

*Technical Report 121*

MAY, 1963

# Camp Century Movement Record



U. S. ARMY  
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY

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# **Camp Century Movement Record**

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and Barrat G. Scott

U. S. ARMY COLD REGIONS RESEARCH  
AND ENGINEERING LABORATORY  
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## PREFACE

This report presents the measurement methods and data of USA CRREL Subtask 5010.02203 (Greenland Project 13a) at Camp Century, Greenland. It covers the period from October 1960, when the first measurements were taken, through May 1962.

The work reported here was begun for the Applied Research Branch, USA SIPRE, and continued, after USA SIPRE became part of USA CRREL, under the Construction Engineering Branch, Mr. E. F. Lobacz, Chief, and the Experimental Engineering Division, Mr. K. A. Linell, Chief. Personnel of the U. S. Army Polar Research and Development Center and the U. S. Army Engineer Research and Development Detachment have materially contributed to this program.

This report has been reviewed and approved for publication by Headquarters, U. S. Army Materiel Command.

  
W. L. NUNGESSER  
Colonel, CE  
Commanding,  
USA CRREL

Department of the Army Task 8S66-02-001-02

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## CAMP CENTURY MOVEMENT RECORD

by

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Wayne N. Tobiasson  
Barrat G. Scott

### A. INTRODUCTION

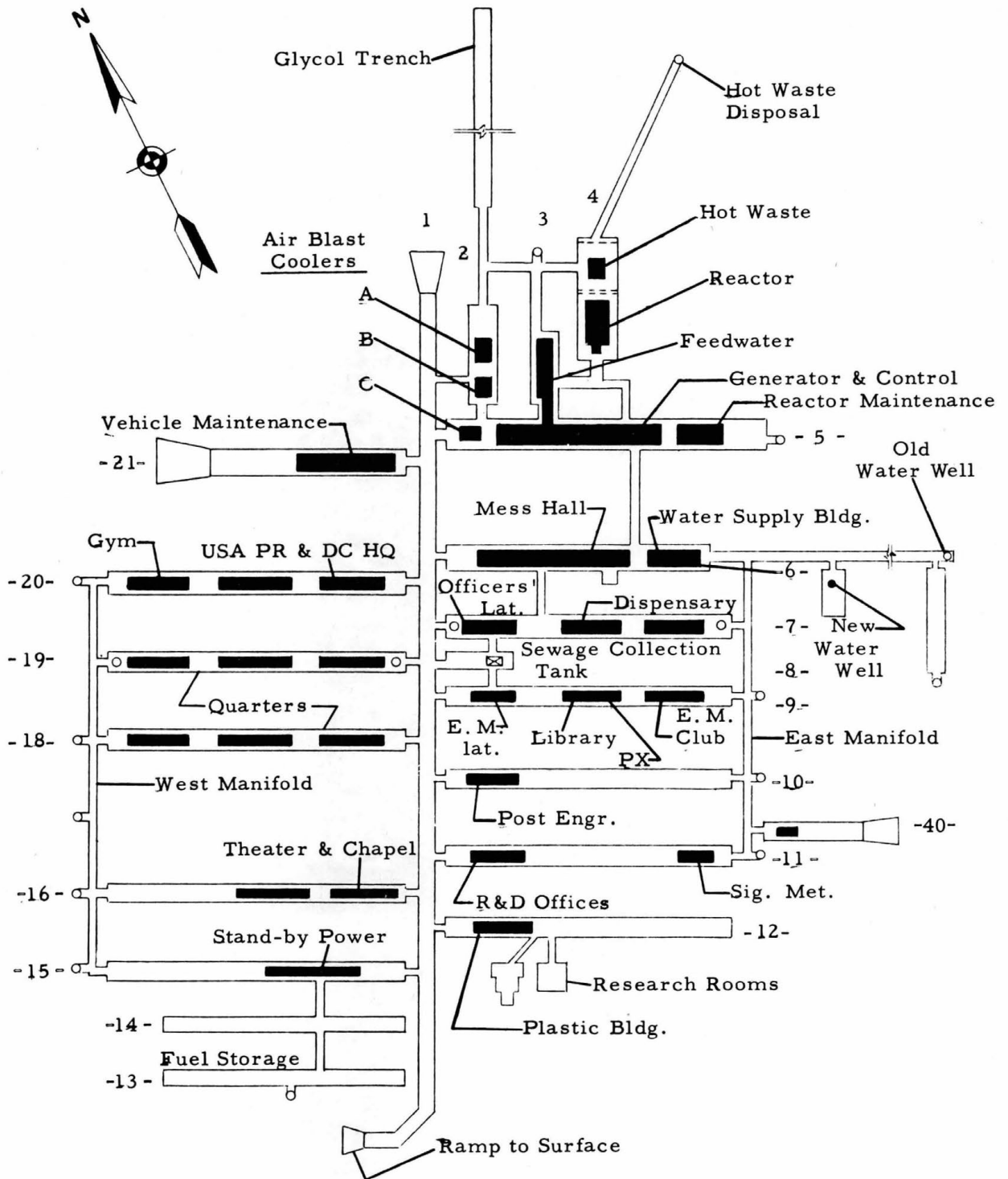
During the 1959 and 1960 construction seasons, the U. S. Army Polar Research and Development Center cut into the snow of the Greenland Ice Cap a system of interconnected trenches designed to house complete year-round living facilities for 150 men. Trenches 1, 5, 6, 7, and 19 at Camp Century were completed and most of the facilities installed in the summer of 1959. The remaining trenches and facilities, including the nuclear reactor power plant, were operational by September 1960. The camp was occupied throughout the winter of 1960-1961 at which time the operational problems of water supply, waste disposal, trench closure and radiation protection were studied in detail. USA CRREL and other agencies at Century were engaged in research projects both in camp and on the surface of the ice cap during the winter. USA CRREL, Project 13, established preliminary installations for movement measurement.

In permanent snow fields, undersnow cavities, such as the trenches of Camp Century, sustain a continuous closure because of the natural consolidation of snow. Observations and study of this process and the mechanics of snow, however, indicate that useful undersnow cavities can be constructed and maintained for significant periods of time.

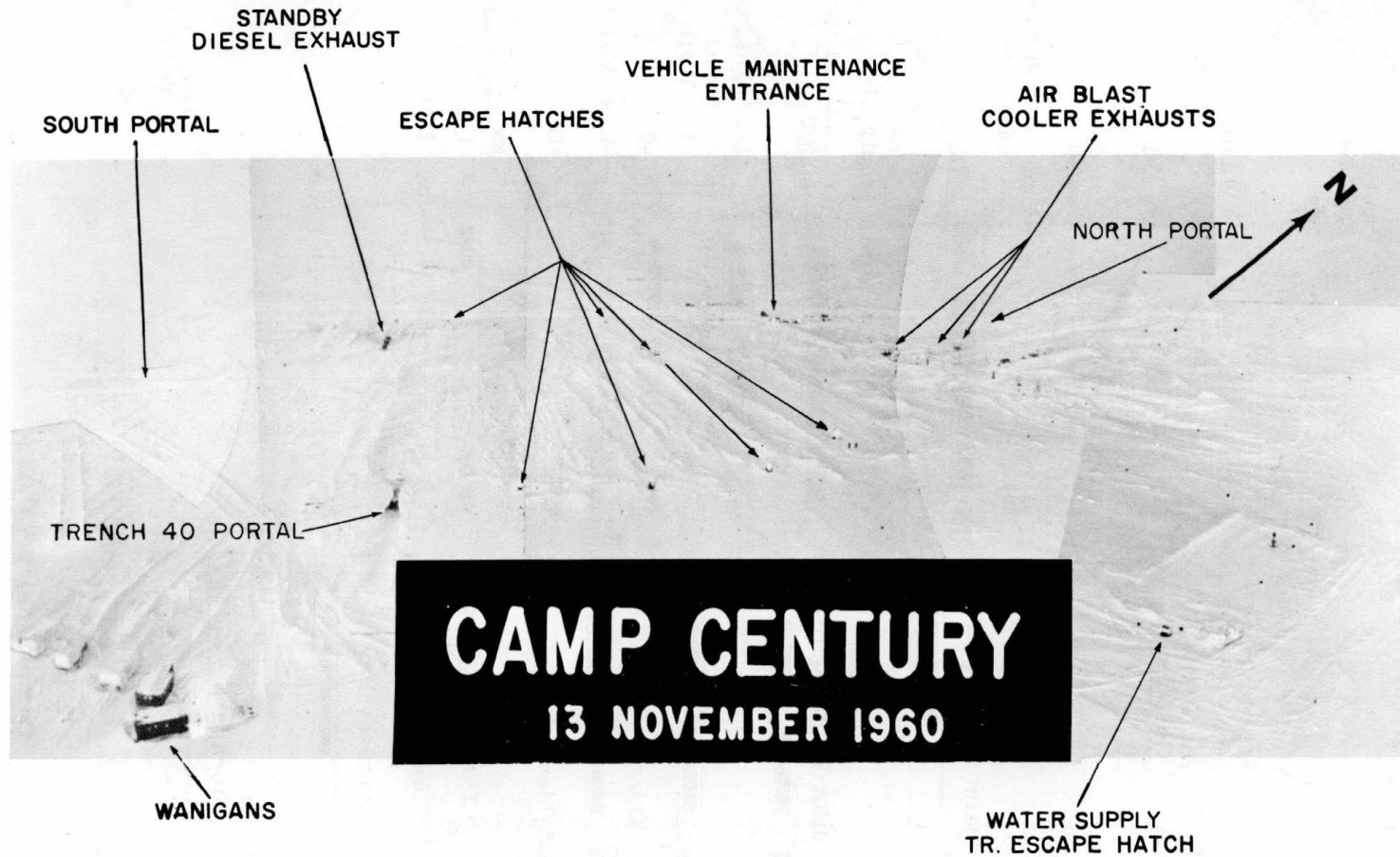
The initial measurement of a typical trench cross section was made in August 1959 at Trench 19. Since that time, 18 additional cross section measurement stations and 29 movement recording Helipots have been installed, a camp bench mark system has been established, and a number of other snow deformation studies initiated. The results to date (May 1962) are presented in the following pages.

The principal purpose of these studies is to define more clearly the term, "useful life" of such installations and to establish design criteria for future construction.

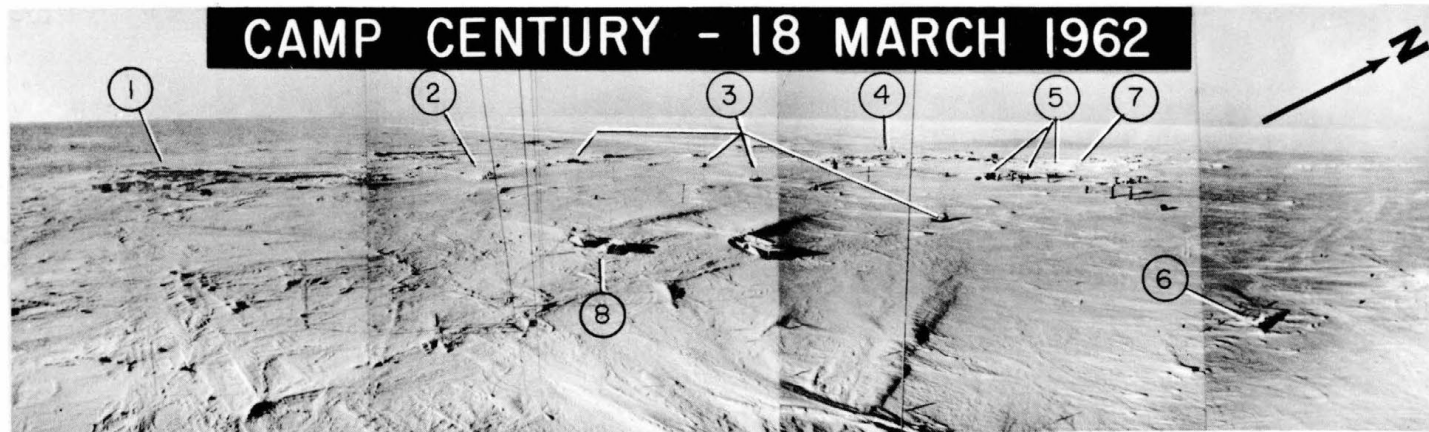
B. CAMP PLAN AND PHOTOGRAPHIC VIEWS



Camp Century - Plan View



Panoramic View - 1960



- 1. SOUTH PORTAL
- 2. STANDBY DIESEL EXHAUST
- 3. ESCAPE HATCHES

- 7. NORTH PORTAL
- 8. WANIGANS

- 4. VEHICLE MAINTENANCE ENTRANCE
- 5. AIR BLAST COOLER EXHAUSTS
- 6. WATER SUPPLY TRENCH ESCAPE HATCH

Panoramic View - 1962



Photo 1A and 1B. Surface penetration and drift.

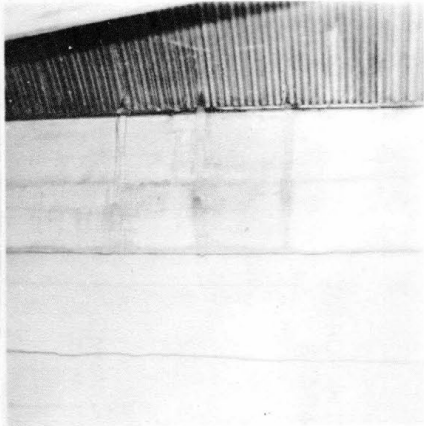


Photo 2. Typical melting along a metal arch.

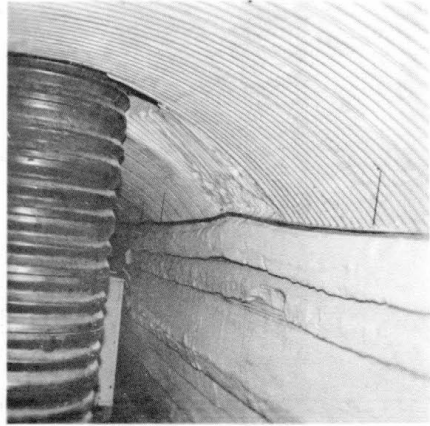


Photo 3. Escape hatch influence on snow wall.

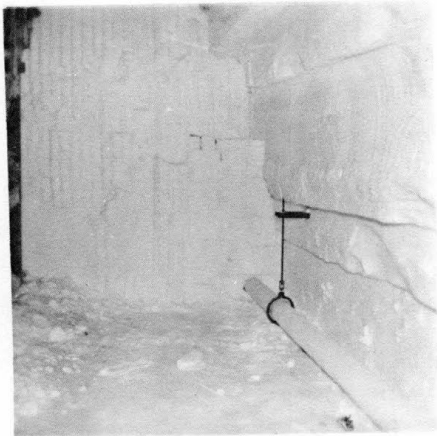


Photo 4. Typical pipe support.

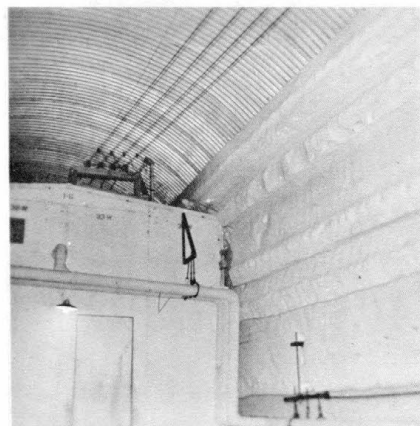


Photo 5. Building clearance problem.

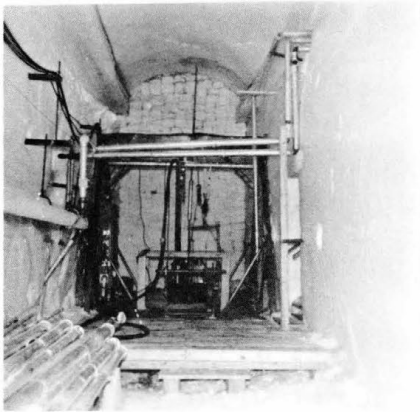


Photo 6. Old water well.

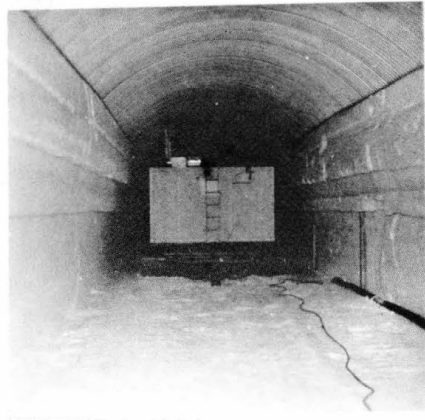


Photo 7. Steam generator for water well.



Photo 8. Portal settlement.

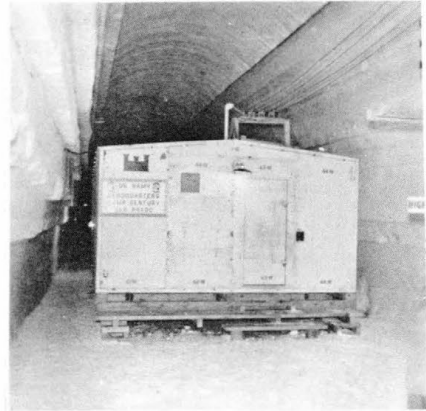


Photo 9. Typical T-5 building.

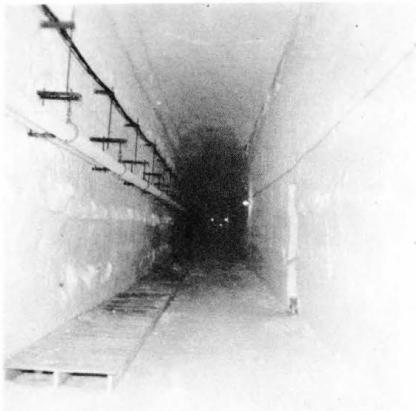


Photo 10. Straight wall trench to water well.

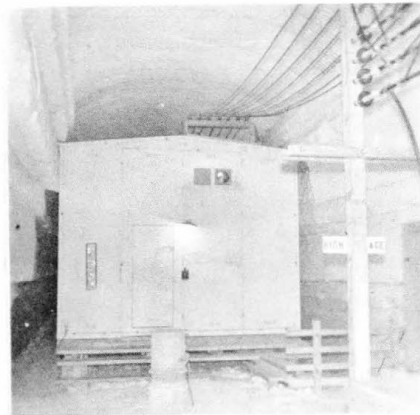


Photo 11. Building clearance problem.



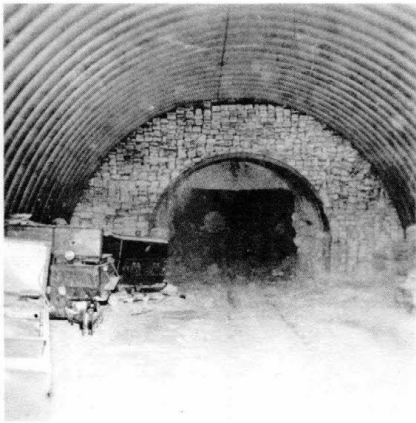


Photo 12. Vehicle storage trench Wonder Arch.

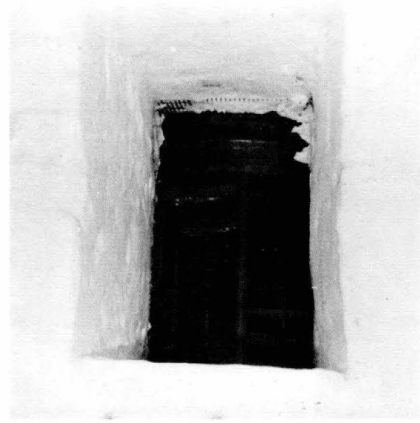


Photo 13. Typical access to escape hatch.

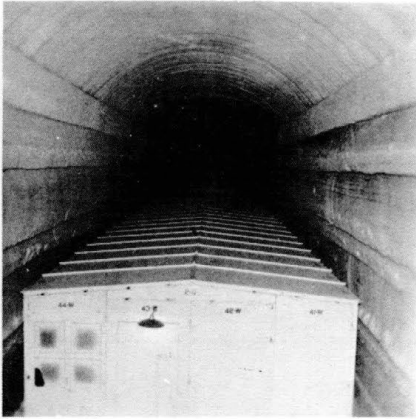


Photo 14. Example of adequate clearance.

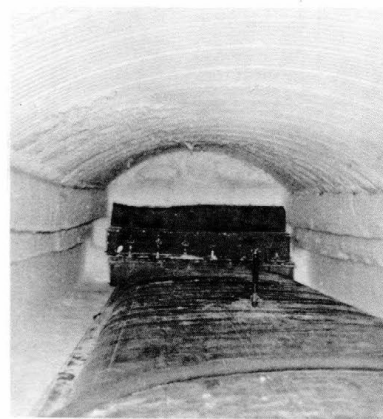


Photo 15. Fuel storage.

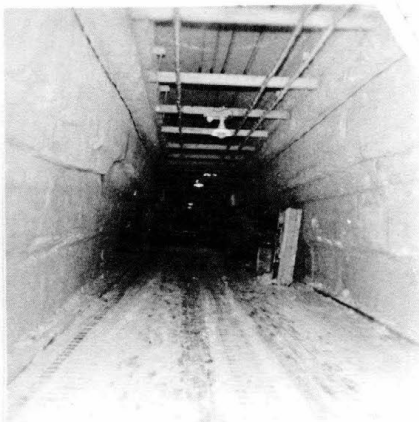


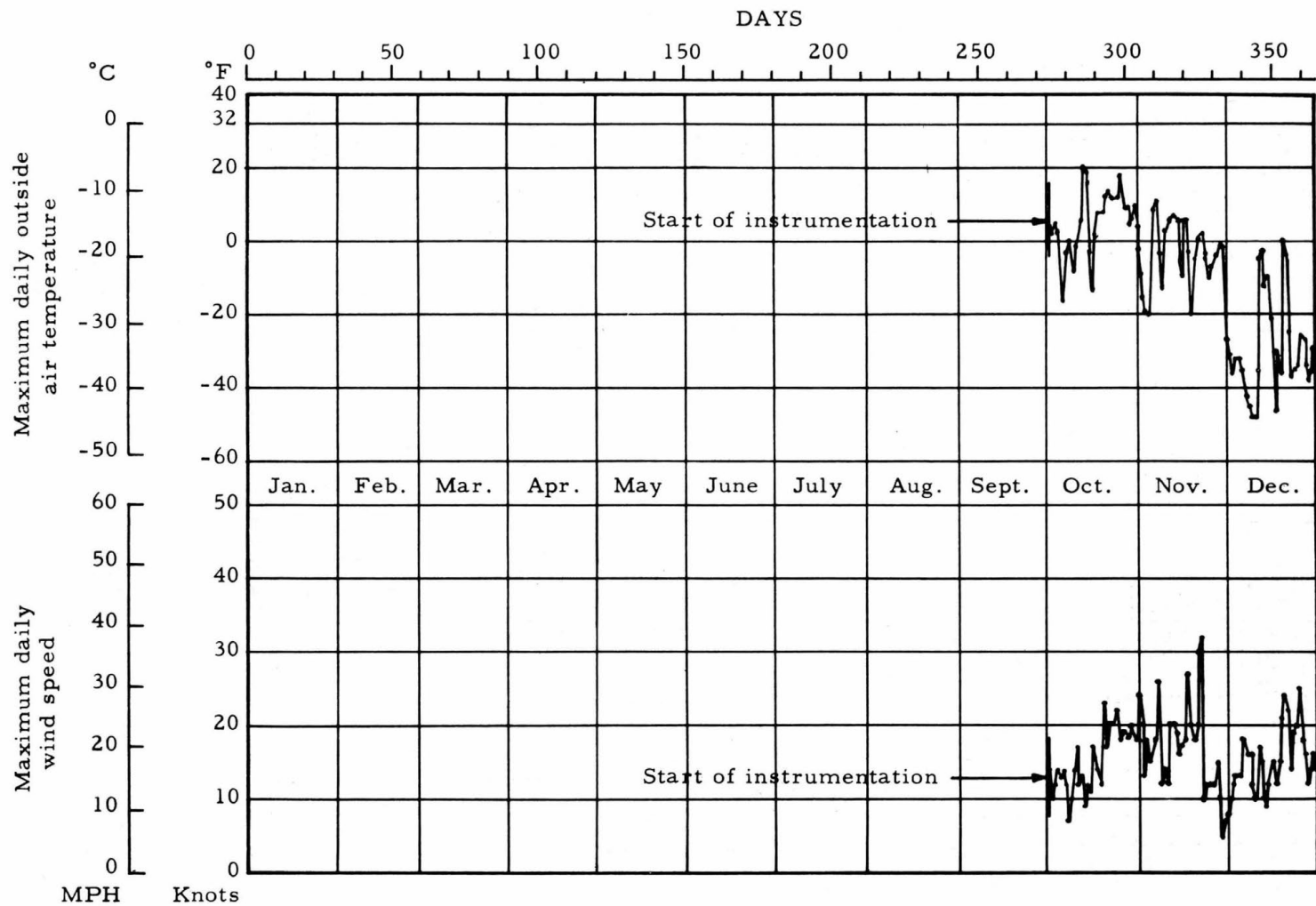
Photo 16. Trench 1 (looking north).

NOTE: Photographs by Photographic Interpretation Research Division, USA CRREL, November - December 1960.

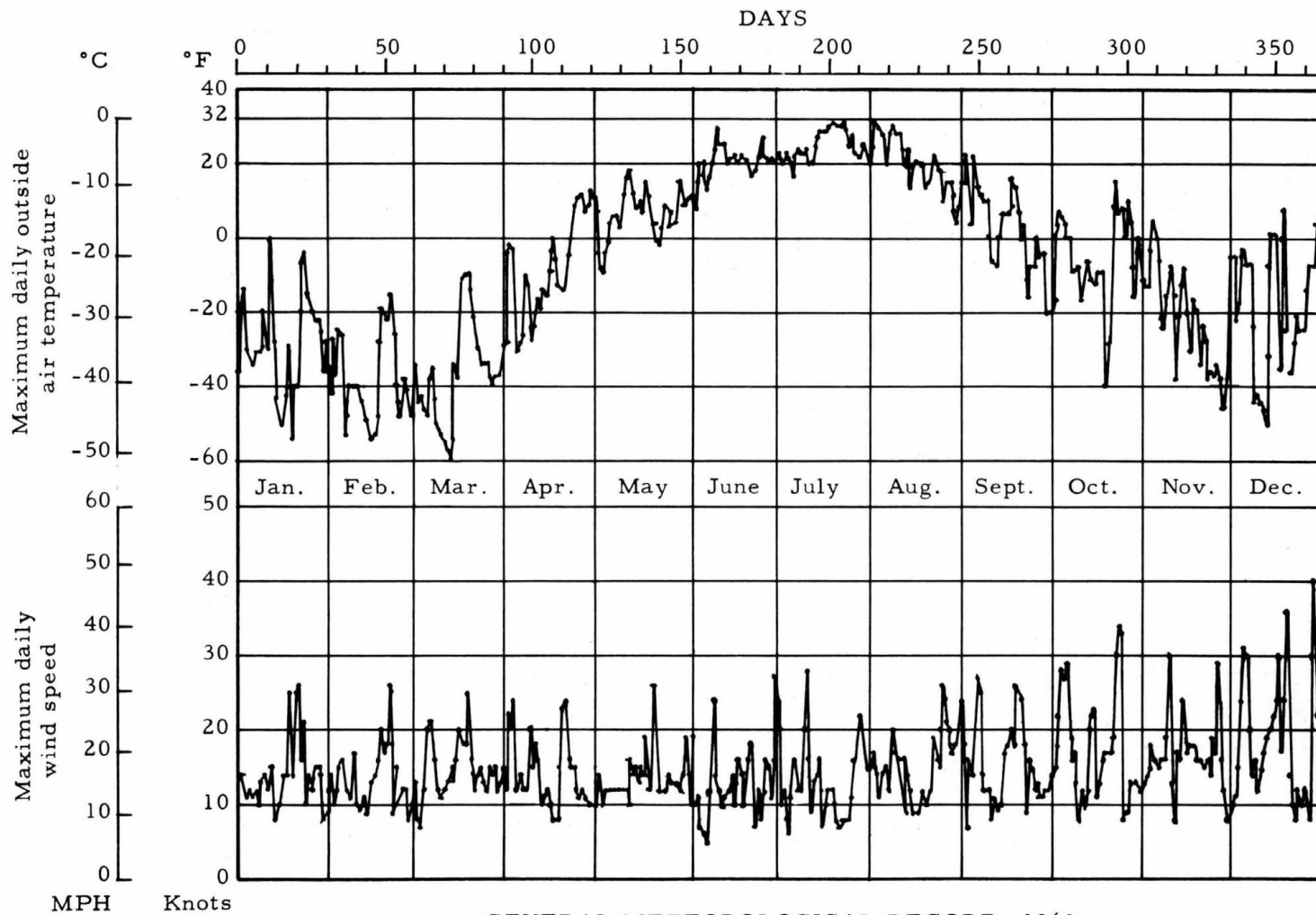


C. GENERAL METEOROLOGICAL RECORD

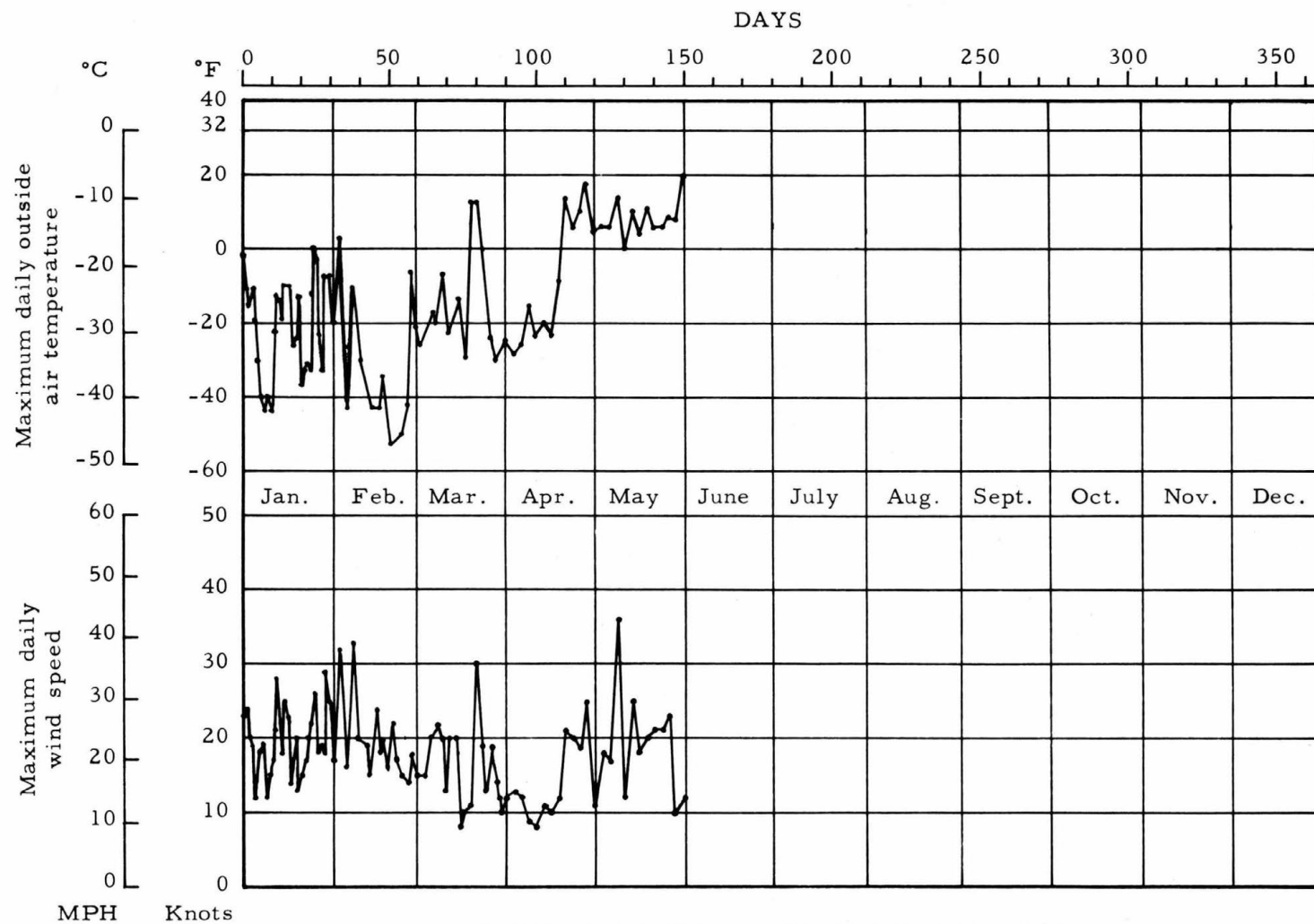
From: U. S. Army Signal Corps Meteorological Data



GENERAL METEOROLOGICAL RECORD, 1960



GENERAL METEOROLOGICAL RECORD, 1961



GENERAL METEOROLOGICAL RECORD, 1962

## D. MOVEMENT MEASUREMENT SYSTEMS

Deformation of the Camp Century trench complex is measured by the following five systems.

1. Helipot system. The use of helical potentiometers (Helipots) has simplified movement studies of the snow and metal arches and building foundations at Camp Century (Fig. 1), particularly in inaccessible places. All Helipots are installed on structures and the movement recorded is that which occurs between the structure and an anchor in the arch or trench floor.

A Helipot (Fig. 2) consists of a helically wound rheostat with a micarta sheave attached to the shaft. A wire is anchored in the arch (or trench floor) and run around the sheave to a counterweight. As the distance between the anchor and the Helipot changes, the sheave rotates causing the resistance within the Helipot to change. A measurement is made by balancing the resistance of this Helipot with an identical unit coupled to a galvanometer at the read-out terminal (Fig. 1). The electrical system is basically a Wheatstone bridge which can be read directly to 1 ohm, corresponding to one hundredth of a rotation of the instrument's shaft. Readings can be estimated to 0.2 ohm, which corresponds to a minimum linear measure of about 1/64 in. for a 2 in. diam. micarta sheave.

To obtain a more positive transmittal of anchor movement into sheave rotation, Helipots 33, 34, 35 and 36 have sprocket and chain linkages rather than sheave and wire systems. The small sprocket used also gives more precise readings, the 1/64 in. available previously being reduced to 0.005 in.

At present, there are 29 Helipots installed on building roofs and foundations throughout Camp Century. A general location of each Helipot is given on pages E1 and E2, and a detailed location is shown with each movement curve.

Since the scale of the movement curves prevented showing each of the 250 to 300 observations made per Helipot, the data have been presented as smooth curves. Individual points almost always coincide with the smooth curves for arch Helipots. However, irregularities occur in the foundation measurements and those curves should be viewed as indicative of the relative movement occurring between Helipot and anchor only. The movement indicated by foundation Helipots consists of more than simple settlement. Since the buildings weigh much less than the excavated snow, the trench floors "rebound" and arch basically as shown in Figure 3. This effect causes the instrument to record variations of foundation settlement. Since no independent measurement of trench floor arching has been undertaken, all movements recorded by foundation Helipots are presented as relative rather than absolute. However, the magnitude of the trench floor arching action and the amount of building settlement are insignificant when compared to the rate of roof movement as measured by Helipots anchored in a snow or metal arch. Measurement of arch movement has been obtained with considerable accuracy.

Information obtained from the 29 Helipot installations has been divided into five cases as shown in Figure 4. All arch installations are covered by Case I. Cases II, III, IV, and V explain various foundation conditions. Each movement curve is identified by a case number.

2. Cross sections. The size and shape of a cavity in snow determines to a large degree the nature of its deformation with time. In order to study these effects, periodic measurements of both horizontal and vertical dimensions of various trench cross sections were initiated.

At 19 stations throughout the camp, wooden reference pegs have been set at various heights in trench walls. A steel tape is used to measure the horizontal and vertical distances between these pegs. As the trench floors are quite irregular and unstable, string stretched between the two lowest pegs is used for horizontal reference when measuring the vertical distances.

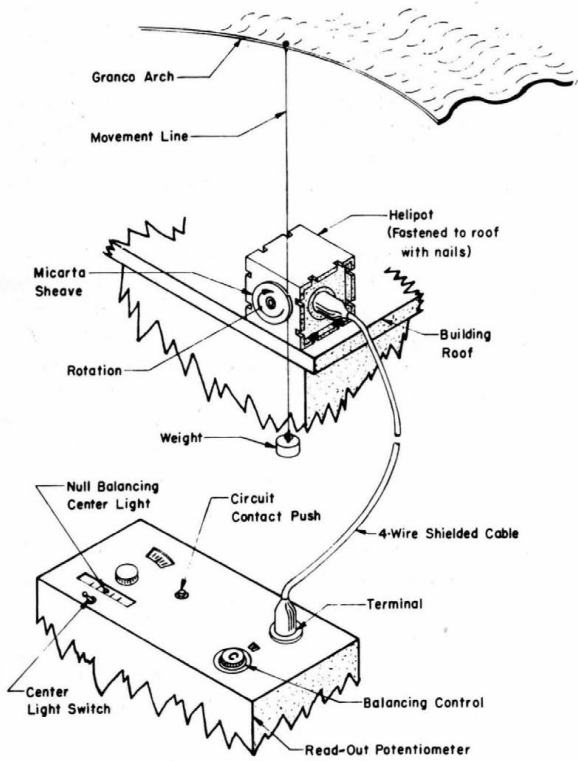


Figure 1. Helipot installation.

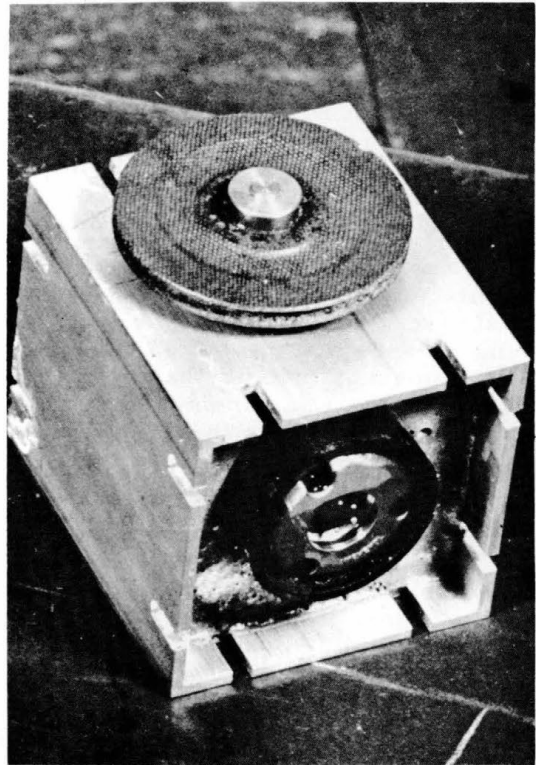


Figure 2. Helipot.

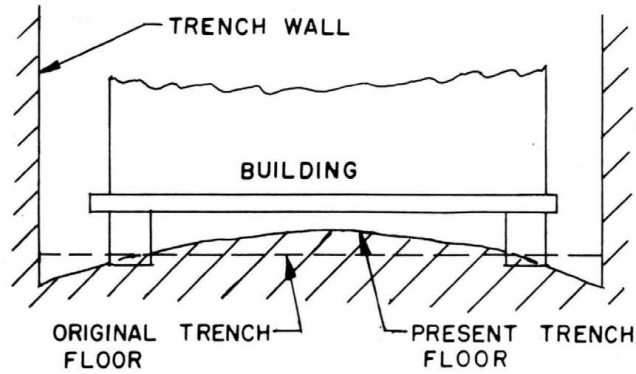
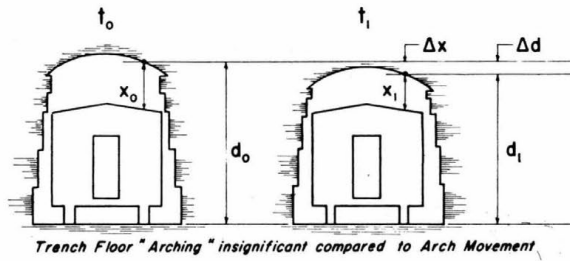
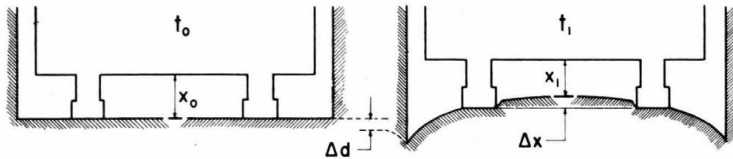


Figure 3. Arching of a trench floor.

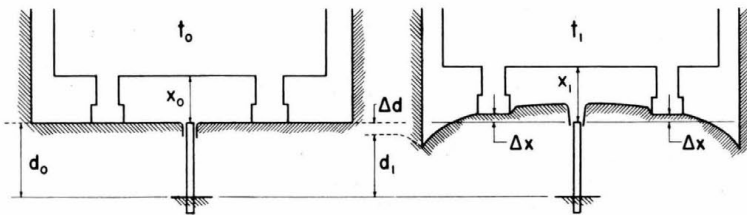
**CASE I**  
 ALL ARCH HELIPOTS  
 $X_0 > X_1$



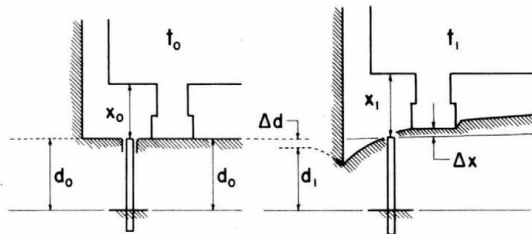
**CASE II**  
 SURFACE ANCHOR  
 $X_0 > X_1$



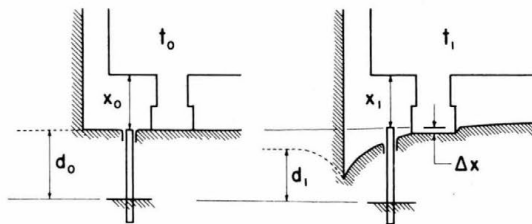
**CASE III**  
 DEEP ANCHOR  
 $X_0 < X_1$



**CASE IV**  
 DEEP ANCHOR  
 $X_0 < X_1$



**CASE V**  
 DEEP ANCHOR  
 $X_0 > X_1$



**NOTE**

"Arching" of floor exaggerated for clarity in Cases II thru V

**LEGEND**

$t_0$  = time, zero;  $X_0$  = measured distance, at  $t_0$ ;  $d_0$  = thickness of a layer at  $t_0$   
 $t_1$  = time, later;  $X_1$  = measured distance, at  $t_1$ ;  $d_1$  = thickness of the layer at  $t_1$   
 $\Delta t = t_1 - t_0$ ;  $\Delta x$  = change in length during  $\Delta t$ ;  $\Delta d$  = natural densification during  $\Delta t$

Figure 4. Five cases of Helipot movement.

## CAMP CENTURY MOVEMENT RECORD

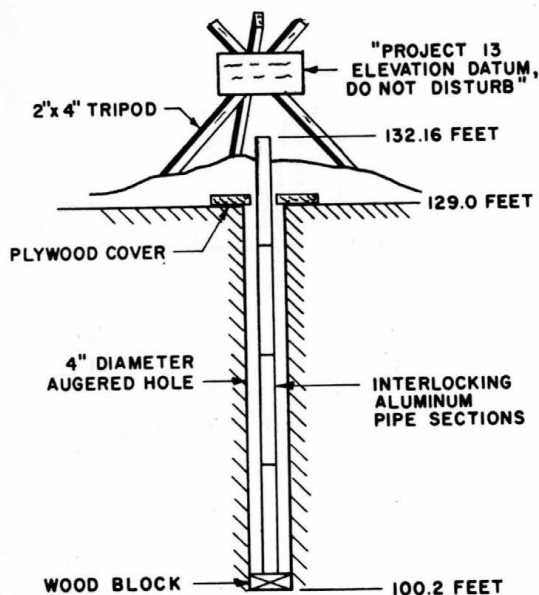


Figure 5. Camp Century elevation datum. 1300 ft south of south portal.

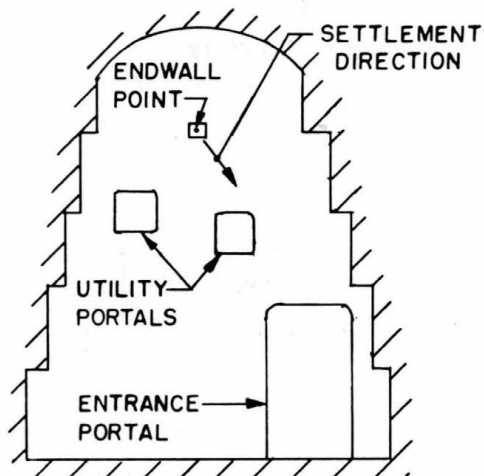


Figure 6. Endwall point settlement showing portal effect.

3. Portal grids. Grid lines have been painted on the Main Trench (Trench 1) wall at several of the side trench portals. Since the geometry of cavities in snow influences the nature of plastic flow, a variety of portal sizes and shapes have been referenced by these grids. Periodic photographs of these sections reveal the pattern of deformation for each portal and provide visual evidence of plastic flow.

4. Profile levels and bench marks. Centerline profile levels are periodically taken on trench floors and arches and on the snow surface above the trenches. This provides information on snow depths above trenches and profiles of the camp area. The profile elevations are tied into the camp bench-mark system.

The bench-mark system can be divided into three parts: trench-floor bench marks, building bench marks, and the elevation datum. The trench-floor bench marks were established during the fall and winter of 1960-61 and consist of pipes and 2 x 4 timbers driven into trench floors. The building bench marks, established in the summer of 1961, are located on the corner nearest the entrance portal of the first building in each trench (H1). Each one is referenced by a 3 x 4 data card stapled nearby. Periodic levels determine the movements of these bench marks relative to the "elevation datum" whose elevation is assumed constant.

The elevation datum consists of sections of interlocking aluminum pipe set in an augered hole and anchored at an elevation approximately equal to that of the lowest trench floor in camp (Fig 5). Its movement is controlled only by the natural densification of the snow. From bench mark 1, the elevation of the accessible top of the datum was established at 132.16 ft. This datum is located 1300 ft directly south of the south portal (Trench 1) and is marked by a painted 2 x 4 tripod. It serves as a vertical control only.

5. Horizontal distortion survey. The camp horizontal distortion survey was undertaken in order to provide some information on the lateral displacement of Camp Century.

A Gurley transit was used to turn the four horizontal angles and to set hubs a, b, and c (West Mainfold Trench floor) and x, y, and z (East Manifold) on line as shown on page J1. The distances between hubs were measured with a 100-ft steel tape.

It was observed that endwall settlement toward the entrance and utility portals (Fig. 6) would be likely to affect the survey's angular changes. Since this would obscure the camp's horizontal distortion pattern, additional points are scheduled for placement on building roofs in the summer of 1962 to more accurately reflect the camp's lateral displacement.



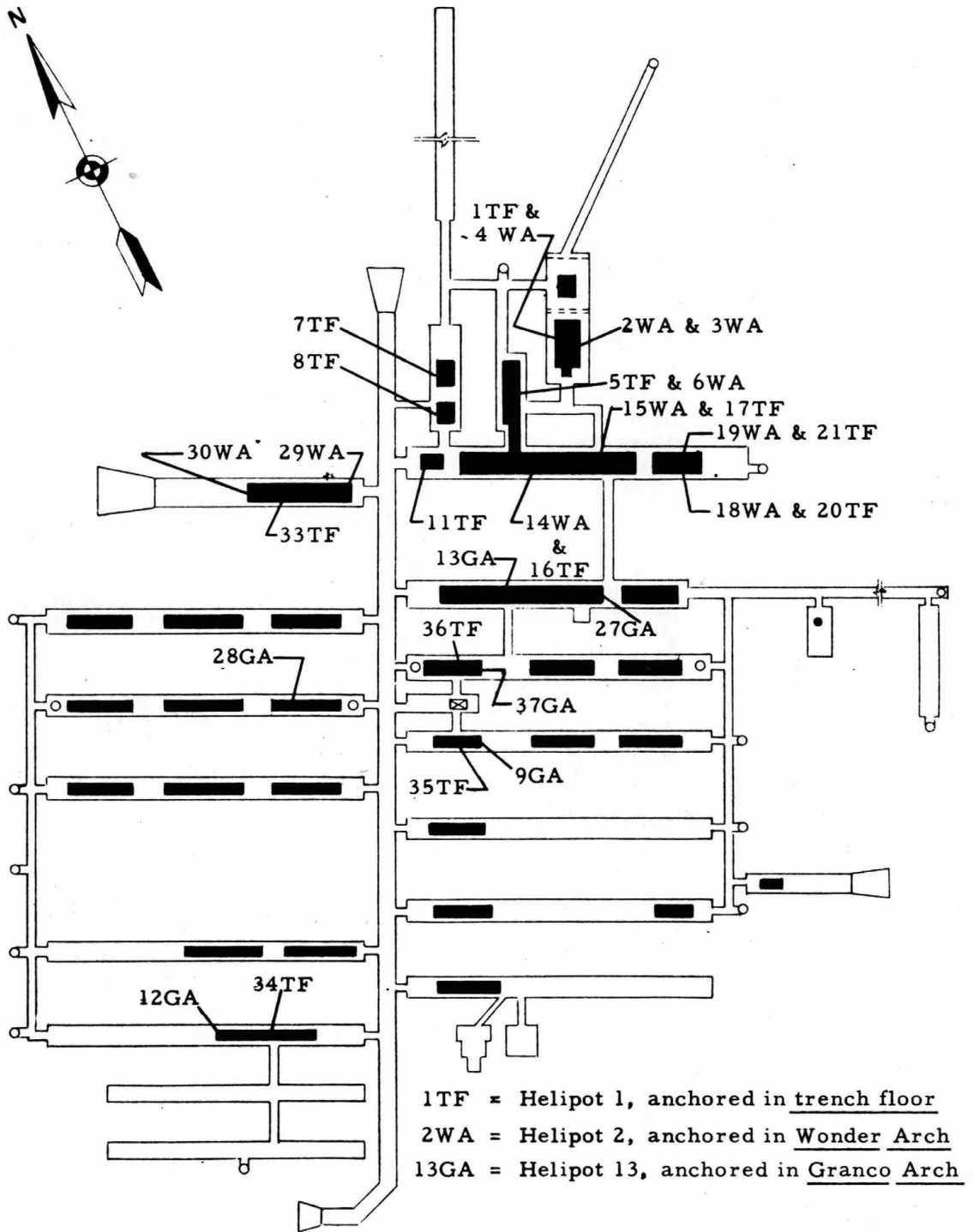
## E. HELIPOT SYSTEM

Table I. Helipot locations.  
Location

Helipot No.	Location
1	Reactor Building floor beam (TF)*
2	Reactor Building floor beam (WA)**
3	Reactor Building roof (WA)
4	Reactor Building roof directly opposite Helipot #3 (WA)
5	Feedwater Building foundation (TF)
6	Feedwater Building roof (WA)
7	Air-Blast Cooler "A" floor beam (TF)
8	Air-Blast Cooler "B" floor beam (TF)
9	E. M. Latrine roof (GA)**
11	Air-Blast Cooler "C" floor beam (TF)
12	Stand-by Power Building roof (GA)
13	Mess Hall roof (GA)
14	Generator and Control Bldg. roof, south side (WA)
15	Generator and Control Bldg. roof, north side (WA)
16	Generator and Control Bldg. foundation, south side (TF)
17	Generator and Control Bldg. foundation, north side (TF)
18	Reactor Maintenance Building roof, south side (WA)
19	Reactor Maintenance Building roof, north side (WA)
20	Reactor Maintenance Bldg. foundation, south side (TF)
21	Reactor Maintenance Bldg. foundation, north side (TF)
27	Mess Hall roof, east end (GA)
28	Quarters Bldg. 19A roof, west end (WA)
29	Vehicle Maintenance Bldg. roof, north side (WA)
30	Vehicle Maintenance Bldg. roof, west side (WA)
33	Vehicle Maintenance Bldg. foundation (TF)
34	Stand-by Power Building foundation (TF)
35	E. M. Latrine foundation (TF)
36	Officers' Latrine foundation (TF)
37	Officers' Latrine roof, east end (GA)

\* (TF) indicates that the movement line is anchored in the trench floor. These helipots measure building foundation settlements.

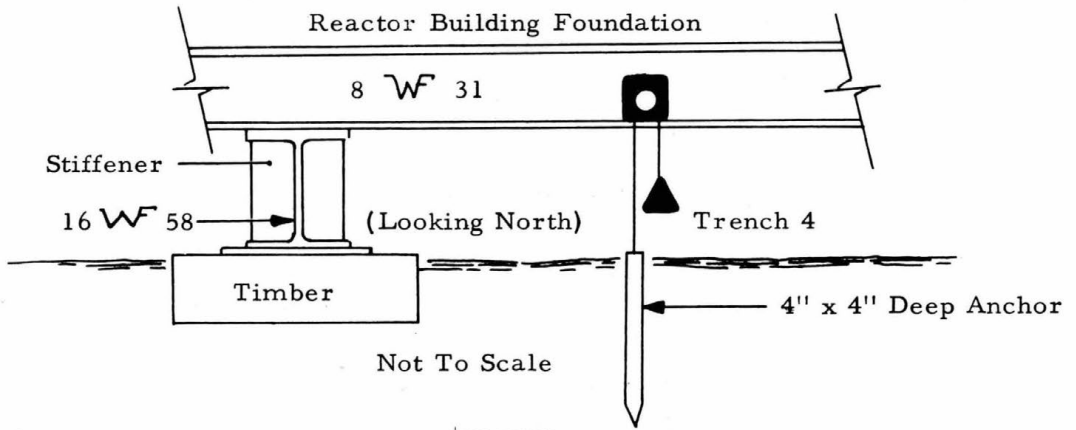
\*\* (WA) - Wonder Arch, or (GA) - Granco Arch indicate that the movement line is anchored in the trench arch. These Helipots measure arch settlements.



Location of Heliports

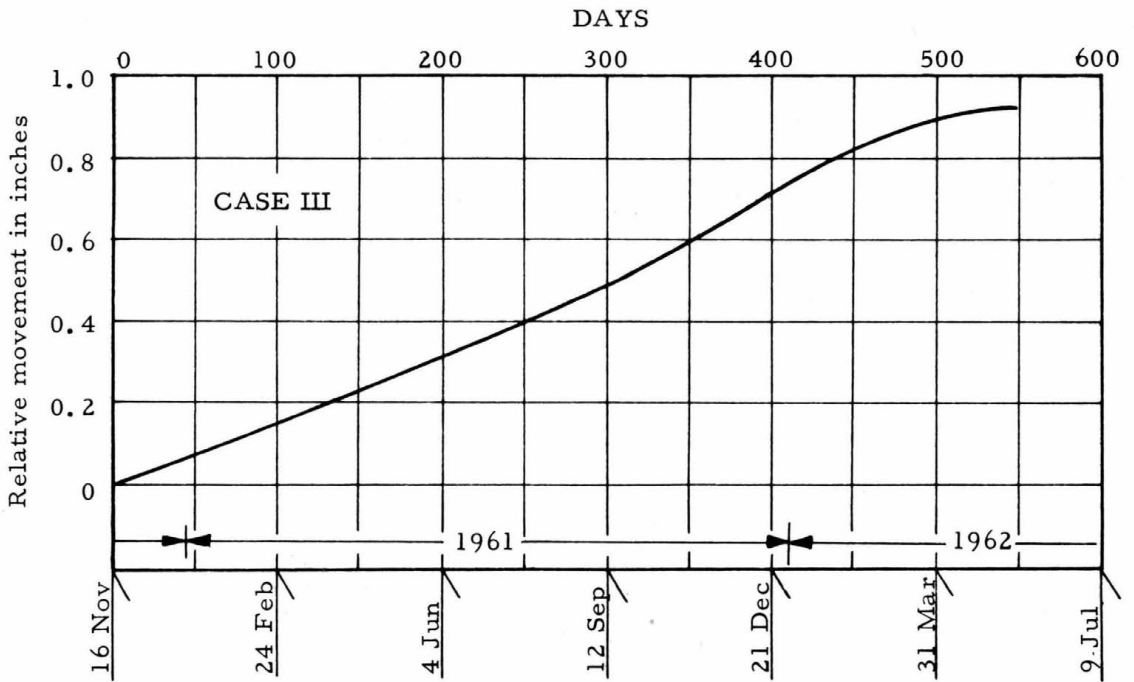
May 1962

HELIPOT # 1



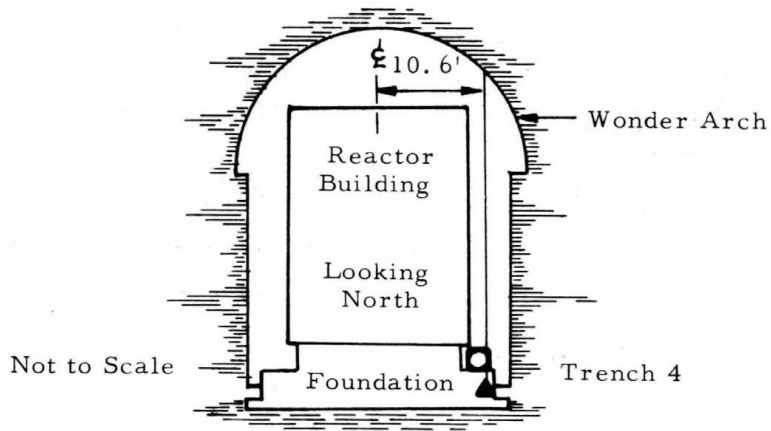
NOTES

Installed 11 Oct '60; Zero time 16 Nov '60  
 Several thousand gallons water removed 6 Dec '60 (20th day)  
 8,000 gallons water added 4 Feb '61 (80th day)



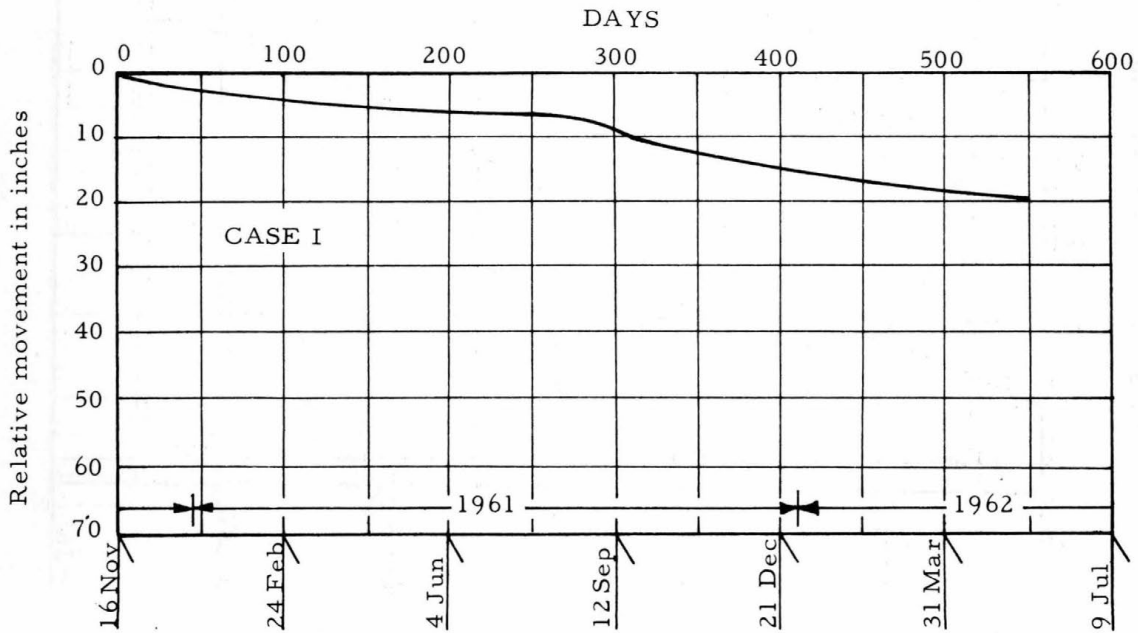
CAMP CENTURY MOVEMENT RECORD

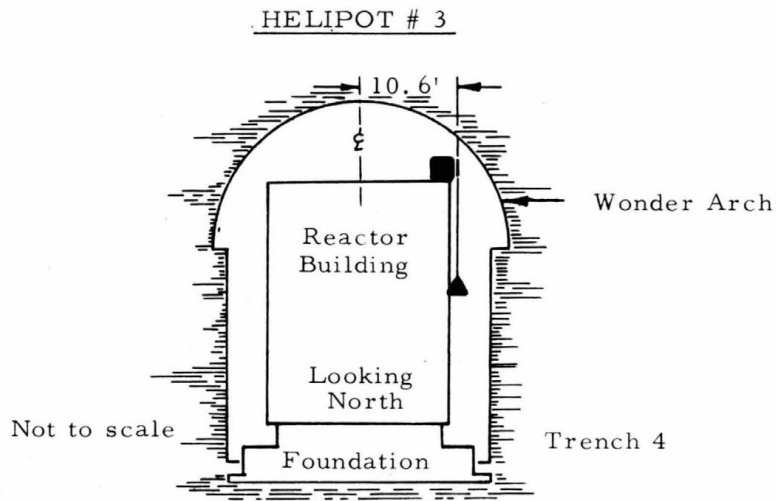
HELIPOT # 2



NOTES:

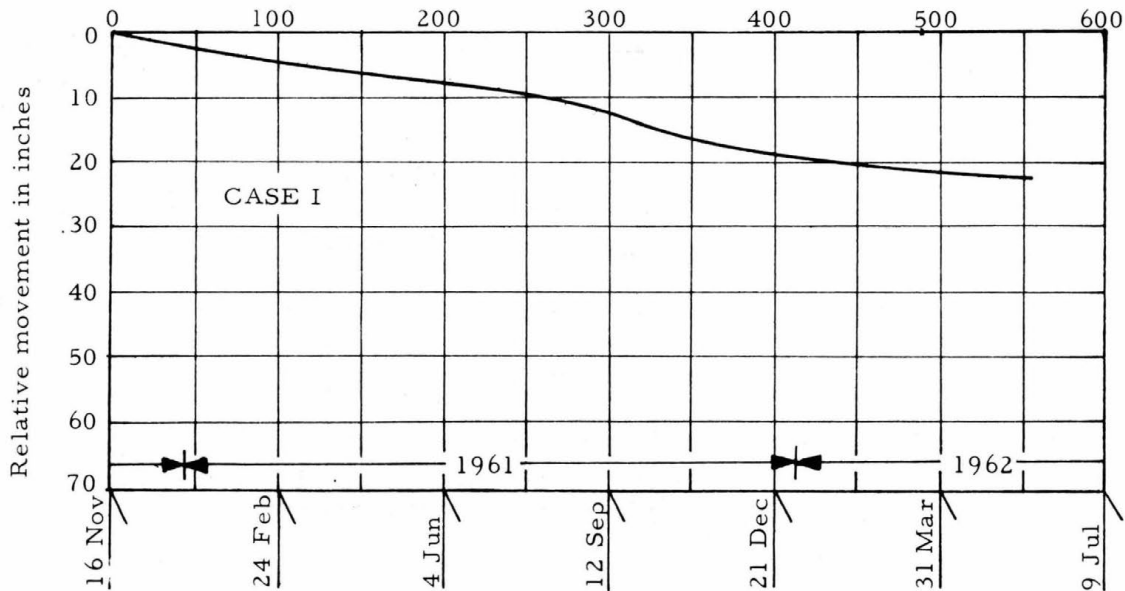
Installed 12 Oct '60; Zero time 16 Nov '60



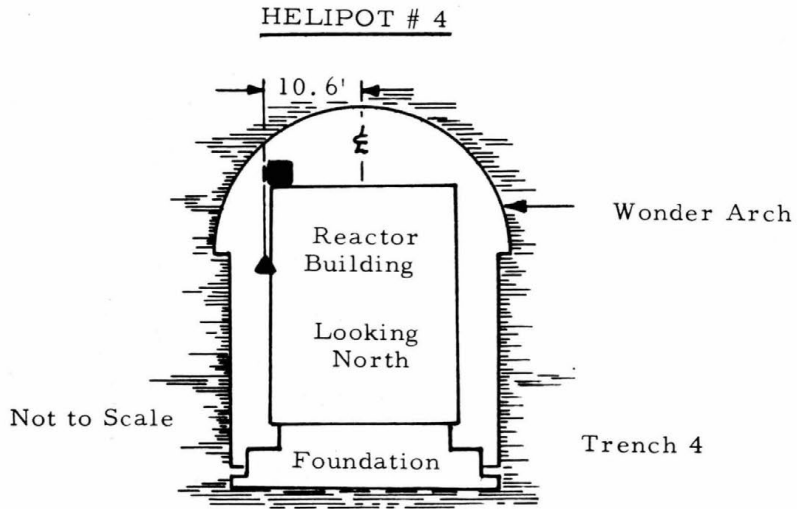


NOTES:

Installed 12 Oct '60; Zero time 16 Nov '60

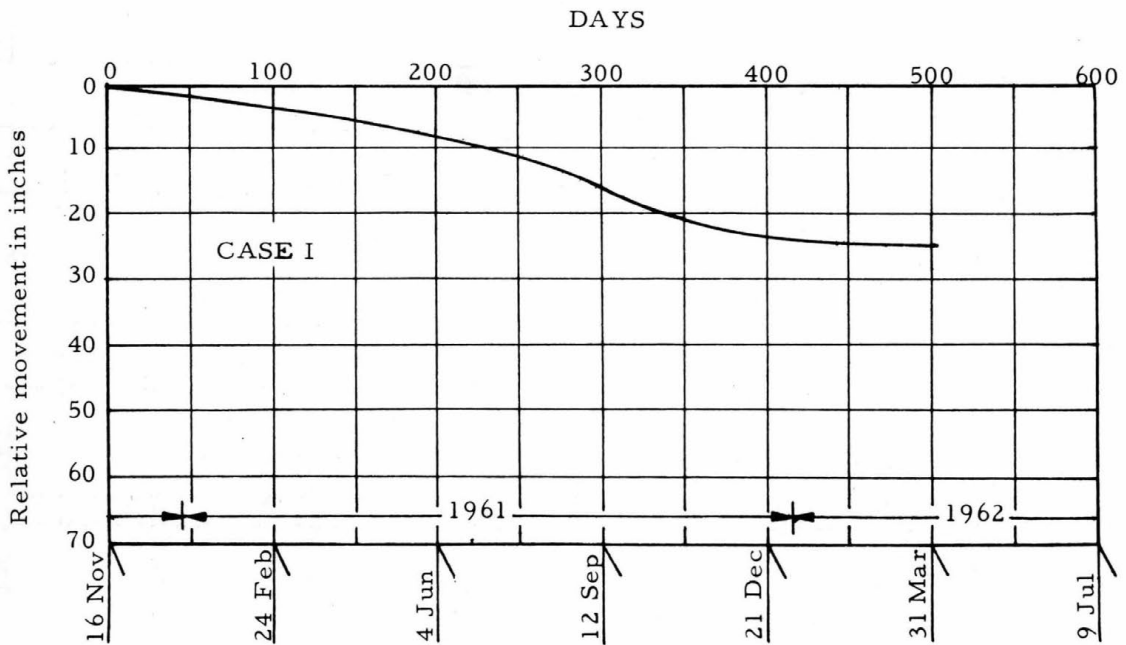


CAMP CENTURY MOVEMENT RECORD

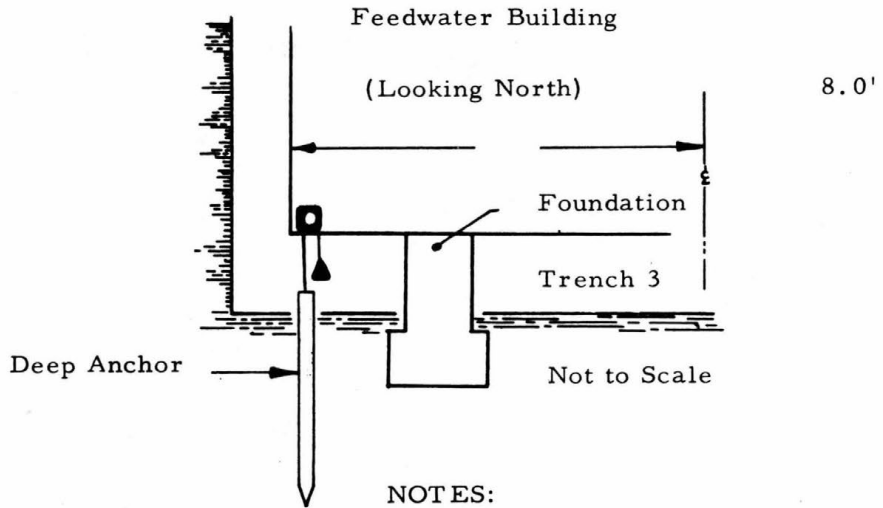


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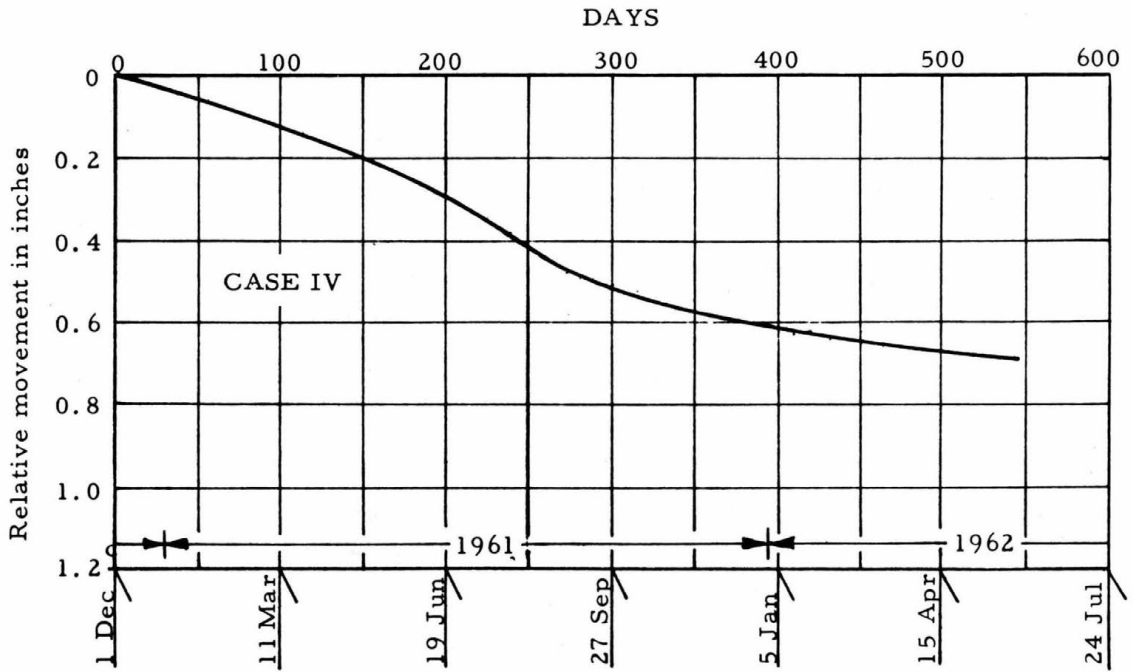
Installed 12 Oct '60; Zero time 16 Nov '60



HELIPOT # 5

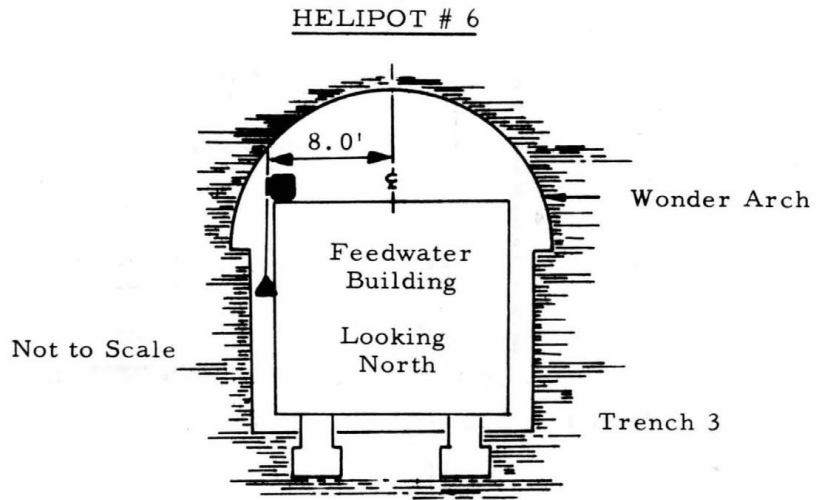


Installed 22 Nov '60; Zero time 1 Dec '60



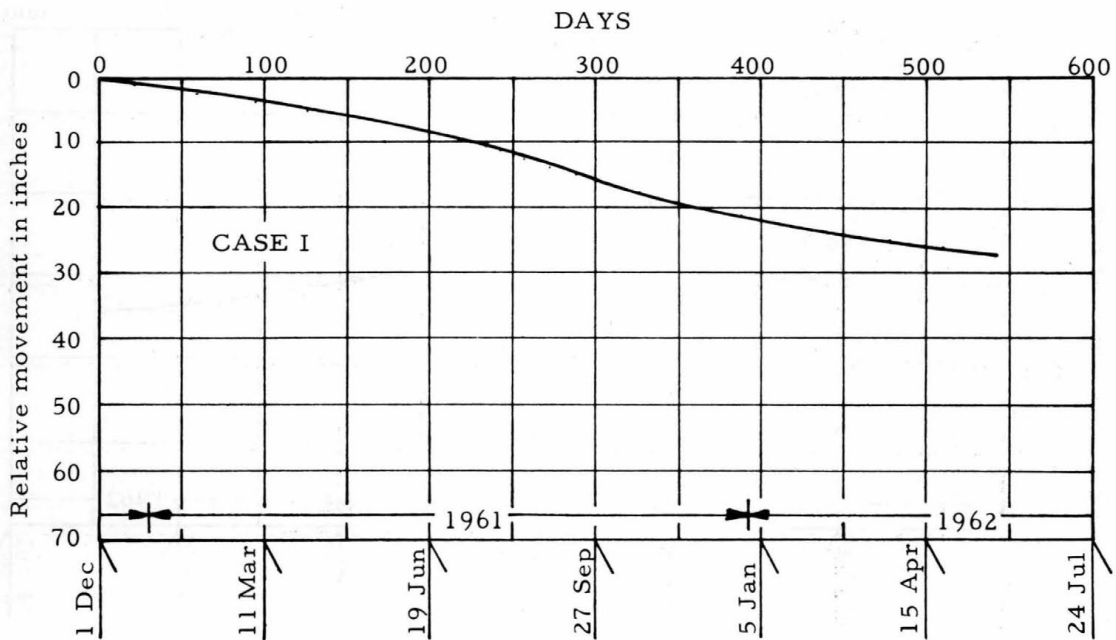


CAMP CENTURY MOVEMENT RECORD

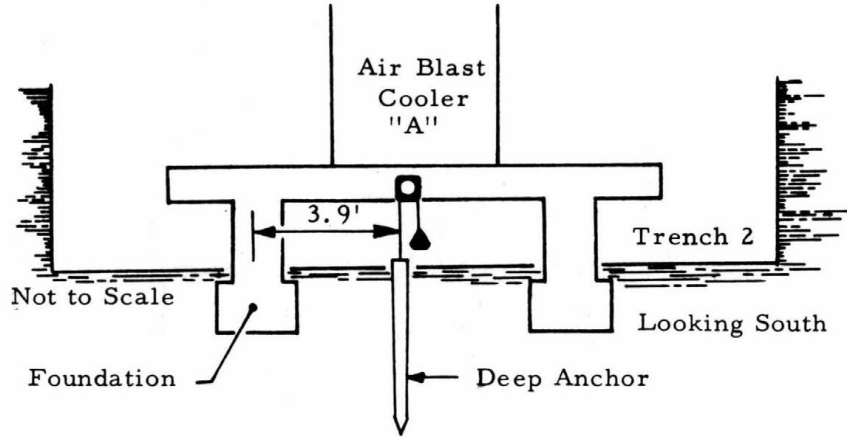


NOTES:

Installed 22 Nov '60; Zero time 1 Dec '60



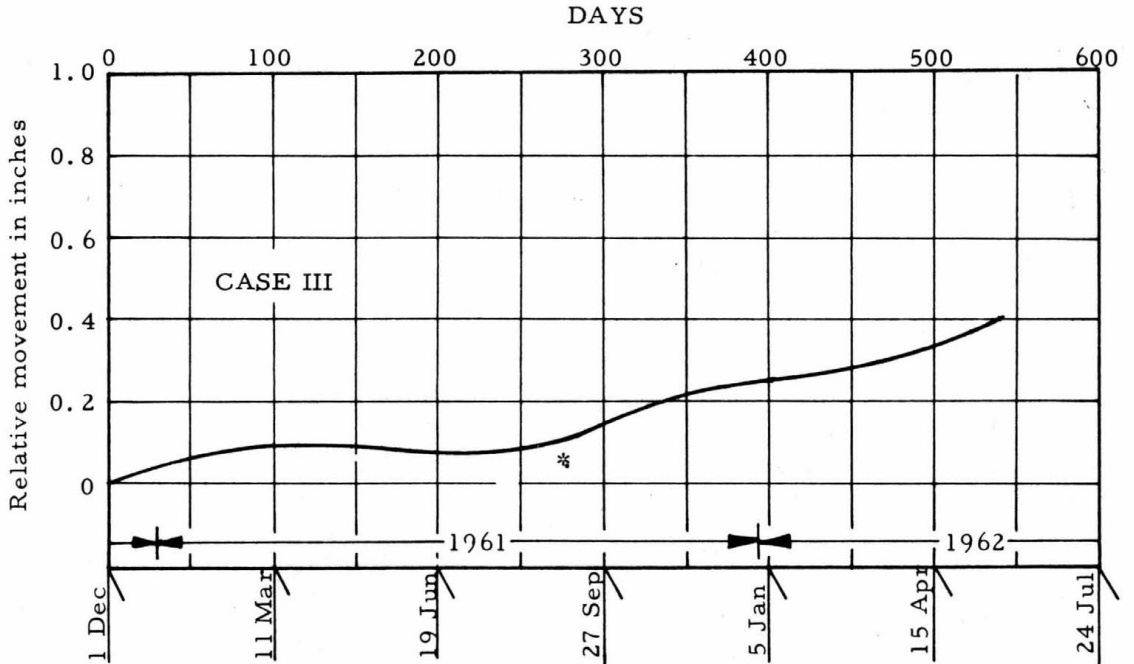
HELIPOT # 7



NOTES:

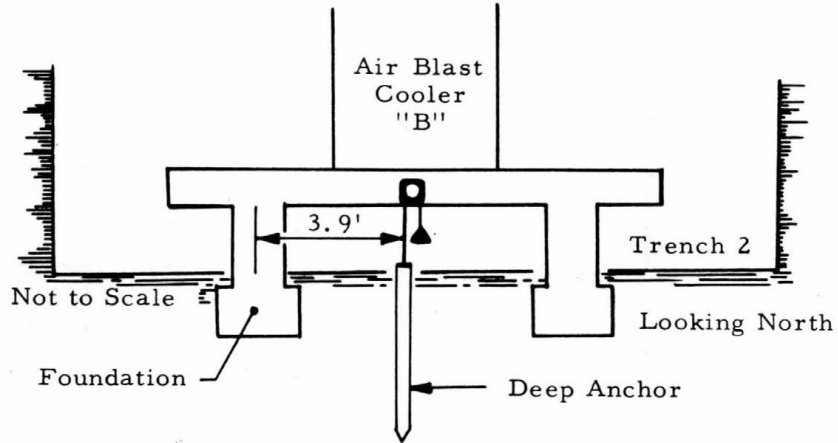
Installed 18 Nov '60; Zero time 1 Dec '60

\* 7 Aug '61 Helipot removed, new Helipot having sprocket and chain linkage installed.



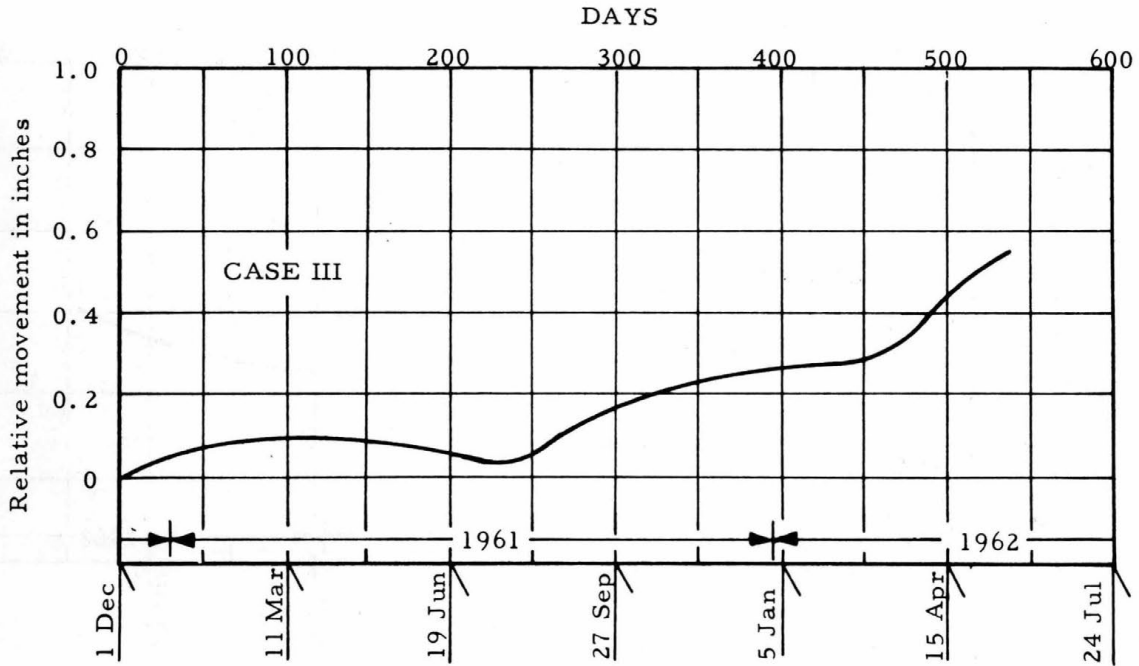
CAMP CENTURY MOVEMENT RECORD

HELIPOT # 8

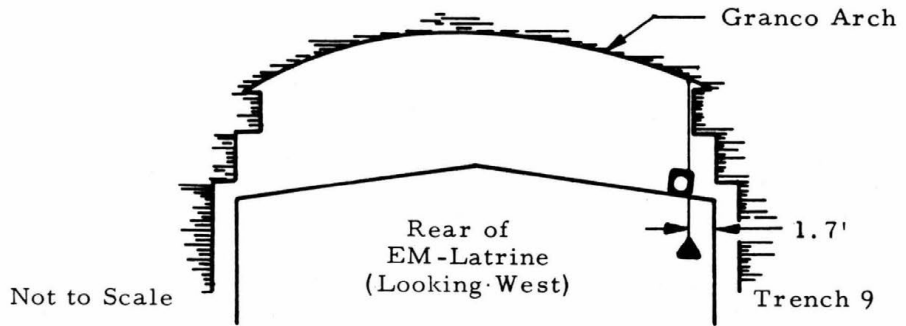


NOTES:

Installed 18 Nov '60; Zero time 1 Dec '60

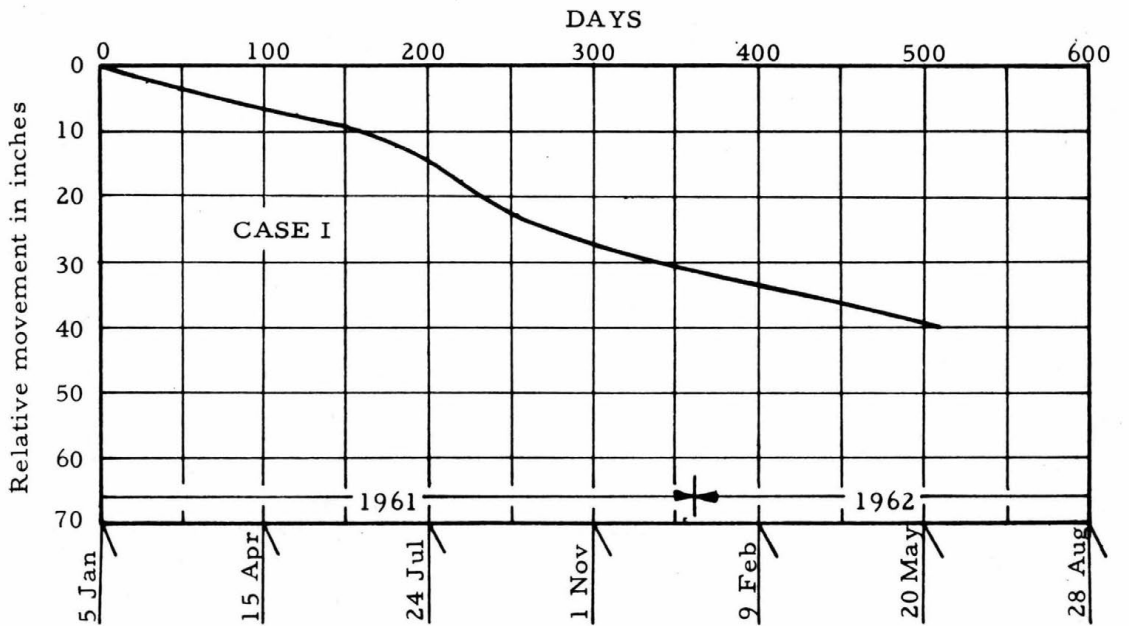


HELIPOT # 9



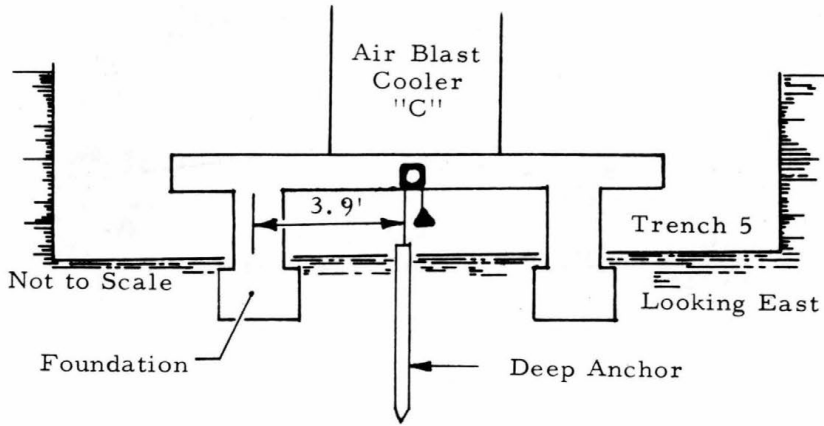
NOTES:

Installed 2 Jan '61; Zero time 5 Jan '61



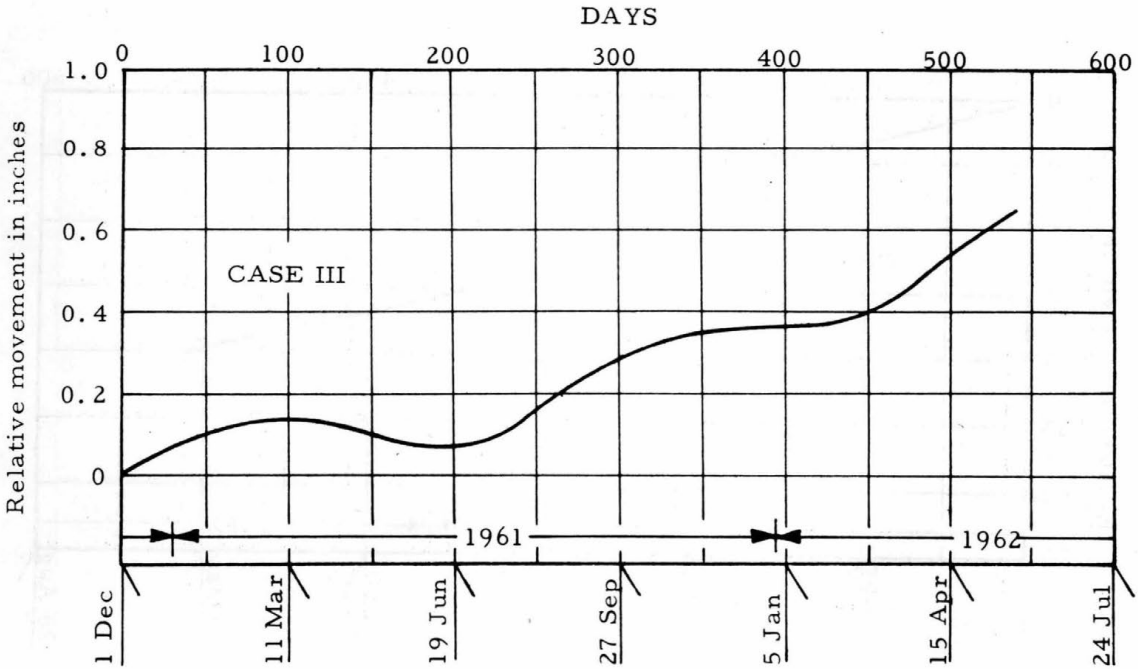
CAMP CENTURY MOVEMENT RECORD

HELIPOT # 11

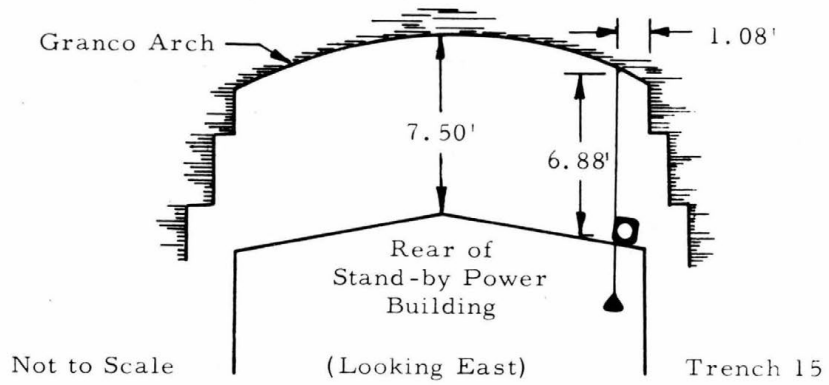


NOTES:

Installed 28 Nov '60; Zero time 1 Dec '60



HELIPOT # 12



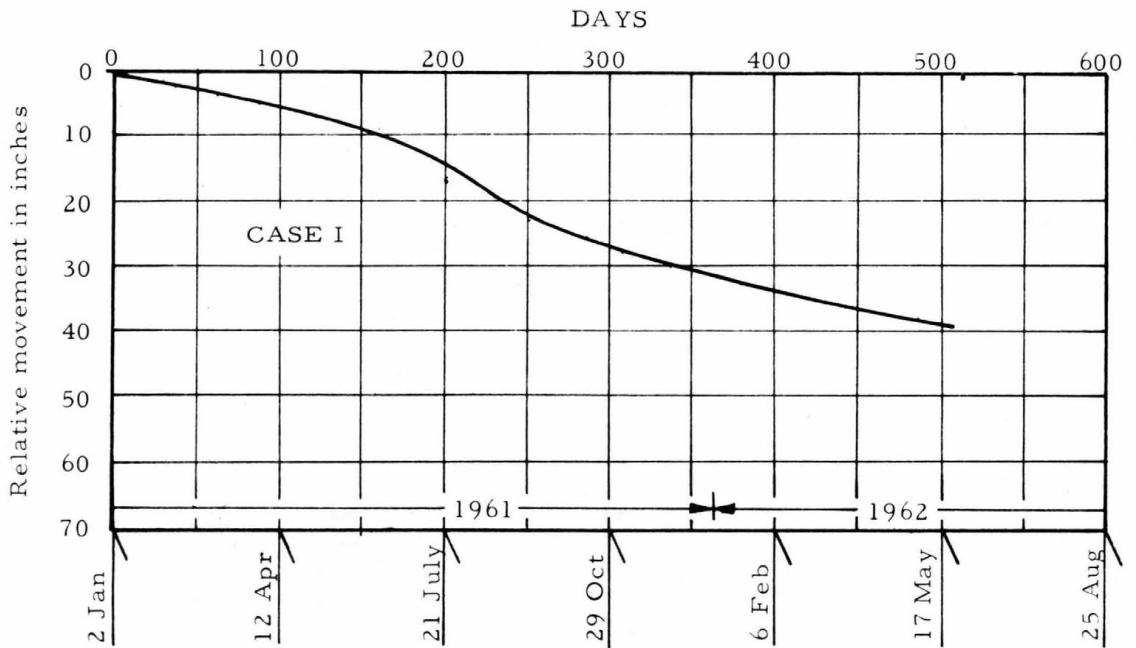
NOTES:

Installed 2 Jan '61 (Zero time)

Dimensions on sketch taken 2 Jan '61

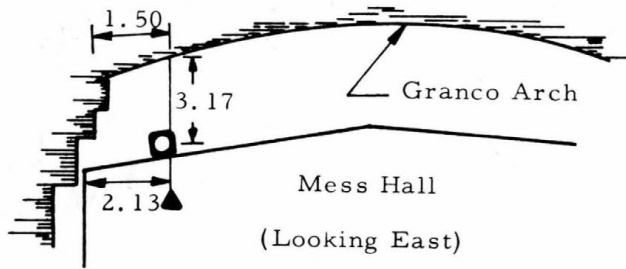
Granco arch removed Sept '61

This trench warm compared to reactor area trenches



CAMP CENTURY MOVEMENT RECORD

HELIPOT # 13



Not to Scale

Trench 6

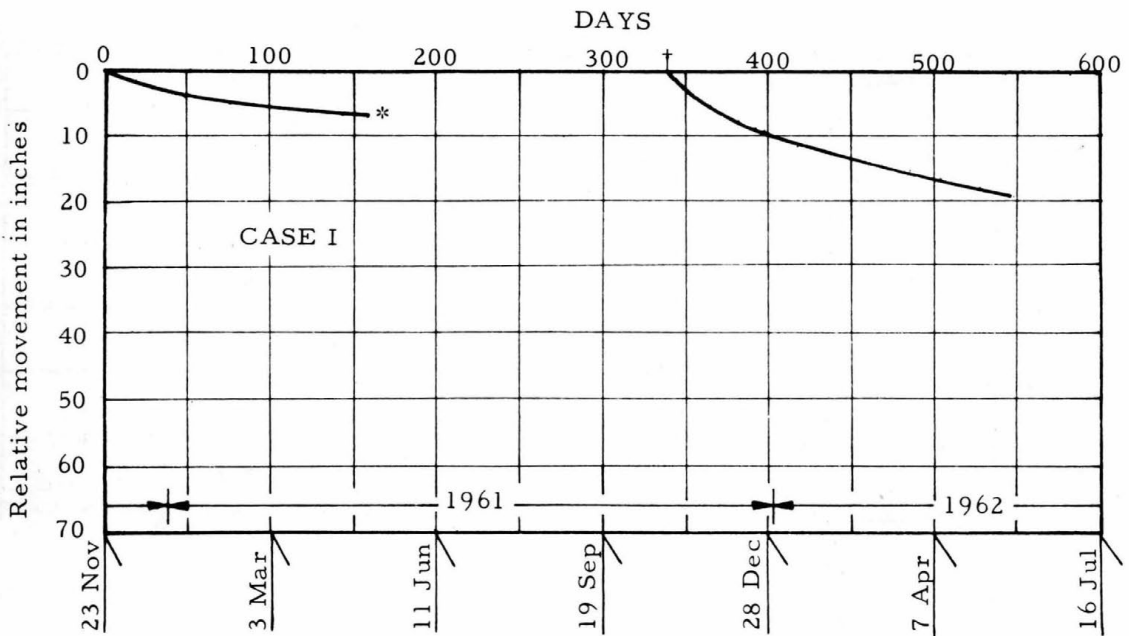
NOTES:

Installed 23 Nov '60 (Zero time)

Dimensions on sketch taken 23 Nov '60

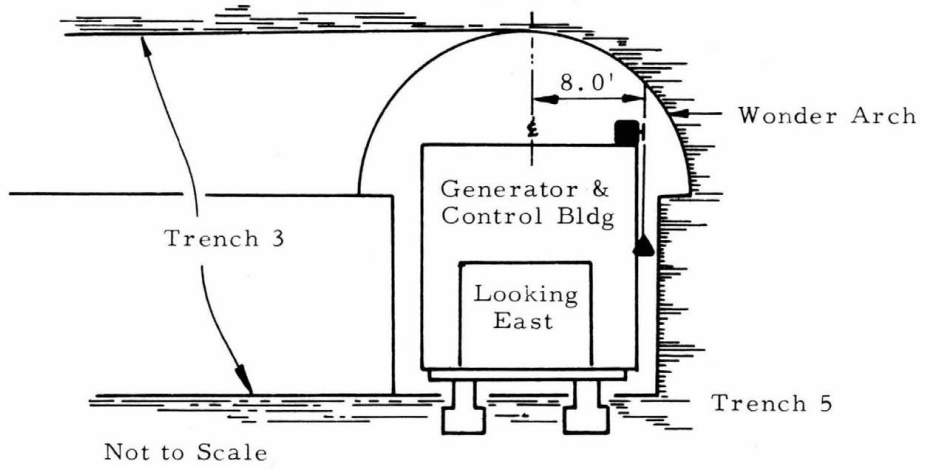
\* Helipot removed because of snow cutting operations

† Helipot re-established



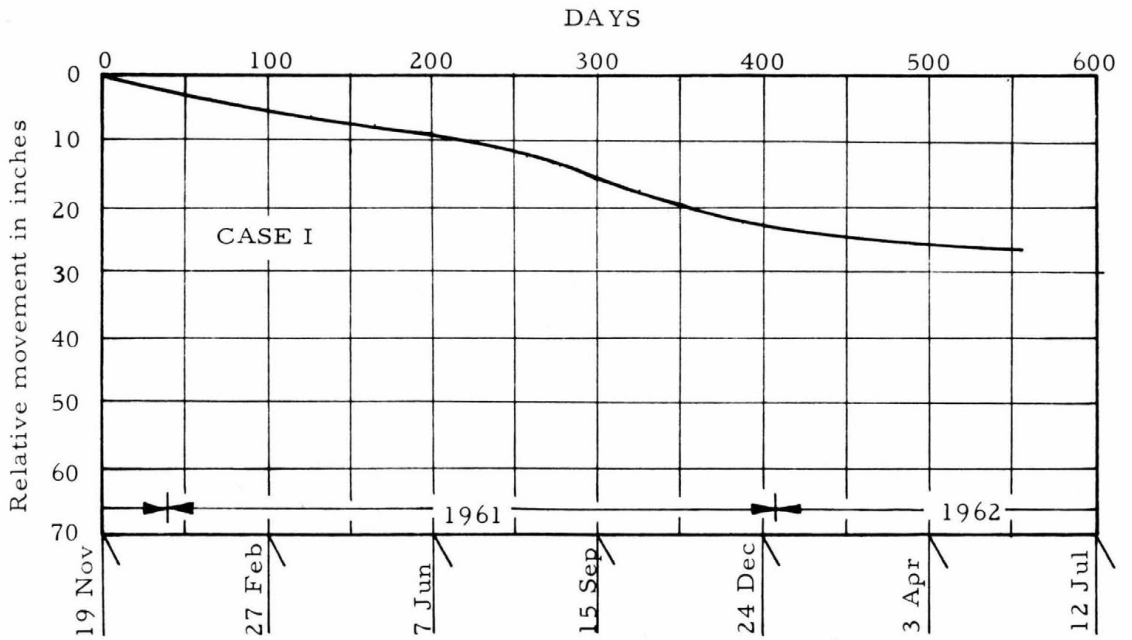


HELIPOT # 14



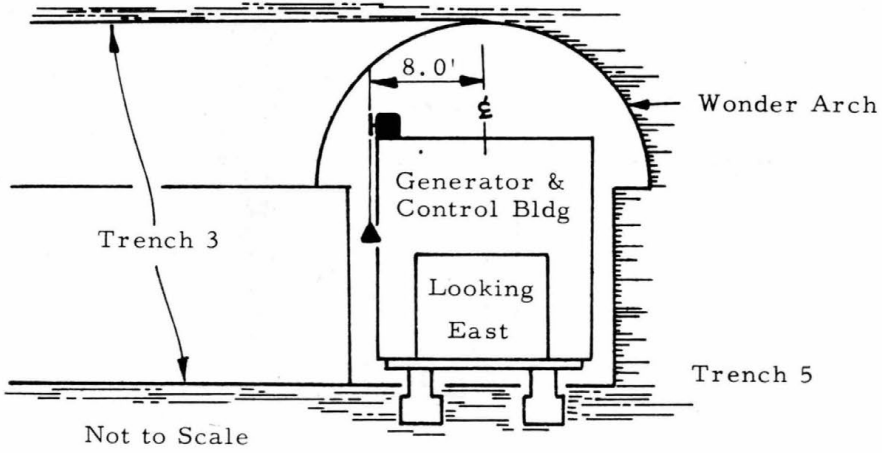
NOTES:

Installed 19 Nov '60 (Zero time)



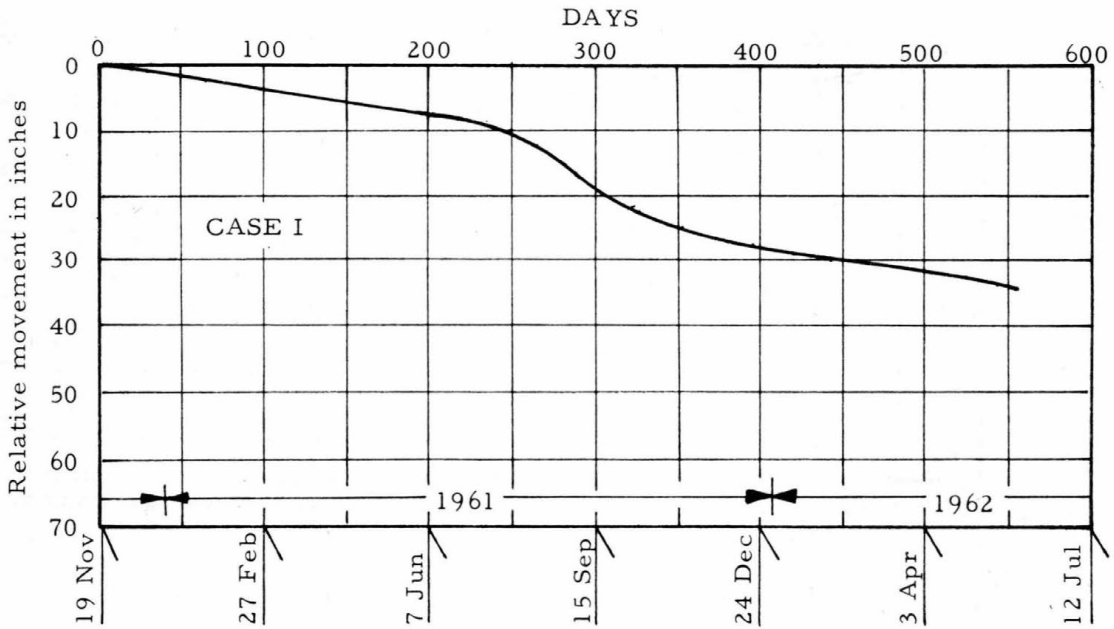
CAMP CENTURY MOVEMENT RECORD

HELIPOT # 15

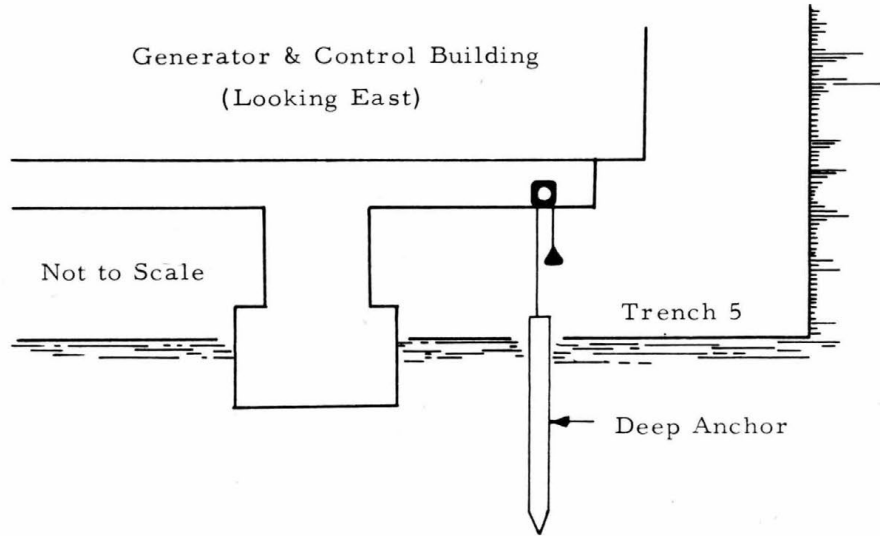


NOTES:

Installed 19 Nov '60 (Zero time)

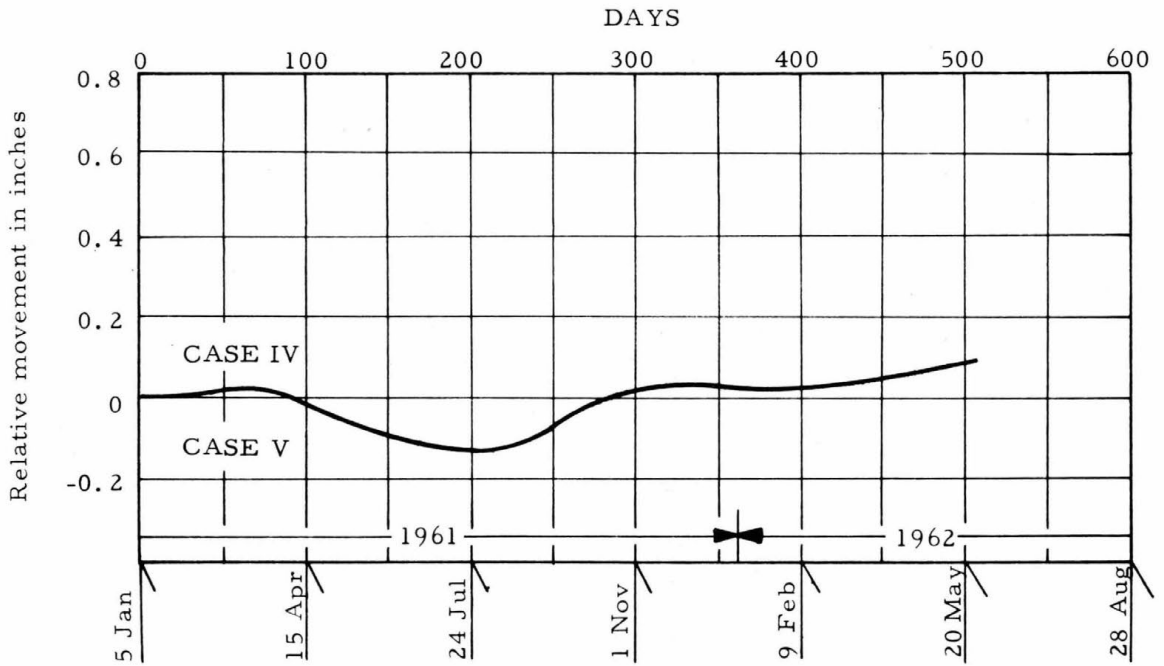


HELIPOT # 16



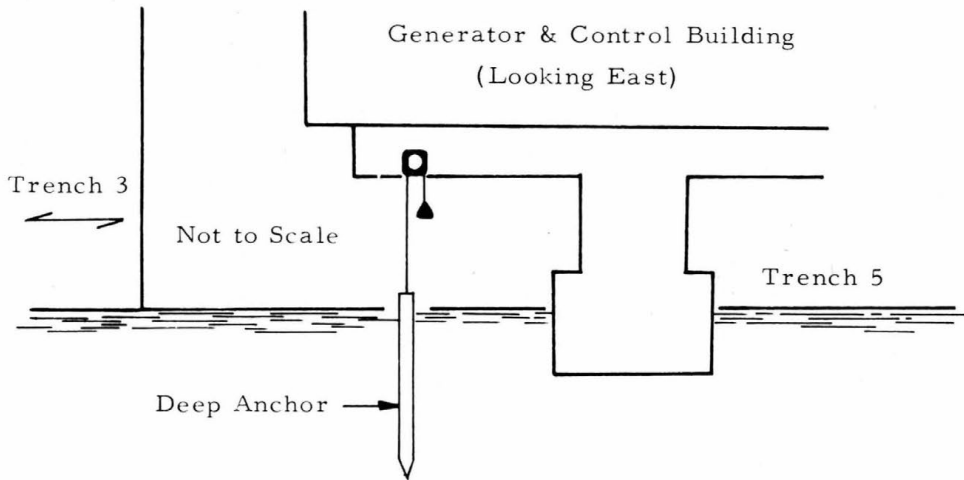
NOTES:

Installed 21 Nov '60; Zero time 5 Jan '61



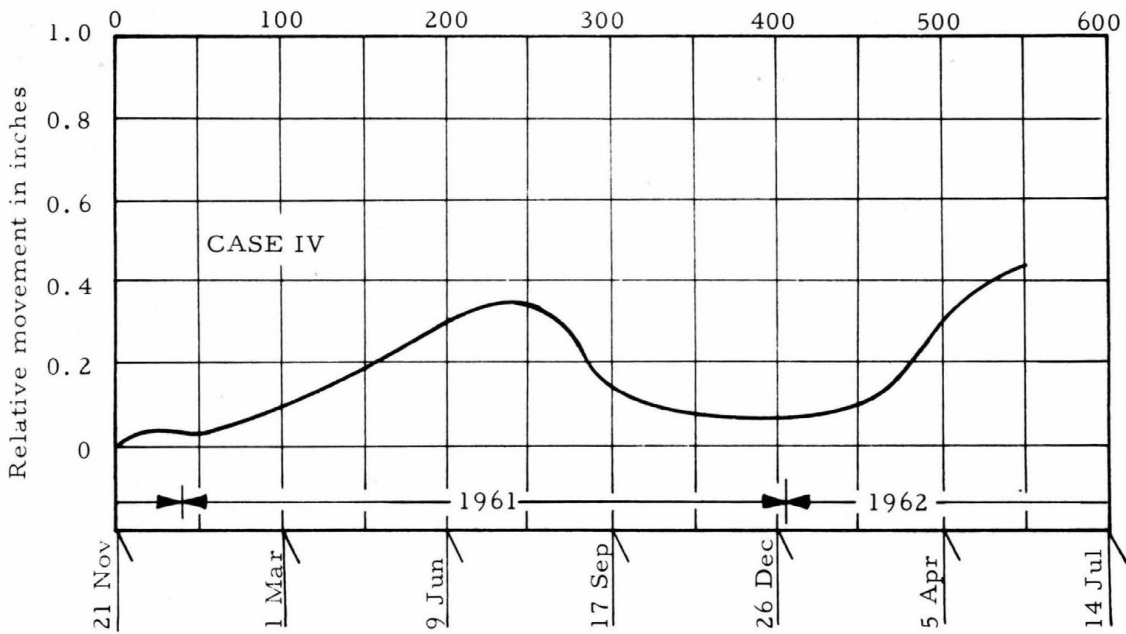
CAMP CENTURY MOVEMENT RECORD

HELIPOT # 17

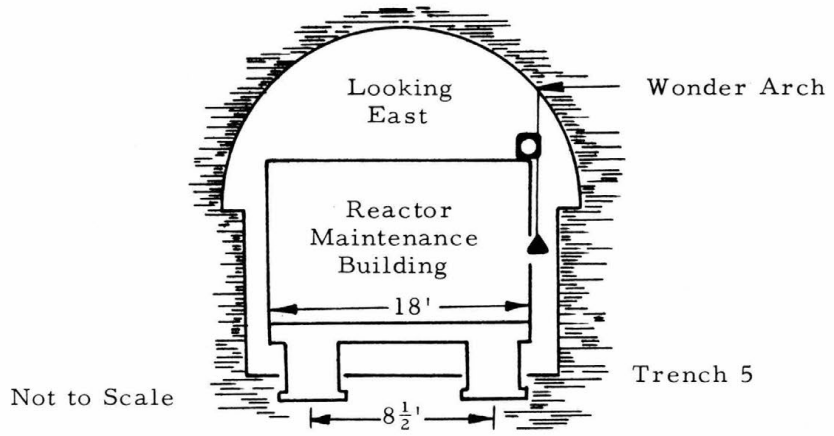


NOTES

• Installed 21 Nov '60 (Zero time)

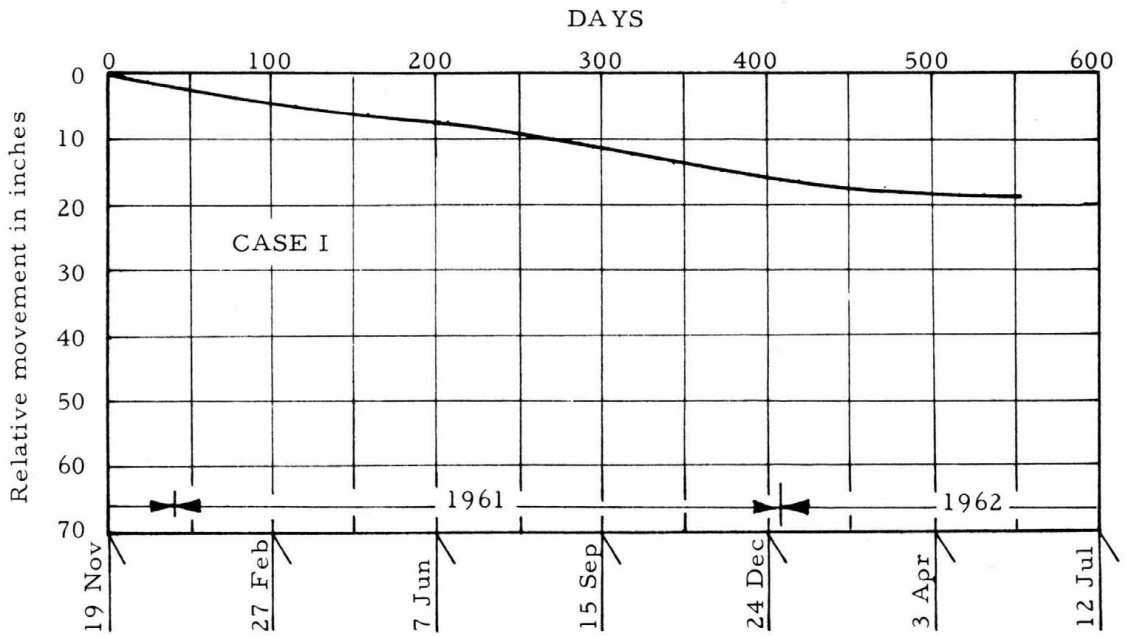


HELIPOT # 18



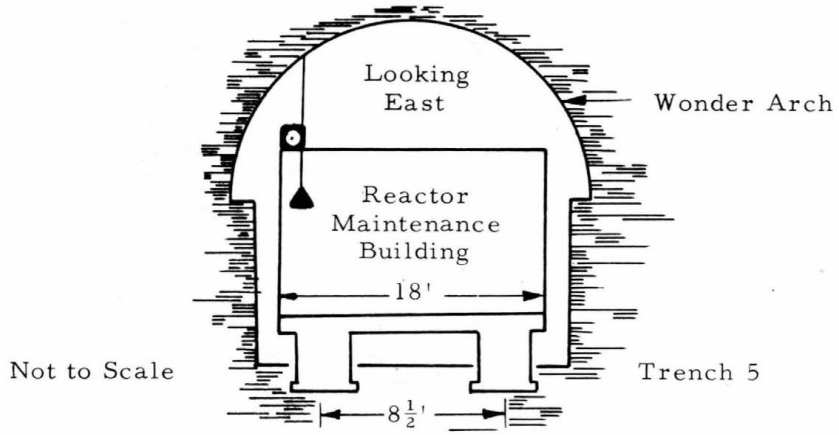
NOTES:

Installed 19 Nov '60 (Zero time)



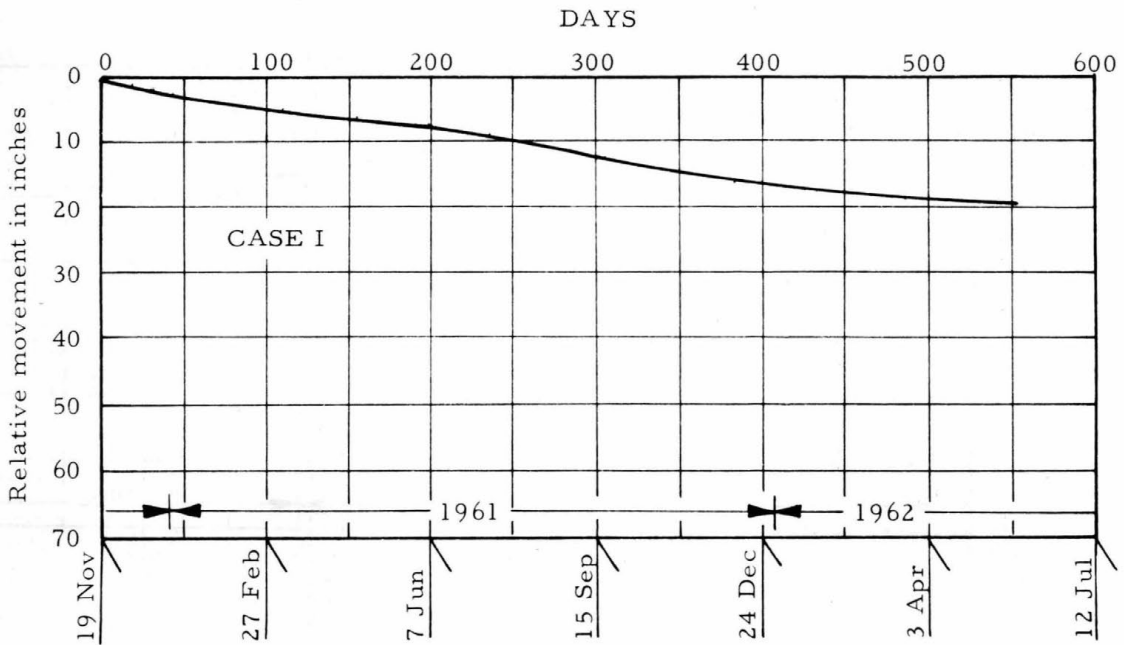
CAMP CENTURY MOVEMENT RECORD

HELIPOT # 19

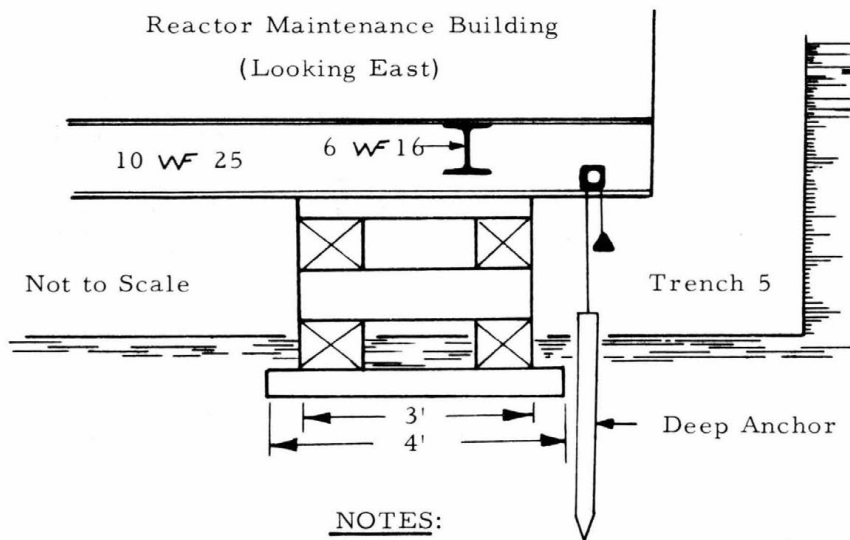


NOTES:

Installed 19 Nov '60 (Zero time)

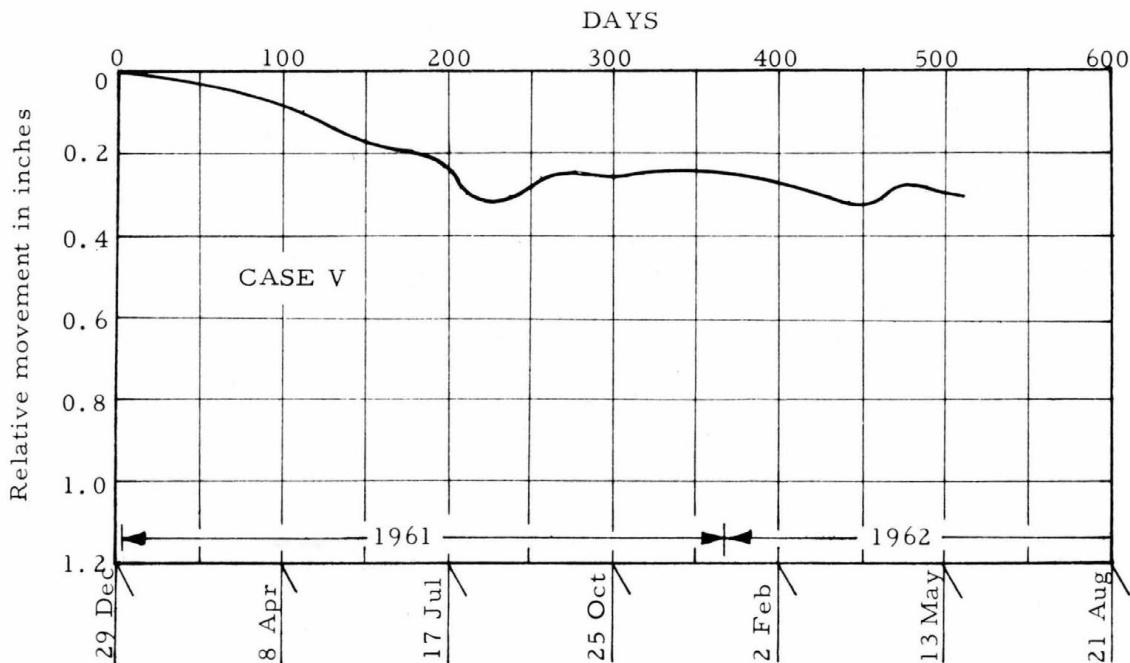


HELIPOT # 20



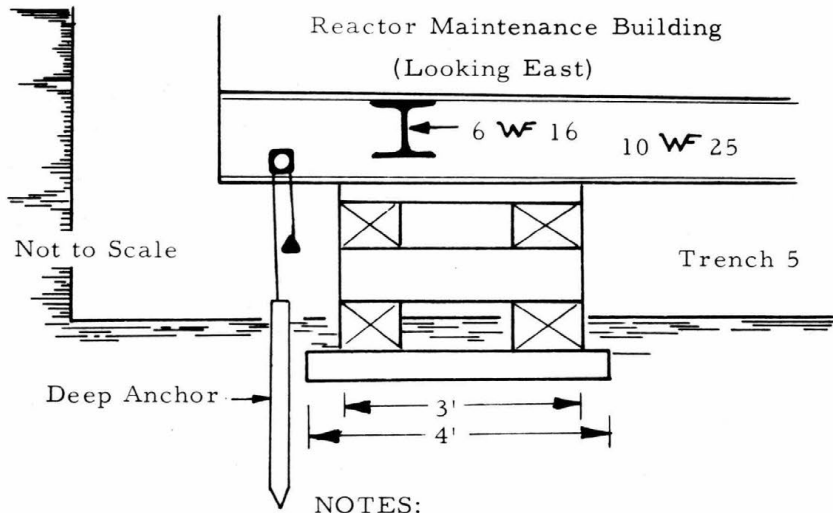
NOTES:

Installed 19 Nov '60; Zero time 29 Dec '60

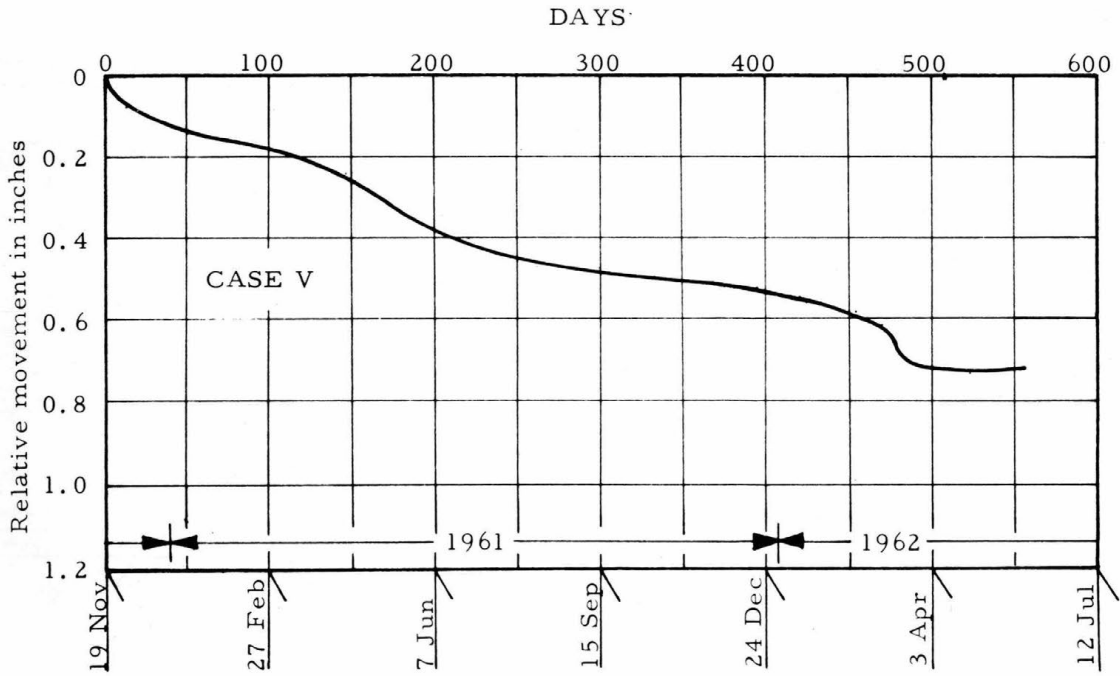


CAMP CENTURY MOVEMENT RECORD

HELIPOT # 21

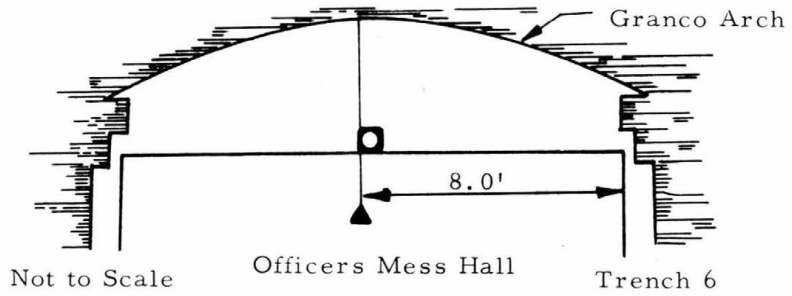


Installed 19 Nov '60 (Zero time)



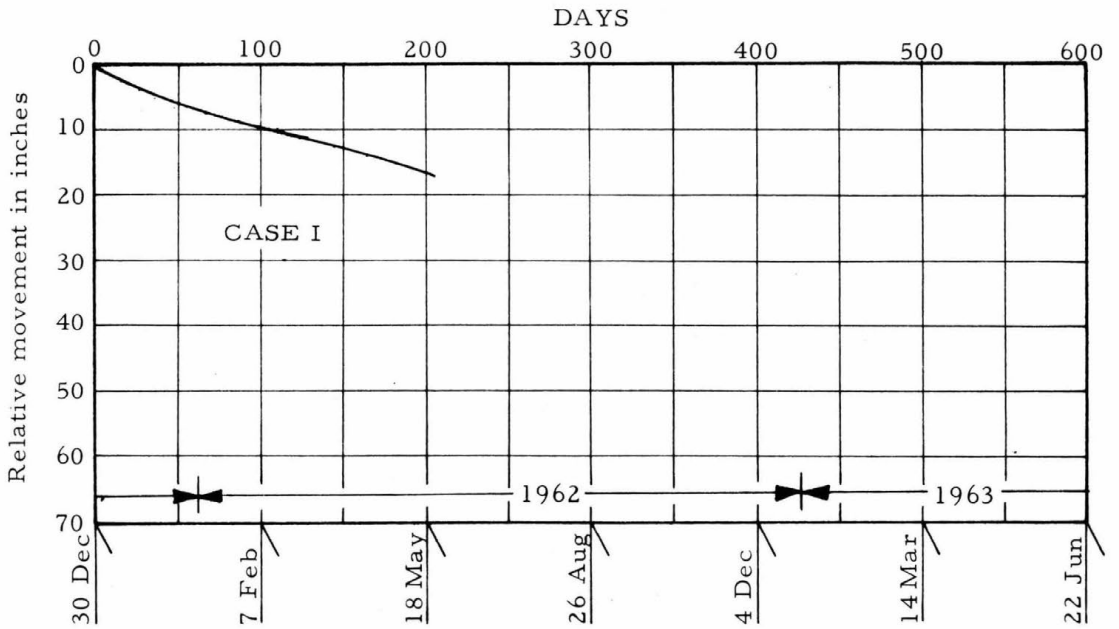


HELIPOT # 27

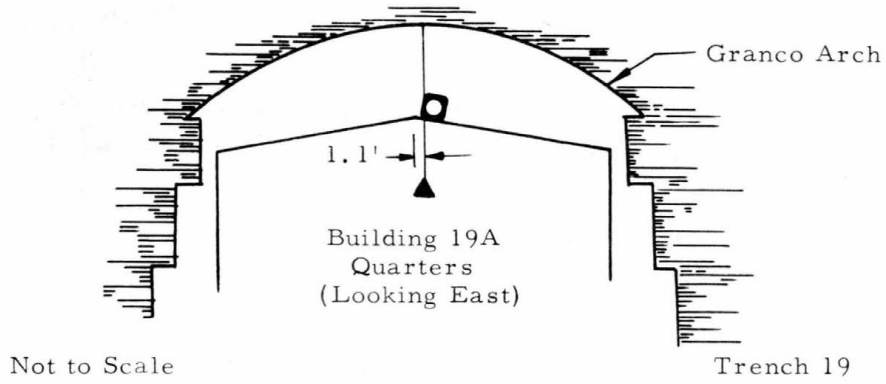


NOTES:

Installed 29 Jul '61; Zero time 30 Oct '61

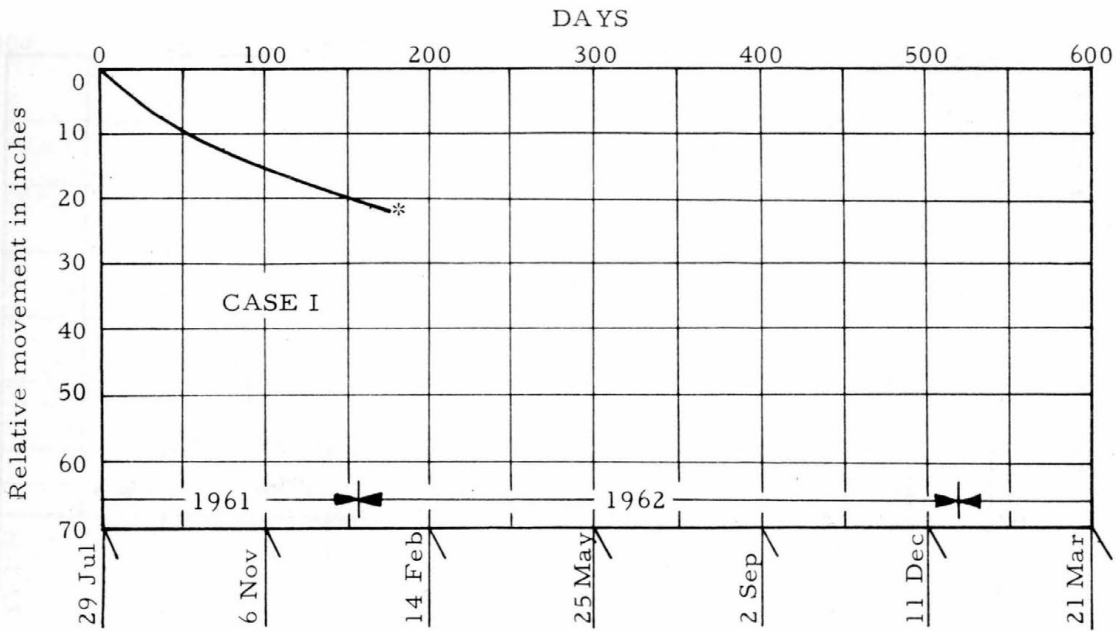


HELIPOT # 28

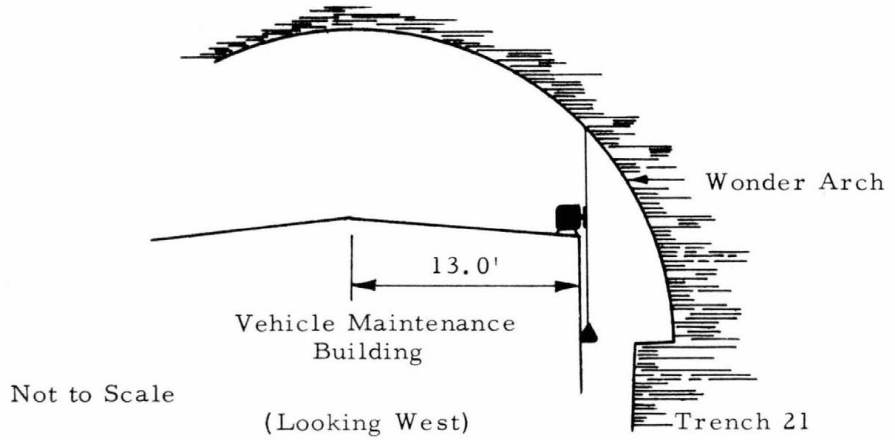


NOTES:

- Installed 29 Jul '61 (Zero time)
- Trench 19 was first side trench constructed
- Granco Arch removed 19 Jan '62
- \* Helipot removed

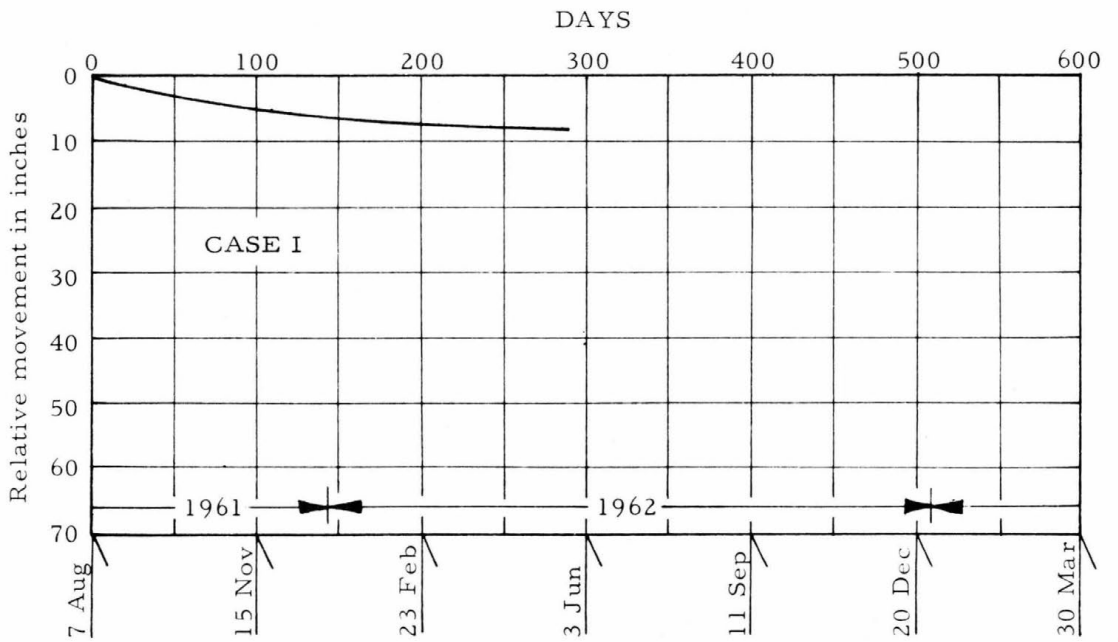


HELIPOT # 29



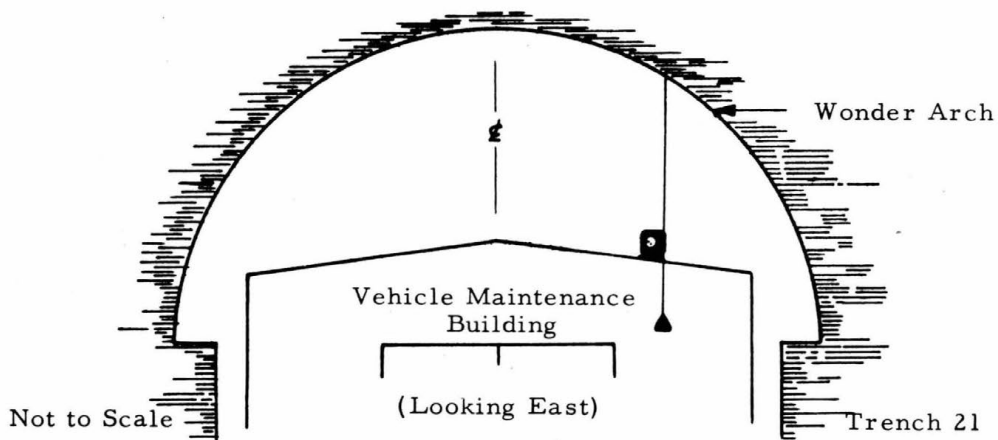
NOTES:

Installed 7 Aug '61 (Zero time)



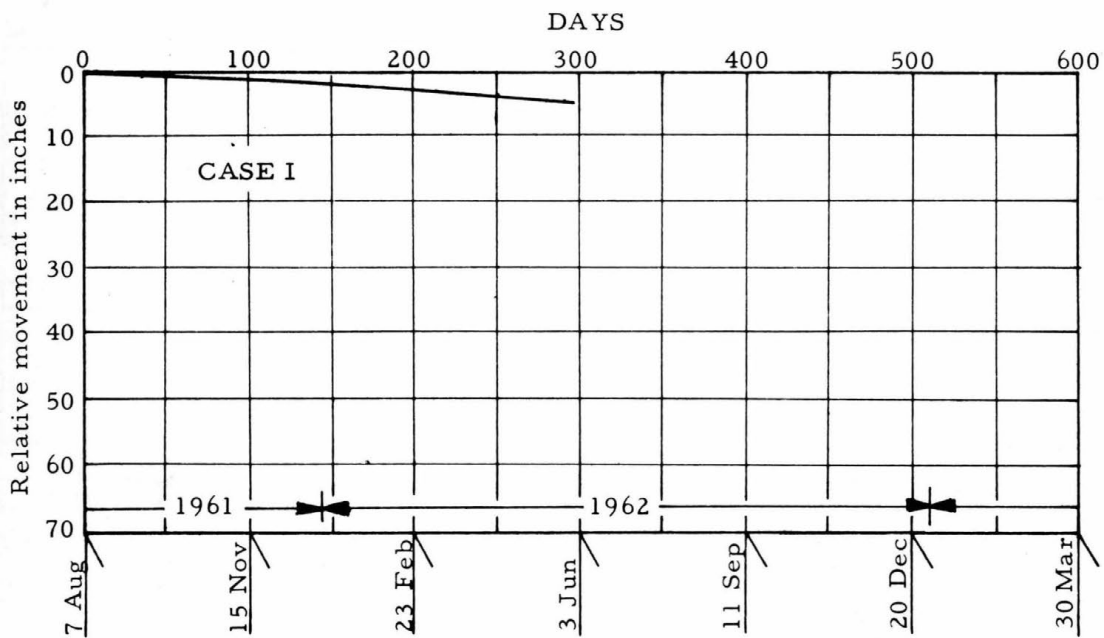
CAMP CENTURY MOVEMENT RECORD

HELIPOT # 30

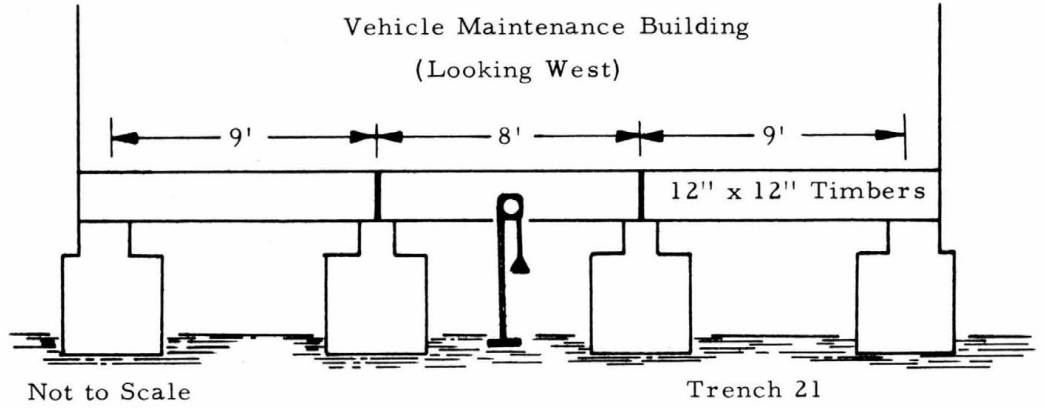


NOTES:

Installed 7 Aug '61 (Zero time)

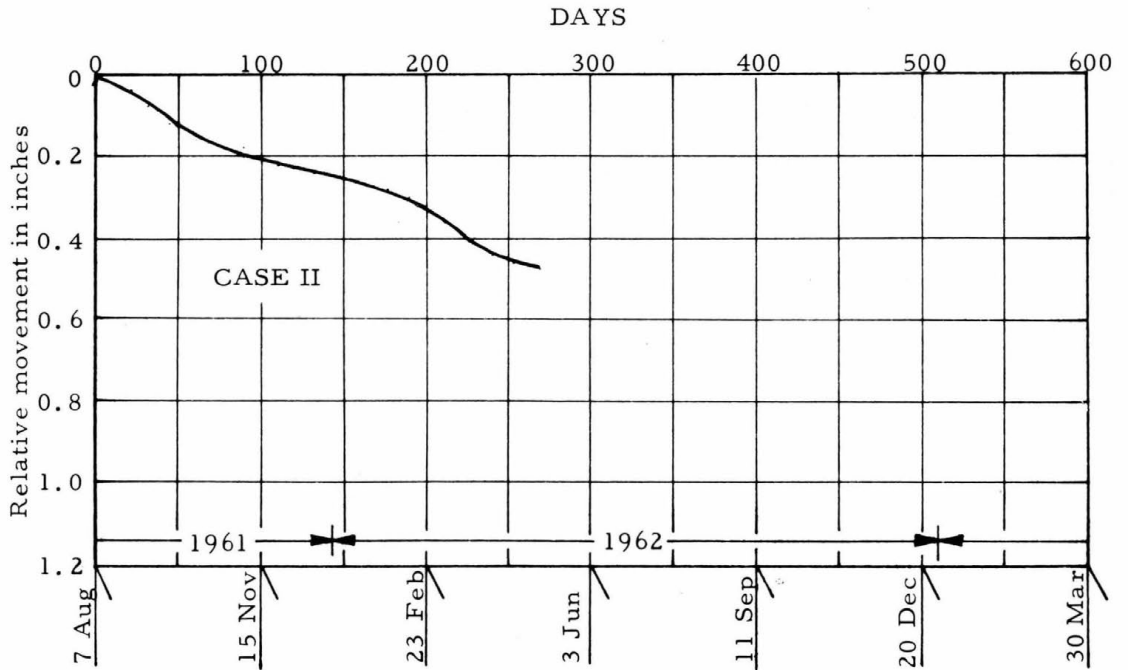


HELIPOT # 33

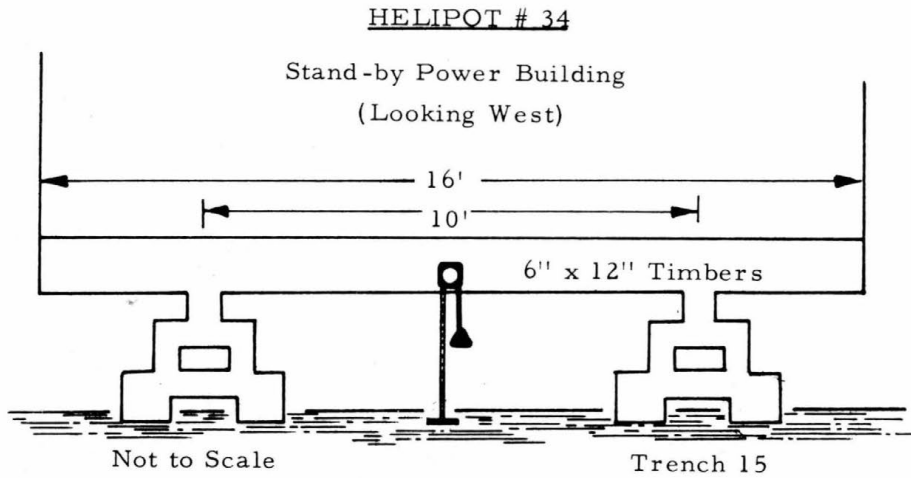


NOTES:

Installed 7 Aug '61 (Zero time)  
 Heavy tractors are moved into this building for repairs  
 Helipot has sprocket and chain linkage

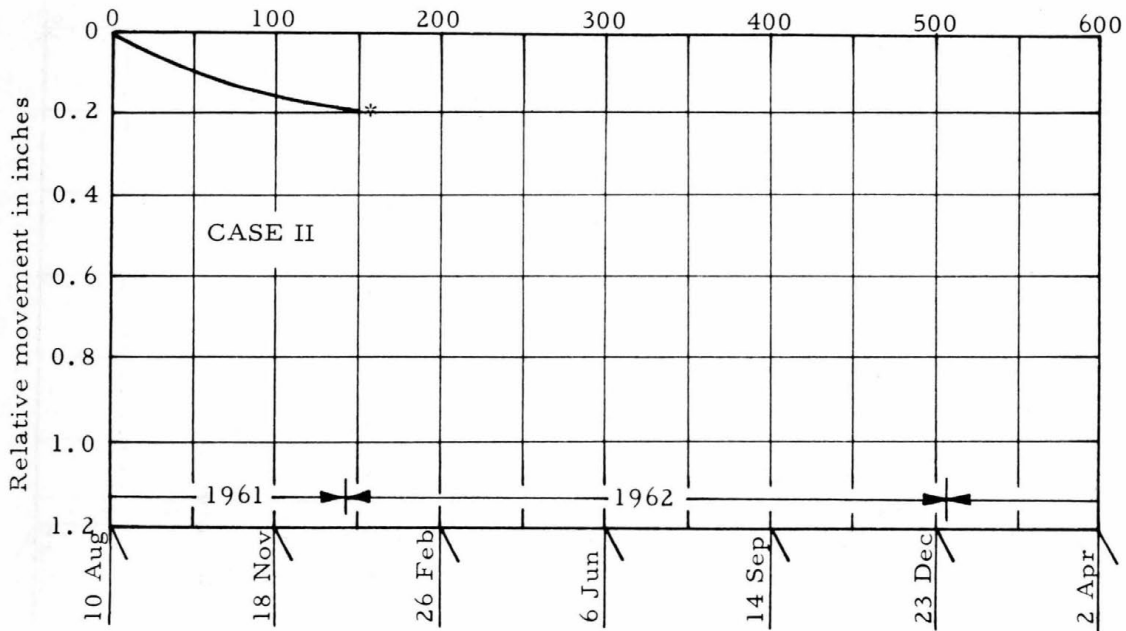


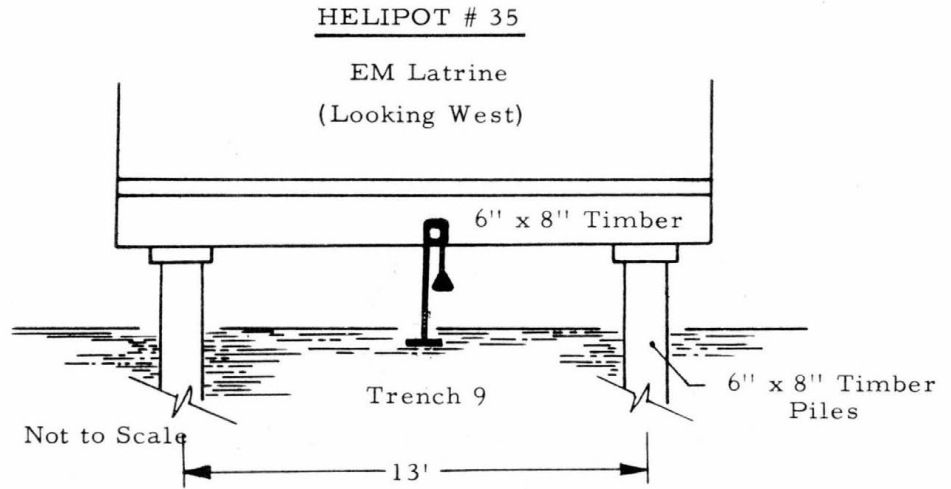
CAMP CENTURY MOVEMENT RECORD



NOTES:

- Installed 10 Aug '61 (Zero time)
- \* 11 Jan '62, cable cut
- Helipot has sprocket and chain linkage

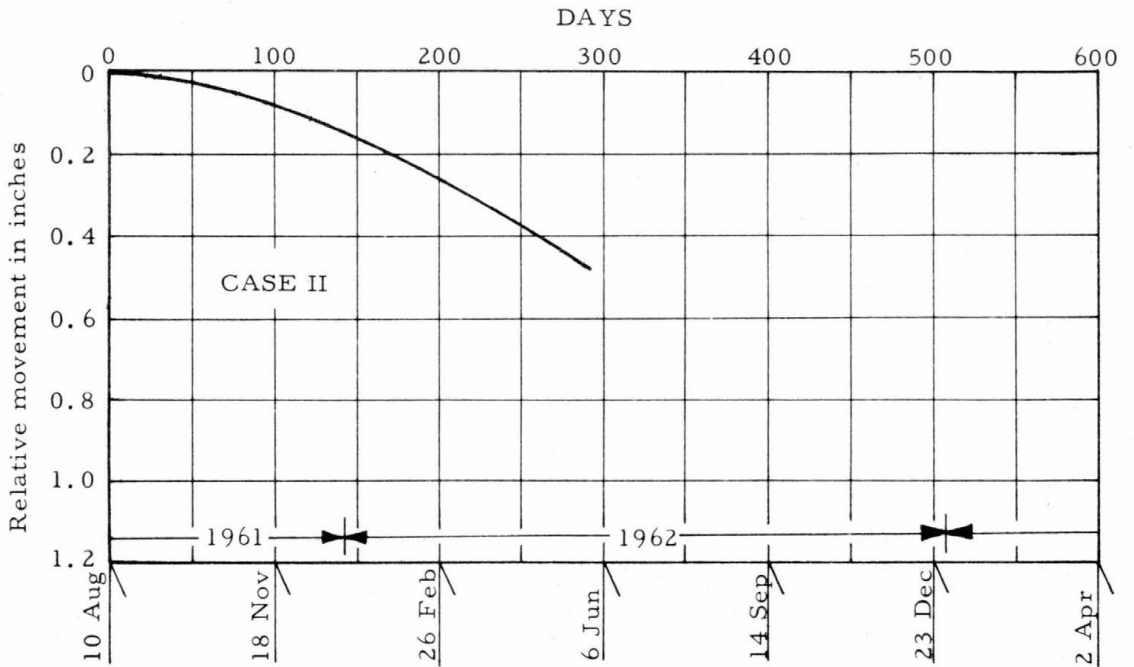




NOTES:

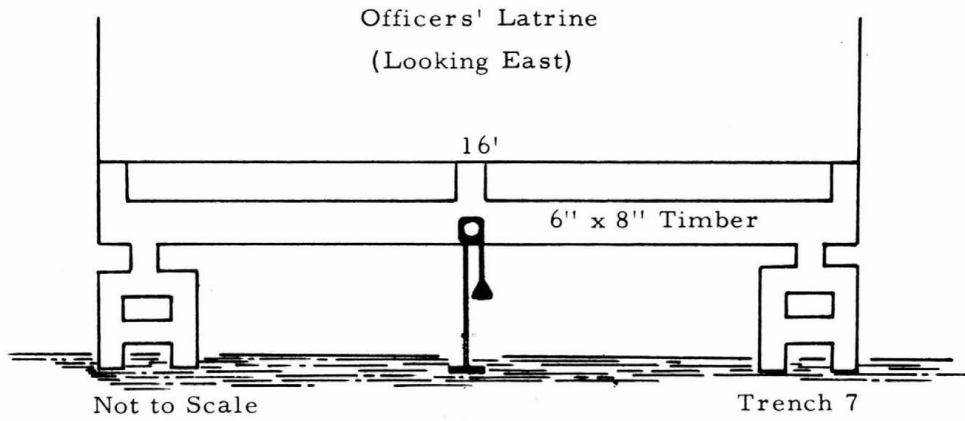
Installed 10 Aug '61 (Zero time)

Helipot has sprocket and chain linkage



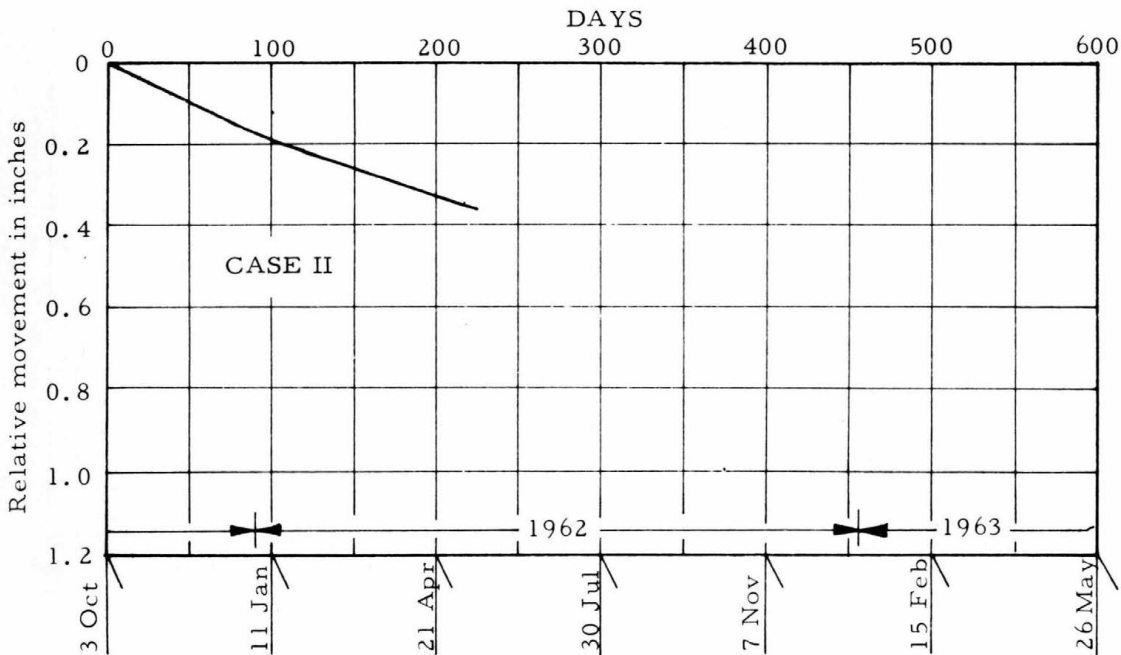
CAMP CENTURY MOVEMENT RECORD

HELIPOT # 36



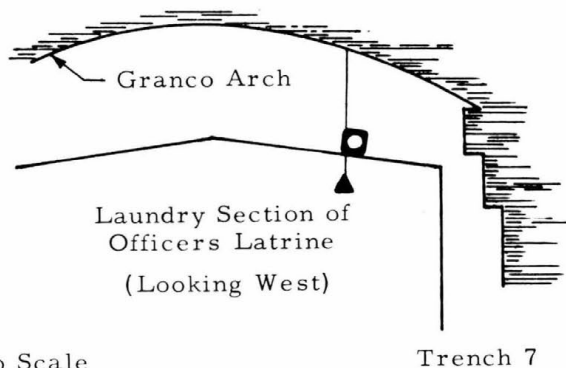
NOTES:

- Installed 3 Oct '61 (Zero time)
- Industrial spin drier causes foundation to vibrate
- Helipot has sprocket and chain linkage



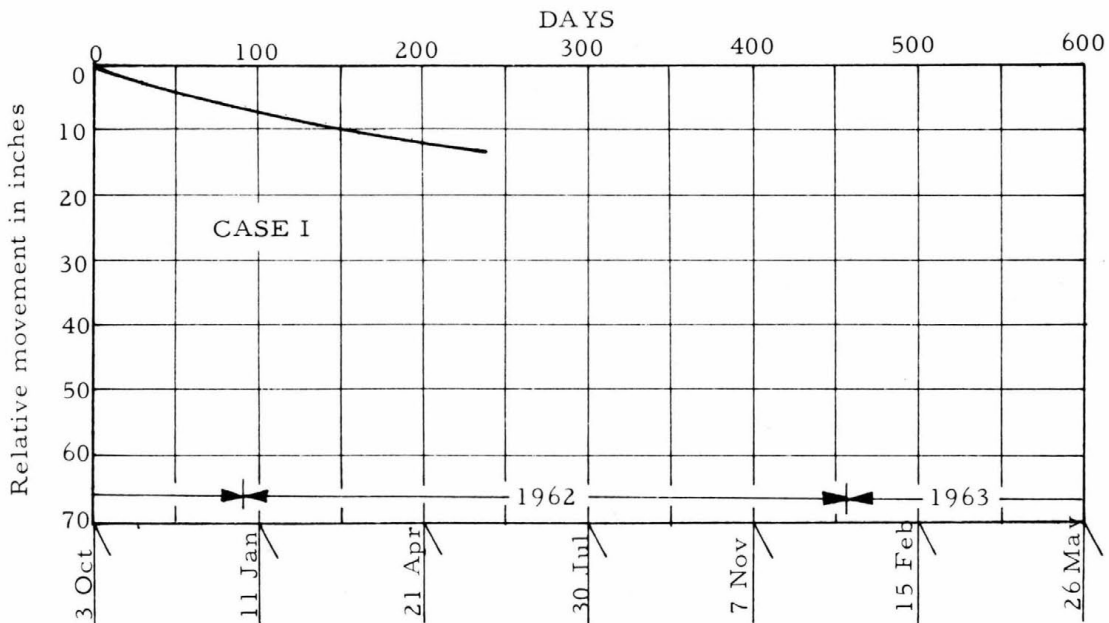


HELIPOT # 37



NOTES:

Installed 3 Oct '61 (Zero time)

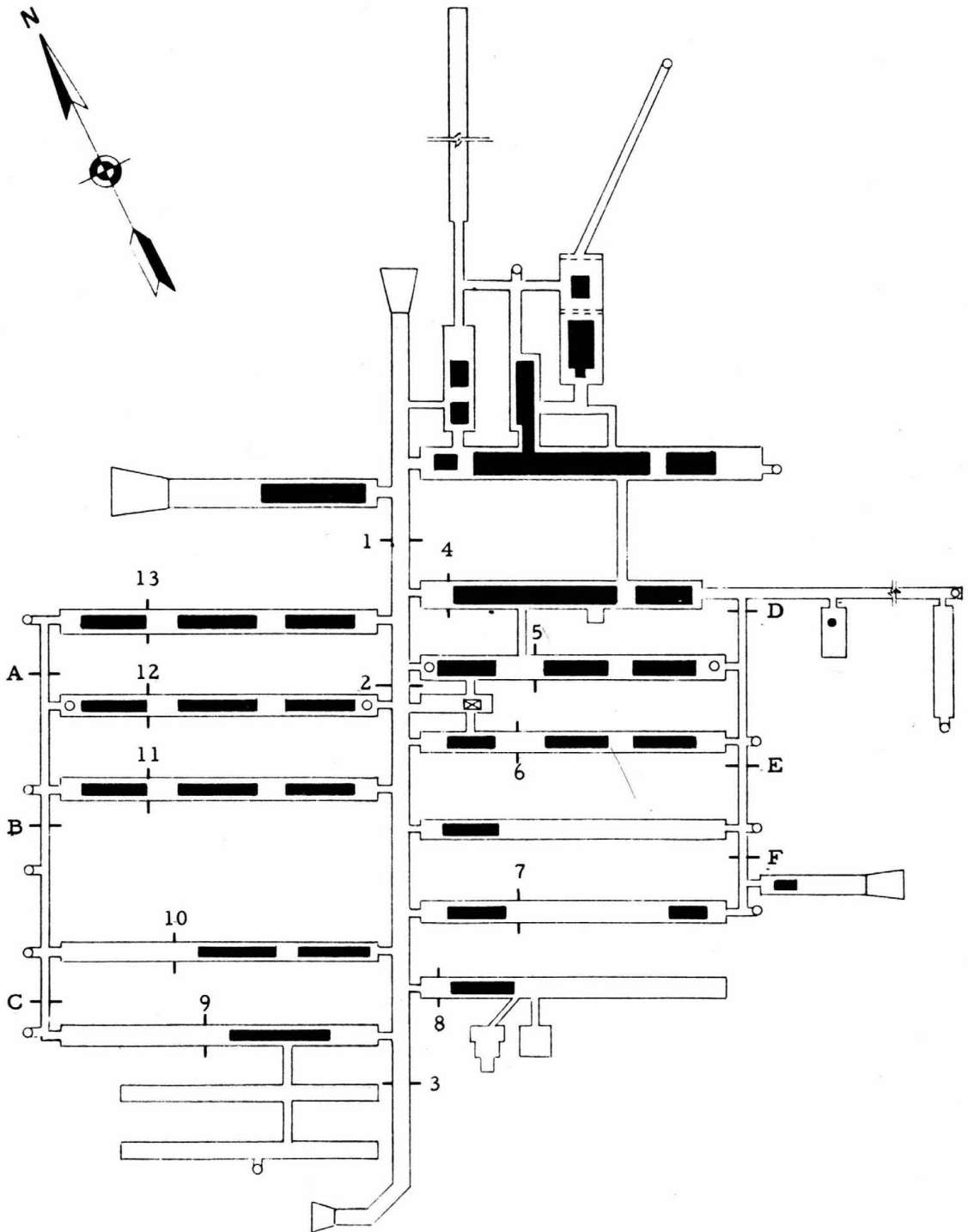


## F. CROSS SECTION SYSTEM

Table II. Cross Section Locations.

<u>Cross Section No.</u>	<u>Trench</u>	<u>Station</u>
1	Trench 1 - Main Trench	2 + 97.6
2	Trench 1 - Main Trench	6 + 00.0
3	Trench 1 - Main Trench	9 + 89.5
4	Trench 6 - Mess Hall Trench	0 + 57.5
5	Trench 7 - Officers' Latrine Trench	1 + 54.7
6	Trench 9 - Enlisted Men's Latrine Trench	1 + 60.2
7	Trench 11 - R&D Offices Trench	1 + 58.4
8	Trench 12 - R&D Trench	0 + 48.2
9	Trench 15 - Stand-by Power Trench	2 + 53.9
10	Trench 16 - Theatre-Chapel Trench	2 + 51.8
11	Trench 18 - Enlisted Men's Quarters Trench	2 + 59.4
12	Trench 19 - Officers' and NCOs' Quarters Trench	2 + 62.1
13	Trench 20 - USA PR&DC HQ Trench	2 + 59.7
A	West Manifold Trench	
B	West Manifold Trench	
C	West Manifold Trench	
D	East Manifold Trench	
E	East Manifold Trench	
F	East Manifold Trench	

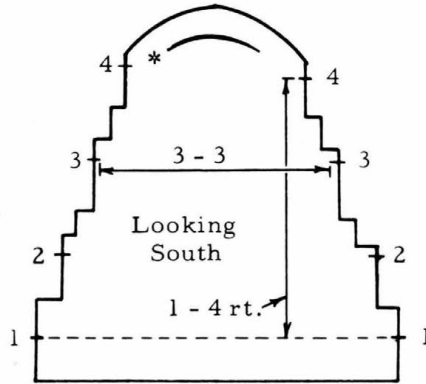
CAMP CENTURY MOVEMENT RECORD



Location of Control Cross Sections

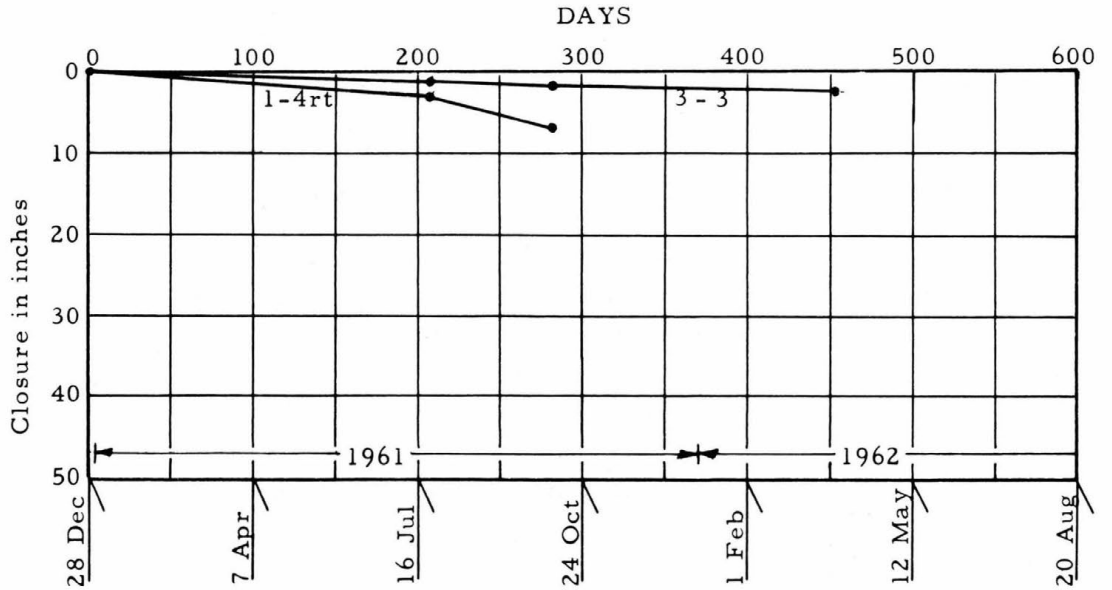
May 1962

GROSS SECTION 1

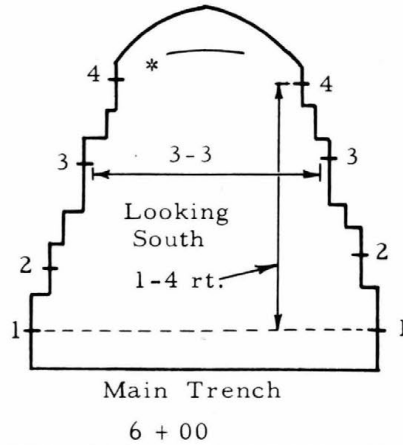


Main Trench  
2 + 97.6

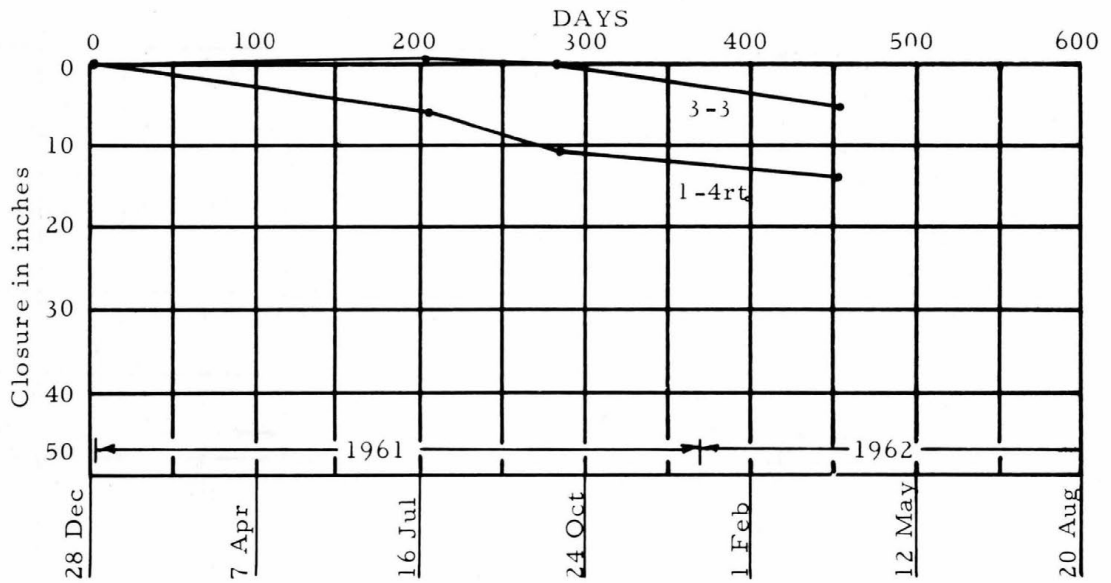
NOTES: 28 Dec '60 Dist. 3 - 3 = 10.94'  
 28 Dec '60 Dist. 1 - 4 rt. = 12.64'  
 \* Arch 21 Apr '62, down 1.4'



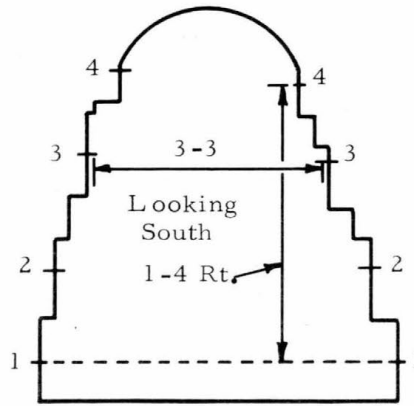
CROSS SECTION 2



NOTES: 28 Dec '60 Dist. 3-3 = 11.12'  
 28 Dec '60 Dist. 1-4 rt. = 11.97'  
 \* Arch 21 Apr '62, down 2.0'



CROSS SECTION 3

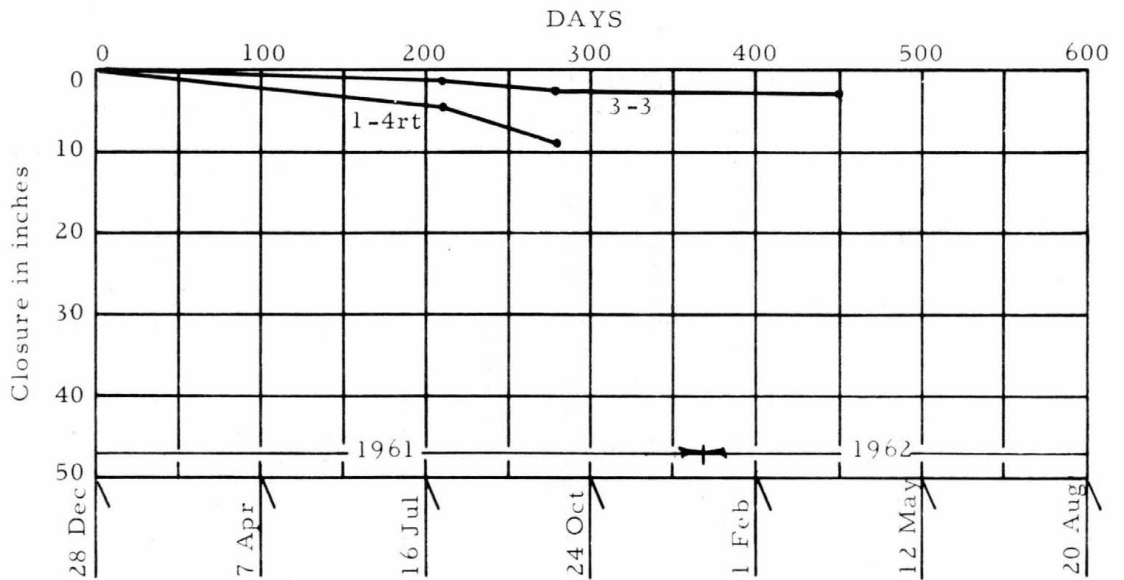


Main Trench

9 + 89.5

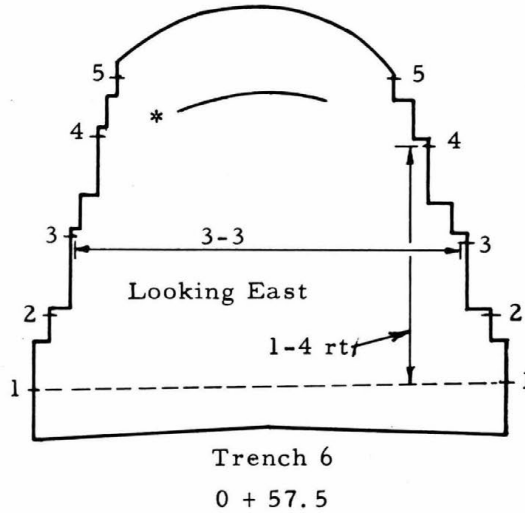
NOTES: 2 Jan '61 Dist. 3-3 = 11.02'

2 Jan '61 Dist. 1-4 Rt. = 13.46'

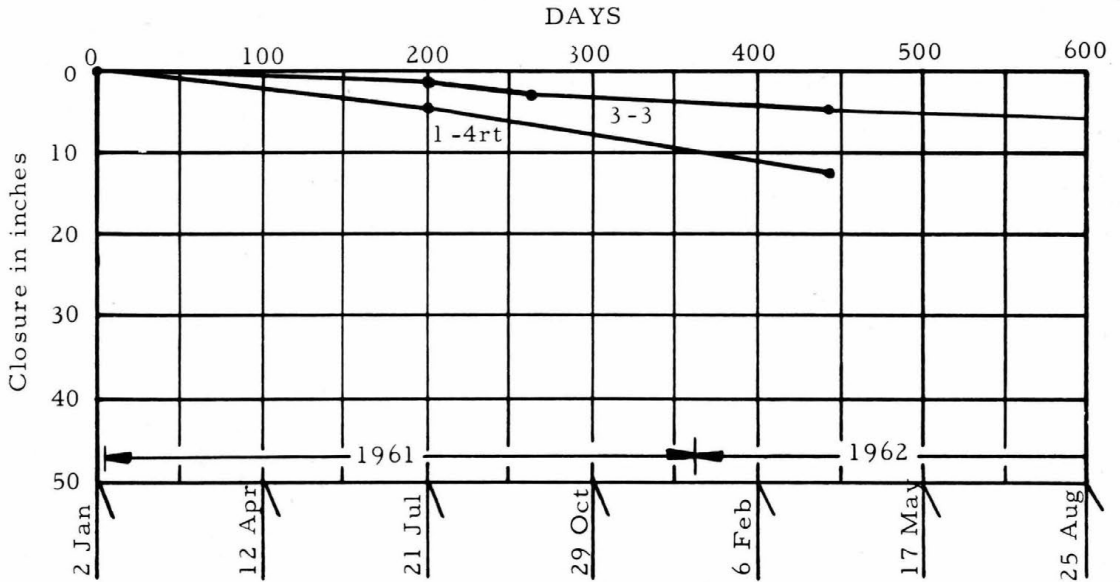


CAMP CENTURY MOVEMENT RECORD

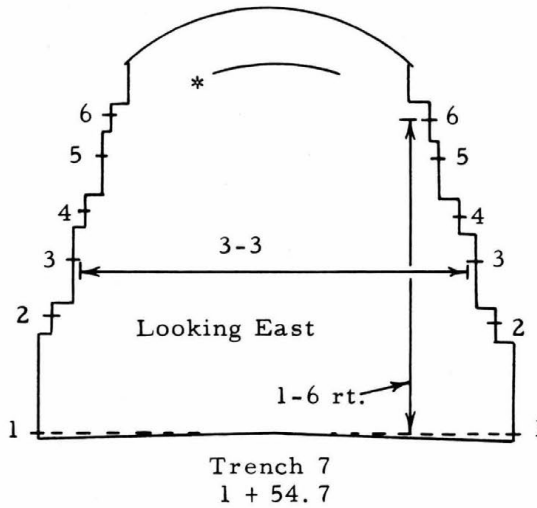
CROSS SECTION 4



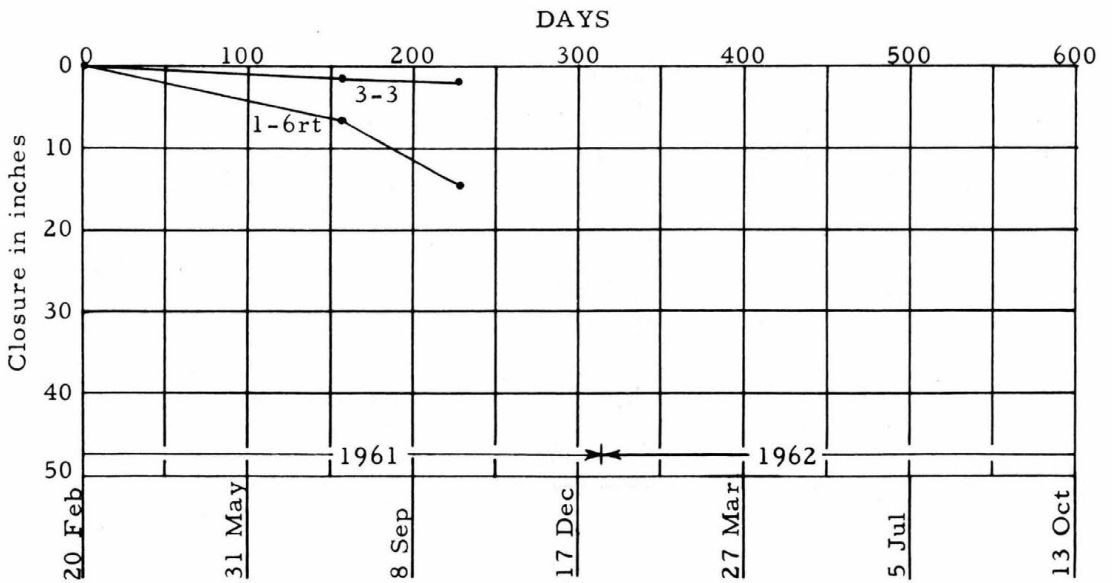
NOTES: 28 Dec '60 Dist. 3-3 = 18.60'  
 28 Dec '60 Dist. 1-4 rt. = 11.60'  
 All pegs destroyed by trimming Sept '61; reinstated Oct '61  
 \* Arch 21 Apr '62, down 4.1'



CROSS SECTION 5

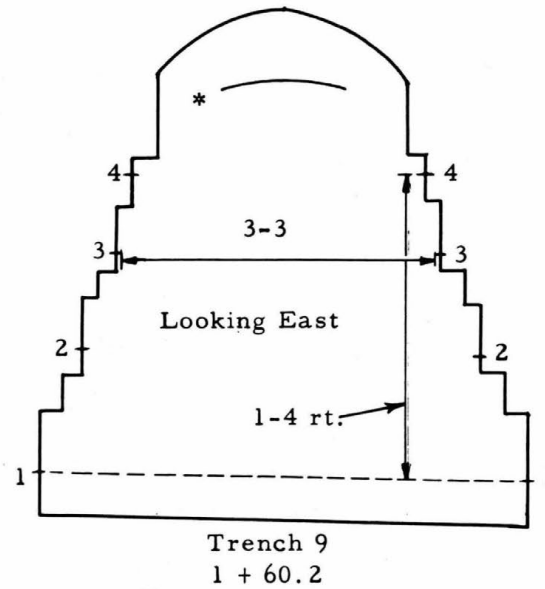


NOTES: 20 Feb '61, Dist. 3-3 = 19.37'  
 20 Feb '61, Dist. 1-6 rt. = 15.26'  
 \* Arch 21 Apr '62, down 2.6'  
 Readings suspended because original points were obliterated

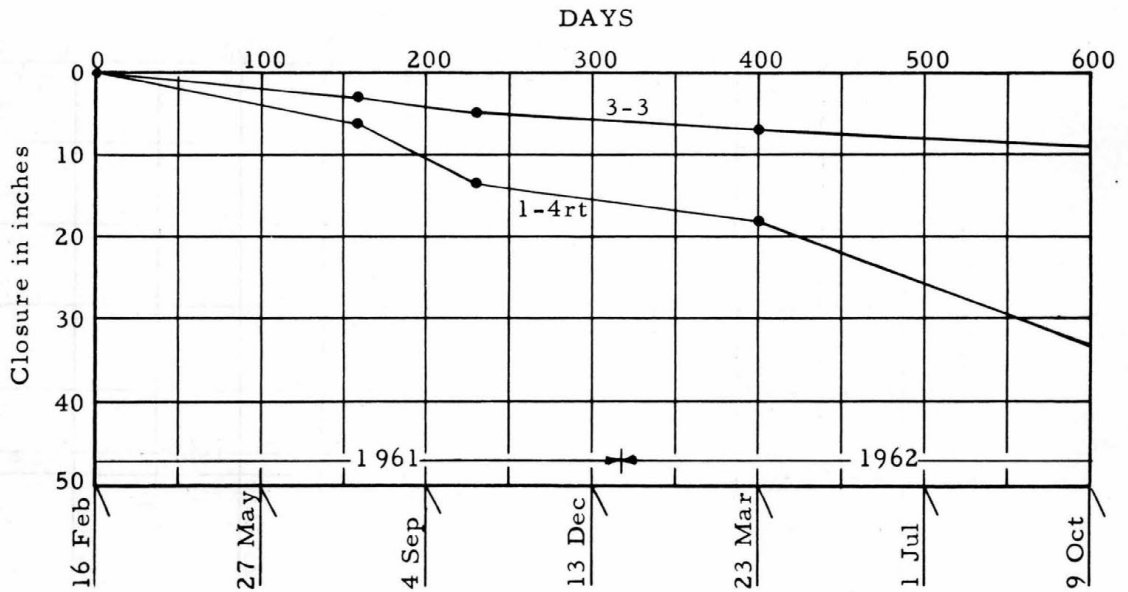




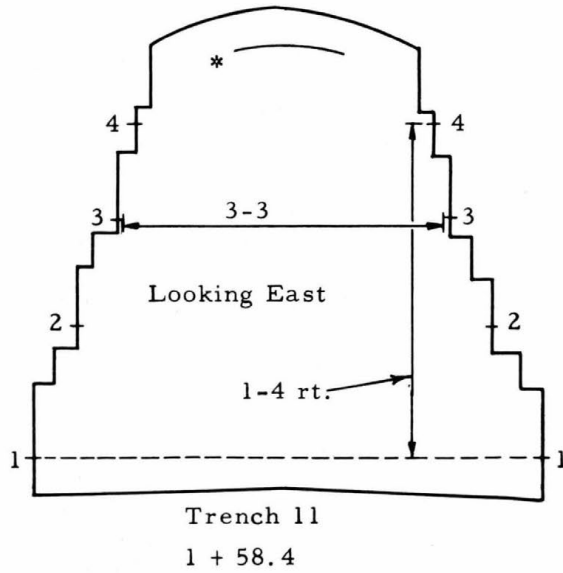
CROSS SECTION 6



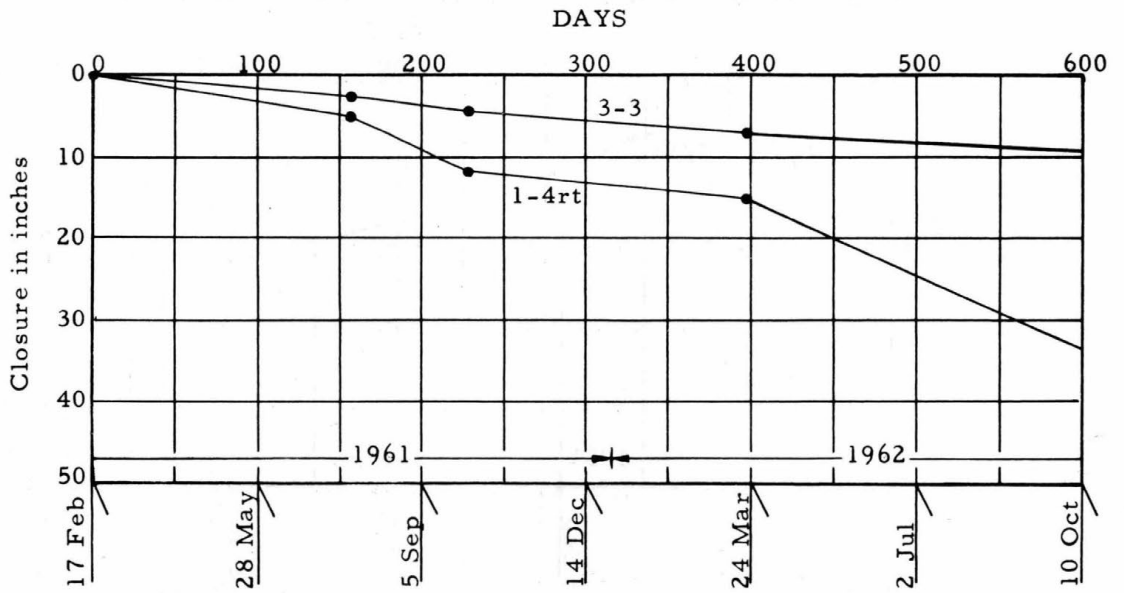
NOTES: 16 Feb '61, 3-3 Dist. = 15.42'  
 16 Feb '61, 1-4 rt. Dist. = 14.74'  
 \* Arch 21 Apr '62, down 3.4'



CROSS SECTION 7

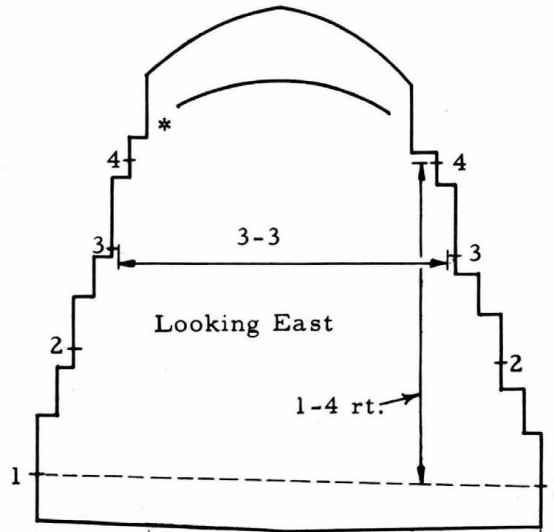


NOTES: 17 Feb '61, 3-3 Dist. = 16.05'  
 17 Feb '61, 1-4 rt. Dist. = 16.37'  
 \* Arch 21 Apr '62, down 1.8'



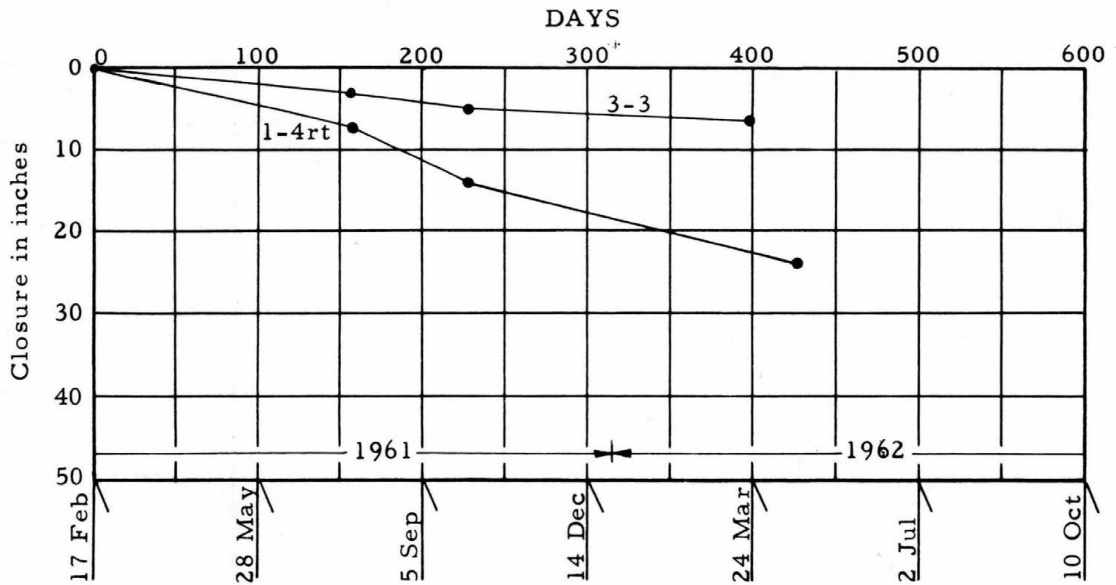
CAMP CENTURY MOVEMENT RECORD

CROSS SECTION 8

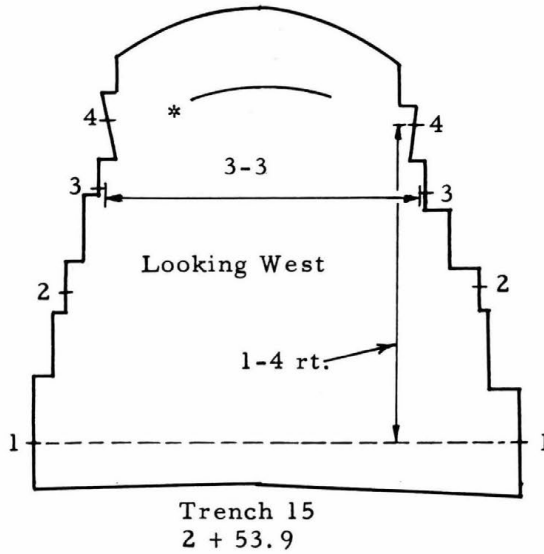


Trench 12  
0 + 48.2

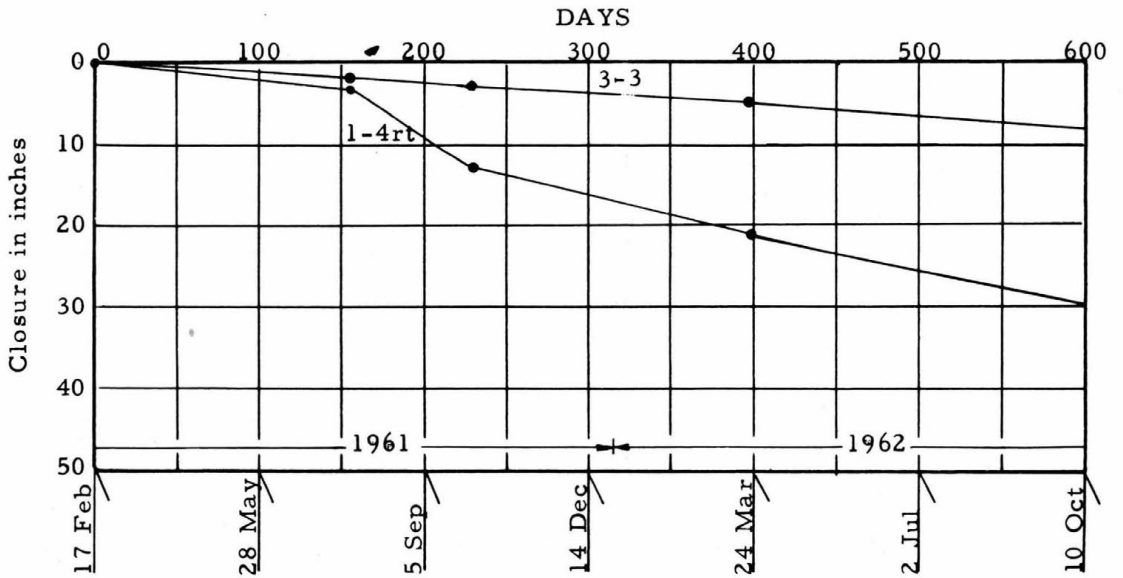
NOTES: 17 Feb '61, 3-3 Dist. = 16.00'  
 17 Feb '61, 1-4 rt. Dist. = 15.64'  
 \* Arch 21 Apr '62, down 3.6'



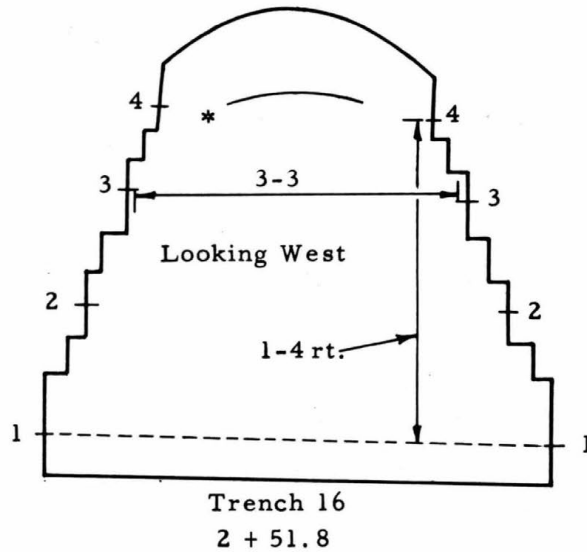
CROSS SECTION 9



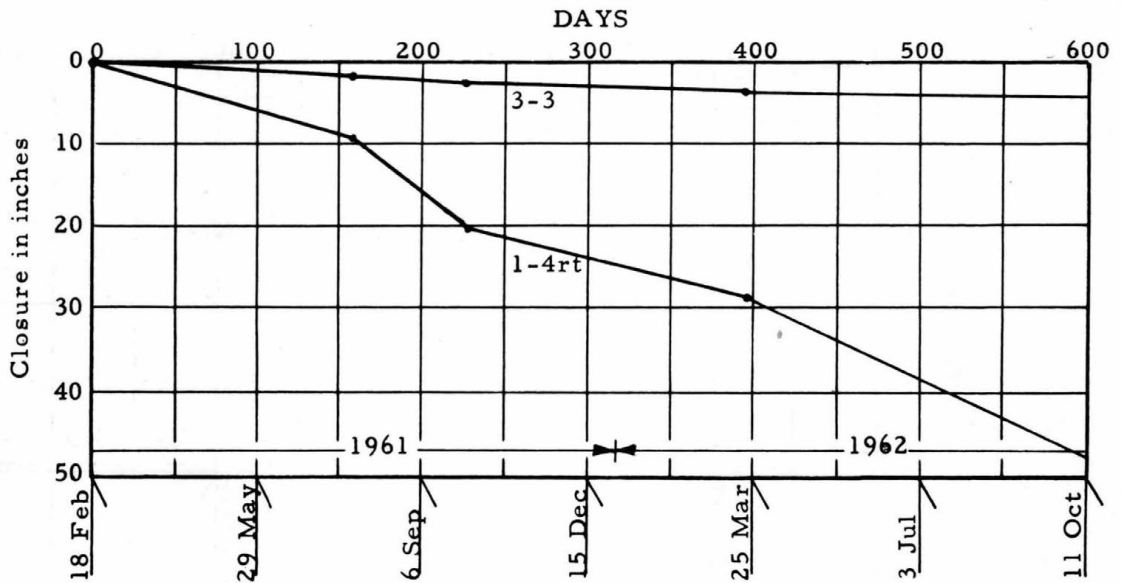
NOTES: 17 Feb '61, 3-3 Dist. = 15.97'  
 17 Feb '61, 1-4 rt. Dist. = 15.43'  
 \* Arch 21 Apr '62, down 3.8'



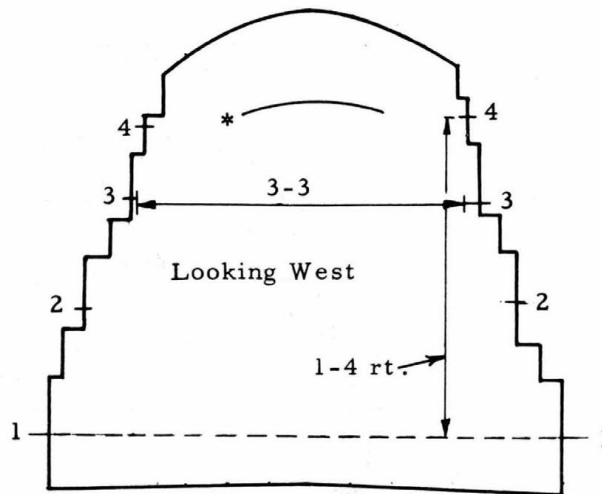
CROSS SECTION 10



NOTES: 18 Feb '61, 3-3 Dist. = 16.11'  
 18 Feb '61, 1-4 rt. Dist. = 15.65'  
 \* Arch 21 Apr '62, down 4.0'

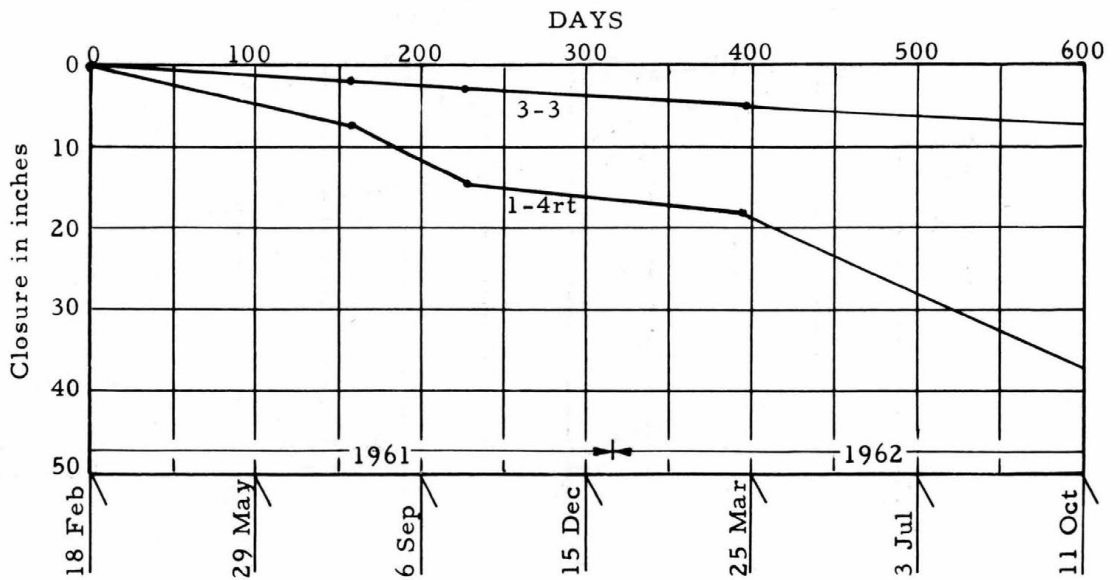


CROSS SECTION 11

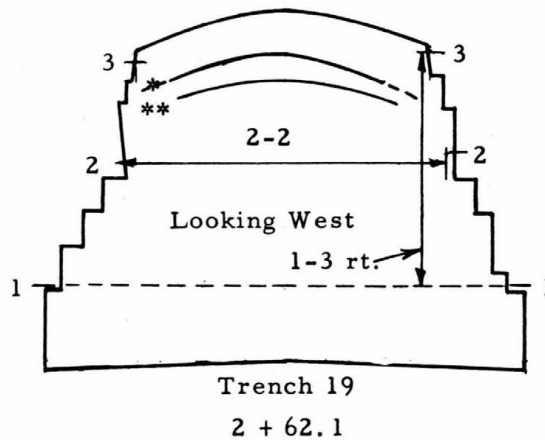


Trench 18  
2 + 59.4

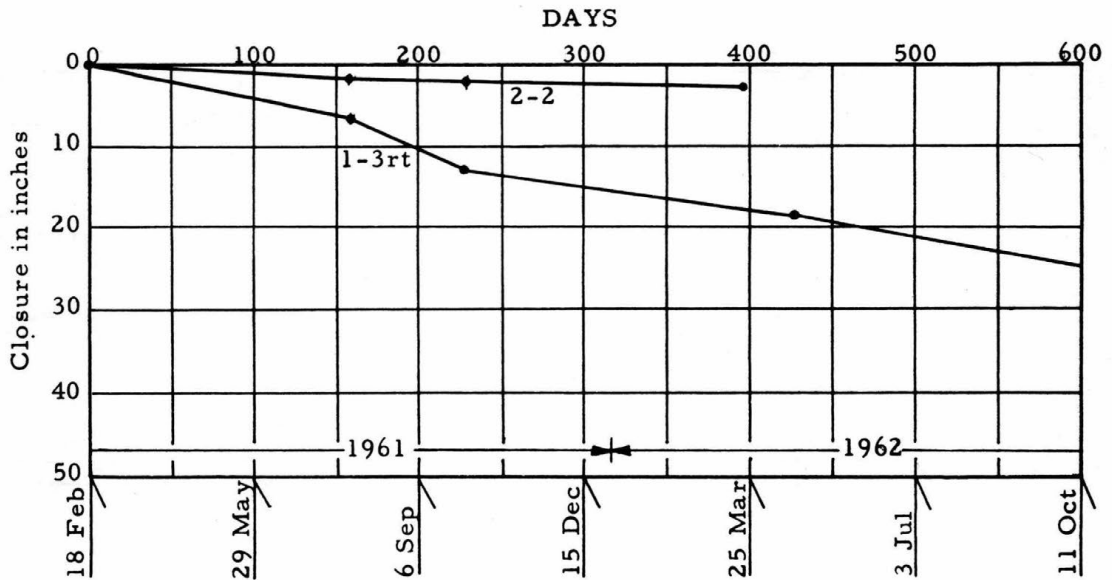
NOTES: 18 Feb '61, 3-3 Dist. = 15.94'  
 18 Feb '61, 1-4 rt. Dist. = 15.48'  
 \* Arch 21 Apr '62, down 4.5'



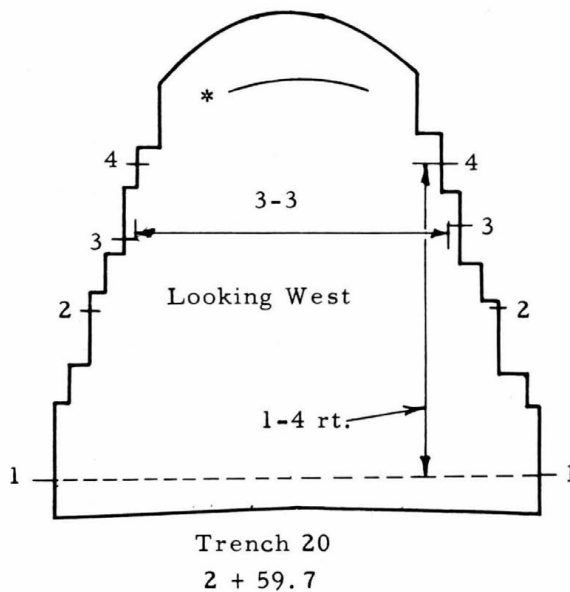
CROSS SECTION 12



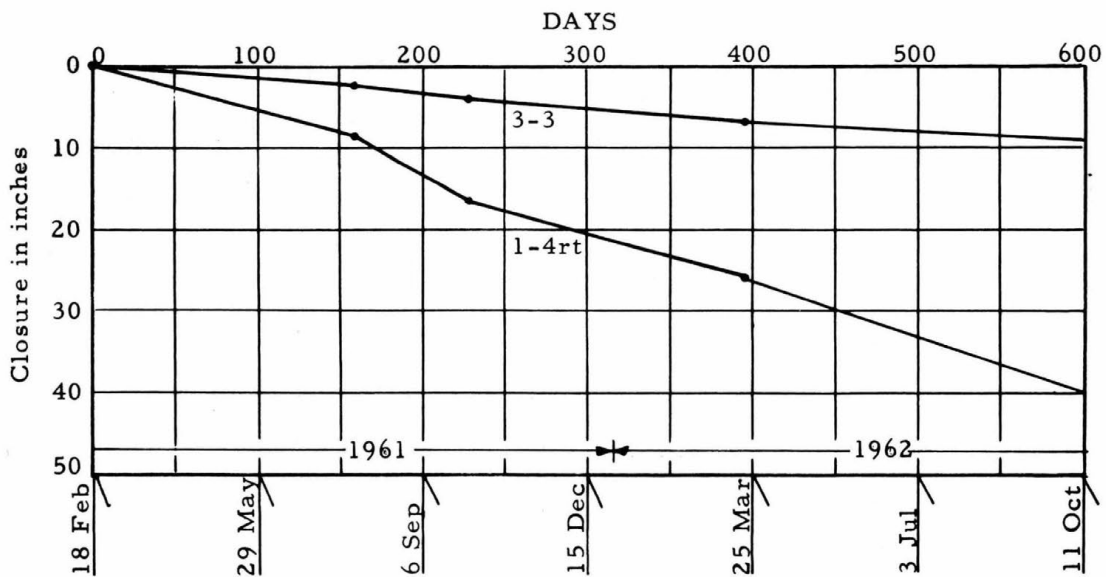
NOTES: 18 Feb '61, Dist. 2-2 = 15.79'  
 18 Feb '61, Dist. 1-3 rt. = 10.53'  
 \* Arch 4 Oct '61, down 2.2'  
 \*\* Arch 21 Apr '62, down 3.4'



CROSS SECTION 13

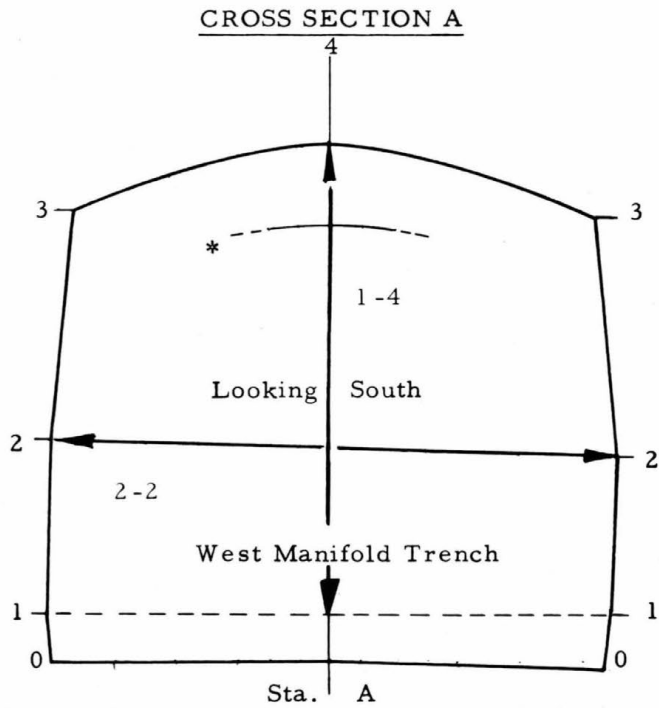


NOTES: 18 Feb '61, 3-3 Dist. = 16.12'  
 18 Feb '61, 1-4 rt. Dist. = 14.94'  
 \* Arch 21 Apr '62, down 3.3'

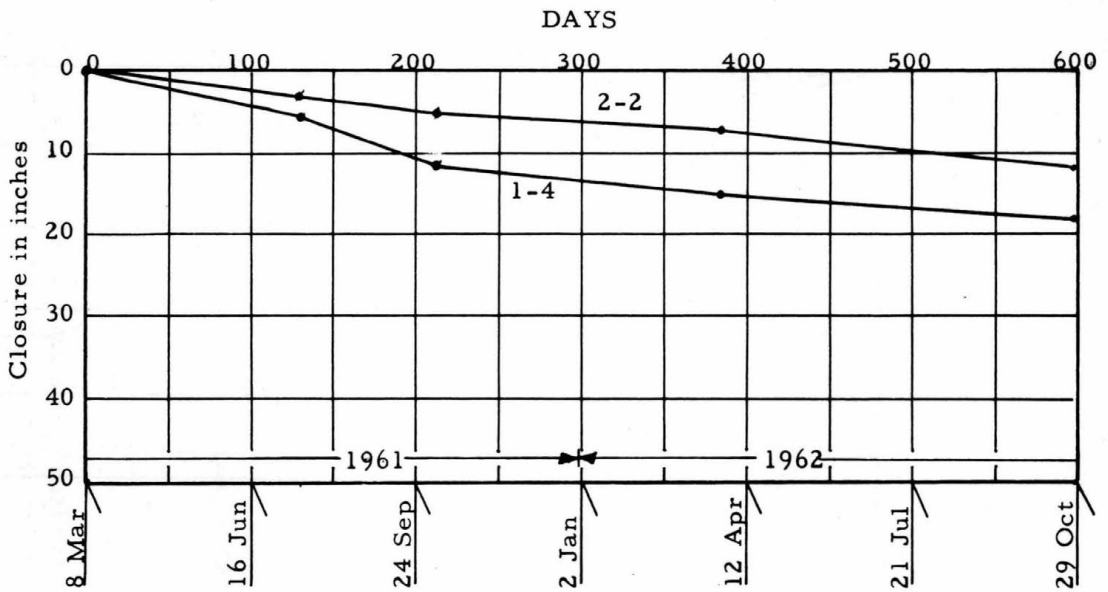


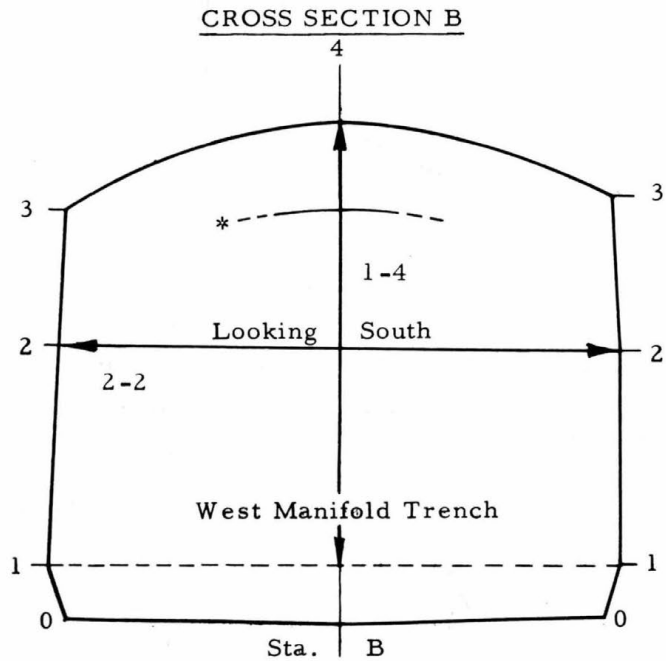


CAMP CENTURY MOVEMENT RECORD

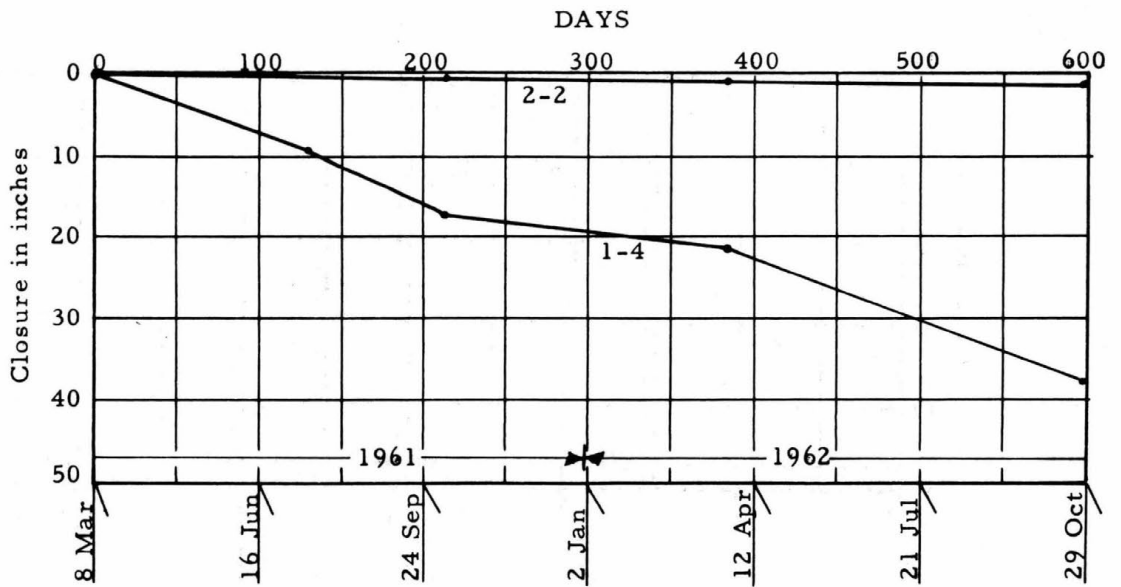


NOTES: 8 Mar '61, Dist. 2-2 = 8.99'  
 8 Mar '61, Dist. 1-4 = 7.52'  
 \* Arch 6 Oct '61, down 1.0'



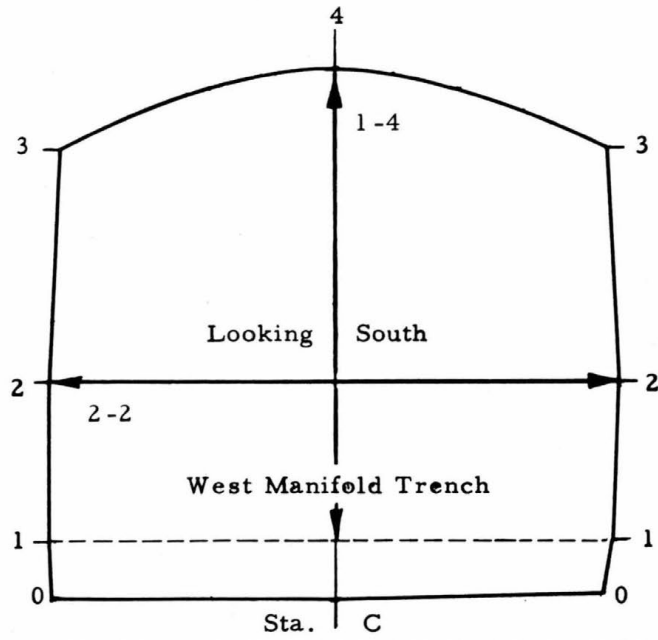


NOTES: 8 Mar '61, 2-2 Dist. = 9.09'  
 8 Mar '61, 1-4 Dist. = 7.14'  
 \* Arch 6 Oct '61, down 1.5'

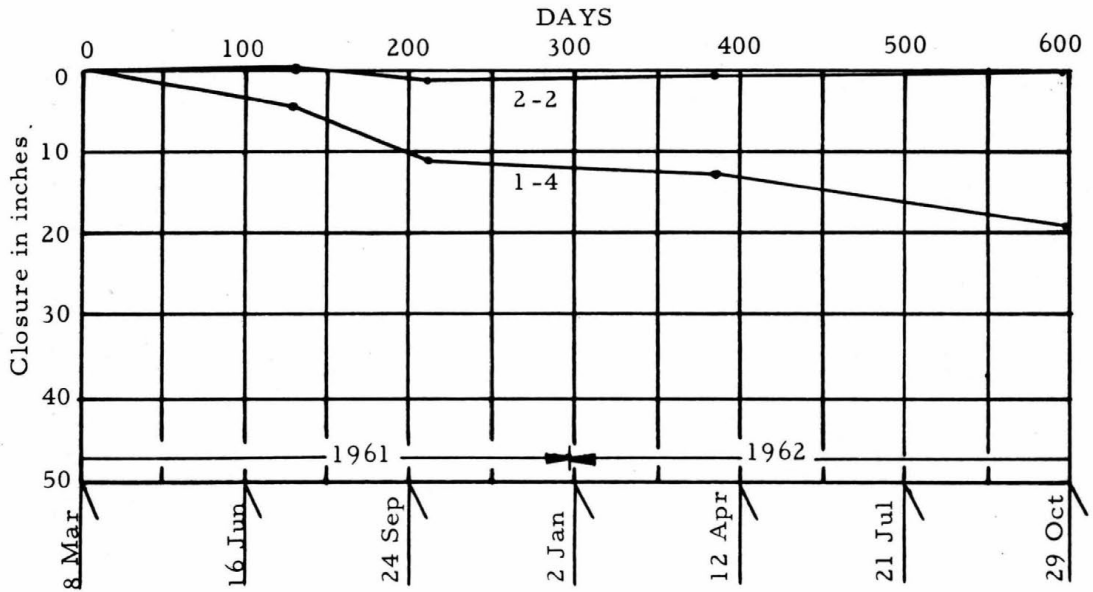


CAMP CENTURY MOVEMENT RECORD

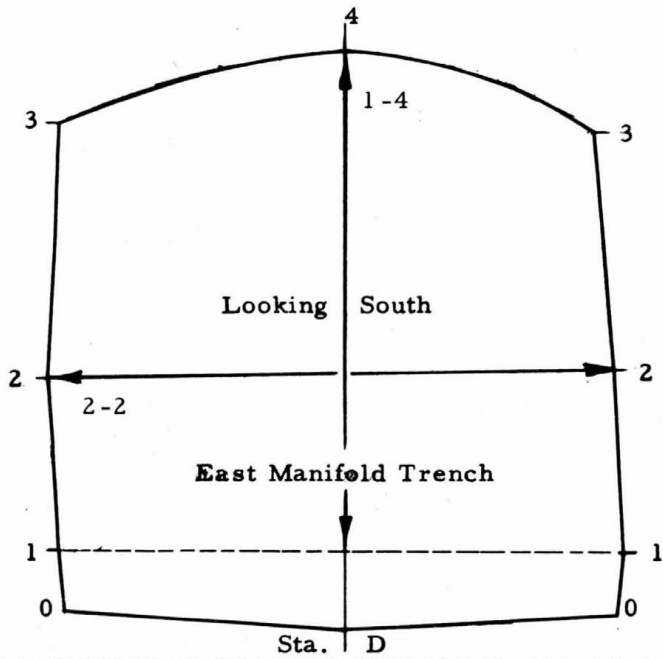
CROSS SECTION C



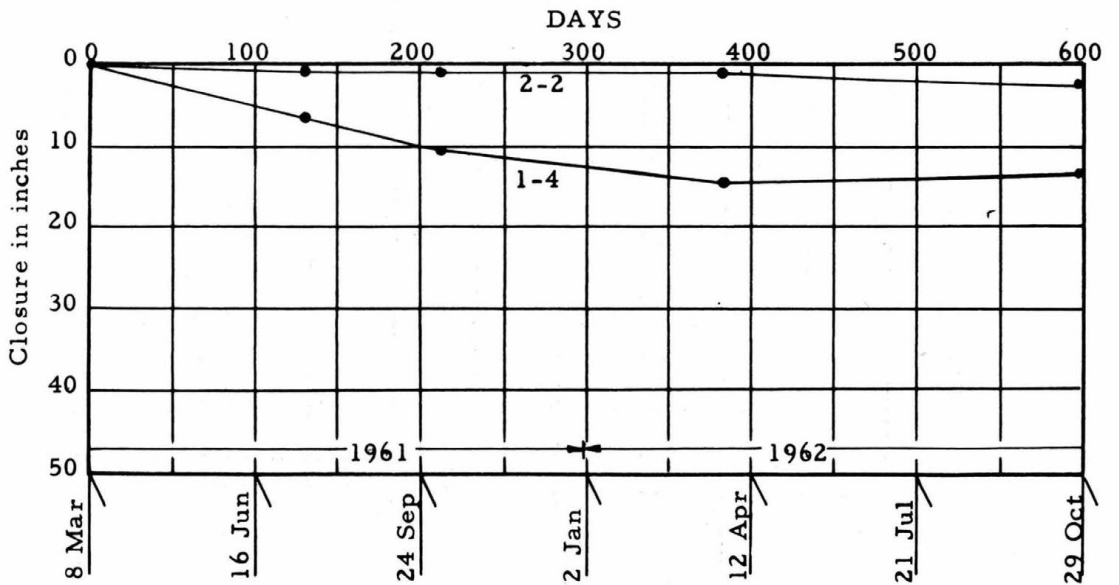
NOTES: 8 Mar '61, 2-2 Dist. = 9.18'  
 8 Mar '61, 1-4 Dist. = 7.48'



CROSS SECTION D

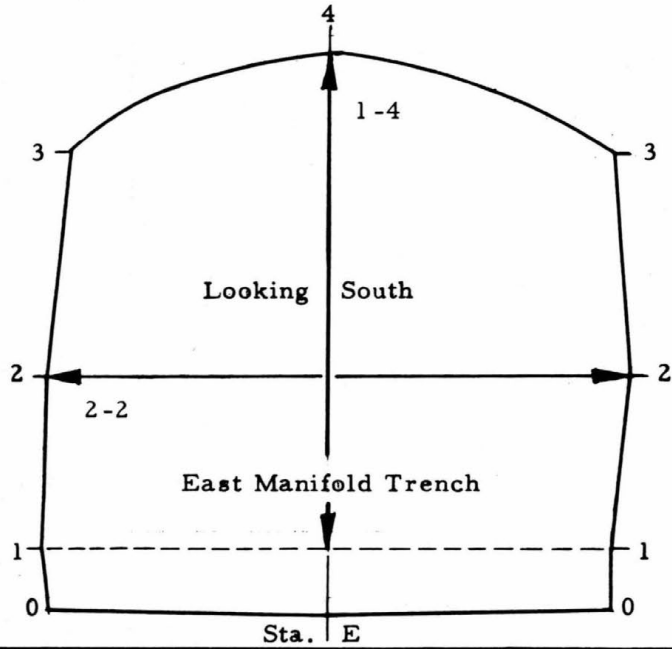


NOTES: 8 Mar '61, 2-2 Dist. = 9.03'  
 8 Mar '61, 1-4 Dist. = 7.98'

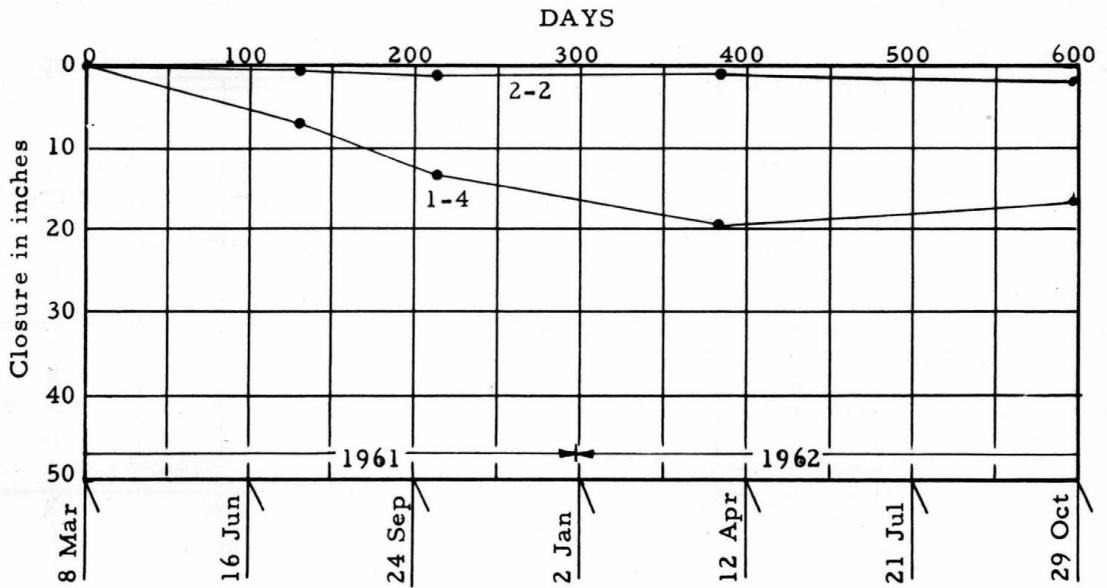


CAMP CENTURY MOVEMENT RECORD

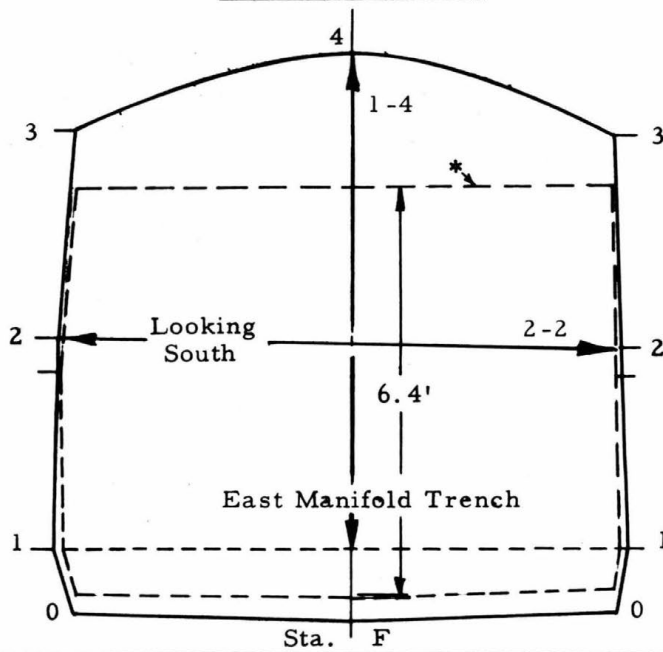
CROSS SECTION E



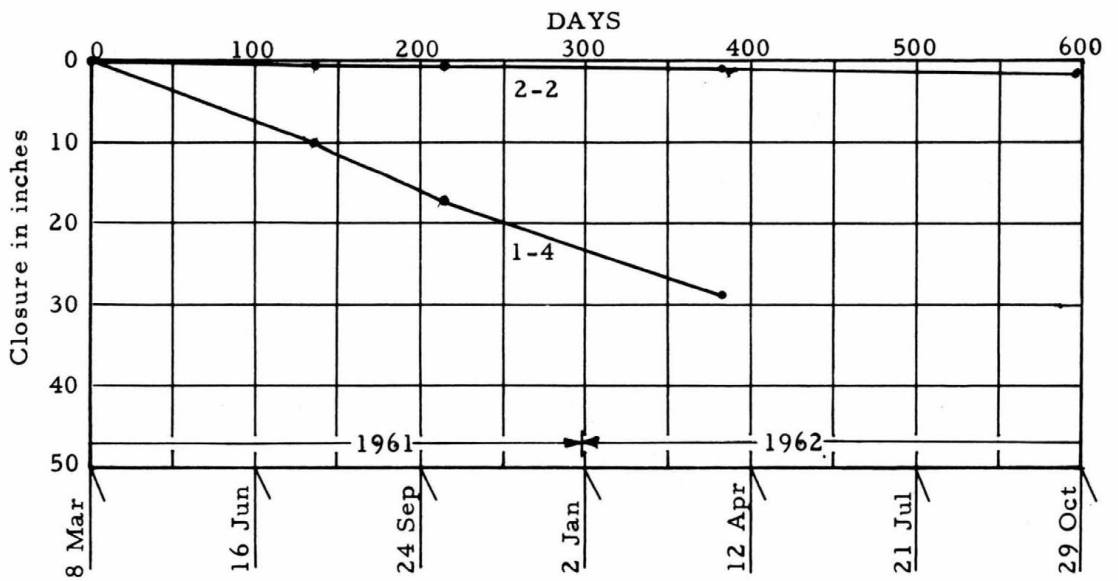
NOTES: 8 Mar '61, 2-2 Dist. = 9.20'  
 8 Mar '61, 1-4 Dist. = 7.73'



CROSS SECTION F



NOTES: 8 Mar '61, Dist. 2-2 = 9.10'  
 8 Mar '61, Dist. 1-4 = 7.96'  
 \* 26 Mar '62, down 2.4'



## G. PORTAL GRID SYSTEM

Table III. Portal Grid Locations.

Portal Shape Referenced by Grid	Date Referenced	Trench
Circular arch	March 1961	Trench 8 - Sewage Collection Tank
Elliptical arch	April 1961	Trench 7 - Officers' Latrine
Octagonal arch	Dec. 1960	Trench 20 - USA PR & DC HQ
45° arch	Jan. 1961	Trench 12 - R & D Trench
30° arch	Jan. 1961	Trench 16 - Theater-Chapel Trench

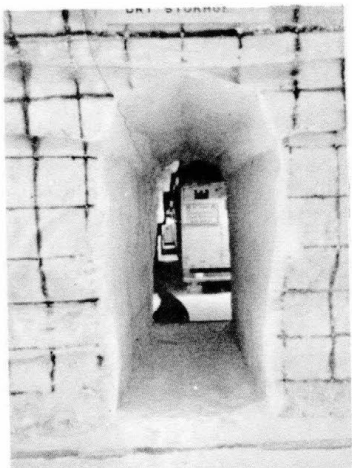


Photo 1. Trench 20, portal constructed and marked in December 1960; photographed on 29 March 1961.

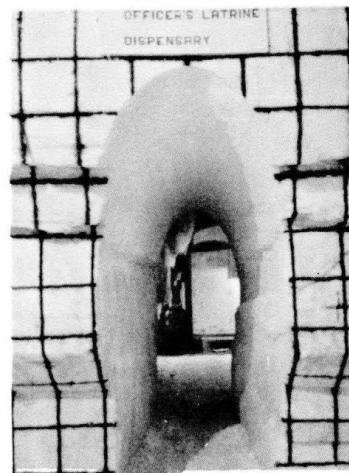


Photo 2. Trench 7, portal constructed and marked in April 1961; photographed on 19 April 1961.



Photo 3. Trench 12, portal constructed and marked in January 1961; photographed on 29 March 1961.

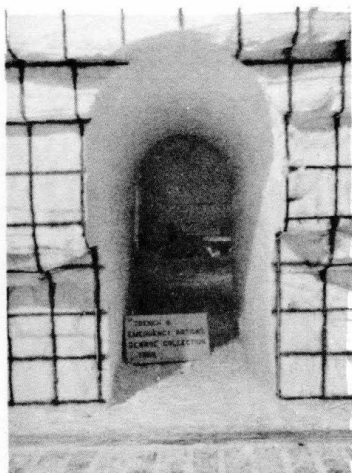


Photo 4. Trench 8, portal constructed and marked in March 1961; photographed on 29 March 1961.

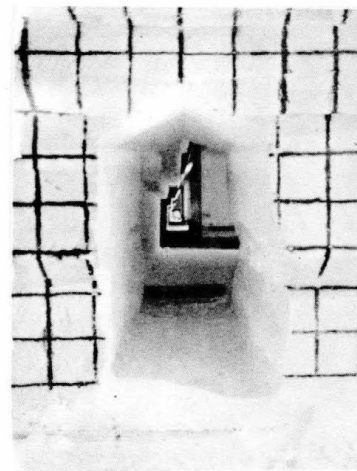
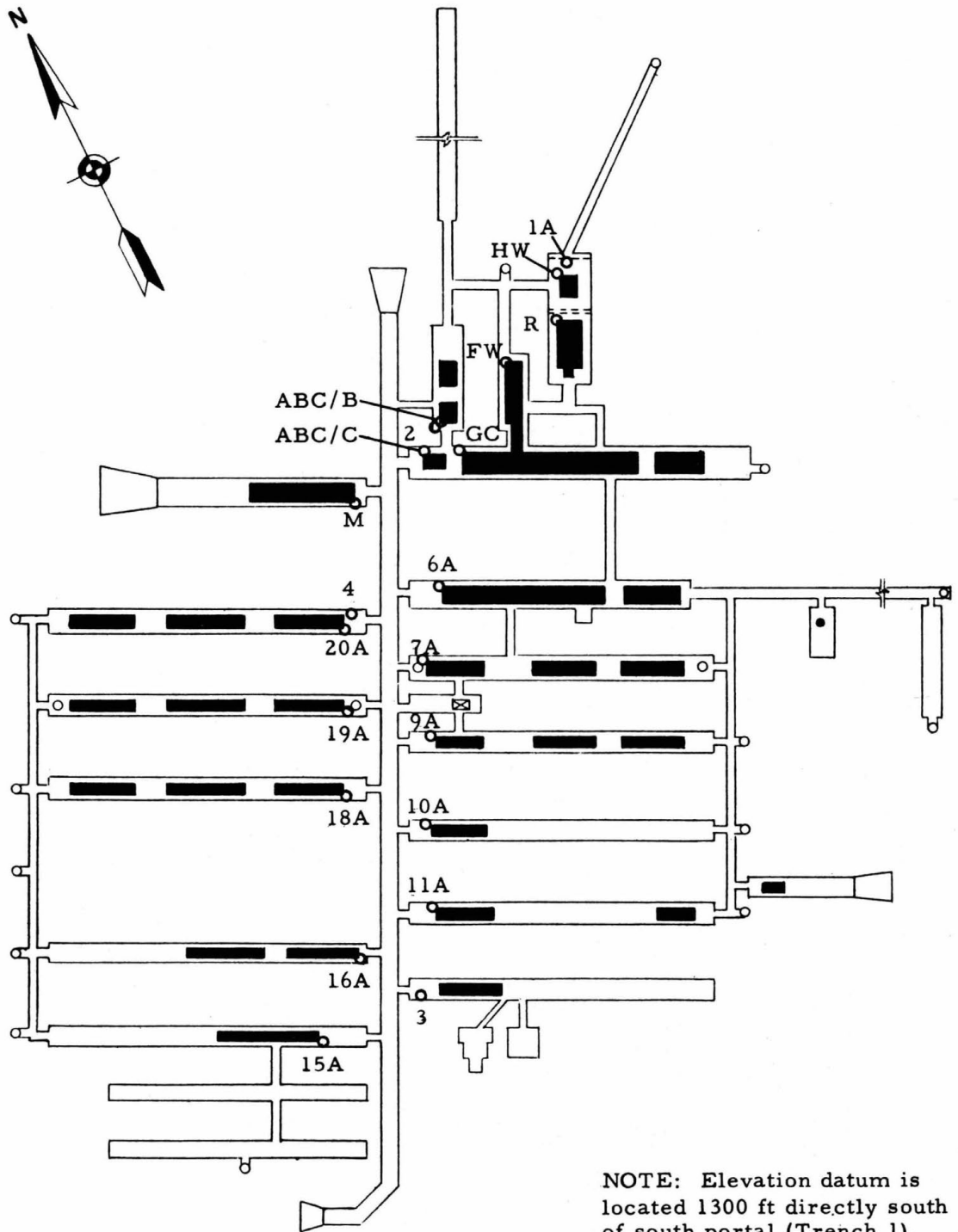


Photo 5. Trench 16, portal constructed and marked in January 1961; photographed on 29 March 1961.



H. PROFILE LEVELS AND BENCH MARK SYSTEM



Bench Mark Locations

May 1962

Table IV. Bench Mark Elevations and Variations.

Elevation of "elevation datum" = 132.16 ft (determined on 21 July 1961).

Elevation of undisturbed snow at the surface near the datum = 129.0 ft (12 August 1961).

B.M.	Location	First elev/date	Second elev/date	$\Delta$ from first ft/days	Third elev/date	$\Delta$ from first ft/days	Fourth elev/date	$\Delta$ from first ft/days
1A	Trench 4 floor	100.81/7-21-61	100.96/8-15-61	+0.15/25	100.91/9-18-61	+0.10/59	101.08/4-19-62	+0.27/272
2	Trench 2 floor	109.82/7-21-61	109.78/8-15-61	-0.04/25	109.79/9-18-61	-0.03/59	109.82/4-19-62	0.00/272
3	Trench 12 floor	107.79/7-21-61	107.84/8-12-61	+0.05/22	107.84/9-18-61	+0.05/59	107.96/4-16-62	+0.17/269
4	Trench 20 floor	107.77/7-21-61	107.83/8-15-61	+0.06/25	107.83/9-18-61	+0.06/59	107.93/4-16-62	+0.16/269
15A	Stand-by Power Bldg	104.03/7-24-61	104.09/8-14-61	+0.06/21	104.10/9-18-61	+0.07/56	104.25/4-12-62	+0.22/262
16A	Bldg 16A	108.68/7-24-61	108.74/8-14-61	+0.06/21	108.74/9-18-61	+0.06/56	108.86/4-12-62	+0.18/262
11A	Bldg 11A	106.16/7-24-61	106.22/8-14-61	+0.06/21	106.23/9-18-61	+0.07/56	106.37/4-12-62	+0.21/262
10A	Bldg 10A	107.79/7-24-61	107.85/8-14-61	+0.06/21	107.86/9-18-61	+0.07/56	107.96/4-12-62	+0.17/262
18A	Bldg 18A	106.67/7-24-61	106.71/8-14-61	+0.04/21	106.72/9-18-61	+0.05/56	106.84/4-12-62	+0.17/262
9A	Bldg 9A	107.82/7-24-61	107.86/8-14-61	+0.04/21	107.85/9-18-61	+0.03/56	107.95/4-12-62	+0.13/262
19A	Bldg 19A	110.33/7-24-61	110.37/8-14-61	+0.04/21	110.36/9-18-61	+0.03/56	110.44/4-12-62	+0.11/262
7A	Bldg 7A	109.31/7-24-61	109.39/8-15-61	+0.08/22	109.38/9-18-61	+0.07/56	109.45/4-12-62	+0.14/262
20A	Bldg 20A	107.51/7-24-61	107.57/8-14-61	+0.06/21	107.57/9-18-61	+0.06/56	107.69/4-12-62	+0.18/262
6A	Bldg 6A	108.15/7-24-61	108.21/8-14-61	+0.06/21	108.19/9-18-61	+0.04/56	108.32/4-10-62	+0.17/260
M	Vehicle Maint. Bldg	118.49/8-14-61	118.48/9-18-61	-0.01/52	118.51/4-12-62	+0.02/241		
HW	Hot Waste Bldg	102.29/9-7-61	102.22/9-18-61	-0.07/28	102.47/4-19-62	+0.18/224		
R	Reactor Bldg	100.66/9-7-61	100.60/9-18-61	-0.06/28				
FW	Feedwater Bldg	111.65/9-7-61	111.53/9-18-61	-0.12/28	111.55/4-19-62	-0.10/224		
GC	Gen. & Con- trol Bldg	111.86/9-7-61	111.83/9-18-61	-0.03/28	111.95/4-19-62	+0.09/224		
ABC/B	Air Blast Cooler "B"	112.59/9-7-61	112.60/9-18-61	+0.01/28	112.72/4-19-62	+0.13/224		
ABC/C	Air Blast Cooler "C"	112.53/9-7-61	112.60/9-18-61	+0.07/28	112.75/4-19-62	+0.22/224		

## EXPLANATION OF TRENCH PROFILE PLOTS

The purpose of the trench profile plots is to provide means for determining the snow overburdens and arch and floor depths for each trench.

In these plots, the vertical scale is ten times the horizontal scale; thus, all vertical dimensions are exaggerated in relation to the horizontal dimensions.

All profiles were measured at the trench centerlines. Therefore, all arch elevations were measured at the apexes, whereas settlement problems begin at the arch shoulders as the shoulders first come into contact with the buildings in the trench.

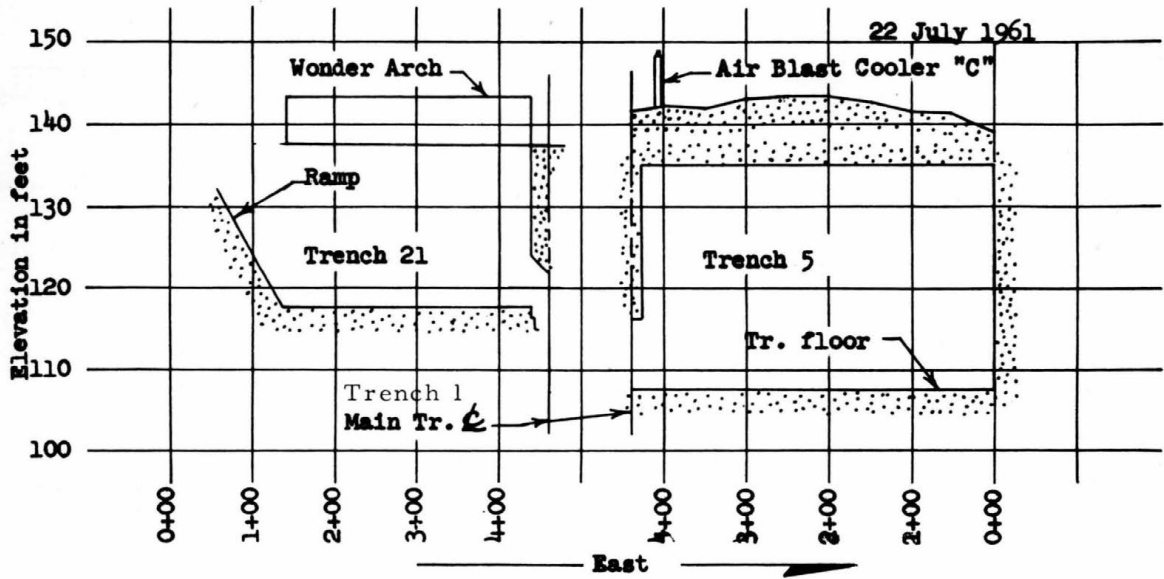
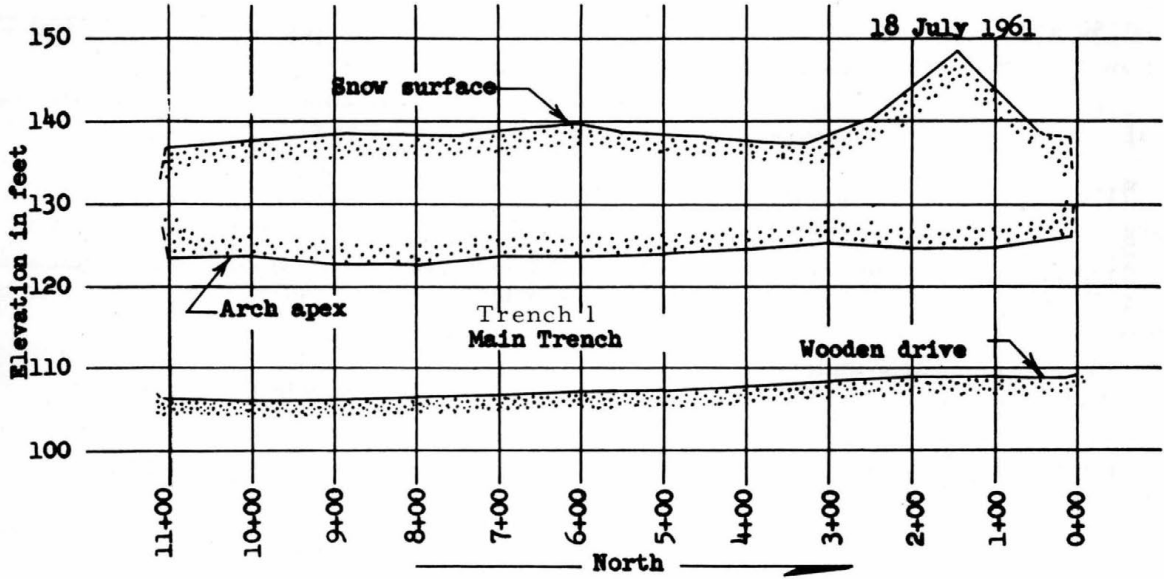
The snow surface above camp is 7 to 15 feet higher than the undisturbed snow surface away from camp, which averaged about 129.0 feet in elevation at the time of this survey.

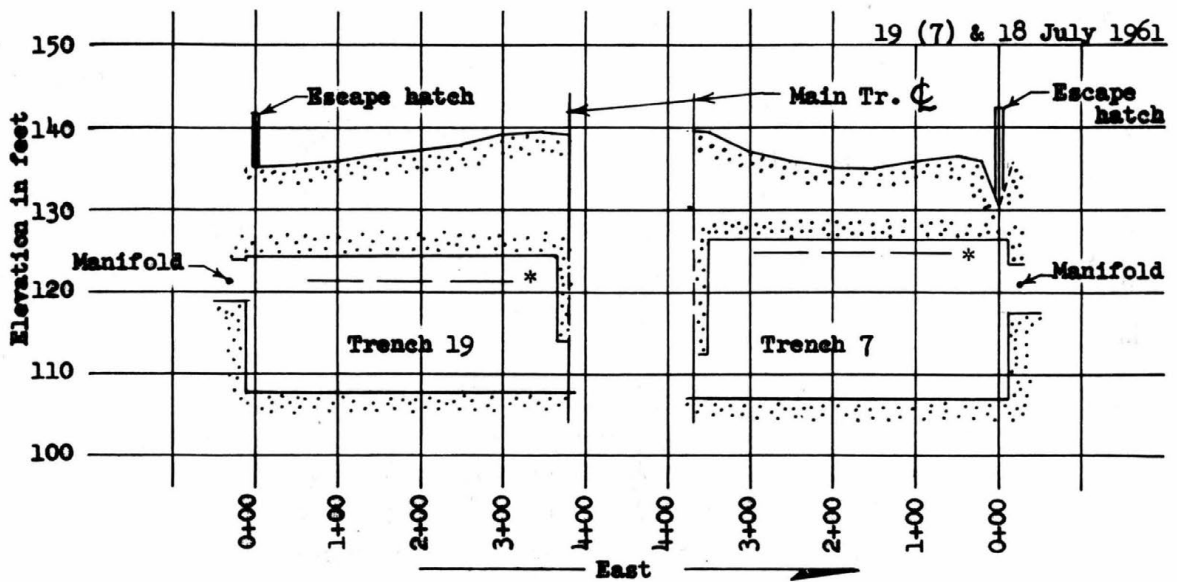
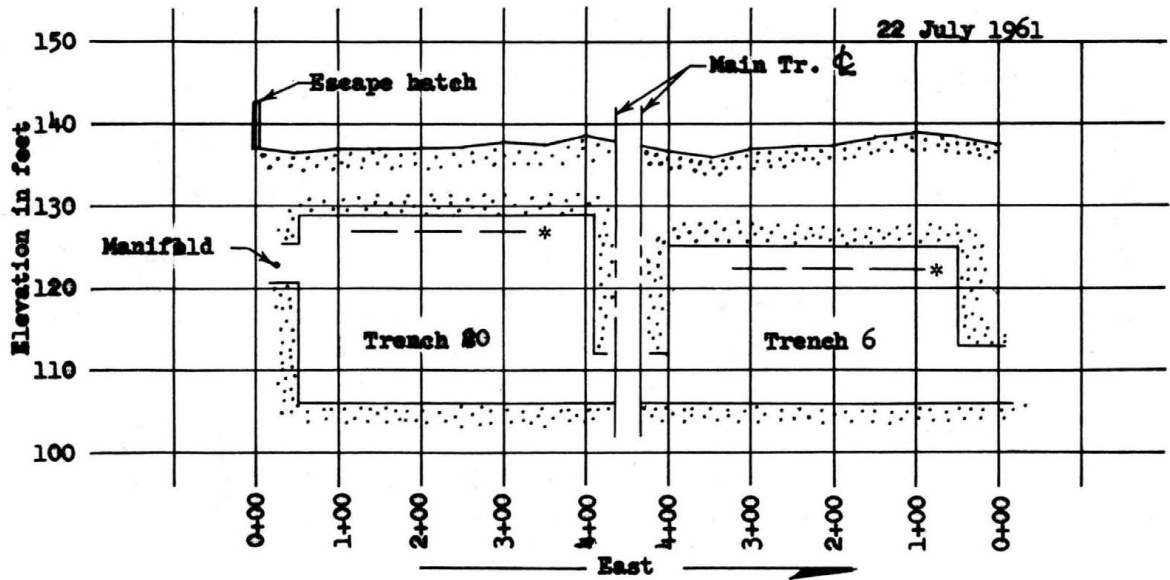
The Trench 21 Wonder Arch (page H4) was above the surface when this survey was undertaken. It was still not completely buried after the winter of 1961-62.

The Trench 12 surface profile is an estimate as there were no escape hatches to utilize as centerline guides as in the other trenches.

Manifold trench elevations are approximate as level data are sketchy in these areas.

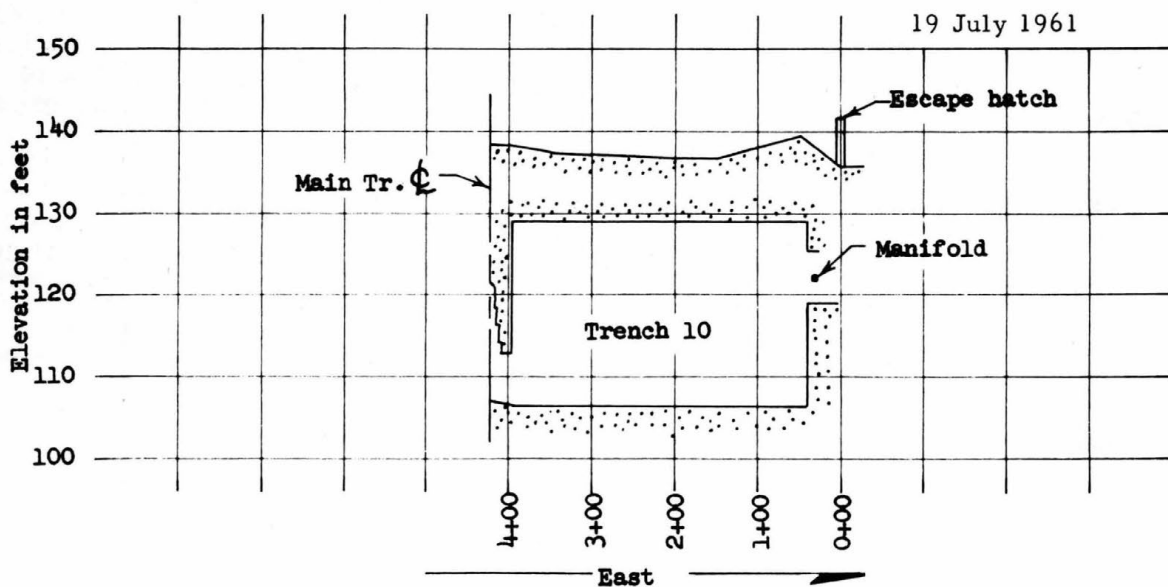
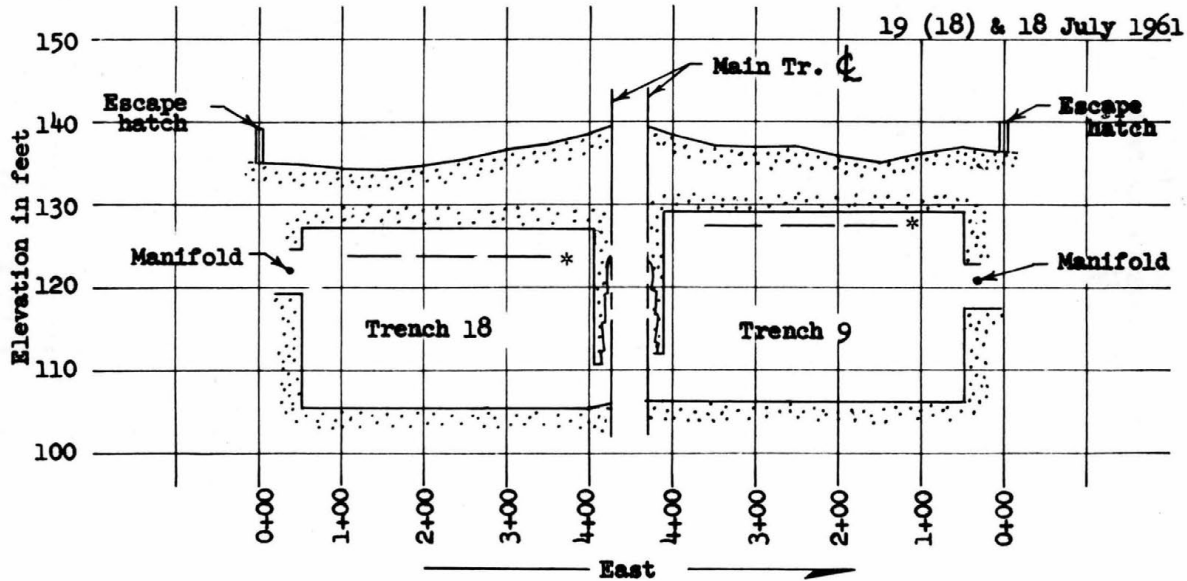
CAMP CENTURY MOVEMENT RECORD



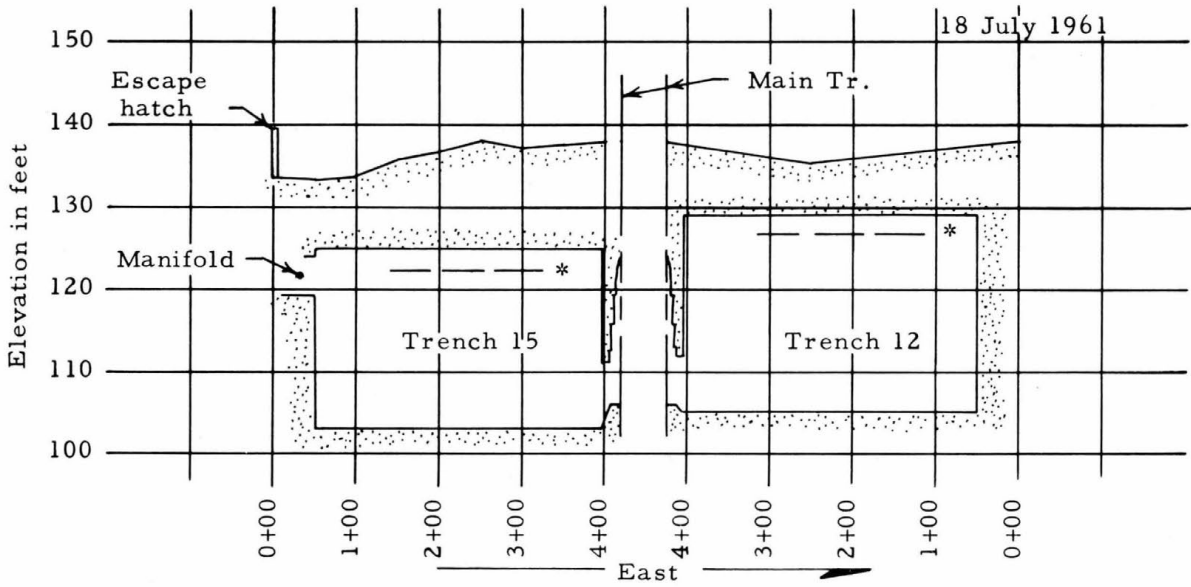
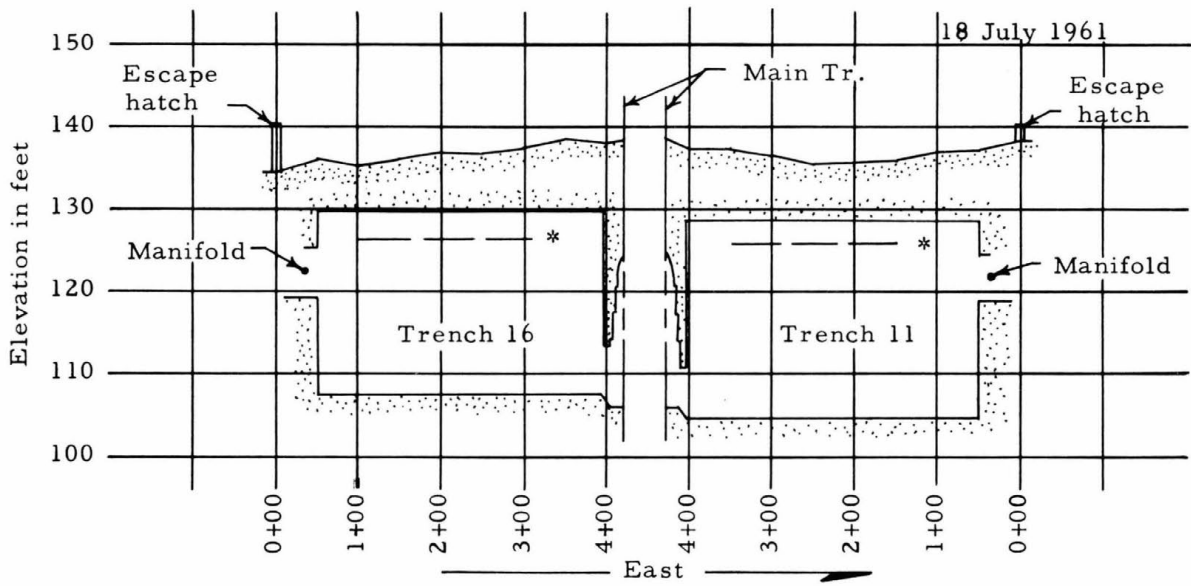


\* Arch on 21 April 1962.

CAMP CENTURY MOVEMENT RECORD

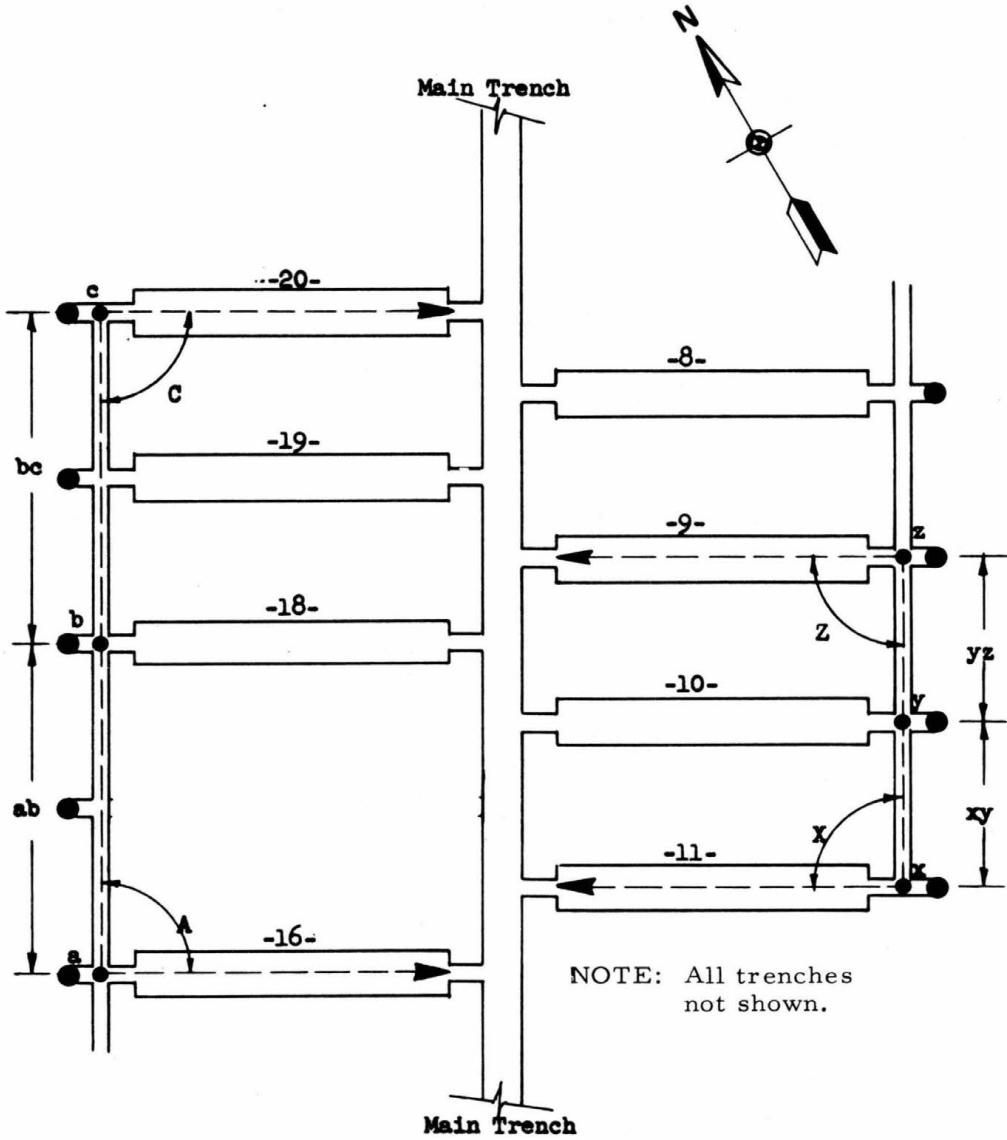


\* Arch on 21 April 1962.



\* Arch on 21 April 1962.

I. HORIZONTAL DISTORTION SURVEY



NOTE: All trenches not shown.

Plan - Horizontal Distortion Survey

May 1962



## CAMP CENTURY MOVEMENT RECORD

Table V. Horizontal distortion survey data.

Angle	20 Aug 61	5 Nov 61	Diff. from original	9 Apr 62	Diff. from original
A	90°02'13"	90°02'27"	+00'14"	90°05'47"	+03'34"
C	90°01'33"	90°02'33"	+01'00"	90°05'53"	+04'20"
X	90°09'27"	89°50'33"	-18'54"	89°49'27"	-20'00"
Z	89°48'33"	89°47'27"	-01'06"	89°47'07"	-01'26"
<hr/>					
Dist.					
ab	200.51 ft	-	-	200.97 ft	+0.46 ft
bc	199.38	-	-	198.66	-0.76
xy	99.77	-	-	99.74	-0.03
yz	100.16	-	-	100.12	-0.04

## REFERENCES

- Bader, Henri (1953) Sorgé's law of densification of snow on high polar glaciers, U. S. Army Snow, Ice and Permafrost Research Establishment, Corps of Engineers, Research Paper 2, 3p.
- \_\_\_\_\_ (1960) Theory of densification of dry snow on high polar glaciers, U. S. Army Snow, Ice and Permafrost Research Establishment, Corps of Engineers, Research Report 69, 8p.
- Signal Meteorological Corps, U. S. Army (1960-62) Camp Century Meteorological Reports (unpublished records).
- Waterhouse, R. W. and Steeves, H. F. (1960) Snow densification theory and its engineering application, U. S. Army Snow, Ice and Permafrost Research Establishment, Corps of Engineers, Research Report 71, 10p.
- U. S. Army Cold Regions Research and Engineering Laboratory, Corps of Engineers, Project 13a (1960-62) Camp Century Movement Record Progress Reports (unpublished).

## K. THEORETICAL SETTLEMENT

The principal purpose of these studies is to define more clearly the term, "useful life" of undersnow installations. Information is needed on how these installations (cavities in glacial snow) affect the natural densification of the snow in which they are constructed.

SIPRE Research Report 71 (Waterhouse and Steeves, 1960) discusses how the density of snow varies with time and depth under a constant accumulation. For instance, a given point, initially at the surface, progresses downward according to

$$h = \frac{(aAt + \gamma_0^2)^{\frac{1}{2}} - \gamma_0}{a}, \text{ which relates } \underline{t} \text{ (time in years), } \underline{A} \text{ (accumulation in g/cm}^2 \text{),}$$

$\underline{a}$  (the change in profile density with depth in g/cm<sup>3</sup>-cm), a constant, and  $\gamma_0$  (the surface density at  $t = 0$ ).

From this equation, or related equations, is derived the change in thickness of a layer  $\Delta h$  or  $h_2 - h_1$  by the amount  $\dot{\epsilon}$  per unit of time.

$\epsilon = A \left[ \frac{1}{\gamma_2} - \frac{1}{\gamma_1} \right]$  and is the velocity  $\dot{\epsilon}$  (or "v") times the thickness  $\Delta h$ . At any depth, according to the Sorgé hypothesis, snow is densifying at a constant rate  $\dot{\epsilon}$  which is equal to  $\frac{aA}{\gamma^2}$ , where  $\gamma$  is the average density at that depth.

All of the foregoing can be applied only to a natural undisturbed ice cap condition where no melting occurs and the accumulation can be assumed constant.

Many special cases will require consideration in the future now that snow masses are being exploited for undersnow shelters and other purposes.

Such a special case arises in considering what happens to a densifying snow when an artificial surcharge is superimposed upon the natural situation.

The effect of a superimposed load, or surcharge, over an infinite plane has been evaluated using simplifying assumptions as to the rate of density change with depth. As a first approximation of the effect of a surcharge of finite extent, this formulation is applied to the case for densification of the Trench 4 wall at Camp Century with a 100-g/cm<sup>2</sup> surcharge.

The equation is:

$$\dot{\epsilon} = v = \frac{1}{h} \frac{dh}{dt} = \frac{Aa}{(\gamma_0 + ah)^2} \left[ \frac{\sigma_s}{(\gamma_0 h + \frac{ah^2}{2} + A(t-1))} + 1 \right]$$

where  $\gamma_0$  = snow density directly under the surcharge;  
 $h$  = depth below the surcharge;  
 $A$  = annual accumulation;  
 $a$  = change of the profile density (assumed constant beneath the surcharge);  
 $t$  = time; units compatible with those in "A" above; and  
 $\sigma_s$  = surcharge.

The annual densification of a 10-meter column of snow, shown for two years in Figure 7, is the sum of the products  $\dot{\epsilon} \Delta h$  for 100-cm increments. The strain rate for each increment is shown as a %/year for the mean depth of the increment. Since for

low stresses,  $\frac{1}{\gamma} \frac{d\gamma}{dt} = \frac{1}{h} \frac{dh}{dt}$ , we say that the decrease in thickness of an increment is proportional to the increase in its mean density.

The Sorgé statement that density at a given depth is constant does not apply to the surcharge situation. The  $d\gamma/dh$  line (density profile) is shifted to a higher density

range. It is quite likely, then, that the  $d\gamma/dh$  constancy is untenable — departing from it, however, raises more difficulties. For the present, progress must rest with the demonstration that a feasible surcharge can account for the densifications being encountered. It is reasonable to set the surcharge on the walls of Trench 4 at  $100 \text{ g/cm}^2$ , as is done in Figure 8.

Figure 8 shows how the theoretical settlement of the walls in Trench 4 under a  $100 \text{ g/cm}^2$  surcharge compares with the actual settlement as obtained from helipot #3 located in that trench.

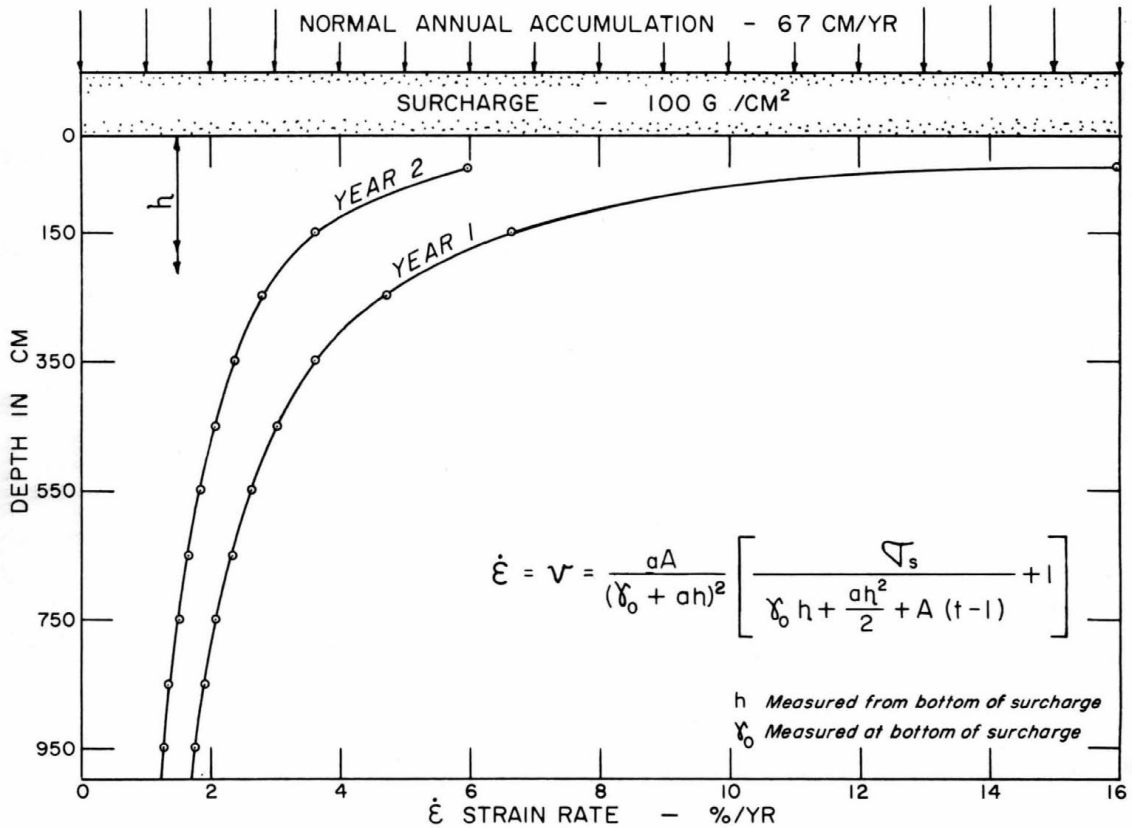


Figure 7. Strain rates under surcharge for years 1 and 2.

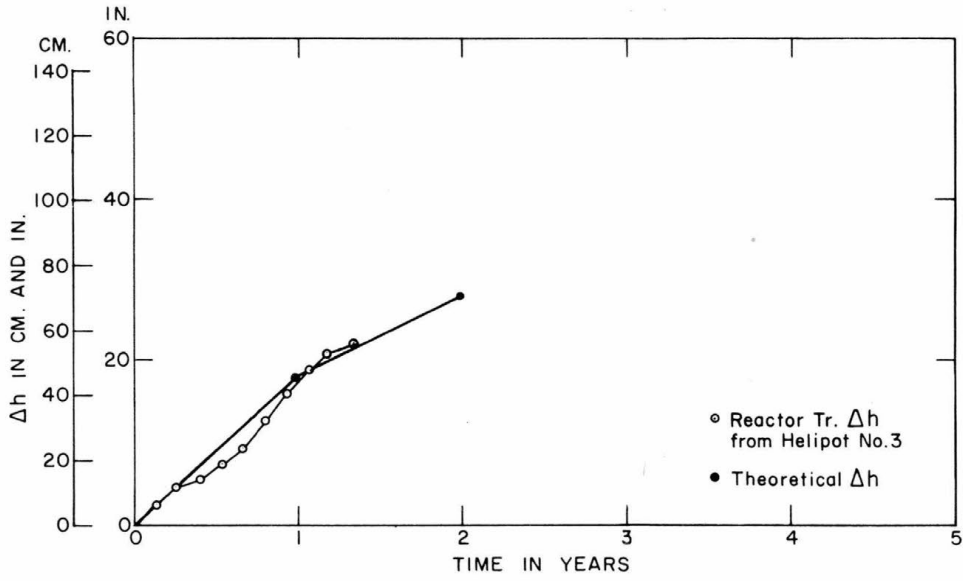


Figure 8. Theoretical settlement under surcharge and actual settlement of the walls of Trench 4.