TELLUROMETER GROUND SWING ON GEODETIC LINES (*)

by S. A. YASKOWICH
Geodetic Survey of Canada

ABSTRACT

This paper presents a study of ground swing on tellurometer measurements of primary triangulation lines. Mainly discussed are the lines, comprising 8 % of the total, that have ground swings larger than 90 centimetres. The large ground swings are caused by reflections from steel observing towers, and from natural reflecting surfaces such as ice, water and land. The validity of theoretically computed ground-swing errors is discussed, as is the value of eccentric measurements, whose purpose it is to reduce ground swing and mean ground-swing errors. Estimates of actual ground-swing errors are made on the basis of comparisons between observed and adjusted lengths.

DATA

During the five-year period 1958 to 1962 the Geodetic Survey measured 496 tellurometer lines in primary triangulation networks in New Brunswick, Quebec, Ontario, the Prairie Provinces, and the Northwest Territories. The lines vary in length from 6 to 73 kilometres and the average length is 26 km. Each line was measured a minimum of 4 times with measurements taken on at least two different days. Each measurement consists of two coarse and 37 fine readings, with the latter taken over the whole cavity range. The average spread of measurements on a line is 16 cm, the minimum being one cm and the maximum 68 cm. The mean peak-to-peak ground swing for all lines is 57 cm.

(*) Paper presented to the 13th General Assembly of the International Union of Geodesy and Geophysics, and the International Association of Geodesy, Berkeley, August 1963.

Ground swing is the variation of observed transit time (measured distance) with changes in cavity tune setting (carrier frequency). The peak-to-peak ground swing on a tellurometer measurement is the difference between the highest and lowest fine transit-time reading observed. This difference will hereafter be referred to simply as ground swing. The mean ground swing on a tellurometer line is the mean of the ground swings of the individual measurements made on the line, and the average ground swing for a group of lines is the average of the mean ground swings of the lines comprising the group.

RESULTS

Table I shows the tellurometer lines measured in various areas and gives a summary of ground-swing data. The largest average ground swing, 84 cm, occurred in Quebec and was due mainly to large ground swings on several lines passing high over water. The second largest average, 72 cm, is for lines in New Brunswick where reflections from steel observing towers were the main cause of large ground swing. Lines in eastern Ontario and on the prairies have near average ground swings even though steel towers were used for measurement of many of the lines. In the Northwest Territories the largest average ground swing is on lines in the Yellowknife area. The smallest average, 26 cm, occurred on lines in the relatively flat area near Dubawant Lake, Northwest Territories. Steel observing towers were not used in the Northwest Territories and Quebec but were used in all other areas.

Forty of the 496 tellurometer lines measured, or 8 % of the total, have mean ground swings larger than 90 cm. Twenty-four of these were measured from steel towers at one or both stations. A summary of these lines is given in Table II. The other 16 lines, with mean ground swings larger than 90 cm, were measured from ground stations and results are summarized in Table III.

LINES MEASURED FROM STEEL TOWERS

Large ground swings occur on lines measured from steel towers when the tellurometer ray passes too close to a steel beam on the tower. The beam reflects part of the outgoing signal back to the tellurometer, causing the crystal current to increase at some cavity tune settings and to decrease at others. This reflected signal causes the large ground swing.

As shown in Table II, the mean ground swing for the 24 lines measured from steel towers varied between 91 and 138 cm, and the range of ground swing for individual measurements was 58 to 213 cm. The latter ground swing occurred on the line Whitemouth - Seddons and is attributed to the effect of the steel fire tower at Seddons.

TABLE I

Tellurometer Ground Swing on Geodetic Lines

Location	Number of lines	Average ground swing (cm)	Min. and Max. mean ground swing (cm)		Number of lines in specific mean swing ranges (ranges in cm)				
					0 - 30	31 - 60	61 - 90	91 - 120	> 120
Quebec	50	84	20	579	4	25	10	5	6
New Brunswick	24	72	33	138	0	10	6	6	2
Eastern Ontario	50	56	28	102	1	36	12	1	—
Toronto	33	68	35	113	0	10	19	4	—
Ontario - Manitoba	44	59	30	126	3	25	8	7	1
Manitoba	72	56	22	112	13	38	19	2	—
Manitoba - Saskatchewan	53	51	24	97	6	32	13	2	—
Bathurst, NWT	129	45	15	117	30	82	14	3	—
Dubawant, NWT	13	26	16	48	8	5	—	—	—
Yellowknife, NWT	28	59	34	94	0	17	10	1	—
All lines	496	57	15	579	65	280	111	31	9
%	100				13	56.5	22.5	6	2
Accumulative %					13	69.5	92	98	100

Three ground-swing curves for the line Whitemouth - Seddons are shown in figure 1. The three measurements were made at Seddons with the tellurometer in different positions, giving different separations between the tellurometer ray and a steel beam on the tower. The curves are typical of ground-swing curves for lines measured from steel towers. Following is a summary of ground swing and length data for this line.

Distance Tel. ray to Steel Beam (cm)	Number of Observations	Mean Ground Swing (cm)	Observed Length (m)	Observed — Adjusted	
				(metres)	(ppm)
2.5	1	213	19 669.71	— 0.03	— 1.5
14	1	160	19 669.88	+ 0.14	+ 7.1
27	6	95	19 669.83	+ 0.09	+ 4.6

The spread among the observed lengths is not large, so that an appreciable ground-swing error cannot be detected.

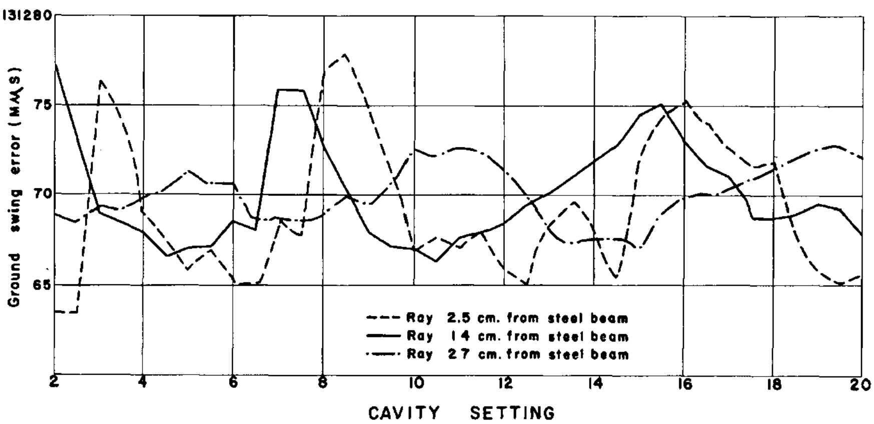

FIG. 1. — Ground swing curves : Whitemouth-Seddons (steel tower)

Adjusted values are given for 14 of the lines listed in Table II. The only line with a large discrepancy between observed and adjusted lengths is St. Clair - Richmond, and this discrepancy is 0.40 m or 14 ppm. If the transit time corresponding to the adjusted length is plotted on the mean ground-swing curve it falls completely outside the curve, so that the apparent error on this line can be only partly due to the large ground swing.

From the data available there is no evidence that large ground swings on lines measured from steel towers result in appreciable errors in measured length. However, large ground swings can and should be reduced by offsetting the instrument to reduce or eliminate the effect of steel beam reflectors. Offsetting the instrument would be especially desirable in the case where large ground swing is caused by reflections from a steel tower and another reflecting surface such as water.

TABLE II

Tellurometer Lines Measured From Steel Towers

Line	Number of Observa-tions	Mean ground swing (cm)	Range of swing (cm)	Observed length (m)	Observed minus adjusted (m)
Sisters* - MacKendrick	4	136	107-153	30 587.88	
Tomahawk - MacKendrick	4	99	67-120	22 504.43	
Sisters* - Taxis	4	113	110-120	25 907.91	
Gilks - Taxis	4	92	60-120	38 730.38	
Gilks - Tomahawk	4	102	82-123	39 009.46	
Blackville - Tomahawk	4	138	121-155	42 190.80	
Blackville - Lockstead*	4	92	73-120	20 718.44	
Ashton - Rosaireville	4	106	99-116	47 654.57	
Plantagenet - Vankleek	5	102	90-135	30 462.34	— 0.10
Jones - Redditt**	7	126	111-145	20 753.25	+ 0.05
Jones - Kenora**	13	127	75-205	30 874.41	+ 0.03
Whiteshell* - Nutimik	6	114	96-153	21 566.12	— 0.01
Whitemouth* - Seddons	8	112	66-213	19 669.83	+ 0.09
Whitemouth* - Contour	6	108	87-120	13 015.73	+ 0.08
Natalie*** - Seddons	8	98	87-119	14 290.31	+ 0.01
Vivian* - Seddons	6	91	76-175	27 900.25	— 0.01
Contour - Richer*	8	93	72-112	34 901.90	+ 0.12
Stony - Orpa	5	108	81-162	7 711.20	+ 0.02
Baldy - Harry	4	92	79-112	38 001.24	
Archer - Hump	6	97	58-146	36 610.36	
St. Clair - Woodbine	4	106	90-124	9 482.34	+ 0.12
St. Clair - Richmond	5	98	86-109	28 793.50	+ 0.40
St. Clair - Imperial***	4	91	77-105	13 590.60	+ 0.08
Steeles - Dufferin	6	113	90-150	9 162.97	+ 0.06

* timber towers. ** ground station. *** roof top.

LINES MEASURED BETWEEN GROUND STATIONS

As mentioned previously, data on the 16 lines measured between ground stations, and having mean ground swings larger than 90 cm, is given in Table III. Normal measurements between station markers were made on all but one line and eccentric measurements were made on 11 lines. The range of ground swing for individual regular measurements is 73 to 768 cm and for eccentric measurements it is 45 to 300 cm. Adjusted lengths are given for 11 of the 16 lines.

Theoretical considerations

According to electromagnetic propagation theory, the signal received at a tellurometer station consists of two or more components, the direct ray and one or more ground reflected rays. The phases of the rays are different upon arrival but the receiver processes them as a single resultant phase. The difference between this resultant phase and the phase of the direct ray is ground-swing error.

TABLE III

Tellurometer Lines With Large Ground Swings Sighted Between Ground Stations

Line	No. of Obs.	Peak-to-peak Ground Swing (cm)				Main Reflecting Surface	dl (m)	Observed Length (metres)	Observed minus adjusted (m)
		Observed			Theor-etical				
		Mean	Min.	Max.					
Fer - Mussett	5	689	486	768	315	Lake	5.8	27 285.58	+ 0.12
Fer - Mussett (2 m ecc)	3	236	175	300				27 285.31	— 0.15
Ekalulia - Mix	3	240	180	300	305	Sea	3.9	31 212.67	
Ekalulia - Mix (11 m ecc)	4	117	71	144				31 212.38	
Shabogamo - Hermine	4	449	191	731	295	Lake	2.1	17 516.61	+ 1.41
Shabogamo - Hermine (10 m ecc)	1	268						17 516.65	+ 1.45
Astray - Marble	4	185	170	202	270	Lake	1.4	24 035.97	— 0.03
Berry Hill - Green Tree	4	91	84	99	140	Lake	0.4	30 531.24	
Hermine - Whiteman	4	102	93	112	170	Swamp	2.4	14 261.08	+ 0.03
Albert - Trader	4	105	84	142	70	Swamp	0.4	32 906.46	— 0.40
Albert - Trader (9 m ecc)	1	80						32 906.40	— 0.46
Squaw - Cayer	14	115	80	153	120	Land	5.1	10 596.49	+ 0.03
Squaw - Cayer (6 m ecc)	5	85	45	118				10 596.51	+ 0.05
Ribero - Otelnuk	4	110	102	128	85	Land	2.5	21 672.22	+ 0.07
Ribero - Otelnuk (4 m ecc)	1	90						21 672.17	+ 0.02
Fer - Hare	6	186	120	232	85	Land	2.4	26 339.22	— 0.21
Fer - Hare (6-16 m ecc)	3	60	54	67				26 339.10	— 0.33
White - Fish	6	159	130	189	85	Land	2.3	13 019.55	— 0.01
White - Fish (9 m ecc)	2	126	120	132				13 019.60	+ 0.04
Rapids - High	4	93	85	100	65	Land	1.1	30 935.94	— 0.19
Rapids - High (6 m ecc)	2	98	87	108				30 935.70	— 0.43
High - Manitou	4	189	165	202	20	Land	0.2	39 927.94	+ 0.19
High - Manitou (6 m ecc)	1	186						39 927.81	+ 0.06
Axle - Och (23 m ecc)	4	109	82	120	100	Sea ice	0.2	23 373.64	
Grate - Ember	4	94	73	109	50	Sea ice	0.1	19 654.24	
Royce - Camp Hughes	7	112	78	147	—	Unknown	—	34 141.87	— 0.13

Ground-swing error is a function of path length difference, dl (reflected ray — direct ray, in metres), the reflection coefficient of the reflecting surface, and the modulation and carrier frequencies of the tellurometer. The modulation frequency is constant and the carrier frequency may be varied in steps over a known range (cavity tune) so that for any line, ground-swing error may be determined if dl and the reflection coefficient are known. The reflection coefficient can be represented by a complex number whose magnitude is the ratio of signal intensities of reflected ray to direct ray, and whose phase angle is the phase shift in the reflected ray caused by the reflecting surface.

WADLEY [1] of Tellurometer Ltd. in South Africa and PODER [2] of Denmark have published formulae for computing ground-swing error. PODER's formula, which assumes that a single reflected ray is present with the direct ray, is as follows:

$$X_M = \text{Arc tan}\left[\frac{a_T \sin 2\pi F_R Q\,(\cos x + a_T)}{1 + \{(1 + \cos 2\pi F_R Q)\, a_T^2 \cos x\} + a_T^2 \cos 2\pi F_R Q}\right]$$

and $x = 2\pi\, f_R Q + r_T$

where

X_M is ground-swing error for the outgoing ray path in angular measure;

a_T is the magnitude of the tellurometer reflection coefficient corrected for divergence;

r_T is the phase angle of the reflection coefficient (approximately $-\pi$);

F_R is the Remote modulation frequency (cycles/sec.);

Q is the transit time in seconds corresponding to the path length difference dl in metres;

Q = dl/c, where c = propagation velocity = 2.998×10^8m/sec.;

f_R is the Remote carrier frequency in cycles/sec.

X_M is a minimum for $x = \pi, 3\pi, 5\pi$, etc. and a maximum for $x = 0, 2\pi, 4\pi$, etc.

X_R, ground-swing error for the returning ray path, is computed in the same manner as X_M. The total ground-swing error on a measurement is the vector sum of $X_M + X_R$ with an angular displacement in x of $2\pi \cdot 33 \cdot 10^6 \cdot Q$.

For small grazing angles, a_T is of the order of 0.9 for reflections from water and 0.3 for reflections from land. The phase angle, r_T, is approximately equal to $-\pi$. The reflection coefficient can be estimated much more accurately for water than for land reflecting surfaces.

In computing ground-swing error, the magnitude of dl determines the number of cycles of ground-swing error that will be developed over the tellurometer carrier frequency range, and is approximately $1.3 \times$ dl, with dl in metres. The magnitude of ground-swing error is determined by dl and a_T.

By assuming the presence of a single reflected ray path, the theoretical ground-swing error on a line may be readily computed. However, before applying a correction for this error, it must be established that the line corresponds closely to the theoretical case. Information in this regard may be obtained from a line profile diagram and from the observed data. The line profile shows the possible reflecting surfaces and the observed data provides the actual ground-swing curve and other pertinent information regarding the measurement. If difficulty is experienced in taking fine readings, because of low AVC at cavity tune settings where the theoretical X_M and X_R are minimums, the indication is that the line closely approximates the theoretical case. At these cavity tune settings it is possible to observe large positive values of ground-swing error if a second, weak, reflected ray is present as well as a strong, main reflected ray.

On many lines multiple path reflections are present and the ground-swing curves are complex. In such cases the true theoretical ground-swing error cannot be determined. However, it appears that the mean ground-swing error on a line tends towards zero as the number of multiple reflections increases. In general, a line with a complex ground-swing curve should have a negligible ground-swing error if the observed length is computed from the mean of a large number of fine readings. However, some ground-swing error will be present on a line where only a few reflected rays are present and an integral number of cycles of swing are not developed.

The sixteen lines shown in Table III may be classified according to the reflecting surface for the main reflected ray. These are sea and lake water, swamp, land, sea ice, and unknown structures. The theoretical ground swing given is the peak-to-peak ground-swing error computed on the assumption of the presence of a single reflected ray. Reflection coefficients used were of the order of 0.9 for water and ice reflecting surfaces, 0.6 for swamp, and 0.3 for land.

Lines passing high over water

The first two lines in the table are located high over water, having path length differences of 5.8 and 3.9 metres respectively. These lines have large ground swings and the large dl values indicate that a large number of cycles of swing are developed over the tellurometer frequency range.

The theoretical ground-swing-error curve for the line Fer - Mussett is shown in figure 2. It somewhat resembles a sine curve with unequal positive and negative peaks. The observed fine readings minus the adjusted value for one measurement are shown in the figure as small circles. It is seen that the 37 fine readings taken are too few to establish the true observed ground-swing curve, and that perhaps a hundred fine readings would be required to do so.

On the theoretical curve, mean ground-swing error corresponds to the horizontal line that equally divides the area under the curve. For each of the two lines the theoretical ground-swing error is $+ 0.67$ m.

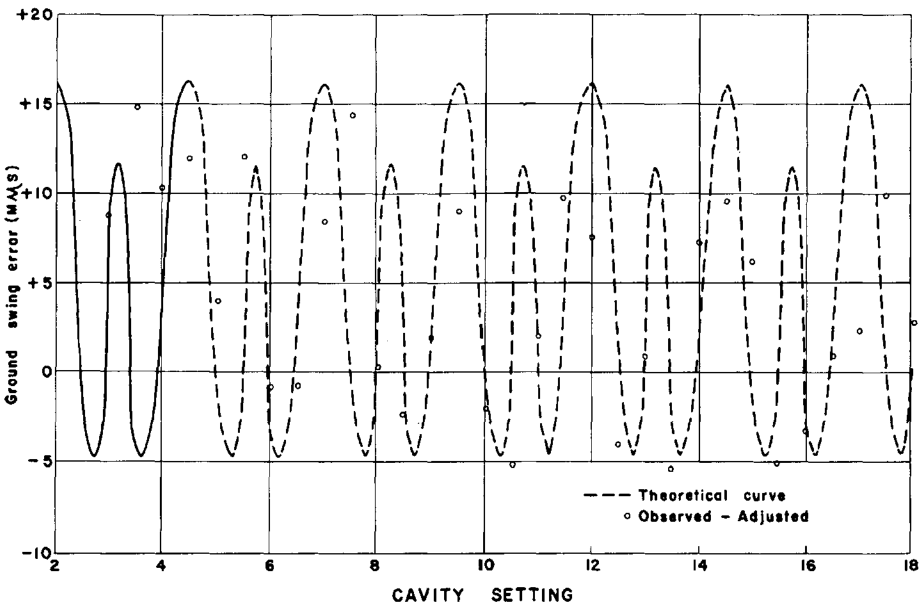

FIG. 2. — Ground swing error : Fer-Mussett.

Eccentric measurements on both lines have less than one half the ground swing and their mean lengths are about 1 part in 10^5 shorter than the regular observations. The adjusted value for the line Fer - Mussett is midway between the means of the eccentric and regular measurements. This evidence indicates that only a small positive ground-swing error may be present on these lines. Also, since too few fine readings were taken to establish the true nature of the ground-swing curve, no correction for ground-swing error should be applied.

Lines at medium height above water

The next two lines in Table III, Shabogamo - Hermine and Astray - Marble, pass at a medium height above water and have path length differences of 2.1 and 1.5 metres respectively. The line profile and theoretical and observed ground-swing-error curves for the line Astray - Marble are given in figure 3, and error curves for the line Shabogamo - Hermine are shown in figure 4.

PODER's method for determining ground-swing error for lines with path length difference of this order is to obtain the mean ground-swing error from the flat positive portion of the theoretical curve and apply the correction to the mean of the corresponding observed readings.

The observed ground-swing curve for the line Astray - Marble resembles the theoretical curve but has a smaller amplitude. This is probably due to the presence of multiple reflection paths, which are also indicated by the fact that there was no difficulty in observing fine readings at all cavity

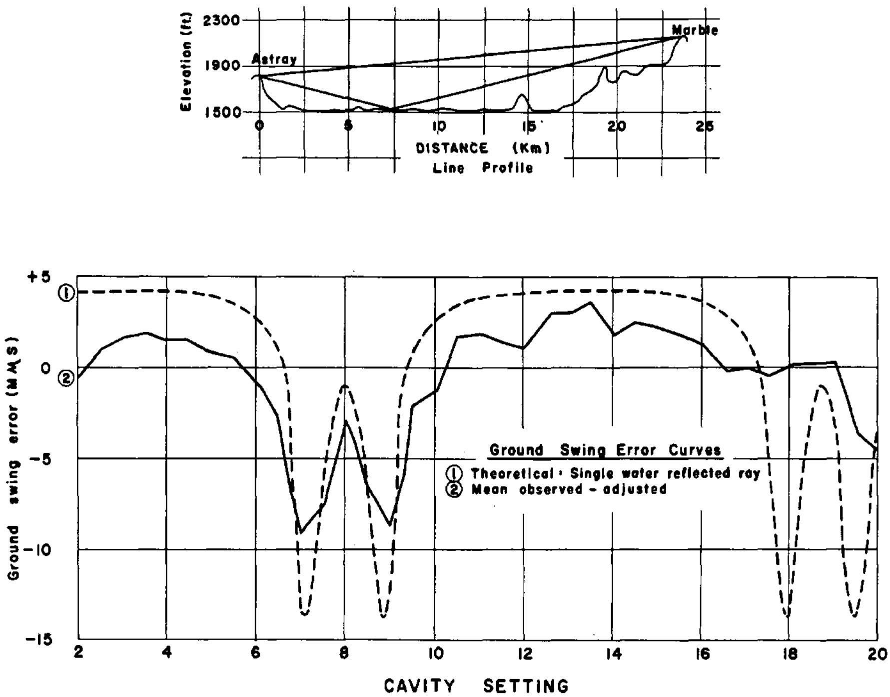

FIG. 3. — Data for line Astray-Marble

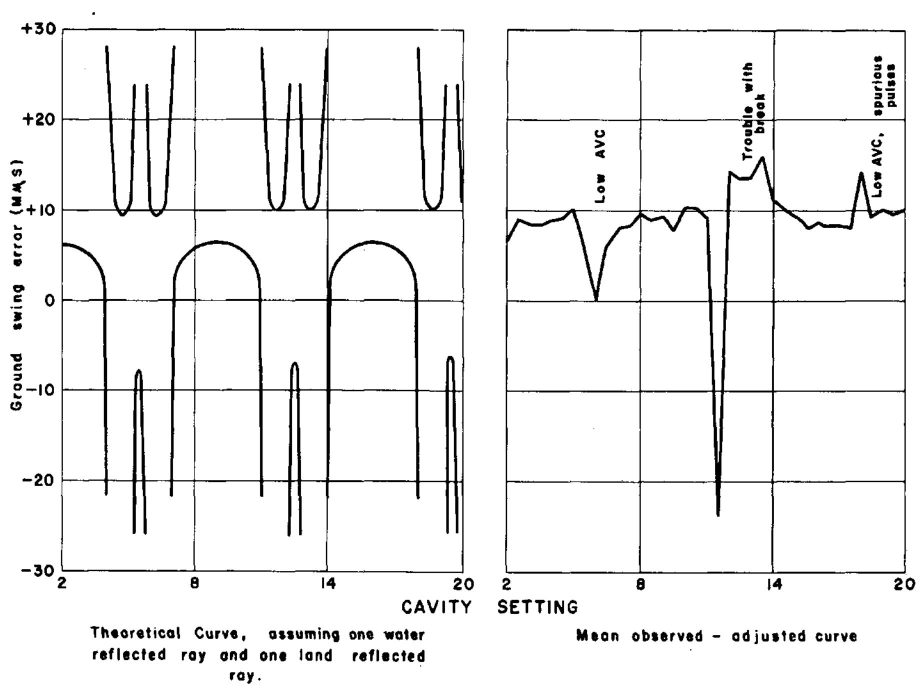

FIG. 4. — Ground swing error curves : Shabogamo-Hermine

tune settings. With multiple reflections present the actual ground-swing error cannot be determined and the theoretical error based on the presence of a single reflected ray, + 31 cm for this line, is not applicable. This is confirmed by the good agreement between the observed and adjusted lengths.

The theoretical ground-swing-error curve for the line Shabogamo - Hermine, shown in figure 4, is computed on the assumption that a weak land-reflected ray is present in addition to the strong water-reflected ray is present in addition to the strong water-reflected ray. The curve is obtained by replacing cos x in the formula for X by $\cos x + a_2 \cos (x - x_2)$, where a_2 is the reflection coefficient of the second reflecting surface and x_2 is a function of the Q for this surface. The flat positive portion of the curve is almost identical with that on the theoretical curve for which only the water-reflected ray is assumed. The remarks pertaining to low AVC, break trouble, and the presence of spurious pulses were recorded in the field notes at the cavity settings where instability of transit time observations are indicated on the theoretical curve. The observed ground-swing curve represents mean observed values minus adjusted value. During measurement, many observations at the difficult cavity settings were omitted and for others the cavity setting was shifted by one half of a normal division.

The difficulty experienced in observing at certain cavity settings is an indication that the line very nearly corresponds to the theoretical case, and a correction based on the theoretical ground-swing error should be applicable. The theoretical error is + 1.0 metre. The corresponding correction would considerably improve the agreement between the measured and adjusted lengths, since the uncorrected observed length is 1.4 metres longer than the adjusted length.

The single eccentric measurement on this line has a slightly smaller ground swing but its length agrees well with the regular observations.

Berry Hill - Green Tree is the only other line whose profile diagram indicates that the main reflecting surface is water — in this case a small lake. The observed ground-swing curve is complex and it is probable that little, if any, ground-swing error is present.

Lines passing over swamp

Line profiles for the lines Hermine - Whiteman and Albert - Trader indicate that swamps are the main reflecting surfaces, with hills providing other possible reflections. The observed ground-swing curves are complex.

The theoretical and observed ground-swing-error curves for the line Albert - Trader are shown in figure 5. With a path length difference of 0.4 metre only about one half cycle of ground swing is developed over the tellurometer cavity range. The theoretical curve consists of the negative portion of a cycle and resembles somewhat the observed ground-swing curve. A negative ground-swing error is indicated but it is very unlikely that the discrepancy of 0.4 metre between the adjusted and observed lengths is due entirely to ground-swing error.

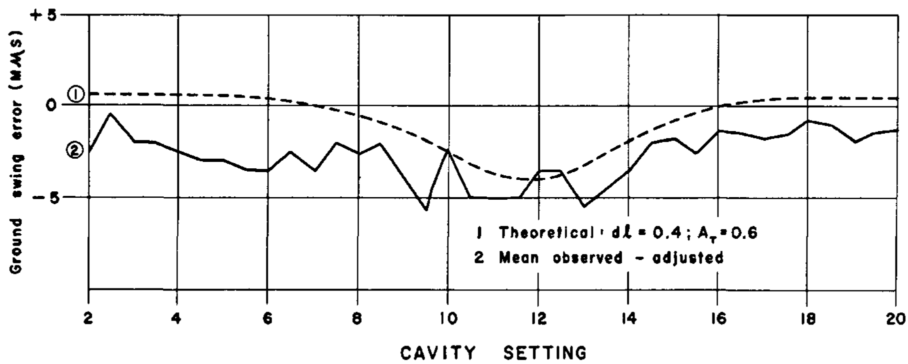

FIG. 5. — Ground swing error curves : Albert-Trader

Lines over land

The next six lines listed in Table III have land as the main reflecting surface. Computed path-length differences are in the range 0.2 to 5.1 metres, and because of the small reflection coefficient for land the ground swings are smaller than for lines over water. The observed ground-swing curves are all complex, indicating the presence of multiple reflected rays. On lines having large observed ground swings compared with the theoretical values, there are probably rays present that are reflected from surfaces having large reflection coefficients.

The line in this group that most nearly resembles a theoretical case is White - Fish. The theoretical and observed ground-swing-error curves are

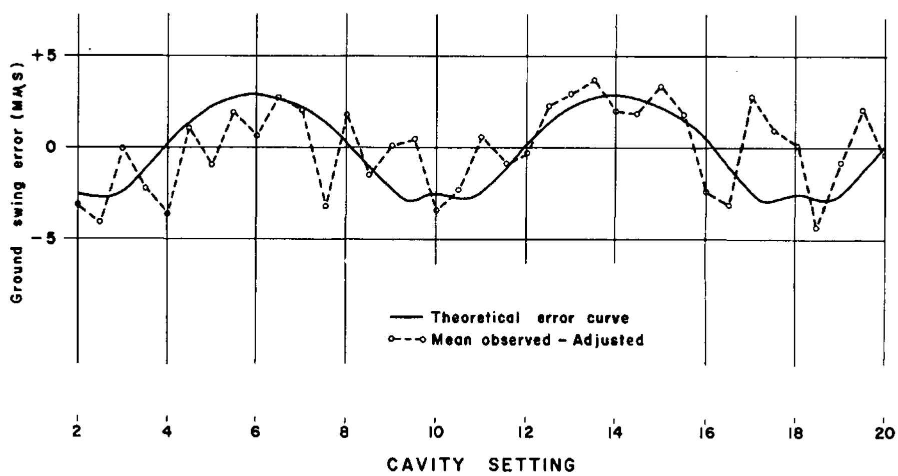

FIG. 6. — Ground swing error curves : White-Fish

shown in figure 6. The theoretical ground-swing-error curve is nearly sinusoidal with a mean error of approximately zero. The observed and adjusted lengths are in good agreement, thus confirming the absence of a significant mean ground-swing error.

On most lines in this group, eccentric measurements have slightly smaller ground swings, and the observed lengths fall within the range of the regular measurements. However, an exception is the line Rapids - High, where two measurements with 6-metre eccentrics had a slightly larger mean ground swing and a mean observed length 0.24 metre shorter than mean observed length of the regular measurements. The overall spread of measurements on this line is less than one part in 10^5 so that it is possible that the discrepancy is due to factors other than ground swing.

Discrepancies between observed and adjusted lengths for lines in this group are small and indicate that there is no appreciable ground-swing error on lines passing over land. This is probably due to the large number of multiple reflections present.

Lines passing over sea ice

The next two lines in Table III, Axle - Och and Grate - Ember, are located low over sea ice. Reflection coefficients for water were used in the computation of ground-swing errors. The theoretical and observed ground-swing curves for the line Axle - Och are shown in figure 7. The path length difference is of the order of 0.2 metre and only one third of a cycle of theoretical ground-swing error corresponds to the whole tellurometer cavity range. The negative peaks of X_M and X_R are only 8° apart and the resultant is a single negative peak. A complete cycle of theoretical ground swing therefore consists of one negative peak and a long flat positive section. As shown in figure 7 the observed ground-swing curve has two negative peaks.

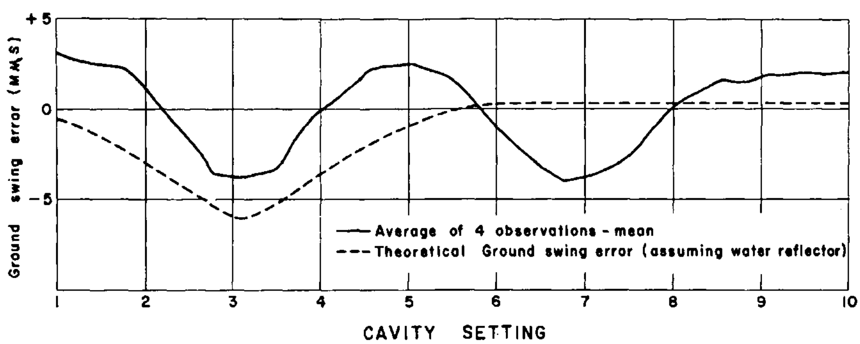

Fig. 7. — Ground swing error curves : Och-Axle (over ice line)

The relative position of the negative peak on the theoretical curve is very dependent on the path-length difference, dl, which in turn is a function of elevations of the stations and the reflecting surface. A change in dl of 1.6 cm, corresponding to a change in reflector elevation of 2 metres, causes the negative peak to shift from one to the other of the negative peaks on the observed ground-swing curve. According to data obtained from the National Research Council, the tellurometer ray is reflected from snow on top of the ice if the snow is packed, or from the ice surface if there is no snow cover or if the snow cover is loose. A snow cover of only one foot was reported during measurement, so that the two negative peaks on the observed ground-swing curve cannot apparently be explained by the presence of two reflecting levels.

The line Axle - Och was measured from eccentric stations because readings could not be taken at high cavity settings when the instruments were at the station markers. No eccentric measurements were made on the line Grate - Ember. This line has a smaller path-length difference but its observed ground-swing curve is similar to that of Axle - Och, with the excéption that the second negative peak is only partly developed.

Data from the two lines indicate that lines sighted over ice are difficult to measure unless the path-length difference is very small. More data on such lines is required, as is an explanation of the two negative peaks on the observed ground-swing curve.

Line passing over flat terrain with an unknown reflector

The last line in Table III is Royce - Camp Hughes. It passes over flat terrain and the ground-reflected ray has negligible path-length difference. One end of the line passes over the city of Brandon, Manitoba, and it is thought that some structure situated in or near the city is acting as a reflector and causing the large ground swing on the line. The ground-swing curves for the individual measurements are complex. Their relative phases are nearly identical, indicating that the reflecting surface is very stable. The agreement between observed and adjusted lengths is very good; so it appears that there is no significant mean ground-swing error.

CONCLUSIONS

Of the 40 lines with ground swings larger than 90 centimetres, 24 were measured from steel towers. Comparisons between adjusted and observed lengths on these lines indicate that errors due to large ground swings are not appreciable. However, ground swings can be reduced considerably by making eccentric measurements.

The remaining 16 lines were measured from ground stations and had large ground swings because of reflections from water, ice, swamp, land, and, in one case, an unknown structure. Lines passing high over water have the largest ground swings and a large number of fine readings are required adequately to establish the ground-swing curve and minimize ground-swing error. Lines located over land have smaller ground swings and the ground-swing curves are complex. Lines passing over ice can be measured only if the path-length differences are very small.

Theoretical ground-swing error based on the assumption of a single reflected ray can be readily computed but in most cases is not applicable because of the presence of multiple reflections. For only one line was it apparent that actual line conditions resembled the theoretical case, making the theoretical error valid. In general, the larger the number of multiple reflections present, the more complex the observed ground-swing curve and the smaller the mean ground-swing error.

Eccentric measurements generally have smaller ground swings but agree in length with regular measurements. Measurements with larger eccentrics should be made on lines suspected of large ground-swing errors.

References

[1] Tellurometer Aerodist Manual, Tellurometer (Pty) Ltd., 1962.
[2] *Reflections*. Paper by Knud PODER, presented at the Tellurometer Symposium held in London, England, July 30-August 3, 1962.