TRANSFERRING THE SURFACE MERIDIAN TO DEEP UNDERGROUND SURVEYS.

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(A Paper read before the Sydney University Engineering Society, July 17th, 1912).

In making an underground survey, one of the first things necessary is to connect the surface and underground survey work, or in other words to transfer the surface meridian underground. It is not sufficient to adopt the magnetic meridian obtained by floating the needle above and below, as owing to varying local attraction this method will only give an approximate result.

If the problem is to fix the position of some particular workings which are located within and under certain property or measured portions, an accurate survey is first made of the surface boundaries and the azimuth decided upon. If the underground workings are reached by tunnel, no unusual difficulty presents itself in carrying the azimuth underground.

First assume that the workings may be approached by two separate vertical shafts, the winding or downcast and the air or upcast shaft. This is the simplest condition for survey where entry is made by a shaft. Briefly, a connection is made from the surface boundary to one or both shafts: if the former, then a connection is also made between the two shafts. At each shaft a point is selected on the firm timbers, through which a small hole is bored, and a plumb-line or fine wire passed through, and on which a weight is suspended at the shaft bottom. A point is then fixed below in each shaft vertically under the surface stations. The bearing and distance between the surface stations having been ascertained, the value of the line between the underground station is known, being the same. The procedure is simple if the underground stations are intervisible: the line joining them is sighted, and the surface bearing adopted. Usually, however, the shaft bottoms are not intervisible, in which cases a traverse is run to connect them, from which the direct bearing and distance are calculated. After comparison with the surface bearing the necessary correction is made and applied to the traverse lines, and these corrected values are used for the completion of the work.

In deciding upon the shaft stations on the surface, it is always necessary to select a position which allows the wire to swing clear of timbers, etc., in the shaft.

If the depth is shallow, say less than 100 feet, though this is an arbitrary depth, the plummet may be brought to rest at the bottom without extreme difficulty, and a spike driven into the floor. Provision must of course be made to dispose of air currents, and splashing of water. Where it becomes necessary to employ a medium, such as water or oil, to bring the plummet to rest, the position of the wire may be fixed when at rest, by sighting with the instrument a few yards away, and measuring the distance with great care, after which, the vessel containing the medium may be removed and the position marked on the floor. If mercury be used as a medium, care should be taken to see that the plummet is only very slightly immersed, as owing to the high specific gravity of mercury, 13.59, the effect of the plummet's weight is much reduced by immersion. The weight used may be suspended on fine copper wire, or on 16 or 17-gauge piano wire, with as few joints as possible.

TRANSFERRING AZIMUTH DOWN A SINGLE SHAFT.

Where the azimuth has to be carried down one shaft: with perhaps only 5 to 15 feet available in the clear, the operation requires extreme care. Two wires will be necessary with a weight attached to each.

The following example of this operation as carried out by me some few years ago in the Balmain Colliery, serves to show the procedure then adopted.* The depth from the point where plummets were suspended is 2920 feet, or more than half a mile, while the length of base line available was 16 feet.

It rarely happens that an azimuth has to be transferred by one operation to such a great depth. No such other instance has occurred in New South Wales, and probably only very rarely, if at all, in Australia, for although there are deeper workings in gold mines in Victoria (over 4000 feet), these are worked at various levels, and in many cases the azimuth has been carried down from the different levels as the mine developed. This applies to metalliferous mines generally. There are at least four deeper coal mines in Belgium, one reaching 3,773 feet, but I have no information in regard to the methods adopted in survey.

**The Surveyor*, January, 1909.

At the time the Balmain survey was made, only one shaft had been sunk, and by means of a temporary division of the shaft into two compartments, one very much larger than the other, a system of natural ventilation was produced, the hot air being forced up through the smaller space. The air current was very slight, a beneficial condition in surveying, though the direction of the current was perceptible if a little fine dust were scattered near the safety lamp. Its rate of motion responded to changes of temperature on the surface, being accelerated by cold and retarded by increased heat. The temperature underground exceeded 80 degrees at the time of survey. Subsequently a second shaft was completed which gave a base line of about $2\frac{1}{2}$ chains, and with the aid of a fan, provided a strong current of air.

Having in view the depth of the shaft, it will be at once recognised that the work of steadying two plummets, suspended on such an enormous length of wire, involved more than ordinary care, and especially having regard to the degree of accuracy necessary.

It may be further pointed out that the amount of water percolating from the sides at that time, was so great as to preclude all possibility of seeing down the shaft, so that the use of an instrument with a side telescope was quite impossible. The effect of the water at the bottom interfered with operations more than can readily be imagined by the inexperienced, for it fell there as a constant shower, sufficient to wet one through within two minutes. Its effect also upon the plummets and wires would be to keep them unsteady and make their movements irregular. Had it been practicable to see down, I should have used a theodolite with a subsidiary telescope, as any method with plumb-lines in a shaft so deep as this is both tedious and slow.

According to a natural law discovered by Galileo, the time occupied by the oscillation of a pendulum is the same whether the swing be long or short, but varies with the length of pendulum and the change of latitude.

In order to find the primary pendulous vibrations at a depth of 2920ft., so that the movements of the plummet might be the better understood, a calculation was made, using the simple pendulum formula $t = \pi \sqrt{\left(\frac{l}{g}\right)}$, t being the time of oscillation in seconds, and the value of π being 3.1416. The value of gravity at the Sydney Observatory, which is practically in the same latitude as the Balmain shaft, has been worked out by Mr. E. F. J. Love, M.A., as 32.1392.* Having l as 2,920

* Journal Royal Society, N. S. Wales, 1894, p. 63.

feet, the time of oscillation *in vacuo* was found to be 3.1416 $\sqrt{\frac{2{,}920}{32 \cdot 14}}$ or 29.94 seconds. The plummet and wire really formed a compound pendulum, and Mr. R. P. Sellors, B.A., has calculated the time of oscillation of this compound pendulum to be 29.06 seconds.*

Subsequently one set of 29 oscillations was recorded as occupying a few seconds under 15 minutes, the watch being read by the light of a safety lamp.

The plummets used were iron cylinders, 9 inches long by 4 inches in diameter, and weighing 31¼lbs. each. These were suspended on No. 16 gauge piano wire, weighing about 13¼lbs., in lengths of 110 feet, with a few 300 feet, and with 23 or 24 joints. In making the joints the two ends of the wires were formed into a hook, and tightly lapped over with soft galvanised wire.

SURFACE OPERATIONS.

The wires were run off fixed rollers and placed in very small V cuts on the side of securely fastened iron plates, all observations being taken to points below these plates. It was possible to use the cage in the shaft while the plummets were suspended, but this, of course, caused vibration of the wires.

On the surface, a 5-inch theodolite, reading to 20secs., was placed in line with the two wires (the far wire being chalked) by moving the traversing head until the correct position was obtained. A connection was then made to the Trig. Survey and the operation checked.

PROCEDURE UNDERGROUND.

Although the method of placing the instrument in line with the wires was adopted on the surface, this idea was abandoned underground owing to the splashing of water, and inadequate light, it being necessary to use safety lamps only, which are not famous for their brightness. In all cases the theodolite was placed only approximately in line with the two wires, and the small angle subtended by the line joining them was measured, also the angle between the more distant wire (N) and a referring mark y beyond.

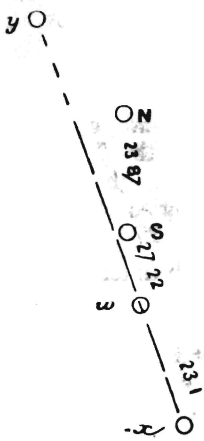
PLUMMETS IN WATER.

In the first experiment, the plummets, which were 23.87 links apart, were allowed to settle in water, the instrument being at x, about 50 links from the nearer or southern plummet, S. No one will be surprised to learn that with the associated conditions at this great depth, it was found impossible to bring the

* *The Surveyor*, May, 1909.

plummets to absolute rest, but on 4th April, 1905, a fairly satisfactory set of observations was taken with the plummets in water, and as nearly at rest as possible, which gave the bearing of line *x y* as 316 degrees 16mins. 58secs.

PLUMMETS IN MERCURY.



On the 16th April an experiment was made by having the plummets slightly immersed in mercury. The first set of angles taken from station *x* was not satisfactory, as for some time the plummets were slightly unsteady, though they appeared quite stationary during the latter half of the observations. The value of these observations was much discounted, however, by the fact that, while the plummets were apparently stationary, the cage was sent up the shaft, which had the effect of disturbing the wires; but when they again settled, although appearing at rest, one was clearly in a different position. The reason for this change was possibly owing to the depth the plummet was immersed, viz., about one inch. The specific gravity of wrought iron is about 7.5, while that of mercury is 13.59. It will thus be seen that if sufficiently immersed the iron would practically float, and in the instance cited it seems possible that the resistance of the mercury prevented the wire from being strained to the necessary tension, and allowed the cylindrical plummet to lie slightly on one side. The movement caused by the ascending cage may have reversed the inclination of the cylinder.

Before the cage was sent up, one set of four angles gave the following result:—8 mins., 8 mins., 8 mins. 20 secs., 7 mins. 40 secs., the mean being 8 mins. These results, obtained underground by the light of a safety lamp, would indicate that the wires must have been practically stationary. After the cage movement the same angle was again measured by four repeats, the instrument not being disturbed, and the following result obtained:—9 mins., 9 mins., 9 mins., 9 mins. 20 secs., mean 9 mins. 5 secs. The values obtained for this second set of angles again seemed to indicate absolute rest for the wires, and yet the values of the angle differ slightly more than 1 minute. By taking the mean of these observations and the angular measurement to *y*, the value of the line *x y* was found to be 316 degrees 36 mins. 22 secs.

The instrument was then moved to station *w*, on the line *xy*, about midway between the southern wire and station *x*, and the two sets of angles again taken with most satisfactory instrumental results. The wires appeared quite at rest, and the angle subtended by the line joining them was found to be 2mins. 7secs. as the mean of eight repeats on vernier A, while the mean of five repeats on vernier B worked out at 2mins. 6secs. The angular measurements taken in this instance gave the line *xy* a value of 316 degrees 40mins. 43secs., or over 4mins. more than the previous value.

PLUMMETS IN OIL.

As the results so far obtained could not be considered at all satisfactory, a series of angles was taken at *w* on the 7th May, with the plummets slightly immersed in oil. Although absolute rest was not obtained, a very satisfactory set of angles was taken, from which the line *xy* was deduced at 316 degrees 27mins. 0secs.

The results up to this stage were very disheartening, the values of a common line being as follow:—

°	′	″			
316	16	58	with	plummets in	water
316	36	22	,,	,,	mercury
316	40	43	,,	,,	,,
316	27	0	,,	,,	oil

FREE SWING OF PLUMMETS.

In view of the various influences which were operating against success, particularly the splashing of water, and possibly slight air currents, it was then decided to conduct operations on an entirely new basis, and one that would, if possible, dispose of these counteracting influences, or at least reduce them to a minimum. The plummets were suspended without any obstruction; while close to each wire, and as nearly as possible at right angles to the line joining them, two 20-scales one foot long were placed, being fastened to boards which were firmly secured across the shaft, the plummets hanging below the boards. It would have been an advantage to have used scales 2 or even 3 feet long. A plummet was then taken slowly, parallel with, and just beyond the end of one of the scales and released, after being first held for about a minute in order that any segmentary vibration in the wire might be eliminated. Naturally it swung back to the other end of the scale, and by carefully watching the wire when the terminal point of its oscillation came within range of the scale, the amplitude was noted. The swinging was allowed to continue until about fifteen pairs of oscillations had been recorded, when the mean position between all these points was accepted as the centre of the swing, and marked with a pin for observation. A similar operation was then performed at the second wire, and the distance to each pin from the observing station carefully measured. The same principle is adopted in the determination of the Magnetic Inclination. The following paragraph occurs in the report of the Superintendent of the U.S. Coast and Geodetic Survey, June, 1881, p. 141:—"It is recommended to observe the needle while slowly oscillating in preference to noting its position at rest, in which latter case the equilibrium may be influenced by any small irregularity in the axle at the point of contact, which it may be supposed would be passed over by an oscillating motion."

The greatest difficulty with this method of procedure is that of accurately reading the extreme points reached by the wires. The work requires the full attention of one person who calls out the values, while a second records them.

By studying the scale readings it will be noticed that the shortening of the plummet swing was not in any absolutely regular progression, and this was probably due to the accidental vibration caused by the splashing and falling of water, and also to the wires occasionally very slightly brushing the edge of the scale, an occurrence which unfortunately cannot be always avoided. The values read on a 20-scale at the north wire (N) were as follow:—

Scale Readings.		*Continued.*		*Continued.*	
51	220	101	170	118	162
68	201	108	165	118	158
82	203	117	177	112	158
82	190	121	160	112	152
88	186	123	163	118	160
103	179	116	160	119	152
		118	160	124	152
				2099	3428
				Mean	139.1

Owing to the shortening of the plummet oscillations, it is necessary to find the centre of all swings from, say, left to right, and also from right to left, and the mean of the two results will give the true central position.

In order to find the mean of a set of scale readings, without working out each pair separately, the following formula was devised:—

From the sum of both columns subtract half the sum of the first and last readings, and divide by the total number of oscillations.

In the above instance the sum of both columns, less half the first and last readings, gives 5425.5, and this divided by the total number of oscillations (39) shows the mean of all readings to be 139.1, or for practical purposes, 139.

At the southern wire (S), 29 pairs of readings (15 from one end of scale and 14 from the other) were taken as given below:—

Scale Readings.		Continued.	
57	185	108	137
61	174	115	135
71	169	112	127
77	165	104	138
82	151	111	138
92	146	114	134
106	138	118	125
106	133		
		1434	2195
		Mean	122

With the pin set at the mean values indicated at N and S, to which careful measurements were taken, a series of seven angles, obtained by noting the mean of both verniers, with the theodolite at the point *w*, gave the following result:—7 mins. 5 secs., 6 mins. 20 secs., 6 mins. 15 secs., 7 mins., 6 mins. 45 secs., 6 mins. 40 secs., 6 mins. 55 secs. Mean 6 mins. 43 secs. These figures are given to show the degree of accuracy obtained in this underground survey, and to illustrate that any unsatisfactory results were not due to defective instrumental work.

A set of angles was also taken between N and the referring mark at *y*, and the bearing of the line *xy* by this fresh method was found to be 316 degrees 29 mins. 38 secs.

On the 14th May the instrument was set under station *x*, and the plummets again allowed to swing freely along 20-scales placed at N and S. The scale readings were as follow:—

Scale Readings at N.		Scale Readings at S.	
38	184	5	222
46	172	27	203
45	163	36	196
60	158	46	188
68	147	60	178
75	140	65	166
81	139	73	162
88	123	74	155
100	118	82	150
102	117	91	146
99	118	97	145
101	118	102	136
95	110	102	130
104	110	110	125
		109	124
1102	1917	112	127
Mean 109		1191	2553
			Mean 118.6.

The mean position of swing was next marked by pins, and observations taken, the angle from station x between the pins being recorded as follows:—12mins. 50secs., 12mins. 10secs., 13 mins. 10secs., 12mins. 55secs., 12mins. 55secs., 13mins. 0secs. Mean 12mins 50secs.

By repeating the angle between N and y the following result was obtained:—45mins. 5secs., 44mins. 20secs., 44mins. 50 secs., 44mins. 50secs. Mean 44mins. 46secs.

From these values and careful measurements to the pins, the bearing of xy was found to be 316deg. 29min. 36 secs., an extraordinary result, as it differed only 2 secs. from that arrived at a week before with the instrument at another station, and the mean position of the plummet oscillations independently obtained. It could not be hoped, however, that any subsequent value would agree with either so closely as this, and in order to test the accuracy of the system the plummets were again allowed to swing and the whole operation repeated, the angles being again measured from x.

The scale readings were as follow:—

Scale Readings at N.		Scale Readings at S.	
9	197	15	213
21	190	36	201
34	177	50	186
47	170	47	183
53	161	45	178
51	153	54	174
67	139	60	170
73	144	61	165
75	125	70	162
83	124	77	155
90	120	77	149
98	121	79	150
93	120	99	131
99	118	110	122
96	121	101	138
989	2180	981	2477
Mean 107.		Mean 116.6,	

As a result of this operation, the bearing of the line xy worked out at 316deg. 30min. 49sec., which was very satisfactory.

Without moving the pins, the theodolite was taken to station w, and a set of angles observed which gave the bearing of the line xy as 316deg. 30min. 10sec.

The four results obtained by the method of taking the mean of the plummet swings are as follow:—

		°	′	″
From station *w* on 7/5/1905	...	316	29	38
„ „ *x* „ 14/5/1905	...	316	29	36
„ „ *x* „ „ „	...	316	30	49
„ „ *w* „ „ „	...	316	30	10
Mean	...	316	30	3

Now the natural question to be asked is how did the azimuth, obtained in the above manner, from the base line of 16 feet, agree with that subsequently derived from a connection between the two shafts. The answer to this is not so satisfactory as was expected, because the difference was found to be 6 minutes. It is only fair, however, to point out the conditions under which this check was obtained. In the first place, nearly two years elapsed before an underground connection between the shafts was completed. This connection necessitated the running of five traverse lines, and the work was carefully performed by Mr. Mining Surveyor Edward Thomas. The distance between the wires in both shafts was found to be 254.69 links on the surface, and 254.67 from the underground connection. Long before this check was made, the marks at *w*, *x*, and *y*, which consisted of nails driven in the roof timbers, had disappeared, but surveys based on the original azimuth had on several occasions been made in the colliery by Mr. Thomas, and at the time of each visit sufficient marks were found to carry on the survey, and new ones were established. In this way it was hoped the original azimuth would be retained, but it is thought that some considerable portion of the 6min. difference, probably at least one-half, may be accounted for by the movement of marks over this period of about two years.

In a new, very deep colliery, particularly where much gas is prevalent in the seam, as in this case, the movements of the strata in the vicinity of the seam are always more considerable than in shallow collieries less troubled with gas. It may also be mentioned that at a depth of nearly 3,000 feet the super incumbent weight is so enormous that the floor of a tunnel is squeezed upwards by pressure, assisted by gas, in some instances to the roof, and the raised material must be removed. In a new tunnel this may happen several times, the uplift becoming less on each occasion. The roof also falls, perhaps for many feet upwards, and there is also a movement of the rib in some cases. The difficulty of maintaining permanent marks in a new and deep colliery is therefore very considerable, and even with the exercise of extreme care the original positions may be lost.

If we assume, however, that the connecting traverse was run on the original azimuth carried down, then it is interesting to note that the bearings derived from the first set of observations taken while the plummets were suspended in mercury were practically correct, although the wires are recorded as not having been at rest the whole time. On the other hand, the bearings obtained from the second set, while the wires were considered to be at rest, would be 4min. in error.

Reviewing the whole of the experiments, it seems clear that the most satisfactory results were obtained by allowing a long free pendulous swing, and marking the extreme points of oscillation on the scales.

The experience gained by trying the other various systems went to show that it is desirable to first allow the plummet to be suspended so that the wire may be properly stretched, then place under it a vessel to receive just sufficient of the substance, whethere oil or mercury, as will allow only the end or point of the plummet to be immersed. Using heavier weights would also assist in more nearly procuring absolute rest. Although at the time the experiments were carried out, it was thought inadvisable to increase the weight for fear of breaking the wire, when half a mile of it might have become entangled at the shaft bottom; yet Mr. Thomas afterwards, on one occasion, successfully used a weight of 75lbs. It may be of interest to know, that when testing the strength of a short length of this wire, containing a joint, it did not break till weighted with 170lbs. At the same time, when using piano wire of about 16 or 17 gauge, I scarcely think it would be advisable to attach a weight of more than 50 to 60lbs., and this would require to be very carefully handled.

In placing before you the nature and results of these experiments, my object has been to furnish any information available concerning matters not met with in everyday practice, and also to record the details of procedure, thinking they might possibly be useful for future reference.

It is not claimed that the long swing eliminates errors of verticality, a condition not secured under any other system, but the air current usually goes in one direction only, and its effect, if any, upon two plummets placed along the course of the current, would operate in the same direction on each. Consequently, if the wires were blown an inch from the vertical it would have no effect upon the bearing of the line joining them, the scales being placed at right angles to the current, and the swing being parrallel to the scales. At the same time, experiments at different periods and under different conditions are recommended, and a judicious mean of the whole should be adopted.