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RESURVEY OF BYRD STATION, ANTARCTICA, DRILL HOLE

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The drill hole at Byrd Station, which was surveyed in January 1968 to a vertical depth of 7063 ft (2153 m) below the top of the casing, was resurveyed in January 1975 to a vertical depth of 4835 ft (1474 m). Inclination and azimuth measurements were made with a Parsons multiple-shot inclinometer and compared with the earlier measurements made during drilling. The results indicate a progressively increasing displacement with depth to a value of 51.2 ft (15.6 m) at the 4835-ft (1474-m) level, or about 7.3 ft/yr (2.23 m/yr). The direction of movement relative to the surface varies from southwest at 300 ft (91.5 m) to northeast at 1100 ft (335 m), to east at 3368 ft (1027 m), and to northeast at 4835 ft (1474 m), indicative of a complex twisting motion. An increase in accessible depth along the hole axis of

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18 ft (5.49 m) beyond the 1969 depth was noted. No attempt was made to measure hole diameter or vertical strain. It is recommended that the hole be resurveyed in 3-5 years if it is still logistically feasible, using a better inclinometer.

PREFACE

This report was prepared by Donald E. Garfield, Research Mechanical Engineer, and Herbert T. Ueda, Mechanical Engineer, Technical Services Division, U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL).

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This report was reviewed technically by Dr. Anthony J. Gow of USACRREL.

CONTENTS

ILLUSTRATIONS

RESURVEY OF BYRD STATION, ANTARCTICA, DRILL HOLE

by

D.E. Garfield and H.T. Ueda

INTRODUCTION

The drill hole at Byrd Station (80° 91′S, 119° 31′W) was started in January 1967 and completed in January 1968 to a vertical depth of 7063 ft (2153 m) below the top of the hole casing.* Inclinometer measurements were obtained as drilling progressed during the 1967-68 season with a Parsons single-shot inclinometer located at the upper end of the drill, 83 ft (25.3 m) from the bottom of the drill (Garfield 1968). At a depth of 7063 ft (2153 m), water was encountered. This condition created numerous problems which ultimately prevented any further significant drill penetration (Ueda and Garfield 1969).

One of the problems was the dilution and subsequent freezing of the aqueous ethylene glycol solution maintained in the bottom 1600 ft (488 m) of the hole during drilling. A heavy slush condition began to form and by the following year the hole was essentially inaccessible beyond 5500 ft (1677 m). In 1969, an attempt was made to clear this portion of the hole and redrilling reached a depth of 6930 ft (2113 m) before the drill became stuck. During the redrilling, inclination measurements were taken from 5500 - 6100 ft (1677 - 1860 m) with the single-shot inclinometer (B.L. Hansen, personal communication). The data obtained were not consistent enough to permit any quantitative conclusions, although there appeared to be a slight increase in inclination and a change of direction towards the north for this depth interval.

During the 1969-70 season, an attempt to recover the drill was unsuccessful, and the drill cable was cut off at a depth of 5067 ft (1545 m) along the hole axis and below the top of the casing (Hansen and Garfield 1970). A single inclinometer measurement at a depth of 5055 ft (1541 m) was made, but no conclusions on the ice movement could be drawn from this one measurement.

In January 1975, the hole was surveyed to a depth of 4835 ft (1474 m) from the top of the casing with a Parsons multiple-shot inclinometer. Beyond this depth the range of the instrument was exceeded. Attempts to use the single-shot instrument with a higher range at lower depth were not successful.

Although a complete hole survey would have included hole diameter and vertical strain measurements throughout the hole depth, no attempt was made to obtain these. Since the bore hole was filled with fluid and presumably near equilibrium, the hole diameters would probably not have changed significantly from the last measurements in 1971 (Rogers and Peden 1972). Had the hole cross section changed, it still would not have been possible to orient the change with available instruments.

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*All depths are vertical depths unless indicated as distance along hole axis. The top of the casing was approximately 45 ft (13.7 m) from the 1975 snow surface.

Whillans (personal communication) determined the average vertical strain rate in the vicinity of Byrd Station to be -6×10^{-4} a^{-1} based on his measurement of horizontal surface strains. The vertical strain rate is expected to be higher near the surface than at greater depths. Based on the movement of the drill casing with respect to the tunnel floor, and assuming that the bottom of the 250 ft (76 m) of casing is fixed with respect to the ice at that depth, the average vertical strain rate was found to be -8.75×10^{-4} a^{-1} over this 250-ft (76-m) interval.

To our knowledge, the only technique to measure the ice sheet or glacier vertical strain at greater depths was developed by Rogers and LaChapelle (1974). This method entails placement of metal rings at measured intervals in the drill hole and use of an electronic sensor to detect the change in location of these rings at subsequent time intervals. However, use of this technique for the Byrd drill hole would not be feasible at this time because of the wide variations in hole diameter, as well as other factors.

EQUIPMENT

Multiple-shot inclinometer

The multiple-shot instrument was purchased several years ago and has been used in other bore holes in ice (Gow 1963; B.L. Hansen, personal communication). The position of a plumb bob and its magnetic bearing are photographically recorded on 10-mm film. A small electric motor-driven mechanism within the unit is actuated from the surface to advance the film and energize the exposure bulbs. The graduated range of the instrument is 7°, but for this operation the calibration was extended to a maximum range of 12°. Because of the magnetic compass, the unit cannot be used in the vicinity of ferrous materials such as inside the steel-cased portion of the drill hole. Conventional Eastman-Kodak Tri-X film, 16 mm reduced to 10 mm with a slitter, was used for this operation. Fifty exposures/ft (0.3 m) of film can be obtained, with about another foot (0.3 m) needed for spooling.

The camera and inclinometer assembly are shown in Figure 1. Figure 2 shows the pressure-tight housing within which the inclinometer is mounted. The housing is suspended from an electromechanical cable. A typical measurement photograph is shown in Figure 3.

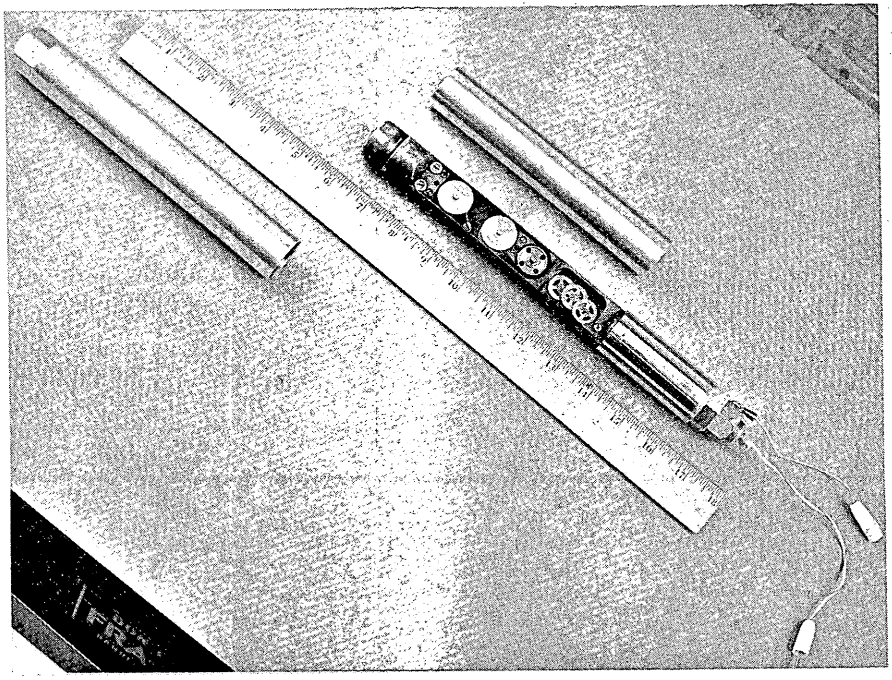


Figure 1. Inclinometer assembly showing 10-mm film camera.

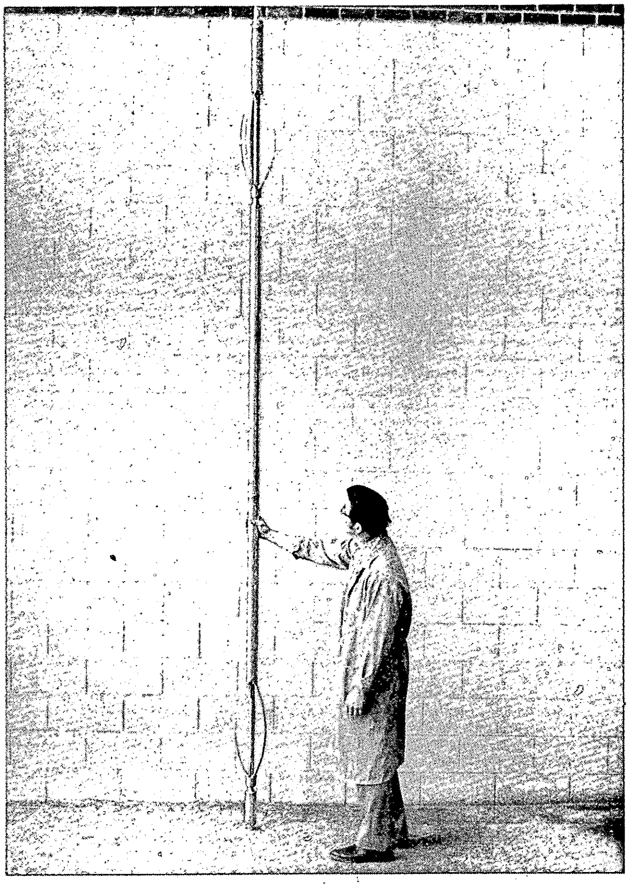


Figure 2. Pressure-tight housing within which inclinometer is mounted.

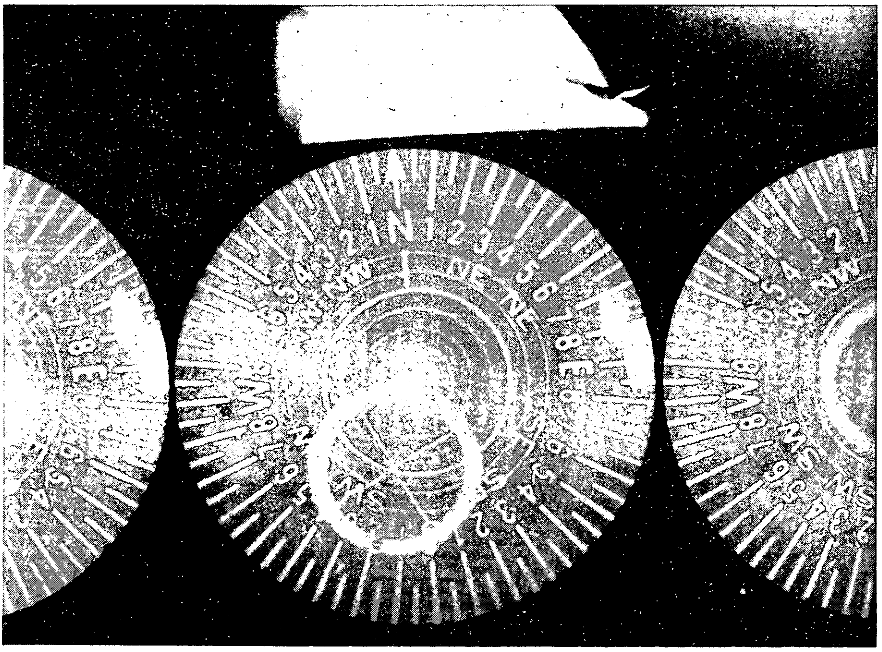


Figure 3. Typical multiple-shot measurement exposure.

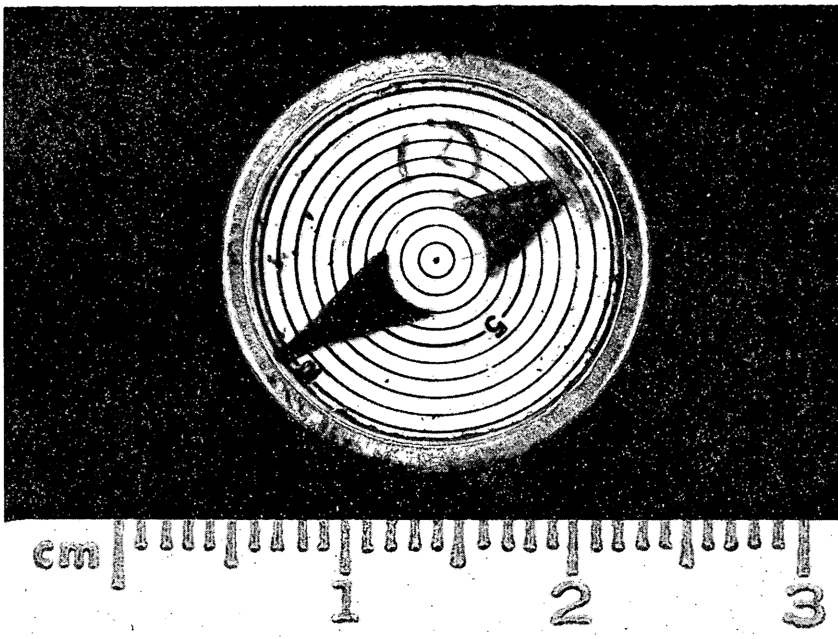


Figure 4. Typical single-shot measurement exposure.

Single-shot inclinometer

The single-shot inclinometer was also purchased several years ago and has been used extensively in ice sheet and glacier drill holes. It utilizes a photosensitive disk to record the position and magnetic bearing of a plumb bob. The disk is easily developed upon retrieval; however, only one shot can be obtained per downhole trip. Considering that a trip down to the 5000-ft (1524-m) level and back in this operation took 9 hours, the disadvantage of this method is obvious. This instrument is also mounted in the above-mentioned, pressure-tight housing. Disk and plumb bob assemblies for 4°, 10°, and 26° ranges can be employed. A typical exposed disk is shown in Figure 4.

Winch

An electrohydraulic winch with 8000 ft (2439 m) of 7-conductor armored electrical cable was used to raise and lower the inclinometer in the hole. This winch had previously been used in the drill recovery attempt and partial hole survey in 1970. The average lowering and raising rate was about 23 ft/min (7 m/min). A 10-ft (3.1-m) tripod with a sheave was used to suspend the cable and instrument assembly over the hole. An electronic footage counter, actuated by the sheave rotation, measured the length of cable payed out.

PROCEDURE

An initial dry run with the instrument housing was taken to determine the accessible hole depth and to check for any leaks in the housing. A contact probe on the bottom of the housing indicated a depth along the hole axis of 5085 ft (1550 m) from the top of the casing, which was 18 ft (5.49 m) beyond the 1969 depth.

On the measurement run, 59 shots were taken at intervals of 50 and 100 ft (15.2-30.5 m) from 4960 ft (1512 m) to the bottom of the casing. On the same run, the single-shot instrument with a 26° disk was sent downhole and a single shot attempted at 5050 ft (1540 m). However, a wire pinched during assembly resulted in a premature exposure.

Upon developing the multiple-shot film, the results revealed inclinations beyond 4500 ft (1372 m) that were near the limit of the instrument range. Another attempt with the single-shot instrument was made immediately. This time a burned out exposure bulb negated the effort. Time did not allow any further attempts.

RESULTS

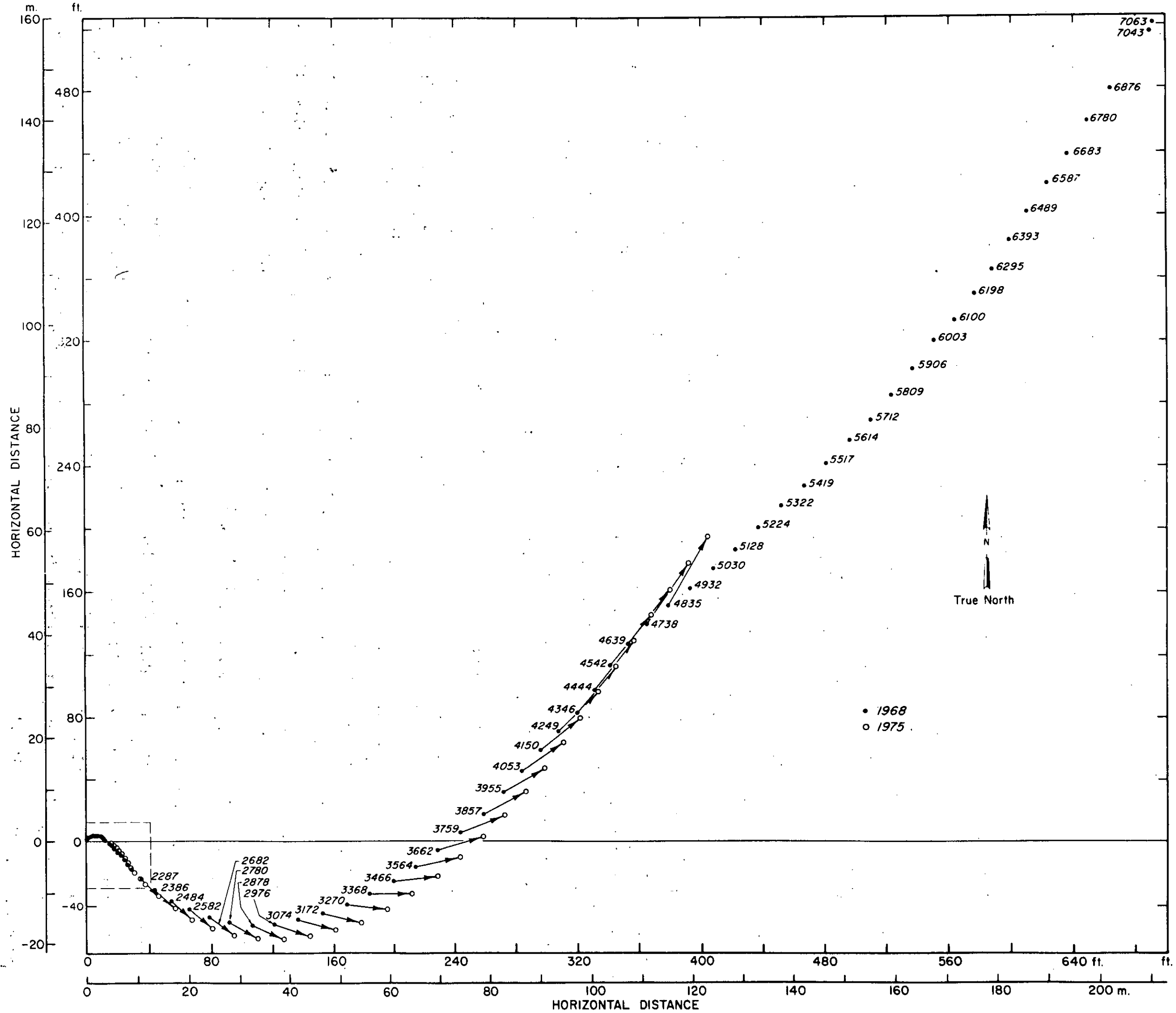
The very small plumb bob deflections recorded in the upper 700 ft (213 m) of the hole made azimuth determinations more difficult than at the lower depths. The slight changes in inclination agree with the results from the old Byrd Station drill hole (Gow 1963). Insignificant changes were noted after four years for the first 1000 ft (305 m) in that hole.

The hole-positions-versus-depth data were computed from the survey data by a technique known as the "balanced tangential method." For details of this method see Appendix A. Measurements taken in 1975 were obtained at depths different from those of the 1968 measurements, so the 1975 data were shifted to obtain the *X* and *Y* coordinates at depths (*Z*-coordinates) identical to those of the 1968 data. Since the "balanced tangential method" assumes a constant inclination between measurement stations, linear interpolation was used to shift the 1975 data. Plan views of the ice movements are shown in Figures 5a and b for various vertical depths. The arrows indicate the magnitudes and azimuths of the hole displacements.

The resultant horizontal displacement of the hole relative to the surface increases progressively with depth to a value of 51.2 ft (15.6 m) at the 4835-ft (1474-m) level, or about 7.3 ft/yr (2.23 m/yr). The interesting feature is the change in the direction of flow with depth, which indicates that the ice mass is undergoing a twisting action. Such a movement might be explained by a large irregularity in the bedrock topography such as the dome reported to be located about 3 km south of Byrd Station (Whillans, personal communication). The surface movement at Byrd Station has been determined by Whillans to be in a generally southwest direction with an apparently rapid acceleration detected in the vicinity (Whillans 1973). The general direction of displacements below about 3500 ft (1067 m) agrees with this direction.

It has been speculated that the inclination of the drill hole may have been caused by movement of the ice mass between drill runs. Although the inclination direction of the lower half of the hole agrees with the direction of ice movement determined by surface measurements, results of this survey indicate that the ice movement between drill runs would have a negligible effect on the inclination. A similar phenomenon was noted in the Camp Century, Greenland, drill hole (B.L. Hansen, personal communication).

The results obtained from this survey certainly suggest that the movement within the ice mass is not simple, at least at this location. This situation was recognized by Bader (1962) several years ago. Unfortunately, the most interesting part of the hole in terms of ice movement is no longer accessible.


m.
ft.
HORIZONTAL DISTANCE
160
140
120
100
80
60
40
20
0
-20
480
400
320
240
160
80
0
-40
0
80
160
240
320
400
480
560
640 ft.
ft.
0
20
40
60
80
100
120
140
160
180
200 m.
HORIZONTAL DISTANCE
7063
7043
6876
6780
6683
6587
6489
6393
6295
6198
6100
6003
5906
5809
5712
5614
5517
5419
5322
5224
5128
5030
4932
4835
4738
4639
4542
4444
4346
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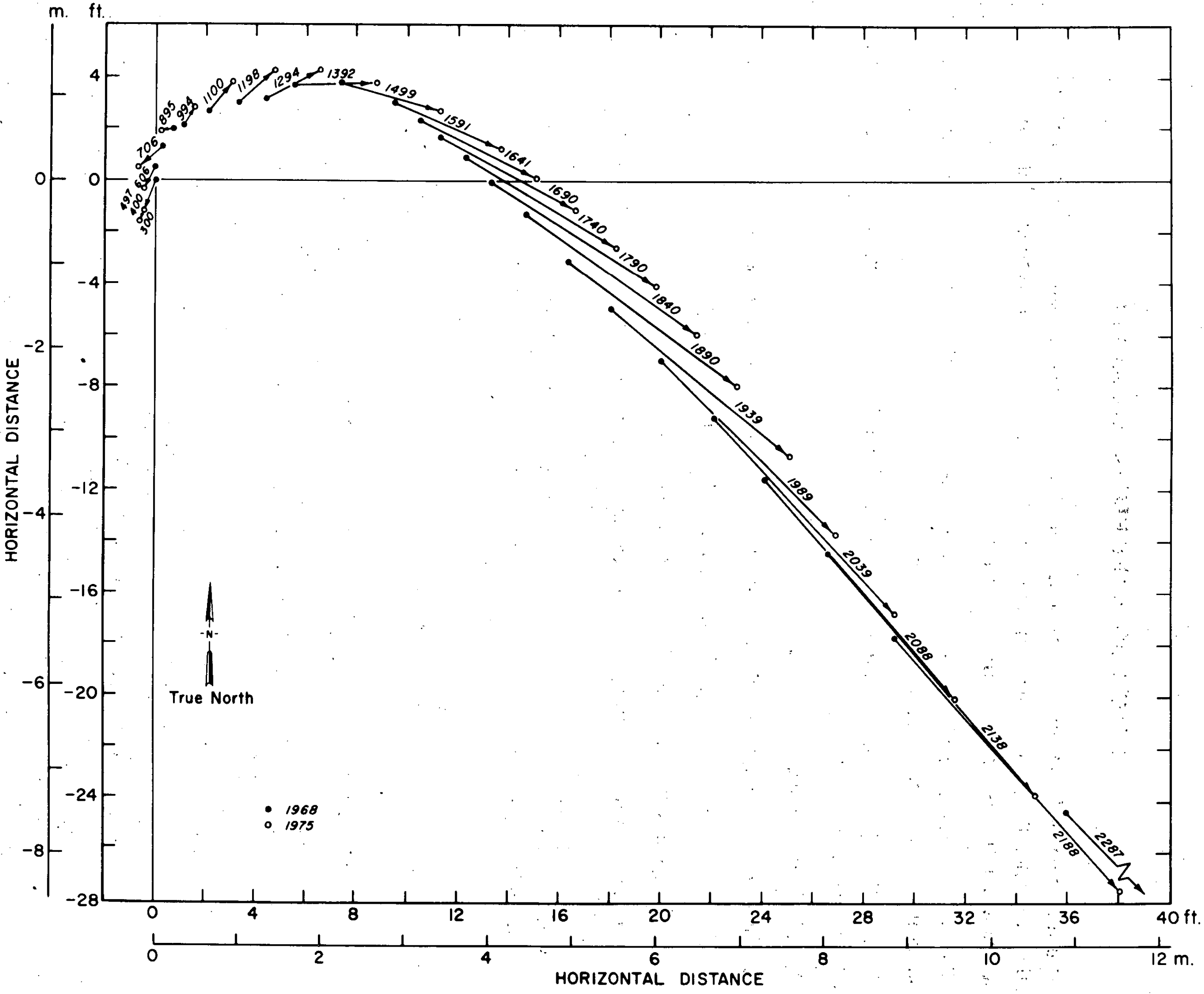
a.



b.

Figure 5. Plan views of displacements relative to tops of hole casings.

The 1968 and 1975 surveys are compared in Appendix B and in Figures 5a and b. All readings are referenced to the top of the hole casing, which as of January 1975, was 45 ft (13.7 m) below the 1975 snow surface. Azimuth readings have been corrected for the magnetic declination at Byrd Station (71°E).

CONCLUSIONS AND RECOMMENDATIONS

It is recommended that another survey be conducted in 3-5 years, assuming that Byrd Station is still accessible. Based on the deformation of the tunnel since 1968, it is estimated that the drill hole site will be accessible for another five years.

The hoist and cable were left intact. A source of electrical power, such as a 7½-kw, 220-VAC, 3-phase electric generator, is required to operate the hoist.

An updating of the measuring equipment should be considered. The multiple-shot inclinometer used here has several drawbacks:

1. It lacks the required sensitivity.
2. The magnetic compass precludes its use in the vicinity of ferrous materials.
3. The quality of the photographs deteriorates with decreasing temperatures.
4. The camera is difficult to load under field conditions.
5. There is no way to determine if the mechanism is operating correctly once the instrument is assembled.

A gyro surveyor with a capability of direct surface readout of inclination and azimuth would eliminate most of the problems above; however, present models lack the required sensitivity.

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APPENDIX A. HOLE SURVEY CALCULATION METHOD (BALANCED TANGENTIAL METHOD)

The positions of points along the axis of the hole are calculated with respect to a coordinate reference frame whose origin is at the top of the hole. For a comparison of various directional survey methods, see Walstrom et al. (1972).

Symbols:

L_i = distance along axis of hole from top of hole to station i, $i = 0, 1, 2, \ldots$

I_i = inclination angle of hole with the vertical, at station i

A_i = azimuth angle of the inclination with the north, at station i

S_i = distance between two stations measured along hole axis, $L_i - L_{i-1}$

X_i, Y_i = horizontal deviation for increment of hole between stations S_i and S_{i-1}, positive east and north respectively

Z_i = vertical depth for increment of hole between stations S_i and S_{i-1}, positive down.

$$X_i = S_i \left[\frac{(\sin I_{i-1})(\sin A_{i-1}) + (\sin I_i)(\sin A_i)}{2} \right]$$

$$Y_i = S_i \left[\frac{(\sin I_{i-1})(\cos A_{i-1}) + (\sin I_i)(\cos A_i)}{2} \right]$$

$$Z_i = S_i \left(\frac{\cos I_{i-1} + \cos I_i}{2} \right)$$

$X = \Sigma X_i$ = total horizontal X-coordinate

$Y = \Sigma Y_i$ = total horizontal Y-coordinate

$Z = \Sigma Z_i$ = total vertical depth of hole.

APPENDIX B. 1968–1975 DISPLACEMENT VERSUS DEPTH

Vertical depth (ft)	*Resultant horizontal displacement (ft)*	*Azimuth of displacement (deg)*
300	1.3	201
400	1.8	201
497	1.3	201
606	0.7	223
706	1.3	230
895	0.5	259
994	0.9	36
1100	1.5	38
1198	1.8	46
1294	2.5	63
1392	3.3	88
1499	4.0	106
1591	4.6	113
1641	5.2	116
1690	6.0	118
1740	6.9	121
1790	7.6	122
1840	8.2	125
1890	8.4	125
1939	8.9	129
1989	9.5	134
2039	10.4	138
2088	11.3	139
2138	12.5	139
2188	13.2	138
2287	15.2	140
2386	16.4	133
2484	17.5	131
2582	18.7	129
2682	19.9	124
2780	21.1	119
2878	22.4	113
2976	24.0	108
3074	25.5	104
3172	26.8	100
3270	27.8	95
3368	28.6	91
3466	29.4	84
3564	30.7	78
3662	31.7	74
3759	31.5	69
3857	31.3	63
3955	31.2	60
4053	31.9	56
4150	33.7	51
4249	35.6	45
4346	38.3	41
4444	40.3	40
4542	41.2	40
4639	43.4	38
4738	47.1	34
4835	51.2	30