U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN REGION
SANPETE RANGER DISTRICT
MANTI, UTAH

FINAL GEOTECHNICAL REPORT

- MANTI CANYON NORTH SLIDE STABILITY STUDIES
- DEBRIS DAM FOUNDATION INVESTIGATIONS

DECEMBER 1976

CRS CALDWELL, RICHARDS & SORENSEN, INC.

IECO INTERNATIONAL ENGINEERING COMPANY, INC.

CONSULTING
ENGINEERS

INTERNATIONAL ENGINEERING COMPANY, INC.

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G. BRYCE BENNETT, P.E.
EXECUTIVE VICE PRESIDENT

December 30, 1976

U. S. Department of Agriculture
Forest Service
Intermountain Region
324 25th Street
Ogden, Utah 34401

Attention: Mr. John K. Campbell, Contracting Officer

SUBJECT: Final Geotechnical Report
Manti Canyon North Slide Stability Studies
Forest Service - Intermountain Region

Gentlemen:

The joint venture team of Caldwell, Richards and Sorensen, Inc. (CRS) and International Engineering Company, Inc. (IECO) is pleased to submit this Final Geotechnical Report for the Manti Canyon, North Slide stability studies in accordance with the terms of the contract between the Forest Service and CRS/IECO.

The purpose of the final report is to present supplemental inclinometer and field surface survey data gathered between September and December 1976, the post monitoring phase of our contract.

Study of supplemental field data obtained during the post monitoring phase of the contract, shows that conclusions presented in the Interim Geotechnical Report, which was submitted to the Forest Service in September 1976, are still valid and require no modifications. The most important conclusion presented in the interim report was that construction of a bypass pipeline across the North Slide is undesirable because of the incipient instability of the slide mass.

The close cooperation of the Forest Service staff during the study period has been much appreciated. It has been a rewarding experience for us to work with your professionals.

Yours very truly,

Robert M. Tarbox
Vice President
for G B Bennett

GBB:acd

A
MORRISON
KNUDSEN
COMPANY

CONSULTING
ENGINEERS

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614-710

24 February 1977

U.S. Department of Agriculture
Forest Service, Intermountain Region
324 25th Street
Ogden, Utah
34401

Attention: Mr. Eugene D. Hanson

Subject: Report Changes - Manti Geotechnical

Gentlemen:

Please find enclosed 14 copies each of errata sheets to accompany the Interim and Final Geotechnical Reports for the Manti Northside Stability Analyses. Also included are 14 copies each of Exhibits 3, 4 and 5 and Fig. 2-1 of the Interim Report, which have been slightly revised to reflect answers to questions presented to Dr. Nielson and myself during recent discussions with Mr. Hanson.

In addition, questions regarding the procedure followed for selection of stability sections and the basis for conclusions presented in the interim and final reports are discussed below.

- Selection of Stability Sections

  Stability sections for both the Bishop Stability Analysis and the Infinite Slope Analysis were selected in the following manner. A geologic study of the slide was first performed. Following the geologic study, a map study was performed on many sections along the slide. Sections at various locations were drawn and approximate factors of safety were determined using approximate methods such as infinite slope analysis and stability charts using idealized sections and soil properties. These approximated methods delineated critical areas. Sections were then drawn in the critical areas and further refined by the two stability methods reported and the four sections given in the Interim Report were selected for detailed analysis.

- Basis of Conclusions

  Conclusions are based on a synthesis of results obtained from geologic studies, seismic surveys, surface surveys, drilling, drill logs, soil samples and cores, soil test results, inclinometer surveys and in-hole permeability tests performed at the proposed dam site. All techniques were authorized in Sec.210 of contract.

It has been our pleasure working with the Forest Service on the Manti contract and we hope an opportunity will again present itself for collaborating on other projects.

Very truly yours,

J. S. Long
Chief Geologist

JSL:tcm

Enclosures: 14 each.

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ERRATA

FINAL REPORT

- Page 1-2 last line.

  "Four miles west" should read "Four miles east"

- Table 2-1 movement rate heading.

  "Movement Rate (in/ft)" should read "Movement Rate (in/yr)"

* * *

CONTENTS

TABLES

FIGURES

EXHIBITS

S.1 SUMMARY

Investigation of the North Landslide in Manti Canyon began in May, 1976 and included a subsurface exploratory program, seismic surveys, laboratory testing, and field instrumentation. Data derived from the above activities between May and August, 1976 was presented in an Interim Geotechnical Report which was submitted to the Forest Service in September, 1976, The information contained in this report, consists of supplemental field information obtained between September and December, 1976. The final report is required by contract to be presented to the Forest Service by January 3, 1977. A summary of contract work items follows:

- Exploration on the North Slide that consisted of four borings which ranged from 150 to 350 feet deep. One 70 ft. deep boring was also drilled at the debris dam site. Total footage of drilling was 1131 linear feet. Soil samples were obtained by Shelby tubes, split spoon samplers, and Nc wire line core barrels.

- A total of 14,065 linear feet of seismic line were run on the North Slide and the debris retention dam site.

- Laboratory testing included gradation, Atterberg limits, moisture content, triaxial and direct shear tests. X-ray defraction and other tests were also made to determine specific clay mineralogy.

- Inclinometer casings were installed in four bore holes on the North Slide. Total amount of casing installed in the four holes was 1008 feet. The holes ranged from 150 and 327 feet deep. The purpose of the casing installation was to detect movement within the North Slide. A special down-hole instrument known as the "mini-probe" was used to measure subsurface horizontal movement within the slide mass.

- Surface survey points were placed on steel casing covers which were imbedded in concrete at each inclinometer site. Purpose of the survey points was to monitor surface landslide movement.

- The surface survey points and inclinometer holes were monitored periodically between June and December of 1976.

- The Bishop's modification of the Swedish circular arc and the planar method were used for stability analyses, which were made of the North Slide.

- A settlement analysis was made for the debris retention dam foundation.

S.2 CONCLUSIONS

The conclusions presented in the interim report are still considered valid. For reference, they are as follows:

- The North Slide mass is composed of glacial material which extends to depths of 350 feet.

- The till is underlain by sandstone shale and siltstone beds of the North Horn formation. (The North Horn formation contains montmorillonite, and shale beds which are associated with numerous landslides in Utah.)

- Till of the North Slide is divided into two layers. An upper layer, from 10 to 80 feet deep, is composed of loose silty gravel, and a lower layer which consists of dense over-consolidated gravel in a stiff matrix of montmorillonite clay. The stiff matrix is derived primarily from glacial rock flour, which contributes to the "milky" turbidity of several streams flowing into Manti Creek.

- Numerous tension cracks, springs, ponds, and irregular hummocky topographic features provide visual evidence of soil creep and/or land flow in the upper layer of the North Slide above elevations of 7500 ft.

- Shear zones were observed in core samples in dense glacial till. Shear zones can be caused by:

  - Deformation in the till resulting from ice action during the glacial periods,
  - Plastic deformation by slow, deep-seated mass soil creep, and
  - Possibly shearing by movement on the Cottonwood fault.

- The ground water table within the North Slide was temporarily influenced by drilling operations. The levels shown on Exhibits 2, 3, 4, and 5 are believed to represent the true piezometric level.

  Water under artesian pressures was encountered in boring DH-2. These pressures were found in the upper bedrock layers or in the gravelly alluvium immediately above bedrock. Sounds similar to running water were heard in DH-2 during the entire length of the project.

- The study area is in a region which has a record of moderate seismic activity. Evidence found during geologic mapping indicates that high magnitude earthquakes and active faulting can also be expected in or close to the study area.

- Factors of safety of the North Slide mass are close to unity. Earthquake forces were not included. Analysis of the North Slide area, assuming continued erosion of the stream bed by Manti Creek, indicate that the factors of safety will be less than 1.

  Analysis also shows that a rock lining of the stream bed for erosion prevention will eliminate further reduction of the already low factor of safety of the North Slide and will provide some degree of buttressing against local and massive failures.

- Inclinometer and surface surveys support the results of the stability analysis. The results show the slide mass to be moving at rates which can be expected with marginal factors of safety.

- Investigations at the proposed site of the 80 ft. high debris detention dam reveal poor geologic conditions for dam construction and operation. The dam foundation is underlain by up to 58 feet of overburden material. All overburden materials appear to be loose and permeable. In addition, the left abutment of the proposed dam will have marginal stability after saturation by the reservoir. Therefore, the site is not considered geologically suitable for an 80-foot high dam.

- Continued small movements occurring in the North Slide may rupture the water line which provides water to the city of Manti.

- A bypass pipeline will remove only part of the sediments in Manti Creek. Sediments in Cottonwood Creek, which are gathered near the head of the Cottonwood Landflow enter Manti Creek downstream from the bypass pipeline diversion point.

S.3 RECOMMENDATIONS

A bypass pipeline should not be considered as a permanent solution for mitigating sediments or flooding problems on Manti Creek due to incipient instability of the North slide. Continued erosion may initiate future slide failure.

To prevent further undercutting of the North Slide, Manti Creek channel should be stabilized by riprap or by similar means. Stability of the North Slide will be increased if the channel can be filled to a depth of 20 feet prior to placing riprap. Energy dissipation methods should be employed to prevent removal of the riprap or other features in the stabilized channel.

Due to stability problems on the left abutment of the debris retention dam site, it is recommended that the site should not be utilized for an 80 foot high debris dam.

CHAPTER 1
INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 REPORT CONTENTS

This report contains the final results and evaluation of surface surveys and inclinometer field measurements made between May and December, 1976 on the North Slide mass. The initial results of measurements made between May and August, 1976 and stability analyses of the North Slide are presented in the Interim Geotechnical Report which was submitted to the Forest Service in September 1976.

1.2 PURPOSE

The purpose of the Final Report is to supplement the information contained in the Interim Geotechnical Report, with additional field measurements of landslide movement made in the, so called, post monitoring phase of the contract.

The ultimate purpose of the study is to determine the geotechnical feasibility of constructing a bypass pipeline to carry the flow of Manti Creek across the toe of the North Slide (See Exhibit 1).

The interim and final reports have also been prepared to assist the Forest Service in determining what measures can be taken to reduce the possibility that debris and sedimentation from the landslide in Manti Creek will cause excessive flooding or interference with the water supply in the town of Manti, Utah.

1.3 AUTHORITY

The engineering services for the study were authorized by the U.S. Forest Service, Intermountain Region, Ogden, Utah, and were performed by Caldwell, Richards, and Sorensen, Inc. (CRS) of Salt Lake City, Utah, and International Engineering Co., Inc. (IECO) of San Francisco, CA, under a contract dated May 6, 1976.

1.4 SCOPE OF WORK

The scope of work for the entire study, as outlined in the contract with the Forest Service, includes the following services:

- Stability analysis of the North Slide
- Foundation analysis of a debris retention dam site for an 80 ft high dam,
- Seismic geophysical survey of the North Slide and the proposed debris retention dam site,
- Drilling and sampling at the North Slide and the debris retention dam site,
- Soil testing,
- Geologic mapping of the slide and the debris retention dam site,
- Installation of the inclinometer casings in four drill holes in the slide area and periodic monitoring of the landslide deformation,
- Surface survey measurements to monitor ground movement.

1.5 BACKGROUND

The town of Manti, Utah, receives much of its water supply for irrigation, power generation, and domestic use from a pipeline which is fed by springs approximately four miles west of the town in Manti Canyon. In May, 1974, the pipeline was severed by movement of a massive landslide on the south side of Manti Canyon approximately three miles west of Manti. Continuing ground movement hampered repairs of the pipeline. Therefore, the pipeline was rerouted along a new alignment on the north side of the canyon. The new alignment crosses the toe of another slide mass known as the North Slide (see Exhibit 1). Also, a "bypass pipeline" has been proposed to divert the flow of the Manti Creek around the toe of the large active slide mass on the south side of Manti Creek. The bypass pipeline would also cross the North Slide.

As indicated earlier, the purpose of this study has been to determine the stability of the North Slide mass and the geotechnical feasibility of pipeline construction across the landslide toe.

1.6 ACKNOWLEDGMENTS

The CRS/IECO team appreciates the assistance received from the U.S. Forest Service, Intermountain Region personnel, particularly Mr. Eugene D. Hanson, Regional Materials Engineer, and Messrs. Darius Coker, Ted Wood, and John Riley, who worked under his direction. Also, the cooperation and assistance given by Mr. Dick Alred, District Ranger, his secretary and the staff of the San Pete Ranger District, Manti-La Sal National Forest, was very helpful.

CHAPTER 2

SURFACE SURVEYS

CHAPTER 2
SURFACE SURVEYS

2.1 SURVEY METHODS

In order to accurately determine the location and elevation of the top of the four inclinometer drill holes on the north slide, the CRS/IECO investigation team selected two survey control points on stable ground (see Exhibit 1). Permanent concrete monuments were constructed at these two points. The survey control was tied to the U.S. Forest Service control points, T-8 and T-9. Initial surveys of the control points and the four inclinometer holes were made on June 30, 1976. Coordinates and elevations were determined using surveying methods that conform to the specifications for second order, Class 2, horizontal control.

Slide movements were monitored after the initial survey on the dates given in Table 2.

2.2 SURVEY DATA

Surface movement rates at the four inclinometer holes have been calculated. Figure 1 shows the movement rate of surface survey points at each hole. The rate of movement at the beginning of the project in June 1976, was high. Rate of movement decreased during the summer months and accelerated again in October 1976.

The total movement of surface survey points are presented on Tables 1 and 2. Amount of surface movement is also presented graphically on Exhibits 2, 3, 4, and 5.

TABLE 2-1

SURFACE CONTROL MOVEMENTS - INITIAL READINGS (June 30, 1976)

Site	Coordinates		Elevation (feet)
Point A	N 339,280.800	E 1,983,961.671	7,866.597
Point B	N 338,087.429	E 1,985,335.999	7,651.375

TABLE 2-2

SURFACE SURVEY - PERIODIC READINGS

Hole No.	Date	Coordinates North	Coordinates East	Elev. (ft)	Movement (in) North	Movement (in) East	Total	Movement Rate (in/ft) Horiz.	Movement Rate (in/ft) Vert.	Movement Azimuth (Deg)
1	6/30/76	336,817.278	1,982,552.845	7005.558	--	--	--	--	--	--
	7/20/76	336,817.220	1,982.552.749	7005.554	-0.696	-1.152	1.346	24.563	-0.876	238.861
	8/10/76	336,817.704	1,982,552.468	7005.468	-0.888	-1.164	1.464	13.034	-0.615	232.660
	9/26/76	336,817.700	1,982,552.735	7005.571	-0.936	-1.320	1.618	6.712	0.647	234.660
	10/14/76	336,817.095	1,982,552.622	7005.622	-2.196	-2.676	3.462	11.920	2.645	230.627
	11/12/76	336,817.177	1,982,552.746	7005.605	-1.212	-1.188	1.697	4.589	1.525	224.427
	12/10/76	336,817.195	1,982,552.766	7005.529	-0.996	-0.948	1.375	3.079	-0.779	223.586
2	6/30/76	336,986.210	1,983,521.800	7166.407	--	--	--	--	--	--
	7/20/76	336,986.181	1,983,521.762	7166.416	-0.348	-0.456	0.574	10.469	1.971	232.651
	8/10/76	336.986.176	1,983,521.776	7166.433	-0.408	-0.288	0.499	4.446	2.778	215.218
	9/26/76	336,986.168	1,983,521.762	7166.405	-0.504	-0.456	0.653	2.708	-0.100	197.103
	10/14/76	336,986.097	1,983,521.697	7166.379	-1.356	-1.236	1.835	6.318	-1.157	222.349
	11/12/76	336,986.138	1,983,521.762	7166.398	-0.864	-0.456	0.977	2.641	-0.292	207.824
	12/10/76	336,986.193	1,983,521.774	7166.419	-0.204	-0.312	0.373	0.835	0.322	236.821
3	6/30/76	337,242.076	1,984,014.991	7272.657	--	--	--	--	--	--
	7/20/76	337,242.046	1,984.014.983	7272.684	-0.360	-0.096	0.373	6.800	5.913	194.931
	8/10/76	337,242.038	1,984,014.980	7272.701	-0.456	-0.132	0.475	4.226	4.700	196.144
	9/26/76	337,242.024	1,984,014.975	7272.688	-0.624	-0.192	0.653	2.708	1.543	197.103
	10/14/76	337,241.974	1,984,014.916	7272.664	-1.224	-0.900	1.519	5.231	0.289	216.327
	11/12/76	337,242.012	1,984,014.961	7272.704	-0.768	-0.360	0.848	2.293	1.525	205.115
	12/10/76	337,242.039	1,984,014.975	7272.687	-0.444	-0.192	0.484	1.083	0.806	203.385
4	6/30/76	337,774.585	1,984,184.431	7361.282	--	--	--	--	--	--
	7/20/76	337,774.573	1,984,184.414	7361.288	-0.144	-0.204	0.250	4.557	1.314	234.782
	8/10/76	337,774.553	1,984,184.444	7361.336	-0.384	-0.156	0.414	3.690	5.769	157,891
	9/26/76	337,774.568	1,984,184.414	7361.314	-0.204	-0.204	0.288	1.197	1.593	225.000
	10/14/76	337,774.519	1,984,184.370	7361.319	-0.792	-0.732	1.078	3.714	1.529	222.745
	11/12/76	337,774.536	1,984,184.407	7361.322	-0.588	-0.288	0.655	1.770	1.298	206.095
	12/10/76	337,774.548	1,984,184.426	7361.305	-0.444	-0.060	0.448	1.003	0.618	187.696

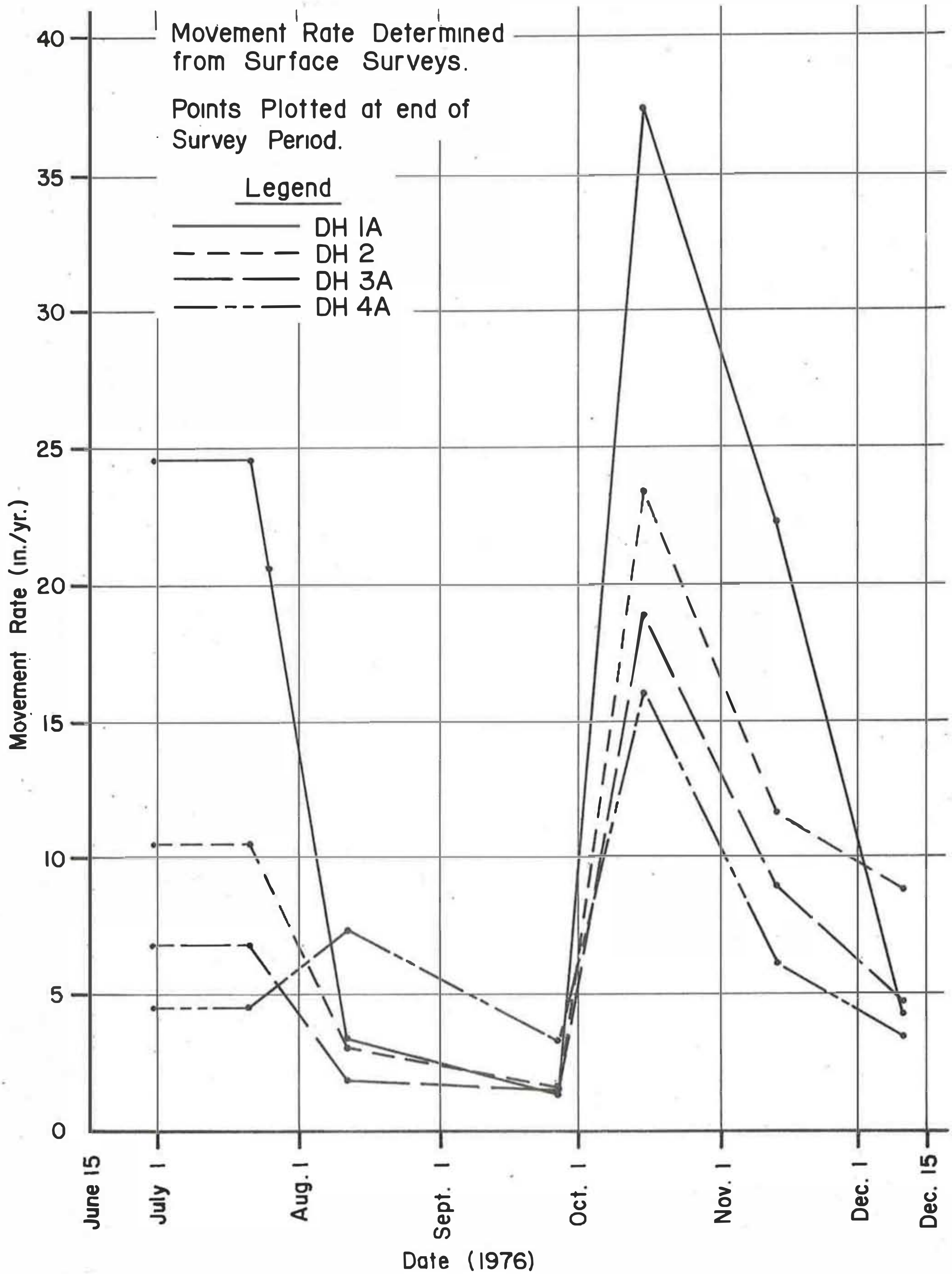


FIGURE 1 SURFACE MOVEMENT RATES

CHAPTER 3
SUBSURFACE SURVEYS

CHAPTER 3

SUBSURFACE SURVEYS

3.1 SURVEY METHODS

Inclinometer surveys were made to determine the depth, and rate of movement of the North SLide. A biaxial miniprobe inclinometer, manufactured by Terra Technology Inc., Seattle, Washington, was used for this purpose. The inclinometer consists of a one inch diameter, two foot long probe with a digital readout unit capable of reading horizontal deflections to the nearest one thousandth of an inch per foot. The probe has wheels that fit into the slots of the inclinometer casing. The inclinometer A and B axes are perpendicular to each other (see Figure 2).

Inclinometer casings were installed in four drill holes during the drilling program.

At the completion of installation of each casing, inclinometer readings were taken. Additional readings were taken on dates as noted in Exhibits 2 through 5. Orientation of the inclinometer casing with respect to north is shown in Figure 2.

During the periodic readings, DH-2 developed problems. It was not possible to measure below 263 feet on the zero orientation for both the Ao and Bo axes in July, August, September, and October (see Figure 2). It was, however, possible to measure the bottom of the hole when the probe was rotated 180 degrees. However, during November and December, it was possible to operate normally for the entire depth of the hole.

3.2 DATA EVALUATION

A large amount of data were gathered with each set of inclinometer readings. The volume of data made it necessary to use a computer for data evaluation.

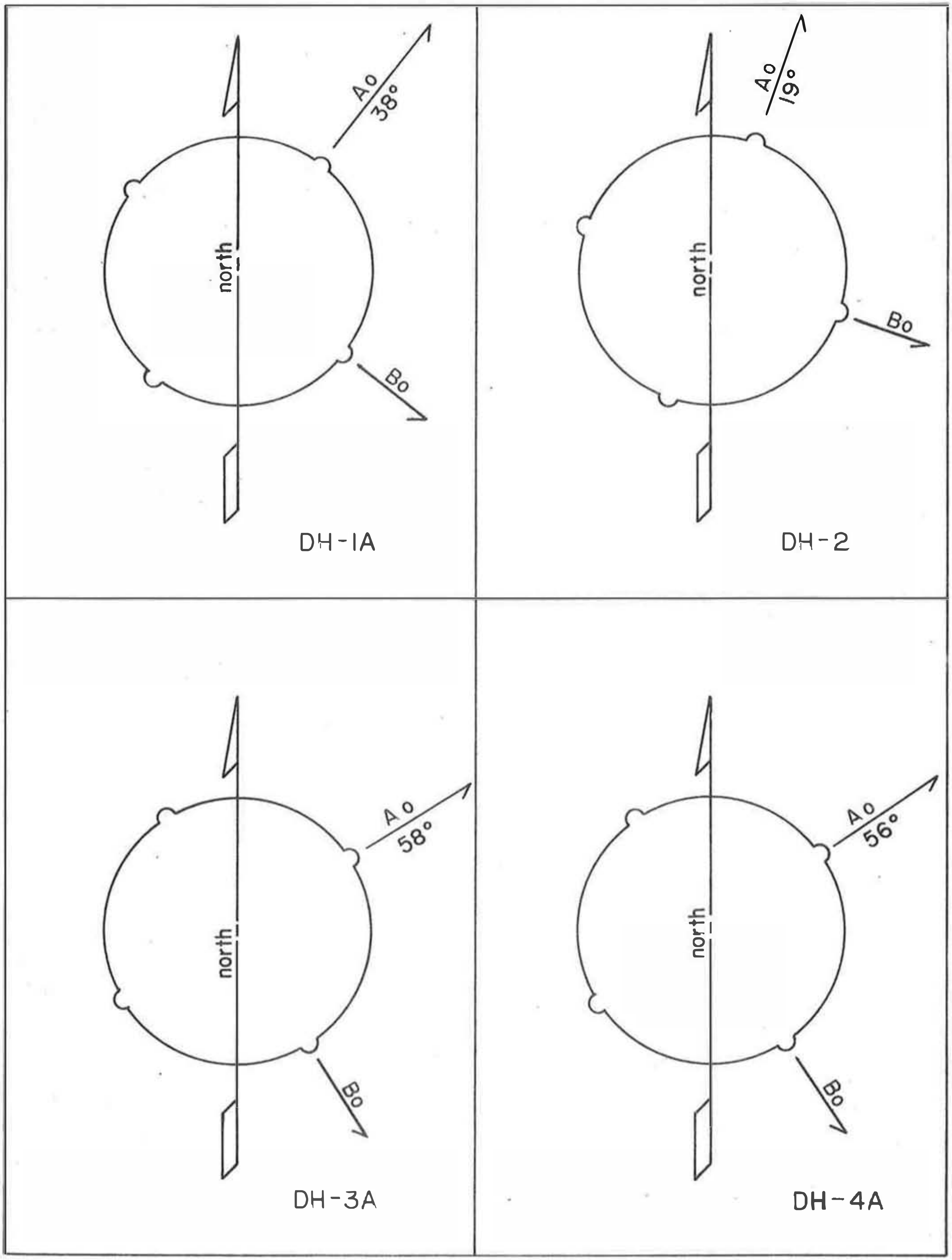


FIGURE 2 INCLINOMETER CASING ORIENTATION

Two sets of readings were taken at two foot intervals from the top to the bottom of each hole each time the holes were surveyed. The first set of readings was taken with the mini probe wheels placed in the Ao orientation slots (see Figure 2). The probe was rotated 180 degrees for the second set of measurements. Data from the two sets of readings were then averaged by computer to provide the amount of deflection of each measurement point.

In order to obtain reliable results of movement below 263 ft in DH 2, it was necessary to calculate an instrument coefficient from data obtained between 0 to 263 feet. This coefficient was applied to the single set of readings which were obtained below 263 feet in DH 2 for surveys made between July and October, 1976. This procedure is considered satisfactory.

The inclinometers in all four drill holes show small amounts of movement. Results of the inclinometer readings are shown in Exhibits 2, 3, 4 and 5. A review of the data shows that no well defined shear planes exist in the inclinometer hole, DH-4A. However, DH-4 did not penetrate the slide. Movement between 240 and 300 ft was noted in DH-2 and DH-3A. The major portion of the movement is occuring near the base of the slide with some plastic movement in the slide mass. Figures 3 through 6 show movement vs. depth in the four drill holes between September and December 1976.

3.3 VERTICAL MOVEMENT OF CASING

Vertical movement of the inclinometer casing was observed in DH-3, between July and December. The casing was rising at a faster rate than the casing cover. Surface surveys show that the cover moved vertically approximately 0.4 inches. Amount of movement of the casing is not known exactly but should be measured during each survey.

Similar differential movement was noted in DH-4 in December, 1976. No changes have been observed in DH-1 and DH-2. The differential movement is most noticeable in DH-3 and should be measured periodically.

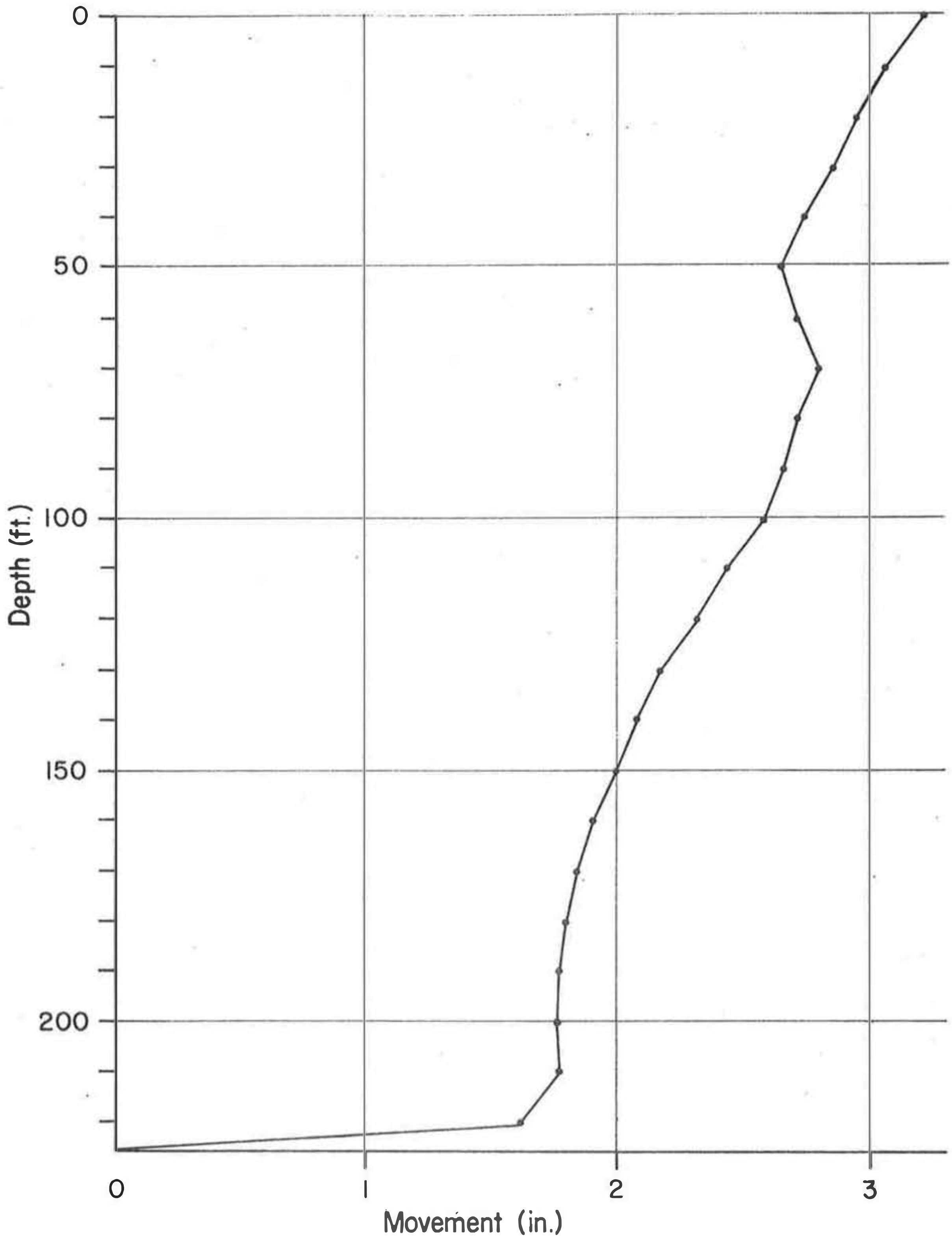


FIGURE 3 MOVEMENT OF DH-1A BETWEEN
JULY AND DECEMBER, 1976

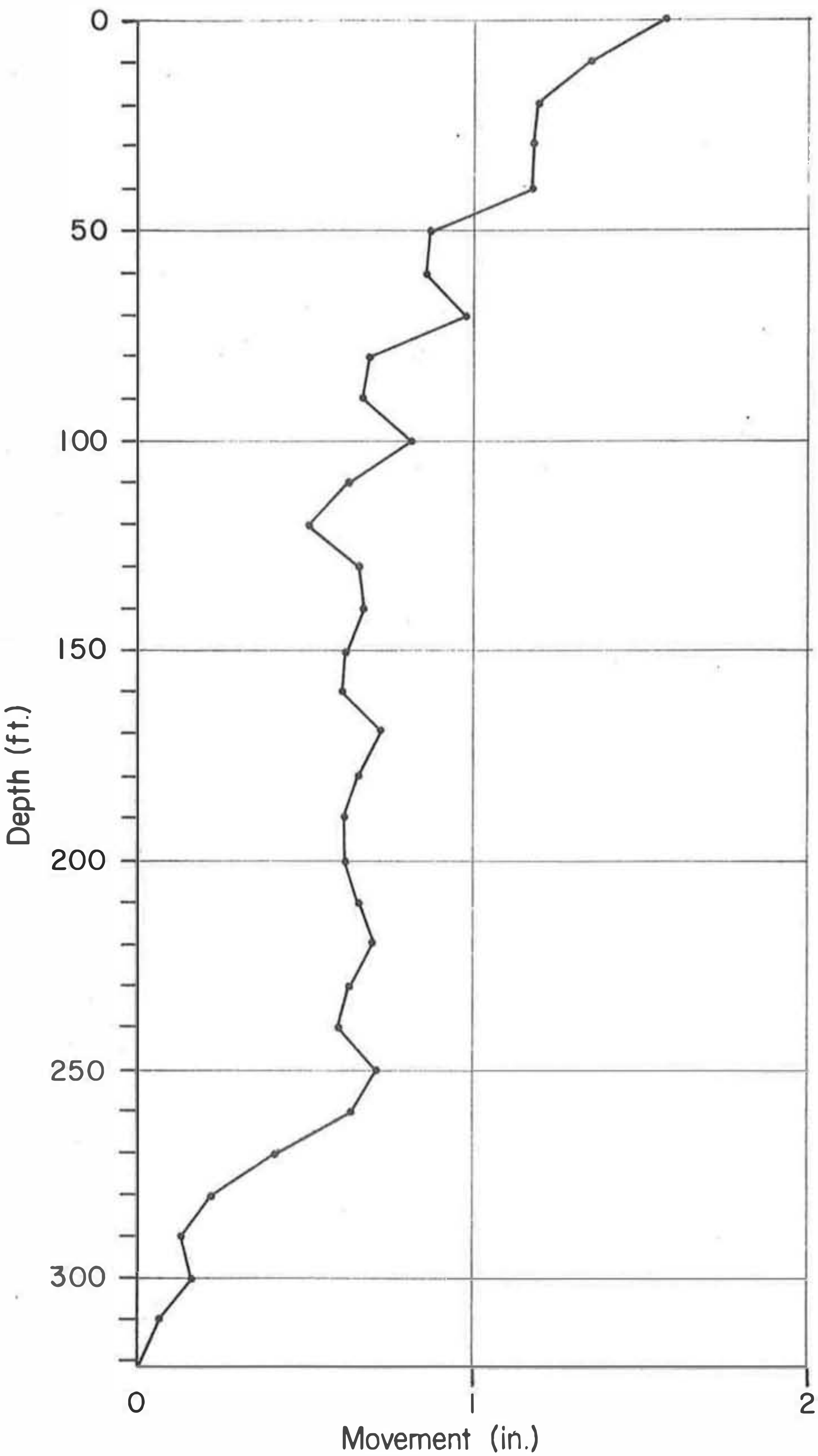


FIGURE 4 MOVEMENT OF DH-2 BETWEEN JULY AND DECEMBER, 1976

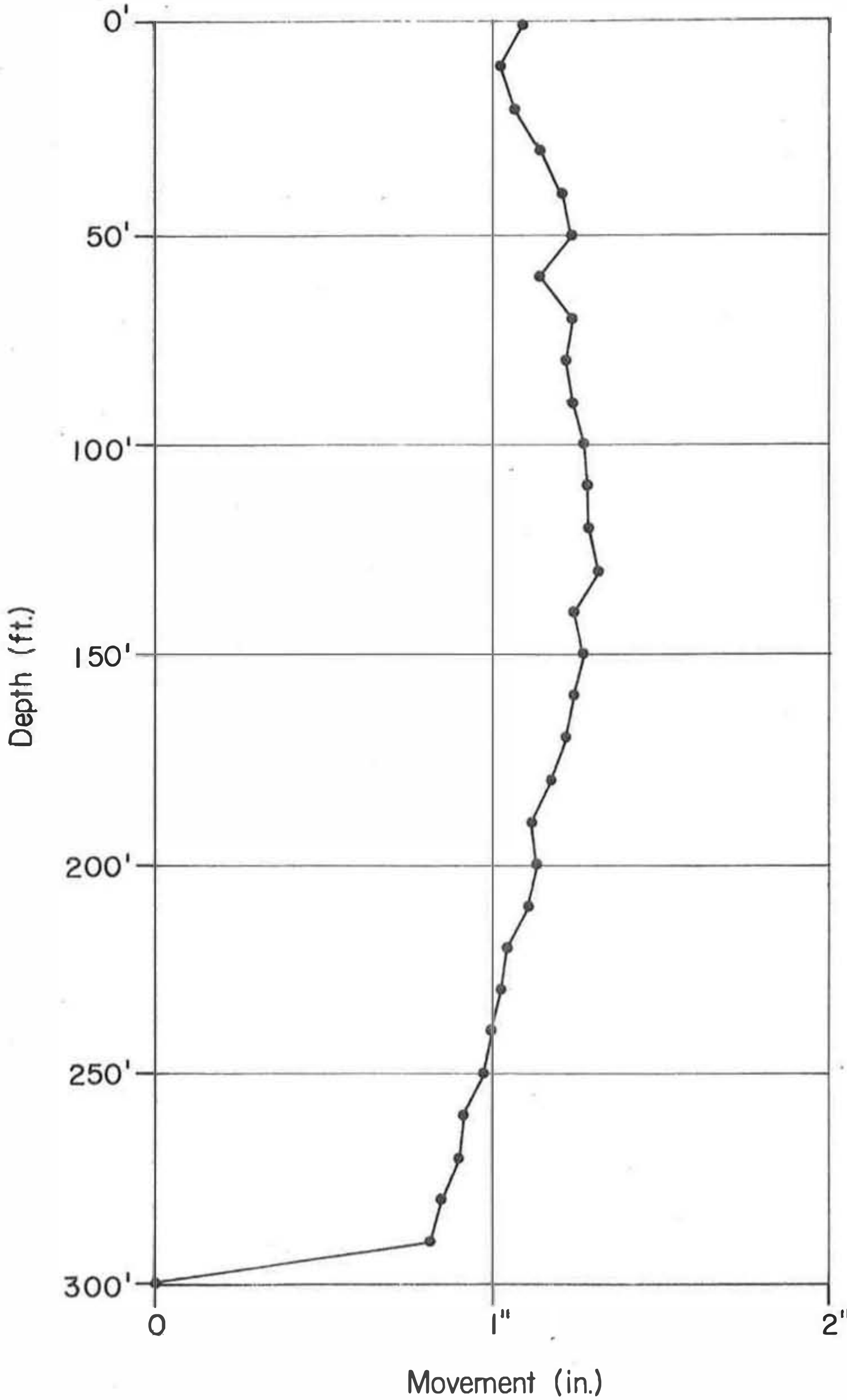


FIGURE 5 MOVEMENT OF DH-3A BETWEEN JULY AND DECEMBER, 1976

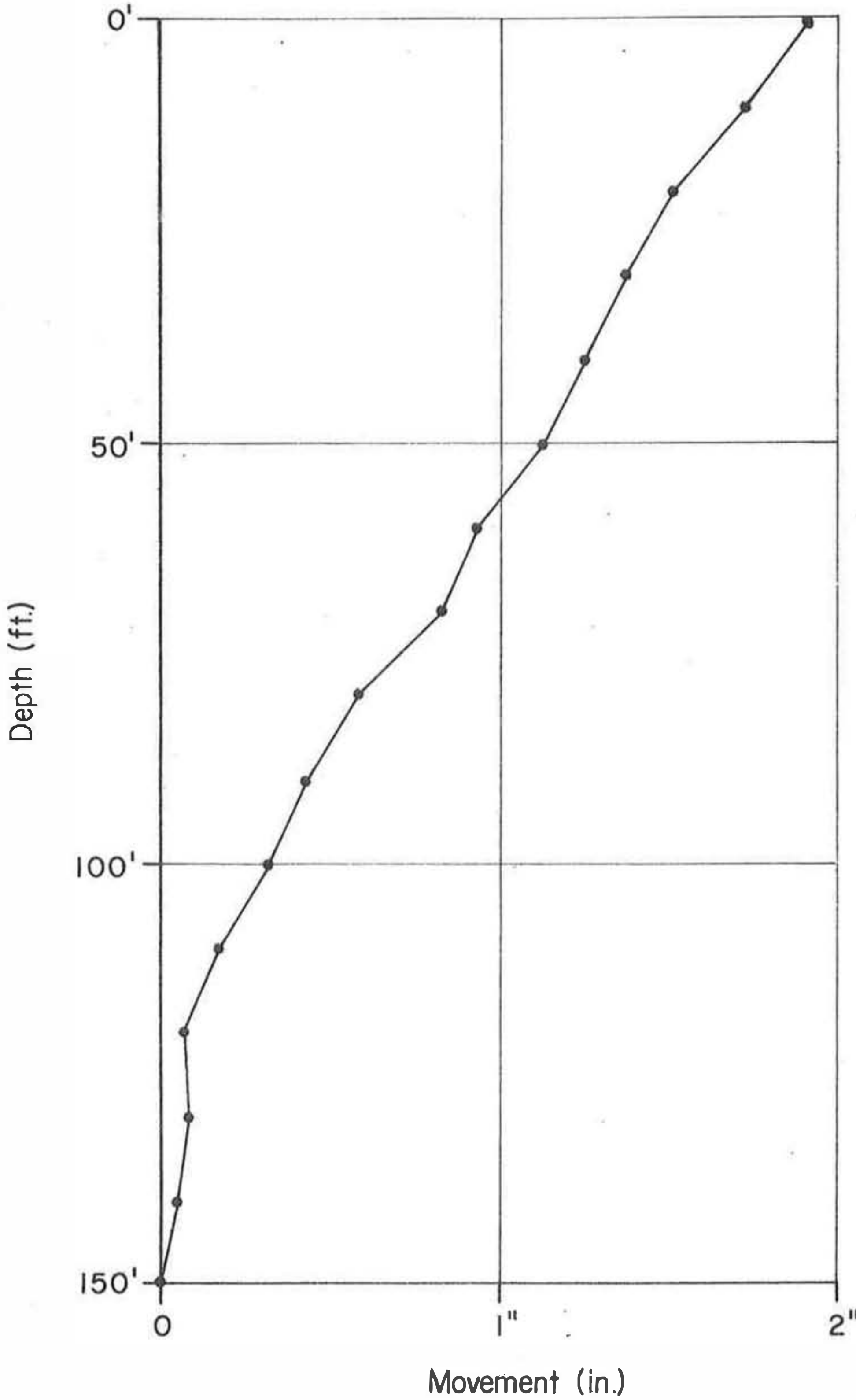


FIGURE 6 MOVEMENT OF DH-4A BETWEEN JULY AND DECEMBER, 1976

CHAPTER 4
DISCUSSION

CHAPTER 4
DISCUSSION OF RESULTS

Surface and inclinometer survey data show the North Slide to be incipiently unstable. The slide mass is moving at a slow rate. Actual rate of movement is difficult to assess at this time due to the length of record. As additional observations are made in the coming years the actual rate of movement and affect of precipitation, snow melt and other variables, which can influence rate of movement, will be ascertained.

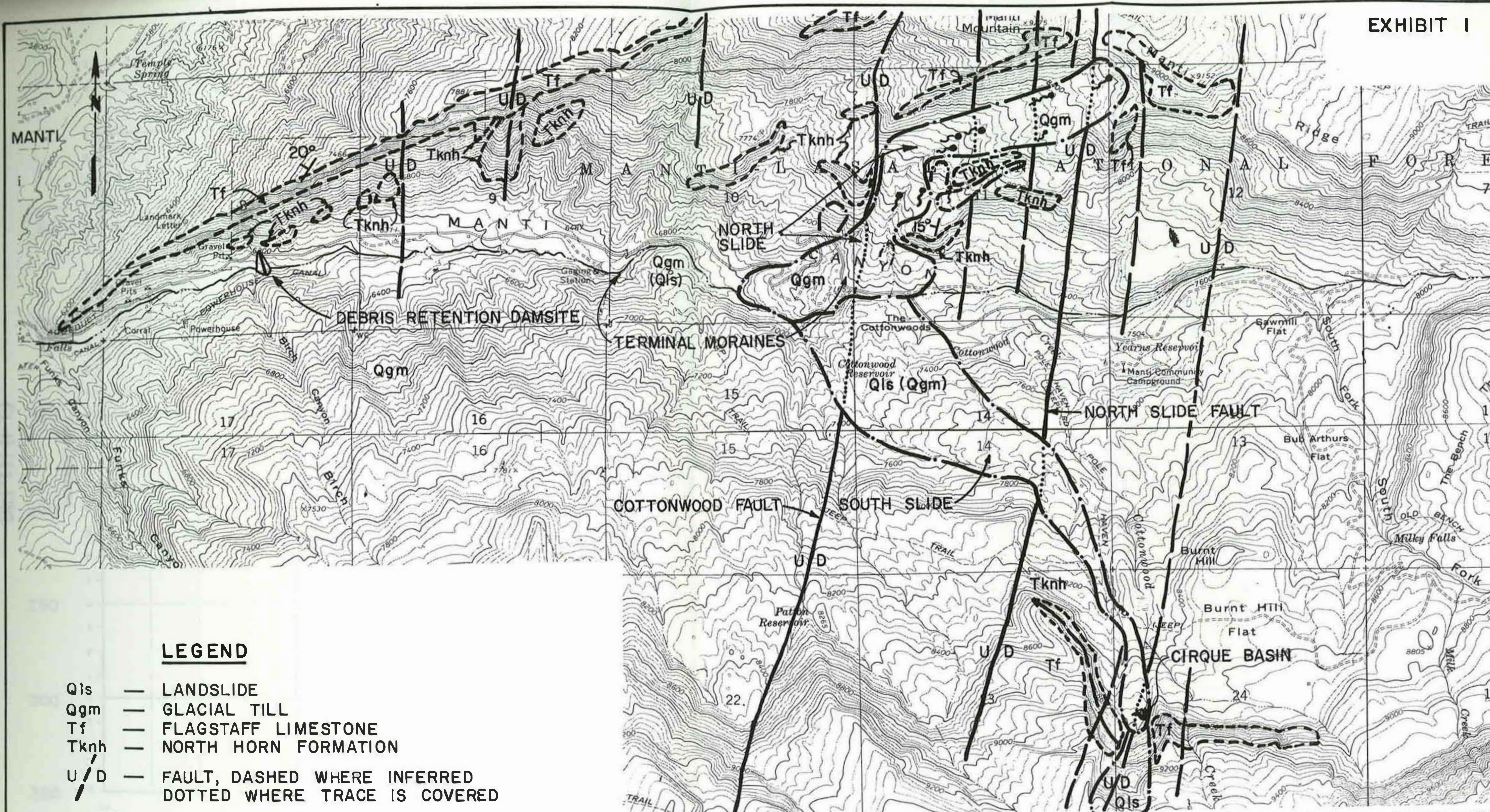
A certain amount of adjustment is required before the inclinometer casing stabilizes in each drill hole. Slide movement records presented on Exhibits 2-5 show that movement recorded by surface surveys and subsurface movement in the upper 0-100 feet of the drill holes had begun to converge in the months of October, November and December, 1976. Convergence of the rate of surface and subsurface movement indicates that at least the upper 100 feet of the slide are moving at the same rate, as would be expected.

Information from inclinometer readings in DH-2 indicate the North Slide is moving downslope on a definable slide plane, or zone. However, the amount of movement measured during the contract period indicates that the movement within the slide mass decreases with depth from the surface. The type of movement within the slide mass can be described as mass soil creep. If the North Slide mass were to fail suddenly, movement would probably be similiar to movement observed on the Cottonwood Landflow.

In conclusion, the interpretations of data as presented in the interim report are still considered to be valid. As more information is obtained, refinements can be expected. However, the basic conclusions and possible remedial measures suggested in the interim report are still believed appropriate. Conclusions and recommendations made in the interim report are repeated in Sections S.2 and S.3 of this report.

EXHIBITS

EXHIBIT I



LEGEND

Qls — LANDSLIDE
Qgm — GLACIAL TILL
Tf — FLAGSTAFF LIMESTONE
Tknh — NORTH HORN FORMATION
U/D — FAULT, DASHED WHERE INFERRED DOTTED WHERE TRACE IS COVERED
— LANDSLIDE
15° — STRIKE AND DIP OF BEDROCK
— SPRING
— GEOLOGIC CONTACT

Scale 0 2000 4000 Feet

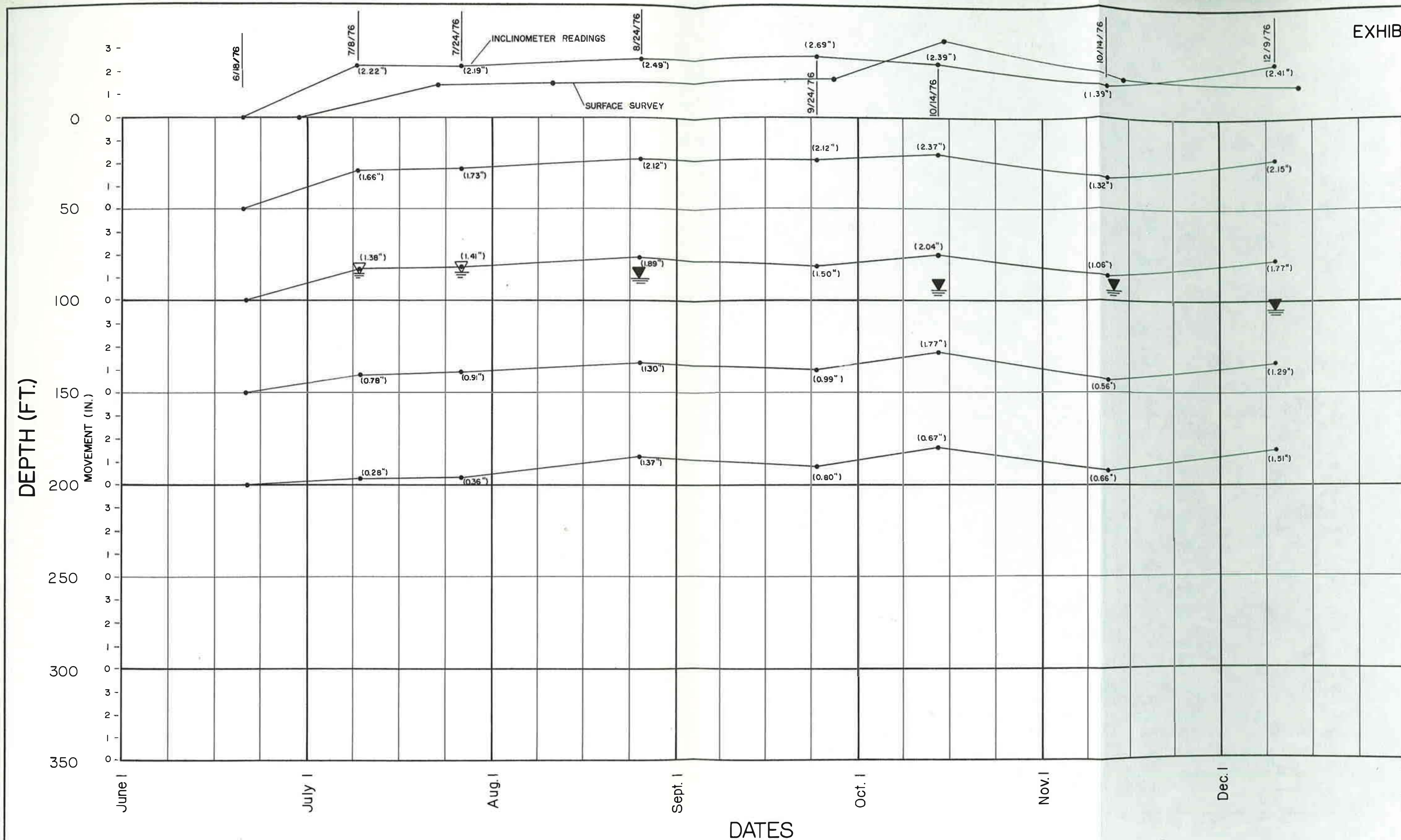
U.S. FOREST SERVICE
SANPETE COUNTY, UTAH

NORTH SLIDE STUDY
REGIONAL GEOLOGY

INTERNATIONAL ENGINEERING COMPANY, INC.

DESIGNED GCP	CHECKED	APPROVED
DRAWN PRT	INSPECT	RECOMMENDED
IECO 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		DATE
		DRAWING NO

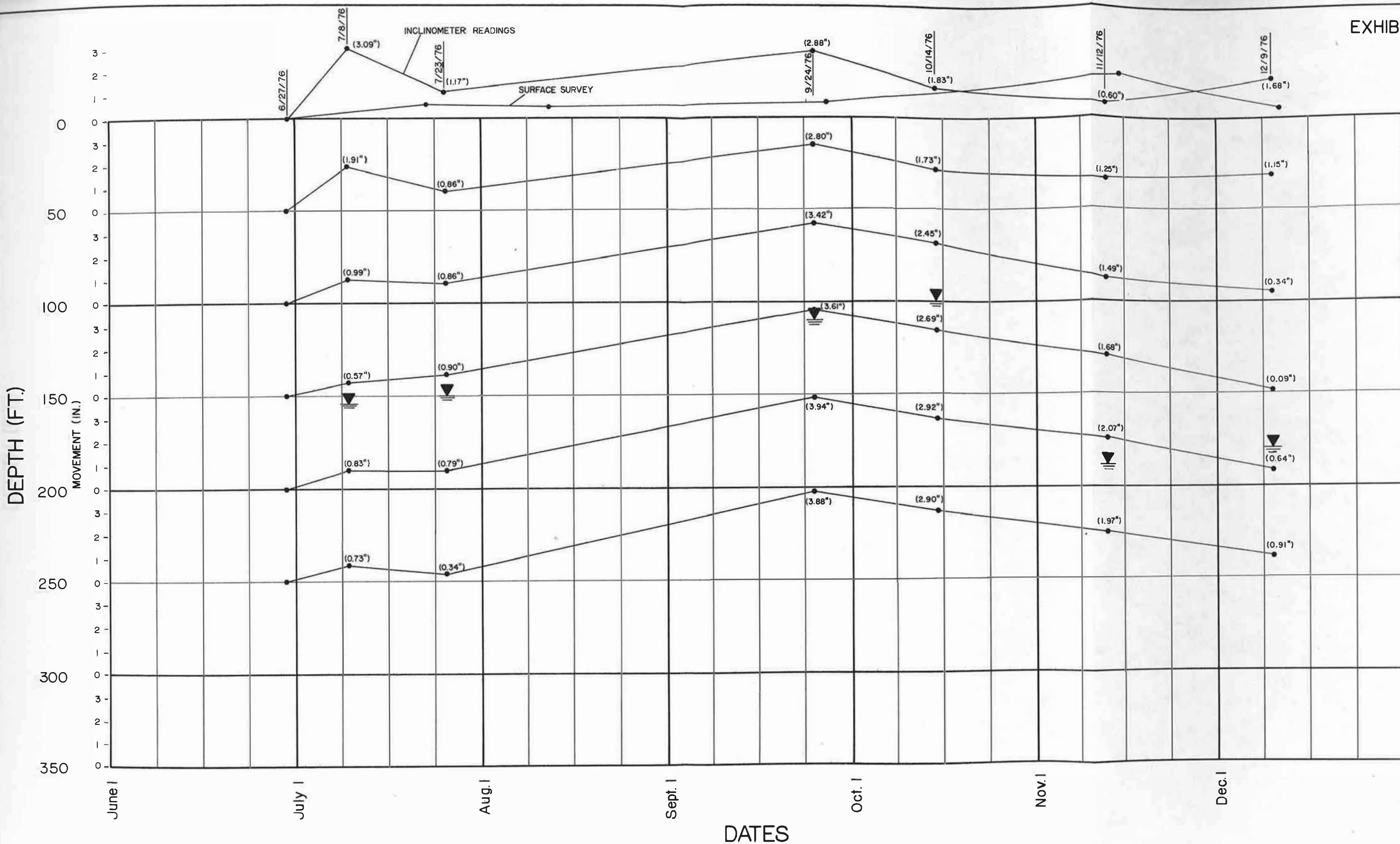
EXHIBIT 2



NORTH SLIDE MOVEMENT
FROM INCLINOMETER READINGS AND SURFACE SURVEYS
HOLE NO. 1A

SLIDE MOVEMENT
DH-1A

EXHIBIT 3

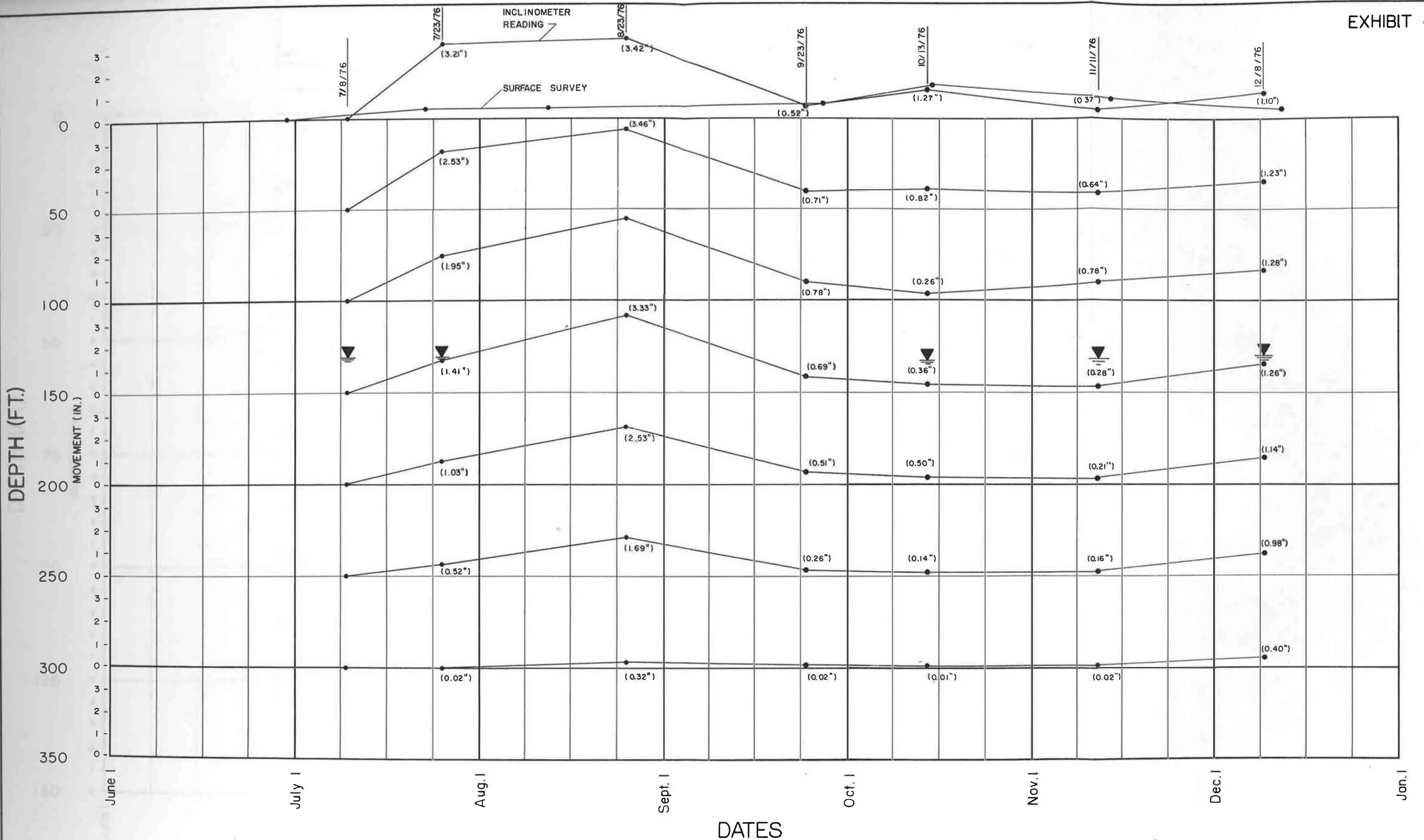


NORTH SLIDE MOVEMENT

FROM INCLINOMETER READINGS AND SURFACE SURVEYS

HOLE NO. 2

SLIDE MOVEMENT
DH-2



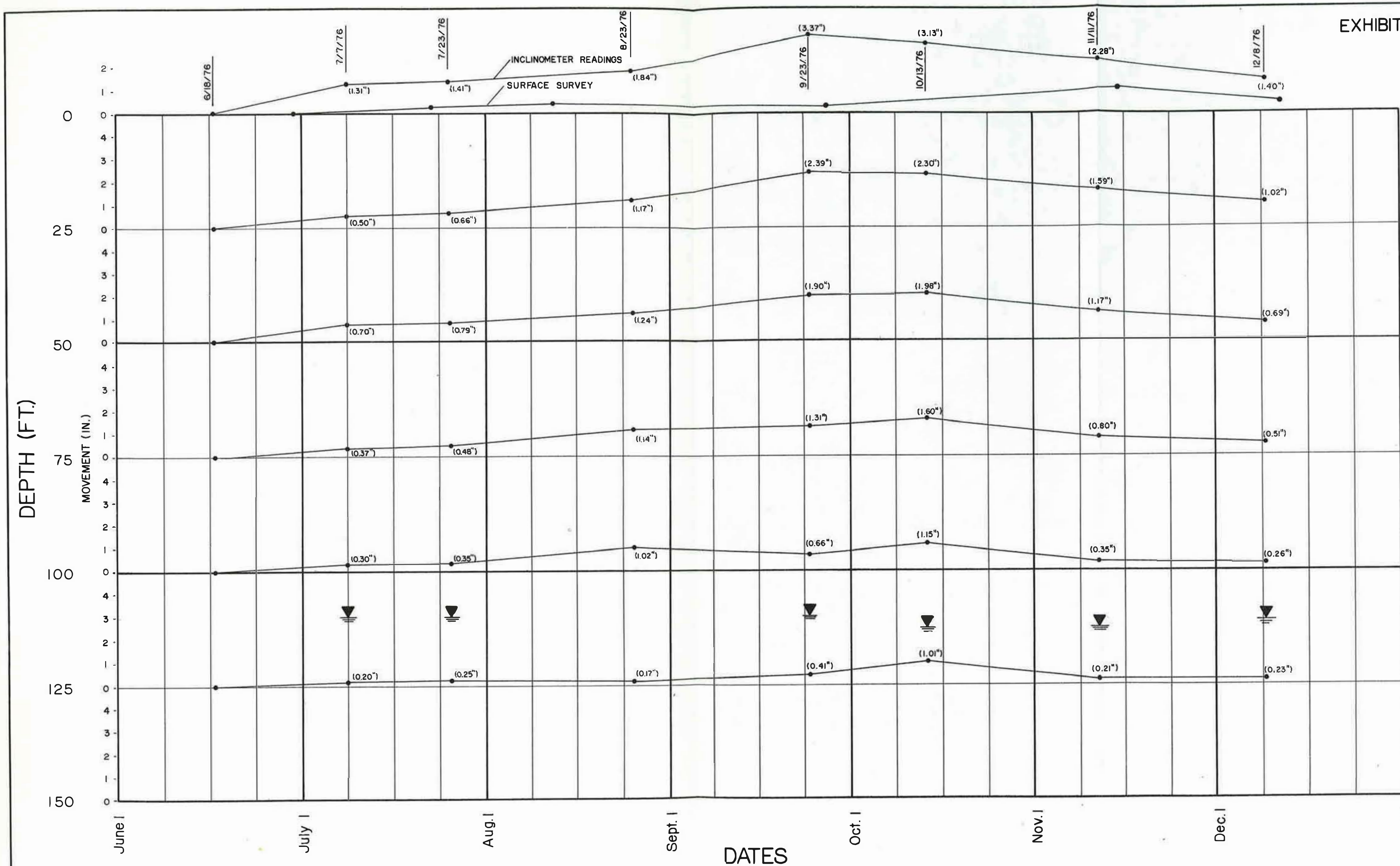
NORTH SLIDE MOVEMENT

FROM INCLINOMETER READINGS AND SURFACE SURVEYS

HOLE NO. 3A

SLIDE MOVEMENT
DH-3A

EXHIBIT 5



NORTH SLIDE MOVEMENT

FROM INCLINOMETER READINGS AND SURFACE SURVEYS

HOLE NO. 4A

SLIDE MOVEMENT
DH-4A