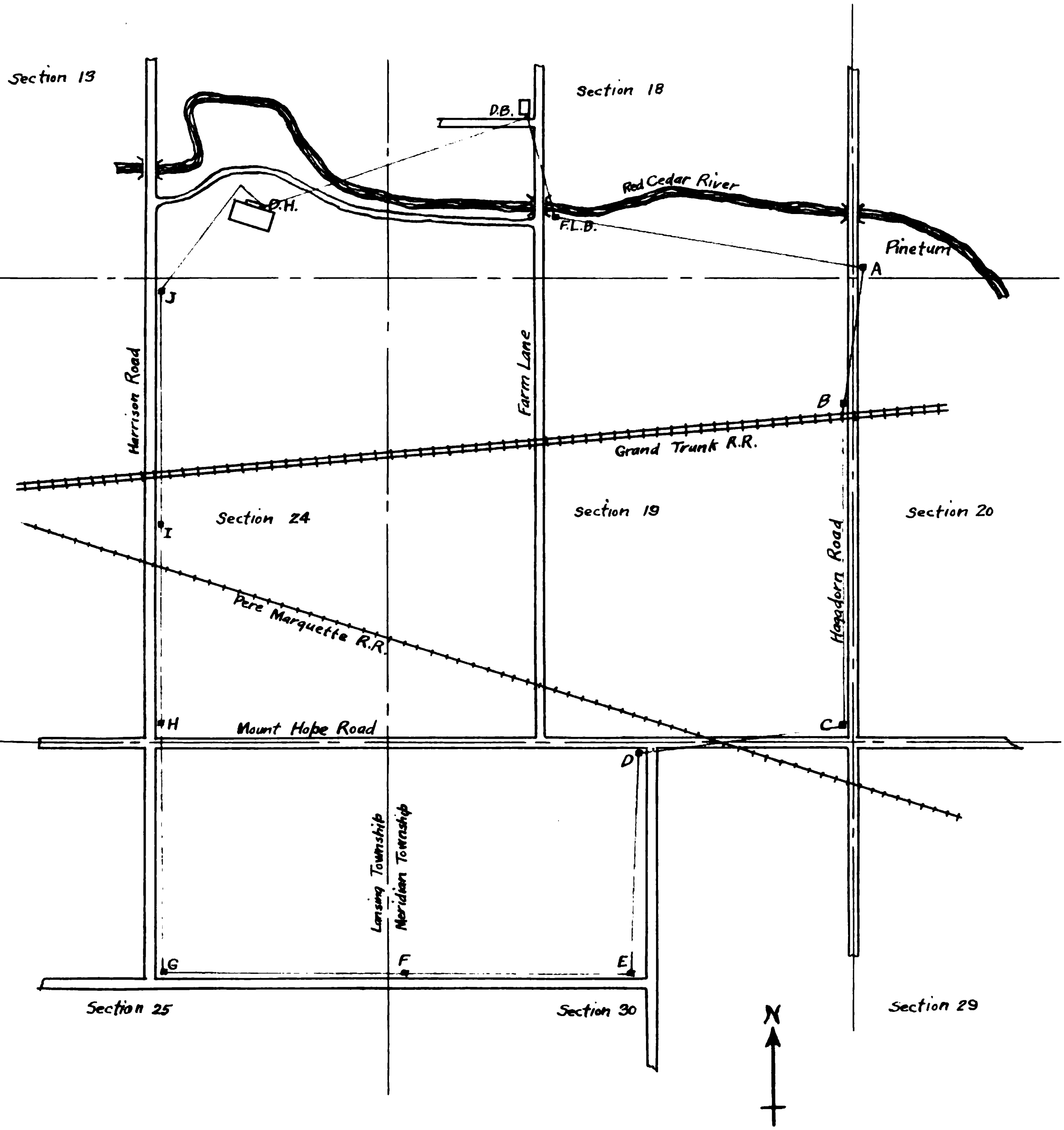
35. It is not thought advisable to state definitly in these instructions the allowable limit on the rate of divergence between the forward and backward lines. but this should be kept small.

36. The record and the preliminary or field computations of precise levels must conform to the examples following, except that in the computation in the field, the five corrections for curvature and refraction. level. index, length of rod, and temperature are not to be applied.

37. Should the experience of the chief of party indicate to him that a change or changes in these instructions would facilitate the work in the field, he is urged to communicate with this office regarding such changes.

When cases arise which are not provided for by these general instructions or by specific instructions, the shief of party will use his own judgment in the matter.

THE LEVEL NET.



DESCRIPTIONS OF BENCH MARKS.

Lost

B.M.-F.L.B.

A square cut in the concrete on the N.E. corner of a Manhole in the East wing of the South abutment of the Farm Lane Bridge.

B.M.-"A".

A concrete monument at the S.W. corner of Pinetum. 4.2' N. and 2.5' W. of fence corner. 25.8' E. of center line of Haggerdorn Road.

B.M.-"B".

Hagadorn

A concrete monument at the intersection of Haggerdorn Road and the Grand Trunk Railroad. On the North side of tracks. 3.5' E. and 2.0' N. of fence cor. and 19.9' W. of center line of Haggerdorn Road.

B.M.-"C".

A concrete monument at the intersection of Mount Hope Rd. and Haggerdorn Rd. 24.5' N. of center line of Mount Hope Rd. and 21.5' W. of center line of Haggerdorn Rd. 85.7' S.E. of S.E. cor. of red-brick farm house.

B.M.-"D".

A concrete monument on the South side of Mount Hope Rd. one-half mile West of the intersection of Haggerdorn and Mt. Hope Rds. 29.4' S. of center line of Mt. Hope Rd.

and 29.4' W. of center line of side road. 2.6' N. of concrete cor. post of fence line.

B.M.-"E".

A concrete monument, one-ha;f mile South of B.M. "E". 52.6' W. and 4.0' S. of concrete cor. post of fence lines. 44.0' W. and 2.0' S. of 24" Elm in the N.W. corner of the intersection.

B.M.-"F".

A concrete monument at the Town Line on the East and West road, one-half mile South of Mt. Hope Rd. 19.5' N. and 40.0' E. of Quarter Corner. 40.0' E. and 3.0' S. of fence corner.

B.M.-"G".

A concrete monument, one-half mile South of the intersection of Mt. Hope Rd. and Harrison Rd. 14.0' N. and 5.4' W. of the N.E. fence corner. 22.0' E. of the center line of Harrison Rd. and 37.8' N. of center line of the cross orad.

B.M.-"H".

A concrete monument at the N.W. corner of School Lot at the intersection of Harrison Rd. and Mt. Hope Rd. 30.0' E. of center line of Harrison Rd. and 1.4' S. of North Boundary of School Lot.

B.M.-"I".

A concrete monument on the East side of Harrison Rd. about mid-way between the Grand Trunk Tracks and the P.M. tracks. 21.5' E. of center line of Harrison Rd.; 21.5' N.W. of 30" Maple and 10.2' S. of 12" Maple.

B.M.-"J".

A concrete monument, one mile North of intersection of Mt. Hope Rd. and Harrison Rd. Across the road from the Michigan State Police Barracks. 45.0' S. and 3.7' W. of fence corner. 29.0' E. of center line of Harrison Rd.

B.M.-"D.H".

A square cut in the concrete coping on the N.W. cor. of the East wing of the Front Steps of Demonstration Hall.

COMPUTATIONS.

The corrections used in these computations were taken from tables given in pages 27 and 28 of the U. S. Coast and Geodetic Survey, Special Publication No. 18 entitled "The Fourth General Adjustment of the Precise Level Net in the United States and the Resulting Standard Elevations".

The level error was obtained by multiplying the difference in the continuous sums (B-F) by the level constant (C). The former quantity is given in column 6 of the left-hand page of the computation sheet and the correction is placed in column 2 of the right-hand page. The sign of the correction is fixed by the signs of the above two quantities.

Sample Determination of (C).

Date: May 16, 1929 Forward From: To:

Sun: C Backward Wind: S

Sta.	Thread Rdg. B.S.	Mean	Thread Interval	Sum of Intervals		Temp.	Thread Rdg. F.S.	Mean	Thread Interval	Sum of Intervals	
1	1495		19			4	0992		230		
	1514	1514.0	19				1222	1222.0	230		
	1533		38				1452		460		
2	1565		223			4	1478		25		
	1788	1788.0	223				1503	1503.0	25		
	2011		446				1528		50		
		1222.0	460					1514.0	38		
		3010.0	906					3017.0	88		
Curv. & ref.		− 1.2	88					3008.8			
		3008.8	818				818	8.2	+.010 = C at 9:00 A.M.		
								818			
								20			

Sample Page of Field Notes.

Date: 5/13/29 Sun: S & C

Forward ~~Backward~~

From: $B.M._A$ Wind: C To: $B.M._B$

Sta.	Thread Rdg. B.S.	Mean	Thread Interval	Sum of Intervals	Temp.	Thread Rdg. F.S.	Mean	Thread Interval	Sum of Intervals
1	1537		131		20	1918		135	
	1668	1667.7	130			2053	2053.3	136	
	1798		261	261		2189		271	271
2	2583		236		20	0837		243	
	2819	2818.7	235			1080	1079.7	242	
	3054		471	732		1322		485	756
3	1348		181		19	1039		173	
	1529	1528.7	180			1212	1212.3	174	
	1709		361	1093		1386		347	1103
4	1609		152		20	0711		138	
	1761	1760.3	150			0849	0848.7	137	
	1911		302	1395		0986		275	1378
3	23 326	7775.4			3	15582	5194.0		
	7775.3					5194.0			

Computation of Precise Levels

Bench Marks	Forward or Backward	No. of Stations	Sum of Rod Intervals	Distance in Kilometers	Rod Intervals $\Sigma B - \Sigma F$	Mean Rod Readings ΣB	Mean Rod Readings ΣF	Approximate Difference of Elevation	Mean Temp. of Rod
			mm.		mm.	m.	m.	m.	
"D.B"	F.	5	2260	0.45	-24	5.3967	9.3520	-3.9553	24
to F.L.B.	B.	3	1919	0.39	+19	5.2683	1.3134	+3.9549	13.
"F.L.B."	F.	10	6772	1.36	+14	19.2374	17.4621	+1.7753	27
to "A"	B.	9	6802	1.36	+20	14.7431	16.5200	-1.7769	18
"A"-"B"	F.	5	2751	0.55	-25	8.5597	5.9694	+2.5903	32
	B.	4	2795	0.56	+1	6.7913	9.3800	-2.5887	35
"B"-"C"	F	7	5210	1.04	+12	12.5800	10.1311	+2.4489	18
	B.	8	5407	1.08	-7	11.4807	13.9251	-2.4444	31
"C"-"D"	F.	5	4060	0.81	-16	7.3600	7.6794	-0.3194	30
	B.	5	4052	0.81	-21	7.9357	7.6200	+0.3157	24
"D"-"E"	F.	5	3945	0.79	-5	9.5540	5.6801	+3.8739	18
	B.	5	3957	0.79	-5	4.9674	8.8430	-3.8756	34
"E"-"F"	F.	7	4768	0.95	+14	8.8600	11.9171	-3.0571	20
	B.	7	4731	0.95	+3	12.3040	9.2484	+3.0556	34
"F"-"G"	F	6	4069	0.82	-5	10.4836	9.5730	+0.9106	20
	B.	7	4081	0.82	+9	10.4620	11.3730	-0.9110	32

Computation of Precise Levels

Corrections					Difference of Elevation		Divergence
Curvature and Refraction	Level Error	Index Error	Length of Rod	Temp. of Rod	Each Line	Mean	B-F
mm.	mm.	mm.	mm.	mm.	m.	m.	mm.
-0.1	-0.2	None - New Rods Assumed O.K.	Not Large Enough to Apply	-0.4	-3.9560	-3.9556	+0.9
-0.2	+0.2			+0.2	+3.9551		
-0.1	+0.2			+0.2	+1.7756	+1.7763	+1.4
-0.2	+0.2			-0.1	-1.7770		
+0.1	-0.3			+0.3	+2.5904	+2.5895	-1.9
+0.1	0.0			-0.3	-2.5885		
0.0	+0.2			+0.1	+2.4492	+2.4471	-4.2
-0.1	-0.1			-0.4	-2.4450		
0.0	+0.2			0.0	-0.3192	-0.3174	+3.6
+0.2	-0.3			0.0	+0.3156		
-0.1	-0.1			+0.3	+3.8740	+3.8751	+2.2
0.0	-0.1			-0.5	-3.8762		
+0.1	+0.2			-0.2	-3.0570	-3.0565	+1.1
-0.1	0.0			+0.4	+3.0559		
0.0	-0.1			+0.1	+0.9106	+0.9107	+0.3
+0.1	+0.1			-0.1	-0.9109		

Computation of Precise Levels

Bench Marks	Forward or Backward	No. of Station	Sum of Rod Intervals	Distance in Kilometers	Rod Intervals ΣB-ΣF	Mean Rod Readings ΣB	Mean Rod Readings ΣF	Approximate Difference of Elevation	Mean Temp. of Rod
			mm.		mm.	m.	m.	m.	
"G"-"H"	F	6	4231	0.85	+3	8.6203	10.9334	-2.3131	16
	B.	6	4237	0.85	+9	9.8507	7.5370	+2.3137	35.
"H"-"I"	F.	4	3437	0.69	-17	5.1200	5.9997	-0.8797	20
	B.	4	3442	0.69	-12	6.5097	5.6270	+0.8827	35.
"I"-"J"	F.	6	4684	0.94	-2	6.2504	9.2653	-3.0149	21
	B.	6	4711	0.94	-7	10.9590	7.9426	+3.0164	35
"J" -	F.	5	3348	0.67	+30	6.6423	7.9924	-1.3501	11
"D.H"	B.	5	3551	0.71	+11	8.7597	7.4090	+1.3507	29
"D.H"	F.	7	4540	0.91	+16	11.6180	8.3260	+3.2920	25
TO "D.B."	B.	7	4604	0.92	+8	9.8868	13.1786	-3.2918	33

Computation of Precise Levels

Corrections					Difference of Elevation		Divergence
Curvature and Refraction	Level Error	Index Error	Length of Rod	Temp. of Rod	Each Line	Mean	B−F
mm.	mm.	mm.	mm.	mm.	m.	m.	mm.
0.0	0.0	None — New Rods Assumed O.K.	Not Large Enough to Apply	+0.1	−2.3130	−2.3136	−1.1
0.0	+0.1			+0.3	+2.3141		
−0.1	−0.2			−0.1	−0.8801	−0.8814	−2.7
+0.1	−0.1			+0.1	+0.8828		
−0.1	0.0			−0.2	−3.0152	−3.0160	−1.5
0.0	−0.1			+0.4	+3.0167		
−0.2	+0.3			0.0	−1.3500	−1.3505	−1.0
0.0	+0.1			+0.2	+1.3510		
−0.1	+0.2			+0.3	+3.2924	+3.2914	−1.0
−0.1	+0.1			−0.4	−3.2914		

Adjustment of Circuit

Line	Distance (km)	Mean Difference +	Mean Difference −	Correction m.m.	Corrected Difference +	Corrected Difference −
"D.B" to "F.L.B"	0.42		3.9556			3.9556
"F.L.B." to "A"	1.36	1.7763		+0.1	1.7764	
"A"-"B"	0.56	2.5895			2.5895	
"B"-"C"	1.06	2.4471		+0.1	2.4472	
"C"-"D"	0.81		0.3174			0.3174
"D"-"E"	0.79	3.8751			3.8751	
"E"-"F"	0.95		3.0565	+0.1		3.0564
"F"-"G"	0.82	0.9107			0.9107	
"G"-"H"	0.85		2.3136			2.3136
"H"-"I"	0.69		0.8814			0.8814
"I"-"J"	0.94		3.0160	+0.1.		3.0159
"J" to "D.H"	0.69		1.3505			1.3505
"D.H." to "D.B."	0.92.	3.2919			3.2919	
Total.	10.86	14.8906	14.8910	+0.4.	14.8908	14.8908

Final Elevation

B.M.'s	Elevation (meters)	Elevation (feet)
"F.L.B."	255.5004	838.2968
"A"	257.2768	844.1252
"B"	259.8663	852.6213
"C"	262.3135.	860.6506
"D"	261.9961	859.6092
"E"	265.8712	872.3234
"F"	262.8148	862.2954
"G"	263.7255.	865.2834
"H"	261.4119	857.6924
"I"	260.5305	854.8006
"J"	257.5146	844.9054
"D.H"	256.1641.	840.4744.