DISTANCE MEASUREMENTS IN THE
KRAFLA-GJASTYKKI GEODIMETER NETWORK,
MARCH 1978 TO MAY 1979

BY

EYSTEINN TRYGGVÁSON

REYKJAVIK
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INTRODUCTION

The Nordic Volcanological Institute (N.V.I.) established a network of stations for precise distance measurements in the Krafla-Gjáestykki area in North Iceland in early 1977. The purpose of this network was to observe ground movements caused by the volcano-tectonic episode which started in that area in 1975 (Björnsson et al., 1977).

When this distance measuring program of the N.V.I. was started, five rifting and/or subsidence events had already taken place and large scale ground movements had been observed (Tryggvason, 1980). Several more subsidence events have occurred since the program started, and efforts have been made to observe the network after each event.

The network of stations covers only a fraction of the Krafla fissure swarm. The choice of area of investigation was based on the location of ground rifting during the subsidence events in late 1976 and early 1977. The stations were placed along eight irregular lines crossing the fissure swarm. Each line was about 5 km long, reaching about one km outside the zone of intense faulting (the fissure swarm).

Addition of several stations in 1978 and 1979 to the west and north of the original network has extended the area of investigation to that shown on Fig. 1. The total area covered by the network of stations is now about 25 km long in N-S direction and about 7 km wide.

THE NETWORK OF STATIONS (Fig. 1)

The first network of stations was constructed in February 1977 by Halldór Ólafsson and Sigurjón Sindrason of the N.V.I. The stations are identified by steel rods hammered into the volcanic rock until the top is about 5 cm above the rock surface. Another steel rod was placed about 1 m to the north of each station. It stands about one m high and is there for
Fig. 1. The network of stations in the Krafla-Gjástykki area, North Iceland, for the distance measuring program of the Nordic Volcanological Institute, as of late 1979.
easier visual detection of the station. Each station was given a number and the letter A (A001, A002, ..., A043). Three of the original stations (A039, A041, and A043) were never occupied, and are not shown on Fig. 1.

The station A003, on Leirhnjúkur was constructed by the National Energy Authority (N.E.A.) and consists of copper rod. It is identified by the N.E.A. as 5590 or LH. The station A024 on Sandmúli was placed close to the N.E.A. station 5593 or SM, and both stations have been used by the N.V.I. The station constructed by the N.V.I. and marked with a steel rod is in this report identified as A024A, while the N.E.A. station 5593 is here named A024B. The distance between the twin stations A024A and A024B is 2.535 m. The station A006 has been used by N.E.A. and then named "KN".

The stations added in 1978 and 1979 to the north and west of the original network are identified as NE77005 through NE77013. Most of them are made of copper rods, cemented in holes drilled in solid bedrock, but the stations NE77011 and NE77013 are made of steel rods as the stations A001 through A043. The station NE77012 was established by N.E.A. and it is identified by them as "HSH".

The coordinates, in the Iceland geodetic system (landsnet), of the N.E.A. stations 5590 (A003) and 5593 (A024B) were determined in 1974 as follows:

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude (m N)</th>
<th>Longitude (m W)</th>
<th>Height (m)</th>
</tr>
</thead>
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<td>444516.86</td>
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</table>

Measurements in September 1977, after the subsidence event of September 8 to 9, gave the approximate coordinates of the stations 5590 (A003), KN (A006), and HSH (NE77012) as follows (Gunnar Thorborgsson, personal communication):

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude (m N)</th>
<th>Longitude (m W)</th>
<th>Height (m)</th>
</tr>
</thead>
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The two stations, NE79077, and NE79078 were added in late 1979 to the south of the original network of stations.
They are shown on Fig. 1, but were not included in the measurements reported here.

THE OBSERVATIONS

The first measurements of the Krafla-Gjástykki network were made in late February and early March 1977. The N.V.I. contracted the engineering firm Hnit to conduct the measurements with their own instruments, a distomat with a range of up to 2 km, and two theodolites (T2 and T16). The N.V.I. acquired their own instruments in the summer of 1977, a geodimeter model 6BL with a range of more than 20 km, and a theodolite model Wild T2. These instruments have been used in all subsequent distance measurements in the Krafla-Gjástykki area.

The procedure followed in the measurements in 1977 was to follow a zig-zag line with one backward and one forward measurement from each station. Beginning in March 1978, a new procedure was used. This implied the use of only a few geodimeter stations, with a number of measurements from each. Most of the stations were occupied only by reflectors. In addition to the distance measurements, the vertical angle from geodimeter station to reflector station is generally observed with a theodolite. This gives the elevation difference of the stations, and also a crude determination of vertical displacements of the stations.

A total of 15 distance measuring expeditions were made to the Krafla-Gjástykki network from February 1977 to May 1979. The dates of these expeditions, and number of lines measured were as follows:

- February 26 to March 3, 1977: 39 lines
- July 19 to 21, 1977: 14
- August 14, 1977: 4
- October 23 to 26, 1977: 8
November 25 to 30, 1977 16 lines
March 10 to 18, 1978 78 "
April 16 to 19, 1978 27 "
June 25 to 27, 1978 30 "
July 11, 1978 2 "
July 20 to 22, 1978 26 "
August 4 to 8, 1978 79 "
August 29 to 30, 1978 21 "
February 20 to March 3, 1979 52 "
May 11 to 12, 1979 11 "
May 19 to 28, 1979 33 "

This is a total of 440 distance measurements, 81 in 1977, 263 in 1978 and 96 in early 1979. Four more measuring expeditions were made to this area in late 1979, but the results obtained during these measurements are not included in the present report.

All these measurements, except those of February and March 1977, have been made by the staff of the N.V.I. Eysteinn Tryggvason has measured about 300 lines in 7 expeditions, Karl Grønvold about 80 lines in 5 expeditions and Gudmundur E. Sigvaldason about 20 lines in 2 expeditions. Most of the scientific and technical staff members of N.V.I. have participated in one or more of the expeditions.

The air temperature and pressure is observed at the geodimeter stations, and usually also at the reflector stations. These temperature and pressure observations are used to correct the observed distances. Sometimes, especially if the wind is calm and sky is clear, the temperature along the direct line between geodimeter and reflector may differ significantly from that observed near ground at either station. This will cause errors in the reduced distances, which may amount to about 10 mm if conditions are very unfavourable.

The corrected distance between geodimeter and mirror is reduced down to the station markers using equations given by Tryggvason (1978). The elevation difference of the stations is calculated from the observed vertical angle,
theodolite and target heights above the markers and the corrected distance. The station elevation as calculated is inaccurate. It is based on the assumption that station A010 is at 600.00 m elevation. This was nearly correct elevation in early 1977, but the reference station has subsided, especially during the subsidence events of April 1977 and September 1977. The correct elevation of the station A010 in 1978 and 1979 is not known, but it probably lies between 597 and 598 m.

During most of the measuring expeditions only a portion of the network of stations was covered, most frequently the southern part. The whole network, or most of it, has been measured four times. First on February 26 to March 3, 1977, next in two expeditions on March 10 to 18 and April 16 to 19, 1978, and again in two expeditions on July 20 to 22 and August 4 to 8, 1978, and finally in two expeditions on February 20 to March 3 and May 11 to 12, 1979.

THE RESULTS

The corrected distances obtained in 1978 and early 1979 are given in Table I in appendix. The results of the 1977 measurements have been reported earlier (Tryggvason, 1978). As the purpose of these distance measurements is to observe ground deformation, and changes in distances due to the ground deformation is only a very small fraction of the length, it is of utmost importance to keep observational errors as small as possible. It is also of utmost importance to know the probable errors of the observed distances in order to draw intelligent conclusions based on the observed distance changes. Estimates of the observational errors can be based on estimates of individual error components, such as errors in the temperature corrections, but these error components cannot be accurately estimated. Another
method is to correlate the observed distance between two markers at different times with some other measured quantity, such as tilt or observed distance between another pair of stations. Comparison of observed tilt at the Krafla power house and observed distances in the southern part of the Krafla-Gjástykki network shows a linear relation between these quantities. Taking the line A001-A002 as an example. The length of this line changed permanently in September 1977 (Tryggvason, 1980), so only the 7 measurements made after the subsidence event of September 1977 are considered. The observed line length correlates well with the readings of the water tube tiltmeter at the Krafla power house, with a coefficient of correlation $r^2 = 0.983$. The maximum change in line length is 302 mm and the corresponding change in the tiltmeter reading is 14.125 mm or 205 µ-rad. The standard deviation of the observed line length from the best linear trend is 12.8 mm.

If it can be assumed that an exact linear relation exists between the length of the line A001-A002 and the tilt at the Krafla power house, then this deviation is entirely caused by observational errors in distance and tilt measurements. The error in the tilt observations is small, certainly less than 0.1 mm, but the observed tilt may not correspond exactly to the regional tilt in the area of the power house. Thus the conclusion of these arguments is that the observational error in the length measurement on the line A001-A002 is less than 12.8 mm (standard error).

Similar study of the lines A002-A003, A003-A005, and A010-A012 for the period July 1978 to February 1979 (four distance observations), indicate that the error of observed distances is generally less than 5 mm, and that the linear relation between distances and tilt changes during some subsidence events.

The observational error certainly depends on the line length, although other factors contribute also. If the standard error $S$ can be expressed as: $S = a + bL$, where a
and b are constants, and L is the length of the measured line, then the constant a should be less than 4 mm, and the constant b should not be greater than 2·10^{-6}.

If two distance observations of the same line differ more than three times the standard error of individual observation, then there is about 95% probability that actual length change occurred. According to the arguments above, this means that the observed distance difference D must be greater than 12 + 6L mm, where L is the line length in km, for the length change to be significant.

The results of the distance measurements in the Krafla-Gjástykkí area are tabulated in appendix. Significant length changes were observed on most of the lines of repeated measurements. Distances between two stations can frequently be calculated from distance measurements involving other stations. Thus changes in distance between stations can occasionally be obtained even if it is not measured.

REFERENCES


APPENDIX

Table I. The corrected distance (slope distance) between station markers and calculated elevation difference of station markers as measured in 1978 and early 1979 in the Krafla-Gjástykki network of stations for precise distance measurements. The horizontal distance between stations at sea-level is also given.

Table II. Coordinates of stations in the Krafla-Gjástykki network of stations for precise distance measurements, calculated from observations in 1978. The coordinates are in a local net with origin at station A003, Leirhnjúkur, and fixed direction from A003 to A010. Calculations are based on sea-level distances and the curvature of the earth’s surface is ignored.

Table III. Calculated distances from station A024B, Sandmúli, when measurements were made from station A024A.

Table IV. Change in observed distance between stations from one measurement to the following one which covers the same stations.
### TABLE IA

Measured distances in the Gjástykkí network March 10 to 18, 1978.

<table>
<thead>
<tr>
<th>Stations</th>
<th>Slope distance m</th>
<th>Elevation difference m</th>
<th>Sea-level distance m</th>
</tr>
</thead>
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### TABLE IIA

Coordinates of bench marks in the Gjástykki network as measured March 10 to 18 and April 16 to 19, 1978.

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**TABLE IIB**

Coordinates of bench marks in the Gjástykki network as measured June 25 to 27, 1978.

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TABLE IIC

Coordinates of bench marks in the Gjástykki network as measured July 20 to 22, 1978.

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^x^) Coordinates based on one distance measurement from A012 and theodolite observation for the azimuth from A012.
Coordinates of bench marks in the Gjástykkí network as measured August 4 to 10, 1978.

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TABLE IIIE

Coordinates of bench marks in the Gjástykki network as measured August 29 to 30, 1978.

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<th>Y (north), m</th>
<th>Elevation, m</th>
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TABLE III

Calculated distances from bench mark A024B when measurements were made from A024A.

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A. November 25, 1977

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B. April 16, 1978

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TABLE IV

Observed differences in slope distance between stations ($\Delta L$) and in elevation differences of stations ($\Delta h$) between two geodimeter observations. Positive values of $\Delta L$ mean that last observation gave greater distance than first observation. Positive values of $\Delta h$ mean that last station appears to have been uplifted relative to first station.

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<th>Time of observations</th>
<th>Stations</th>
<th>$\Delta L$ (cm)</th>
<th>$\Delta h$ (cm)</th>
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<td>25</td>
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<td>A003 A004</td>
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<td>15</td>
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<td>13</td>
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<td>A008 A009</td>
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<td></td>
</tr>
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<td>August 4 – 8, 1978</td>
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