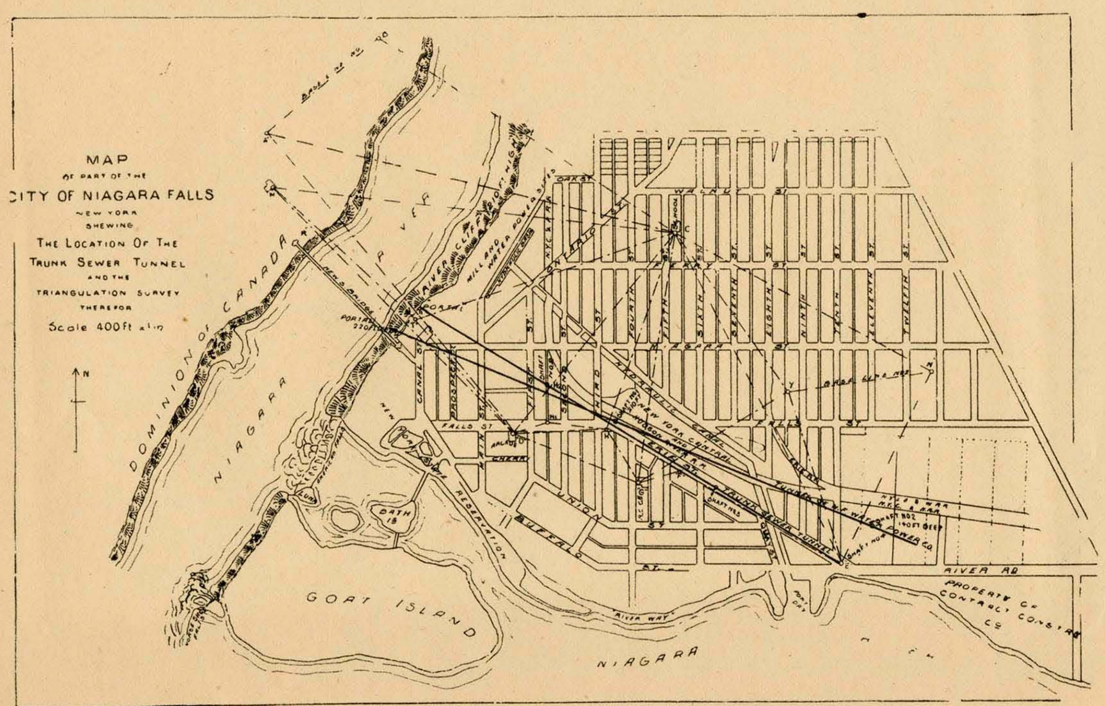
MAP
OF PART OF THE
CITY OF NIAGARA FALLS
NEW YORK
SHEWING
THE LOCATION OF THE
TRUNK SEWER TUNNEL
AND THE
TRIANGULATION SURVEY
THEREFOR
Scale 400ft =1 in
N
DOMINION OF CANADA
NIAGARA
RIVER
GOAT ISLAND
NIAGARA
RIVER RD
WALNUT ST
FERRY
NIAGARA
FALLS ST
UNION
BUFFALO
RESERVATION
TRUNK SEWER TUNNEL
NEW YORK CENTRAL
ERIE ST
HYDRAULIC CANAL
SHAFT NO 2
140 FT DEEP
PROPERTY OF
CONTRACT. CONSTR
Co

Fig. 7.

Niagara

A TRIANGULATION SURVEY

For a Tunnel at Niagara.

By C. H. MITCHELL, Grad. S.P.S.

1892

MR. PRESIDENT AND GENTLEMEN :

Young engineers are generally led to look upon a triangulation survey as something belonging to the highest sphere of mathematical surveying and practice. A so-called "triangulation survey" is generally shadowed by spherical and spheroidal trigonometry, calculus, and least squares in abundance, with the accompanying shades of "single second" and micrometer transits, heliographs, long-distance signals, "sixty-mile sights," and operations in high places. We are too often liable to look upon such as the business of a few government officials, who are the soul of mystery itself, and who take no thought for the common order of things. In all this we forget that similar operations, involving similar practices on a reduced scale, are quite frequently carried on by private and public corporations for widely different objects from those which we usually attribute to such surveys.

Very few graduates (and the writer speaks from personal knowledge), when they leave college, have any idea of being for some years to come engaged in field operations on such a large scale as is required in a triangulation of even an ordinary kind. It was with such beliefs, at any rate, that three graduates of '92 (of which the writer was one) left their alma mater. It was with such beliefs still lingering that they were suddenly called on to execute a triangulation survey, on a small scale, for a tunnel at Niagara Falls.

To make a short explanation, this tunnel, as designed, was to be used as a trunk sewer to dispose of the sewage of a district of the city of Niagara Falls, N.Y., situated near the river, about a mile above the Falls. Fig. 7. The original intention was to sewer this district into the "Niagara Falls Water Power Company's" tunnel (at present under construction) by means of a vertical or inclined shaft from the surface. This scheme being abandoned for certain reasons, the city decided to have a trunk sewer built from a point near Port Day, and continuing through the city to empty into the gorge below the Falls, near the new Suspension Bridge.

It was finally decided to build a tunnel through the rock of a size of 8′ x 8′, and at a mean depth below the surface of about sixty feet. As this tunnel would be a mile long and pass under the heart of the city, a triangulation survey for it must needs be made, of a sufficiently accurate character as to enable the centre lines to be located and produced from each of the three shafts.

In a paper of this kind, it is not intended to describe in detail this proposed tunnel; the preliminary survey being the object. A few points, however, must be introduced, so as to convey a general idea of the nature of the work.

The tunnel, as proposed, was to pass under Erie Street, and parallel thereto, and continue in a straight line till it emerged at the cliff in the gorge. There are three shafts, and it is from these, together with the opening at the "portal" in the gorge, that the centre line is to be run. The running of these lines is, of course, the most delicate operation in all the surveys, and must be exceedingly accurate. There are two ways for dangerous errors to creep in: first, in the original survey, *i.e.*, in laying down the centre line of the tunnel *on the surface*, by getting the points in the several shafts in line; and, second, having the shafts sunk, and the tunnel under construction, the running of the centre line by means of plumb bobs in the shafts, etc.

Now, to particularize. This paper is to deal with the survey above ground, or the triangulation necessary to place the lines on the surface.

The first thing to be done was, naturally, a general reconnaissance of the "ground." This meant about three days "knocking about" the city and suburbs, and thinking out the ways and means, the location of survey stations, and of an economical base line. This proceeding is somewhat harder than would be supposed, as so many contingencies and obstacles are met with. I will not enter into an account of the trials and tribulations we encountered and overcame at this juncture of the work; suffice it to say that we had read a number of angles, and discarded them before we finally decided upon the arrangement of the present survey.

As for the base line, it must receive considerable attention. In this survey we had two base lines—No. 1 being situated on high level ground on the Canadian side of the river, and No. 2 on a very convenient stretch of level meadow land, in the present eastern suburbs (cut up into city lots, and selling at $30 per front foot). We made No. 2 our primary base, and used No. 1 to check on. Each line was about 1,475 feet long. No. 1 ran over very gentle undulations of grass land, having a total fall of about six feet. The line was run out with a transit and stakes 2″x 2″x 18″ (oak) were driven in convenient places, in depressions or summits on the line; the distances between these stakes ranging from 30 to 99 feet, so that they could be measured with a hundred-foot tape. Each stake was driven very solidly to within an inch of the surface, and had a copper tack with a well-defined head driven in it on top. The end stakes consisted of large oak stakes driven well down, and firmly supported by smaller ones; the copper tack in these having a cross cut in the head. All the stakes being driven (21 in case of base No. 1), levels were taken on each. Then commenced the actual chainage. The tape used was a hundred foot aluminium, tested and compared before using; it was graduated only in feet. In conjunction with this was used a small steel tape reading to tenths, hundreths, and thousandths. At each measurement of the line the temperature was read. A scale was attached to the tape and every reading was taken with a pull of sixteen pounds, for which we had the catenary correction to apply. In taking the first reading, *i.e.*, from stake 0 to stake 1, the distance was measured between the centre or cross in the tack in stake 0 and the south *edge* of the tack in No. 1; and the next was between the south edge of tack in No. 1 and that of No. 2, and so on, ending at the centre of the tack in the end station. In this way, ten measurements of the whole line were taken. Two men held the tape; one having the scale; while a third did the reading and took the notes.

In the office the ten readings for each short distance were first averaged; next, each average distance was corrected and reduced for temperature correction to the standard of 20° Centigrade, the correction being ·0013 feet per 1° C. per 100 feet, which is for steel—aluminium being considered the same. Then, again, each distance, where it was necessary according to the field notes, was treated to the catenary correction for a pull of sixteen pounds. All the corrections being applied, the result was (in the case of base No. 1) a set of twenty distances, comprising the whole line. These distances were in themselves the hypothenuses of the respective vertical right-angled triangles, of which the differences in elevation between the stations formed the perpendiculars. By solving these triangles, the *horizontal* distances between each two tacks were obtained, and hence the whole base line. The measurement of No. 2 base line was essentially the same as that for No. 1, except that we made an improvement by driving the stakes at distances apart of between 99 and 100 feet, so that every distance read 99 feet and a fraction, thus shortening the work.

Now, to turn our attention to the reading of the angles at the respective stations. We had, of course, four base-line stations. Two stations, very centrally situated and on elevated points, formed our principal places of operation. One of these, station C, was in the belfry of a large city school—a stone building with a heavy tower—and the other, station D, was on the top of a large brick chimney of a prominent business block. Stations H and F were so located as to be on a line parallel to the proposed tunnel. Station E was located at a convenient point near the intersection of Erie and Buffalo Streets, and as nearly in the line of H F as could be judged roughly—being unable to sight between them. These last three stations consisted of 18″ oak stakes, driven to about 6″ below the surface of the ground, and well supported by other stakes. These were then covered by a flat stone, macadam, and earth, so as not to be disturbed, but as to be easily accessible to "set up" over. Station G was the extreme top of the cross on the R. C. Church spire, and was used as a reference point only. This point was sufficiently stable to be relied on at any time, except in high wind. Station T was located on the verge of the cliff at the river, and consisted of a cross cut in the stone masonry of the foundation of a gas tank at the gas works. Station M was a point in the gable of a stone residence on the Canadian bank, and was used only as a reference point.

From Station	A	could	be seen	C and D.
"	B	"	"	C and A.
"	C	"	"	A, B, D, T, G, F, E, Y, Z, M.
"	D	"	"	A, M, C, G, H.
"	H	"	"	F, D, and G.
"	F	"	"	C, G, and H.
"	T	"	"	M and C.
"	E	"	"	C, G, Y, Z.
"	Y	"	"	C, E, G, Z.
"	Z	"	"	Y, C, E.

The above table, with the accompanying "angle sheet," will serve to show what angles were read. (See table, Angle and Distance Sheet, pages 27 and 28.)

The details of the survey will now be described. The precise station consisted (as before stated) of either a copper tack (about ⅛″ head), or a chiselled cross in stone. The sight boards we used were rather an experiment, and a new idea in this kind of work. They consisted of ½″ pine boards, 6′ long and 8″ wide. They were painted red and white, in blocks of 21″ x 4″ alternately, with a dividing line down the centre. At the top was a hook from which hung a plumb line and bob, intended when plumbed to cover the centre line. The boards were placed and plumbed directly over the tacks, and guyed firmly in place by a set of three stout wires. Con-

Angle and Distance Sheet of Triangulation for Trunk Sewer Tunnel.

Completed September 29th, 1892.

TRIAN.	ANGLES	OBSERVED ANGLES.	INDIRECTLY OBSERVED ANGLES.	COMPUTED ANGLES.	SUM OF ANGLES.	VARIA'N FROM 180°	CORRECT'N FOR EACH ANGLE.	CORRECTED ANGLES.	SIDES.	LENGTH OF SIDES.	LATITUDES (EAST + WEST −).	DEPARTURE.
	Z E Y	43°04′00″	....	....	....	....	—00″.6	43°03′59″.4	Z E	2099.314	....	....
E Y Z	E Y Z	79°06′58″.3	....	....	180°00′01″.8	01″.8	—00″.6	79°06′57″.7	E Y	1809.313	....	....
	Y Z E	57°49′03″.5	....	....	....	....	—00″.6	57°49′02″.9	Y Z	Base No. 2. 1459.768	....	....
	Y C Z	27°32′16″	....	....	....	....	+00″.2	27°32′16″.2	Y C	1999.537	....	....
C Z Y	C Z Y	39°17′33″	....	....	179°59′55″.7	04″.3	+02″.3	39°17′35″.3	C Z	2902.739	....	....
	Z Y C	113°10′06″.7	....	....	....	....	+01″.8	113°10′08″.5	....	....	....	....
	E C Z	33°22′20″	....	....	....	....	+01″.6	33°22′21″.6	E C	3787.090	....	....
C Z E	C Z E	97°06′36″.5	....	....	179°59′55″	05″.0	+01″.7	97°06′38″.2	....	....	....	....
	Z E C	49°30′58″.5	....	....	....	....	+01″.7	49°31,00″.2	....	....	....	....
	E C Y	....	5°50′05″.4	....	....	....	00″	5°50′05″.4	....	....	....	....
C Y E	C Y E	....	167°42′50″	....	179°59′56″.2	03″.8	+03″.8	167°42′53″.8	....	....	....	....
	Y E C	....	6°27′00″.8	....	....	....	00″	6°27′00″.8	....	....	....	....
	G C E	36°24′22″.5	....	....	....	....	—01″.0	362°4′21″.5	G C	2522.152	....	....
C E G	C E G	40°25′37″	....	....	180°00′01″.0	01″.0	00″.0	402°5′37″	....	....	+2766.276	00.0
	E G C	....	103°10′01″.5	....	....	....	00″.0	1031°0′01″.5	E G	2308.334	....	....
	G C Y	42°14′27″.9	....	....	....	....	—01″.0	42°14′26″.9	....	....	....	....
C Y G	C Y E	85°37′06″.0	....	....	179°59′59″.1	00″.9	+01″.9	85°32′07″.9	....	....	....	....
	Y G C	....	52°13′25″.2	....	....	....	00″.0	52°13′25″.2	Y G	1700.672	....	....
	Y E G	46°52′37″.8	....	....	....	....	00″.0	46°52′37″.8	....	....	....	....
E G Y	E G Y	....	50°56′36″.3	....	179°59′58″.1	01″.9	00″.0	50°56′36″.3	....	....	+ 480. 90	+ 324.837
	G Y G	82°10′44″	....	....	....	....	+01″.9	82°10′45″.9	....	....	....	....
	G C F	11°46′35″.5	....	....	....	....	00″.0	11°46′35″.5	....	....	....	....
C F G	C F G	92°57′44″	....	....	180°00′00″	00″.0	00″.0	92°57′44″	C F	2442.426	+ 897.940	+ 21.8968
	F G C	....	75°15′40″.5	....	....	....	00″.0	75°15′40″.5	F G	5154.472	....	....

Angle and Distance Sheet.—*Continued.*

TRIAN.	ANGLES	OBSERVED ANGLES.	INDIRECTLY OBSERVED ANGLES.	COMPUTED ANGLES.	SUM OF ANGLES.	VARIA'N FROM 180°	CORRECT'N FOR EACH ANGLE.	CORRECTED ANGLES.	SIDES.	LENGTH OF SIDES.	LATITUDES (EAST + WEST −).	DEPARTURE.
	H F G	35°59'40"	......	......	......	......	00".0	35°59'40"	H F	897.940	......	......
F G H	F G H	......	111°47'51"	......	180°00'00"	00".0	00".0	111°47'51"	......	......	......	......
	G H F	32°12'29"	......	......	......	......	00".0	32°12'29"	G H	568.373	......	......
	G C D	30°01'48"	......	......	......	......	00".0	30°01'48"	C D	2640.131	......	......
C G D	C G D	......	79°51'25"	......	180°00'00"	00".0	00".0	79°51'25"	......	......	......	......
	G D C	70°06'57"	......	......	......	......	00".0	70°06'57"	G D	1342.241	......	......
	G D H	22°46'30"	......	......	......	......	00".0	22°46'30"	......	......	......	......
D H G	D H G	113°54'24"	......	......	180°00'00"	00".0	00".0	113°54'24"	D H	1007.260	0.00	+ 21.8968
	H G D	......	43°19'06"	......	......	......	00".0	43°19'06"	......	......	......	......
	D A C	37°08'43"	......	......	......	......	+01".4	37°08'44".4	D A	3993.855	......	......
A C D	A C D	65°59'17"	......	......	179°59'56"	04".0	+01".3	65°59'18".3	A C	4257.838	— 433.494	− 2025.72
	C D A	76°51'56"	......	......	......	......	+01".3	76°51'57".3	......	......	......	......
	T C D	31°34'01"	......	......	......	......	00".0	31°34'01"	T C	2759.027	......	......
C D T	C D T	......	......	78°40'16".6	180°00'00"	00".0	00".0	78°40'16".6	......	......	— 836. 2	+ 383.487
	D T C	......	......	69°45'42" 4	......	......	00".0	69°45'42".4	D T	1473.035	......	......
	M C T	26°09'25"	......	......	......	......	00".0	29°09'25"	M C	3918.485	......	......
C T M	C T M	109°08'59"	......	......	180°00'00"	00".0	00".0	109°08'59"	......	......	—2219. 47	+ 77. 25
	T M C	......	41°41'36"	......	......	......	00".0	41°41'36"	T M	2020.930	......	......
	M C D	604°3'26"	......	......	......	......	00".0	60°43'26"	......	......	......	......
C D M	C D M	780°2'30"	......	......	180°00'00"	00".0	00".0	78°02'30"	......	......	......	......
	D M C	......	41°14'04"	......	......	......	00".0	41°14'04"	D M	3493.810	......	......
	C A B	......	54°11'33"	......	......	......	00".0	54°11'33"	......	......	......	......
A B C	A B C	106°22'32"	......	......	180°00'00"	00".0	00".0	106°22'32"	A B	Base No. 1. 1476.427	......	......
	B C A	19°25'55"	......	......	......	......	00".0	19°25'55"	B C	......	......	......
	F C E	24°37'46"	......	......	......	......	00".0	24°37'46"	......	......	......	......
C E F	C E F	......	......	33°00'31".3	180°00'00"	00".0	00".0	33°00'31".3	......	......	......	......
	E F C	......	......	122°21'42".7	......	......	00".0	122°21'42".7	E F	1868.464	......	......

derable pains were taken to get this board perfectly plumb, and keep it so. It being known to the signal man just what angles were to be read by the instrument during the day's work, he attended to the signal boards under his charge by keeping them plumb and squarely facing the line of sight. Only where a number of angles were to be read from one station were more than two signal men needed. The instrument party consisted of two men; these, together with the accompanying signal men, constituted the survey party. Each man on the party was provided with a strong field glass, and a code of telegraphic signals (with white flags) was arranged for long-distance signalling.

The instrument used was a 7″ transit by a well-known American firm. The instrument had a power of twenty-four diameters, and was provided with all the latest improvements, including shifting centre. The graduations were on silver, and read to twenty seconds. It was supplied with a very steady extension tripod. The instrument was examined for adjustment very frequently, principally for the horizontal axis and levels.

Now, as to reading angles. Several methods were used and experimented on. (1) A repetition of ten readings—that is, (for the benefit of the junior years) reading the same angle continuously, accumulating the number of degrees. Thus an angle of, say, 60° read ten times would read 600°, or the Vernier reading would be 240°(600° – 360°=240°). In this way, by taking the average from the final reading, the angle is determined (all things being equal) to two seconds. (2) By "four sets of five readings"—that is, four sets of five repetition readings—each set commencing at different points in the circle; thus: (*a*) at 0°; (*b*) at 180°; (*c*) at 90°; (*d*) at 270°. (3) A repetition of *twenty* to *thirty* readings. This was the method finally adopted. It proved to be of the greatest accuracy, and involved fewer instrumental errors. By this method each angle could be read to one second, or even half a second. In reading the angles, of course the *first* reading would not be expected to give the angle any closer than ten seconds (though the Vernier really read to twenty seconds). The fifth reading should give it to two or three seconds; while the tenth should determine it definitely to two seconds; and, lastly, the twentieth to one second. The usual criterion for the successful reading of an angle was the relation between the results of the tenth and twentieth readings. If the angles as determined by each differed by more than 1.5 seconds, the previous results were thrown out, and the angle read again by twenty more readings.

If, during a set of observations, the instrument was known to have received a shock or jar from any cause, the whole was unclamped and the readings commenced again. If, also, it was found that the wind affected the instrument to any great extent, the operations were suspended.

Readings Taken at Fifth Street (F),

September, 1893.

Mr.............. } Inst.
Mr.............. }

.... }
.... } Signals.
.... }

Sta. Observed.	Vernier A.	Vernier B.	Remarks.	Calculation.	Mean Angle.
G	0°-00′00″	0′-20″	— v v v v v	104-47-55 360 464-47-55 10	
C	104-47 45	48′-05″		5 | 464-47-55 92-57-33	92° 57′ 33″
C	180-00-00	0′-30″	+ v v v v v	180-00-15 360 500-00-15 75-12-00	
G	75-11-50	12′-10″	—	5 | 464-48-15 92-57-39	92° 57′ 39″
G	90-00-00	0′-20″	— v v v v v	194-48-35 360 554-48-35 90-00-10	
C	194-48-20	48′-50″	+	5 | 404-48-25 92-57-41	92° 57′ 41″
C	270-00-00	0′-20″	+	270-00-10 360 630-00-10 165-11-30	
G	165-11-20	11′-40″	—	5 | 464-48-40 92-57-44	92° 57′ 44″ Final Mean = 92° 57′ 39″

Readings Taken at Fifth Street, Station F, Angle *G F C*

September, 1892.

92° 57′40″		1st Reading		92° 57′ 40″
104° 47′ 40″	v v v v v	5th Reading	104-47-40 360 5 | 464-47-40	92° 57′ 32″
209° 37′ 00″	v v v v v	10th Read.	209-37-00 (360x2) 720 10 | 929-37-00 92-57-42	92° 57′ 42″
59° 13′ 40″	v v v v v v v v v v	20th Read.	59-13-40 1800 20 | 1859-13-40 92-57-41	92° 57′ 41″
			Final Reading.	92° 57′ 41″

The *modus operandi* of reading an angle is as follows :

(1) Set up.

(2) Set plates as accurately as possible at 0°, clamping upper plate. This is checked and corroborated by the assistant instrument man.

(3) Receive "all right" signals from stations between which angle is being read.

(4) Set telescope on the signal of that station which is to the left of the angle read, "split" it with the cross wires, and clamp the lower plate. In "setting" on the signal, the tangent screw is used in such a way that the cross wires will advance from left to right on the signal; that is, the motion of the plate is always positive in the direction of the hands of a clock. This was the case in our instrument, as in this way the tangent screw is turned against the spring. If the tangent screw were placed the opposite way, the motion would be from right to left. This is the direction in which the plates are usually graduated. If, in "setting," the wires pass beyond the signal, bring them back past the centre, and then move them up in the proper way.

(5) Unclamp the upper plate, and, moving it from left to right, set the telescope on the second signal, advancing in the proper way. Then clamp the upper plate and read the angle.

(6) Unclamp the lower plate, and move the *whole* around (left to right) until again at the first signal, on which set the wires as before, and again clamp lower plate.

(7) Unclamp upper plate and sight again on the second signal ; and so on, in this way—always making every movement from left to right.

In this way the first, fifth, tenth, and twentieth readings are read and recorded in degrees, minutes, and seconds ; whilst the intermediate so-called "readings" are not recorded.

Most of our readings were taken with only one Vernier, as any index error does not enter. One man always conducted the observations on one angle, and in this way obviated the correction for personal error. The other man kept notes and checked all the Vernier readings. In this way errors in reading or sighting were quickly detected.

After considerable practice, it was found that, all being favorable, an angle of twenty repetitions could be read in from twenty to thirty minutes of time.

In the triangulation in hand, there were only five triangles in which it was possible to read with the instrument the three angles. Of the rest, with the exception of two, only two angles were read. This fact made the success of the survey much less possible, as in such cases there was no way to check on the readings. Where three angles were read, the error of closure to 180° was limited to five seconds, and was apportioned to each angle, as will be seen on the accompanying angle sheet. In a large triangulation this apportioning would have been arrived at by least squares, but in this case the errors were apportioned directly. It very often happened that such angles as were already corrected in this way would be included in *some other triangle*, and would also require a correction as regards the second triangle, in which case it was quite difficult to arrive at a result.

The calculation of the sides of the triangle of the triangulation was no small task. We found in this that system was everything, and also "the more hurry, the less speed." Having determined the exact length of the base lines on the horizontal, and having the final and accepted reading of every angle, we set to work. Four men were employed—two on each side of the table. One set started and solved a triangle on the base line; one man doing the work, and the other giving logarithms. This triangle being solved, the data used was handed across the table; and the other set of computers traced the data back to its source, and thus checked it. They then solved the given triangle any way they pleased, and compared their result with that of the first set. If the results differed by more than two or three thousandths of a foot, it generally showed that "some one had blundered," and there was forthwith a general overhauling of figures. In this overhauling one man from each set interchanged places, and the two sets then went over the work afresh. The method of giving logarithms was as follows: The computer wanting the logarithmic sine of an angle wrote the angle down on a blank slip of paper provided for the purpose, and at the upper left-hand corner wrote his initials, while in the upper right-hand corner he designated the name of the angle. This slip was handed to his assistant, who wrestled with a ponderous book of tables, found the necessary logarithm, and placed the result beneath the angle designated, together with the accompanying work. He then signed his initials in the lower left-hand corner, and passed back the slip to the computer. In this way there was no confusion by talking; the result was on paper, and an absolute check was obtained on the computers. All the logarithm slips were preserved and filed away for future reference.

By the above means, all the triangles were computed and checked, with the result as shown on the angle sheet. Wherever it was possible, the triangles were solved by the ordinary formula:

$$\frac{\text{Sine } A}{a} = \frac{\text{Sine } B}{b}$$

I describe this method of computation so minutely because it may be valuable to some of our members as a simple and correct way, and one which we found to give entire satisfaction.

In computing we commenced at base No. 2, and proceeded toward No. 1, intending, of course, to get a result for the length of the latter which we could compare with our measured length. It may be interesting to know that the discrepancy or the error of closure in this way was .59 of an *inch*, which was considered a very satisfactory result.

This result of the calculations warranted our accepting the computed triangulation as sufficiently correct to proceed with the secondary surveys.

The latitudes and departures of all the stations were then computed, assuming a line through E parallel to FH as the meridian and centre line of the proposed tunnel.

Each of the shaft centres was then located by means of a secondary survey, simple in itself, but necessarily as accurate as the triangulation itself.

The surveys and works were under the direction of the city engineer, E. Z. Burns, E.M. ('87 Columbia, New York).

NIAGARA FALLS, N.Y., January 20th, 1892.

TUNNEL AT NIAGARA

For Development of Power.

By J. B. GOODWIN, Grad. S.P.S.

MR. PRESIDENT AND GENTLEMEN,—In the proceedings of one or two of the meetings of the Engineering Society last year, several suggestions were made relative to the preparation of papers which would be of greater interest to those in the first-year courses. It was often stated, and stated undoubtedly with justice, that the wants of the first-year students were, to a great extent, overlooked ; and that if more papers were read and discussions started bearing more directly on subjects which were not so full of abstruse mathematics and complicated engineering problems, the attendance and interest of this very important part of our members would be greatly enhanced.

The want of such was greatly felt by the writer in his first year, and it may also be said, in part, of his second year ; and with this principally in view, the present paper is constructed.

In order to at once comprehend the situation, it would be well to first give a general geographical location of the work under consideration. This tunnel is driven in from the cliff which forms the east bank of the Niagara River below the "Falls," and below the new International Suspension Bridge which spans the river between the part of the present city of Niagara Falls, formerly known as the village of Niagara Falls, and Niagara Falls South, on the Canadian side. The course of the river a mile above the Falls is about at right angles to its course after its plunge into the narrow gorge below.

The main line of the tunnel is about at right angles to this latter course, which evidently will make it about parallel to the first course. The supplying of water for power in use in the mills along this bank was brought about in this way. A canal was excavated about 75 or 80 feet wide, leading from a point about three-quarters of a mile above the Falls to a basin about 350 feet from the cliff at the tunnel (Fig. 8). This basin, though excavated some years ago, was deepened in order to make of service every available inch of water entering the canal. The sill on which rests the rack at the intake was also lowered for a similar purpose. This reservoir, as it may be called, is walled up with masonry. In the "river-side" walls are placed racks and gates, admitting water to the several flumes of manufacturers which get their supply through the canal. In this particular case the water passes through the rack and gate, down a vertical shaft into the tunnel, and then into the wheel-pit, passing out from below into the river. Hence the tunnel acts as a sort of conduit, conveying water to the wheel.

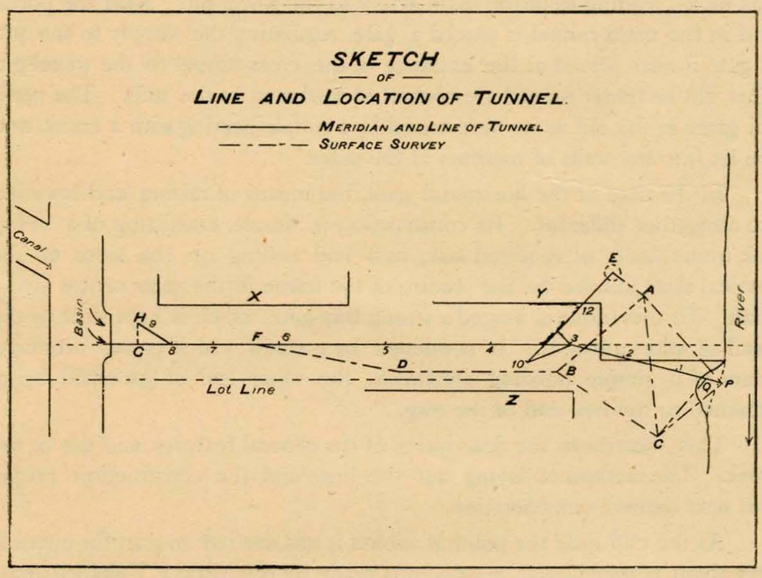

Fig. 8.

The rack at the intake is made of flat bars of iron ⅝" x 3½", placed 1½" apart, being kept apart by sleeves over long bolts or rods, which pass through at about four or five feet apart. These are all fastened to "I" beams, the ends of which are set in masonry on each side of the intake.

The whole has an inclination of three feet in twelve. This serves the purpose of collecting all sorts of grass, weeds, and sticks, of which there seems to be quite a quantity.

Before the tunnel was constructed, the water was conveyed to the wheel-pit by the ordinary flume, in which were placed two gates—one being near the intake, a short distance behind the rack, and the other in front of the rack, which is placed near the wheel-pit. Thus, with this double set of rack and gate, very little floating débris was allowed to enter the pit, endangering the wheel.

In order to increase the power and to make way for foundations for an extension of the mill, it was proposed to abandon the old flume and drive a tunnel through to a point under the intake, a few feet behind the rack at the basin. This was to connect with the intake by a vertical shaft, which is covered by a horizontal gate hinged on to a heavy oak frame around the edges of the shaft.

Now, since the wheel-pit to which access was to be made is situated under the mill, at the edge of the cliff, a small or rather short cross-tunnel was made, leading from the main artery to the wheel-pit. Near the portal and in the main tunnel is placed a gate regulating the supply to the pit. A gate is also placed at the entrance of the cross-tunnel to the wheel-pit. This will be under immediate control of workmen in the mill. The vertical gates in the old flume were raised by a simple gearing with a crank, and are let into the walls of masonry at the sides.

In the case of the horizontal gate, the means of raising and lowering are altogether different. Its construction is simple, consisting of a heavy oak frame built of required size, and laid resting on the sides of the vertical shaft alluded to, the centre of the frame in the same centre as the shaft. To this frame is hinged a strong trap-gate, which is kept shut by the head of water above it. It is opened by a chain which passes around a drum of a simple hoisting apparatus, the other end of the chain being attached to the free end of the trap.

This constitutes the description of the general features and use of the work. The method of laying out the lines and the construction proper will next deserve consideration.

As the cliff near the point at which it was desired to start the opening was about perpendicular, a ledge was made by removing a V-shaped mass out of the face of the rock, from the surface of the ground to the desired level of the floor at the portal of the tunnel.

After this was done, it was necessary to construct a sort of staging or floor over it, on which to place a windlass to handle the materials and implements used below. This consisted simply of beams let into the rock at both sides. This staging was about ten or twelve feet below the surface of the ground, but was readily accessible from it. These beams were made use of from which to suspend two wires, the line of these wires being the direction of the first part of the tunnel. Attached to the wires were weights, which swung in vessels of water, in order to prevent undue swaying. The centres of the nail-heads over which these weights were swung are the points marked P′ and Q.′ A station "C" was established near the cliff, and at a point from which P′ and Q′ could be seen. As previously mentioned, these stations were ten or twelve feet below the level of the ground on which "C" was located. It, therefore, became necessary to use a more convenient and accurate method than ordinary of arriving at the horizontal distances between " C " and P′ and " C " and Q.′ This was done by setting the transit at station " C," and sighting to the centres of the nails at P′ and Q′ in turn; then reading the angles made with the horizontal, and stretching the tape from the centre of the telescope to the points in question. Thus the measured distances form the hypothenuses of right-angled triangles, and the angles read the remaining necessary data to solve the triangles, one side of each being the horizontal distance between points.

It will be seen from the foregoing description that the points P′ and Q′ form connecting links between the surface and underground stations.

Naturally following upon this is the description of the *surface* survey. In order to aid in understanding this, it will be well to give the limits and position of the property lines. Since these lines only extended about fifteen feet from the building marked "X" in the drawing, it necessarily limited the line of tunnel to within this strip. The dotted line represents the property limit over which no part of tunnel was to extend. As the foundations had, as far as possible, to be avoided, this again limited the bounds to a strip about eleven feet wide along the building " Y." It was, however, impossible to avoid the foundations of the wing of this building, but the depth of excavation here precluded all probability of danger.

It was from the position of these buildings and lot lines that the line of tunnel was derived. Since the object was to connect with the intake at the basin, the direction was easily obtained.

Stations " F " and " G " were established on a line approximately midway between the line of building " X " and the lot line. Stations " D " and " B " were taken on a line about parallel to building " Z."

Station " A " was a point in the mill floor in the building " Y," which could be observed from " B " and " C " through doorways. The horizontal distances to this point were similarly measured as from " C " to P′ and Q′, as this floor was ten or twelve feet higher than " B " and " C." Station " E " is a point in the same floor, directly over the centre of the wheel-pit, *i.e.*, as far as the centre could be gotten at—the sides of the pit being very irregular.

These points established, the horizontal angles between them were then read, and the horizontal distances either calculated as described, or directly measured.

These points being thus fixed with reference to each other, the next thing to be considered is to connect the surface and underground points. First of all, the line of tunnel proper bisects the strip of property referred to between building "Y" and the lot line. The position of station "B" with reference to these buildings and lines being known, it is evident that it can readily be found how far station "B" is from this line of tunnel. Using a point directly opposite "B" on the line of tunnel, or *meridian* line, as it shall be called, for a reference point, or the point from which to measure *latitudes* and *departures*, a method is thus obtained to answer the requirements. Calling towards the basin positive, and the opposite way negative; and to the right positive, and to the left negative; station "B" has about 8 feet departure, and o feet latitude. The angle that "B D" makes with this meridian line is easily found by knowing the positions of these various lines at the ends of the buildings (these buildings and lines being divergent).

Knowing this angle and the angle that the line "B C" makes with "B D," it is easily seen that the angle that "B C" makes with the meridian can be found. Thus, knowing the distance "B C," and the inclination to the meridian, this distance, multiplied by the sine of the angle of inclination, gives the *departure; i.e.*, the number of feet to the right or left of the meridian. This same distance into the cosine of the angle gives the *latitude; i.e.*, the number of feet forward or back from the reference point. This, of course, gives the position of "C" with reference to "B." From the sketch it will be seen that the departure of "B," together with the departure of "C" from "B," gives the total departure of "C" from the meridian. The latitude of "B" (which here is o), together with the latitude of "C" with reference to "B," will give the total latitude of "C" from the starting point of o latitude and o departure. (See table.) Thus, in brief, is the method of "Latitudes and Departures," as applied to the location of points. This description will probably be, to a great extent, superfluous; but it is repeated that it may freshen the memories of those to whom it once was familiar, and to aid those to whom it is not quite so clear.

If, now, the position of "B" is clearly understood, it can be readily seen how successive points can thus be fixed, and, after tabulating them in the order obtained, the exact location of any one point with reference to any other point can be at once determined. In this way the method of *surface* survey was carried out.

To locate and connect with these points, those in the tunnel constitutes the *underground* survey.

Slight reference was made to the hanging of plumb-lines from the stations P′ and Q′. Fine wire was used in the hanging, care being taken to suspend directly over the points to which connection was made with "C" and "B." Since the stations P′ and Q′ were only about four and a half feet apart, a slight deviation here would throw the whole line of tunnel out; hence, at these points, it required more than ordinary care.

Now, from the line given by these two plumb-lines the first thirty or forty feet of the excavation was made; but here the question might be raised as to where the point of turn-off to the main line was to be, and also how the exact distance was obtained.

However, by reference to our tabulated "Latitudes and Departures," we obtain the position of P′ and Q′, or "P" and "Q" (as they are termed on the ledge of rock about thirty-three feet directly beneath). From this, the angle that "P Q" makes with the meridian can at once be calculated; for the difference between their departures, divided by the difference between their latitudes, will give the natural tangent of the angle made with meridian. Having thus obtained the angle, it is next necessary to know how far to proceed before the turn is made. Looking into the table of "Latitudes and Departures" for the total departure of "Q," and multiplying this by the cosecant of the angle just obtained, we get the required distance from "Q" to the point of deflection. This point was called station 3, the stations underground being numbered instead of lettered, to distinguish from points in the surface survey.

After this distance was driven, a station was established exactly at the point 3. The transit was set here and sighted back to "P" and "Q," which of course should be in line; then reversed, and the calculated angle turned off. This gives the main line of tunnel, and the instrument is now in the meridian.

The method of establishing these underground stations is somewhat different from that in the ordinary surface survey. In this the stations are located in the roof, instead of floor. To establish a station, suppose, for instance, the instrument is still set at station 3, and we wish to locate station 4, farther along the tunnel; the distance is first measured off, and an approximate point located at which to drill a hole three or four inches in depth. In this hole is inserted a plug of wood, which is driven up flush with the roof. On this is established the exact point; the line being given by the instrument, and the distance by the measurement. At this point a nail with an eye on the head is driven so that the centre of the eyehole is on line, and also at the required distance.

In order to "set up" under a station, the plumb bob of the instrument is suspended from this nail, and the instrument is shifted till the point of the plumb bob is directly over the intersection of the axes of the instrument, which point is exactly under a small drilled hole on the top of telescope, when the telescope is truly horizontal.

LATITUDES AND DEPARTURES—UNDERGROUND.

Course.		Angle with Meridian.			Distance.	Latitude. F +	Latitude. B —	Departure. R +	Departure. L —	Total Latitude. F +	Total Latitude. B —	Total Departure. R +	Total Departure. L —
Q	3	13°	25′	34″	Calculated	33.85		8.08			7.96	0	0 (Refer to Q′)
3	4	0	0	0	35.41	35.41		0	0	27.45		0	0
4	5	0	0	0	67.83	67.83		0	0	95.28		0	0
5	6	0	0	0	59.93	59.93		0	0	155.21		0	0
6	7	0	0	0	77.50	77.50		0	0	232.71		0	0
7	8	0	0	0	25.00	25.00		0	0	257.71		0	0
8	9	22°	46′	25″	(Cal.) 15.76	14.53		6.10		272.24		6.10	
3	11	30°	58′	00″	5.83	5.00		3.00			2.96	3.00	(See surface points.)
11	E	44°	09′	21″	24.09		17.22	16.72			20.18	19.72	
11	10	44°	09′	21″	6.00	4.30			4.18	1.345	1.18		

NOTE.—Stations 10, 11, and also 12, are on line of cross-tunnel.

LATITUDES AND DEPARTURES—SURFACE.

Course.		Angle with Meridian.			Distance.	Latitude.		Departure.		Total Latitude.		Total Departure.	
						Forw'd +	Back —	Right +	Left —	F +	B —	R +	L —
0	B	90°	00′	00″	8.62	0	0		8.62	0	0		8.62
B	C	23°	55′	00″	33.71		30.82		13.67		30.82		22.29
C	Q′	52°	16′	40″	17.965		10.99	14.21			41.81		8.08
Q′	P′	13°	25′	34″	4.60		4.47		1.07		46.28		9.15
P′	A	49°	04′	02″	27.89	18.27		21.07			28.01	11.92	
A	E	44°	54′	12″	11.05	7.83		7.80			20.18	19.72	
C	A	85°	16′	40″	34.37	2.82		34.27			28.00	11.96	
B	D	0°	28′	00″	96.83	96.82			0.788	96.82			9.41
D	F	5°	02′	40″	110.8	110.37		9.74		207.19		0.33	
F	G	0°	15′	20″	66.65	66.65			.297	273.84		0.033	
G	H	75°	51′	24″	6.25		1.5	6.06		272.34		6.10	

Columns of "Total Latitude and Departure" give the location of the points to which reference is made.

NOTE.—Station "H" was not established except by calculation.