THE MAKING, PLACING, AND PRECISE DETERMINATION OF THE ELEVATION OF BENCH MARKS IN THE VICINITY OF THE CITY OF EAST LANSING AND THE COLLEGE CAMPUS

THESIS FOR THE DEGREE OF B. S.

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SUPPLEMENTARY
MATERIAL
IN BACK OF BOOK

THE MAKING, PLACING, AND PRECISE DETERMINATION OF THE ELEVATION OF BENCH MARKS IN THE VICINITY OF THE CITY OF EAST LANSING AND THE COLLEGE CAMPUS.

A Thesis Submitted to
The Faculty of

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By

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Bachelor of Science

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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 United States Coast and Geodetic Survey both in our computations and adjustment of the level net, and in our observations in the field.

Table of Contents.

Precise Leveling

The purpose of Precise Leveling is to determine with greatest precision the elevation above sea level of points on the earth's surface, even when these points are at great distances from the sea.

The elevations are referred to mean sea level as a datum. The mean sea level is found at a number of places by means of automatic tide guage records which extend over several years. In the work of the United States Coast and Geoditic Survey the elevation of mean sea level is taken the same for the Atlantic and Pacific Oceans and for the Gulf of Mexico.

Precise leveling differs from ordinary leveling in the refinements introduced into the construction of the instruments and into the method used.

In the United States and its Possessions, the greater part of the precise leveling has been done by the U.S. Coast and Geoditic 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 discriptions of these bench marks may be found in the published reports of the Superintendent of the Coast and Geoditic Survey.

The Need and Benefit of a Precise Level Net

In all cities and towns there is considerable construction work going on, such as buildings, laying of water mains and sewer systems, etc. In the laying out of this work it has to be tied in or referred to some established datum. This means that a line of levels has to be run from some known and fixed elevation. In some cities this line may be of considerable length and it will take time and probably cost considerable to run every time as needed.

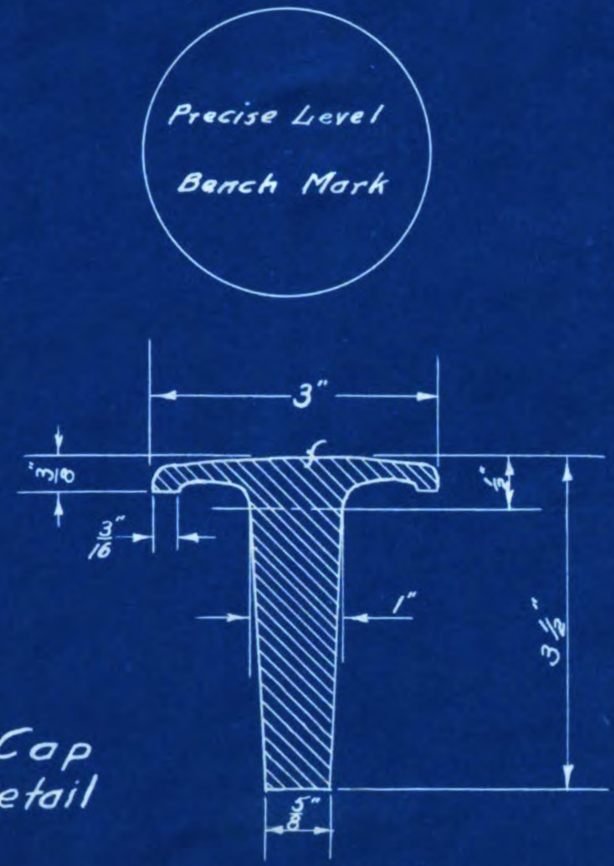
By having a Precise Level Net which covers the entire city, an accurate line of levels can be run in a much shorter time. A greater accuracy is obtained by making an adjustment of the Net according to the method of least squares which is very precise. Therefore, there is a saving of time and money; and also, a greater accuracy is obtained.

The Bench Marks.

In this work a matter of great importance is placed in the making and placing of the bench marks. They have be of a very permanent nature in order to give the accurate results desirable. The following design was decided upon. The monument was to be of concrete, cylindrical in shape with the following dimensions:- 6" diameter by 4' 2" long. This length places the base of the monument well below the frost depth found in this locality. Into the top of this was set a brass plate (for detail, see Plate I, 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 reenforcement for the monument, preventing any cracks. A pattern was made for this brass cap, and the cap cast in the College foundry. These caps were later ground and smoothed on a buffer. Fig b of plate I shows the assembly of the monument.

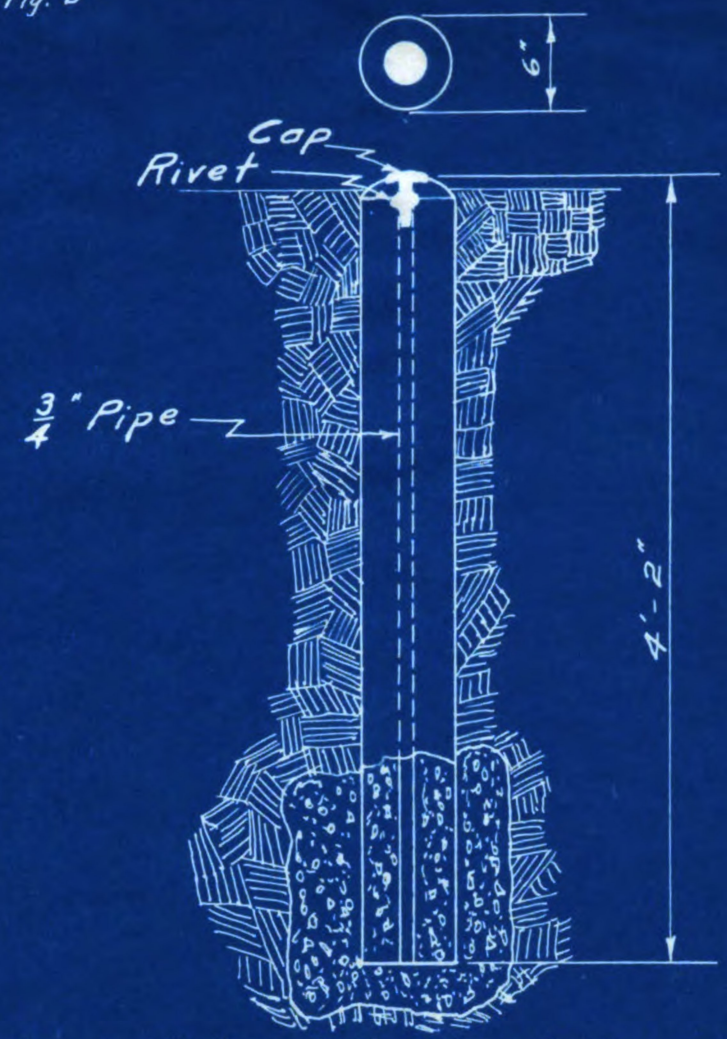
In placing these monuments wet cement was placed in the bottom of each hole and the monument set in this. Dirt was then firmly tamped about the monument up to the ground surface. By placing these monuments in wet cement a wide firm base was formed which will prevent any possible heaving of the monuments due to frost action. All of the monuments were placed withthe top flush with the surface of the ground.

Fig. a



Cap
Detail

Fig. b



Assembled and Emplaced Monument

PLATE-I

The Instrument.

The dumpy level is the form of instrument now used by the United States Coast and Geodetic Survey and the United States Geological Survey. With it the most precise, most rapid and cheapest precise leveling is done at the present time.

The distance between the level tube and the line of collimation is reduced by placing the tube in an opening cut in the telescope. This reduces to a minimum the effect of temperature changes on the parallelism of the axis of the bubble tube and the line of collimation. The telescope with its inseted bubble tube is placed within a tube-shaped support toward one end of which two pivot screws provide a horizontal axis about which the telescope can be rotated a small amount and the line of collimation made horizontal by means of a micrometer screw mounted at the other end. The tubular form gives the strongest and lightest form of support of the telescope and also serves to protect the level mounted in it. The level-reading device, consisting of a pair of prisms mounted in a tube at the side of the telescope and at binocular distance from it, enables the observer to stand with body and head erect while observing the level with one eye and the rod with the other. A small mirror is attached at the top of the tubular support and reflects the light from the level to the prisms of the level-reading device.

The telescope, the tube incasing the level vial, the draw tube, the reticle ring and the tubular support are made of an alloy of nickel and cast iron. The pointed screws pivoting the telescope, the screws holding in place the bubble tube, the screws holding in place the reticle ring and the micrometer screw are made of nickel-steel. The telescope, its tubular support and the bubble tube, are covered with a coating of cloth dust of bluish-gray color, giving a finish which has the appearance of a cloth of fine quality. By using these materials and finish the effect of temperature changes is reduced to a minimum.

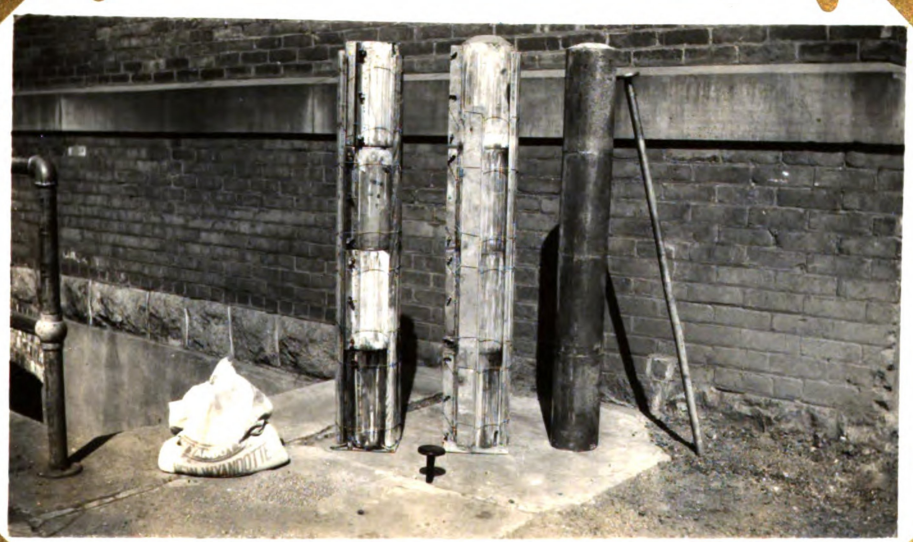
The main points in the construction of the level are:

First. The telescope is not reversible, being supported on trunnions between the objective and the middle of the telescope and on the point of the micrometer screw near the eye end. The bubble tube is fixed with respect to the telescope, except the small change provided for adjustment.

Second. 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 changing the attention from the one to the other.

Third. The design and materials used greatly reduces the effect of temperature changes in different parts of the instrument.


BUGGIES
LUMBER WAGONS
H. L. WILLSON




BUGGIES
LUMBER WAGONS
H. L. WILLSON

Adjustment of the Level.

The only adjustment of this instrument, wncih should be made daily, is as follows: TO MAKE THE AXIS OF THE BUBBLE PARALLEL TO THE LINE OF SIGHT. This adjustment is made by the ordinary peg method, the bubble tube being raised or lowered at the adjusting end as may not be disturbed at any time because they have been permanently adjusted for collimation by the maker of the level. In testing the adjustment the rod reading is taken as the mean of the three crosshair readings, and the rod interval as the difference between the outside cross-hair readings, the bubble being kept exactly in the center while all of the three cross-hairs are being read.

Two turning points are set about 100 meters apart, each rod being kept on its own point if two rods are used, or one rod being shifted as the case requires.

The level is set up approximately in line with the tow points, forst about ten meters beyond one point, and then about the same distance beyond the other point.

The rod reading is taken for each point and for each point and for each position of the instrument, the terms "distant rod" and "near rod" being used to indicate the relative position of the rods for each set up.

Now having taken the four readings we have.

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

in which C is called the bubble error or constant for the day's work. If C does not exceed 0.010 (numerically) it is not advisable to change the adjustment. The telescope looks up when C is negative and down when C is positive, so that is an adjustment is necessary the line of sight (here taken as the middle cross-hair) is raised or lowered on the distant rod by C times that distance, and the bubble tube adjusted to bring the bubble to the center.

A correction equal to C time the excess interval between the foresights and backsights are in excess the correction has the same sign as C, and if the foresights are in excess the correction has the opposite sign.

The Precise Leveling Rods

The rod used in precise leveling work is of the self-reading type. It is non-extensible and in section are -- shaped. It is made of high grade white pine and treated with paraffin to make them impervious to moisture. The rod is 3.2 meters long and graduated in meters and centimeters. the meter graduations are marked with silver plugs. As the telescope of the level used in precise leveling is inverting, the figures are placed on the rod upside down, so that they appear erect when seen through the telescope of the level. Attached to the rod is a centigrade thermometer, reading from -23° to 55°, and a circular 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 pin.

The foot pin which is used as a turning point is driven into the ground with a wooden mallet.

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 destroyed 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 the several classes such as bolts or other marks on buildings, squares cut or bolts or discs set in railroad masony, 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 conditions.

7. When elevations and descriptions of bench marks established by railroad (over which a line is to be run) are furnished to this office with a request by 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 benefits 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 letters 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 foresight 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 occur 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 secire 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 fall 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 a misreading of 1 decimeter or 1 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 measure of the section 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 (established), and the bubble being held continuously in the middle of the tube (i.e., both ends reading the same). As soon as possible thereafter read the three lines of the diapgragm 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 stt-up, it being the rod used for the backsight at the first instrument station.

19. The difference in length between a doresight 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 rod intervals subtended by the extreme lines of the diaphragm on each backsight, together with their continuous sum between each two contiguous bench marks (temporary or permanent). A similar record shall be kept for the foresights. The two continuous sums shall be kept as nearly equal as is feasible without the expenditure 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 foresight 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 meddle of its tube. The required constant C to be determined, namely, the ratio of the required 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 0.010 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, sharacter of ground, elevation of line 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 of 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 observations and when moving from station to station.

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

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

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 measured carefully with a steel tape which shall be kept continuously with the party during the season for that purpose only. The temperature 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 is 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 doincide 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 tape 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 the 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 attached to the tape near the upper or top end of the rod.

27. The field computations and abstracts are to be kept up as the work progresses. As soon as each book of the original 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 as 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 showin 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, must be determined. The deviation from the vertical of the plane coinciding with the face of the rod, must also be determined. If the deveation from the vertical exceeds 10 millimeters on a 3-meter length of the rod, the rod level must be adjusted.

30. On the left-hand page of the record the numbe of each instrument station at which the instrument is not st 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, the the distance along the track between these two points must be shown in the record. The purpose of these requirements is 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 readings of the rod taken on each point. 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, withe 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 whichone of the two points was used to carry the elevation, and it is believed that it is a good policy to use the same point (backward or forward) in each case as for as may be practicable. It is believed that, by employing this method, no mistake of a meter or a decimeter made in reading the rod, held on a bench mark, will escape detection.

32. As far as possible, all the permanent 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 sour, 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 bench line, which has only one set-up, the forward and backward lines of the spur or branch should be run at a 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 permanent bench marks should be established before or during the first running of the line. It is believed to be inadvisable to delay the tying in of the permanent bench marks until after the line has been run, even in only one direction. When is is impracticable to establish a permanent bench mark before or during 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 arrangement 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 for two points, the difference in elevation between which are known, on each side of the permanent bench marks and the distance between the two pairs of points makes a section

in the main line of level. A diagram showin the arrangment of the stakes and the permanent bench mark is shown below:

----0----X----0----X----B----X----0----X----0----

The position of the instrument are shown by X, the position of the temporary bench marks by 0, 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 moderate 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 month 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 will 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 observations

that little or no rerunning would be necessary. Observers have found a convenient rule in fixing the length of sight to be shortened 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 esperience 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 reading the rods.

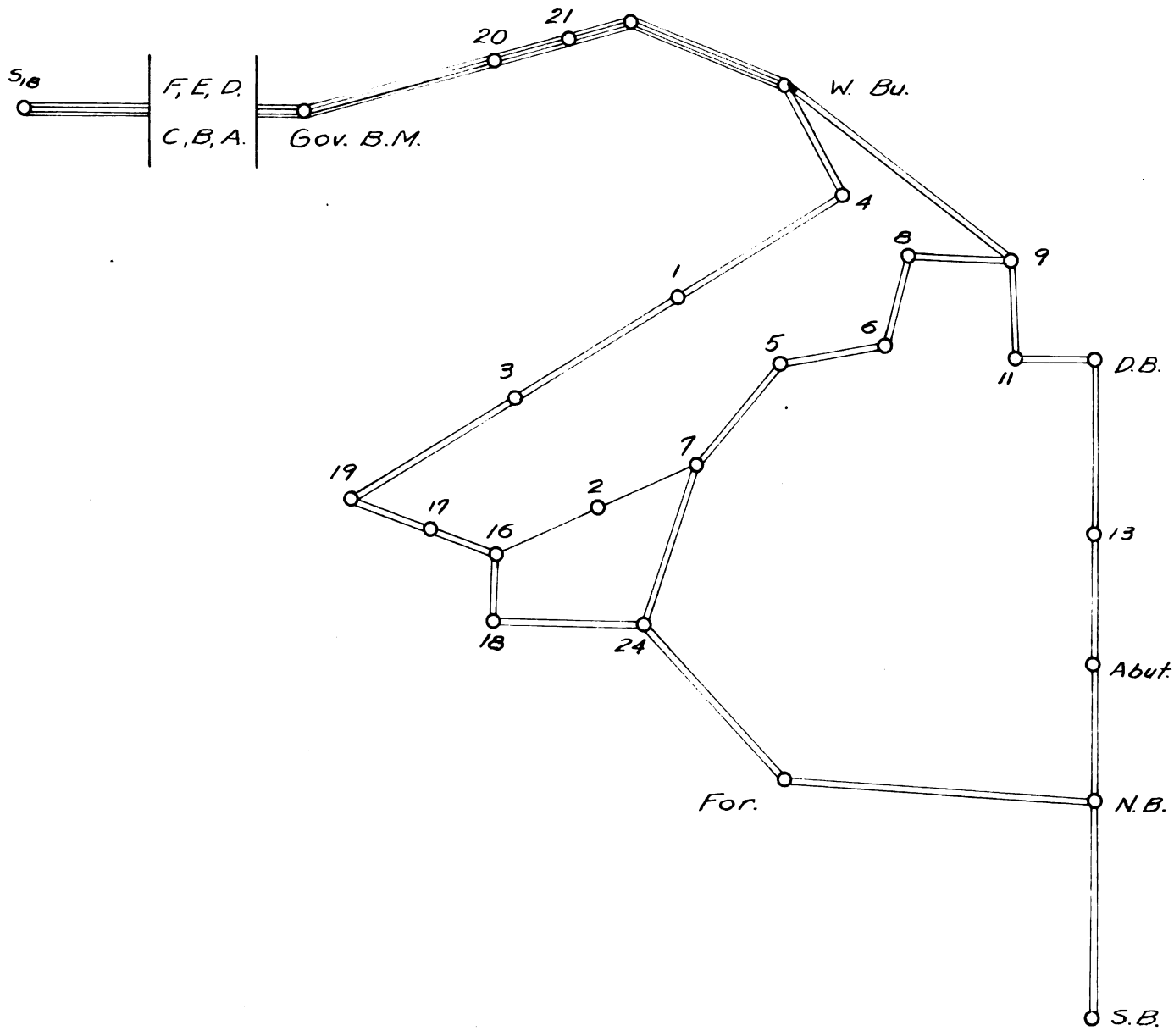
35. It is not thought advisable to state definitely in these instructions the allowable limit on the rate of divergence between the forward and backward lines, but this should be kept small.

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 chied 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 chief of party will use his own judgement in the matter.

THE LEVEL NET



DESCRIPTION AND LOCATION OF BENCH MARKS.

Note I. This station mark consists of a copper plate 3" in diameter set flush with the surface in cement and having a horizantal bar across the face.

Note 2. This station mark consists of a cross made with a hammer and cold chisel.

Note 3. This station mark consists of an iron pipe.

Note 4. This station consists of a 6"x6"x4' concrete post set flush with the surface of the ground and having in the center of the top an iron or copper bolt with a punch mark in the center.

B.M. #I.

In front of Dean Shaw's Old House 50' south of S. E. cornerof Shaw's House and 6' W. of S. E. corner of Said House. Marked as in Note 4.

B.M. #2.

I47' N. E. of the N. E. corner of the new Gymnasium and I36' S. W. of the S. W. corner of the Armory and 6' N. E. of tree stump. Marked as in Note 4.

B.M. #3.

In front of Pres. Shaw's new House. 45' S.E. of Evergreen Tree and 68' S.W. of the S.W. corner of Shaw's House and 33' N.W. of iron hitch-post on drive in front of House. Marked as in Note 4.

B.M. #4. In front of Old Taft House. I3.5' South of the Main Drive, 26.4' East of shrubbery. An elm 30" diam. on North side of road bears N37°W distant 38'. Other references are: a maple bearing S70°E distance 55', 24" diam; and a basswood 24" diam., bearing S4o°E distance 64.6'. Marked as in Note 4.

B.M. #5. West and North of College Hall just N. E. of fountain.
References:- N. W. Corner College Hall to E. 66.5'; N. E. CORNER Sink of fountain 7.2'. Marked as in Note 4.

B.M. #6.

Directly in front of library and near top of slope up to College Hall.
References;- I. N.E. Corner College Hall S76° 30'W. distance 80.I'; 2. Oak Tree N89°W distance 28.I'; 3. Fire Hydrant S33°E distance 78.0'; 4. Evergreen N8°E distance 28.7'. Marked as in Note 4.

B.M. #7.

In lawn North and West of the Greenhouse. I2' N. of N. line of Greenhouse and 75' W. of same. References:-

Water plug to N. 30.8' (I" pipe); Iron clothes post to W.- 35.0'; N.E. corner Hot-bed Wall - 28.6'. Marked as in Note 4.

B.M. #8

In front of Woman's Building. 70' N.W. of end of walk in front of building and 3-5' S.W. side of Main Drive. Marked as in Note 4.

B.M. #9

In front of Bacteriology Building. 7.5' N. from the center line of walk leading from building and 8" West of walk leading to Horticultural Building. References:- Fire Hydrant to E. - 10.5'

Marked as in Note 4

B.M. #11.

On Soth side of road passing Agricultural Building, at N.W. corner of pasture lot. 2.6' N.W. of corner post at South side of large boulder 3" beneath the surface. References:- N.E. Corner Farm Mech. Bldg. 18.2' Bearing W. S.W. Corner Ag. Bldg. bearing N.E. app. Marked as in Note 4.

B.M. #13.

On farm lane situated 32.5' S.E. of concrete gate post at South Entrance to Campus and 17' W. of East fence. References:- Corner fence post - N.E. 37' W. Marked as in Note 4.

M.M. #16

On East side of Main Drive 55' North of old culvert wall at road to athletic field. References:- 1. Iron electric light pole 36,9' N.; 2 Oak tree on edge of bank to west -blazed- 54.5' . Marked as in Note 4.

B.M. #17

At intersection of Main Drive and Hospital Drive. References:- S.W. Corner of Hospital 129' N.E.; Fence 30' S. Marked as in Note 4.

B.M. #18

On athletic field just next to curb on south side of running track. References:- S.E. Corner of Grand Stand 146' S.E.; Curve in Curb 25' S.E. Marked as in Note 4.

B.M. # 19

About 450' West of B.M. #17 and North of the Main Drive. References:- Shrubbery 28' North; Main Drive 20' S.; Pine Tree 50' S.W. Marked as in Note 4.

B.M. #20

In Elm Row across street from 216 Michigan Avenue. References:- 8' S. of South Rail of M.U.T Co. Marked as in Note 8.

B.M. #21.

In Elm Row on South side of M.U.T. Tracks and West of Stone Walk. References:- S. Rail M.U.T. 7' N.W.; Stone Walk 15' N.E.
Marked as in Note 4.

B.M. #24.

Sothwest of Greenhouse on South side of River Drive, 5' from South edge of Road. References:- A on South trunk of double oak tree distant 16.6' to Eastward; A on main trunk of a clump of maples to South distant 17.5'; An Oak to S.W. distant 17.7'.
Marked as in Note 4.

B.M. #D.B.

On S.E. corner steps of Dairy Building. References:- 3.5' S. of Dairy Bldg.; 15' E. of Center Line of Dairy Bldg.
Marked as in Note 2.

B.M. #ABUT.

On S.W. abutment of Farm Lane Bridge. References:- 10' W. of W. side of Bridge. Marked as in Note 2.

B.M. #N.B.

On West side Farm Lane about 400' South of Bridge over Red Cedar. References; ¾ 18' S. of N.E. Corner post of Field 8; 15.5' E. of E. Fence Field 8.
Marked as in Note 4.

B.M. #S.B.

On West side of Farm Lane about 900' South of North Base. References:- 313' S. of N.E. corner post of Field #10; 12.5' E. of E. Fence Field #10.
Marked as in Note 4.

B.M. #GOV. B.M. HAR. AVE.

Across the road from and nearly in front of the"White Elephant" 33' N. of the center line of street car track; 61' W. of sidewalk crossin Michigan Ave/
U.S.G.S Iron pipe 10" above surface. Marked as in Note 3.

B.M. #F.

Cross cut on curb on West side of Pennsylbania Ave. (Lansing, Mich.).
Reference:- 1' N. of Telephone pole #2326 on curb.
Marked as in Note 2.

B.M. #W.B.

7.5' W. of S.W. Corner of porch on weather Bureau, Copper disc cemented on top of step.
Marked as in Note 1.

B.M. # FOR.

2" Gaspipe 6' East of East Fence Forestry Plant and 63' S. of center line of P. M. Spur. Marked as in Note 3.

B.M. #S18.

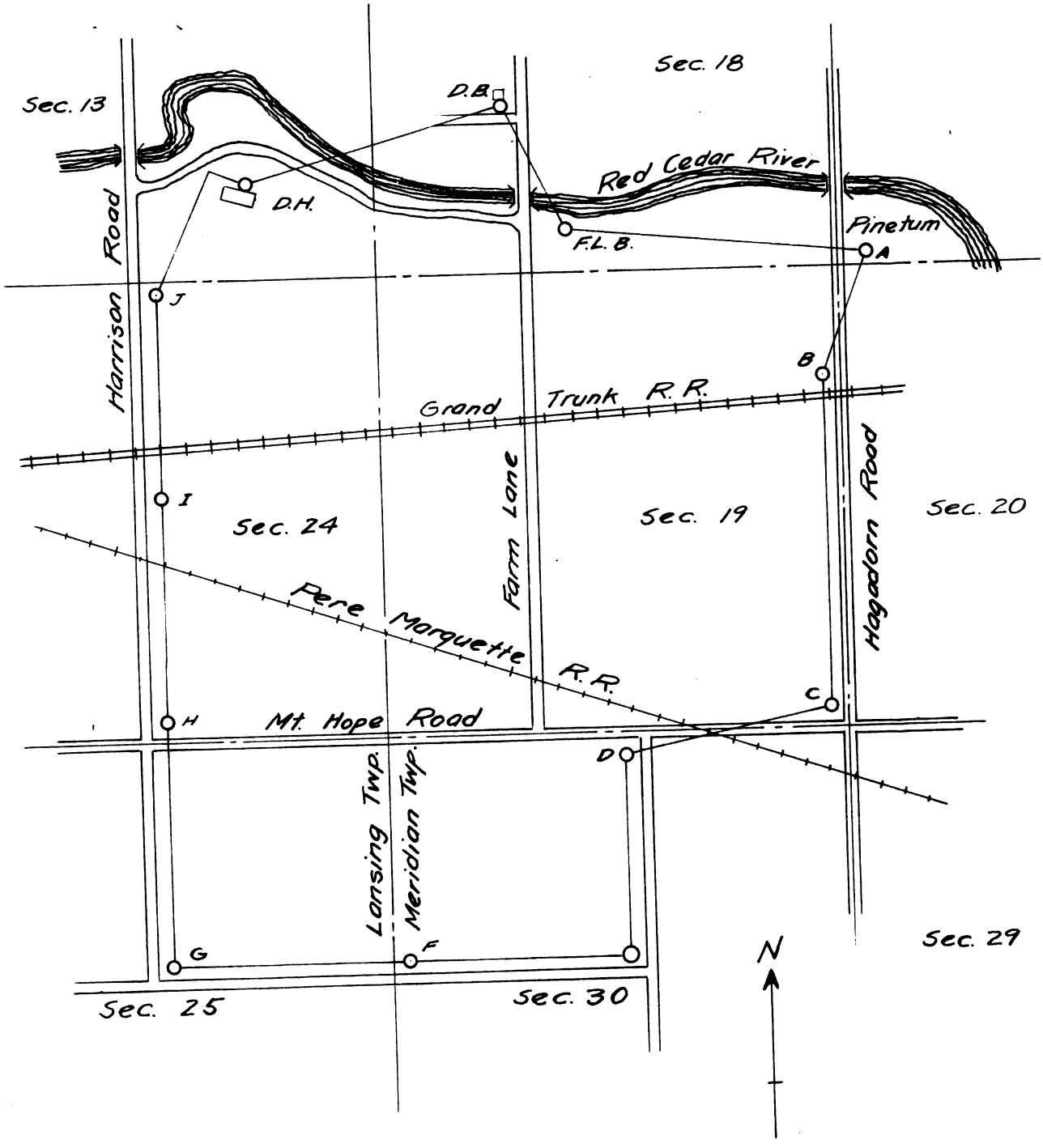
Situated 34' south of the Northeast corner of the D. M. C. Depot and 14.5 North of the North side of the smoking room door and 2.16' above the pavement.

Copper disc set in cement in East Wall of M. C. Depot at Lansing, Michigan.

FINAL ELEVATION

B. M's.	ELEVATION (Meters)	ELEVATION (Feet)
S/B	258.9680	849.631
W. Bu.	261.2745	857.197
F.	263.5413	864.634
E	259.3879	851.006
D	258.5931	848.401
C	258.3028	847.446
B	253.6453	832.167
A	253.9561	833.187
Gov. B.M.	255.2633	837.475
20	258.8544	849.257
21	258.8769	849.329
9	257.7711	845.704
11	258.6272	848.512
D.B.	259.4560	851.232
13	256.0117	839.930
Abut.	254.7644	835.838
N. B.	261.0479	856.452
S. B.	261.6651	858.479
For.	258.2500	847.275
24	252.6234	828.814
18	253.1105	830.414
16	258.4273	847.856
17	262.6144	861.593
19	262.7002	861.875
3	260.7396	855.441
1	260.2818	853.939
4	257.0187	843.233
8	256.3844	841.153
6	259.8221	852.433
5	258.0477	846.609
7	257.2880	844.119
2	256.9035	842.945

THE LEVEL NET



DESCRIPTIONS OF BENCH MARKS.

B. M. -F.L.B.

A square cut in the corner 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 Hagardorn road.

B. M.-"B".

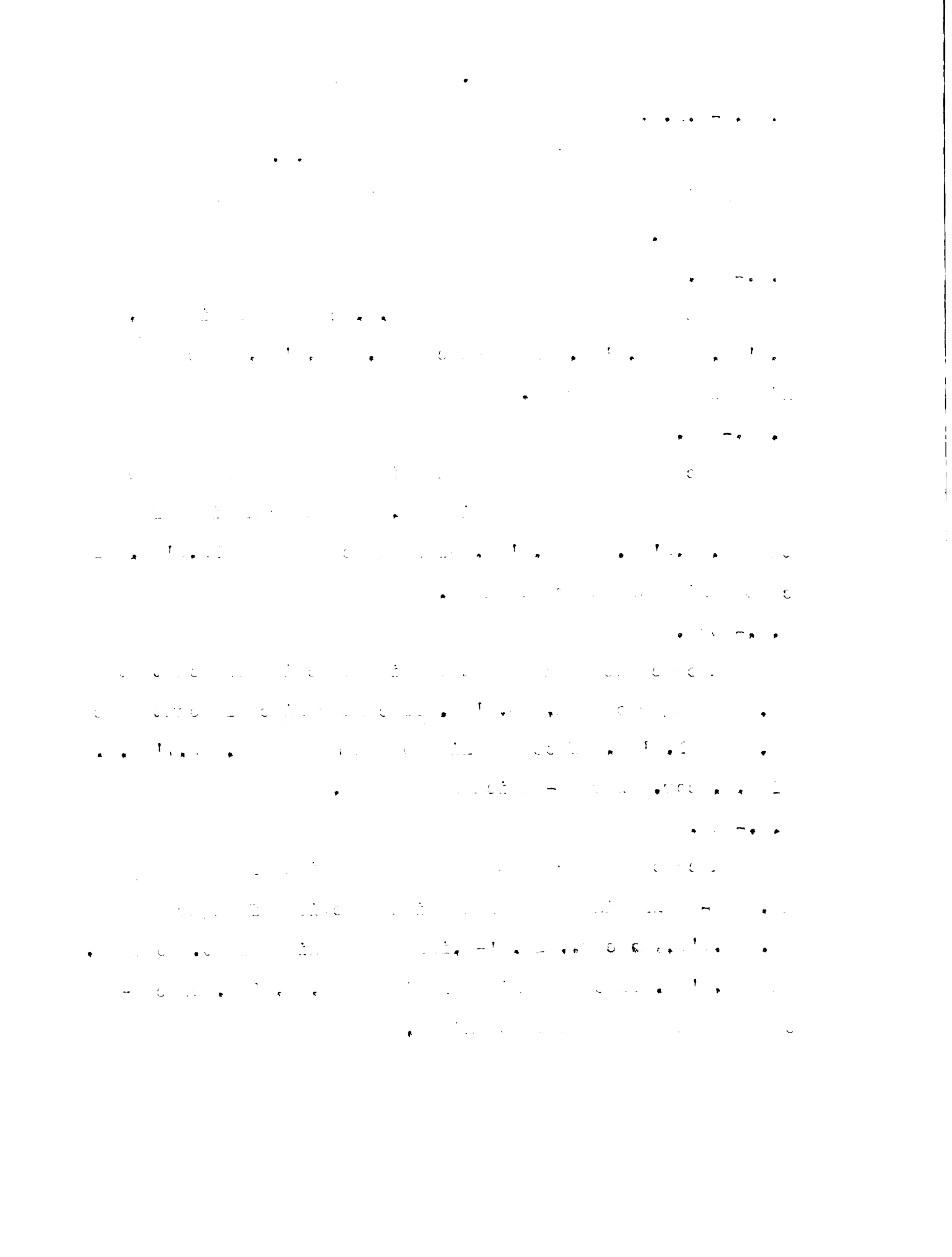
A concrete monument at the intersection of Hagardorn road and the Grand Trunk Railroad. On theNorth side of tracks. 3.5' E. and 2.0' N. of fence corner and I9.9' W. of center line of Hagardorn Road.

B.M.-"C" .

A concrete monument at the intersection of Mount Hope Rd. and Hagardorn Rd. 24.5' N. of center line of Mount Hope Rd. and 2I.5' W. of center line of Hagardorn 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 Hagardorn Rd. and Mt. Hope Rd. 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 corner post of fence lines.



B.M. -"E".

A concrete monument, one-half mile South of B.M. "E". 52.6' W.and 4.0' S.of concrete corner 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. I9.5' 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. I4.0' N. and 5.4' W. of the N.E. fence corner. 22.0' E. ofthe center line of Harrison Rd. and 37.8' N. of center line of the cross road.

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 I.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 College Police Barracks. 45.0' S. and 3.7' W. of fence corner, 29.0' E. of center line of Harrison Rd.

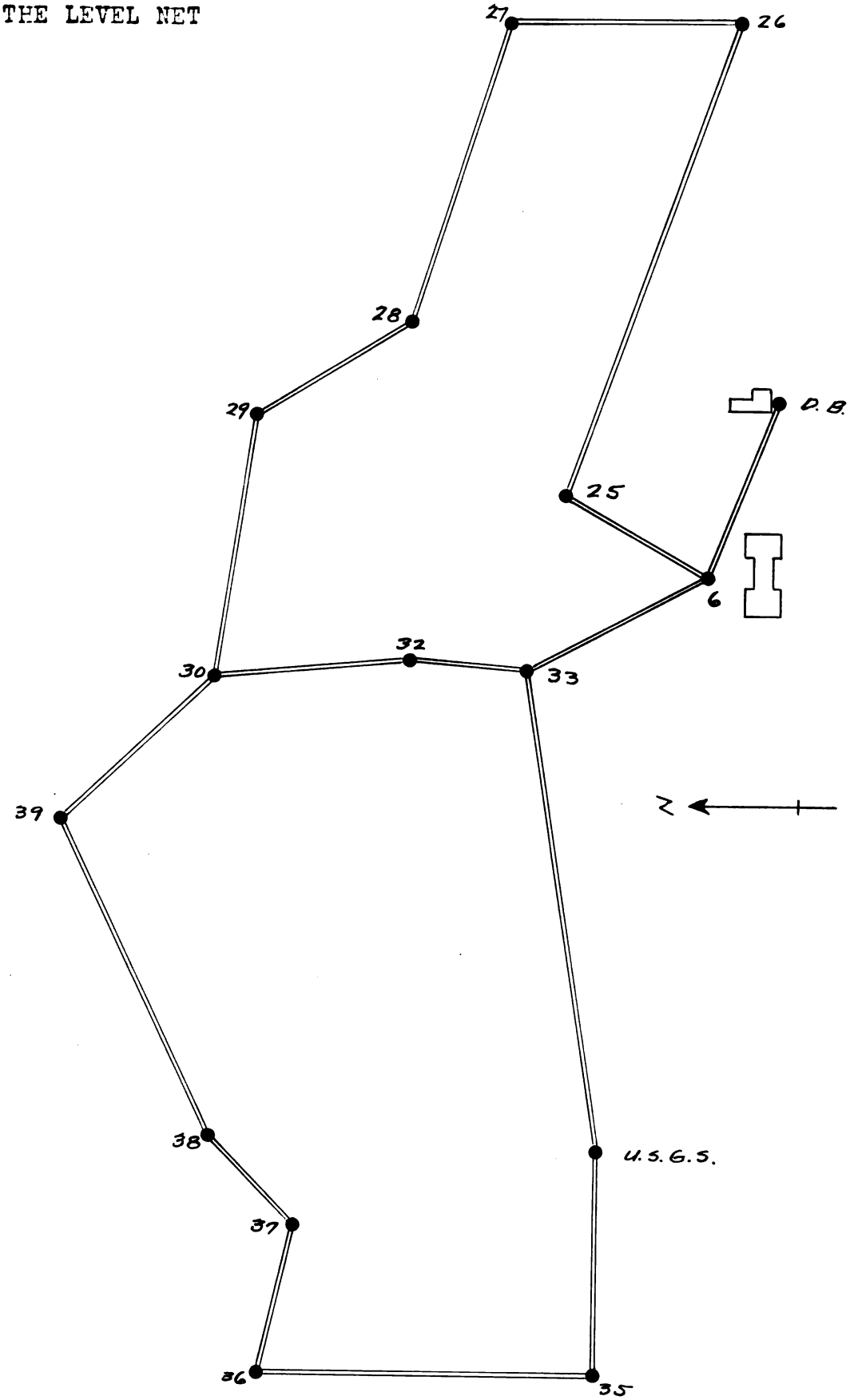
B.M.-D.H.

A square cut in the concrete coping on the N.W. corner of the East wing of the Front Steps Of Demenstration Hall.

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	859.6072
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

THE LEVEL NET



DISCRIPTIONS OF BENCH MARKS

B. M. #25

Concrete monument in N. W. cor. of intersection of Grand River Ave. and Charles St. 57.1' N. N. W. to S.E. cor. of Standard Oil Station. 5.5' N. to walk. 2.3' E. to walk. 2.8' S. to inside edge of curb.

B. M. #26

Concrete monument in N.W. cor. of intersection of Grand River Ave. and Gunson St. 3.0' E.N.E. to S.W. cor. of concrete base for lamp post. 51.5' E.N.E. to S.W. cor. of Hauer's Grocery Store. 4.0' N. to walk. 3.8' S. to inside edge of curb.

B. M. #27

Concrete monumentin S. W. cor. of intersection of Gunson and Ann Sts. 1.8' W. to walk. 2.5' E. to inside edge of curb. 82.8' W. to N.E. cor. of House #289. 58.9' S.S.W. to N.E. cor. House #285.

B. M. #28

Concrete monument in S.E. cor. of intersection of Linden and Bailey Sts. 59.6' W.N.W. to center of Fire Hydrant. 33.4' N.W. to center of manhole cover. 30.6' W. to water shut off valve. 1.9' W. to inside edge of curb.

B. M. #29

Concrete monument in S.W. cor. of intersection of Division and Beech Sts. 54.7' N.N.E. to center of Fire Hydrant. 2.6' W. to walk. 35.1' W.S.W. to N.E. cor. House #549. 61.8' S.S.W. to N.E. cor. House #545.

B. M. #30

Concrete monument in N.W. cor. of intersection of Abbott Road and Fern St. 58.3' N.W. to S.E. cor. of House #631. 5.4' W. to walk. 3.9' E. to inside edge of curb.

B. M. #32

Concrete monument in N.E. cor. of intersection of Abbott Road and Linden St. 46.4' E.N.E. to S.W. cor. of Fire Station. 7.2' E. to walk. 2.4' W. to inside edge of curb. 5.9' E.S.E. to center of Fire Hydrant.

B. M. #33

Concrete monument in between the entrance and exit to College. S. of Abbott Road And Grand River Ave. 63.6' N. to base of signal post. 2.1' N. to inside edge of curb. 78.8' W.N.W. to N.E. cor. of Music Building.

B. M. #U.S.G.S.

Government B.M. on N. side of Michigan Ave. near Harrison Road. 1.3' S. to walk. 86.4' N.N.E. to S.W. cor. of Chevorlet Garage. 41.1' N.W. to S.E. cor. of House.

B. M. #35

Concrete monument in N.E. cor. of intersection of Michigan and Crowley Aves. 56.0' W.N.W. to center of Fire Hydrant. 1.1' W. to walk. 0.9' S. to walk. 10.1' S. to center of Bell System manhole cover.

B. M. #36

Concrete monument in S.E. cor. of intersection of Grand River and Crowley Aves. 3.8' E. to walk. 2.4' N. to walk. 69.5' N.N.W. to center of Fire Hydrant. 76.5' W.S.W. to N.E. cor. of Porch of House.

B. M. #37

Concrete monument in N.E. cor. of intersection of E. Oakwood and Grand River Ave. 1.4' N. to walk. 100.7' E.S.E. to center of Fire Hydrant. 111.9' S.E. to N.W. cor. of House #919.

B. M. #38

Concrete monument in S.W. cor. of intersection of Wildwood Drive and Harrison Ave. 1.1' E. to inside edge of curb. 9.8' W. to walk. 43.9' N. to center of manhole cover.

B. M. #39

Concrete monument in N.W. cor. of intersection of Center Lawn and Sunset Lane. 1.8' N. to walk. 41.4' W.N.W. to S.E. cor. of House #901. 69.4' E.N.E. to S.W. cor. of House #904.

DETERMINATION OF C. 3:00 P.M. May 5, 1931.

No of Station	Thread Reading Backsight	Mean	Thread Interval	Sum of Intervals	Rod	Thread Reading Foresight	Mean	Thread Interval	Sum of Intervals
	1327					0582			
A	1338	1337.7	11		W	0721	0720.3	139	
	1348		10	21		0858		137	276
	1565					2053			
B	1573	1572.3	08		W	2194	2193.3	141	
	1579		06	35		2333		139	556
		+2910.0					-2913.6		35
							+2910.0		521
							521 | -3.6 (	-.0069 = C	

Date: May 5, 1931. From B.M.#33 to B.M.#6
Sun: C. Forward Wind S.T.

No of Station	Thread Reading Backsight	Mean	Thread Interval	Sum of Intervals	Rod and Temp.	Thread Reading Foresight	Mean	Thread Interval	Sum of Intervals
	1195					2138			
1	1299	1298.7	104		20°	2238	2237.7	100	
	1402		103	207		2337		99	199
	0539					2897			
2	0612	0611.4	73		15°	2975	2974.4	78	
	0683		71	351		3051		76	351
	1042					0221			
3	1166	1165.4	124		13°	0347	0347.0	126	
	1288		122	597		0471		126	603
	2401					0461			
4	2438	2437.4	37		13°	0493	0492.7	32	
	2473		35	669		0524		31	666
		+5512.9					-6051.8		
							-0538.9	mm. Diff.	

COMPUTATION OF PRECISE LEVELS

B. M'S.	FORWARD OR BACKWARD	NO OF STATIONS	SUM OF ROD INTERVALS	DISTANCE	ROD INTERVALS ΣB-ΣF	MEAN ROD READINGS		APPROX. DIFF. OF EL	MEAN TEMP. OF RODS
						ΣB	ΣF		
			mm.	x 3/2 = KMS	mm	M.	M.	M.	
6-25	F	3	1031	.20	-05	2.6900	5.3899	-2.6999	28
	B	4	1298	.26	-04	7.6074	4.9093	+2.6981	27
25-26	F	6	3018	.60	0	11.7906	9.4683	+2.3223	25
	B	6	3006	.60	+06	8.1430	10.4623	-2.3193	26
26-27	F	3	1443	.29	+01	4.5829	3.3073	+1.2756	23
	B	3	1446	.29	+10	3.4302	4.7042	-1.2740	23
27-28	F	4	2019	.40	+03	7.3957	8.7708	-1.3751	12
	B	4	2036	.41	+12	8.6116	7.2390	+1.3726	23
28-29	F	2	1355	.27	-09	3.2497	2.4744	+0.7753	11
	B	3	1417	.28	+11	3.7212	4.4987	-0.7774	15
29-30	F	3	1680	.34	+02	4.2717	3.8833	+0.3884	7
	B	3	1602	.32	+06	6.4148	6.8018	-0.3870	16
30-39	F	3	1418	.28	-04	4.5880	5.7536	-1.1676	24
	B	3	1432	.29	+02	5.5523	4.3870	+1.1653	24
39-38	F	5	2100	.42	-04	10.4111	8.7557	+1.6554	20
	B	5	2109	.42	+01	8.9317	10.5898	-1.6581	22
38-37	F	2	1015	.20	-17	3.8733	2.1713	+1.7020	17
	B	2	1007	.20	-27	2.0427	3.7453	-1.7026	20
37-36	F	2	919	.18	+05	3.1883	2.0510	+1.1373	18
	B	2	922	.18	+36	1.6916	2.8277	-1.1361	19

COMPUTATION OF PRECISE LEVELS

CORRECTIONS					DIFFERENCE OF ELEVATION		
CURVATURE AND REFRACTION	LEVEL ERROR	INDEX ERROR	LENGTH OF ROD	TEMP. OF ROD	EACH LINE	MEAN	DIVERGENCE B-F
m.m.	m.m.	mm.	m.m.	mm.	M	M	mm
0	0			.2	-2.7001	-2.6992	-1.8
0	0			.2	+2.6983		
0	0			.2	+2.3225	+2.3210	-3.0
0	0			.2	-2.3195		
		O.K.					
0	0			.1	+1.2757	+1.2750	-1.4
-.1	-.1		Apply	.1	-1.2740		
0	0	Assumed		0	-1.3751	-1.3738	-2.6
-.1	-.1		to	.1	+1.3725		
+.1	+.1		Enough	0	+0.7755	+0.7766	+2.2
-.1	-.1			.1	-0.7777		
0	0	Rods		0	+0.3884	+0.3878	-1.2
-.1	0			.1	-0.3872		
			Large				
0	0	New		.1	-1.1677	-1.1665	-2.3
0	0			.1	+1.1654		
0	0	-	Not	.1	+1.6555	+1.6568	+2.7
0	0			.1	-1.6582		
		More					
+.1	+.1			.1	+1.7023	+1.7023	0
+.2	+.2			.1	-1.7023		
0	0			.1	+1.1374	+1.1371	-0.6
-.3	-.3			.1	-1.1368		

COMPUTATION OF PRECISE LEVELS

B. M's.	FORWARD OR BACKWARD	NO OF STATIONS	SUM OF ROD INTERVALS	DISTANCE	ROD INTERVALS ΣB-ΣF	MEAN ROD READINGS		APPROX. DIFF. OF EL.	MEAN TEMP. OF RODS
						ΣB	ΣF		
			mm.	x 3/2 = Kms.	mm.	M.	M.	M.	
36-35	F	6	2104	.42	-06	4.2873	13.6796	-9.3923	24
	B	6	2098	.42	+02	13.3712	3.9813	+9.8899	21
35-U.S.G.S.	F	2	1397	.28	+01	4.2456	3.4223	+0.8233	26
	B	3	1400	.28	-08	4.5677	5.3887	-0.8210	27
U.S.G.S.-33	F	6	2996	.60	0	11.9724	6.8759	+5.0965	23
	B	6	2980	.60	+04	6.3987	11.4925	-5.0938	25
33-6	F	4	1335	.27	+03	5.5129	6.0518	-0.5389	17
	B	5	1368	.27	0	7.9934	7.4554	+0.5380	30
30-32	F	3	1187	.24	+13	5.6967	4.7120	+0.9847	5
	B	3	1201	.24	-05	4.6320	5.6187	-0.9860	17
32-33	F	1	684	.13	0	0.8906	2.0254	-1.1348	18
	B	1	688	.13	-02	2.0267	0.8917	+1.1350	18
6-DB	F	3	1369	.27	+11	5.1334	5.4967	-0.3633	33
	B	3	1378	.28	-02	5.3567	4.9936	+0.3631	27

COMPUTATION OF PRECISE LEVELS

CORRECTIONS					DIFFERENCE OF ELEVATION		DIVERGENCE B.-F.
CURVATURE AND REFRACTION	LEVEL ERROR	INDEX ERROR	LENGTH OF ROD	TEMP. OF ROD	EACH LINE	MEAN	
mm	mm	mm.	mm.	mm.	M.	M	mm
0	0			.9	-9.3932	-9.3914	-2.5
0	0			.8	+9.3907		
0	0			.1	+0.8234	+0.8221	-2.5
+.1	+.1	O.K.		.1	-0.8209		
0	0			.5	+5.0970	+5.0956	-2.7
0	0	Assumed	Apply	.5	-5.0943		
0	0			.1	-0.5390	-0.5386	-0.9
0	0	Rods	to	.1	+0.5381		
			Enough				
-.1	-.1			0	+0.9845	+0.9853	+1.6
0	0	New		.1	-0.9861		
0	0		Large	.1	-1.1349	-1.1350	+0.3
+.1	0			.1	+1.1352		
		None					
			Not				
-.1	-.1			.1	-0.3636	-0.3634	-0.4
0	0			.1	+0.3632		

ADJUSTMENT OF CIRCUIT

LINE	DISTANCE Kms.	MEAN DIFFERENCE		CORRECTION	CORRECTED DIFFERENCE	
		+	−		+	−
6-25	.30		2.6992	−.2		2.6994
25-26	.90	2.3210		−.5	2.3205	
26-27	.43	1.2750		−.3	1.2747	
27-28	.60		1.3738	−.4		1.3742
28-29	.41	0.7766		−.2	0.7764	
29-30	.49	0.3878		−.3	0.3875	
30-39	.42		1.1665	−.3		1.1668
39-38	.63	1.6568		−.4	1.6564	
38-37	.30	1.7023		−.2	1.7021	
37-36	.27	1.1371		−.2	1.1369	
36-35	.63		9.3919	−.4		9.3923
35-USGS	.42	0.8221		−.2	0.8219	
USGS-33	.90	5.0956		−.5	5.0951	
33-6	.40		0.5386	−.2		0.5388
	7.10	15.1743	15.1700	4.3	15.1715	15.1715
		15.1700			Check	
		Error 4.3				
30-33	.60		0.1467			
30-32	.41	0.9853		+2.1	0.9874	
32-33	.19		1.1350	+0.9		1.1341
	.60	0.9853	1.1350	3.0	0.9874	1.1341
			0.9853			0.9874
			0.1497		Check	0.1467
			0.1467			
			Error 3.0			
6-DB	.42		0.3634			

FINAL ELEVATION

B. M'S.	ELEVATION (Meters)	ELEVATION (Feet)
6	259.8221	852.433
25	257.1227	843.577
26	259.4432	851.189
27	260.7179	855.372
28	259.3437	850.863
29	260.1201	853.411
30	260.5076	854.682
39	259.3408	850.854
38	260.9972	856.288
37	262.6993	861.873
36	263.8362	865.603
35	254.4439	834.788
USGS	255.2658	837.484
33	260.3609	854.201
6	259.8221 ✓	852.433 ✓
30	260.5076	854.682
32	261.4950	857.921
33	260.3609	854.201
D.B.	259.4587	851.241

APPENDIX.

Computations for the Adjustment of Level Circuit by the Method of Least Squares .

Condition Equations -

	V	V	V	q
A	+I	-I		+4.3
B	-I		+I	+5.2
S	0	-I	+I	

Normal Equations -

	A	B	q	S
I	+2.0	-I	+4.3	+5.3
(2)		+2.0	+5.2	+7.2
(2)		+2.0	+5.2	+7.2
(3)		+0.5	+2.15	+2.65
II		+2.5	+7.35	+9.85

From equation II, get B

$$2.5\,B + 7.35 = 0$$

$$B = -4.054$$

Substituting B in equation I, get A

$$2\,A + 4.054 + 4.3 \quad 0$$

$$A = -4.177$$

Correction for Line 6 - 25

$$\frac{.30}{7.10}\,(-4.177) = -\,0.2\text{mm.}$$