THESIS

PRECISE LEVELING
TO DETERMINE THE ACCURATE ELEVATION
OF BENCH MARKS
ON THE MICHIGAN AGRICULTURAL COLLEGE
CAMPUS AND FARM.

H. F. ANDERSON R. C. SMITH

JUNE 1917

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ON THE MICHIGAN AGRICULTURAL COLLEGE CAMPUS AND FARM.

A THESIS

submitted to the Faculty of

Michigan Agricultural College

by

H. F. ANDERSON. R. C. SMITH.

Candidates

for the

Degree of Bachelor of Science.

June 1917.

THESIS

PREFACE.

The reason for undertaking this work was, first, to ascertain the accurate elevation of the Bench Marks on the Michigan Agricultural College Campus and Farm; second, to attest to the correctness of the results.

The elevation of these Bench Marks had never been determined by Precise Leveling. Some of the elevations were known to be in error by as much as one foot.

In performing this work we have conformed with the methods used by the United States Coast and Geodetic Survey, which are later described in detail under the section entitled "Instructions for Field Work".

As an aid to our work we have referred to the U.S.C. & G.S. Reports of 1909, also to Ingram's "Geodetic Surveying".

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Section 1. DATUM PLANE FOR ELEVATIONS ABOVE SEA LEVEL.

Spirit leveling is the name applied to the determining differences of elevation by use of the leveling instrument.

The grade of leveling used in carrying accurate elevations from the sea coast to the interior of the country is called precise leveling.

The datum plane to which all elevations are referred is mean sea level as determined at points on the sea coast by continuous automatic tide gauge records extending over a period of several years.

The mean of the hourly elevation of the surface of the sea as scaled off the graphical record is taken as mean sea level and is assumed as being the same for all points on the surface of the several other oceans.

This has been proven by running a line of precise levels across the United States and also across the Isthmus of Panama.

Section 2. THE LEVELING INSTRUMENTS.

Previous to the year 1900 the precise leveling of the U.S.C. & G.S. was done with the European Type of instrument. Commencing with the summer of 1900 this work has been done with a type of instrument designed by the U.S.C. & G.S. and is known as the Coast Survey Level. A view of the level is shown on page 3a.

The instrument is essentially a dumpy level, as the telescope does not rest in wyes, cannot be removed from its supports, and can neither be reversed or inverted.

The base of the instrument is of the usual three leveling screw type except that the center socket is unusually long and extends downward through the tripod head. An outer protecting tube, through which the telescope passes, is rigidly attached to the vertical axis.

The telescope is pivoted at one end of this outer tube and has its inclination controlled by a micrometer screw at the other end.

The collimation adjustment is permanently fixed by the maker.

VIEWS OF INSTRUMENT.

The level tube is attached to the telescope, but has provision for adjustment. The strong point of the instrument is the proximity of the bubble to the line of sight, the level tube being let part way into a slot cut in the top of the telescope tube, the top of the level tube comming approximately flush with a slot in the outer tube. The level vial is chambered for adjusting the length of the bubble.

The level reading device deserves especial attention, as with it rests the credit for much of the superiority of this instrument over ordinary types.

Attached to the left side of the instrument is a light auxillary tube through which an image of the bubble may be seen with the left eye while the right eye is observing the rod. The tube is adjustable sideways to suit the eyes of different observers. Besides the lens in the eyepiece the tube contains two prisms, adjustable for length of bubble, and placed opposite a slot running abreast of the level vial.

The bubble is brought within the view of the left eye through the eye lens, the two prisms,

and a mirror attached to the telescope.

The vial is of the chambered type; it rests within the level tube upon the ends of four small screws, two at each end, and is held in place by a flat spring at each end. Tow cork rings hold it in place longitudinally. The method of setting allows the vial to expand and contract independently of the metal parts of the tube.

The reticle has one vertical and three horizontal cross-hairs cemented to the reticle ring which is held in place by four screws which screw into the ring. These screws are covered by a cap, screwed on, to prevent injury, and give a smooth finish to the level.

The telescope tube and outer casing are made of a nickle-iron alloy that has a coefficient of expansion which is only one-fourth that of brass, while the micrometer screw and other important screws are made of nickle steel having a coefficient of expansion as low as 0.000001 per degree centigrade.

This level has two constants and one adjustment.

Section 2 cont. ADJUSTMENTS OF THE LEVEL.

The only adjustment of this instrument, which 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 be required. The cross-hairs must 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 cross-hair 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 two points, first 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 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

$$C \quad \frac{(\text{sum of near rod readings}) - (\text{sum of distant rod readings})}{(\text{sum of distant rod intervals}) - (\text{sum of near rod intervals})}$$

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 times the excess interval between the foresights and backsights is applied to the final elevation; if the 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.

Section 2 cont. RODS AND TURNING POINTS.

The rods used in precise work are 3.25 meters long and are graduated in the metric system by the U.S.C. & G.S. The subdivisions on this rod are to centimeters. No targets are used but the mean of the three cross-hair readings is taken out to tenths of millimeters. The wood of which the rods are constructed is treated with parafine to prevent absorption of moisture. A "watch glass" bubble is fastened to the back of the rod and also a thermometer reading to degrees centigrade is set in the rod with a wooden slide near the handle used for carrying and also to afford a grip for holding the rod plumb while a reading is being taken.

The foot of the rod is a small bronze cylinder with a bearing face the segment of a sphere. The center of this face is directly in line with the face of the rod. The face of the rod is two centimeters wide, and has a line running down the middle, the centimeter squares of the rod are painted alternately black and white. The meter and decimeter graduations are on the body of the rod two centimeters

PARTY IN ACTION.

VIEW OF ROD.

back of the face. Two silver plugs are set into the face of the rod for comparative measurements with a steel tape. As shown in the illustration, the figures on the rod are so formed as to read with an inverting instrument.

The turning points are cast iron foot-plates about six inches in diameter with a socket about an inch and a half in diameter for the bronze cylinder of the rod to set in. A chain about two feet long is attached to the foot-plate thus enabling it to be carried very easily. On the bottom of the plate are three steel spurs about a half inch in length which hold the plate in position after it has been firmly placed.

Section 3. INSTRUCTIONS FOR FIELD WORK.

1. All lines are to be leveled independently in both the forward and backward directions.

2. The line of levels is to be broken by temporary bench marks into sections.

3. The program of observations 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 milimeter (estimated), and bubble being held continuously in the middle of the tube.

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

5. 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

setup, it being the rod used for the backsight at the first instrument station.

6. The difference in length between a foresight and the corresponding backsight should not exceed ten meters. The difference is to be made as small on each pair of sights as is feasible by the use of good judgement.

7. The recorder shall keep a record of the rod intervals subtended by the extreme lines of the diaphragm on each backsight, together with their continuous sum between bench marks. A similar record shall be kept for the foresights. The two continuous sums shall be kept as nearly equal as is feasible, by setting the instrument beyond (or short of) the middle point between the back and front rod.

8. Every morning before starting work the error of the level should be determined. Take a reading on the rod about 100 meters distant. Then take a reading on the back rod about 10 meters distant. Move the instrument to a position about 10 meters behind the front rod, read the front rod and then the back rod.

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 required correction to any rod reading to the corresponding subtended interval, is

$$C \quad \frac{\text{(sum of near rod readings)}-\text{(sum of distant rod readings)}}{\text{(sum of distant rod intervals)}-\text{(sum of near rod intervals)}}$$

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.

9. Notes for future use in studying leveling errors shall be inserted in the note book, indicating the time of beginning and ending the work of each section, indicating the weather conditions, especially as to cloudiness and wind, indicating whether each section of the line is run toward or away from the sun and such other notes as may be of value in studying errors.

10. The instrument shall be shaded from the direct rays of the sun, both during the observations and the movement from station to station.

11. The maximum length of sight shall be 150 meters, and the maximum is to be obtained only under the most favorable conditions.

12. The field computations are to be kept up as the work progresses.

13. The allowable error is to be $4mm\sqrt{Km}$.

14. Rods should never be laid on the ground or taken off foot-plates between readings.

Section 4. THE FIELD WORK.

The precise level as used at present, weighs with the tripod 27½ pounds. The increased weight of the tripod to enable the observer to stand erect is more than offset by the advantages of being able to work in this position.

In leveling up, after the instrument has been set and the legs of the tripod clamped, the level is unclamped from the tripod, the watch glass bubble is brought to the center of its run, then the micrometer screw is set at its reversing point, (determined by reversing the instrument 180 degrees and bringing the bubble half way back to the center) and the leveling up completed by placing the telescope over two screws and bringing the bubble to the middle of the run, then over the third screw. It is necessary in leveling up to look at the images of the bubble in the mirrors.

It is necessary to keep the level at all times protected from the direct rays of the sun. A large wagon umbrella is used for this purpose. It also serves the double purpose of protecting the instrument from vibrations caused by the wind.

When readings are being taken, the rodman should hold the rod on the point marked, one hand grasping the handle and the other raised above his head to steady the rod as high up as possible. In high winds, the knee can be used to steady the rod. The bubble should be kept as near the center of the watch glass as possible. The face of the rods should be kept clean.

After the readings have been taken and before the instrument has been moved, the recorder figures the wire intervals. If they do not differ by more than two mm. he says "check".

The sights are kept nearly equal by pacing. When the discrepancy of the continuous sum of intervals reaches any considerable amount, the recorder notifies the observer by calling the foresights long or short, as the case may be, telling him also the number of intervals discrepancy. At the next set up the observer equalizes the sights by setting ahead or back of the middle point.

Section 5. THE RECORD.

The record has opposite pages for back- and foresights. These pages are identical with the exception of the first column of each. On the backsight page this column is used for the recording of the number of the instrument station. On the foresight page it is used for the designating letter of the foresight rod and the temperature of the backsight rod. The second column contains the readings of the three cross-hairs as given to the recorder by the observer. The third contains the mean of the readings, the fourth the differences between the first and second and the second and third and their sum. The fifth column contains the continuous sum.

The mean is taken out by the following short method: the quantities in the fourth column are computed at once, then if the difference between readings of the first and second wire is equal to the difference between the second and third wire, the mean is the reading of the middle wire. If the latter is one more than the former, add 0.3 to the reading of the middle wire; if two more add 0.7; if less, subtract instead of adding.

A difference of more than two is seldom permissable in precise work and indicates a too hasty reading. The record should be made in ink, and no erasures are permissable. Footings and computations of difference in elevation are made in pencil.

SPIRIT LEVELING

DATE: APR. 3, 1917 ~~FORWARD~~ - BACKWARD

SUN: C.

FROM B.M. W.B. TO B.M. S.18

WIND: 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
14	1525		210		B	1070		208	
	1735	1735.0	210		13	1278	1278.0	208	
	1945		420			1486		416	
15	1280		218		A	1085		227	
	1498	1498.0	218		13	1312	1312.0	227	
	1716		436	856		1539		454	870
16	1950		130		B	1108		118	
	2080	2080.0	130		13	1226	1226.0	118	
	2210		260	1116		1344		236	1106
17	2008		80		A				
	2088	2088.0	80		A-13	1002		83	
	2168		160	1276		1085	1085.0	83	
						1168		166	1272
18	2428		105		B	0525		108	
	2538	2533.0	105		13	0633	0633.0	108	
	2638		210	1486		0741		216	1488
19	2639		209		A	1760		210	
	2848	2848.0	209		13	1970	1970.0	210	
	3057		418	1904		2180		420	1908
20	0820		217		B	1833		209	
	1037	1036.7	216		13	2042	2042.0	209	
	1253		433	2337		2251		418	2326
	41456					28638			
	13818.7 ✓	13818.7 ✓	R.C.S. ✓			9546.0 ✓	9546.0 ✓		R.C.S. ✓
			H.A.H.						H.A.H.

SPIRIT LEVELING

DATE: Apr. 3, 1917 FORWARD - BACKSIGHT FROM B.M. TO B.M.

SUN: C WIND: M

NO. OF STATION	THREAD READING BACKSIGHT	MEAN	THREAD INTERVAL	SUM OF INTERVALS		ROD AND TEMP.	THREAD READING FORESIGHT	MEAN	THREAD INTERVAL	SUM OF INTERVALS
	1547		141				1770		78	
	1688	1688.0	141				1798	1798.0	78	
	1829		282				1876		56	
	1498		136				1500		23	
	1634	1634.0	136				1523	1523.0	23	
	1770	3372.0	272	554			1546		46	102
		3371.0		102						
		1.0		456						
	456		.002 = C at 7:00 AM. APR. 3, 1917							
	1578		142				1802		30	
	1720	1720.0	142				1832	1832.0	30	
	1862		284				1862		60	
	1532		134				1528		24	
	1666	1666.0	134				1552	1552.0	24	
	1800	3386.0	286	552			1576		48	108
		3384.0		108						
		2.0		444						
	444		.004 = C at 7:00 AM. APR 28, 1917							

Section 6. ERRORS IN PRECISE LEVELING.

Errors are of two classes: compensating and cumulative. The small errors in estimating millimeters, in holding the rod on the turning point, and in the position of the bubble belong to the former class. If a reasonable amount of care is taken in the execution of the work these errors tend to cancel out.

Errors due to rising of the rod supports, to settling of the instrument between pointings on fore and back rods, and errors due to unequal refraction on grades belong to the latter class.

The error due to settling of the instrument between pointings is eliminated by reading the same rod first at each set-up, thus making the process a symmetrical one.

If a too hasty reading is taken, the bubble may not be in the exact center of the tube. A few seconds should always be given it to come to rest. When a reasonable amount of care is taken, any error due to small displacements of the bubble, is compensating.

The accurate check, so-called, is made by dividing the sum of the thread readings in the first column of each page by three. The result equals the footing of the backsight (or foresight) column or agrees with it within the number of residual tenths which have been added or discarded at each reading.

Section 7. DESCRIPTION AND LOCATION OF BENCH MARKS.

Note 1. This station mark consists of a copper plate 3" in diameter set flush with the surface in cement and having a horizontal bar across the face.

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

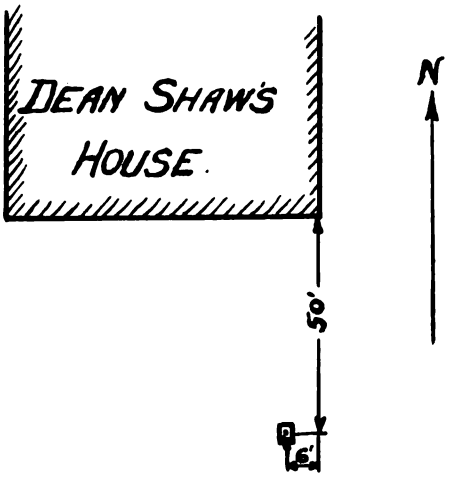
Note 3. This station mark consists of an iron pipe.

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. #1.

In front of Dean Shaw's House 50' south of S. E. corner of Shaw's House and 6' W. of S. E. corner of Said House.

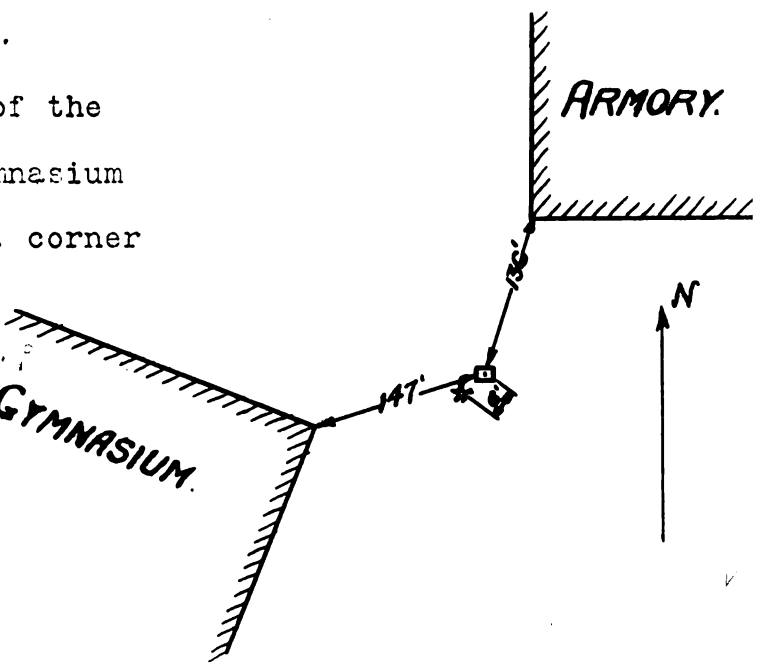
Marked as in Note 4.



B.M. #2.

147' N. E. of the N. E. corner of the new Gymnasium and 136' S. W. of the S. W. corner of the Armory and 6' N. E. of Evergreen Tree.

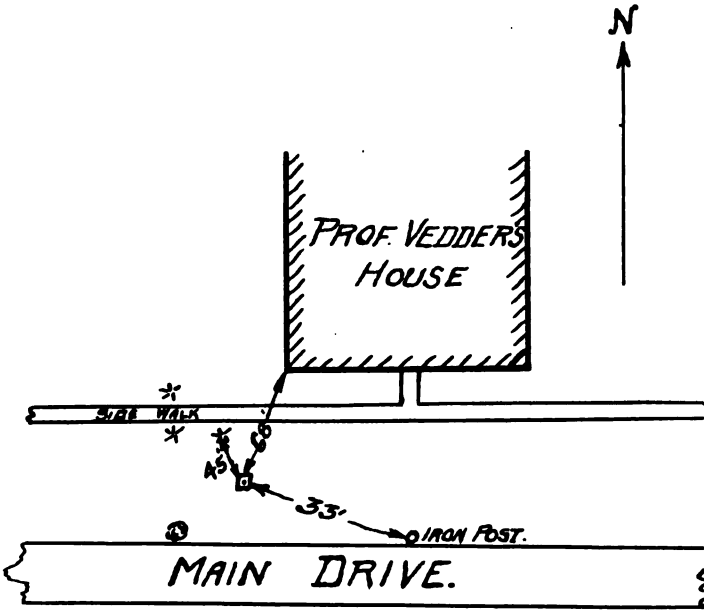
Marked as in Note 4.



B.M. #3.

In front of ~~Prof.~~ Vedder's House. 45' S. E. of Evergreen Tree and 68' S. W. of the S. W. corner of ~~Vedder's~~ House and 33' N. W. of iron hitching post on drive in front of House.

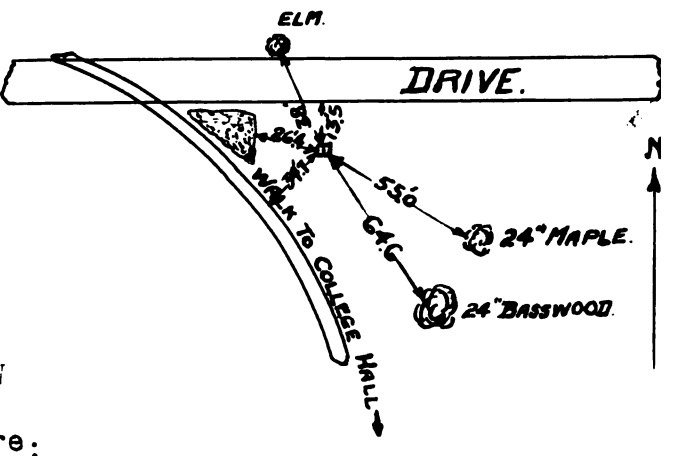
Marked as in Note 4.

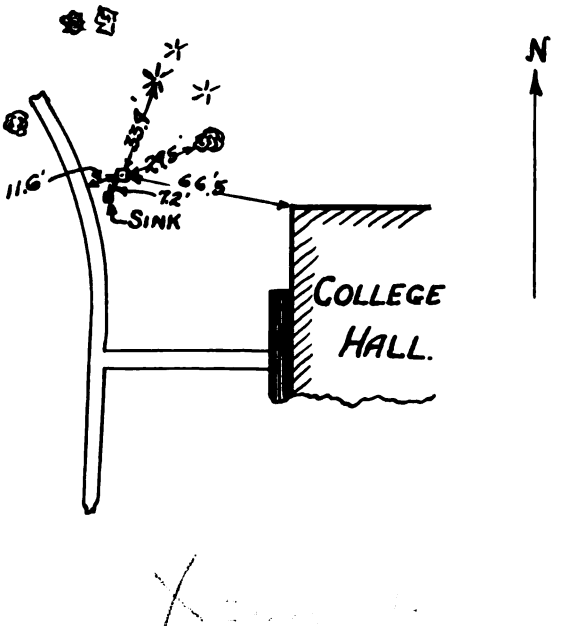


B.M. #4.

In front of Taft House. 13.5' 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 distant 55', 24" diam; and a basswood 24" diam., bearing S40°E distant 64.6'

Marked as in Note 4.





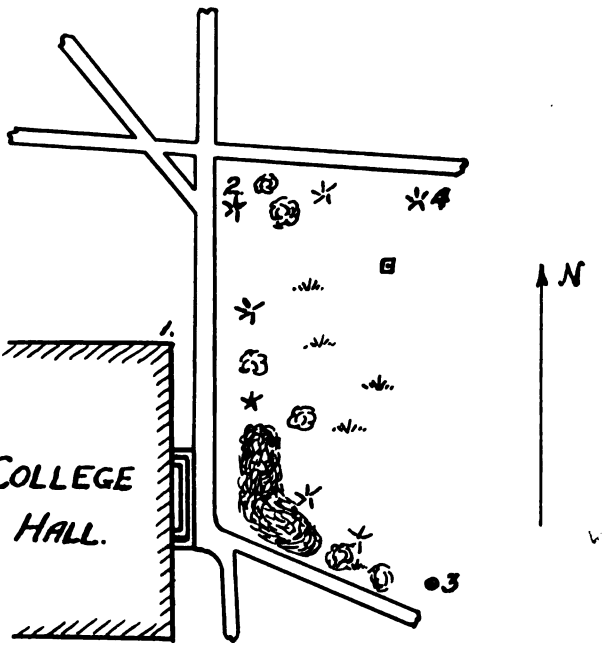
B.M. #5.

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.

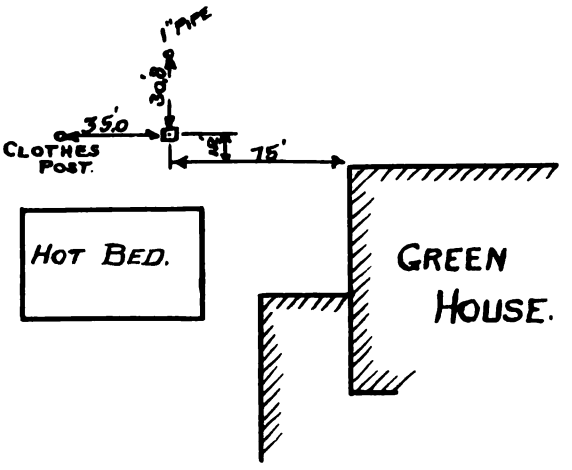
References;-

1. N.E. Corner College Hall S76° 30'W. distance 30.1'; 2. Oak Tree N80°W. distance 30.1'; 3. Fire Hydrant S33°E distance 78.0'; 4. Evergreen N9°E distance 28.7'.

Marked as in Note 4.

B.M. #7.

In lawn North and West of the Greenhouse. 12' N. of N. line of Greenhouse and 75' W. of same.



References:-

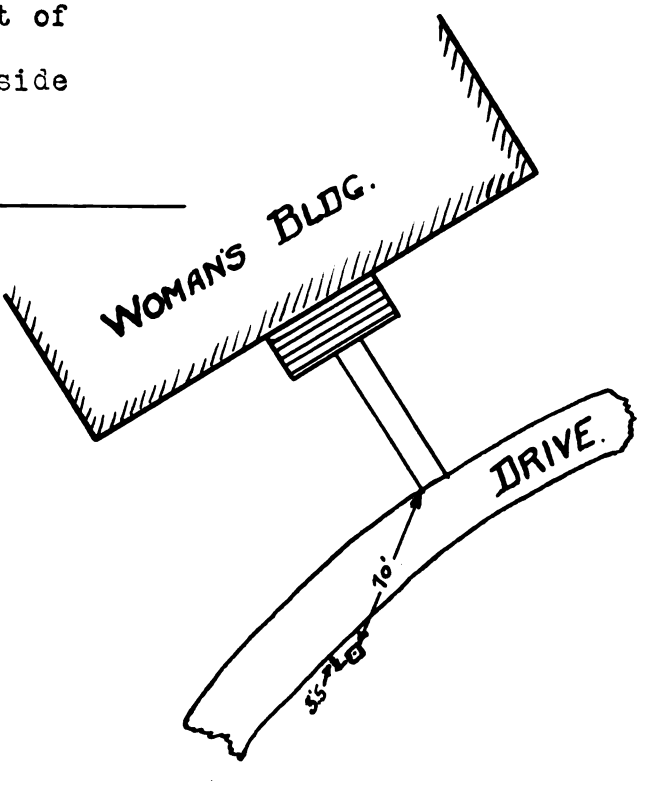
Water plug to N. - 30.8' (1" pipe); Iron clothes post to W.- 35.0'; N.E. Corner Hot-bed Wall - 28.6'.

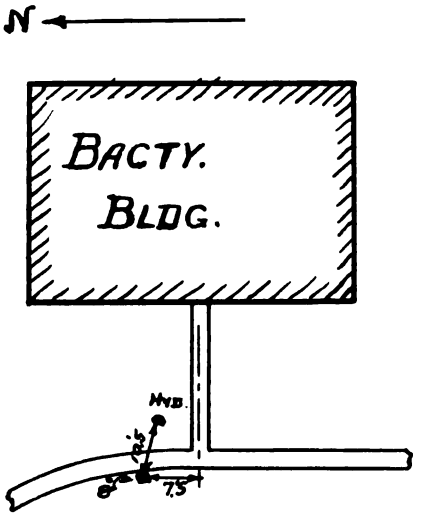
Marked as in Note 4.

B.M. #8.

In front of Woman's Building. 70' N.W. of end of walk in front of building and 35' S.W. of S.W. side of Main Drive.

Marked as in Note 4.





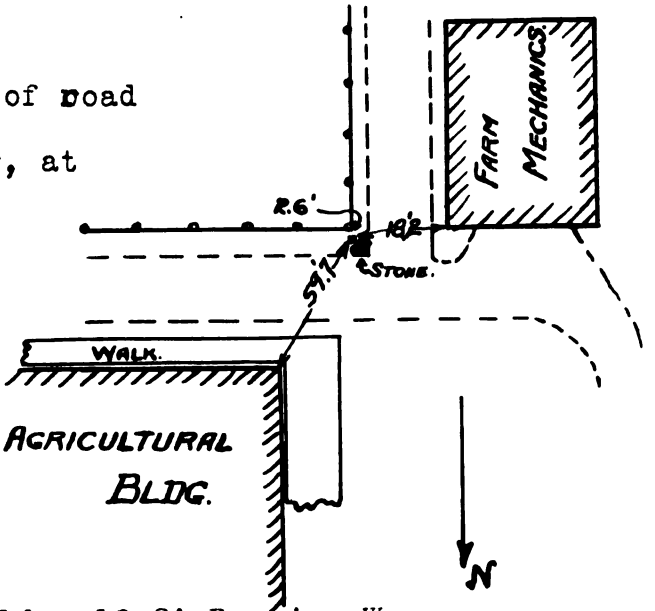
B.M. #9.

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.

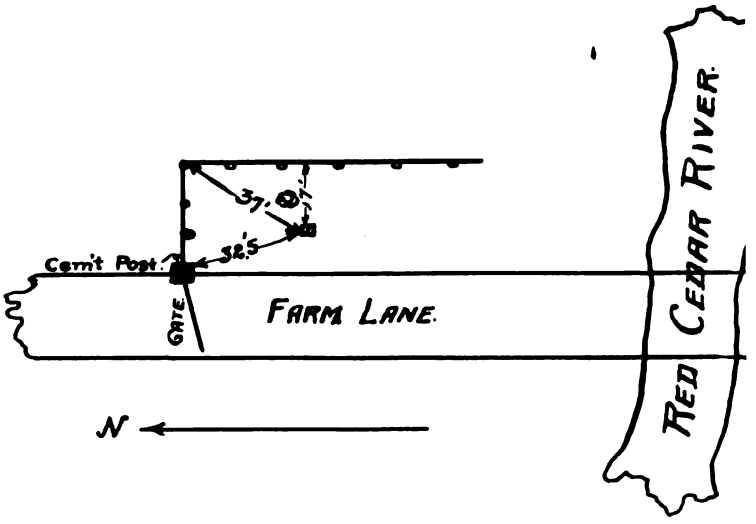
On South side of road passing Agricultural Building, at N.W. corner of pasture lot. 2.6' N.W. of corner post at South side of large boulder 3" beneath the surface.

References:-

N.E. Corner Farm Mech. Bldg. 18.2' Bearing W.

S.W. Corner Agricultural Bldg. bearing N.E. app.

Marked as in Note 4.



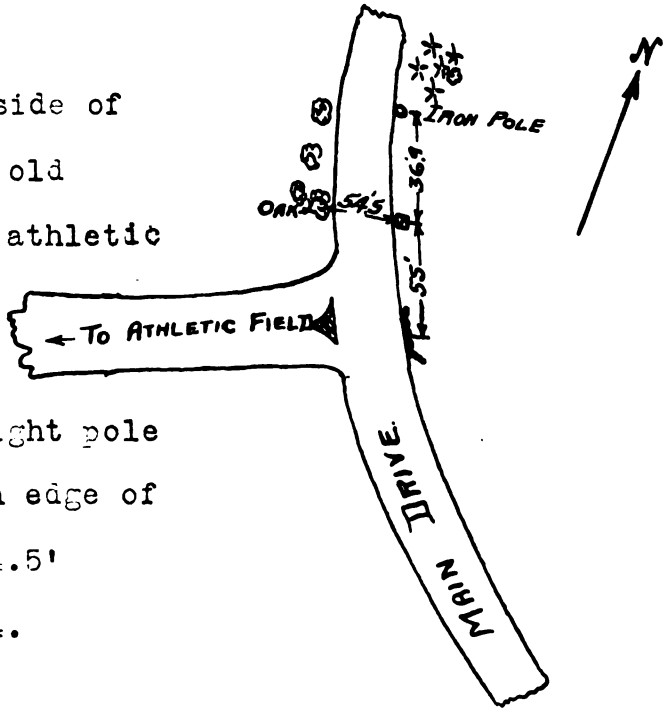
B.M. #13.

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'

Marked as in Note 4.



B.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'

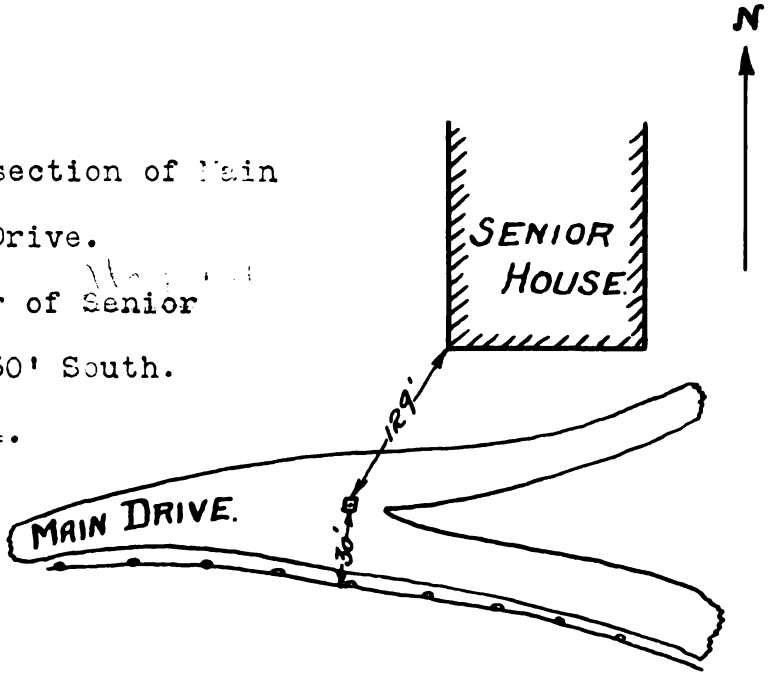
Marked as in Note 4.

B.M. #17.

At intersection of Main Drive and ~~Senior~~ House Drive.

References:- S.W. Corner of Senior ~~House~~ 129' N.E.; Fence 30' South.

Marked as in Note 4.

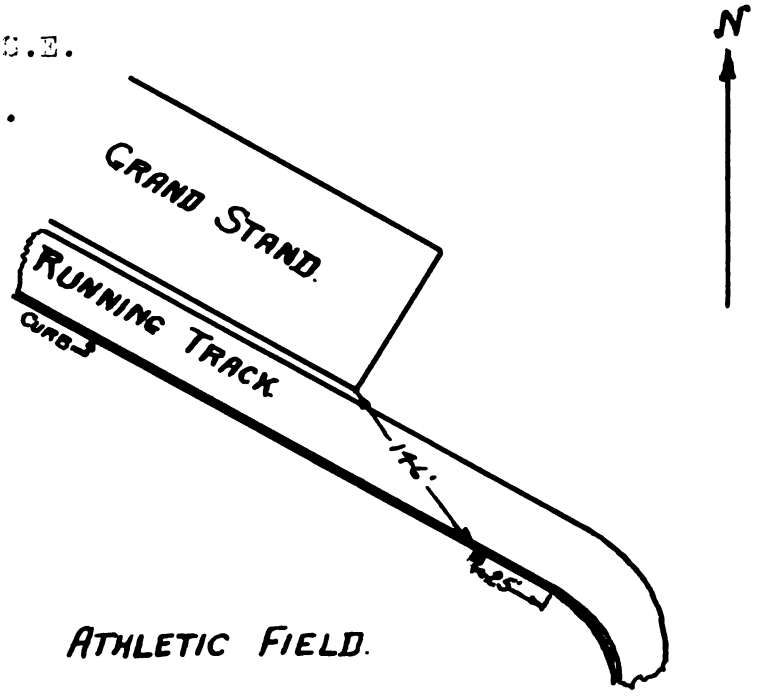


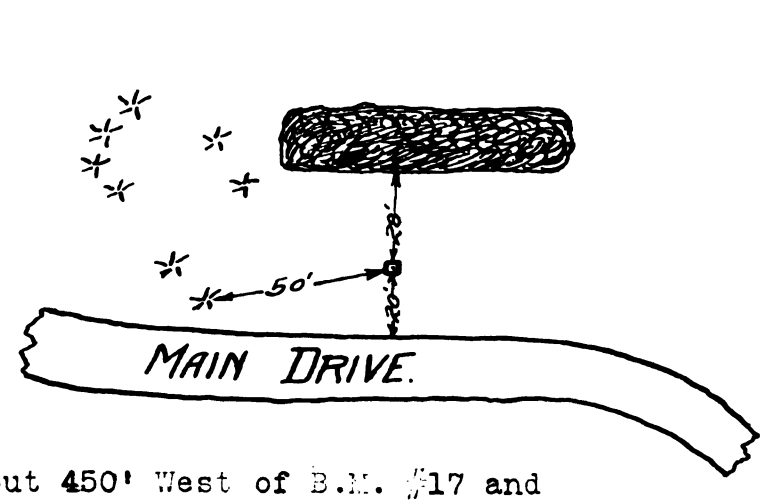
B.M. #18.

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' South; Pine Tree 50' S.W.

Marked as in Note 4.

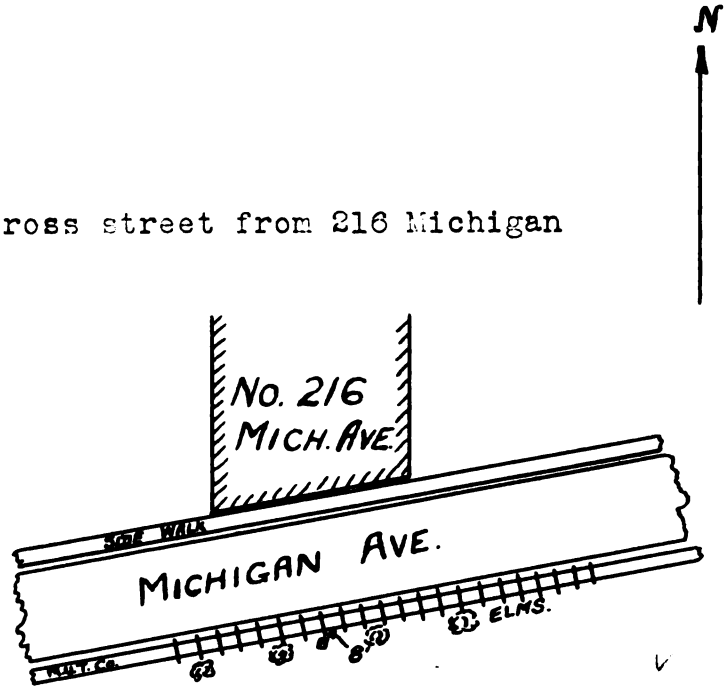
B.M. #20.

In Elm Row across street from 216 Michigan Avenue.

References:-

8' S. of South Rail of M.U.T. Co.

Marked as in Note 4.



B.M. #21.

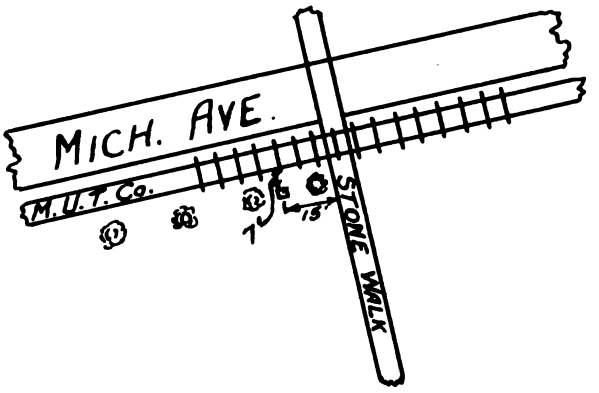
In Elm Row

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.

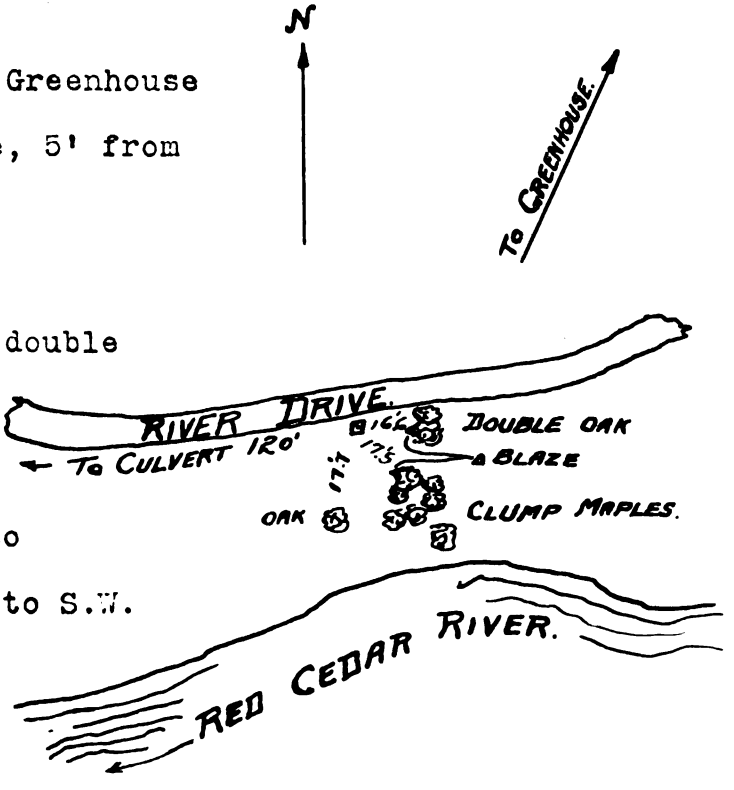
Southwest of Greenhouse

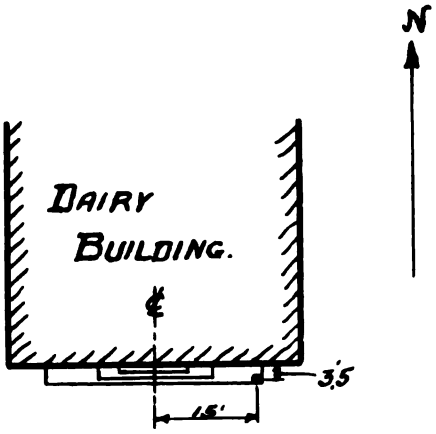
on South side of River Drive, 5' from South edge of Road.

References:-

A Δ on South trunk of double oak tree distant 16.6' to Eastward; A Δ 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.





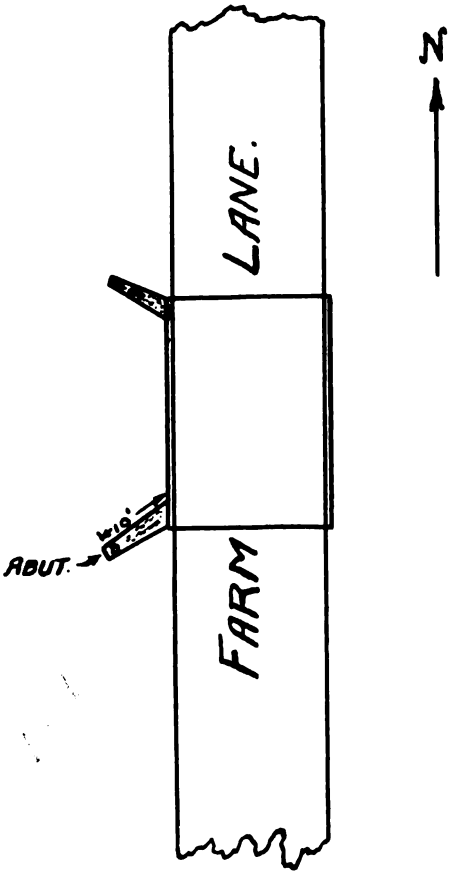
B.M. # D.B.

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.

Reference:-

10' W. of W. side of Bridge.

Marked as in Note 2.

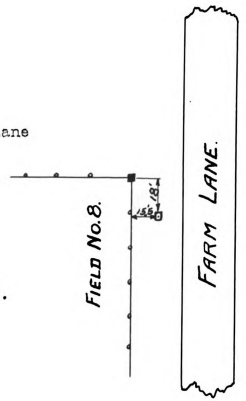
B.M. #N.B.

On West side of Farm Lane about 400' South of Bridge over Red Cedar.

References:-

18' S. of N.E. Corner post of Field 8; 15.5' E. of E. Fence Field 8.

Marked as in Note 4.



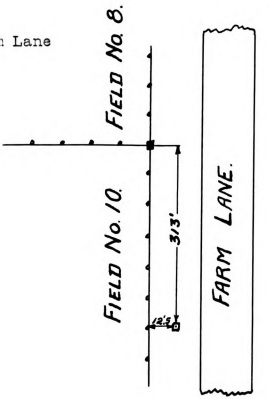
B.M. #S.B.

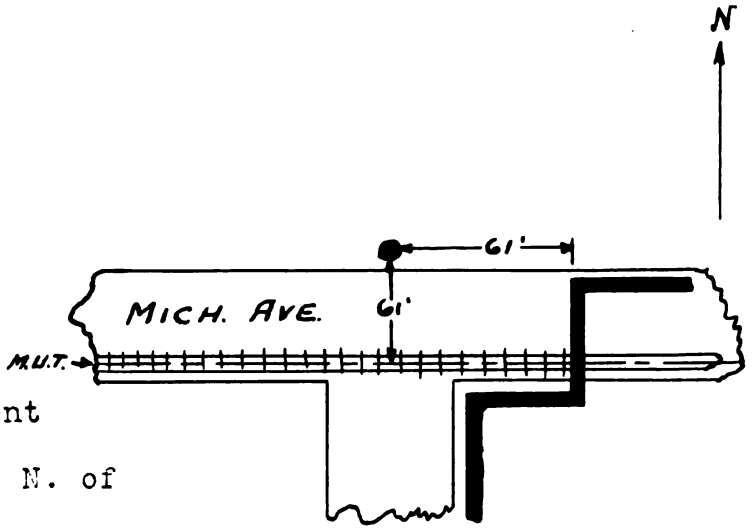
On West side of Farm Lane about 900' South of North Base.

References:-

313' S. of N.E. corner post of Field #10; 12.5' E. of E. Fence Field #10.

Marked as in Note 4.

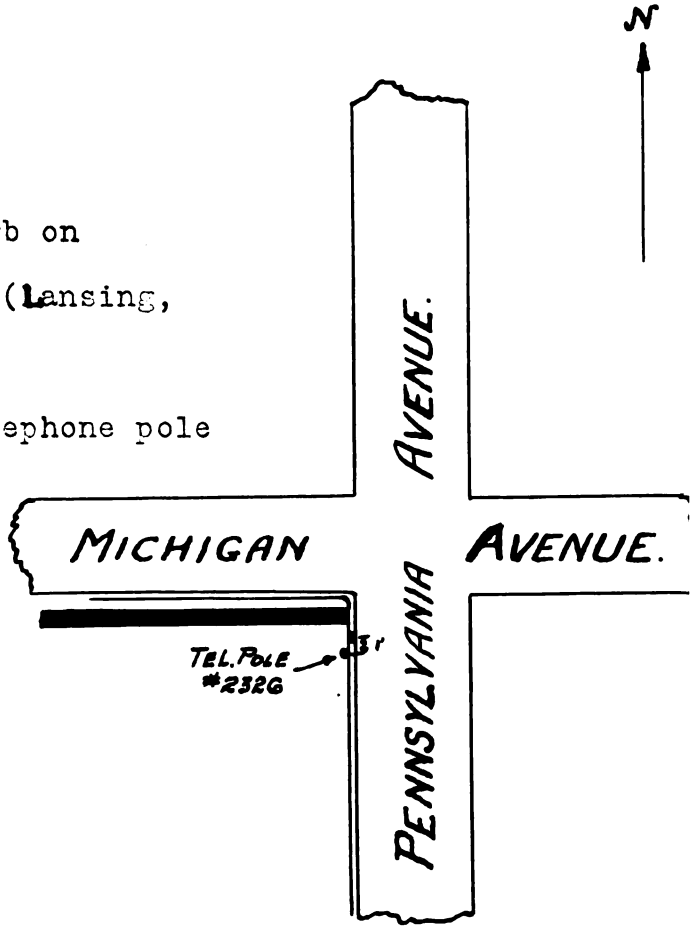




B.M. #GOV. B.M. HAR. AVE.

Across the road from and nearly in front of the "White Elephant" 33' N. of the center line of Michigan Ave., 61' N. of center line of street car track; 61' W. of sidewalk crossing 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 Pennsylvania Ave. (Lansing, Mich.).

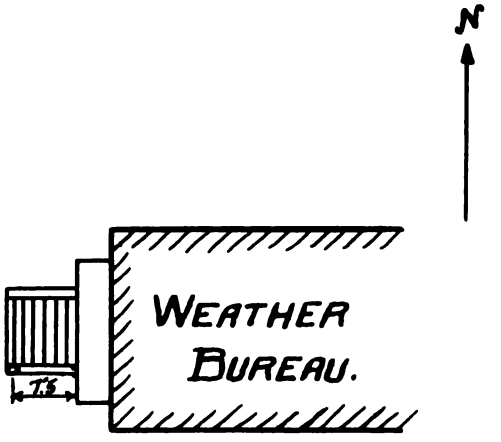
References:- 1' N. of Telephone pole #2326 on curb.

Marked as in Note 2.

B.M. #W.B.

7.5' West of S.W. corner of porch on weather Bureau, Copper disc cemented on top of step.

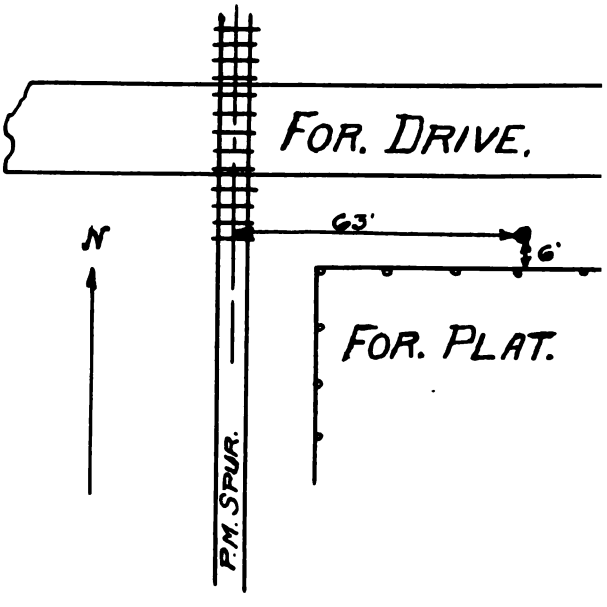
Marked as in Note 1.



B.M. #FOR.

2" Gaspipe 6' East of East fence Forestry Plat and 63' S. of center line of P. M. Spur.

Marked as in Note 3.

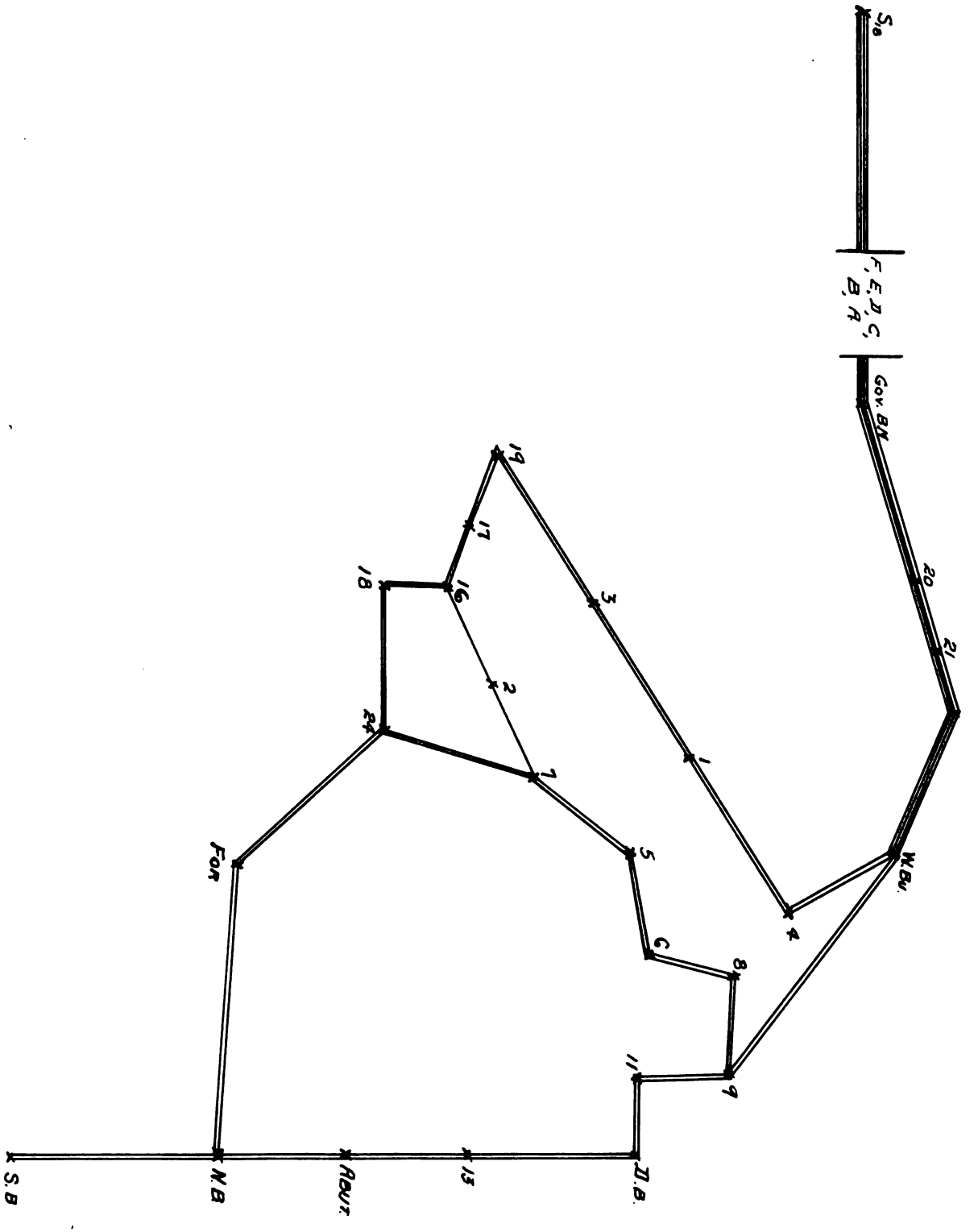


B.M. $\frac{4}{S}_{18}$.

Situated 34' south of the Northeast corner of the 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, Mich.

SKETCH OF LEVEL NET.



Section 8. COMPUTATIONS.

The corrections used in these computations were taken from tables given on pages 27 and 28 of the U.S.C. & G.S. Special Publication #18 titled "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 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.

COMPUTATION OF PRECISE LEVELS

B.M.'S	FORWARD OR BACK-WARD	NO. OF STA-TIONS	SUM OF ROD INTERVALS.	DISTANCE	ROD INTERVALS ΣB-ΣF	MEAN ROD READINGS. ΣB	ΣF	APPROXIMATE DIFF. OF ELEV.	MEAN TEMP. OF RODS.
			m.m.	K.m.s.	m.m.	M.	M.	M.	
S_{18} - W.B	F	31	24811	4.96	+39	49813.6	47523.9	+2.2897	10
	B	34	24855	4.97	-205	54742.0	57069.6	-2.3276	13
	B	37	25165	5.03	+17	59995.1	62294.1	-2.2990	13
	F	34	24809	4.96	-13	57603.9	55295.6	+2.3083	13
S_{18} - F	F	4	2440	.49	-14	9169.7	4593.0	+4.5767	15
	B	4	2435	.49	-47	13471	8916.0	-4.5689	13
F-E	F	5	3840	.77	+18	6619.0	10770.6	-4.1516	13
	B	5	3837	.77	-13	10806.0	6650.3	+4.1557	13
E-D	F	2	1959	.39	-5	3171.7	3965.4	-.7937	13
	B	2	1957	.39	-181	3951.4	3156.0	+.7954	13
D-C	F	4	3186	.64	+72	7753.0	8042.0	-.2890	13
	B	4	3184	.64	+66	7939.1	7647.0	-.2921	13
C-B	F	4	3441	.68	-243	3617.3	8271.1	-4.6588	12
	B	5	3446	.68	-56	10641.4	5983.4	+4.6580	13
B-A	F	4	3339	.67	+191	6591.4	6279.7	+.3117	12
	B	4	3372	.67	+46	6078.4	6388.0	-.3096	13

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.	METERS.		METERS.		mm.
+.4	0			.1	+2.2902		+2.3065		-28.4
+.7	-.1			.1	-2.3281				
-.1	0			.1	-2.2990				
+.3	0			.1	+2.3087				
		NONE - NEW RODS ASSUMED OK.	NOT LARGE ENOUGH TO APPLY.						
+.1	0			.2	+4.5770		+4.5730		-8.0
-.3	0			.2	-4.5690				
0	0			.2	-4.1518		-4.1538		+4.0
-.1	0			.2	+4.1558				
0	0			0	-0.7937		-0.7950		+2.6
+.9	-.1			0	+0.7963				
-.6	0			0	-0.2896		-0.2905		+1.9
-.5	0			0	+0.2915				
+1.4	-.1			.2	-4.6572		-4.6578		+1.3
+.3	0			.2	+4.6585				
-.7	+.1			0	+0.3110		+0.3105		-1.0
-.4	0			0	-0.3100				

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 ΣB	Mean Rod Readings ΣF	Approximate Diff. of Elev.	Mean Temp. of Rods.
			mm.	Kms.	mm.	M.	M.	M.	
A-Gov.B.M.	F	2	2137	.43	-3	3968.0	2663.3	+1.3047	12
	B	3	2223	.44	-109	4856.7	6166.3	-1.3096	12
Gov.B.M.-20	F	4	2290	.45	-64	8750.7	5162.1	+3.5886	12
	B	5	2659	.53	+251	5998.7	9591.4	-3.5927	12
20-21.	F	2	883	.18	+47	3070.7	3048.0	+.0227	12
	B	2	883	.18	+69	2981.0	3002.7	-.0217	12
21-W.B.	F.	3	1264	.25	-40	4897.4	2500.4	+2.3970	12
	B.	3	1264	.25	-106	2395.3	4793.0	-2.3977	14

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.	METERS.		METERS.		mm.
-.3	0			0	+1.3	044	+1.3	070	+5.1
+.2	-.1			0	-1.3	095			
+.4	0			.1	+3.5	891	+3.5	909	+3.5
+.1	+.1			.1	-3.5	926			
-.1	0			0	+0.0	226	+0.0	224	-0.5
-.4	0			0	-0.0	221			
+.1	0			.1	+2.3	972	+2.3	974	+0.5
+.2	-.1			.1	-2.3	977			

ASSUMED ORIG. NEW RODS NONE - NOT LARGE ENOUGH TO APPLY

COMPUTATION OF PRECISE LEVELS

B.M's.	FORWARD OR BACK-WARD.	NO. OF STA-TIONS.	SUM OF ROD INTERVALS	DISTANCE	ROD INTERVALS ΣB-ΣF	MEAN ROD READINGS ΣB	MEAN ROD READINGS ΣF	APPROXIMATE DIFF. OF ELEV	MEAN TEMP. OF RODS.
			mm.	Kms.	mm.	M.	M.	M.	
W.B.-9.	F	6	3059	.61	-15	8314.7	11818.1	-3.5034	12
	B	5	2726	.55	-74	8253.0	4748.4	+3.5046	18
9-11	F	1	929	.19	+31	2955.3	2101.7	+0.8536	15
	B	2	922	.19	-104	3769.3	4627.7	-0.8584	17
11-W.B	F	2	798	.16	+60	3533.3	2705.3	+0.8280	16
	B	2	798	.16	+72	2864.4	3693.3	-0.8289	18
W.B.-13	F	2	1725	.25	-119	1524.7	4967.0	-3.4423	15
	B	2	1738	.25	-94	4717.0	1271.3	+3.4457	18
13-Abut.	F	1	673	.13	-121	0280.0	1525.7	-1.2457	14
	B	2	675	.13	+73	3557.0	2307.7	+1.2493	18
Abut-NB	F	3	713	.14	-139	8296.7	2013.0	+6.2837	14
	B	4	712	.14	+288	2907.7	9190.0	-6.2823	14
NB-S.B	F	2	1447	.29	+36	3692.7	3075.7	+.6170	14
	B	2	1441	.29	-253	3038.0	3655.7	-.6177	14

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.	METERS.	METERS.	mm.
0	0			.1	-3.5035	-3.5040	+1.2
-.2	-.1			.2	+3.5045		
-.1	0	O.K.	APPLY	.1	+0.8536	+0.8559	+4.6
+.2	-.1			.1	-0.8582		
-.1	+.1	ASSUMED	TO	.1	+0.8281	+0.8286	+1.1
-.1	+.1			.1	-0.8290		
+.5	-.1		ENOUGH	.2	-3.4429	-3.4445	+3.1
+.2	-.1	RODS		.2	+3.4460		
+.2	-.1		LARGE	.1	-1.2455	-1.2474	+3.9
-.1	+.1	NEW		.1	+1.2494		
+.1	-.1	-		.3	+6.2840	+6.2834	-1.3
-.4	+.3		NOT	.3	-6.2827		
0	0	NONE		.1	+0.6171	+0.6172	+0.3
+.7	-.3			.1	-0.6174		

COMPUTATION OF PRECISE LEVELS

B.M's.	FORWARD OR BACK-WARD	NO. OF STA-TIONS.	SUM OF ROD INTERVALS.	DISTANCE	ROD INTERVALS ΣB-ΣF	MEAN ROD READINGS. ΣB	ΣF	APPROXIMATE DIFF. OF ELEV	MEAN TEMP. OF RODS.
			m.m.	Kms.	m.m.	M.	M.	M.	
9-8	F	1	800	.16	-40	0791.3	2180.0	-1.3887	28
	B	1	804	.16	+80	2173.0	0785.0	+1.3880	27
8-6	F	2	697	.14	+59	4321.0	0884.7	+3.4363	29
	B	2	689	.14	-47	1080.7	4516.4	-3.4357	27
6-5	F	1	341	.07	-33	1314.0	3088.7	-1.7747	29
	B	1	322	.06	-38	3018.0	1243.0	+1.7750	28
5-7	F	2	886	.18	+2	2774.3	3535.0	-0.7607	29
	B	2	910	.18	-14	2944.0	2182.0	+0.7620	28
7-24	F	3	937	.19	-141	3460.7	8126.0	-4.6653	31
	B	3	534	.11	+18	7341.0	2675.0	+4.6660	27
24-18	F	3	1710	.34	0	4709.7	4223.7	+0.4860	15
	B	3	1710	.34	-2	4198.0	4684.7	-0.4867	14
18-16	F	3	852	.17	+108	8003.0	2686.0	+5.3170	29
	B	3	847	.17	-153	2233.7	7550.0	-5.3163	27

COMPUTATION OF PRECISE LEVELS

CORRECTIONS.					DIFFERENCE OF ELEVATION		
CURVATURE AND REFRAC-TION.	LEVEL ERROR.	INDEX ERROR.	LENGTH OF ROD.	TEMP. OF ROD.	EACH LINE	MEAN.	DIVER-GENCE B-F.
mm.	mm.	mm.	mm.	mm.	METERS.	METERS.	mm.
+.1	0			.1	-1.3885	-1.3882	-0.7
-.4	+.1			.1	+1.3878		
-.1	+.1			.4	+3.4367	+3.4364	-0.7
0	0			.3	-3.4360		
0	0			.1	-1.7748	-1.7750	+0.3
0	0			.1	+1.7751		
0	0			.1	-0.7608	-0.7614	+1.2
-.1	0			.1	+0.7620		
0	-.1			.5	-4.6657	-4.6660	+0.6
-.1	0			.4	+4.6663		
+.3	0			.1	+0.4864	+0.4868	+0.7
-.3	0			.1	-0.4871		
-.2	+.1			.6	+5.3165	+5.3166	+0.3
+.1	-.1			.5	-5.3168		

O.K. ASSUMED TO APPLY. NEW RODS - NONE NOT LARGE ENOUGH

COMPUTATION OF PRECISE LEVELS

B.M's.	FORWARD OF BACK-WARD	NO. OF STA-TIONS.	SUM OF ROD INTERVALS	DISTANCE	ROD INTERVALS ΣB-ΣF	MEAN ROD READINGS. ΣB	ΣF	APPROXIMATE DIFF. OF ELEV.	MEAN TEMP. OF RODS.
			mm.	Kms.	mm.	M.	M.	M	
16-17	F	2	617	.12	-96	5426.0	1239.0	+4.1870	21
	B	2	614	.12	+122	1406.6	5593.0	-4.1864	26
17-19	F	1	596	.12	-34	1772.7	1686.7	+0.0860	21
	B	1	597	.12	-67	1644.7	1730.0	-0.0853	26
19-3	F	3	1152	.23	+62	3566.1	5527.3	-1.9612	20
	B	3	1155	.23	-31	6551.0	4591.1	+1.9599	26
3-1	F	2	764	.15	-10	3167.7	3625.7	-0.4580	20
	B	2	765	.15	-23	3375.7	2918.0	+0.4577	25
1-4	F	2	672	.13	-20	1292.0	4555.0	-3.2630	20
	B	2	671	.13	+65	4674.4	1411.7	+3.2627	25
4-W.B.	F	3	1050	.21	+16	5552.3	1297.6	+4.2547	22
	B	3	1054	.21	-80	1484.7	5740.7	-4.2560	25

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.	METERS.	METERS.	mm.
+.1	-.1			.3	+4.1873	+4.1870	-0.5
-.1	+.1			.4	-4.1868		
+.1	0			0	+0.0861	+0.0857	-0.8
+.1	-.1			0	-0.0853		
-.2	+.1			.2	-1.9615	-1.9608	+1.3
+.1	0			.2	+1.9602		
0	0			.1	-0.4581	-0.4580	+0.2
+.1	0			.1	+0.4579		
+.1	0			.2	-3.2633	-3.2632	+0.3
-.1	+.1			.3	+3.2630		
-.1	0			.4	+4.2550	+4.2556	+1.2
+.3	-.1			.4	-4.2562		

ASSUMED OK.
RODS NEW - NONE
TO APPLY.
ENOUGH
LARGE
NOT

COMPUTATION OF PRECISE LEVELS.

B. M's.	Forward or Back-ward.	No. of Sta-tions	Sum of Rod Intervals	Distance	Rod Intervals ΣB-ΣF	Mean Rod Readings.		Approximate Diff. of Elev.	Mean Temp. of Rods.
						ΣB.	ΣF		
			mm.	Kms.	mm	M	M	M.	
24-For.	F	5	2319	.46	+71	10799.0	5173.4	+5.6256	14
	B	5	2315	.46	+11	4896.7	10524.6	-5.6279	15
For.-N.B.	F	4	2717	.54	-57	8164.7	5366.3	+2.7984	14
	B	4	2715	.54	-41	5957.1	8755.4	-2.7983	15
7-2	F	2	1224	.24	-22	2482.7	2839.7	-0.3570	27
	~~B~~								
2-16	F	2	1028	.21	-40	3685.6	2188.4	+1.4972	27
	~~B~~								

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.
mm.	mm.	mm.	mm.	mm.	METERS.		METERS.		mm.
-.1	+.1			.3	+5.6259		+5.6271		+2.4
0	0			.4	-5.6283				
+.4	-.1			.2	+2.7989		+2.7984		-1.0
+.6	0			.2	-2.7979				
+.3	0			0	-0.3567		-0.3567		0
+.3	0			.1	+1.4976		+1.4976		0

NONE - NEW RODS ASSUMED OK.

NOT LARGE ENOUGH TO APPLY.

ADJUSTMENT OF CIRCUIT

LINE	DISTANCE	MEAN DIFFERENCE		CORRECTION	CORRECTED DIFFERENCE	
		+	−		+	−
S_{18}-W.B.	4.98 Km	2.3065		ACCEPTED MEAN - 4 RUNNINGS		
		INTERMEDIATE B.Ms.		- 2 RUNNINGS ONLY.		
S_{18}-F	.49	4.5730		+.3	4.5733	
F-E	.77		4.1538	+.4		4.1534
E-II	.39		0.7950	+.2		0.7948
II-C	.64		0.2906	+.3		0.2903
C-B	.68		4.6578	+.3		4.6575
B-A	.67	0.3105		+.3	0.3108	
A-Gov.BM	.44	1.3070		+.2	1.3072	
Gov.BM-20	.44	3.5909		+.2	3.5911	
20-21	.16	0.0224		+.1	0.0225	
21-W.B	.25	2.3974		+.2	2.3976	
	4.93	12.2012	9.8972	2.5	12.2075	9.8960
		-9.8972			-9.8960	
		+2.3040			+2.3065	
		+2.3065			CHECK	
		ERROR 2.5				

FINAL ELEVATION

B.M's.	ELEVATION (METERS)	ELEVATION (FEET)
S_{18}	258.968	849.631
W.B.	261.2745	857.197
S_{18}	258.968	849.631
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
W.B.	261.2745	857.197

ADJUSTMENT OF CIRCUIT

LINE	DISTANCE	MEAN DIFFERENCE		CORRECTION	CORRECTED DIFFERENCE	
		+	−		+	−
W.B.-9.	.58		3.5040	+.6		3.5034
9-11	.19	0.8559		+.2	0.8561	
11-D.B.	.16	0.8286		+.2	0.8288	
D.B-13	.25		3.4445	+.2		3.4443
13-Abut.	.13		1.2474	+.1		1.2473
Abut-NB	.14	6.2834		+.1	6.2835	
NB.-SB	.29	0.6172			0.6172	
NB-For	.54		2.7984	+.5		2.7979
For-24	.46		5.6271	+.5		5.6266
24-18	.34	0.4868		+.3	0.4871	
18-16	.17	5.3166		+.2	5.3168	
16-17	.12	4.1870		+.1	4.1871	
17-19	.12	0.0857		+.1	0.0858	
19-3	.23		1.9608	+.2		1.9606
3-1	.15		0.4580	+.2		0.4578
1-4	.13		3.2632	+.1		3.2631
4-W.B.	.21	4.2556		+.2	4.2558	
	3.92	22.2996	22.3034	3.8	22.3010	22.3010
			+22.2996		CHECK	
		ERROR	3.8			

FINAL ELEVATION

B.M's.	ELEVATION (METERS)	ELEVATION (FEET)
W. Bu.	261.2745	857.197
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	830.412
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
W. Bu.	261.2745	857.197 CHECK

ADJUSTMENT OF CIRCUIT

LINE	DISTANCE	MEAN DIFFERENCE		CORRECTION	CORRECTED DIFFERENCE	
		+	−		+	−
9-24	.69		5.1477			
9-8	.16		1.3882	+1.5		1.3867
8-6	.14	3.4364		+1.3	3.4377	
6-5	.06		1.7750	+ .6		1.7744
5-7	.18		0.7614	+1.7		0.7597
7-24	.15		4.6660	+ 1.4		4.6646
	.69	3.4364	8.5906	6.5	3.4377	-8.5854
			+3.4364			+3.4377
			-5.1542			-5.1477
			-5.1477			CHECK
			ERROR 6.5			
7-16	.45	1.1393				
7-2	.24		0.3567	-.8		0.3575
2-16	.21	1.4976		-.8	1.4968	
	.45	1.4976	0.3567	-1.6	1.4968	0.3575
		-0.3567			-0.3575	
		+1.1409			+1.1393	CHECK.
		+1.1393				
		ERROR -1.6				

FINAL ELEVATION

B.M's.	ELEVATION (METERS)	ELEVATION (FEET)
9	257.7711	845.704
8	256.3844	841.153
6	259.8221	852.433
5	258.0477	846.609
7	257.2880	844.119
24	252.6234	828.814
7	257.2880	844.119
2	256.9305	842.945
16	258.4273	847.856

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