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MONITORING SOIL STRUCTURE INTERACTION IN THE EISENHOWER TUNNEL

Offices of Research and Development
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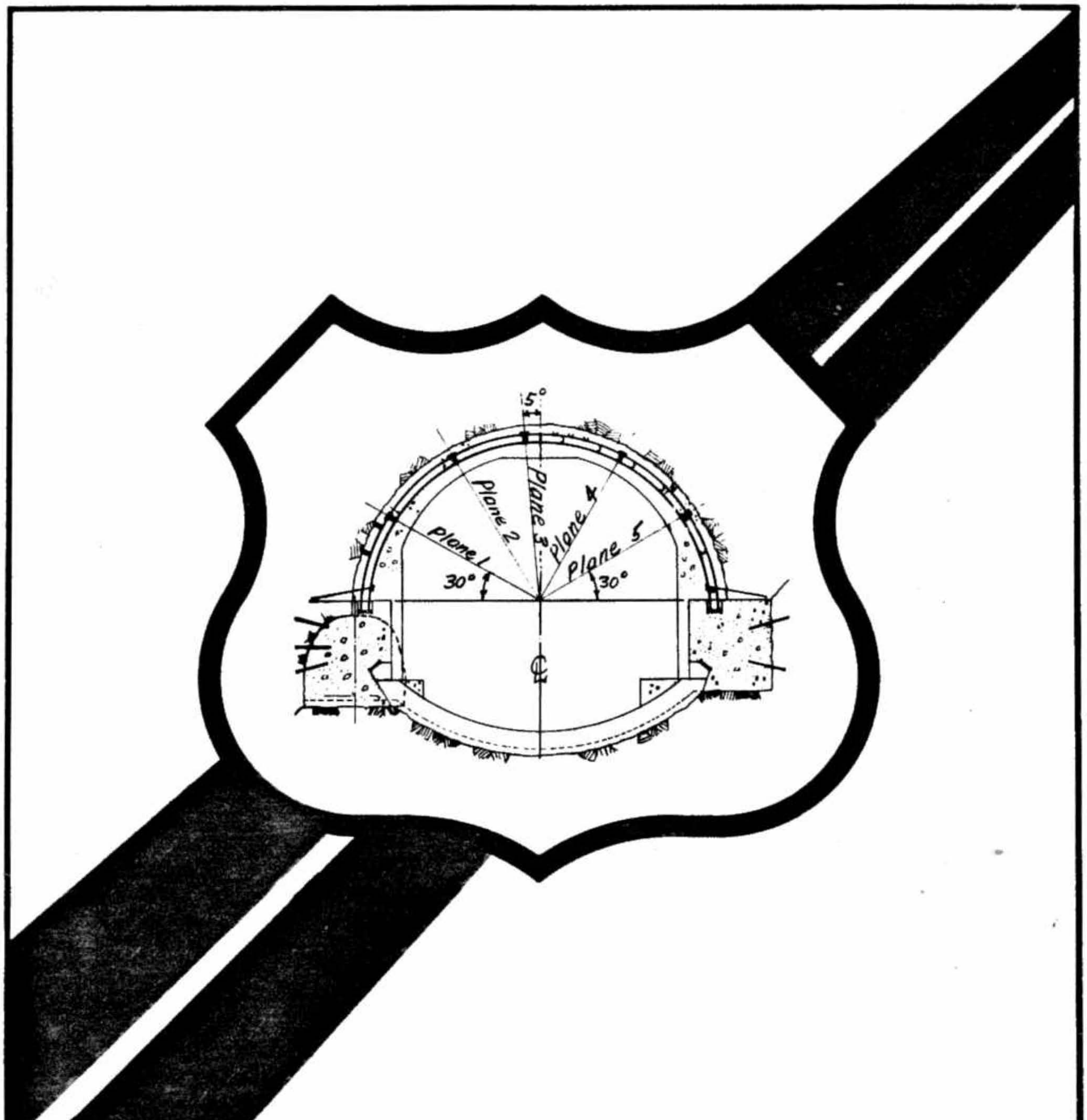

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16. Abstract

The objective of this study was to generate data on rock properties both in situ and in the laboratory, and of the interaction between the in situ rock and the support-lining-system during the construction of a vehicular tunnel. These data could then be utilized by others to assist in determining if an appropriate tunneling method or a magnitude of load on the support-lining-system can be predicted for future tunnels.

The first phase of the study involved obtaining the in situ properties of a rock mass at two locations within the tunnel. The second phase included the monitoring of the rock and/or support-lining-system to the tunnel excavation process at the location of the in situ tests. Concurrent with the field work, laboratory tests were performed on rock core specimens from the in situ test and monitoring sites. These tests provided information on standard rock properties. The data from this total study when combined with data from other tunnel studies, may assist others to improve designs and reduce cost of underground construction.

Results have not indicated any new major parameter correlations. The largest loads on the support system occurred in areas of highest in situ stress and poorest in situ and core rock quality.

17. Key Words
Tunnel instrumentation/in situ stress/in situ modulus/laboratory core test

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ABBREVIATIONS

ASTM	American Society for Testing and Materials
AVG	Average
Az	Azimuth
CDOH	Colorado Division of Highways
cm	Centimeter
E_d	Deformation modulus
Ex	Hole size 1-1/2 inches, core size 7/8 inch
FDN	Foundation
FHWA	Federal Highway Administration
ft	Feet
ft/s	Feet per second
GPa	Gigapascal
in	Inch
I	Inclination; also moment of inertia
IKE	Eisenhower
K-in	Kip inch
km	Kilometer
kPa	Kilopascal
K/in^2 (KSI)	Kips per square inch
M	Million; also bending moment
MAX	Maximum
MIN	Minimum
MPa	Megapascal
MPBX	Multiple position bore hole extensometer
m	Meter
m/s	Meter per second
N	Normal stress
N·m	Newton meter
NX	Hole size 3 inches, core size 2-1/8 inches
PVC	Polyvinyl chloride
PHI	Angle of fricton (shear test)
lb/in^2 (PSI)	Pounds per square inch
RQD	Rock quality designation
S	Shear stress
S_1, S_2, S_3	Principal stresses (in situ)

ABBREVIATIONS - (continued)

UAJT	Uniaxial Jacking Test
USBR	U.S. Bureau of Reclamation

CODES

101A	Angle MPBX drill hole at test site station 101+70
101V	Vertical MPBX drill hole at test site station 101+70
111A	Angle MPBX drill hole at test site station 111+75
111V	Vertical MPBX drill hole at test site station 111+75
UJ1	Uniaxial jacking test, site 1, station 101+70
UJ2	Uniaxial jacking test, site 2, station 111+75
UJ1E	Horizontal drill hole, uniaxial jacking test, site 1, east side, station 101+70
UJ1W	Horizontal drill hole, uniaxial jacking test, site 1, west side, station 101+70
UJ2E	Horizontal drill hole, uniaxial jacking test, site 2, east side, station 111+75
UJ2W	Horizontal drill hole, uniaxial jacking test, site 2, west side, station 111+75
101-A through 101-E	Strain meter locations in concrete lining, station 101+70
111-A through 111-E	Strain meter locations in concrete lining, station 111+75
P-1 through P-10	Stress meter locations in multiple drift section, station 83+50
101+70	Station in pilot and second highway bores where testing and instrumentation were performed
111+75	Station in pilot and second highway bores where testing and instrumentation were performed
83+50	Station in multiple drift area of second highway bore where instrumentation was performed
Planes 1 through 5	Strain gage locations on steel supports
Types I, II, III, IV	Rock Classification (CDOH)

Conversion table

To convert		Multiply
From	to	by
Inch (in)	Centimer (cm)	2.540
Inch (in)	Meter (m)	0.0254
Foot (ft)	Meter (m)	0.3048
Mile	Kilometer (km)	1.609
Pounds per square inch (lb/in^2)	Kilopascal (kPa)	6.900
Kip per square inch (KSI)	Megapascal (MPa)	6.900
Kip-inch (K-in)	Newton meter (N·m)	11.30

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SECTION 1. - INTRODUCTION AND SCOPE OF EFFORT

Background

The present high cost of tunneling is often due in part to the incorrect prediction of the behavior of the soil and rock materials. Loads on the tunnel supports and lining, stability of the face of the excavation, standup time of the bore, and earth movements in and around the tunnel are seldom accurately predicted. Although there are analytical techniques available to describe the physical phenomena, they rely upon assumptions because of the lack of basic field data. In some cases where these analytical techniques are used, the deficiencies of the methods are not apparent, but there are other cases where simplifying assumptions on the soil-structure behavior lead to serious and costly errors. In large diameter highway tunnels, small errors in assumptions are greatly magnified. More accurate analytical models could be developed if reliable, precise field data were available for verification.

At present, engineering judgment is the major determining factor in the selection of design parameters. Where conditions are similar from job to job, past experience is an excellent guide. Design by past experience, however, hampers innovation in design and construction. A more rational way is needed to select design parameters leading to improved design and reduced cost of tunneling.

In April 1975, the USBR (U.S. Bureau of Reclamation) formally submitted a research proposal to the FHWA (Federal Highway Administration) entitled "Monitoring Soil-Structure Interaction in a Colorado Tunnel." The proposal was in response to an FHWA inquiry for conducting research on a major tunneling project in order to investigate the possibility of developing more economical designs for future underground construction.

The USBR undertook the research study in June 1975 to obtain in situ and laboratory rock properties and field measurements on the rock-support-lining system during the construction of a major highway tunnel.

The Eisenhower Tunnel, second highway bore, located on Interstate 70 approximately 60 miles (96 km) west of Denver, Colorado, see figure 1, was selected for the research study. The tunnel, approximately 8800 ft (2680 m) in length and at 11 000-ft (3350-m) elevation, had excavated dimensions of about 45 by 50 ft (13.7 by 15.2 m) (semicircular), was steel supported, and the rock was reinforced with cement and resin-grouted steel spiling. Depending on ground conditions, two, three, or nine drifts were excavated, supported, and concrete backfilled and used as part of the support system for the main highway tunnel, as shown on figure 2.

Scope of Effort

The USBR's involvement in the research program was designed to obtain data which could be utilized by others to verify, supplement, or provide basic information for various new tunnel designs which are being or will be generated.

The research effort included studies in several categories, namely:

- Geological Investigations
- In Situ Stress Determination (stress relief tests)
- In Situ Deformation Modulus Determination (uniaxial jacking tests)
- Rock Monitoring Instrumentation [extensometer (MPBX) installations]
- Steel Support Instrumentation (strain gage installation)
- Lining Instrumentation (strain meter installations)
- Multiple Drift Stress Measurements (stress meter installations)
- Laboratory Core Tests
- Petrographic Studies

Project Schedule

The work effort began June 13, 1975, access to the tunnel site was obtained August 31 1976, and the research work was scheduled to be completed by December 31, 1980.

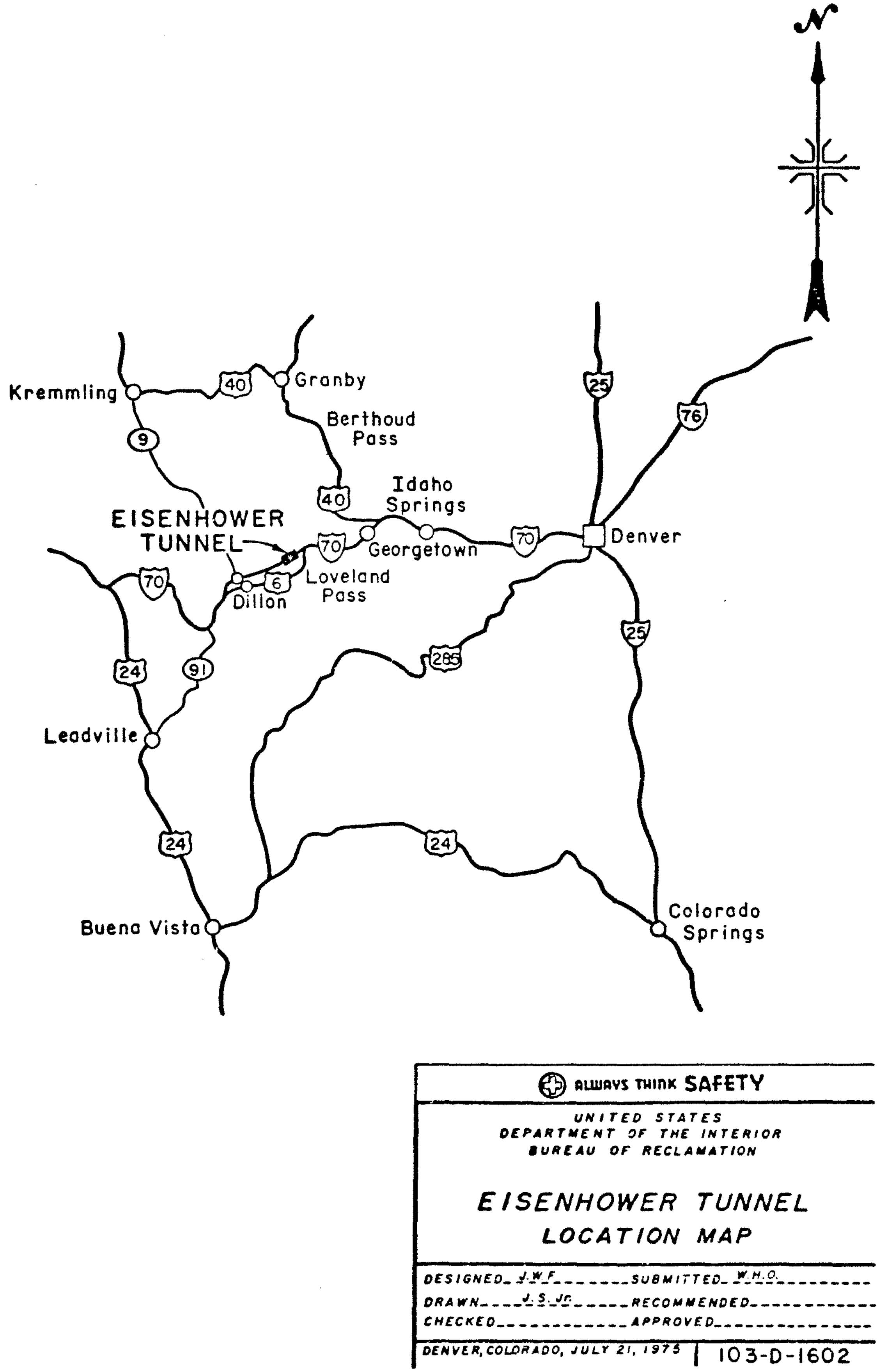

Figure 1. - Eisenhower Tunnel Location Map.

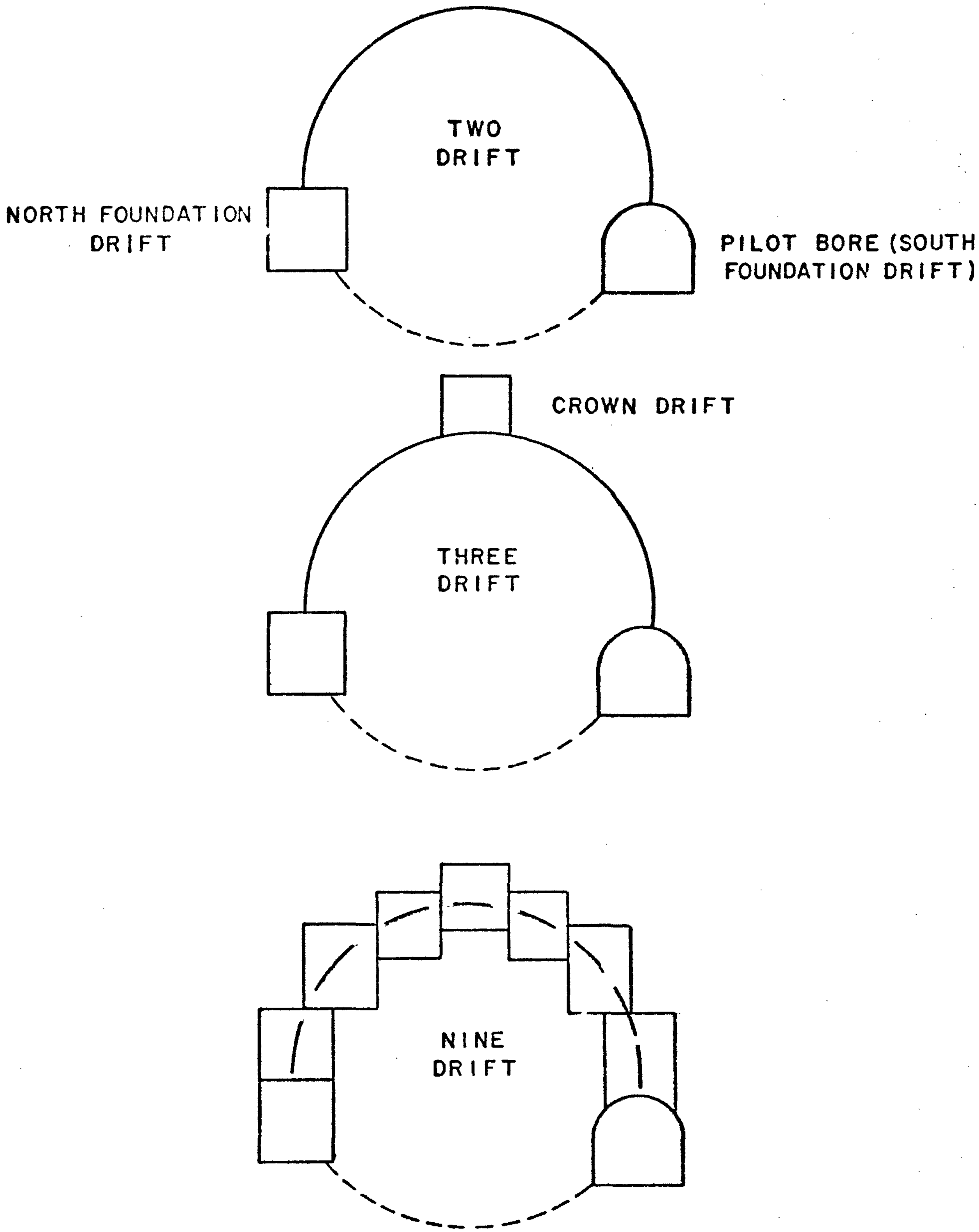

Figure 2. - Drift Arrangements - Eisenhower Tunnel.

Organization of Report

The following sets forth the organization of this report:

Section 1 provides the introduction and scope.

Section 2 discusses test site locations and geological conditions of the test sites and the general area of the instrumented sections of the second highway bore.

Section 3 discusses the method of determining the in situ stress conditions at the test sites and the data obtained.

Section 4 discusses the tests conducted to determine the in situ modulus of the rock mass at the test sites and the data obtained.

Section 5 discusses the rock monitoring instrumentation and the problems encountered which resulted in no usable data being obtained for this phase of the study.

Section 6 discusses the steel support instrumentation scheme and the data obtained.

Section 7 discusses the lining instrumentation and the data obtained.

Section 8 discusses the instrumentation scheme for the multiple drift area and the rock load reactions to the crown and bench heading excavations.

Section 9 discusses the results of laboratory tests on rock core from in situ tests and instrumentation drill holes.

Section 10 contains the results of petrographic examination of the cores tested in the laboratory.

Section 11 contains the summary and conclusions.

The remainder of the report includes the appendixes.

SECTION 2. - GEOLOGICAL INVESTIGATIONS AND TEST SITE LOCATIONS

Geology

The nomenclature used to describe geology at the test sites conforms with that used by previous investigators. The CDOH (Colorado Division of Highways) has classified the rock at the Eisenhower Tunnel as being contained in four types, I through IV, and further divided into a and b categories; type Ia being best and IVb the worst.

> "The classification is based on both mechanical properties (joint spacing, plasticity, etc.) and chemical properties (degree of alteration) and type of decomposition in the rock. The rock classification has been further qualified by such parameters as the thickness and character of the clay gouge in the seams and faults, the amount of movement that has taken place in various support arrangements during the nine years the pilot bore had been open, and the type and amount of work that has been performed in resupporting the tunnel during this time."

The above classification was developed by Post [10]*.

A brief description of the classification as contained in the construction specifications [5] is as follows:

Rock class	Description
Ia - Ib	Massive to slightly blocky, no alteration, joint spacing 1.0 ft (0.3 m) or greater
IIa - IIb	Moderately blocky, little or no alteration, joint spacing 0.5 ft (0.15 m) or greater
IIIa - IIIb	Very blocky, moderately to highly altered, joint spacing less than 1.0 ft (0.3 m)
IVa	Highly crushed and altered, nonplastic, abundant clay, joint spacing less than 0.5 ft (0.15 m)
IVb	Plastic, highly altered, squeezing or swelling ground, mainly clay fault gouge

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* Numbers in brackets refer to entries in references.

The rocks excavated in the area of the two in situ test sites and the multiple-drift instrumentation site consisted of metasediments and granite. The metasediments are gneisses and schists of the Precambrian age, Idaho Springs Formation, the oldest formation encountered in the tunnel. The Silver Plume Granite exposed at the test sites is younger than the metasediments but is also Precambrian in age. Pegmatites of granitic composition are present at the in situ test sites. These dikes intrude both the metasediments and the granite. A summary of the general geology of the entire project is discussed by Robinson [12], et al.

The geological investigation of the in situ test sites was performed by USBR geologists. Geological information from the area of the multiple-drift instrumentation site, pilot bore, and the main highway bore was provided by John Post, Senior Geologist, CDOH.

The test sites used by the USBR were located at stations 101+70 and 111+75, as shown on figure 3. At these stations small drifts, which hereafter will be called adits so as not to be confused with the nomenclature for the multiple drift area, were excavated normal to the pilot bore. They were utilized to conduct stress relief tests, rock deformation tests, and rock instrumentation, as shown in figure 4. At these same stations in the second highway bore, steel support and lining instrumentation were installed.

At station 83+50 in the multiple-drift area, instrumentation was installed in excavated drifts, which were then concrete backfilled, to measure reactions of the crown and bench heading excavations of the second highway bore on the multiple drift support system.

Test Adit Station 101+70. - The rock exposed in the test adit at station 101+70 was predominately gneiss with small amounts of granite and pegmatitic granite. The core from four NX-instrumentation holes drilled at this location, 101A, 101V, UJ1W, and UJ1E, indicate that geologic conditions around the adit were similar to those later exposed in the main highway bore excavation, see figures 5 and 6.

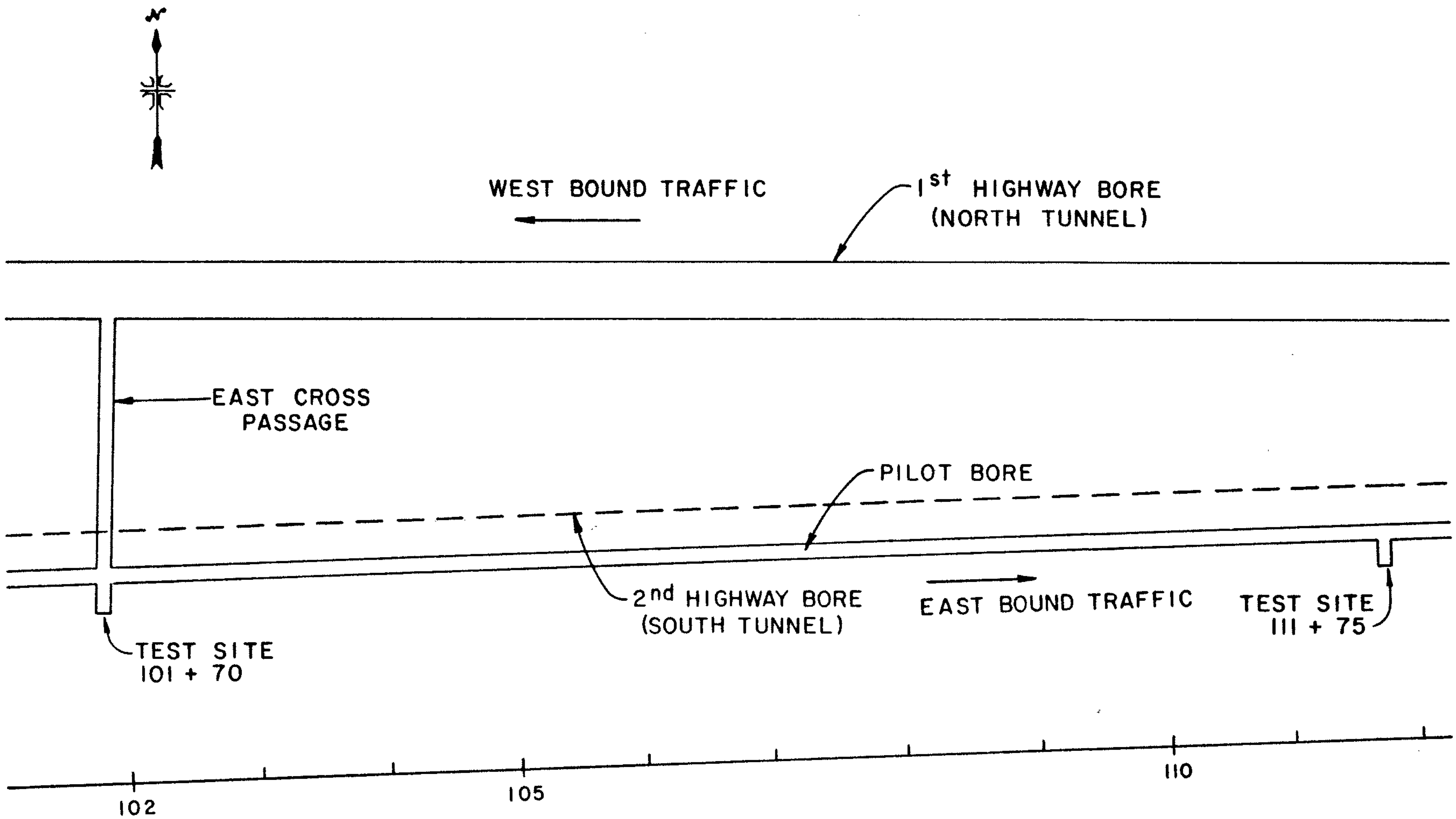


FIGURE 3 - PLAN VIEW OF EISENHOWER MEMORIAL TUNNEL
SHOWING TEST SITE LOCATIONS

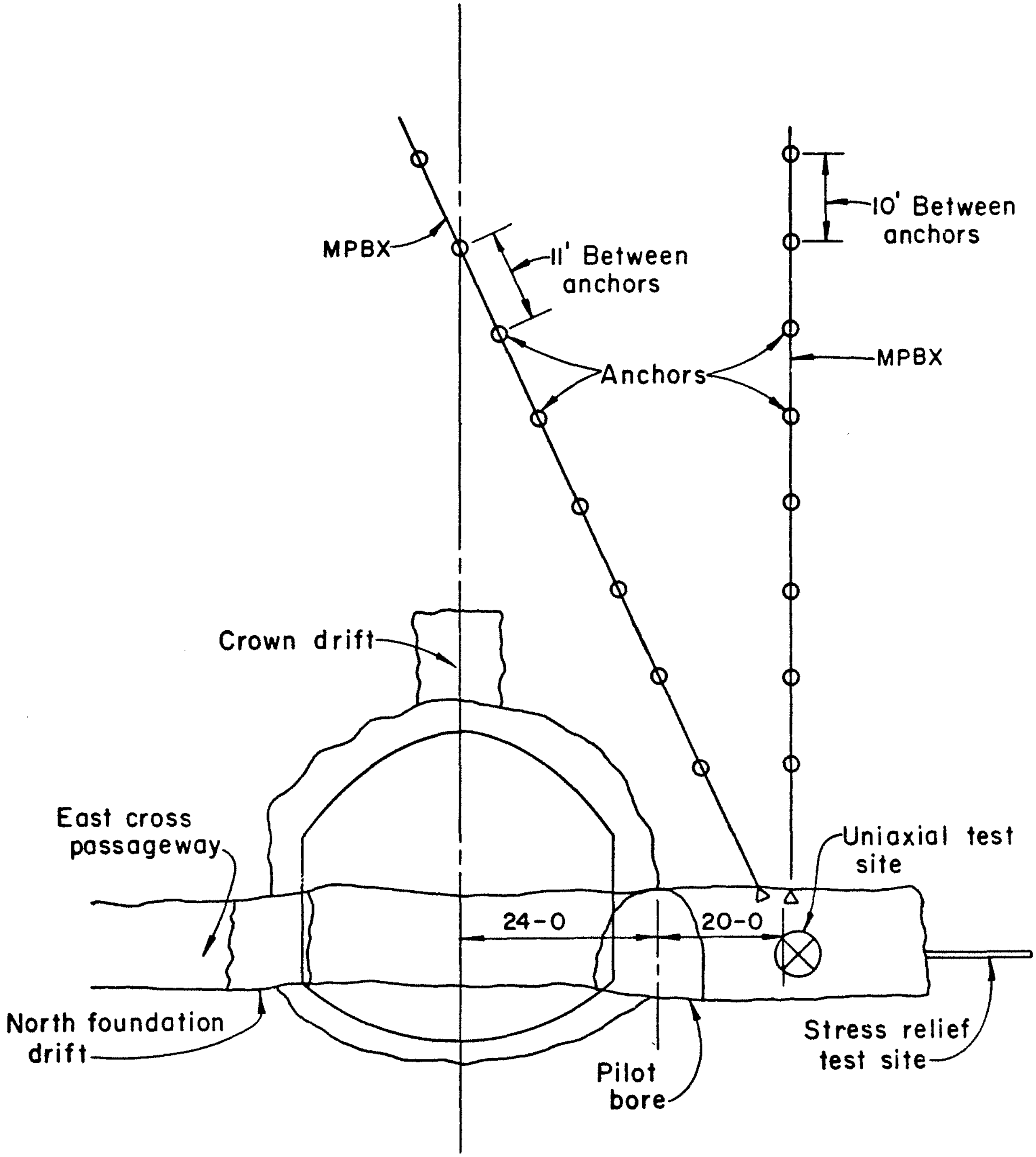


FIG. 4 - GENERAL PLAN OF TEST AND INSTRUMENTATION LOCATIONS IN ADITS AT STATIONS 101 + 70 AND 111 + 75

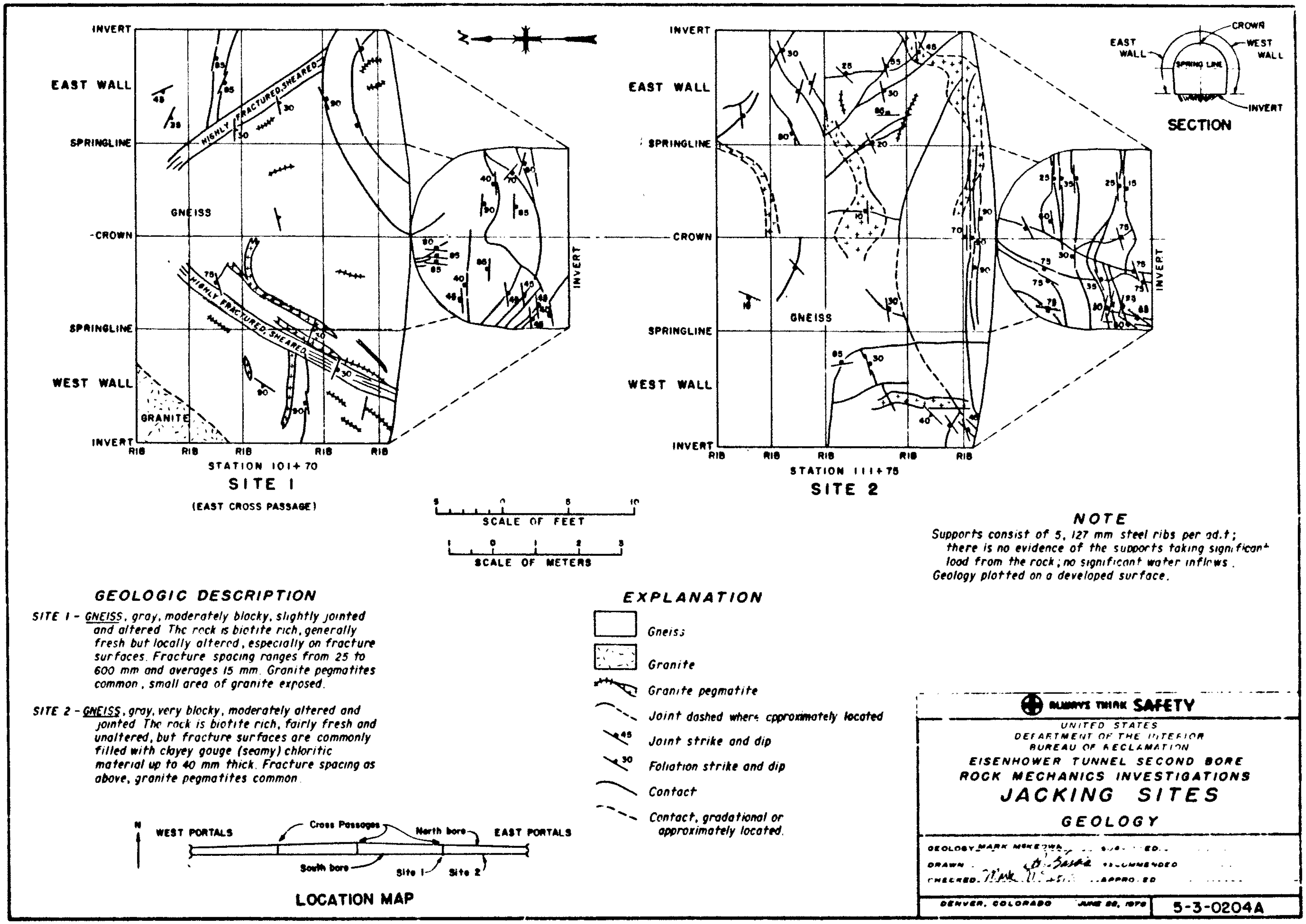


Figure 5. - Geology Jacking Sites. Stations 101+70 and 111+75

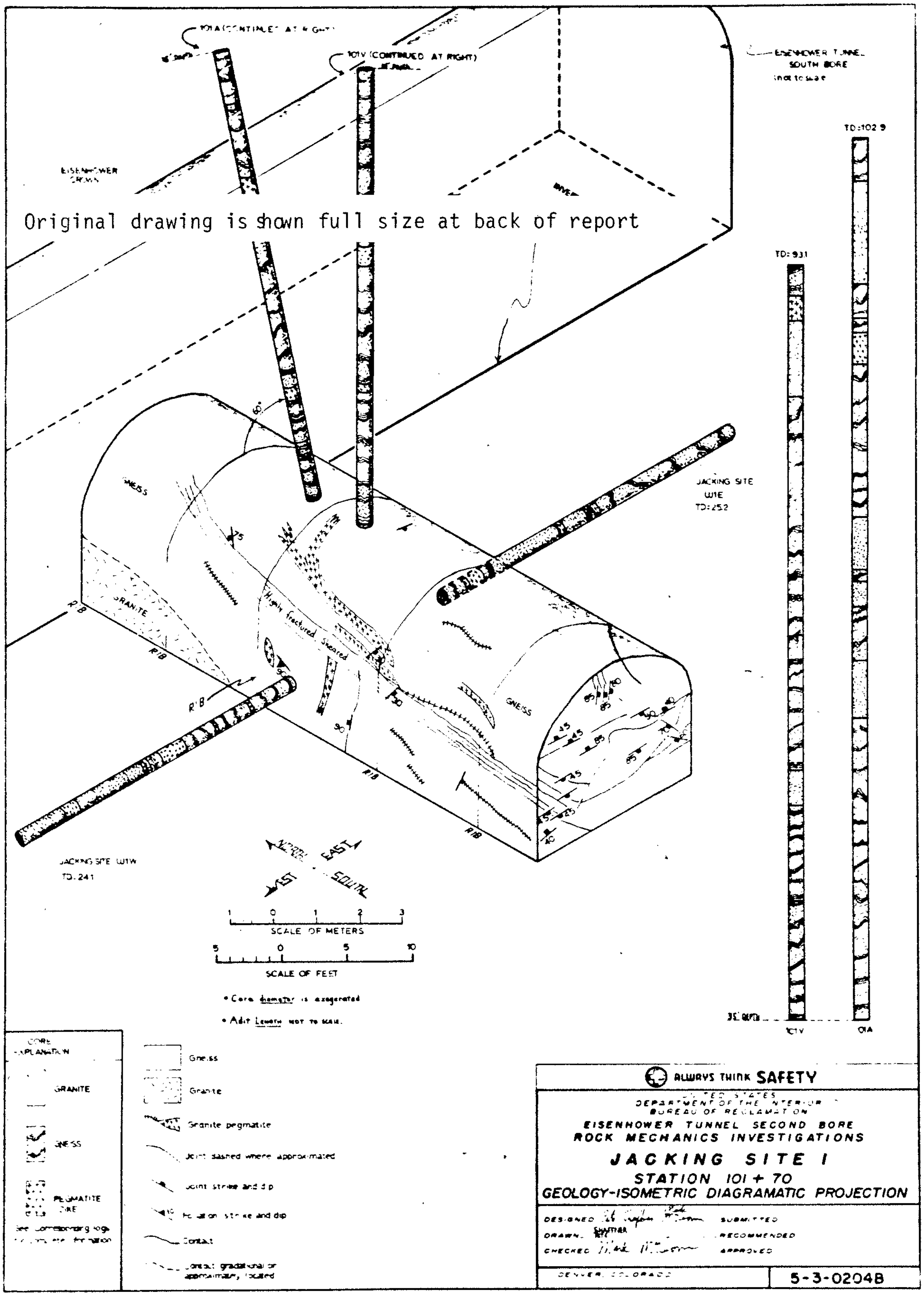


Figure 6. - Geology - Isometric Jacking Site 1, Station 101+70

The drill hole designation codes 101A, 101V, 111A, and 111V refer to angle and vertical rock monitoring instrumentation holes at stations 101+70 and 111+75, respectively.

The drill hole designation codes UJ1W, UJ1E, UJ2W, and UJ2E refer to west and east oriented instrumentation holes for in situ modulus determination tests at stations 101+70 and 111+75, respectively.

The coding for instrumentation drill holes and core is explained in more detail in Section 9 - Laboratory Core Testing Investigations.

The gneiss was initially classified as type IIb, moderately blocky, slightly altered, jointed rock as observed in the pilot bore. (Upon excavation of the second highway bore the rock mass was reclassified as type IIIa.) It was biotite rich and generally fresh but locally altered (chloritized), especially on fracture surfaces. Petrographic analysis of eight thin sections of gneiss made from NX-core retrieved in the four drill holes indicated varying amounts of feldspar, biotite, and quartz. In two cases augite and hornblende were present in sizable amounts. The feldspar in seven of these gneisses was predominately potash feldspar while the eighth sample consisted chiefly of sodic feldspar. All samples contained only minute amounts of alteration minerals.

Foliation in the exposed gneiss was not generally well developed but ranged from poorly to well developed and was schistose locally. Some tight folds were present in the gneiss but these were uncommon. Granite pegmatites were present in much of the gneiss and were often parallel to foliation.

A very small amount of unaltered granite was exposed in the adit. Petrographic examination of two granite specimens from two NX-core holes indicate differing structure and mineralogy. Both granites were medium-grained but one was massive while the second was gneissic and contained a high percentage of biotite. Traces of alteration minerals were found in both specimens.

The fractures, visible in the exposed granite, were spaced from 8 to 24 in (20.3 to 61.0 cm) with the majority being 24 in (61.0 cm) apart.

Fracture spacing in the gneiss ranged from 1 to 24 in (2.5 to 61.0 cm) and averaged 6 in (15.2 cm). These fractures usually had a thin chlorite-calcite surface coating. Some movement along fractures resulted in altered, chloritic, clayey-gouge zones, up to 2 in (5.1 cm) thick between intact rock surfaces; however, these areas were quite localized.

Detailed descriptions of the rock, joints, and fracture surfaces for cores from drill holes UJ1W, UJ1E, 101V, and 101A are contained in the drill logs, appendix A, tables A-1 to A-4. Petrographic details are contained in appendix D.

No large inflows of water occurred during excavation of the test adit but the rock was damp. The four NX-instrumentation holes drilled from this adit were dry. Much of the overlying rock had apparently been previously drained by the pilot bore and first highway bore excavations.

There was no visual evidence of the steel supports or wood lagging taking any load from the rock from the time of excvation to backfilling the test adit with concrete, a period of 7 months.

The geology of the second highway bore, as developed from the foundation drifts and the crown drift, Post [11], is shown on figure 7. The area around station 101+70 consisted of a series of zone materials ranging from type IIb to IVa and from gneiss to granite. The area was intersected by numerous faults which dip 60 to 80°.

<u>Test Adit Station 111+75</u>. - The rock exposed in the test adit at station 111+75 consists of gneiss and granite pegmatite, figures 5 and 8. The gneiss in the pilot bore was classified as type IIIa, very blocky, locally altered (chloritized), but generally fairly fresh and unaltered. (Upon excavation of the second highway bore the rock mass maintained its type IIIa characteristics.) A specimen of gneiss taken

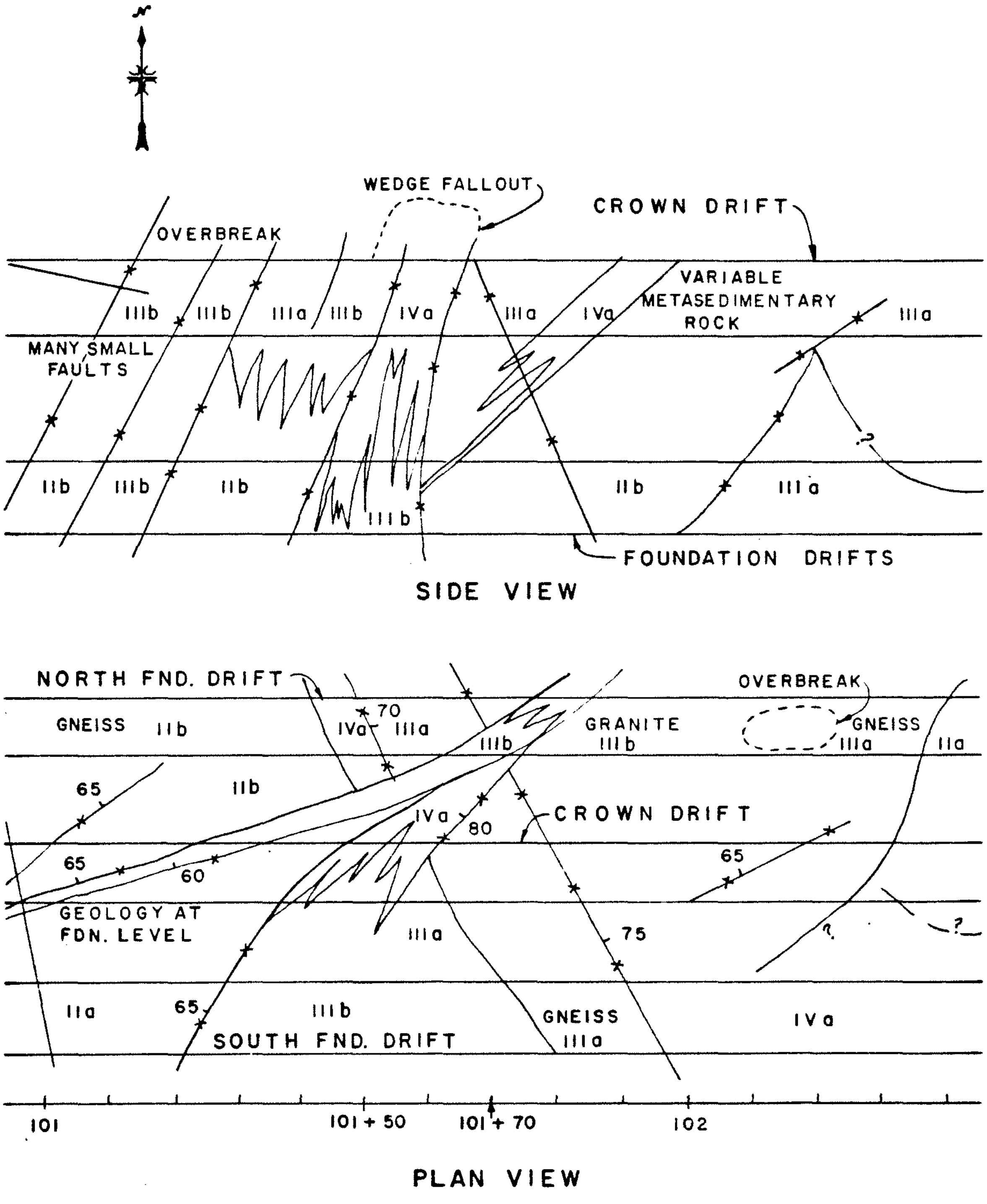


FIGURE 7 - GEOLOGIC MAP - SECOND HIGHWAY BORE
STATION 101 + 70 AND VICINITY

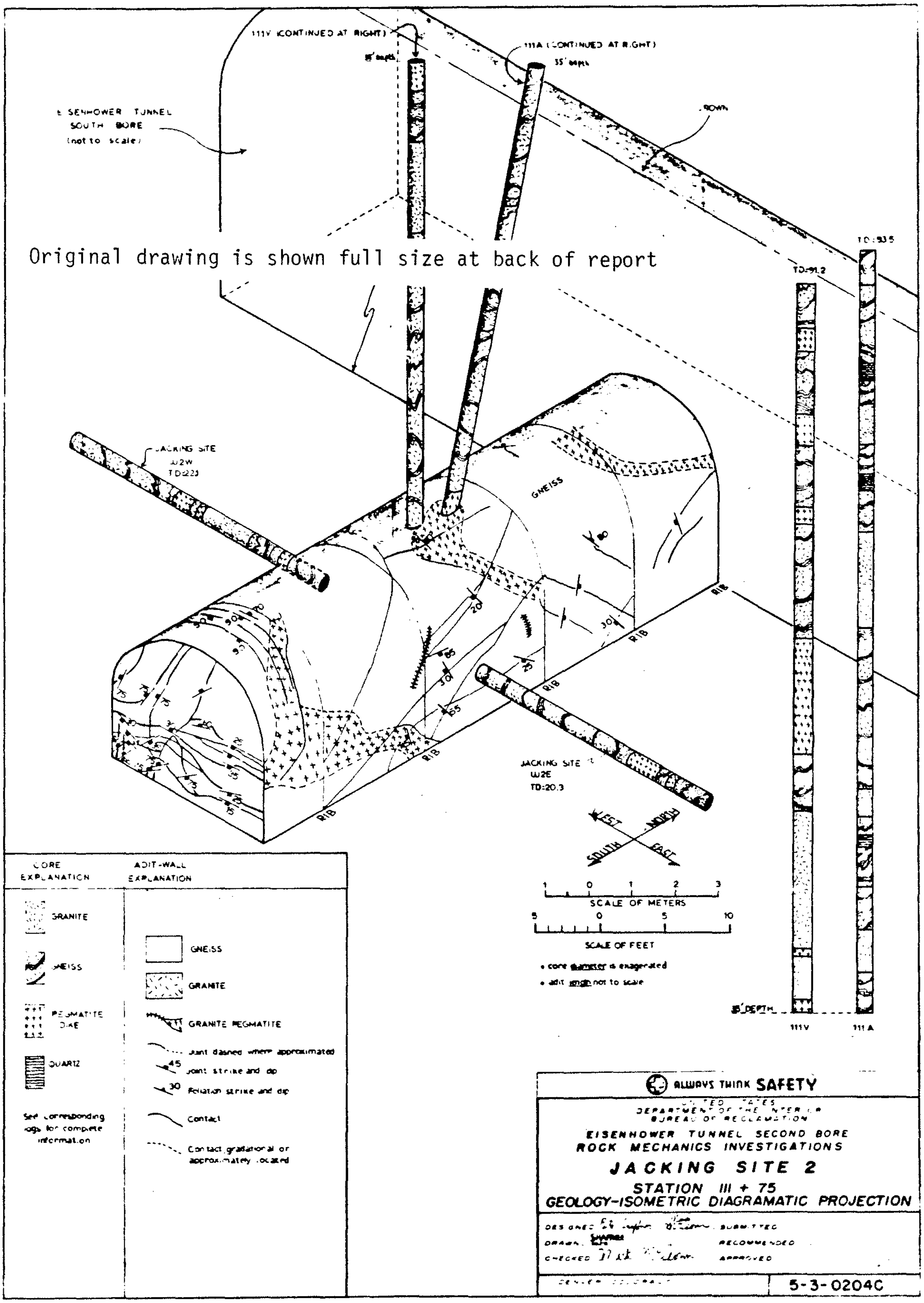


Figure 8. - Geology - Isometric Jacking Site 2 - Station 111+75

from an NX-instrumentation hole drilled at this location was examined petrographically. The petrographic classification of this sample was fine-grained, biotite-quartz-feldspar gneiss. The feldspar minerals were orthoclase and microcline with minor amounts of albite. Very minor amounts of clay minerals were also noted.

Foliation in the exposed gneiss ranged from poorly to well developed but was generally not well developed. Fracture spacing ranged from 1 to 24 in (2.5 to 61.0 cm) and averaged 6 in (15.2 cm). Fracture surfaces commonly were filled with a clayey-gouge (seamy) and chloritic material up to 1.5 in (3.8 cm) thick.

Granite pegmatites were present in most of the gneiss and were locally soft and altered.

The core from the four NX-instrumentation holes drilled from this location, 111A, 111V, UJ2W, and UJ2E, revealed the granite was common in the area surrounding the adit excavation although no granite (other than pegmatites) was exposed in the adit, see figure 8. Petrographic classification of a sample of granite from an NX-core indicated a fine- to medium-grained, quartz-biotite-feldspar granite.

Fracture surfaces intersected by the instrumentation holes were mostly chloritized and/or calcite filled with slickensides common. Detailed descriptions of the rock, joints, and fracture surfaces for cores from drill holes UJ2W, UJ2E, 111V, and 111A are contained in the drill logs, appendix A, tables A-5 to A-8. Petrographic details are contained in appendix D.

No large inflows of water occurred during excavation of the test adit but the rock was damp. The four NX-instrumentation holes drilled at this location were dry. Much of the overlying rock had apparently again been previously drained by the pilot bore and first highway bore excavations.

There was no visual evidence of the steel supports or wood lagging taking any load from the rock from the time of excavation until the test adit was backfilled with concrete, a period of about 5 months. The geology of the second highway bore as developed from the foundation drifts and crown drifts, Post [11], is shown on figure 9. The area consisted of primarily type III rock, containing schist, gneiss, and granite with a few faults dipping 45 to 80°.

From figures 7 and 9 it can be seen that the geology was more complex and faulted at station 101+70 than at station 111+75. This condition appears to have contributed to the higher support loads at station 101+70 which is discussed under Section 6 - Support Instrumentation.

Multiple-drift Instrumentation Station 83+50. - The instrumentation station in the multiple-drift area lies partially within the Straight Creek Fault Zone. This zone was about 50 ft (15.2 m) wide of unknown displacement with a strike and dip of N. 30° W. 40° NE., Post [11].

The rock at this station was type IV, highly altered with abundant clay. Three rock variations were mapped at this station, schist in the north foundation drift, gneiss and granite in the south foundation drift, and granite in the crown drift, Post [11] and are shown on figure 10. The rocks mapped in the foundation drifts were within the Straight Creek Fault Zone and were highly altered. A high percentage of clay fault gouge gives these rocks plastic properties and as a result floor heave was present in this area.

The granite which was mapped in the crown was in the hanging wall of the fault zone and has been described as moderately decomposed. This granite was further classified as nonplastic, Post [11].

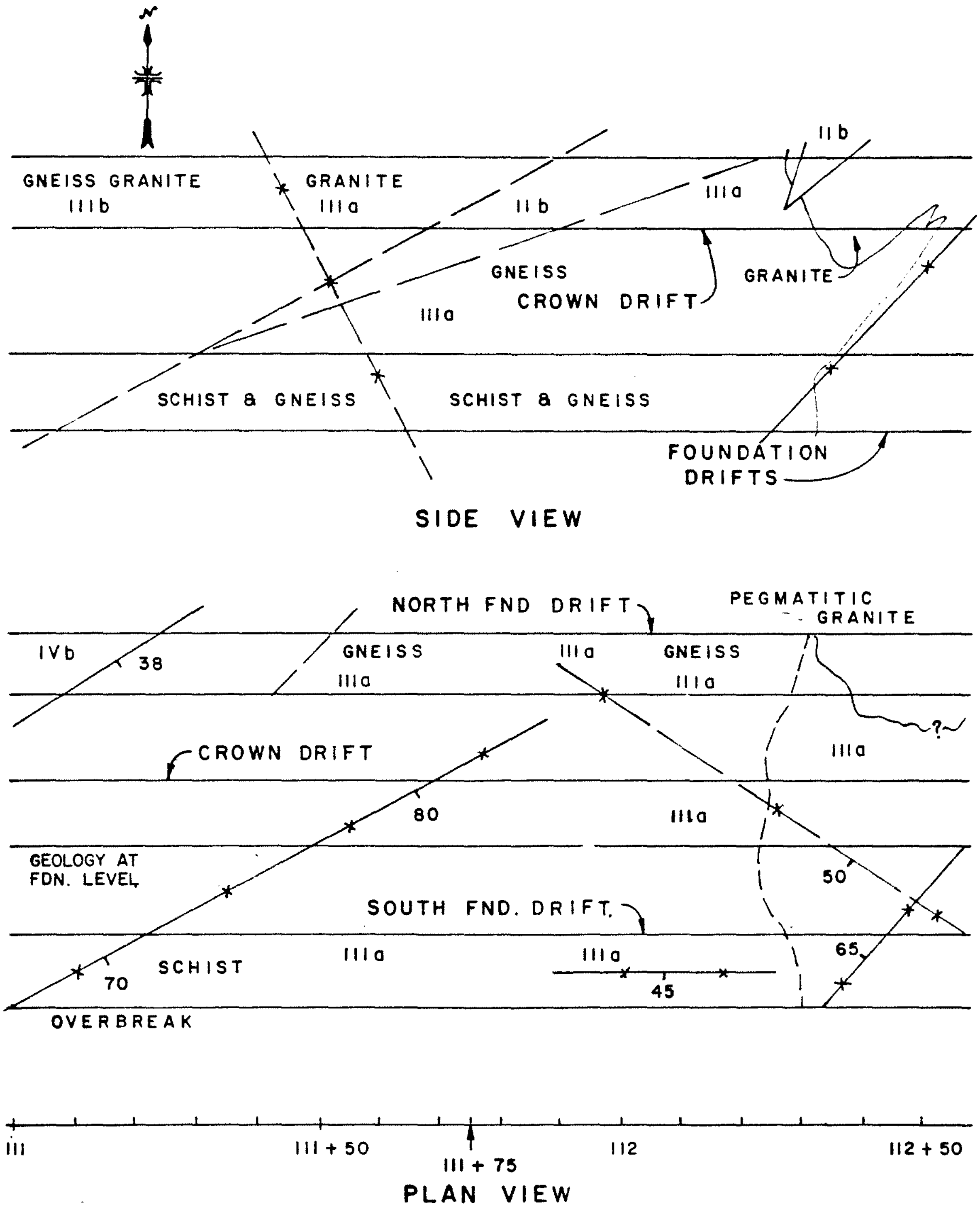


FIGURE 9 - GEOLOGIC MAP - SECOND HIGHWAY BORE
STATION 111 + 75 AND VICINITY

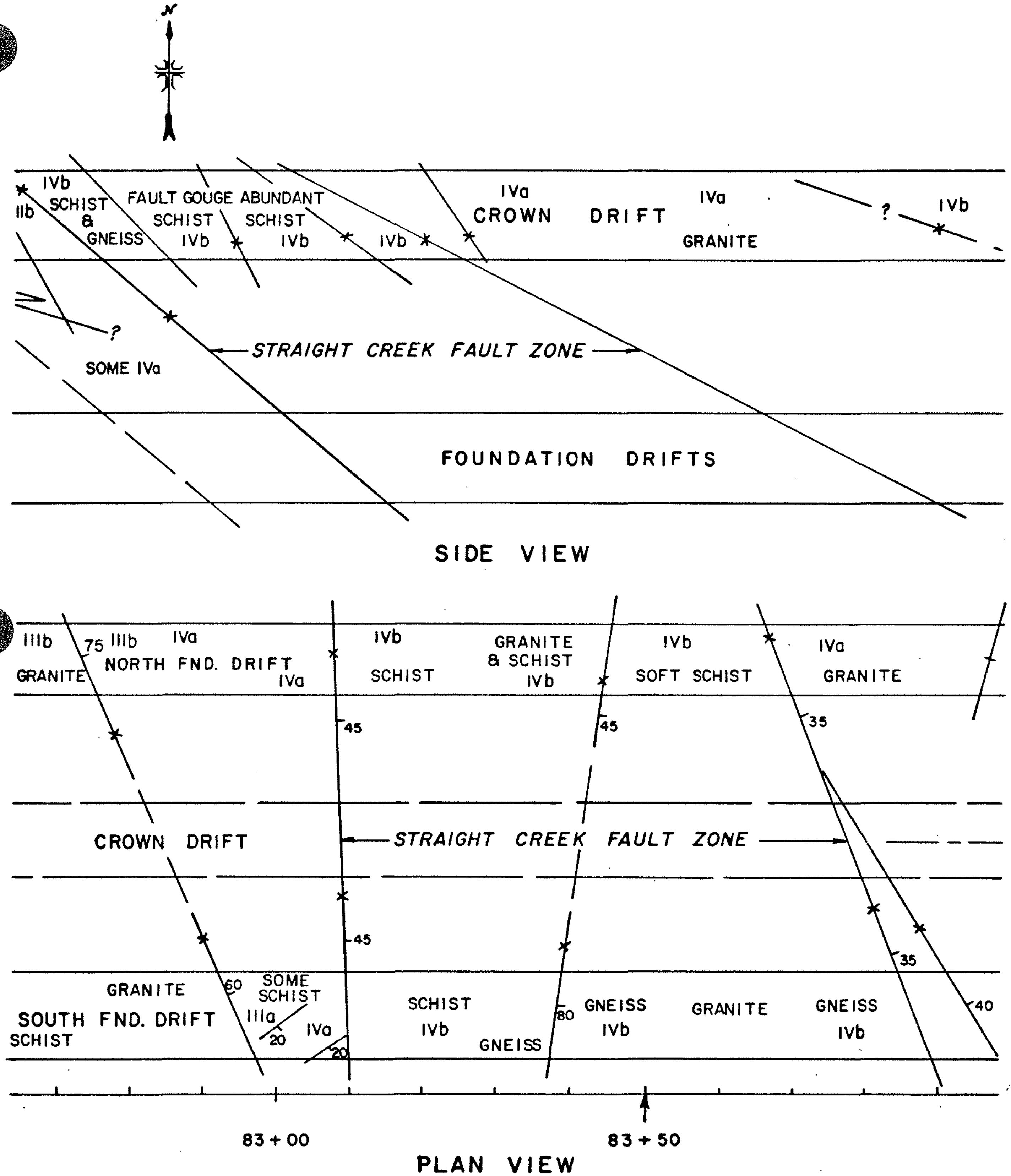


FIGURE 10 - GEOLOGIC MAP - SECOND HIGHWAY BORE - STA. 83 + 50 & VICINITY

SECTION 3. - IN SITU STRESS DETERMINATION

Stress Relief Tests

The overcore stress relief method was employed to determine the in situ stresses at the two test sites. This method is based on the theoretical relationship between the deformation (strain relief) of the drill hole and the corresponding change of stress in an isotropic elastic body. If a small volume of the mass containing the drill hole is cut away, it may be assumed that all stresses were relieved in the cut away portion, and the change of the stress is numerically equal, but opposite in sign, to the stress existing in the mass.

To measure the strains necessary for calculating stress fields, a three-directional borehole deformation gage was utilized. The gage and the stress relief method techniques, initially developed by the U.S. Bureau of Mines, are described by Austin [1, 2] in Bureau of Reclamation reports. The drill setup and overcoring operation are shown on figure 11 and depicted schematically on figures 12 and 13.

For a single drill hole, the method is capable of providing two-dimensional stress fields in planes perpendicular to the axis of the drill hole. Three nonparallel drill holes are required to obtain a complete three-dimensional stress field in a rock mass. The optimum orientation is mutually perpendicular holes but this was not possible at the two test sites.

The testing setup at the first test adit (station 101+70) consisted of three drill holes in a horizontal plane [approximately 4.0 ft (1.22 m) above invert] having 45° angles between adjacent holes. The center hole was perpendicular to the axis of the pilot bore (south foundation drift). The projected intersection of these holes (in plan view) occurred in the adit about 6 ft (1.83 m) outside from the collar of the center hole. The test hole configuration at the second test adit site (station 111+75) was the same as that of the first site except due to a smaller size adit, the drill holes were oriented with 35° angles between adjacent holes. The center hole remained perpendicular to the axis of the pilot bore.

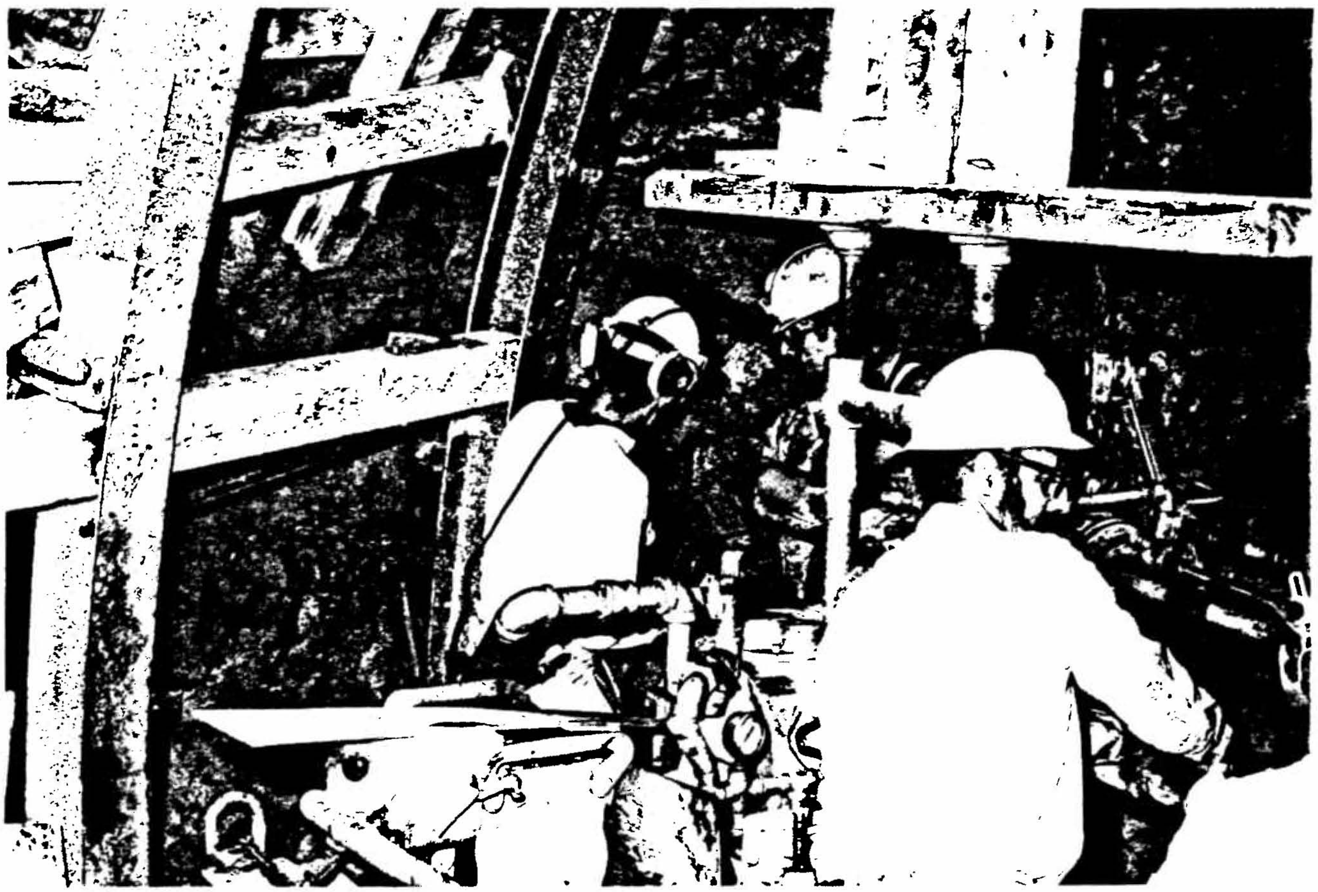


Figure 11. - Overcoring Stress Relief Operation.

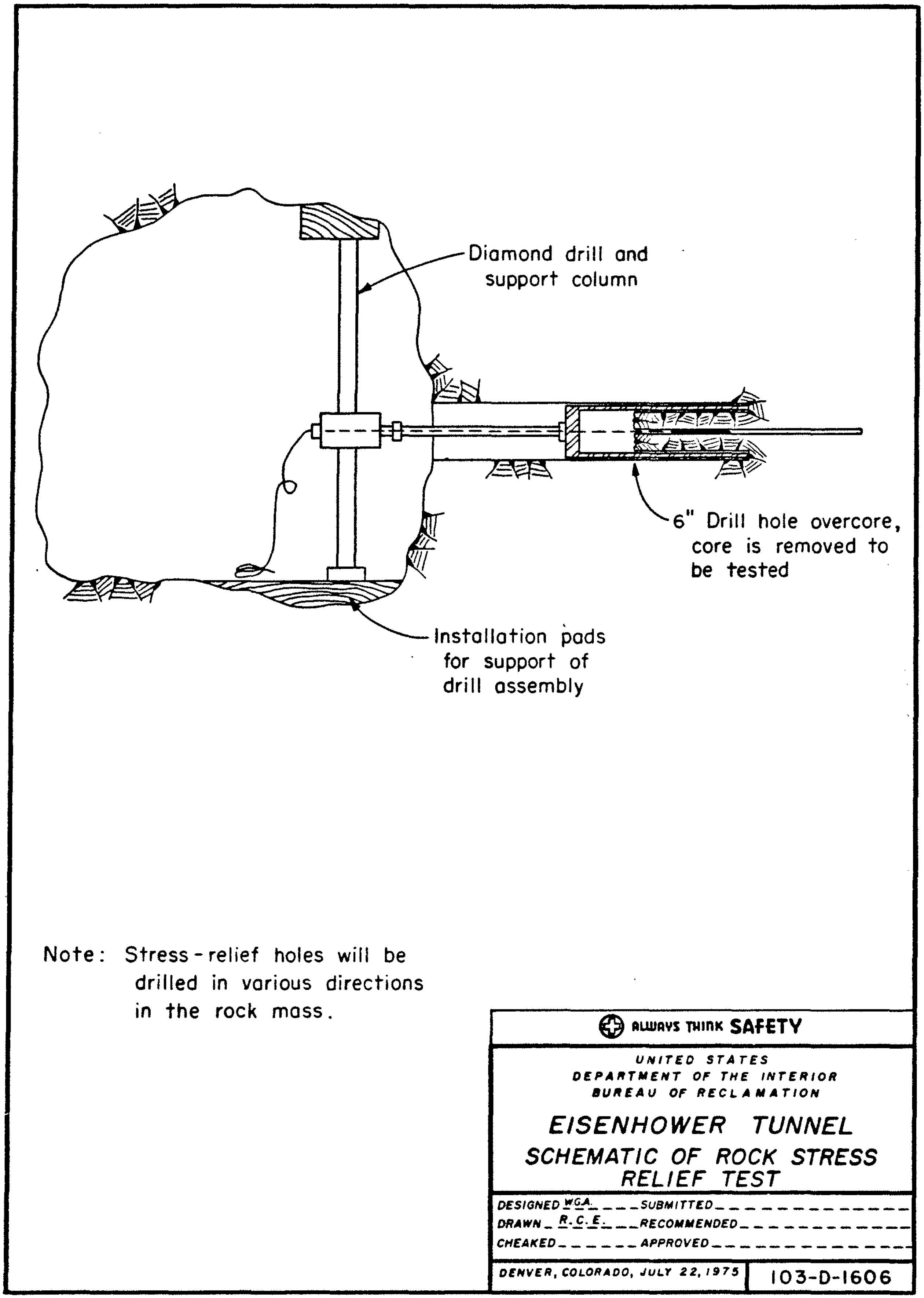


Figure 12. - Schematic of Rock Stress Relief Test

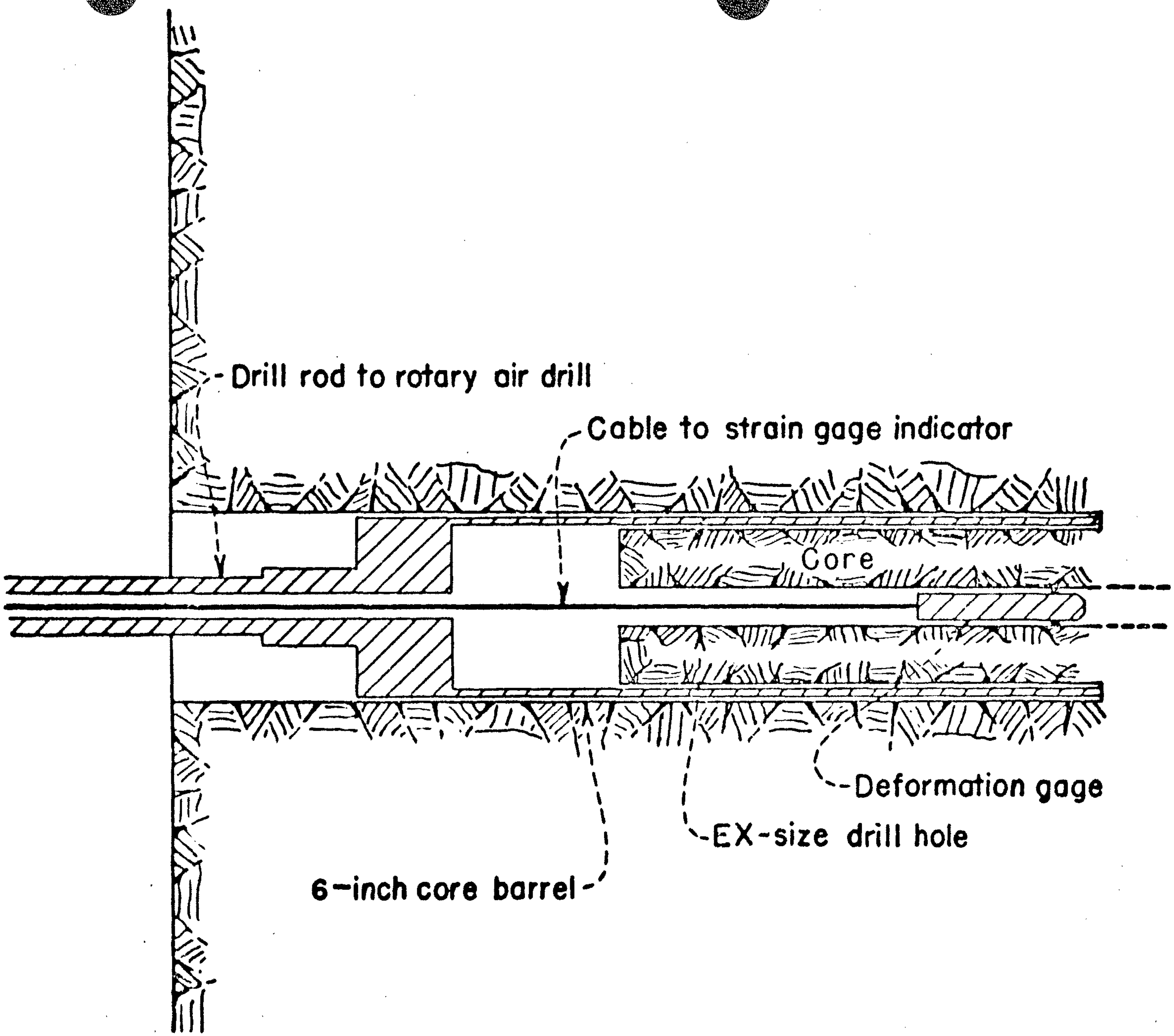


Figure 13. - Schematic of Overcoring Process in Borehole Stress Relief Test.

The approximate overburden at station 101+70 was 800 ft (244 m) and at station 111+75, 400 ft (122 m). Testing at both sites was unusually difficult due to the high degree of fracturing in the rock. Seldom did the rock remain intact during overcoring to provide a satisfactory test run. However, 6 satisfactory tests were made at the first test adit and 13 at the second test adit. Modulus of elasticity tests were performed on all core specimens of at least 8-in (20.3-cm) lengths.

At the second test adit (station 111+75) the two-dimensional stress results obtained fell into two distinct magnitude groups. There was potentially an alternating pattern of two-dimensional stresses but no firm conclusions were made due to the lack of sufficient satisfactory test locations in each bore hole. Therefore, the results of the two-dimensional stress analyses for the second site were incorporated into the three-dimensional computer program in three different groups; namely, low stresses, high stresses, and a combination of the two.

Discussion of Data

The large number of joints and fractures had produced a very nonuniform appearing stress field. Some sections of the rock mass appear to be carrying a disproportionate share of the force while the stress in adjacent sections was much less. The two- and three-dimensional stress results are shown in tables 1 and 2. The intense jointing as stated before, made it difficult to obtain very many satisfactory test results. There was only one location in each of two holes and four locations in the third hole at station 101+70 which provided excellent and complete data. A greater number of measurements would have been desirable to provide better statistical calculations concerning the stress field.

White [14], et al., reported in situ stress measurements at the tunnel site. The tests were apparently conducted in the center cross passageway at approximately station 79+50. This area was in predominately type Ib rock. White reported vertical stresses of 900 ± 200 lb/in^2 (6.21 ± 1.38 MPa) and horizontal stresses of from 100 to 400 ± 200 lb/in^2 (0.69 to 2.76 ± 1.38 MPa). The overburden at the test site was 950 ft (290 m), so

Table 1. - Two-Dimensional Stress Results

Location	Drill hole designation	Azimuth (°)	Depth (in)	1/ Angle (°)	2/ Sigma 1 (lb/in²)	2/ Sigma 2 (lb/in²)	Modulus of elasticity (10^6 lb/in²)
101+70	A	135	80	145	-1,970	-2,588	3/ 7.5
			95	12	-942	-1,719	3/ 7.5
			176	4	-4,462	-7,209	3/ 7.5
			210	0	-2,376	-5,690	3/ 7.5
	B	180	84	117	-1,468	-6,273	3/ 7.5
	C	225	274	5	-2,424	-3,265	3/ 7.5
111+75	A	145	160	-20	-1,289	-3,760	8.3
			272	8	-358	-638	7.9
			314	-7	-557	-780	8.1
			325	130	-256	-875	4/ 8.1
	B	180	162	126	-133	-477	9.9
			180	134	-365	-559	10.8
			348	-22	-89	-2,903	9.4
	C	215	157	165	102	-77	8.0
			168	59	-163	-197	4/ 8.0
			223	151	-475	-2,170	4/ 9.0
			281	121	-1,778	-3,182	4/ 9.0
			331	22	-1,304	-3,261	4/ 9.0
			343	114	-116	-447	4/ 9.0

1/ Angle is measured counterclockwise from right horizontal and corresponds to Sigma 1.
2/ Negative stresses are compressive stresses. Sigma 2 is perpendicular to Sigma 1.
3/ The retrieved core was not suitable for obtaining the modulus of elasticity by standard stress relief methods so seven representative core samples from uniaxial jacking drill holes were tested using standard core test procedures and the results averaged ($E = 7.5 \times 10^6$ lb/in²).
4/ Estimated values.
NOTE: 1 in = 2.54 cm
1 lb/in² = 6.900 kPa

Table 2. - Three-dimensional principal stresses

101+70 all stations		
S_1 = 139	Az = 180°	I = 96°
S_2 = -3,583	Az = 256°	I = 24°
S_3 = -5,578	Az = 272°	I = 113°
111+75 all stations		
S_1 = -469	Az = 84°	I = 110°
S_2 = -1,371	Az = 135°	I = 30°
S_3 = -1,655	Az = 182°	I = 111°
111+75 high stresses		
S_1 = -582	Az = 84°	I = 109°
S_2 = -2,870	Az = 141°	I = 33°
S_3 = -4,096	Az = 183°	I = 116°
111+75 low stresses		
S_1 = -146	Az = 155°	I = 91°
S_2 = -320	Az = 244°	I = 35°
S_3 = -545	Az = 246°	I = 125°

S_1, S_2, and S_3 = principal stresses in lb/in^2 and all indicate compression except S_1 at station 101+70 which indicated tension.
Az = Azimuth and is measured clockwise from north.
I = Inclination and is measured along Az upward from vertically down.
NOTE: 1 lb/in^2 = 6.900 kPa

the vertical stress was about equal to overburden load. At USBR station 111+75, with overburden of approximately 400 ft (122 m) the calculated vertical stress component was 1306 lb/in^2 (9.0 MPa) and the horizontal stress components were from 580 to 1609 lb/in^2 (4.0 to 11.1 MPa). At station 101+70, with approximately 800 ft (244 m) of overburden, the calculated vertical stress component was 3844 lb/in^2 (26.5 MPa) and the horizontal stress components were from 93 to 5272 lb/in^2 (0.64 to 36.4 MPa). [All stresses at stations 111+75 and 101+70 were compressive except the 93 lb/in^2 (0.64 MPa) horizontal stress at station 101+70, which was tensile.]

The vertical stresses at stations 111+75 and 101+70 were approximately three and five times greater than the overburden load, respectively. The maximum horizontal stresses at stations 111+75 and 101+70 were about equal to the 1.5 times greater than the vertical, respectively.

The high vertical stresses (above overburden loads) at stations 101+70 and 111+75 are possibly attributed to lower grade rock, type IIIa, and a redistribution and concentration of the in situ stress field due to numerous structural discontinuities and that the rock is not behaving linearly elastic. However, one cannot discount the minimum number of test data points when assessing the reliability of the in situ stresses obtained. The additional 400 ft (122 m) of overburden at station 101+70, would not have contributed sufficiently to the support load difference between the two test sites discussed in section 6. It is assumed that higher in situ stresses at station 101+70 contributed to higher support loads at that station in the main highway bore.

SECTION 4. - IN SITU MODULUS DETERMINATION

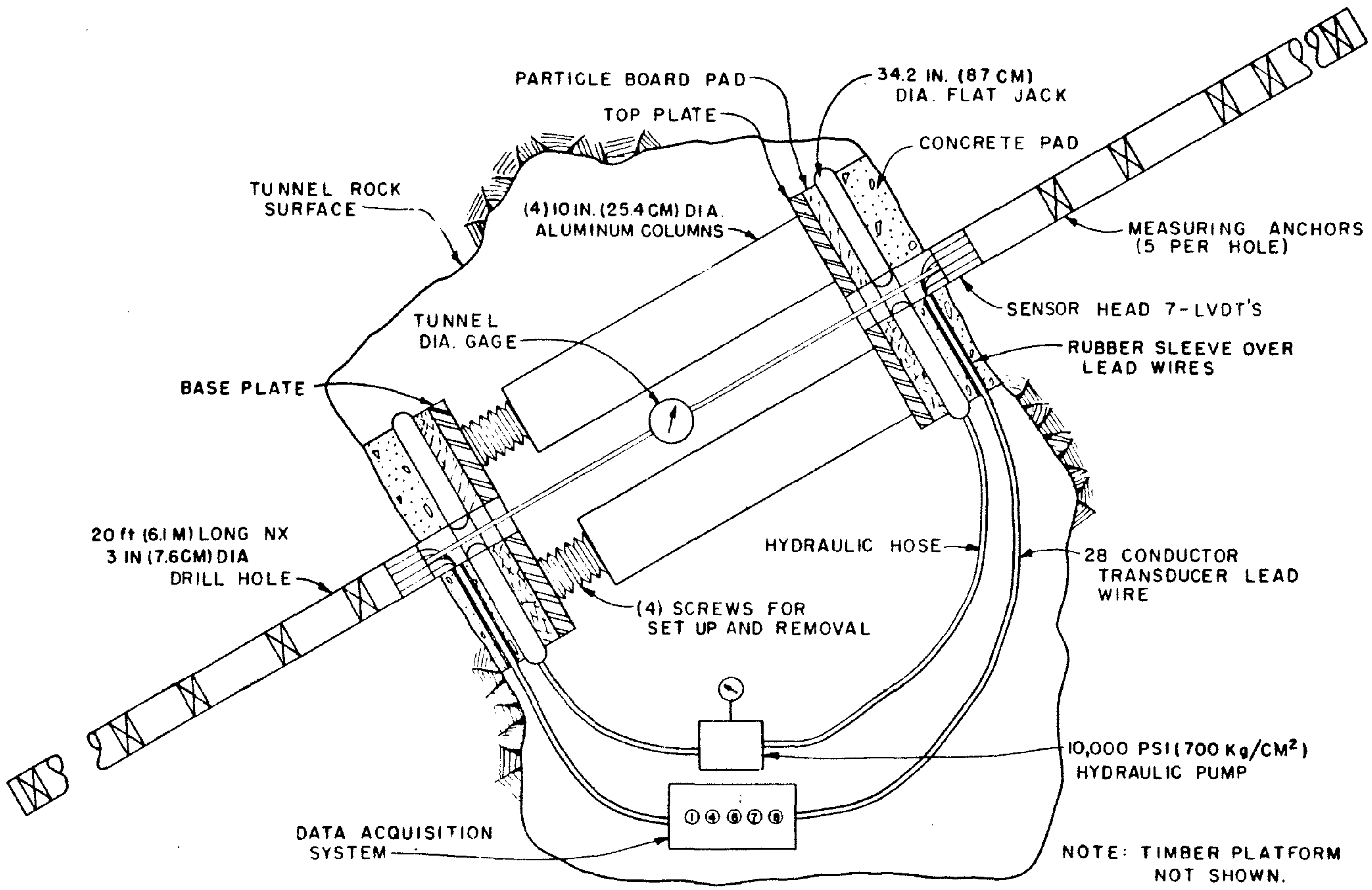
UAJT (Uniaxial Jacking Test)

In situ tests were performed at each test adit site to determine the deformation modulus of the rock mass. The tests were similar to plate bearing tests except that flat jacks applied the loads to the rock rather than a hydraulic ram and a steel bearing plate. Both procedures utilize a mortar or concrete pad between rock surface and the steel plates or flat jacks to transmit the loads to the test surface.

The UAJT's were performed in such a manner so as to uniformly distribute a load over a rock surface 34.7 in (0.9 m) in diameter. Five measuring points were located at various depths in a drill hole directly under and perpendicular to the loaded surfaces. A schematic of a typical setup is shown on figure 14. Figures 15, 16, and 17 show the actual setup at station 101+70. ASTM publications by Wallace, et al., [13] and Misterek, et al., [8] provide details of the USBR's test procedures.

Test Details and Data

At station 101+70, the UAJT was performed in the test adit in types IIb to IIIa rock. Site preparation consisted of smoothing the rough rock surface by light blasting, drilling, chipping, and, finally, hand finishing each test surface. Two diametricaly opposite NX-instrumentation holes were then drilled into the prepared rock surfaces. The orientation of the drill holes was horizontal in an east-west direction, parallel with the existing pilot bore and the second highway bore being excavated. The depths of instrumentation anchors in the drill hole from the loaded rock surface (to reference rock deformation) were 1.50, 3.50, 8.75, 13.50, and 22.0 ft (0.46, 1.07, 2.67, 4.11, and 6.70 m) on the west side of test site and 1.50, 3.75, 8.50, 11.25, and 23.50 ft (0.46, 1.14, 2.59, 3.43, and 7.16 m) on the east side. Jointing, determined from cores recovered, was used to determine anchor locations. The anchors were installed so as to avoid placement on joint systems, whenever possible.



UNIAXIAL JACKING TEST

FIGURE 14

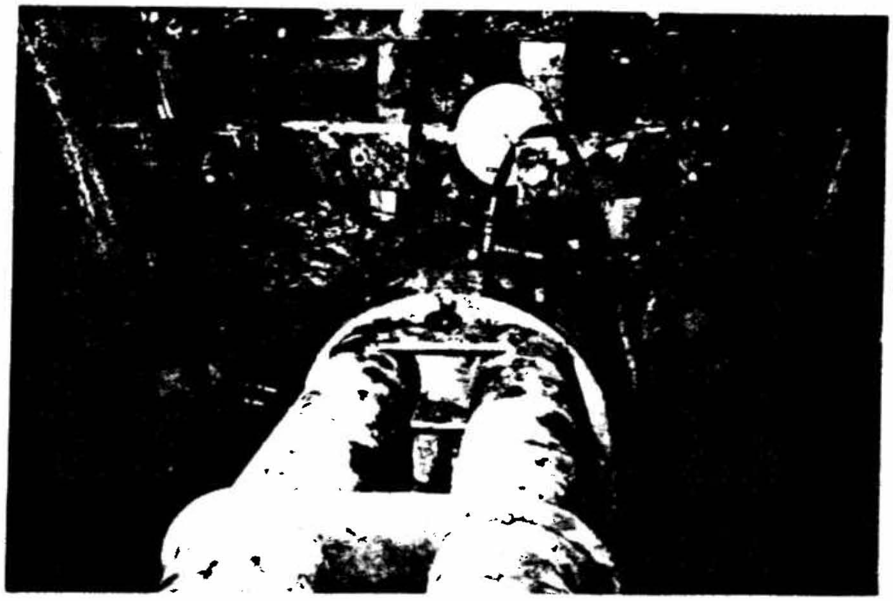


Figure 15. - Uniaxial Jacking Test Station 101+70, West Side.

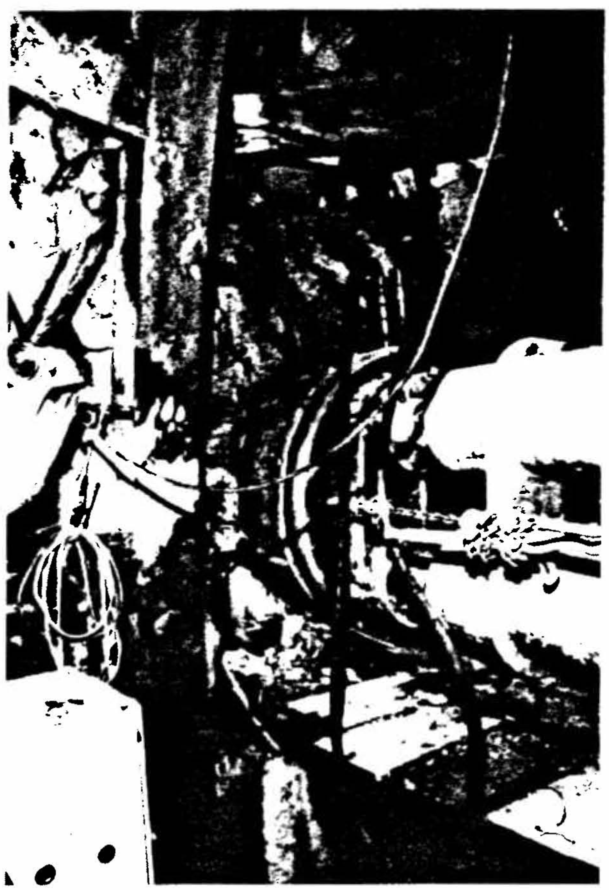


Figure 16. - Uniaxial Jacking Test Station 101+70, East Side.

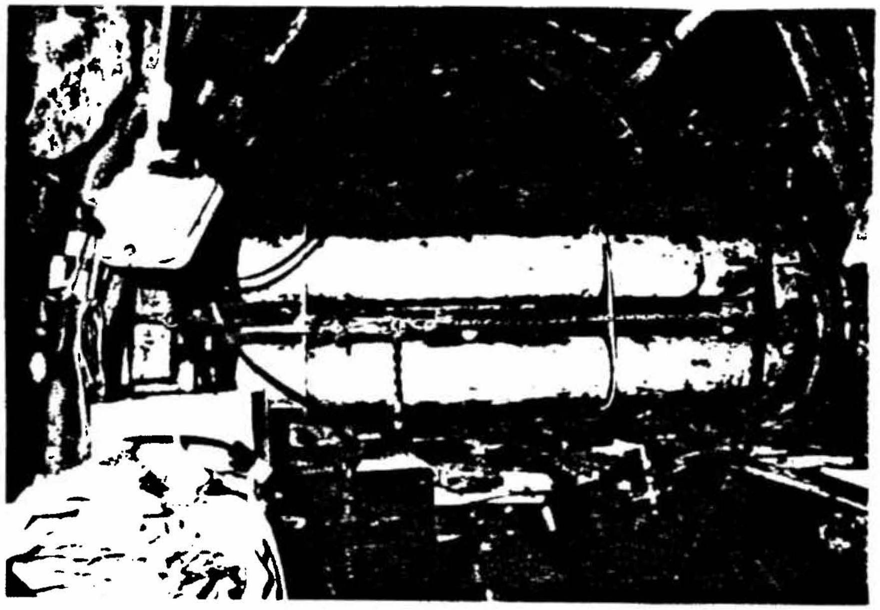
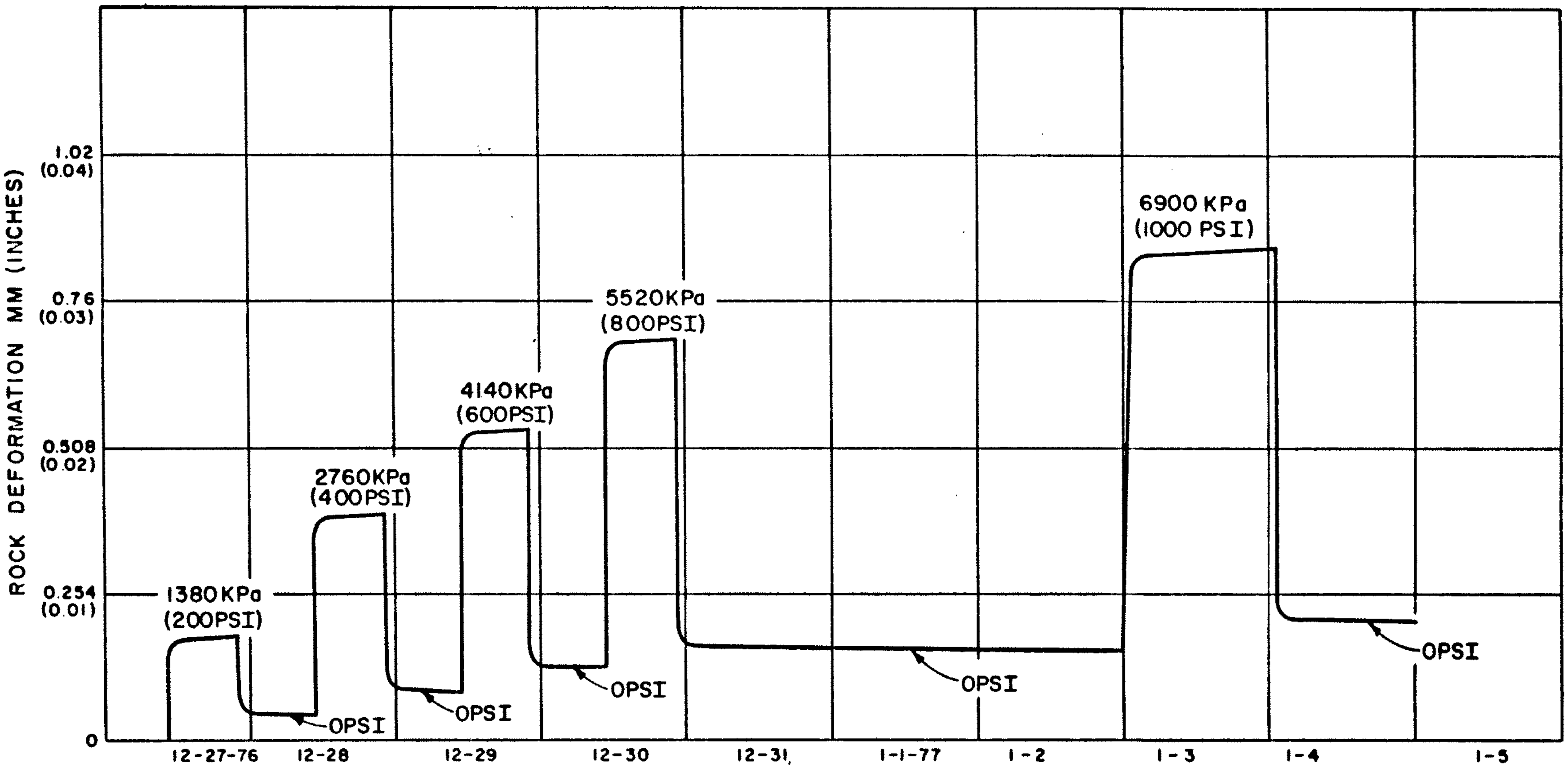


Figure 17. - Uniaxial Jacking Test Station 101+70, Overall View Looking South.

The initial load of 200 lb/in^2 (1380 kPa) was applied on December 27, 1976, and maintained for 12 hours. The load was then removed (zero load) for 12 hours. This sequence was repeated for the 400- and 600-lb/in^2 (2760- to 4140-kPa) load cycles. For the 800-lb/in^2 (5520-kPa) load cycle, the load was maintained for 10 hours and the zero load continued for 88 hours. The long unload condition was maintained to allow the accumulaion of data for rebound observations. The 1000-lb/in^2 (6900-kPa) load was maintained for 24 hours and the zero load for 19 hours. The variations in hours for various load increments were a result of no measured changes in deformation, sufficient data accumulation, and accessibility to the test site. Data from this test resulted in deformation moduli which ranged from 0.35 to 7.02 x 10^6 lb/in^2 (2.4 to 48.4 GPa) at the 1000-lb/in^2 (6900-kPa) load. When discussing ranges of deformation moduli, the lower value, 0.35 x 10^6 lb/in^2 (2.4 GPa) refers to the value for the total depth of rock instrumented, or in this case 23.5 ft (7.16 m) for the east side of the test. The higher value of 7.02 x 10^6 lb/in^2 (48.4 GPa) is for a partial instrumented depth, in this case from 8.75 to 22.0 ft (2.67 to 6.70 m) for the west side. Typical rock deformation vs. time and rock deformation vs. depth plots are shown on figures 18 and 19.

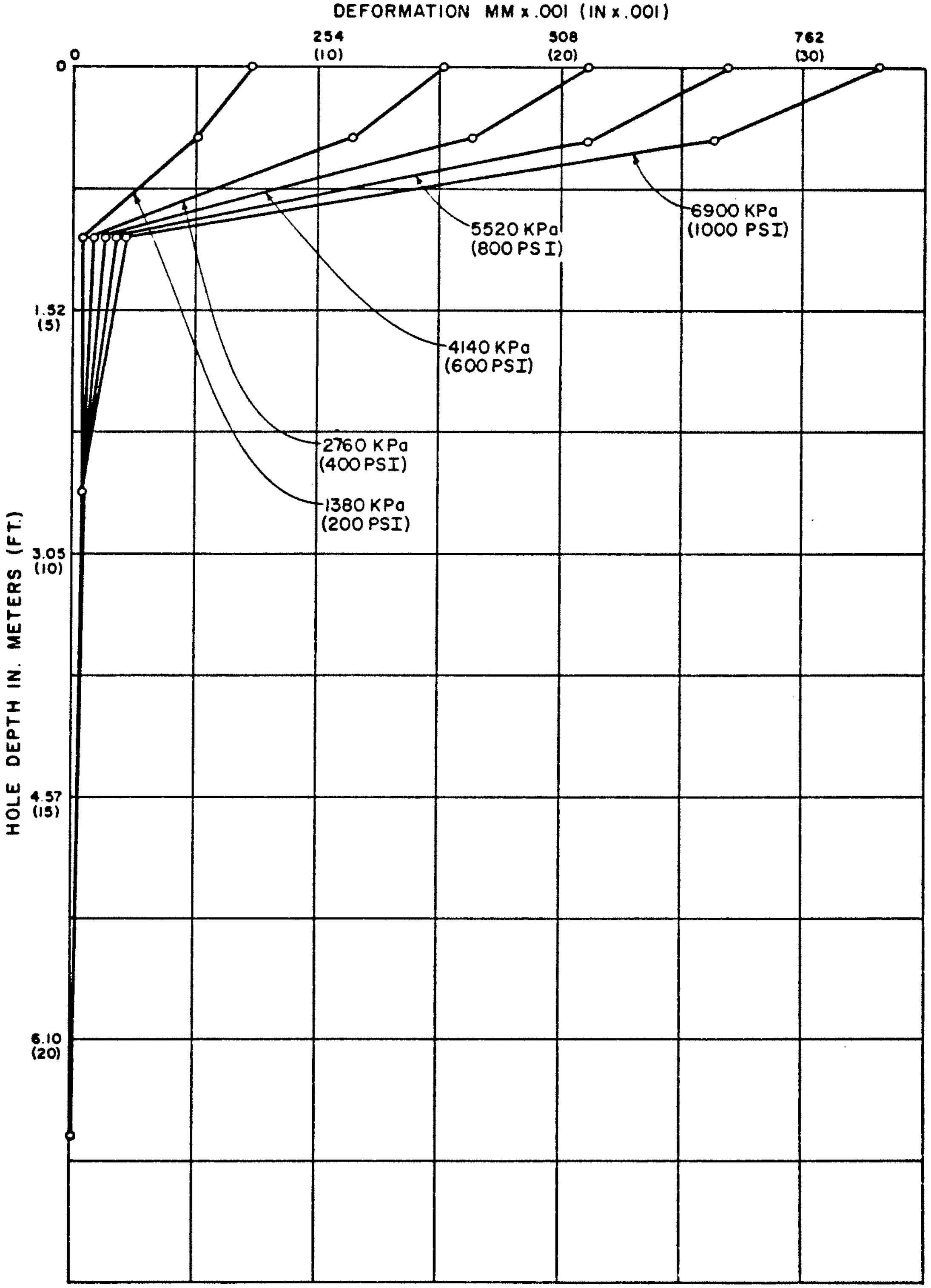


EISENHOWER TUNNEL-2nd BORE

TIME DAYS

FIG. 18- ROCK DEFORMATION VS TIME

STATION 101+70 (WEST)



EISENHOWER TUNNEL-2nd BORE

FIG. 19 ROCK DEFORMATION VS HOLE DEPTH

STATION 101 + 70 (WEST)

At station 111+75, located in type IIIa rock, similar procedures were followed regarding site preparation except that the instrumentation holes were drilled prior to rock surface preparation. Anchor depths were 1.50, 3.00, 6.25, 12.25, and 21.00 ft (0.46, 0.91, 1.90, 3.73, and 6.40 m) on the west side of the test site and 1.50, 2.50, 5.00, 9.00 and 19.50 ft (0.46, 0.76, 1.52, 2.74, and 5.94 m) on the east side. No data were obtained for the west side due to instrument malfunction. Time durations for load cycles were similar except no long duration zero load condition was performed. The deformation moduli at the 1000-lb/in^2 (6900-kPa) load ranged from 0.60 to 3.41 x 10^6 lb/in^2 (4.1 to 23.5 GPa).

As a matter of interest it should be noted that UAJT's were also to be conducted in a vertical direction. However, unstable rock in the arch of both test adits precluded this arrangement.

In reviewing the data it was noted that deformation moduli, when calculated for the rock mass from the rock test surface, ranged from 0.35 to 0.89 x 10^6 lb/in^2 (2.4 to 6.1 GPa). However, the deformation moduli, when calculated for the rock mass from depths of approximately 5 to 9 ft (1.54 to 2.74 m) below the rock test surface, ranged from 1.26 to 7.02 x 10^6 lb/in^2 (8.7 to 48.4 GPa). The lower values of deformation moduli, when calculated from the rock test surface, includes the stress relieved zones developed by excavating the adit and preparing the test surface. This would also be the condition during the excavation of the second highway bore.

Table 3 illustrates the range of deformation moduli when calculated from the rock surface to the bottom reference (Ref.) anchor and for various zones below the rock surface to the bottom reference anchor.

The final deformation modulus, E_d, for the rock mass was determined by averaging the values obtained when calculating the modulus from the rock test surface and 1.5 ft (0.46 m) below the surface. This was done to eliminate some of the effects of stress relief when excavating the test adit and preparing the rock test surface. In two cases, UJ1W and UJ2E, a

Table 3. - Deformation Moduli vs. Depth

Deformation moduli (E_d) x 10^6 lb/in^2 at 1000 lb/in^2 normal load

Station 101+70

West side - UJ1W Depth	E_d	East side - UJ1E Depth	E_d
Surface	0.89	Surface	0.35
1.5 ft	0.71	1.5 ft	0.45
3.5 ft	5.53	3.75 ft	-
8.75 ft	7.02	8.50 ft	3.61
13.50 ft		11.25 ft	-
22.0 (Ref.)		23.50 ft (Ref.)	

Station 111+75

West side - UJ2W

(Malfunction of instrumentation)
(No data)

East side - UJ2E Depth	E_d
Surface	0.74
1.5 ft	0.60
2.5 ft	0.99
5.0 ft	1.26
9.0 ft	3.41
19.5 ft (Ref.)	

Note: 1 lb/in^2 = 6.900 kPa 1 ft = 0.3048 m

Table 4. - Comparison of Deformation Modulus to Core Recovery, RQD and Joints

	E_d (x 10^6 lb/in^2)	Core recovery (percent)	RQD	No. of joints
Station 101+70				
UJ1W	0.80	96	52	75
UJ1E	0.40	95	48	55
Station 111+75				
UJ2W	-	98	53	28
UJ2E	0.67	99	77	21

NOTE: 1 lb/in^2 = 6.900 kPa

slightly lower modulus was obtained at 1.5 ft (0.46 m) below the rock test surface than at the surface. This was unaccounted for, based on the logs of core from the instrumentation holes at the test sites.

The deformation modulus, E_d, for the rock mass at UJ1W is (0.89 + 0.71) / 2 = 0.80 x 10^6 lb/in^2 (5.52 GPa), at UJ1E (0.35 + 0.45) / 2 = 0.40 x 10^6 lb/in^2 (2.76 GPa), and at UJ2E (0.74 + 0.60) + 2 = 0.67 x 10^6 lb/in^2 (4.62 GPa).

The drill logs, appendix A, for the UAJT contain percent core recovery, RQD, and number of open joints. These values are compared with E_d and are listed in table 4.

The deformation moduli for UJ1E and UJ2E, 0.40 and 0.67 x 10^6 lb/in^2 (2.76 and 4.62 GPa), respectively, correlate well with the RQD and number of joints. In this case the RQD for UJ2E was approximately two times higher than for UJ1E and the number of joints for UJ2E was about one-half that for UJ1E.

The correlation using the same criteria of RQD and open joints does not hold true for the deformation modulus of 0.80 x 10^6 lb/in^2 (5.52 GPa) at UJ1W. This site had the maximum number of joints, 75, and RQD of 52, yet had a higher in situ moduli than UJ2E or UJ1E. No television monitoring of the drill holes was performed. It is assumed that the jointing in the rock mass at UJ1W may have been tighter (or closed) than indicated by the extracted core which may account for the higher modulus.

SECTION 5. - ROCK MONITORING INSTRUMENTATION

Scope

MPBX (multiple position bore extensometers) were included in the instrumentation program with the intent of determining the zone of influence and magnitude of displacements resulting from second highway bore excavation. A very comprehensive system was first planned using six instruments at each of the two test adit sites, stations 101+70 and 111+75. Due to construction procedures, drill crew shortages, and tunnel and site availability, the program as installed consisted of only two instruments at each site.

Since the orientation of the holes and instrument installation at each site was essentially the same, the following narrative applies to both. The instruments were inserted in two NX drill holes. These holes were located in the crown of the test adit approximately 20 ft (6.1 m) south from the centerline of the pilot bore. The vertical holes ranged from 91 to 93 ft (27.7 to 28.3 m). The other holes were inclined back over the pilot tunnel at 65° from the horizontal and ranged from 93 to 102 ft (28.3 to 31.1 m). The inclined holes extended over the area where the second highway bore was to be excavated. In the vertical hole, the nearest anchor to the sensor head was 15 ft (4.6 m) and subsequent anchors were placed every 10 ft (3.0 m). The anchors in the angle hole are 11 ft (3.3 m) apart with the first being 17 ft (5.2 m) from the sensor head. Figure 4 shows the general scheme at both sites. Core recovery was good (approximately 85 percent) and selected specimens from all four holes were used in the laboratory test portion of the investigation.

Instrumentation

The anchor strings were fabricated in the laboratory from 1-in (25-mm) diameter sealtite conduit encased in a PVC sleeve. This provided longitudinal flexibility while being laterally stiff enough to resist crushing during grouting operations in the immediate area. The anchors were of the expandable bellows type which were actuated by a hydraulic hand pump. The measuring wires from the anchors to the sensor head were 0.041-in

(1.0-mm) diameter stainless steel. The sensor head consisted of eight strain gaged cantilevers which deflect, after preloading, as the anchors move. The sensor heads are attached to a collar anchor which was secured in place by a concrete mixture, hand packed to sensor a fixed head. Figure 20 shows completed installation, prior to applying the protective cover.

Figure 20. - Extensometer (MPBX) Installation
Prior to Applying Protective Cover

Because both test adits were to be backfilled with concrete before excavation of the second highway bore commenced, a remote system for monitoring all MPBX's was devised. A bridge completion circuit board, small power supply, and an automatic data scanning system were fabricated into a box which was concreted into the pilot bore (south foundation drift). Electronic cables housed in a 2-in (5.1-cm) diameter conduit went from the box at test adit station 111+75 to the box at test adit station 101+70 and then continued across the area of the unexcavated second highway bore through the east cross passageway. The cables were then continued to the transformer vault in the existing east cross passageway. The cables terminated at an automatic data recording system which would scan all MPBX's (32 readings) at a specified interval and print the results on paper tape.

Technical Difficulties

After the instruments were installed, readings were taken to check out the system and obtain zero reference data. Everything operated well during this trial period. However, in the course of preparing for backfilling the south foundation drift, the conduit carrying the instrumentation cables was hit on numerous occasions by the contractor's equipment and twice several of the cables were severed. Repairs were carried out when these accidents occurred and new zero readings were taken. At the time of concrete backfilling, the system was still operating satisfactorily. After a few more trial runs on successive days, the system was deactivated to await mining of the second highway bore. When the system was turned on, about 2 weeks before the heading was to pass test adit station 111+75, a completely open circuit to the two MPBX's located at that station was noted. The readings from station 101+70 appeared okay but there was a large zero shift. Repeated attempts were made to reconcile the problem at station 111+75 but nothing could be accomplished and data acquisition was abandoned.

When the heading neared the east cross passage at test adit station 101+70, the system was again activated and readings taken continuously every hour as the heading approached. These readings showed movements at each anchor location but the numerical displacements were too large to correlate when compared to laboratory calibrations. When the explosive charge at the station was shot, a large change was noted and these readings, hopefully, were to be utilized to determine the zone that was disturbed by the blasting and subsequent excavation. This shot occurred on a Friday evening April 7, 1978, and readings continued through the weekend. The rock mass appeared to be stabilizing, but about 1 p.m. on Sunday April 9, 1978, all of the readings went off scale. Monday morning the system was again completely deactivated.

It is speculation as to what happened Sunday afternoon as the contractor indicated he had no men working that day. A large overbreak occurred at station 101+70 and perhaps this affected the instrument strings enough to cause malfunction. The box at station 101+70 containing the completion circuits became accessible in September 1978 as the benching operation passed it, and it was examined to determine whether fhe failure was electrical or whether the anchor strings actually displaced enough to cause malfunction. Once the box was open, it was very apparent that the problem was caused by water in the system. The box and all connections into it were perfectly watertight; however, the conduit carrying the leads to station 101+70 was dripping at a fairly constant rate. Evidently, when the concrete backfilling operation was going on, the pipe was damaged in some way and water found its way in and migrated to the test station. The water mark in the box indicated that the microswitches had all been submerged at one time. It is assumed that the water leak occurred at a conduit connection. In future installations consideration should be given to waterproof the conduit connections and, if possible, provide for a drain in the box housing the electronic components. Data obtained from the MPBX instrumentation after being studied and analyzed have been determined to be questionable and inconclusive.

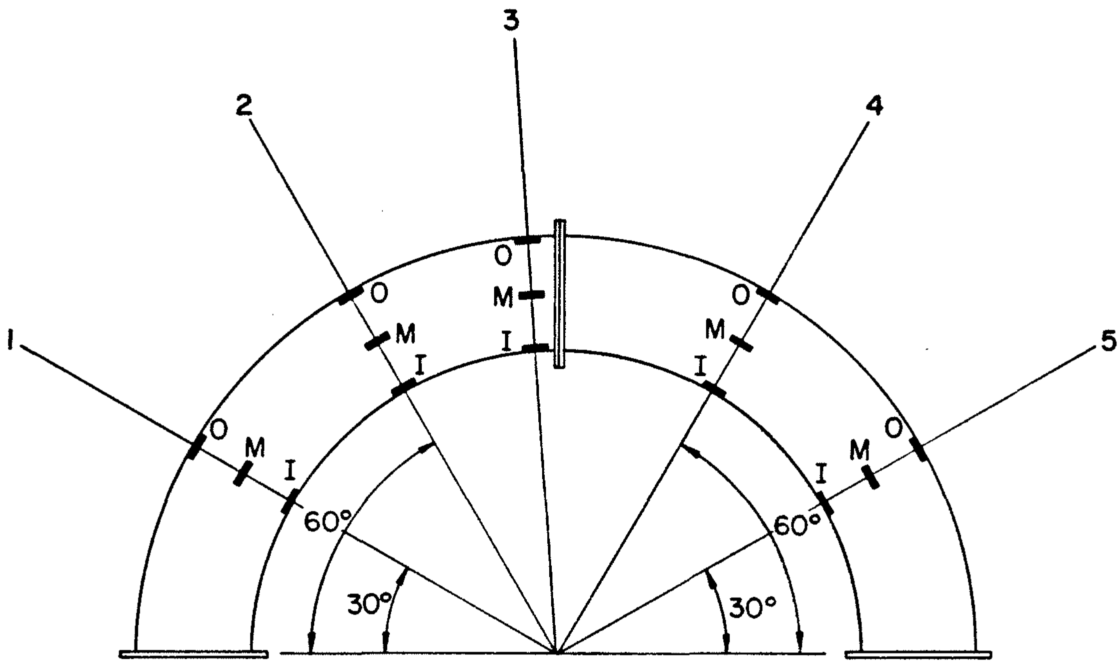
SECTION 6. - SUPPORT INSTRUMENTATION

Introduction and Procedures

Instrumented steel supports, W 14 by 135 and W 14 by 95, were installed in the second highway bore at stations 101+70 and 111+75. Orginally three instrumented steel supports with one noninstrumented support between each were to be installed at each station. All supports were to be on 4-ft (1.22-m) centers with the instrumented supports 8 ft (2.44 m) apart. This was done at station 111+75 for steels sets No. 225, 227, and 229 which were W 14 by 95. At station 101+70, three consecutive instrumented supports, steel sets No. 477, 478, and 479, were installed. This occurred because of the intersection of the existing East Cross Passageway with the second highway bore. At this location a change in support size and spacing was contemplated due to rock conditions. However, the supports were eventually installed as shown in the specifications. After installing the first instrumented support, No. 477, on the east side of the East Cross Passageway, alternate installation of the remaining two instrumented supports on the west side of the passageway would have made the test section longer than desirable. The final spacing of instrumented supports was 10 feet (3.05 m) between sets No. 477 and 478 and 4 ft (1.22 m) between sets No. 478 and 479. Sets No. 477 and 478 were W 14 by 135 and set No. 479 was W 14 by 95.

Each support had a total of 15 weldable strain gages located on one side of the steel supports as shown on figures 21, 22, and 23. The gages, protected with styrofoam, wood blocking, and steel banding, were mounted on the supports several months before installation and stored outside. Twenty-four hours prior to installation the supports were moved into the tunnel to allow them to reach tunnel temperature. When installed the supports had the protected strain gages facing away from the direction of the tunnel heading.

Strain gages on the north half of the steel supports at station 111+75 were lost several days after the first stage concrete lining was placed. Moisture from the concrete apparently penetrated the waterproof covering



RIB E

(A) Planes I thru 5 represent position
(B) O, M, I represent outside flange, middle of web, and inside flange.
(C) Gage M, Position 2 on Rib E station 101 + 70 would have nomenclature of 101 E M2

FIG. 21 LOCATION AND IDENTIFICATION OF STRAIN GAGE INSTRUMENTATION FOR STEEL SUPPORTS EISENHOWER TUNNEL

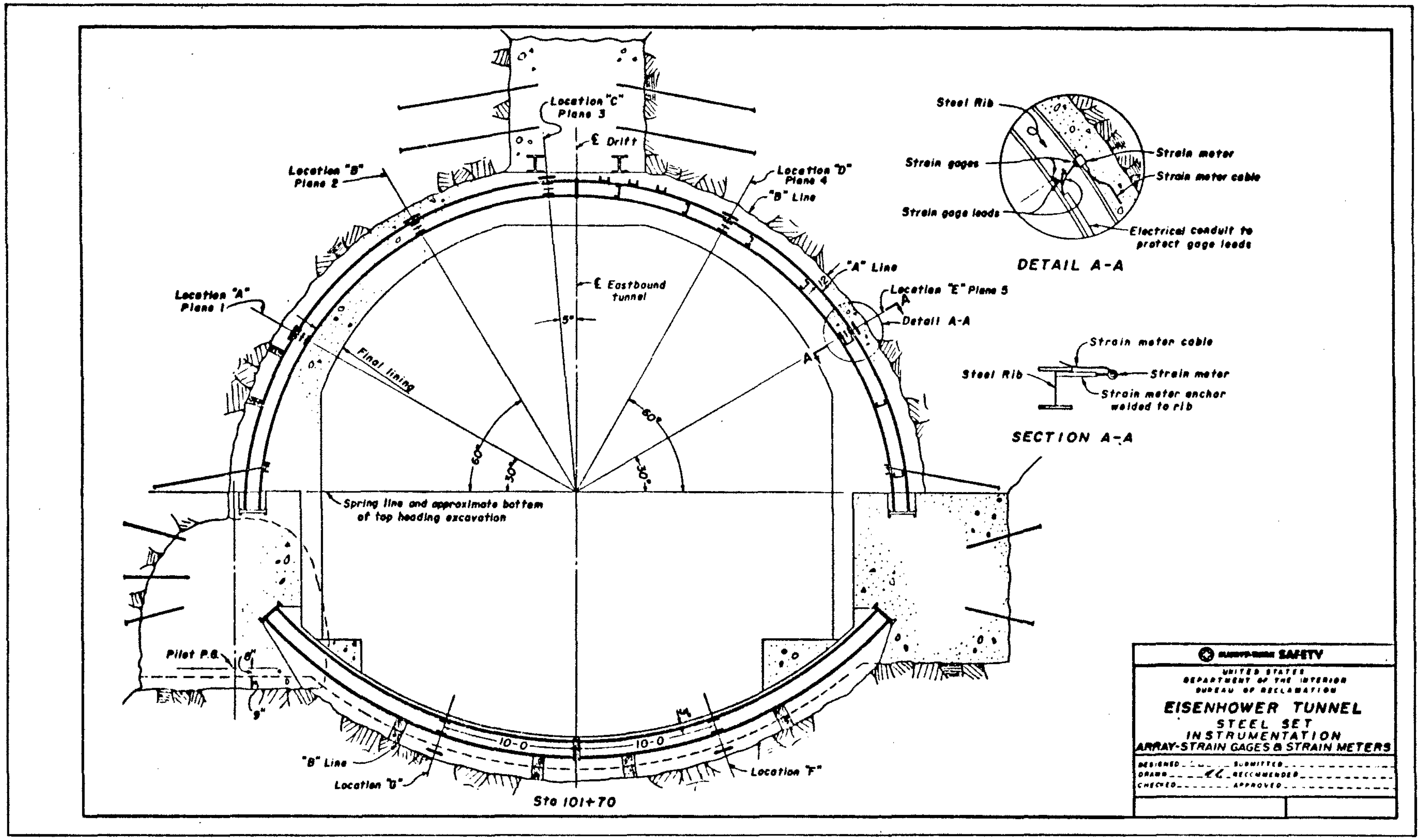


Figure 22. - Steel Set Instrumentation Array - Strain Gages and Strain Meters - Station 101+70.

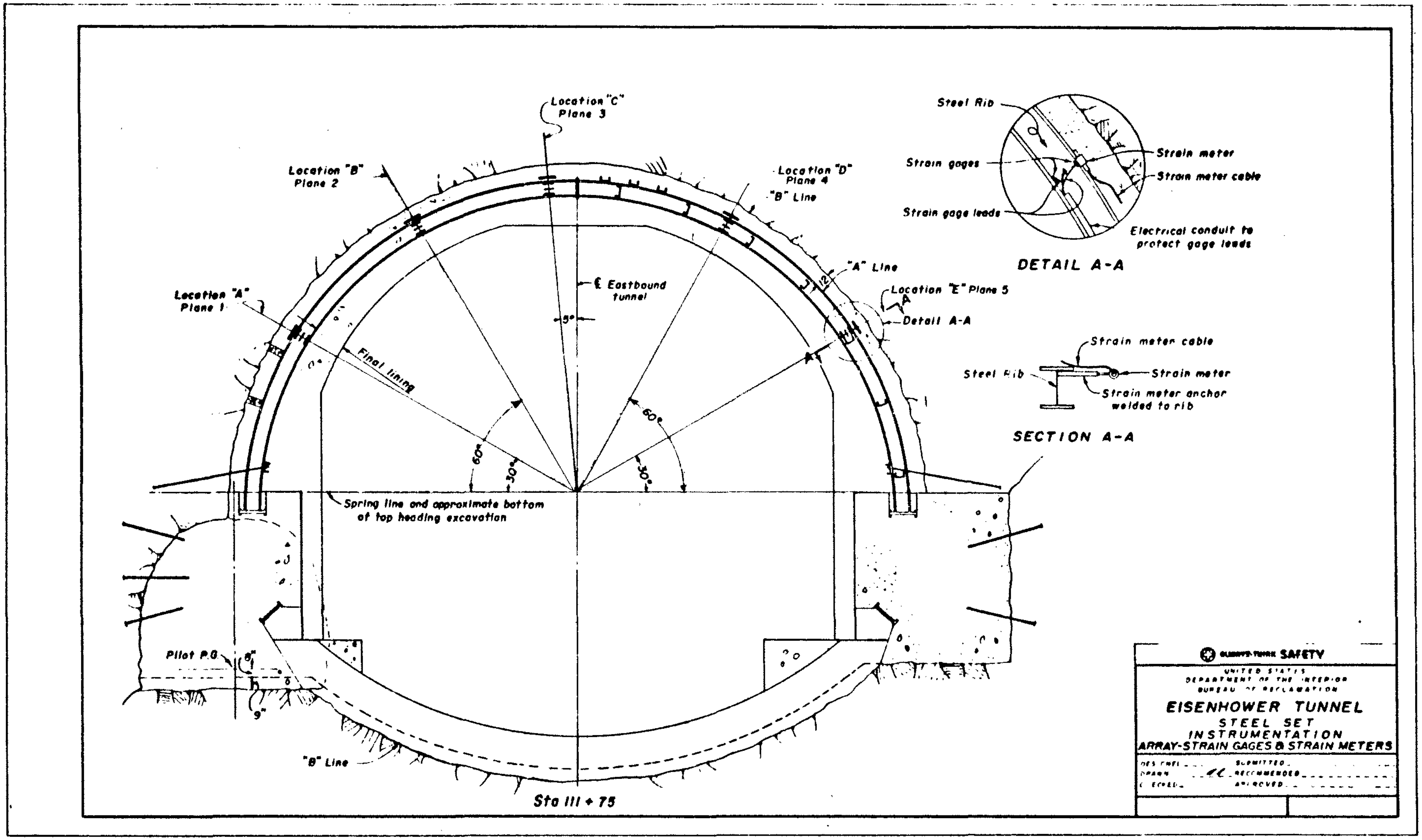


Figure 23. - Steel Set Instrumentation Array - Strain Gages and Strain Meters - Station 111+75.

placed around the plug which was used to connect the gages on the north support to the readout box. A change in the type of connection for similar gages at station 101+70 proved to be successful with no loss of gages due to moisture. Failure of all other gages at both stations was due to damage to the gages or lead wires during mining operations even though precautions had been taken to protect both the gages and lead wires. Three sets of invert struts were instrumented with gages at station 101+70; however, these gages were lost when the instrument cable was severed during mining operations.

A computer program, developed by the CDOH was utilized to obtain axial, fiber, percent yield, and bending stresses on the steel support system.

The following formulas were used in the reduction of strain gage readings:

Strain = current gage reading minus the initial reading
Stress = Strain X modulus of elasticity

Stress at the neutral axis was obtained as follows:

$$S_N = \frac{S_I + S_0}{2}$$

where S_N = stress at neutral axis
S_I = stress at gage mounted on inner flange
S_0 = stress at gage mounted on outer flange

The stress at the inner and outer fiber were obtained by linear extrapolation of the stress at the neutral axis and the stress at the inner or outer flange gage.

The bending moment is obtained as follows:

$$M = \frac{S_0 - S_I}{2Y} (I)$$

where M = bending moment

Y = distance from gage to neutral axis

I = moment of inertia

Percent of yield = the absolute value of the larger of either the inner or outer fiber stress divided by the specified yield strength times 100.

Data sheets containing these data are located in appendix B.

Examination of the data indicates that any early peak loads that may have developed were not recorded. After the instrumented supports were installed and read, subsequent readings were taken when the heading was about four- to five-tunnel diameters away from the supports and the first stage concrete lining placed. Dutro, et al., [4] stated that in the pilot bore maximum peak loads on the supports sometime occurred when the heading was only three-tunnel diameters away and that many of these early peak loads did not again reappear. Korbin and Brekke [7] found in their spiling reinforcement studies, at the second highway bore, that the majority of stress relaxation within the reinforcement occurred by the time the tunnel face had advanced 50 ft (15.2 m). Therefore, the full reaction of the steel supports to any early rock loading may not have been obtained. The failure to obtain the early readings was a result of the USBR's inability to schedule personnel at critical times, difficulty in obtaining access to instrument supports during excavation at the headings, and concern of blast damage to instrument and readout leads.

Discussion of Data

At station 111+75 the maximum calculated stresses on steel supports No. 225, 227, and 229 ranged from 12 000 lb/in^2 (82.8 MPa) tension to 10 000 lb/in^2 (69.0 MPa) compression. The maximum range of bending moments was from 884 K-in (9990 N·M) tension to 280 K-in (3160 N·m) compression. The maximum percent yield was 33 percent. The supports were initially in tension but gradually went into compression over a 10-month time span, December 1977 to September 1978. The aforementioned trends are shown in tables B-1 through B-3 and on figures B-1 through B-18, appendix B.

The first stage concrete lining at this station followed the same approximate time pattern of initial tensile followed by compressive stresses and is discussed in Section 7, Lining Instrumentation.

At station 101+70 the maximum calculated stresses on steel supports No. 477, 478, and 479 ranged from 10 000 lb/in^2 (69.0 MPa) tension to 47 000 lb/in^2 (324.3 MPa) compression. Bending moments ranged from 2402 K-in (27 140 N·m) tension to 5802 K-in (65 550 N·m) compression. The maximum stress was 85 percent of the yield stress. Readings were taken on these supports from May 1978 to September 1978. After September the readout location for all support and lining instrumentation was not accessible until January 1979. At that time extensions were added to all instrumentation leads and were terminated at the final readout box location. However, all cables were severed by second stage concrete lining construction activities in January 1979. Replacement cables were installed but most subsequent readings fluctuated and were considered unreliable. After the cables were replaced data indicated that stresses on some of the supports were over 300 percent of yield strength. These data fluctuated and could not be resolved even though adjustments were made by taking readings before and after cable extensions were added and when the severed cables were replaced. It is assumed that unknown additional damage occurred during the second stage lining operation, other than severing the cables, which was not rectified. The aforementioned trends are shown in tables B-4 through B-6 and on figures B-19 through B-37, appendix B. Data for station 101+70 was very erratic after January 1979 and was not included in the analyses, but is included in appendix B since some of the instrumentation appeared to continue to function properly. (In addition correlations of steel support and first stage concrete lining instrumentation could not be continued after January 1979 since the severed leads of the lining instrumentation could not be repaired.)

SECTION 7. - LINING INSTRUMENTATION

Description and Location

Carlson [3] strain meters were installed in the first stage concrete lining of the second highway bore at stations 101+70 and 111+75. The meters were located between steel supports No. 477 and 478 at station 101+70 and between supports No. 226 and 227 at station 111+75. Five meters were installed at each station as shown on figures 22 and 23. The meters were to be located in the concrete lining approximately 3 in (7.6 cm) from the rock at points of possible maximum stress; however, with about 3 to 5 ft (0.91 to 1.52 m) overbreak and heavy timbering it was impossible to install the strain meters at the planned depth. The anchors for the meters were, therefore, welded to the outer flange of the steel support. The meters were located in the same plane as the outer flange parallel to and centered between the steel supports.

Location designation of each meter begins with the letter "A" (south side of tunnel) and ends with the letter "E" (north side of tunnel). Station 101+70 uses the designation 101-A through 101-E and station 111+75 uses designation 111-A through 111-E. Strain meter 101-A installed on April 21, 1978, was lost on June 8, 1978, and meter 111-B was damaged during placement of first stage concrete lining.

Discussion of Data

Meters installed at stations 101+70 and 111+75 measured loads, in the sequence of occurrence, on the concrete lining as follows:

101-A - Maximum tensile load of 127 lb/in^2 (0.88 MPa). Meter was lost on June 8, 1978.

101-B - Maximum compressive load of 119 lb/in^2 (0.82 MPa), maximum tensile load of 41 lb/in^2 (0.28 MPa).

101-C - Maximum tensile load of 9 lb/in^2 (0.06 MPa), maximum compressive load of 522 lb/in^2 (3.60 MPa).

101-D - Maximum compressive load of 456 lb/in^2 (3.15 MPa).

101-E - Maximum tensile load of 521 lb/in^2 (3.59 MPa).

111-A - Maximum tensile load of 49 lb/in^2 (0.34 MPa), maximum compressive load of 520 lb/in^2 (3.6 MPa).

111-B - Damaged during placement of concrete.

111-C - Maximum tensile load of 369 lb/in^2 (2.5 MPa), maximum compressive load of 699 lb/in^2 (4.8 MPa).

111-D - Maximum tensile load of 193 lb/in^2 (1.3 MPa), maximum compressive load of 812 lb/in^2 (5.6 MPa).

111-E - Maximum compressive load of 448 lb/in^2 (3.1 MPa).

Figures 24 and 25 show typical tension and compression zones developed early (1 to 3 months after placement) in the concrete lining. Subsequently, some zones changed from compression to tension loading or vice versa.

At station 101+70 strain meter readings were taken over a 9-month period, May to September 1978 and January 1979, before they were damaged during second stage concrete lining operations. The area was inaccessible for readings from September 1978 until January 1979. The stresses ranged from 522 lb/in^2 (3.60 MPa) compression to 521 lb/in^2 (3.6 MPa) tension. Both north and south sides of the lining remained in tension and the arch in compression throughout the data accumulation period. The ranges of stresses are listed in table 5.

At station 111+75 strain meter readings were taken over a 1-1/2-year period December 1977 to September 1979, before they became erratic. The stresses

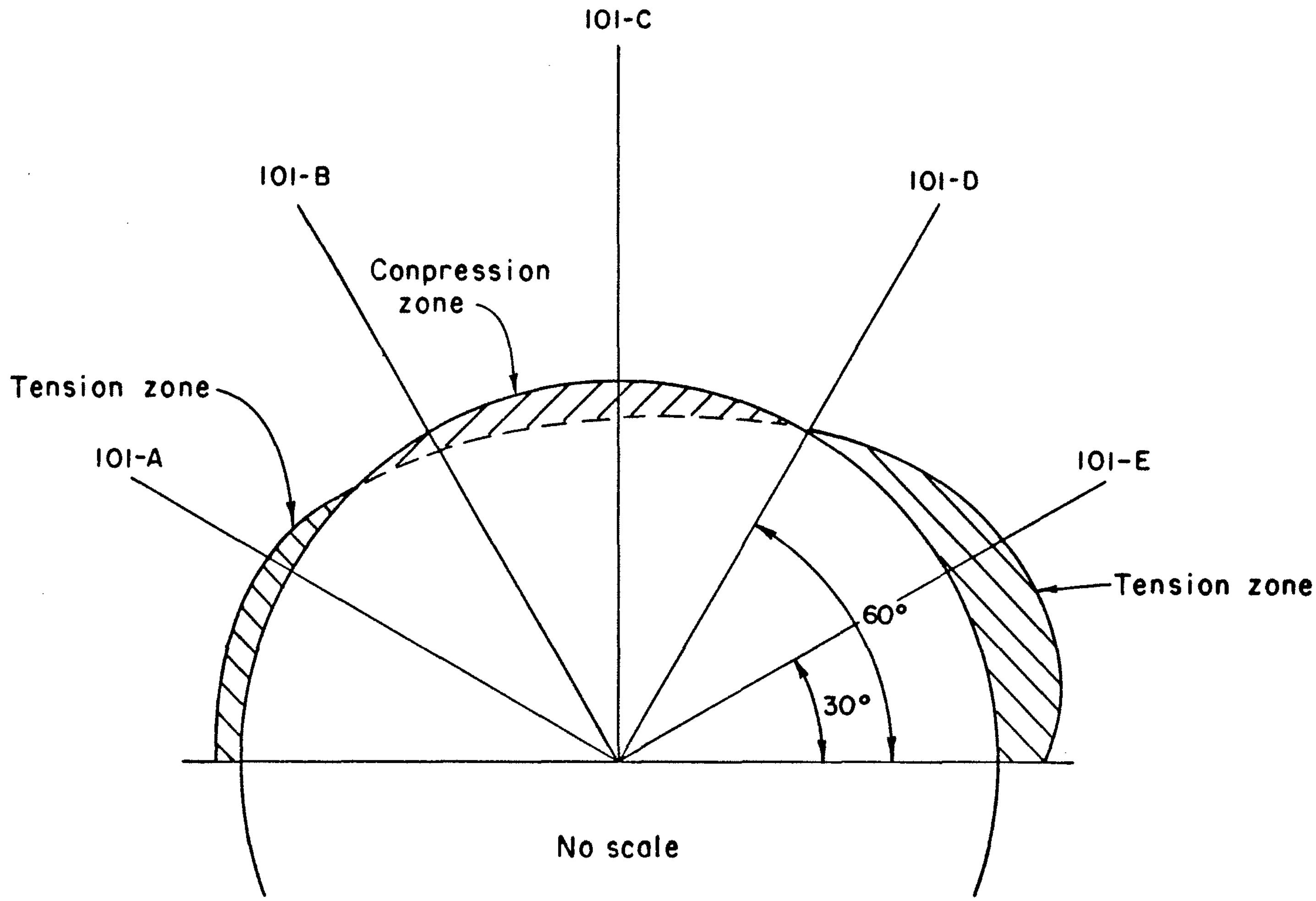


FIG 24 STRESS ZONES IN CONCRETE LINING
STATION 101 + 70, EISENHOWER TUNNEL

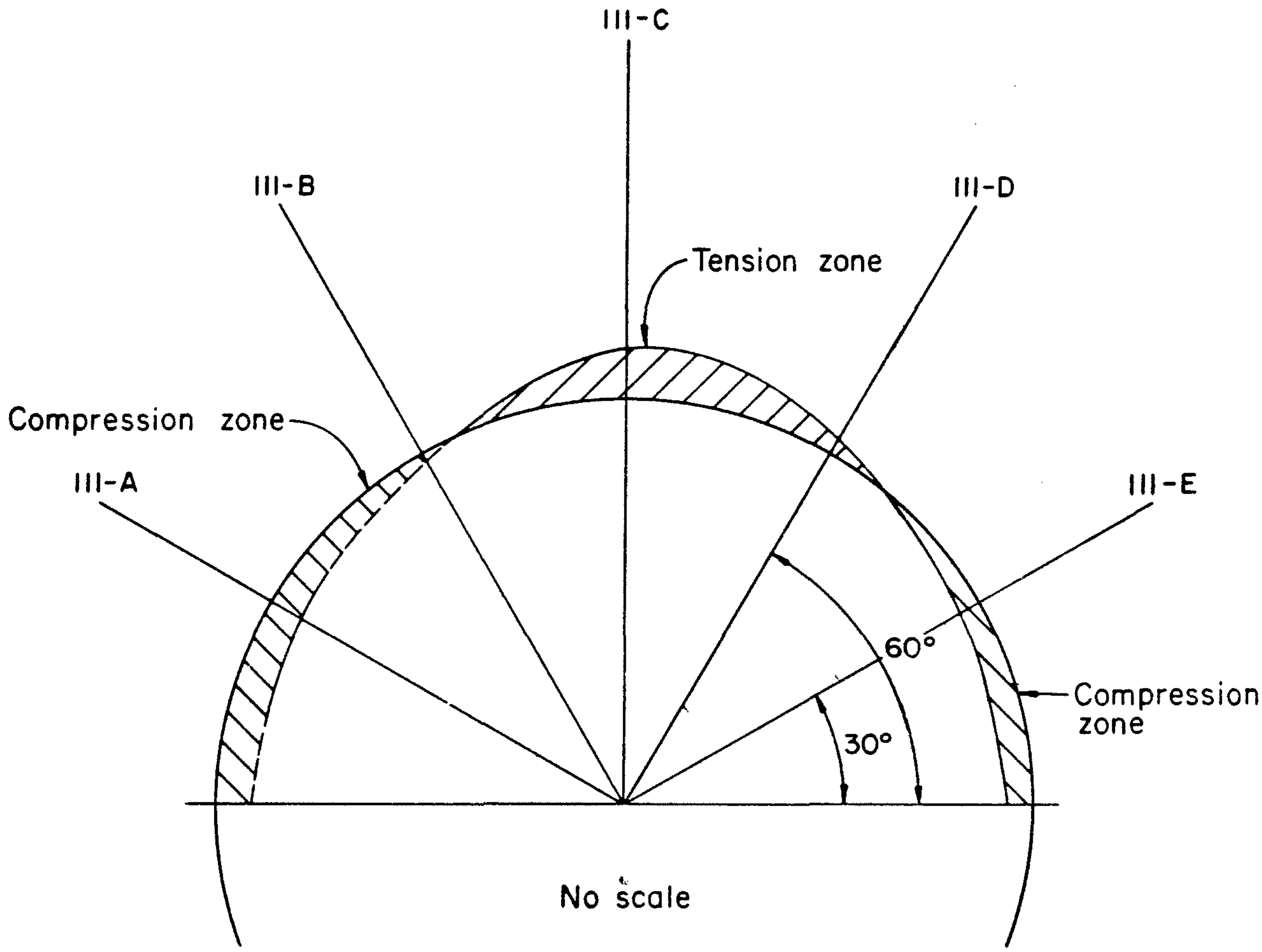


FIG. 25 STRESS ZONES IN CONCRETE LINING
STATION 111+75, EISENHOWER TUNNEL

Table 5. - Stress in Concrete Lining (lb/in^2)
Eisenhower Second Highway Bore - Station 101+70

Date	Meter				
	101-A	101-B	101-C	101-D	101-E
5-02-78 (ref.)	0	0	0	0	0
5-03-78	92	-47	9	-8	421
5-10-78	127	-98	-	62	-
5-16-78	37	-91	-	-53	521
6-08-78	-	-119	-38	27	518
7-26-78	-	-100	-161	-59	443
9-07-78	-	-61	-130	-	363
1-15-79	-	41	-522	-456	137

+ Tension
- Compression
NOTE: 1 lb/in^2 = 6.900 kPa

Table 6. - Stress in Concrete Lining (lb/in^2)
Eisenhower Second Highway Bore - Station 111+75

Date	Meter				
	111-A	111-B	111-C	111-D	111-E
12-19-77 (ref.)	0	-	0	0	0
12-28-77	49	-	365	193	-17
01-05-78	16	-	349	89	-96
01-12-78	16	-	329	113	-94
01-23-78	11	-	369	171	-68
03-22-78	-26	-	296	87	-123
04-20-78	-3	-	289	89	-102
05-02-78	-26	-	299	97	-124
05-10-78	-36	-	271	-15	-152
05-16-78	14	-	285	89	-116
06-08-78	14	-	269	83	-138
07-26-78	-64	-	129	-97	-194
09-07-78	-172	-	-80	38	-400
02-02-79	-414	-	-530	-516	-348
02-21-79	-520	-	-688	-812	-448
04-05-79	-326	-	-470	-553	-321
06-22-79	-366	-	-536	-684	-
09-26-79	-472	-	-587	-713	-403

+ Tension
- Compression
NOTE: 1 lb/in^2 = 6.900 kPa

ranged from 812 lb/in^2 (5.6 MPa) compression to 369 lb/in^2 (2.5 MPa) tension. The south side of the lining and the arch were initially in tension but after 3 to 6 months began to load in compression. After 8 months all readings indicated a compression loading for the entire lining. The ranges of stresses are listed in table 6.

Pore Pressure Meters

Pore pressure meters were installed at stations 101+70 and 111+75. Two 12-ft (3.65-m) deep holes were drilled 5 ft (1.52 m) apart each at an angle of 10° down from the horizontal. The holes were drilled through the first stage concrete lining of the second highway bore.

The holes were drilled toward the south and were 2.5 in (6.35 cm) in diameter. Two pore pressure meters were installed one at a depth of 12 ft (3.65 m) and a second at 4.5 ft (1.37 m) from the collar of the hole. Figure 26 shows the details.

The installation procedure was as follows:

1. Drill, wash, and clean holes.

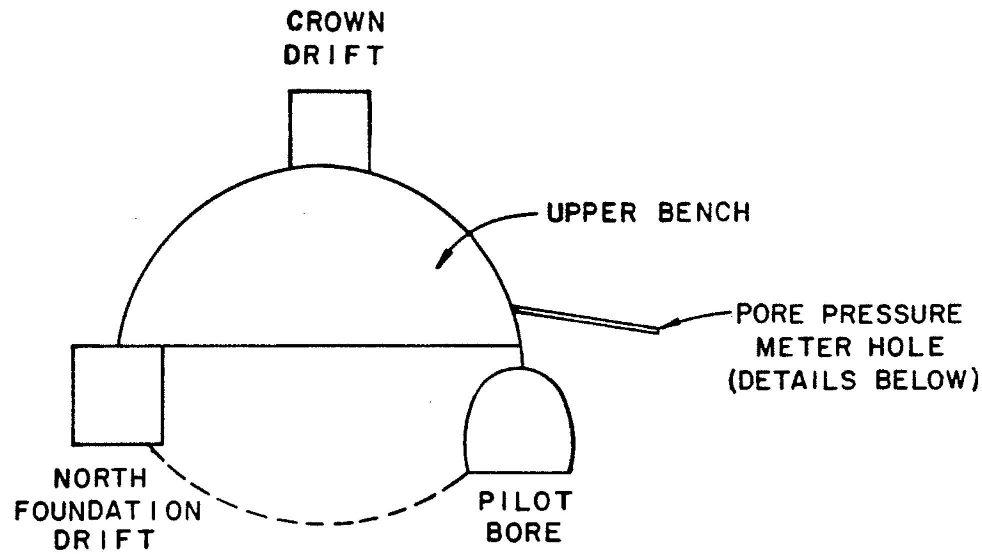
2. Insert 6-inch (15.24-cm) long wooden block and push to bottom of hole.

3. Insert first pressure meter and push gently until it makes contact with wooden block.

4. Insert wooden dowel into hole - length of dowel was long enough to hold second meter in desired location.

5. Insert second meter to top of dowel.

6. Inset clean rags into hole to second meter. Tamp gently.



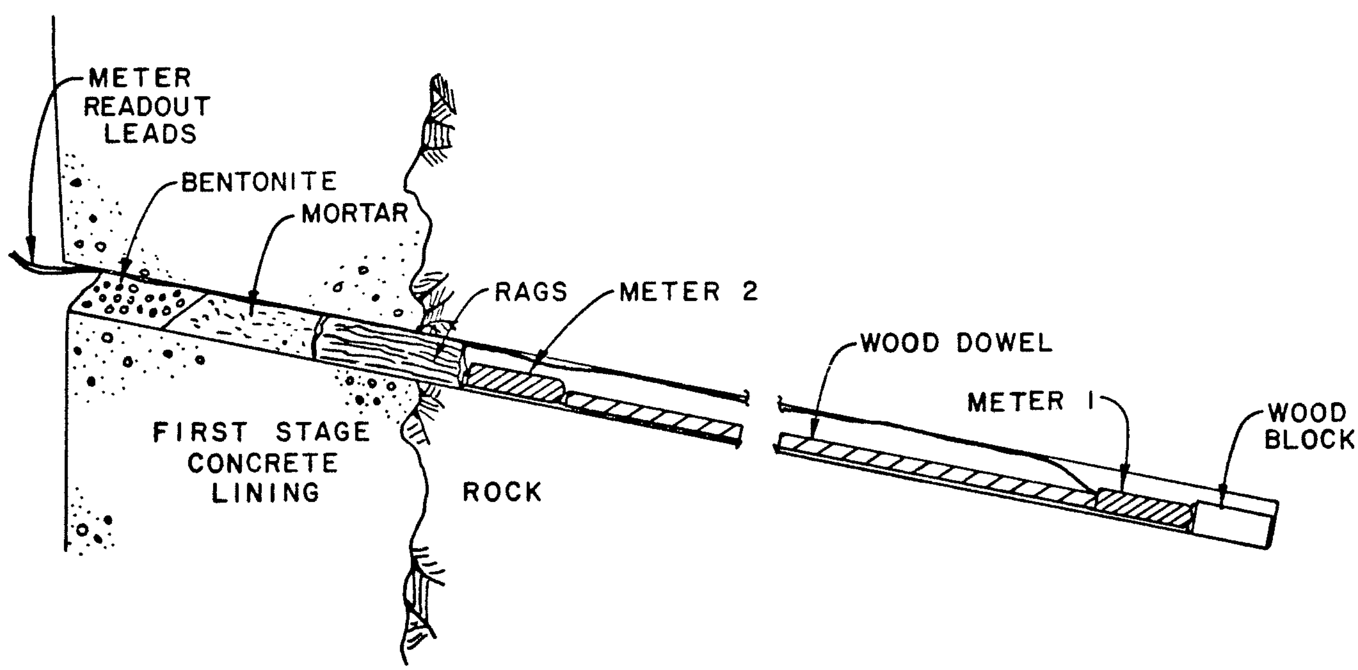


FIGURE 26 - PORE PRESSURE METER INSTALLATION DETAILS
STATIONS 101 + 70± AND 111 + 75±

7. Mix and place mortar to top of rags. Tamp gently. Let set until firm (2 hrs ±).

8. Add bentonite pellets and water to activate pellets.

9. Seal collar of hole with tapered wooden plug.

The ends of leads for the two meters were kept outside the hole while rags, mortar, and bentonite pellets were added. Before adding a wooden plug to seal the holes, the meter leads were cut to proper size and fittings attached for the pneumatic readout. The leads were covered with tape and tucked back into the hole. All readings indicated no pressure buildup behind the concrete lining. Maximum readings were from 1 to 3 lb/in^2 (6.9 to 20.7 kPa). This indicated that the tunnel drainage system was operating properly. However, because additional grouting had to be done after the pore pressure meters were installed, it is possible that continued subsequent low readings may be the result of inoperative meters.

SECTION 8. - MULTIPLE DRIFT INSTRUMENTATION

Scope

Because of the heavy ground encountered in the first highway bore, a section of the bore had to be excavated by utilizing a series of smaller drifts. Nine individual drifts were excavated, steel supported, and backfilled with concrete. These nine drifts formed an arch over the first highway tunnel bore and provided support while the bore was being excavated.

The same procedure was used for the excavation of approximately 500 ft (152 m) of the second highway bore. It was decided to do a small instrumentation program at this site and include the results in this report.

Installation and Location

In the multiple drift area (nine individual drifts) station 83+00$^{\pm}$ to station 87+50$^{\pm}$ of the second highway bore, Carlson [3] stress meters were installed to determine the distribution of rock loads during excavation. Not all of the drifts could be instrumented due to construction scheduling. The pilot bore and the crown drift were backfilled with concrete before it was possible to install instruments. The north foundation drift and the remaining six drifts had stress meters installed.

Stress meters were installed in the nine-drift area as shown on figure 27. The meters were installed on the side walls or arch of the individual drifts. A mortar coating (Sika Set) was applied to the rock surface to form a contact plane while installing the meters. The meters were held in place, until the mortar pads set firm, with a variety of pins, blocking, and wire.

All of the meters were located in a plane approximately 50 ft (15.2 m) from the west end of the multiple drift area at station 83+50. The meter in the north foundation drift could not be read because the cable stored in a box wired immediately above the receiver beam was lost during placement

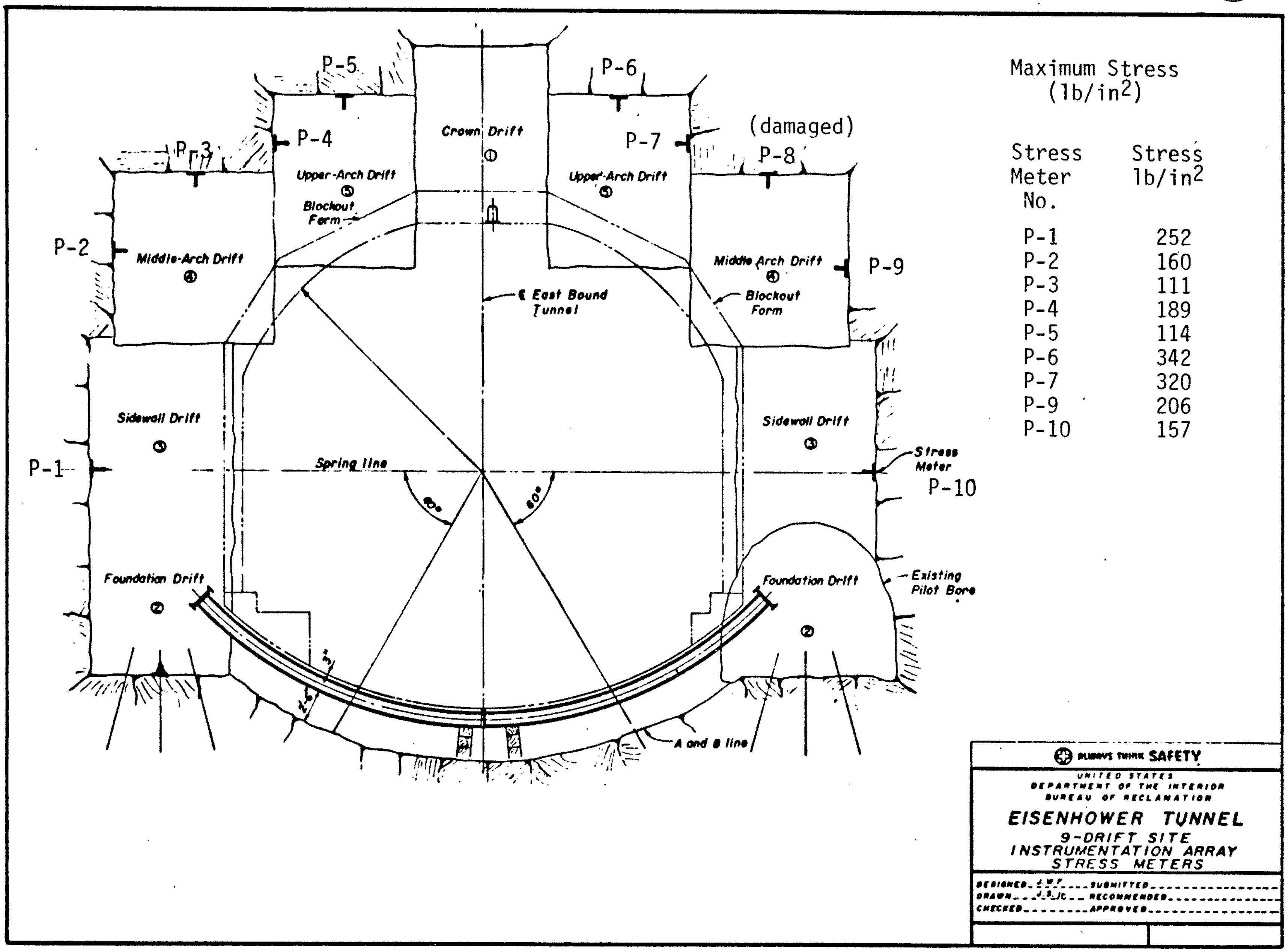


Figure 27. - Nine-Drift Site Instrumentation Array - Stress Meters - Station 83+50 (Looking East).

of the concrete in the drift. One meter in the south middle arch drift became inoperative. The remaining nine stress meters appeared to operate satisfactorily.

Discussion of Data

The maximum stresses measured at each of the stress meters are listed in table 7 (all stresses are compressive).

Table 7. - Maximum Stresses Measured in Multiple Drift (Nine-Drift) Section

Drift	Stress (lb/in^2)	Stress meter No.
North sidewall	252	P-1
South sidewall	157	P-10
North middle - arch (rib)	160	P-2
North middle - arch (crown)	111	P-3
South middle - arch (rib)	206	P-9
North upper - arch (rib)	189	P-4
North upper - arch (crown)	114	P-5
South upper - arch (rib)	320	P-7
South upper - arch (crown)	342	P-6

NOTE: $1\ lb/in^2 = 6.900$ kPa

Loads obtained from stress meters are shown on figure 28. With the exception of meters P-5 and P-10, all show an increase in load during excavation of the upper heading. These peak loads generally decreased and another small increase in load appeared as the bench heading approached the instrumented station. A final peak load occurred when the multiple drift excavation was completed.

All of the meters, except P-1, P-9, and P-10, had an initial drop in load (tension) after installation which may be caused by shrinking of the mortar (Sika Set) used to form a smooth surface between the face of the meter and the rock prior to filling the drifts with concrete.

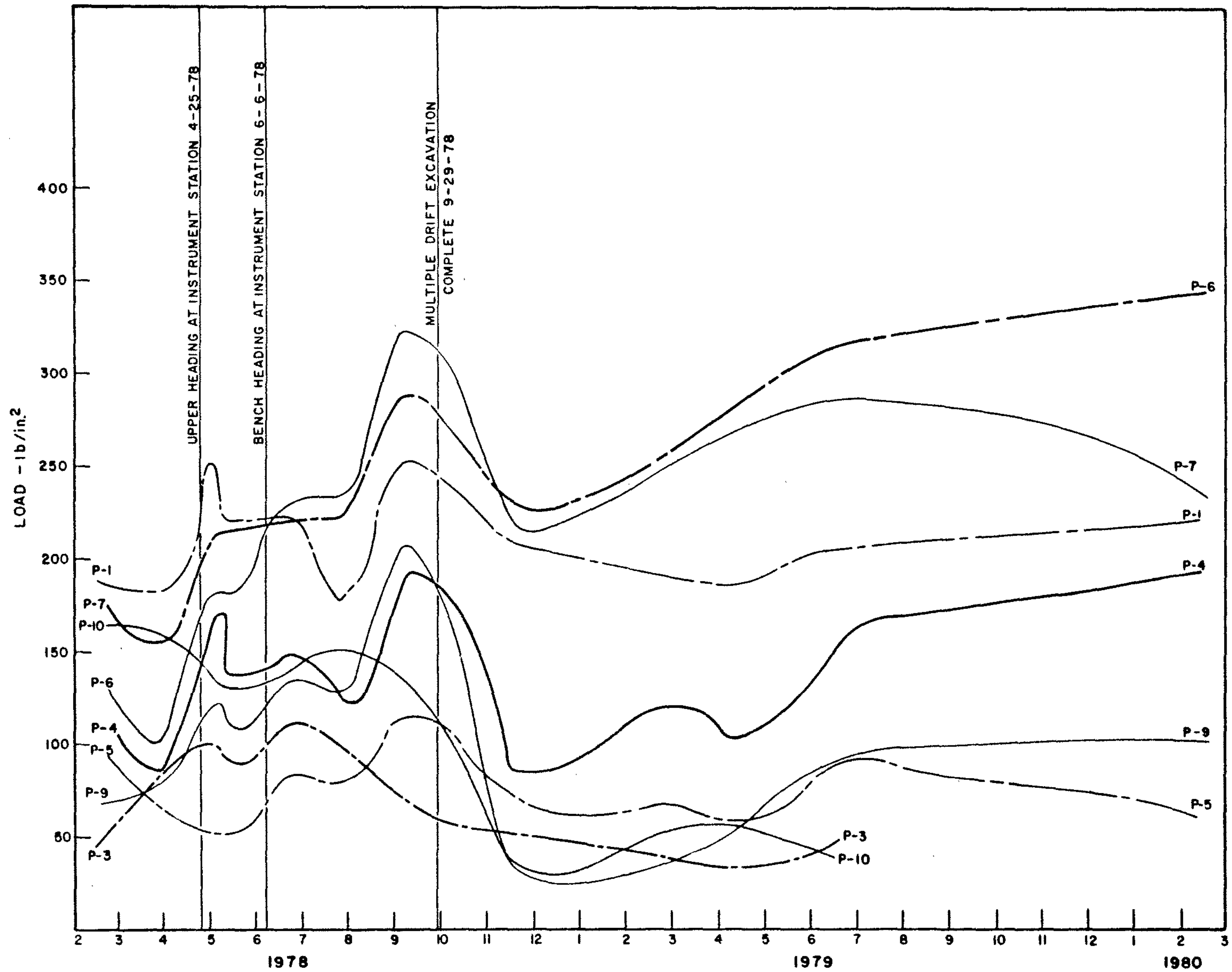


FIGURE 28 LOADS ON STRESS METERS IN MULTIPLE DRIFT AREA RELATED TO UPPER AND BENCH HEADING EXCAVATIONS AND THE COMPLETED EXCAVATION — STATION 83+50

It was noted that the north side of the multiple drift area, the side nearest to the existing first highway bore, generally had lower maximum stresses on the individual drifts than the south side, see figure 27. The two highway bores are approximately 200 ft (61 m) or about 4 tunnel diameters apart. It is not known if the existence of the reinforced multiple drift area or the first highway bore had any partial stabilizing effect on the adjacent side of the multiple drift in the second highway bore.

Also it is not known why the maximum load on most of the multiple drifts occurred as the multiple drift excavation neared its completion as shown on figure 28.

SECTION 9. - LABORATORY CORE TESTING INVESTIGATIONS

Introduction

Laboratory tests were conducted on NX-size, 2.12 in (5.4 cm) diameter core specimens from instrumentation drill holes for the uniaxial jacking tests, and from the MPBX rock measurement system, figure 4. The specimen numbers from the horizontal jacking test across test adit site 1 (station 101+70) were coded UJ1 and further coded to UJ1W and UJ1E, indicating the west and east sides. The 101A and 101V codes refer to specimens from the angle (A) and vertical (V) MPBX holes. The number behind the code, such as 6.2 (101A-6.2), is the specimen depth in feet from the collar of the drill hole. The same nomenclature was used for specimens from test adit site 2, station 111+75 (i.e., UJ2W-12.8, 111A-56-1). This nomenclature is used in various tables and graphs in the appendixes.

Station 101+70

Specimens tested from this station included granites, granite gneisses, biotite gneisses, and pegmatites. The detailed data are contained in tables C-1 through C-10, and the data sheets and plots, appendix C. The petrographic description and afterbreak summary of select specimens are contained in appendix D. A brief summary of the test data is contained in the following narrative:

Specific Gravity, Absorption, and Porosity. - Specific gravity, absorption, and porosity were determined using vacuum saturation procedures. Specimens from UJ1 had specific gravities from 2.55 to 2.69, absorptions from 0.79 to 2.22 percent and porosities from 2.09 to 5.97 percent.

Specimens from 101A and 101V had specific gravities from 2.57 to 3.02, absorptions from 0.11 to 1.14 percent, and porosities from 0.30 to 6.55 percent.

Elastic Modulus, Poisson's Ratio, Compressive Strength, and Ultrasonic Velocity. - The secant modulus of elasticity and Poisson's ratio were determined using the procedure which is documented in USBR Report SP-39 [9]. The secant modulus of elasticity values are given at 1000-lb/in^2 (6.9-MPa) axial load of the first test cycle. Unconfined compressive strengths were determined using a procedure which is in accordance with Standard ASTM method D 2938-71a. Ultrasonic compressional wave velocity was measured axially using a procedure which conforms to Standard ASTM method D 2845-69.

Specimens from UJ1 had elastic moduli ranging from 6.06 to 9.52 M lb/in^2 (41.8 to 65.7 GPa), Poisson's ratio from 0.03 to 0.15, compressive strengths from 8620 to 28 530 lb/in^2 (59.4 to 197.0 MPa) and ultrasonic velocities from 9700 to 18 080 ft/s (2960 to 5510 m/s).

Specimens from 101A had elastic moduli ranging from 1.59 to 10.64 M lb/in^2 (11.0 to 73.4 GPa), Poisson's ratio from 0.02 to 0.21, compressive strengths from the 6370 to 29 600 lb/in^2 (43.9 to 204.2 MPa), and ultrasonic velocities from 10 400 to 17 900 ft/s (3170 to 5460 m/s).

Specimens from 101V had elastic moduli ranging from 2.58 to 14.08 M lb/in^2 (17.8 to 97.1 GPa), Poisson's ratio from 0.02 to 0.18, compressive strengths from 6600 to 19 500 lb/in^2 (45.5 to 134.5 MPa) and ultrasonic velocities from 12 400 to 18 700 ft/s (3780 to 5700 m/s).

Tensile Strength. - Indirect tension tests (tensile splitting or Brazilian method) were performed because insufficient specimens were available for direct tension tests. NX-specimens, 1 inch thick, were prepared and tested. The modified curved loading block assembly, used for testing, is shown on figure 29. Specimens from 101A had tensile strengths ranging from 300 lb/in^2 (2.07 MPa) for a granite to 2010 lb/in^2 (13.9 MPa) for a granite gneiss. Specimens from 101V had

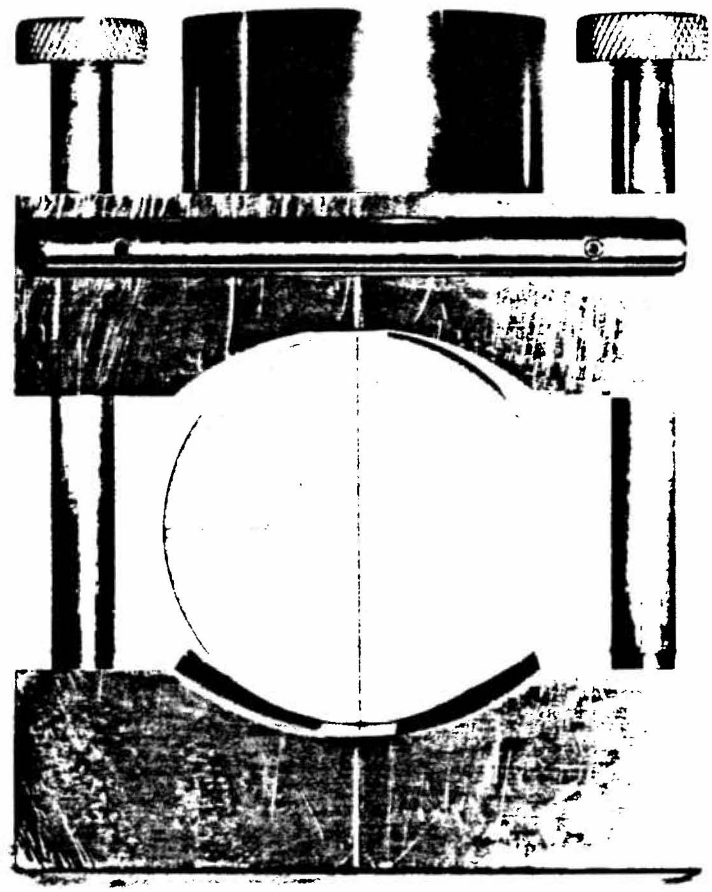


Figure 29. - Modified Bearing Block for Indirect Tension Test on Rock Specimens.

tensile strengths ranging from 635 lb/in^2 (4.38 MPa) for a granite to 2015 lb/in^2 (13.9 MPa) for a gneiss.

Shear Strength. - Direct shear tests were performed on NX-cores. The ends of the core were encapsulated in metal holding rings separated by a 1/4-inch (0.63-cm) air space in which the shearing action takes place. The test specimen was placed into a shear machine and vertical (normal) load applied and maintained until a horizontal (shear) load breaks the specimens. After shear failure the surfaces, without repositioning, were subjected to sliding action under a series of normal loads and the horizontal load required to overcome sliding friction was recorded. The relation between the normal and shear loads was then analyzed by the angle envelope and the linear regression methods to determine cohesion, friction angle, etc. The angle-envelope method is discussed by Haverland [6] in USBR Report No. GR-15-76.

Five shear tests on intact rock cores from 101V and 101A and seven sliding friction tests on open joints in cores from 101V, 101A, UJ1E, and UJ1W were performed.

Based on the averages of the linear regression and angle envelope methods, the cohesion and friction angle (Ø) of the intact rock were 2025 lb/in^2 (14.0 MPa) and 43°, respectively. Utilizing the same criteria, the cohesion and friction angle (Ø) obtained from sliding friction tests of open joints were 36 lb/in^2 (0.25 MPa) and 30°, respectively.

It should be noted that when sliding friction tests were performed on open joints, low values of cohesion were obtained. These "cohesion" values are used to compare the two test site rock conditions rather than to specifically establish a cohesion value for open joints.

Station 111+75

Specimens tested from this station included granites, granite gneisses, biotite gneisses, and pegmatites. The detailed data are contained in tables C-11 through C-17 and the data sheets and plots, appendix C.

A brief summary of the test data is contained in the following narrative. (Note: The general statements pertaining to test procedures for specimens from station 101+70 also apply here to specimens from station 111+75.)

Specific Gravity, Absorption, and Porosity. - Specimens from UJ2 had specific gravities from 2.65 to 2.85, absorptions from 0.08 to 0.31 percent, and porosity of less than 1 percent. Specimens from 111A and 111V had specific gravities from 2.61 to 2.77, absorptions from 0.13 to 0.73 percent, and porosities from 0.24 to 1.94 percent.

Elastic Modulus, Poisson's Ratio, Compressive Strength, and Ultrasonic Velocity. - Specimens from UJ2 had secant moduli of elasticity ranging from 1.06 to 11.63 M lb/in^2 (7.3 to 80.2 GPa), Poisson's ratio from 0.04 to 0.26, compressive strengths from 14 950 to 23 850 lb/in^2 (130.1 to 164.5 MPa), and ultrasonic velocities from 12 250 to 18 900 ft/s (3730 to 5760 m/s).

Specimens from 111A had elastic moduli ranging from 7.25 to 9.80 M lb/in^2 (50.0 to 67.6 GPa), Poisson's ratio from 0.04 to 0.24, compressive strengths from 12,750 to 25,100 lb/in^2 (88.0 to 173.2 MPa), and ultrasonic velocities from 16,100 to 17,150 ft/s (4910 to 5230-m/s).

Specimens from 111V had elastic moduli ranging from 7.14 to 9.52 M lb/in^2 (49.3 to 65.7 GPa), Poisson's ratio from 0.02 to 0.28, compressive strengths from 10 250 to 19 700 lb/in^2 (70.7 to 136.0 MPa), and ultrasonic velocities from 15 300 to 17 300 ft/s (4660 to 5270-m/s).

Tensile Strength. - Pegmatite dike and granite gneiss specimens from UJ2 had tensile strengths ranging from 1140 to 2520 lb/in^2 (7.87 to 17.4 MPa), respectively. Granite gneiss specimens from 111A had tensile strengths from 1040 to 2120 lb/in^2 (7.18 to 14.6 MPa). Pegmatite dike specimens from 111V had tensile strengths from 800 to 1740 lb/in^2 (5.5 to 12.0 MPa).

Shear Strength. - Nine shear tests on intact rock cores from 111A, 111V, and UJ2W and seven sliding friction tests on open joints in cores from 111A and UJ2E were performed.

Based on the average of the linear regression and angle-envelope methods, the cohesion and friction angle (Ø) of the intact rock features, such as banding and foliation, were 1730 lb/in^2 (11.9 MPa) and 60°, respectively. Utilizing the same criteria, the cohesion and friction angle (Ø) obtained from sliding friction tests of open joints were 68 lb/in^2 (0.48 MPa) and 42°, respectively.

Summary of Results. - Reviewing the laboratory rock core test data from stations 101+70 and 111+75, it appears that both sites have similar intact rock properties. Numerical averages of test data are listed in table 8.

Table 8. - Numerical Averages of Laboratory Core Test Data

	Station	
	101+70	111+75
Specific gravity	2.68	2.70
Absorption - percent	0.72	0.30
Porosity - percent	2.05	0.80
Sonic velocity (ft/s)	14 660	16 240
Poisson's ratio	0.10	0.16
Modulus of elasticity (x 10^6 lb/in^2)	7.16	7.95
Compressive strength (lb/in^2)	13 970	18 220
Tension (lb/in^2)	1 270	1 700
Cohesion (intact) (lb/in^2)	2 025	1 730
Cohesion (open joints) (lb/in^2)	36	68
Phi degree (intact)	43	60
Phi degree (open joints)	30	42

NOTE: 1 lb/in^2 = 6.900 kPa

Laboratory Core Test Data Analysis. - Although the average core test data indicate similar intact rock properties, a higher compressive strength range spread was noted at station 101+70 which indicates lower rock quality than at station 111+75. The 25 compressive strength values at 101+70 ranged from 6370 to 29 600 lb/in^2 (43.9 to 204.2 MPa). At station 111+75 the 21 compressive strength values ranged from 10 250 to 25 100 lb/in^2 (70.7 to 173.2 MPa). The number of specimens falling into each strength range group are listed in table 9.

Table 9. - Compressive Strength Range, Stations 101+70 and 111+75

Compressive strength 1,000 lb/in^2	Number of specimens	
	Station 101+70	Station 111+75
5-10	8	0
10-15	8	6
15-20	3	8
20-25	4	6
25-30	2	1

NOTE: 1 lb/in^2 = 6.900 kPa

A higher percentage of core tested, from station 111+75, had compressive strengths of 10,000 lb/in^2 (69.0 MPa) or higher.

The moduli of elasticity ranged from 1.59 to 14.08 M lb/in^2 (11.0 to 97.1 GPa) at station 101+70 for 26 specimens and from 1.06 to 11.63 M lb/in^2 (7.3 to 80.2 GPa) at station 111+75 for 21 specimens. The number of specimens falling into each moduli range group are listed in table 10.

Table 10. - Modulus of Elasticity Range, Stations 101+70 and 111+75

Modulus of elasticity M lb/in^2	Number of specimens	
	Station 101+70	Station 111+75
1-3	4	1
3-6	2	2
6-9	16	11
9-12	3	7
12+	1	0

NOTE: 1 lb/in^2 = 6.900 kPa

The secant modulus of elasticity for rock cores from both sites is similar with about the same number of test results falling in the 3 to 12 M lb/in^2 (20.7 to 82.8 GPa) range group.

The range of tensile strength values at station 101+70 varied from 300 to 2015 lb/in^2 (2.07 to 13.9 MPa), and at station 111+75 from 800 to 2520 lb/in^2 (5.5 to 17.39 MPa). The number of specimens following into each tensile strength range are listed in table 11.

Table 11. - Tensile Strength Range, Stations, 101+70 and 111+75

Tensile strength 100 lb/in^2	Number of specimens	
	Station 101+70	Station 111+75
3-5	1	0
5-7	2	0
7-9	2	1
9-11	2	1
11-13	0	2
13-15	2	3
15-17	1	4
17-19	2	4
19-21	3	1
21-23	0	2
23-25	0	2
25+	0	1

NOTE: 1 lb/in^2 = 6.900 kPa

As can be seen the tensile strengths of cores from station 111+75 were higher than cores from station 101+70. At station 111+75 less test results were in the lower strength ranges and more in the upper strength ranges. More specimens were available from station 111+75. As a result a greater total number of tests were performed from this site.

SECTION 10. - PETROGRAPHIC EXAMINATION

A petrographic examination was performed on rock cores from rock monitoring and in situ test instrumentation holes. This examination included the determination of the mineral composition, texture, grain size, and structure of the rock and a detailed description of the mineralogy as observed in thin sections. From this information a petrographic classification was determined.

The mode of failure of the rock core specimens from laboratory tests were observed and described. In addition, the angle of failure to the rock core axis was determined and the material associated with the failure plane identified. The results are contained in appendix D.

SECTION 11. - SUMMARY AND CONCLUSIONS

Comparison of the Two Test Stations

The results of field and laboratory investigations for stations 101+70 and 111+75 are summarized in table 12. The deformation modulus at the two sites are about the same magnitude. The in situ stress field at station 101+70 is about three times the magnitude at station 111+75. The inclinations of the principal in situ stresses were similar for both stations but the azimuth was about 100° greater at station 101+70.

The steel support system at station 101+70 had higher stresses, bending moments, and percent yield than at station 111+75. The maximum stress was about five times higher in compression, 47 000 vs. 10 000 lb/in^2, (324.3 vs. 69.0 MPa) and about equal in tension 10 000 vs. 12 000 lb/in^2 (69.0 vs. 82.8 MPa). The maximum bending moment was three times higher in tension, 2,402 vs. 884 K-in (27 140 vs. 9990 N·M) and about 20 times higher in compression, 5802 vs. 280 K-in (65 550 vs. 3160 N·M). The maximum stress was 85 and 33 percent of the yield stress at stations 101+70 and 11+75, respectively.

The maximum tensile load in the first stage concrete lining at station 101+70 was about 1.5 times greater than at station 111+75, 521 vs. 369 lb/in^2 (3.59 vs. 2.55 MPa). The maximum compressive load in the lining at station 101+70, however, was about 1.5 times <u>less</u> than at station 111+75, 522 vs. 812 lb/in^2 (3.60 vs. 5.60 MPa).

The rock properties obtained from laboratory tests, indicate that the intact rock at station 111+75 is slightly better than at station 101+70. All numerically averaged core test data indicated better rock properties at station 111+75 except for the cohesion properties for intact rock obtained from direct shear tests.

The varied results of the three instrumented supports at station 101+70 are in part attributed to the intersection of the second highway bore and the existing east cross passageway. The loads on the three supports do not correlate as well as those at station 111+75. The loss of the rock instrumentation prevented any correlation of loads on the supports and the rock movement. In addition the large rock fallout at station 101+70 during excavation of the second highway bore may be an indication that a deeper zone of rock may have been influenced by the excavation. This may account in part for the higher support loads at station 101+70. The damage to instrumentation leads and the erratic data obtained after repair further prevents a positive statement as to the loading history on the supports. The higher overburden, higher in situ stress field, slightly lower rock quality, as based on laboratory tests, and the more complex geology all appear to contribute to higher loads on the steel supports and concrete lining at station 101+70 than those at station 111+75.

Table 12. - Comparison of Two Test Stations - Stations 101+70 and 111+75
(Tension is +, Compression is -)

	Station 101+70	Station 111+75
Rock type	IIb - IIIa	IIIa
Overburden - feet	800	400
In situ properties		
Moduli of deformation x 10^6 lb/in^2	0.40 to 0.80	0.67
In situ stresses (all compressive, except S1, station 101+70)		
S_1 lb/in^2	139	-469
Azimuth - degrees	180	84
Inclination - degrees	96	110
S_2 lb/in^2	-3583	-1371
Azimuth - degrees	256	135
Inclination - degrees	24	30
S_3 lb/in^2	-5578	-1655
Azimuth - degrees	272	182
Inclination - degrees	113	111

NOTE: 1 1/bin^2 = 6.900 kPa
k/in^2 = 6.900 MPa
k-in = 11.30 N·m

Table 12. - Comparison of Two Test Stations -
Stations 101+70 and 111+75 - (continued)

	Station 101+70	Station 111+75
Steel Support System		
Support 477 (yield stress 55 K/in^2)		
Stresses (to nearest K/in^2)		
Inside fiber	3 to -22	
Neutral axis	-1 to -14	
Outside fiber	5 to -7	
Moment K-in	1988 to -1052	
Percent yield	40	
Support 478 (yield stress 55 K/in^2)		
Stresses (to nearest K/in^2)		
Inside fiber	7 to -19	
Neutral axis	1 to -21	
Outside fiber	5 to -47	
Moment K-in	2262 to -5802	
Percent yield	85	
Support 479 (yield stress 36 K/in^2)		
Stresses (to nearest K/in^2)		
Inside fiber	10 to -24	
Neutral axis	-1 to -12	
Outside fiber	8 to -25	
Moment K-in	2402 to -2236	
Percent yield	69	
Support 225 (yield stress 36 K/in^2)		
Stresses (to nearest K/in^2)		
Inside fiber		8 to -5
Neutral axis		8 to -3
Outside fiber		12 to -1
Moment K-in		555 to -190
Percent yield		33

NOTE: 1 1/bin^2 = 6.900 kPa
k/in^2 = 6.900 MPa
k-in = 11.30 N·m

Table 12. - Comparison of Two Test Stations - Stations 101+70 and 111+75 - (continued)

	Station 101+70	Station 111+75
Steel Support System - (continued)		
Support 227 (yield stress 36 K/in^2)		
Stresses (to nearest K/in^2)		
Inside fiber		5 to -10
Neutral axis		6 to -6
Outside fiber		7 to -3
Moment K-in		884 to -224
Percent yield		28
Support 229 (yield stress 36 K/in^2)		
Stresses (to nearest K/in^2)		
Inside fiber		5 to -9
Neutral axis		6 to -7
Outside fiber		6 to -9
Moment K-in		543 to -280
Percent yield		25
Lining System		
Maximum tensile load lb/in^2	521	369
Maximum compressive load lb/in^2	-522	-812
Average Laboratory Core Test Data		
Specific gravity	2.68	2.70
Absorption - percent	0.72	0.30
Porosity - percent	2.05	0.80
Sonic velocity ft/s	14 660	16 240
Poisson's ratio	0.10	0.16
Modulus of elasticity (x 10^6 lb/in^2)	7.16	7.95
Compressive strength (lb/in^2)	13 970	18 220
Tension (lb/in^2)	1270	1700
Cohesion (intact) lb/in^2	2025	1730
Cohesion (open joints) lb/in^2	36	68
Phi degree (intact)	43	60
Phi degreee (open joints)	30	42

NOTE: 1 $1/bin^2$ = 6.900 kPa
k/in^2 = 6.900 MPa
k-in = 11.30 N·m

Conclusions

In almost every facet of this study some problems were encountered which resulted in incomplete or questionable data accumulation. Although detail plans were developed and precautions taken, problems developed. The challenges presented were no different than those facing other rock mechanics investigations; namely, "Perform tests and instrumentation, accumulate data, and avoid interferring with the contractor's operations." Nevertheless, the various problems mentioned previously and summarized below did occur and therefore precluded the accumulation of an ideal and complete set of field data.

Problems encountered:

In Situ Stress Determination. - Limited number of successful test locations in each borehole to determine the complete in situ stress condition.

In Situ Modulus Determination. - Inability to perform vertical jacking test due to poor rock conditions in the test adit arch.

Rock Monitoring Instrumentation. - Failure of the instrumentation due to damage to the conduit carrying the leads which allowed water to submerge the microswitches.

Support Instrumentation. - Loss of 50 percent of the gages at station 111+75 when first stage concrete was placed. Cable leads at station 101+70 severed and replaced during second stage concrete lining operations. Data were erratic thereafter.

Pore Pressure Meters. - Meters were installed after grouting operations but additional grouting was conducted later which made subsequent data questionable.

Part of the objective of this study was to obtain basic field data which could be used by others to suplement, verify, or extend existing theoretical data for the design of large tunnels and underground openings. Because of the aforementioned problems a firm set of conclusions, which can be incorporated into guidelines, cannot be derived.

However, several correlations developed as a result of this investigation. The in situ stress field measured at station 101+70 was approximately three times greater than at station 111+75. The maximum loads and percent yield of the steel supports at station 101+70 were about five to three times higher, respectively, than at station 111+75. The geology is more complex at station 101+70. There are more faults and the rock is of poorer quality which appear to contribute to the higher support loads at station 101+70.

In situ and laboratory tests indicate very similar rock properties with station 101+70 having slightly poorer rock properties, which again appears to contribute to the higher support loads.

The steel support and lining system reactions were generally compatible and tend to follow tension and compression trends.

The concept of obtaining in situ and laboratory rock properties and monitoring the rock-support-lining system to advance the art of underground construction is sound. However, the success of obtaining reliable data involves an element of risk. The USBR received full cooperation from the CDOH and the management of the contractor, Peter Kiewit Sons' - Brown and Root. Nevertheless, instrumentation was damaged or rendered inoperative during this study for which no one but the USBR could be held accountable or responsible for.

In developing this investigation more success may have been realized if consideration had been given to more contractor involvement. An engineer from the contractor should have been assigned and made coresponsible for the instrumentation. This may have resulted in less damaged instrumentation and more useable data.

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APPENDIX A

DRILL HOLE LOGS

Table A-1 Geologic Log of Drill Hole UJ1W

Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 1 OF 4

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado

HOLE NO. UJ1W LOCATION West wall GROUND ELEV. DIP (ANGLE FROM HORIZ.) 0°

COORDS. N. E.

BEGUN FINISHED DEPTH OF OVERBURDEN 0 TOTAL DEPTH 24.1' BEARING 270°

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Dry LOGGED BY S. Volz LOG REVIEWED BY M. McKeown

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	CORE RECOVERY RQD	ELEVATION (FEET)	DEPTH (FEET) x10⁻¹	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
Drill Rig: Joy 128, air driven Core Barrel: Christensen Double tube D3 Drilling Fluid: Water No casing	NX	62 100 100	0 57 65		10, 20, 30, 40, 50, 60, 70, 80, 90			see below

0.0 - 3.8'; BIOTITE GNEISS, gray-black, mostly fresh with some biotite altered to chlorite. Crystals approximately 1/32-inch across, foliation dips 67-85°* generally dips 60°.

1.3'; JOINT, dip 37°.

2.0'; JOINT, dip 75°, slickensides parallel to strike. Minor chlorite on joint surfaces.

2.4'; JOINT, dip 60°, slickensides parallel to strike, minor chlorite on joint surfaces.

2.6'; JOINT, dip 60°, slickensides parallel to strike, calcite on joint surfaces.

2.7'; JOINT, dip 27°, chlorite on joint surfaces.

2.95'; JOINT, dip 60°, slickensides parallel to strike, calcite and chlorite on joint surfaces.

3.15'; JOINT, dip 35°, slickensides discontinuous, 1/32-inch thick calcite - chlorite on surfaces.

3.3'; JOINT, dip 42°, slickensides, chlorite on joint surfaces.

3.5'; JOINT, dip 75°, slickensides parallel to strike, calcite and chlorite on joint surfaces.

3.8 - 3.9'; PEGMATITE DIKE, pink, biotite altered to chlorite up to 1/4-inch thick.

3.9 - 6.8'; BIOTITE GNEISS, fresh, gray-black, some biotite altered to chlorite.

3.9'; JOINT, dip 58°, slickensides, minor chlorite on joint surfaces.

4.0'; JOINT, dip 25°, calcite up to 1/32-inch thick on joint surfaces.

4.3'; JOINT, dip 30°, discontinuous calcite on joint surfaces.

4.6'; JOINT, dip 55°, slickensides, chlorite, minor calcite on joint surfaces.

4.9'; JOINT, dip 34° , discontinuous calcite crust, minor chlorite on joint surfaces.

5.5'; JOINT, dip 30°, discontinuous calcite crust, chlorite on joint surfaces.

5.5 - 5.7'; FRAGMENTED INTERVAL, discontinuous calcite crust on some fragments, chlorite on many fragment surfaces.

5.7'; JOINT, dip 29°, chlorite on joint surfaces.

6.0'; JOINT, dip 0°, chlorite on joint surfaces.

EXPLANATION

CORE LOSS

CORE RECOVERY

NOTE: Rock is hard except where noted. Only those joints which have separated are recorded. Many unseparated joints may be observed which go wholely or partly through the core. Many of these joints are filled with calcite. *All angles measured from perpendicular to core axis unless otherwise noted. "Strike' is perpendicular to core axis.

	Ex	Ax	Bx	Nx
Approx. size of hole (X-series)	1-1/2"	1-7/8"	2-3/8"	3"
Approx. size of core (X-series)	7/8"	1-1/8"	1-5/8"	2-1/8"
Outside dia. of casing (X-series)	1-13/16"	2-1/4"	2-7/8"	3-1/2"
Inside dia. of casing (X-series)	1-1/2"	1-29/32"	2-3/8"	3"

FEATURE South bore PROJECT Eisenhower STATE Colorado SHEET 1 OF 4 HOLE NO. UJ1W

GPO 770-K

Table A-1 Geologic Log of Drill Hole UJ1W (continued)

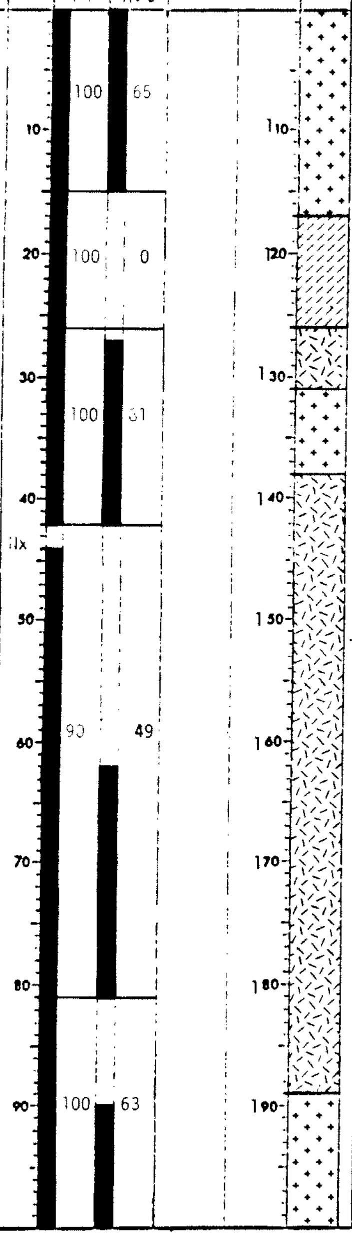
reau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 2 OF 4

EATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado
OLE NO. UJ1W LOCATION West wall COORDS. N. E. GROUND ELEV. DIP (ANGLE FROM HORIZ.) 0°
EGUN FINISHED DEPTH OF OVERBURDEN 0 TOTAL DEPTH 24.1' BEARING 270°
EPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Dry LOGGED BY S. Volz LOG REVIEWED BY M. McKeown

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	CORE RECOVERY RQD	ELEVATION (FEET)	DEPTH (FEET) X10⁻¹	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION



Drill Rig:

Joy 128, air driven

Core Barrel:

Christensen Double tube D3

Drilling Fluid:

Water
No casing

6.0 - 6.3'; FRAGMENTED INTERVAL, discontinuous calcite crust on some fragments, chlorite on many fragment surfaces, some slickenslides.

6.3'; JOINT, dip*56°, chlorite on joint surfaces.

6.8 - 6.9'; PEGMATITE DIKE, pink, rectangular feldspar crystals up to 1/4-inch long, biotite crystals, mostly 1/32-inch across, some biotite altered to chlorite.

6.9 - 9.6'. BIOTITE GNEISS, gray-black, mostly fresh with some biotite altered to chlorite, foliation 30° to 70°

7.0 - 7.8'; FRAGMENTED INTERVAL, as from 5.5 to 5.7', fine-grained, some fragments slightly friable, slickensides on some fragments, chlorite up to 1/32-inch thick, calcite on some fragment surfaces.

7.8'; JOINT; dip 40°, slickensides, calcite and chlorite on joint surfaces.

7.9'; JOINT, dip 18°, calcite and chlorite on joint surfaces.

8.2'; JOINT, dip 68°, slickensides, calcite and chlorite on joint surfaces.

8.3'; JOINT, 25° , chlorite on joint surface.

8.3'; PEGMATITE DIKE, 3/4-inch thick, pink, cuts partly into core.

9.0'; TWO JOINTS, intersecting, dips 69° and 58°, slickensides, minor chlorite on joint surfaces.

9.5'; JOINT, dip 76°, slickensides, chlorite on joint surfaces.

9.6 - 11.7'; PEGMATITE DIKE, pink, rectangular feldspar crystals up to 1/2-inch long, biotite crystals mostly 1/16-inch across, some biotite altered to chlorite.

10.2'; TWO JOINTS, intersecting, dips 30° and 75° slickensides, chlorite on joint surfaces.

10.6'; JOINT, dip 30°, chlorite on joint surfaces.

10.9'; JOINT, dip 72°, calcite, chlorite 1/32-inch thick on joint surfaces.

11.15'; JOINT, dip 25°, chlorite on joint surfaces.

11.7 -12.6'; BIOTITE GNEISS, Fresh with some biotite altered to chlorite. Foliation dip ranges from 30° to 70°.

11.66'; JOINT, dip 40°, chlorite on joint surfaces.

11.8'; JOINT, dip 45°, slickensides, chlorite on joint surfaces.

11.83'; JOINT, dip 27°, chlorite on joint surfaces.

EXPLANATION

CORE LOSS
CORE RECOVERY

NOTE: Rock is hard except where noted. Only those joints which have separated are recorded. Many unseparated joints may be observed which go wholely or partly through the core. Many of these joints are filled with calcite. *All angles measured from perpendicular to core axis unless otherwise noted. "Strike" is perpendicular to core axis.

Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of cas'ng (X-series). Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of cas'ng (X-series). Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

FEATURE South Bore PROJECT Eisenhower STATE Colorado SHEET 2 OF 4 HOLE NO. UJ1W

GPO 779-40

Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 3 OF 4

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado

HOLE NO. UJ1W LOCATION West wall GROUND ELEV. DIP (ANGLE FROM HORIZ.) 0°

COORDS. N. E.

BEGUN FINISHED DEPTH OF OVERBURDEN 0 TOTAL DEPTH 24.1' BEARING 270°

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Dry LOGGED BY S. Volz LOG REVIEWED BY M. McKeown

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	CORE RECOVERY RQD	ELEVATION (FEET)	DEPTH (FEET) x10^-1	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
Drill Rig:		100	63					11.9'; JOINT, dip*15°, chlorite on joint surfaces.
Joy 128, air driven								11.93'; JOINT, dip 18°, chlorite on joint surfaces.
	10				210			12.03'; JOINT, dip 18°, chlorite on joint surfaces.
Core Barrel:								12.[illegible]'; JOINT, dip 50°, slickensides.
Christensen Double tube D3								12.16'; JOINT, dip 18°, slickensides, chlorite on joint surfaces.
Drilling Fluid:	20				220			12.3', JOINT, dip 40°, slickensides, chlorite on joint surfaces.
Water No casing		100	98					12.4'; JOINT, dip 30°, chlorite on joint surfaces.
								12.43'; JOINT, dip 18°, slickensides, chlorite on joint surfaces.
	30				230			12.5'; JOINT, dip 43°, slickensides, chlorite on joint surfaces.
								12.56-12.6'; FRAGMENTED INTERVAL
	40				240			12.6-24.1'; BIOTITE GRANITE, gray, fresh, crystals about 1/16-inch across. Most joints discolored pinkish white.
		Totals 96	52					12.6'; JOINT, dip 45°, calcite on joint surfaces.
	50				250			13.1-13.8'; PEGMATITE DIKE, as from 9.6 to 11.5'. Dike cuts across 1/5 of core.
								14.05'; JOINT, dip 45°, slickensides.
								14.2'; JOINT, dip 30°, minor calcite on joint surfaces.
	60				260			15.0'; JOINT, dip 40°, calcite on joint surfaces.
								15.7', JOINT, dip 25°, calcite on joint surfaces.
								15.95'; JOINT, dip 43°, minor calcite on joint surfaces.
	70				270			16.0'; JOINT, dip 43°, minor calcite on joint surfaces.
								16.2'; JOINT, dip 17°, calcite on joint surfaces.
								16.4'; JOINT, dip 64°, calcite on joint surfaces.
	80				280			16.8'; JOINT, dip 35°, calcite on joint surfaces.
								16.85'; JOINT, dip 35°, calcite on joint surfaces.
								17.1'; JOINT, dip 17°, minor calcite on joint surfaces.
	90				290			17.25'; JOINT, dip 17°, minor calcite on joint surfaces.
								17.4'; JOINT, dip 15°, calcite on joint surfaces.
								18.5'; JOINT, dip 32°, discontinuous calcite crust, chlorite on joint surfaces.

EXPLANATION

CORE LOSS / CORE RECOVERY

NOTE: Rock is hard except where noted. Only those joints which have separated are recorded. Many unseparated joints may be observ[ed] which go wholely or partly through the core. Many of these joints are filled with calcite. *All angles measured from perpendicular to core axis unless otherwise noted. "Strike" is perpendicular to core axis.

Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

FEATURE South Bore PROJECT Eisenhower STATE Colorado SHEET 3 OF 4 HOLE NO. UJ1W

GPO 779-404

Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 4 OF 4

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado
HOLE NO. UJ1W LOCATION West wall GROUND ELEV. DIP (ANGLE FROM HORIZ.) 0°
COORDS. N. E.
BEGUN FINISHED DEPTH OF OVERBURDEN 0 TOTAL DEPTH 24.1' BEARING 270°
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Dry LOGGED BY S. Volz LOG REVIEWED BY H. McKeown

18.9 - 20.1', PEGMATITE DIKE pink, some biotite altered to chlorite, rectangular feldspar crystals up to 1/2" long.

19.1', JOINT, dip 34°.

19.5', JOINT, dip 50° , slickensides, chlorite on joint surfaces.

19.60'; JOINT, dip 40°, slickensides.

19.90'; JOINT, dip 32°, slickensides, calcite, and minor amounts of chlorite on joint surfaces.

20.2' ; JOINT, dip 29°, calcite on joint surfaces.

20.3' ; JOINT, dip 40°, calcite on joint surfaces.

20.65'; JOINT, dip 38°, calcite on joint surfaces.

20.85', JOINT, dip 38°, calcite on joint surfaces.

21.35'; JOINT, dip 70°, calcite on joint surfaces.

21.55'; JOINT, dip 35°, calcite on joint surfaces.

22.35'; JOINT, dip 20°, calcite on joint surfaces.

22.55'; JOINT, dip 39°, calcite on joint surfaces.

22.8' ; JOINT, dip 37°, calcite on joint surfaces.

23.0' ; JOINT, dip 66°, calcite on joint surfaces.

23.1' ; JOINT, dip 59°, calcite on joint surfaces.

23.2' ; JOINT, dip 25°, calcite on joint surfaces.

23.7' ; JOINT, dip 45°, calcite on joint surfaces.

23.9' , JOINT, dip 45°, calcite on joint surfaces.

FEATURE South Bore PROJECT Eisenhower STATE Colorado SHEET 4 OF 4 HOLE NO. UJ1W

Table - A-2 Geologic Log of Drill Hole UJ1E

Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 1 OF 3

FEATURE: South Bore PROJECT: Eisenhower Tunnel STATE: Colorado

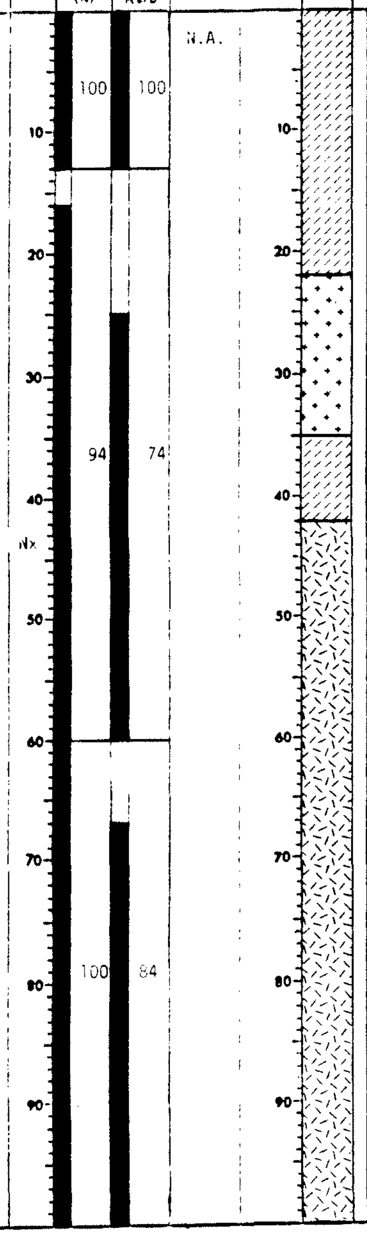
HOLE NO.: UJ1E LOCATION: East Wall GROUND ELEV.: DIP (ANGLE FROM HORIZ.): 0

COORDS. N. E. TOTAL DEPTH: 25.2 BEARING: 90°

BEGUN: FINISHED: DEPTH OF OVERBURDEN: 0

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: Dry LOGGED BY: M. McKeown LOG REVIEWED BY:

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	CORE RECOVERY RQD	ELEVATION (FEET)	DEPTH (FEET) X10⁻¹	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION



Drill Rig:

Joy 12B, air driven

Core Barrel:

Christensen Double tube D3

Drilling fluid:

Water
No casing

0.0 - 2.2'; BIOTITE GNEISS, gray, locally granitic, fresh, poorly to well foliated, dip 58°*, fine-grained.

0.4'; JOINT, dip 35°, chlorite-calcite coated surface.

1.9'; TWO JOINTS, intersecting, dips 47°, fresh unweathered surfaces.

2.2 - 3.5'; PEGMATITE DIKE, pink, granitic, K-feldspar crystals to 1/2 inch, seams of biotite up to 1-inch thick, some healed or unseparated fractures.

2.3', JOINT, dip 13°, surface fresh.

2.4'; JOINT, dip 19°, surface slightly altered, very irregular.

2.7'; JOINT, dip 32°, parallel to biotite band in the pegmatite dike. Surface fresh but polished, slickensides, direction 30° from strike.

3.2'; JOINT, dip 60°, surface slightly altered, very irregular.

3.3', JOINT, dip 60°, surface slightly altered, extremely irregular, some slickensides parallel to strike.

3.4'; JOINT, dip 58°, slight alteration of surface, talcy, very irregular.

3.5 - 4.2', BIOTITE GNEISS, gray, fine-grained, locally granitic, fresh, foliation poorly developed, dip irregular.

3.8', JOINT, dip 68°, thin calcite coating on surface.

4.1', JOINT, dip 20°, slight alteration of surface.

4.2 - 10.1', GRANITE, grayish-pink, fresh crystals range from 1/32 inch to 1/4 inch, locally banded by K-feldspar zones.

6.4'; JOINT, dip 48°, slightly altered on surface.

8.0'; JOINT, dip 60°, slightly altered on surface.

8.7'; JOINT, dip 59°, slightly chloritized on surface, some calcite coating, slickensides parallel to strike.

8.8'; JOINT, dip 57°, slight alteration on surface, thin (1/64 inch) calcite filling.

9.1', TWO JOINTS, dips 65°, 1/4-inch apart, slightly altered of some calcite filling, slickensides parallel to strike.

9.6', TWO JOINTS, dips 67°, slightly altered on surfaces, talcy.

EXPLANATION

CORE LOSS

CORE RECOVERY

Rock is hard except where otherwise noted. Only those joints which are separated are recorded. Unseparated joints may go wholly or partly through the core. Many of these joints are filled with calcite.
*All dips from perpendicular to core axis. "Strike" is a line perpendicular to core axis.

Approx. size of hole (X-series)	Ex = 1-1/2",	Ax = 1-7/8",	Bx = 2-3/8",	Nx = 3"
Approx. size of core (X-series)	Ex = 7/8",	Ax = 1-1/8",	Bx = 1-5/8",	Nx = 2-1/8"
Outside dia. of casing (X-series)	Ex = 1-13/16",	Ax = 2-1/4",	Bx = 2-7/8",	Nx = 3-1/2"
Inside dia. of casing (X-series)	Ex = 1-1/2",	Ax = 1-29/32",	Bx = 2-3/8",	Nx = 3"

FEATURE: South Bore PROJECT: Eisenhower Tunnel STATE: Colorado SHEET 1 OF 3 HOLE NO. UJ1E

GPO 778-404

Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 2 OF 3

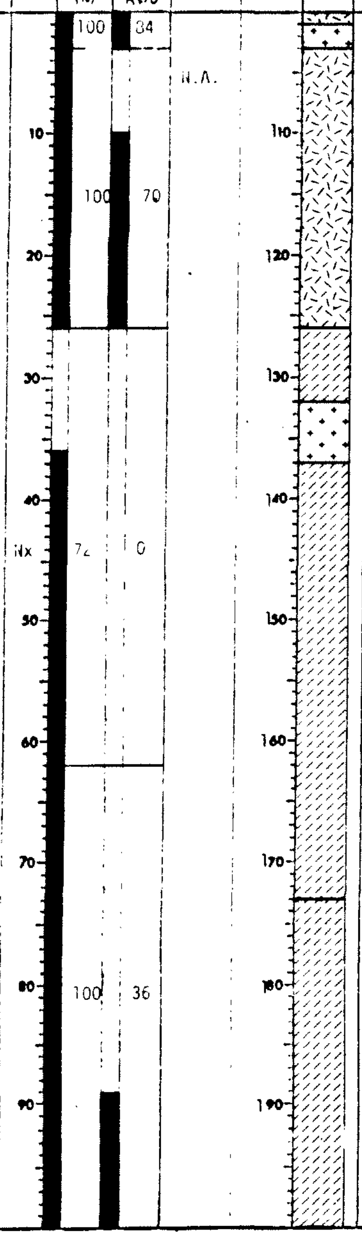
FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado

HOLE NO. UJ1E LOCATION East wall COORDS. N. E. GROUND ELEV. DIP (ANGLE FROM HORIZ.) 0

BEGUN FINISHED DEPTH OF OVERBURDEN 0 TOTAL DEPTH 25.2 BEARING 90°

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Dry LOGGED BY M. McKeown LOG REVIEWED BY

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	CORE RECOVERY RQD	ELEVATION (FEET)	DEPTH (FEET) X10⁻¹	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION



10.1 - 10.3'; PEGMATITE DIKE, pink, granitic, K-feldspar crystals to 1 inch, minor amount of biotite and pyrite, numerous healed fractures. Each contact separated from adjacent rock. *Dips of contacts 15° and 30°.

10.3 - 12.6', GRANITE, as between 4.2' and 10.1.'

10.6'; TWO JOINTS, 1/2-inch apart, dips 38°, surfaces slightly altered, calcareous and talcy.

11.6'; JOINT, dip 45°, surface slightly altered, calcareous and talcy.

11.9'; JOINT, dip 65°, surface irregular, slightly altered, calcareous, passes through biotite-rich zone 4-inches thick, across alinement of crystals.

12.6 - 13.2', BIOTITE GNEISS, gray, locally granitic, fresh, fine-grained, foliation poorly developed, grades to pegmatite dike.

12.6', JOINT, dip 23°, chlorite-calcite coating on surfaces.

12.8'; JOINT, dip 14°, chlorite-calcite coating on surfaces.

13.1', JOINT, dip 19°, chlorite-calcite coating on surfaces.

13.2 - 13.7'; PEGMATITE DIKE, pink, granitic, K-feldspar crystals to 1 inch, minor pyrite, grades to gneiss each side, dip approximately 30° each side. Material is fractured but unseparated.

13.3', JOINT, dip 18°, chlorite-calcite coating on surfaces.

13.6'; TWO JOINTS, 1/2-inch apart, dips 15°, chlorite-calcite coating on surfaces.

13.7 - 25.2'; BIOTITE GNEISS, gray, locally granitic, fresh, fine-grained, foliation well to poorly developed, dips irregular, 55° at 21.4', 52° at 22.5', 48° at 23.7'.

13.8'; JOINT, dip, 20°, slight alteration of surfaces.

14.0'; JOINT, dip 20°, slight alteration of surfaces.

14.1'; JOINT, dip 80°, slight alteration of surfaces, chloritized.

14.2'; JOINT, dip 23°, slight alteration of surfaces.

EXPLANATION

CORE LOSS

CORE RECOVERY

Rock is hard except where otherwise noted. Only those joints which are separated are recorded. Unseparated joints may go wholly or partly through the core. Many of these joints are filled with calcite.
*All dips from perpendicular to core axis. "Strike" is a line perpendicular to core axis.

Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
[illegible] Bx = 2-3/8", Nx = 3"

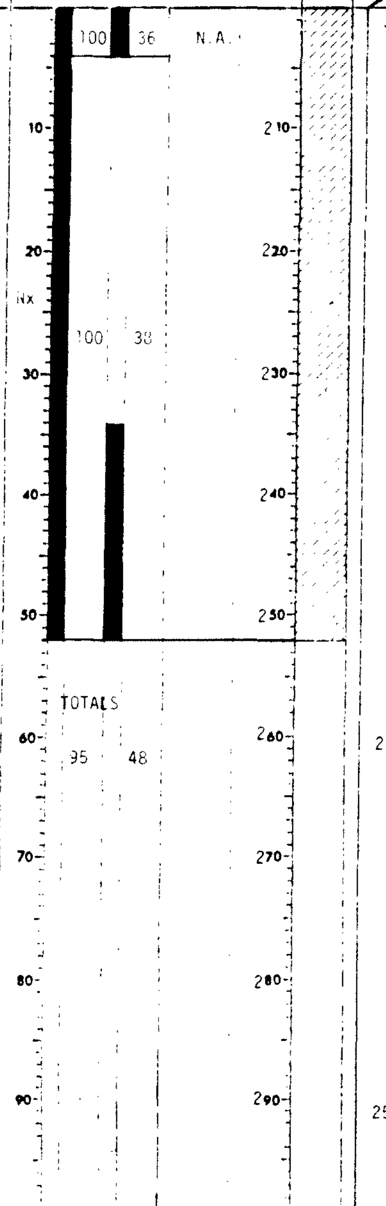
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 3 OF 3

FEATURE South bore PROJECT Eisenhower Tunnel STATE Colorado
HOLE NO. UJ1E LOCATION East wall COORDS. N. E. GROUND ELEV. DIP (ANGLE FROM HORIZ.) 0°
BEGUN FINISHED DEPTH OF OVERBURDEN 0 TOTAL DEPTH 25.2 BEARING 90°
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Dry LOGGED BY M. McKeown LOG REVIEWED BY

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	CORE RECOVERY RQD	ELEVATION (FEET)	DEPTH (FEET) X10⁻¹	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
	Nx	100 / 100 / TOTALS 95	36 / 38 / 48	N.A.				see below



14.2 - 15.0'; FRAGMENTED INTERVAL, mostly intersecting joints with slight chloritization on surfaces.

15.0'; TWO JOINTS, intersecting, dips*30° and 25°, slight alteration of surfaces.

16.2'; JOINT, dip 24°, surfaces chloritized and calcite coated.

16.4'; TWO JOINTS, 1/2-inch apart, dips 13°, surfaces calcite and chlorite coated, one very irregular.

16.6'; JOINT, dip 20°, chlorite and calcite filled.

16.75'; JOINT, dip 20°, chlorite and calcite filled.

17.1'; JOINT, dip 51°, chlorite and calcite on surfaces.

17.3'; PEGMATITE DIKE, pink, granitic, mostly K-feldspar, dip approximately 50°, 1/2-inch thick.

17.6'; JOINT, dip 75°, slight chloritization of surfaces.

17.7'; JOINT, dip 24°, chloritized, filled with calcite.

17.8'; JOINT, dip 60°, slightly altered on surfaces.

18.0'; JOINT, dip 30°, slightly altered on surfaces, calcite filled.

22.3'; TWO JOINTS, 1/4-inch apart, dips 30°, slight alteration on surfaces.

23.1'; JOINT, dip 50°, slight alteration of surfaces, calcite filling, talcy.

23.1 - 23.4'; FRAGMENTED INTERVAL, surfaces altered, chloritized and calcite filled and coated, probably intersecting joints.

23.8'; TWO JOINTS, 1/2-inch apart, dips 16°, surfaces chloritized and calcite filled.

24.2'; JOINT, dip 23°, surfaces chloritized and calcite filled.

24.7'; JOINT, dip 10°, surface chloritized and calcite coated.

24.8'; JOINT, dip 16°, surfaces chlorite and calcite coated.

25.2'; TWO JOINTS, intersecting, dips 30° and 46°, surfaces chloritized and calcite coated.

25.2' - Total depth of hole.

EXPLANATION

Rock is hard except where otherwise noted. Only those joints which are separated are recorded. Unseparated joints may go wholly or partly through the core. Many of these joints are filled with calcite. *All dips from perpendicular to core axis. "Strike" is a line perpendicular to core axis.

CORE LOSS
CORE RECOVERY

Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

FEATURE South bore PROJECT Eisenhower Tunnel STATE Colorado SHEET 1 OF 3 HOLE NO. UJ1E

GPO 778-404

Table A-3 Geologic Log of Drill Hole 101V

Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 1 OF 1

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado

HOLE NO. 101V LOCATION Crown GROUND ELEV. DIP (ANGLE FROM HORIZ.) +90

COORDS. N. E.

BEGUN FINISHED DEPTH OF OVERBURDEN 0 TOTAL DEPTH 93.1 BEARING N.A.

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Dry LOGGED BY M. McKeown LOG REVIEWED BY

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS

Drill Rig:

Joy 12B, air driven

Core Barrel:

Christensen Double tube D3

Drilling fluid:

Water
No casing

Core Recovery (%)	RQD
67	12
100	69
95	55
100	82
100	92
91	30
100	30
100	47
100	9
100	0
100	83
95	76
100	74
100	30
100	86
100	30
100	65
100	73
100	20
100	30
96	12
100	85
TOTAL: 91	51

CLASSIFICATION AND PHYSICAL CONDITION

0 - 10.6'; BIOTITE GNEISS, gray, fresh, fine- to medium-grained, foliated, dips * range from 0° to 45°. Joint dips range from 0° to 90°, generally parallel to foliation surfaces chloritized.

10.6 - 11.0'; PEGMATITE DIKE, pink, fresh, K-feldspar rich, granitic.

11.0 - 20.2'; BIOTITE GNEISS, gray, fresh, foliated, dips range from 10° to 45°. Joints dip parallel to foliation, surfaces generally chloritized.

20.2 - 21.6'; PEGMATITE DIKE, pink, fresh, K-feldspar rich, granitic.

21.6 - 44.0'; BIOTITE GNEISS, gray, fresh, fine- to medium-grained, foliated, dips range from 0° to 70°, locally tightly folded. Joint dips range from 0° to 90°, surfaces commonly chloritized, calcite filled and locally healed.

44.0 - 51.5'; GRANITE GNEISS, gray, fresh to locally altered, fine- to medium-grained, poorly to locally well foliated, dip 40°, highly fractured but healed, grades to granite below.

51.5 - 54.2'; GRANITE, gray, slightly altered, chloritized, medium- to coarse-grained, highly fractured.

54.2 - 83.3'; GRANITE GNEISS, gray, fine- to coarse-grained, locally very dark gray and biotite rich, pegmatitic and migmatitic, altered, foliation generally dips 40°. Joint dips range from 30° to 70°, chloritized and calcite filled locally with some fractures healed.

83.3 - 89.1'; GRANITE, gray, fresh, coarse-grained, grades to pegmatite below. Joints dip 75°.

89.1 - 91.1'; PEGMATITE, pink, granitic, K-feldspar and biotite rich. Fractures calcite and chlorite filled.

91.1 - 93.1'; BIOTITE GNEISS, very dark gray, biotite rich but granitic, foliation poorly developed, dips 45°, grades from pegmatite above. Fractures calcite healed.

EXPLANATION

CORE LOSS / CORE RECOVERY

*All angles measured from perpendicular to core axis unless otherwise noted.

Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

South Bore PROJECT Eishenhower Tunnel STATE Colorado SHEET 1 OF 1 HOLE NO. 101V

GPO 779-404

Table A-4 Geologic Log of Hole 101A

Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 1 OF 2

FEATURE South bore PROJECT Lisenhower Tunnel STATE Colorado

HOLE NO. 101A LOCATION Crown COORDS. N. ... E. ... GROUND ELEV. ... DIP (ANGLE FROM HORIZ.) +60°

BEGUN ... FINISHED ... DEPTH OF OVERBURDEN 0 TOTAL DEPTH 102.9' BEARING 0°

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Dry LOGGED BY W. Collins LOG REVIEWED BY N. McKeown

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	CORE RECOVERY RQD	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION

Drill Rig:

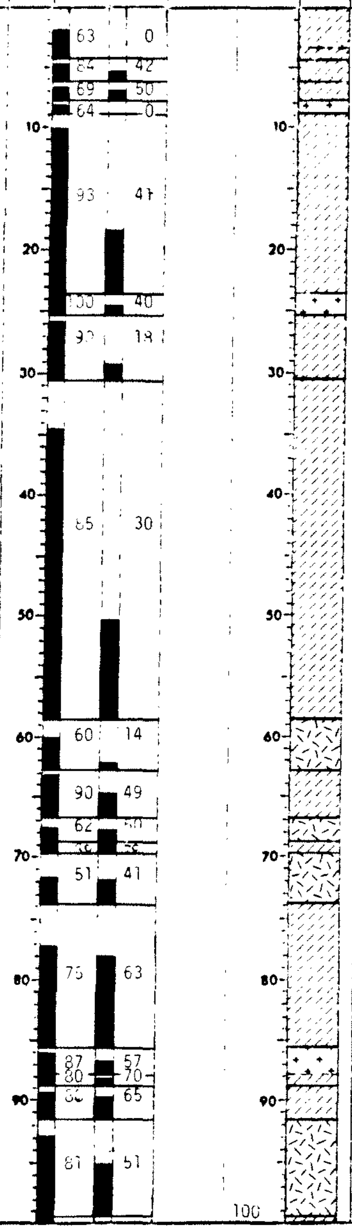
Joy 12B, air driven

Core barrel:

Christensen Double tube D3

Drilling fluid:

water no casing



0 - 4.3' GRANITE GNEISS, fresh, joints slickensided and coated with thin, pink calcite. Joint dips * vary from 45° to 60°, generally parallel to foliation which dips from 45° to 60°.

3.5 - 4.6' PEGMATITE DIKE

4.3 - 6.2'; BIOTITE GNEISS, fresh, joint surfaces slickensided and chloritized, dips vary from 60° to 75°, generally parallel to foliation.

6.2 - 7.8'; GRANITE GNEISS, fresh, joints coated with thin greenish calcite. Dips vary from 40° to 50°. Foliation dips from 40° to 50°.

7.8 - 8.9', PEGMATITE DIKE, fresh with large K-feldspar crystals. Joints coated with thin chlorite and gray calcite. Dips vary from 40° to 50°.

8.9 - 23.6'; GRANITE GNEISS, fresh and tightly folded. Joints coated with thin greenish chlorite and slickensided. Dips vary from 35° to 50°, foliation dip 0°, generally.

23.6 - 25.3'; PEGMATITE DIKE, dip 45°, contains large K-feldspar crystals and 1/8- to 1/4-inch veins of biotite, fresh except on joint surfaces which are crumbly and coated with thin calcite or chlorite. Some joints are slickensided. Dips vary from 25° to 40°.

25.3 - 30.4'; GRANITE GNEISS, fresh. Joints slickensided, coated with thin chlorite or calcite. Dips vary from 40° to 50° and are parallel to foliation. Joints crosscut foliation dipping 45° from 25.3 to 26.1, well developed foliation from 28.1' to 28.6'.

30.4 - 30.6'; PEGMATITE DIKE, dip 45°, across foliation, badly fractured.

30.6 - 58.5', GRANITE GNEISS, fresh, joints slickensided and chlorite and calcite coated, dips range from 5° to 60°, parallel and cross foliation. Foliation dips range from 25° to 60°. Localized areas of pegmatite, garnets at 58.5'.

58.5 - 62.8'; GRANITE, gray to pink, generally fresh, coarse-grained. Joints dip from 30° to 40°, slickensided, surfaces are calcite coated. Altered zone from 59.0 to 60.4', highly fractured.

62.8 - 66.9'; BIOTITE GNEISS, locally granitic and slightly [illegible] generally fresh, medium-grained. Joints dip from 5° to 45°, slickensided, surfaces are calcite coated.

66.9 - 66.7'; GRANITE, pink, fresh, contains xenoliths of biotite gneiss and large phenocrysts of ferromagnesian minerals. Joints dip from 20° to 45°, surfaces are coated with calcite.

EXPLANATION

*All angles measured from perpendicular to core axis unless otherwise noted. Percent recovery and RQD are calculated for lithologic intervals.

CORE LOSS

CORE RECOVERY

Approx. size of hole (X-series)	Ex = 1-1/2"	Ax = 1-7/8"	Bx = 2-3/8"	Nx = 3"
Approx. size of core (X-series)	Ex = 7/8"	Ax = 1-1/8"	Bx = 1-5/8"	Nx = 2-1/8"
Outside dia. of casing (X-series)	Ex = 1-13/16"	Ax = 2-1/4"	Bx = 2-7/8"	Nx = 3-1/2"
Inside dia. of casing (X-series)	Ex = 1-1/2"	Ax = 1-29/32"	Bx = 2-3/8"	Nx = 3"

FEATURE South bore PROJECT Lisenhower STATE Colorado SHEET 1 OF 2 HOLE NO. 101A

GPO 779-404

Table A-4 Geologic Log of Drill Hole 101A (continued)

Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 2 OF 2

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado

HOLE NO. 101A LOCATION Crown COORDS. N. ... E. ... GROUND ELEV. ... DIP (ANGLE FROM HORIZ.) +60°

BEGUN ... FINISHED ... DEPTH OF OVERBURDEN 0 TOTAL DEPTH 102.9' BEARING 0°

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Dry LOGGED BY W. Collins LOG REVIEWED BY M. McKeown

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	CORE RECOVERY RQD	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
Drilling Rig: Joy 12B, air driven		100	31		100			68.7 - 69.7'; BIOTITE GNEISS, fresh, medium-grained, foliation dips 35°. Joints dip *60°, surfaces coated with calcite.
Core Barrel: Christensen Double tube D3		TOTAL 82	40		110			69.7 - 73.8', GRANITE, pink, fresh, coarse-grained. Xenolith of biotite schist at 72.1'. Joints dip from 5° to 30°, surfaces are coated with calcite to 1/16-inch thick.
Drilling fluid: Water No casing					120			73.8 - 85.6'; BIOTITE GNEISS, fresh, medium-grained, locally granitic, foliation dips 45°. Joints dip from 50° to 60°, slickensided, pyrite and calcite on surfaces. Highly fractured.
								85.6 - 87.9'; PEGMATITE DIKE, pink, fresh, large K-feldspar crystals. Joints dip from 40° to 60°, slickensided, calcite and chlorite on surfaces. Minor amount of schist at 87.3'.
					130			87.9 - 88.9'; BIOTITE GNEISS, fresh, foliation dips from 25° to 60°. Joints dip from 25° to 60°, parallel to foliation, slickensided, coated with up to 1/8-inch of calcite on surfaces.
					140			88.9 - 91.5'; GRANITE GNEISS, fresh, contorted foliation. Joints dip from 30° to 70°, calcite on surfaces.
					150			91.5 - 99.4'; GRANITE, pink and gray, fresh, coarse-grained, few large K-feldspar phenocrysts. Joints dip from 35° to 60°, coated with thin calcite and chlorite.
					160			99.4 - 102.9'; GRANITE GNEISS, gray, fresh, foliation contorted, subparallel to core axis. Joints dip 15°, surfaces coated with greenish calcite, fine- to coarse-grained.

Depth scale (left): 10, 20, 30, 40, 50, 60, 70, 80, 90; depth scale: 110, 120, 130, 140, 150, 160, 170, 180, 190

EXPLANATION

CORE LOSS / CORE RECOVERY

*All angles measured from perpendicular to core axis unless otherwise noted. Percent recovery and RQD are calculated for lithologic intervals.

Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

FEATURE South Bore PROJECT Eisenhower STATE Colorado SHEET 2 OF 2 HOLE NO. 101A

GPO 770-404

Table A-5 Geologic Log of Drill Hole UJ2W

GEOLOGIC LOG OF DRILL HOLE

SHEET 1 OF 3

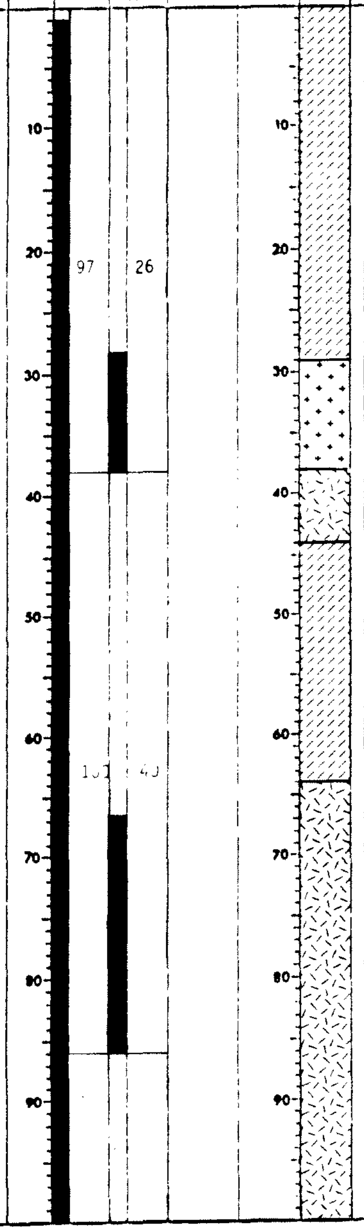
FEATURE: South Bore | PROJECT: Eisenhower Tunnel | STATE: Colorado

HOLE NO.: UJ2W | LOCATION: West Wall | GROUND ELEV.: | DIP (ANGLE FROM HORIZ.): 0

BEGUN: | FINISHED: | COORDS. N. | E. | DEPTH OF OVERBURDEN: 0 | TOTAL DEPTH: 22.1' | BEARING: 90°

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: Dry | LOGGED BY: P. Shaffner | LOG REVIEWED BY: M. McKeown

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	CORE RECOVERY RQD	ELEVATION (FEET)	DEPTH (FEET) $x10^{-1}$	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION



Drill Rig:

Joy 12B, air driven

Core Barrel:

Christensen Double tube D3

Drilling fluid:

Water
No casing

0.0 - 2.9'; GRANITE GNEISS, degree of foliation varies from easily recognizable to unrecognizable. Localized banding of K-feldspar and biotite foliation, dips* 80°.

0.2'; JOINT, dip 0°, calcite powder on surfaces.

0.35'; JOINT, dip 90°, calcite and chlorite on surface.

0.6'; JOINT, dip 2°, fresh, only trace amounts of calcite.

0.75'; JOINT, dip 10°, calcite powder on surface.

0.9'; JOINT, irregular fracture, slightly weathered with oxidized iron particles.

1.3'; JOINT, dip 32°, calcite on surface.

1.6'; JOINT, dip 20°, calcite in thin, flakey form and chlorite up to 1/64" thick. Joint follows plane of weakness in biotite due to chloritization.

2.0'; JOINT, dip 0°, gray calcite on surface.

2.2'; JOINT, dip 45°, white crushed material, partially calcite and igneous minerals.

2.45'; JOINT, dip 3°, calcite and slickensides on surface.

2.9 - 3.8'; PEGMATITE DIKE, coarse grained, granitic, pink, lower 0.4 feet contains high concentration of biotite and is highly fractured with chlorite on surfaces.

3.8 - 4.4'; GRANITE, locally gneissic, becoming more and more foliated towards bottom.

3.8 - 4.4'; JOINT, dip 80°, follows biotite alignment. chlorite on joint surface, fragmented zone.

4.6 - 6.4'; GRANITE GNEISS, medium-grained, dominance of biotite, locally chloritized.

4.4-5.1'; HIGHLY FRACTURED ZONE, fragments range from coarse sand-size up to 3" near diameter. Many joints appear to follow foliation which dips 50°, others crosscut foliation.

5.6'; JOINT, dip 30°, light gray calcite on a slightly weathered joint surface.

5.62'; JOINT, dip 30°, crust-like flakes of calcite coat surface.

5.6-5.9'; JOINT, dip 90°, slightly weathered with green chlorite on surface.

6.4 - 8.6'; GRANITE, pink, foliated locally, dip of foliation is approximately 40° where noticeable. Minor metamorphism causing local alignment of granitic minerals

EXPLANATION

CORE LOSS / CORE RECOVERY

*All angles measured from perpendicular to core axis unless otherwise noted.

Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series). Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series). . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

FEATURE: South Bore | PROJECT: Eisenhower Tunnel | STATE: Colorado | SHEET 1 OF 3 | HOLE NO. UJ2W

GPO 778-464

Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 2 OF 3

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado

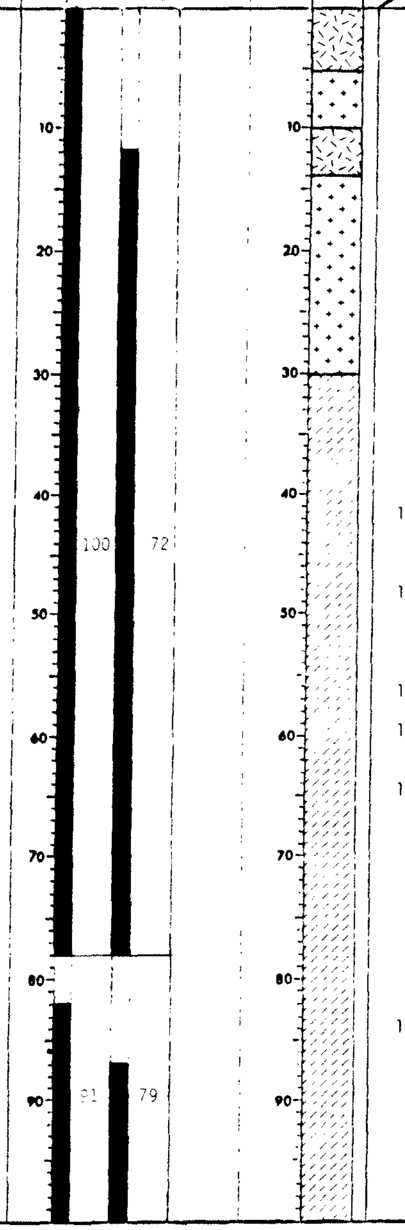
HOLE NO. UJ2W LOCATION West wall GROUND ELEV. DIP (ANGLE FROM HORIZ.) 0

COORDS. N. E.

BEGUN FINISHED DEPTH OF OVERBURDEN 0 TOTAL DEPTH BEARING 90°

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Dry LOGGED BY P. Shaffner LOG REVIEWED BY M. McKeown

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	CORE RECOVERY RQD	ELEVATION (FEET)	DEPTH (FEET) x10^-1	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION



7.1 - 8.6'; HIGHLY FRACTURED AND WEATHERED, maximum size of fragments is 2". Joints dip 60°* where measurable.

8.6 - 13.0'; GRANITE, pink, coarse to medium-grained, locally pegmatitic, lacks the local foliation of above unit.

8.6'; JOINT, dip 50°, slight weathering.

8.8'; JOINT, dip 35°.

8.9'; JOINT, dip 35°, follows plane of weakness along biotite interface.

9.0'; JOINT, dip 30°, fresh.

9.3 - 9.8'; HIGHLY FRACTURED, coarse-grained, weathered and chloritized surfaces. Fractures dip 90° approximately.

9.8 - 10.5'; FOLIATION, slightly recognizable, approaches a gneissic structure, highly fractured, medium-grained, fresh surfaces.

10.5 - 11.0'; PEGMATITE DIKE, fresh, unbroken.

10.6'; JOINT, dip 70°, calcite and chlorite on surface.

11.0 - 11.4'; GRANITE, pink, coarse-grained, localized concentrations of K-feldspar.

11.4'; JOINT, fresh, angular, dip 30°.

11.4 - 13.0'; PEGMATITE DIKE, granite, unfractured.

13.0 - 22.1'; BIOTITE GNEISS, foliation dip ranges from 20° to 40°

13.0 - 14.0'; HIGHLY FRACTURED ZONE, very weathered, crushed between fingers.

14.2'; JOINT, highly weathered, dip 30°, calcite present.

15.1'; JOINT, dip 20°, calcite on surface.

16.0'; JOINT, dip 50°, weathered.

16.2'; JOINT, dip 20°, (dominant orientation in this section).

16.2 - 17.0'; SOLID BIOTITE GNEISS

17.2'; JOINT, dip 30°, weathered.

19.2'; JOINT, dip 30°, calcite on surface.

20.0'; JOINT, weathered, dip 10°, calcite on surface.

21.4'; JOINT, dip 30°, calcite on surface.

EXPLANATION

CORE LOSS

CORE RECOVERY

*All angles measured from perpendicular to core axis unless otherwise noted.

Approx. size of hole (X-series)	Ex = 1-1/2"	Ax = 1-7/8"	Bx = 2-3/8"	Nx = 3"
Approx. size of core (X-series)	Ex = 7/8"	Ax = 1-1/8"	Bx = 1-5/8"	Nx = 2-1/8"
Outside dia. of casing (X-series)	Ex = 1-13/16"	Ax = 2-1/4"	Bx = 2-7/8"	Nx = 3-1/2"
Inside dia. of casing (X-series)	Ex = 1-1/2"	Ax = 1-29/32"	Bx = 2-3/8"	Nx = 3"

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado SHEET 2 OF 3 HOLE NO. UJ2W

GPO 779-404

Table A-5 Geologic Log of Drill Hole UJ2W (Continued0

...eau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 3 OF 3

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado

HOLE NO. UJ2W LOCATION West wall GROUND ELEV. DIP (ANGLE FROM HORIZ.) 0

COORDS. N. E.

BEGUN FINISHED DEPTH OF OVERBURDEN 0 TOTAL DEPTH ??.1' BEARING 90°

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Dry LOGGED BY P. Shaffner LOG REVIEWED BY M. McKeown

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	CORE RECOVERY RQD	ELEVATION (FEET)	DEPTH (FEET) X10^{-1}	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
				BOTTOM OF HOLE				
		TOTAL						
		98	53					

Depth scale: 10, 20, 30, 40, 50, 60, 70, 80, 90

EXPLANATION

CORE LOSS

CORE RECOVERY

*All angles measured from perpendicular to core axis unless otherwise noted.

Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado SHEET OF ? HOLE NO. UJ2W

GPO 778-404

Table A-6 Geologic Log of Drill Hole UJ2E

...au of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 1 OF 2

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado

HOLE NO. UJ2E LOCATION East Wall GROUND ELEV. DIP (ANGLE FROM HORIZ.) 0

COORDS. N. E.

BEGUN FINISHED DEPTH OF OVERBURDEN 0 TOTAL DEPTH 20.3' BEARING 90^{o}

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Dry LOGGED BY S. Volz LOG REVIEWED BY M. McKeown

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	CORE RECOVERY RQD	ELEVATION (FEET)	DEPTH (FEET) $X10^{-1}$	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
Drill Rig: Joy 12B, air driven								0.0 - 13.6'; BIOTITE GNEISS, gray, fresh, grain size ranges from 1/8" to 1/64".
Core Barrel: Christensen Double tube D3		95	54		10			0.0 - 0.8'; FRAGMENTED INTERVAL, fragments coated with chlorite and pink calcite.
Water Fluid: Water No casing					20			0.8'; JOINT, dip 67^{o}* chlorite-calcite coated surface.
		100	77		30			2.8'; JOINT, dip 37^{o}, calcite powder on surface.
					40			2.9'; JOINT, dip 7^{o}, calcite powder on surface.
					50			3.7'; JOINT, dip 71^{o}, chlorite on surface.
					60			4.2'; JOINT, dip 37^{o}, calcite on surface.
		100	78.9		70			4.4'; JOINT, dip 47^{o}, calcite powder up to 1/64" thick on joint surface.
					80			4.52'; JOINT, dip 15^{o}.
					90			5.27'; JOINT, dip 76^{o}, slickensided surface with chlorite.
								6.0'; JOINT, dip 50^{o}, calcite on surface.
								6.75'; JOINT, dip 47^{o}, calcite on surface.
								7.55'; JOINT, dip 27^{o}.
								7.78'; JOINT, dip 33^{o}, calcite on surface.
								9.6'; JOINT, dip 24^{o}.
								9.9'; JOINT, dip 58^{o}, slickensides and calcite on joint surface.
								10.9'; JOINT, dip 77^{o}, chlorite and pink calcite on surface.
								12.75'; JOINT, dip 49^{o}, slickensides.
								13.1'; JOINT, dip 29^{o}, calcite on surface.
								13.6 - 16.1'; PEGMATITE DIKE, pink, some biotite altered to chlorite. Large K-feldspar crystals.
								13.9 - 14.1'; BIOTITE GNEISS
								14.5'; JOINT, dip 28^{o}, calcite on surface.
								15.0'; JOINT, dip 3^{o}
								16.1 - [illegible]'; BIOTITE GNEISS, gray, fresh, coarse to medium.
								16.9 - 17.6'; PEGMATITE DIKE, pink, large K-feldspar crystals.
								17.6 - 20.[illegible]; BIOTITE GNEISS, gray, fresh.

EXPLANATION

CORE LOSS

CORE RECOVERY

*All angles measured from perpendicular to core axis unless otherwise noted.

Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado SHEET 1 OF 2 HOLE NO. UJ2E

GPO 770-4C

Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET ... OF 2

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado

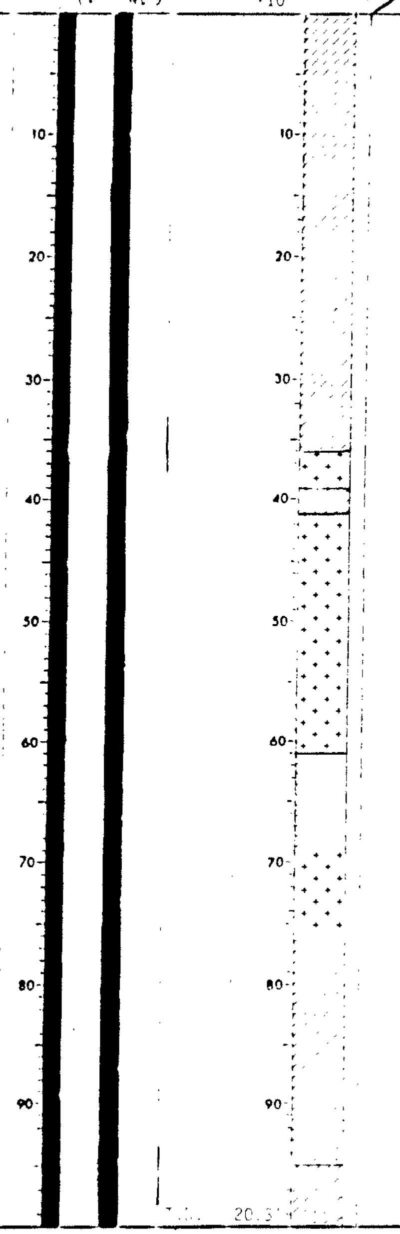
HOLE NO. UJ2E LOCATION East wall GROUND ELEV. DIP (ANGLE FROM HORIZ.) 0

COORDS. N. E.

BEGUN FINISHED DEPTH OF OVERBURDEN 0 TOTAL DEPTH 20.3' BEARING 90°

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Dry LOGGED BY S. Holz LOG REVIEWED BY M. McKeown

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	CORE RECOVERY RQD	ELEVATION (FEET)	DEPTH (FEET) x10^-1	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
Total Core Recovery: 99 Total RQD: 77								18.7': JOINT, dip 63°, calcite and chlorite on surface. 19.5': JOINT, dip 28°, calcite on surface.



20.3'

EXPLANATION

*All angles measured from perpendicular to core axis unless otherwise noted.

CORE LOSS

CORE RECOVERY

Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . x = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . . x = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . x = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado SHEET OF HOLE NO. UJ2E

GPO 779-404

Table A-7 Geologic Log of Drill Hole 111V

GEOLOGIC LOG OF DRILL HOLE

...au of Reclamation SHEET 1 OF 2

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado

HOLE NO. 111V LOCATION Crown GROUND ELEV. DIP (ANGLE FROM HORIZ.) +90°

COORDS. N. E.

BEGUN FINISHED DEPTH OF OVERBURDEN 0 TOTAL DEPTH 91.2' BEARING N.A.

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Dry LOGGED BY P. Shaffner LOG REVIEWED BY M. McKeown

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS

Drill Rig:

Joy 12B, air driven

Core Barrel:

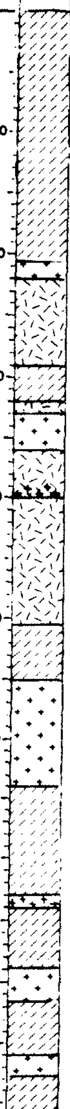
Christensen Double Tube D3

Drilling Fluid:

Water
No casing

CORE RECOVERY (%)	CORE RECOVERY RQD
[illegible]	0
[illegible]	0
100	[illegible]
[illegible]7	[illegible]
[illegible]0	[illegible]
1[illegible]	[illegible]
7	0
[illegible]	[illegible]
[illegible]	0
[illegible]	0
[illegible]	0
[illegible]0	[illegible]
[illegible]	0
[illegible]	0
[illegible]	29
[illegible]	8
9[illegible]	16
100	[illegible]3
100	0
100	0
71	71
BOTTOM OF HOLE	
TOTAL 86	18

DEPTH (FEET): 10, 20, 30, 40, 50, 60, 70, 80, 90



CLASSIFICATION AND PHYSICAL CONDITION

0 - 20.4'; GRANITE GNEISS, fine- to medium-grained, locally pegmatitic. Highly fractured towards top. Joint dips range from 0 to 90°, surfaces slightly weathered and coated with thin calcite and/or chlorite.

20.4 - 22.0'; PEGMATITE DIKE, pink, fresh, granitic, K-feldspar rich.

22.0 - 29.0'; GRANITE, pink and gray varieties, coarse- to medium-grained. Joints are weathered and coated with calcite. Several joints follow K-feldspar concentrations. Joint dips range from 0 to 90°.

29.0 - 32.0'; BIOTITE GNEISS, highly fractured, tightly folded locally. Foliation dips 70°. Fractures contain small amount of calcite.

32.0 - 33.0'; GRANITE, highly fractured, joint surfaces heavily coated with green fissile chlorite.

33.0 - 36.0'; PEGMATITE DIKE, granitic, joint dips range from 20° to 80° and are coated with calcite and chlorite.

36.0 - 39.3'; GRANITE, fine- to medium-grained. Localized foliation. Joint surfaces highly weathered. Joint dips range from 0° to 60°

39.3 - 39.9'; PEGMATITE DIKE, granitic, mineral alteration at top and bottom of intrusion. Joints weathered.

39.9 - 50.6'; GRANITE, pink, slightly weathered, coarse- to medium-grained, highly fractured. Some joint surfaces show slickensides. Surfaces coated with calcite and chlorite.

50.6 - 53.0'; GRANITE GNEISS, coarse-grained, bottom grades to biotite gneiss. Highly fractured, fracture dips range from 70° to 90° where measurable.

53.0 - 55.0'; BIOTITE GNEISS, highly fractured. Joint surfaces weathered and dips range from 50° to 60°.

55.0 - 64.0'; PEGMATITE DIKE, granitic, joint surfaces highly weathered and contain calcite. Joint dips range from 30° to 40°. Local laminations of biotite. Pyrite crystals (1 mm average).

64.0 - 72.8'; BIOTITE GNEISS, fine-grained, tightly folded, foliation dip ranges from 55° to 65°. Joints slickensided and follow foliation. Calcite up to 5-mm thick on joint surfaces, several joints are calcite healed.

72.8 - 74.0'; PEGMATITE DIKE, granitic. pink, chlorite on top and bottom contacts.

74.0 - 77.9'; GRANITE GNEISS, coarse-grained, fresh. Joints dip approximately 60° and are weathered. Grades to biotite gneiss towards bottom.

EXPLANATION

*All angles measured from perpendicular to core axis unless otherwise noted.

CORE LOSS / CORE RECOVERY

Approx. size of hole (X-series)	Ex = 1-1/2"	Ax = 1-7/8"	Bx = 2-3/8"	Nx = 3"
Approx. size of core (X-series)	Ex = 7/8"	Ax = 1-1/8"	Bx = 1-5/8"	Nx = 2-1/8"
Outside dia. of casing (X-series)	Ex = 1-13/16"	Ax = 2-1/4"	Bx = 2-7/8"	Nx = 3-1/2"
Inside dia. of casing (X-series)	Ex = 1-1/2"	Ax = 1-29/32"	Bx = 2-3/8"	Nx = 3"

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado SHEET 1 OF 2 HOLE NO. 111V

GPO 779-404

Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 2 OF 2

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado
HOLE NO. 111V LOCATION Crown COORDS. N. E. GR. ELEV. DIP (ANGLE FROM HORIZ.) +90°
BEGUN FINISHED DEPTH OF OVERBURDEN 0 TOTAL DEPTH 91.2 BEARING N.A.
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Dry LOGGED BY P. Shaffner LOG REVIEWED BY M. McKeown

77.9 - 78.3'; BIOTITE GNEISS, fresh, joints are weathered and range from 0° to 90°.

78.3 - 81.3'; PEGMATITE DIKE, fresh, granitic, joint dips range from 40° to 90° and are thinly coated with calcite.

81.3 - 86.0'; BIOTITE GNEISS, medium- to coarse-grained. Joints subparallel and cross-cut foliation which dips from 30° to 40°. Joint surfaces coated with calcite or chlorite. Bottom contact is biotite.

86.0 - 87.8'; PEGMATITE DIKE, fresh, granitic, coarse-grained, quartz and biotite dominate.

87.8 - 91.2'; GRANITE GNEISS, medium- to coarse-grained. Foliation dip varies. Fracture dips range from 30° to 90°, paralleling and cross-cutting foliation. Joint surfaces contain calcite and chlorite.

EXPLANATION

*All angles measured from perpendicular to core axis unless otherwise noted.

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado SHEET 2 OF 2 HOLE NO. 111V

Table A-8 Geologic Log of Drill Hole 111A

Bureau of Reclamation — **GEOLOGIC LOG OF DRILL HOLE** — SHEET 1 OF 2

FEATURE South Bore — PROJECT Eisenhower Tunnel — STATE Colorado

HOLE NO. 111A — LOCATION Crown — COORDS. N. ... E. ... — GROUND ELEV. ... — DIP (ANGLE FROM HORIZ.) +60°

BEGUN ... FINISHED ... DEPTH OF OVERBURDEN 0 — TOTAL DEPTH 93.5' — BEARING 0°

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Dry — LOGGED BY W. Collins — LOG REVIEWED BY M. McKeown

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS

DRILL RIG:

Joy 12B, air driven

CORE BARREL:

Christensen Double Tube D3

DRILLING FLUID:

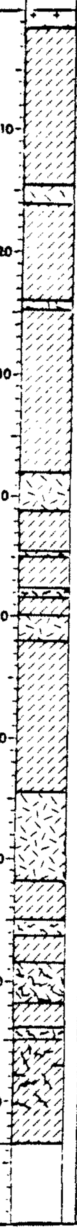
Water

No casing

TYPE AND SIZE OF HOLE / CORE RECOVERY (%) / CORE RECOVERY RQD / ELEVATION (FEET) / DEPTH (FEET) / GRAPHIC LOG / SAMPLES FOR TESTING

CORE RECOVERY (%)	RQD
43	11
100	53
100	94
80	67
100	70
100	40
100	100
100	0
29.2	33.6
78	25
76	27
96	19
92	37
94	0
?	30
76	53
54	5
100	100
100	96
100	96
81	37
100	31
70	25
91	12
100	53
100	88
80	12
BOTTOM OF HOLE	
TOTAL 83	49

Depth (feet): 10, 20, 30, 40, 50, 60, 70, 80, 90



CLASSIFICATION AND PHYSICAL CONDITION

0 - 6.5'; BIOTITE GNEISS, fresh, foliated, dip* approximately 40°. Joint surfaces slickensided and coated with calcite, chlorite and iron oxide. Joint dips range from 40° to 50° and are subparallel to and crosscut foliation. Upper 1.5' is pegmatite dike.

6.5 - 11.2'; GRANITE GNEISS, fresh, foliated, dips range from 0° to 80°. Joint dips range from 35° to 40° and are calcite coated. Numerous healed fractures.

11.2 - 14.5'; BIOTITE GNEISS, fresh, foliated, dips range from 0° to 50°. Joint surfaces coated lightly with chlorite. Joints dips 40° and parallels foliation. Pyrite present.

14.5 - 16.0'; GRANITE, fresh, pink, coarse grained. No jointing. Some biotite zones within granite.

16.0 - 22.3'; GRANITE GNEISS, fresh, foliated, dip approximately 30°. Joints coated with thin pink calcite. Joint dips range from 30° to 40°.

22.3 - 23.3'; BIOTITE GNEISS, fresh, very fine grained, veins of quartz K-feldspar. Joint dips 70° to 85°, jointing fresh, no slickensides or coating on surfaces, may be mechanical fractures.

23.3 - 24.0'; GRANITE GNEISS, fresh, foliated, dip approximately 30°. Joints coated with pink calcite. Joint dips from 30° to 40°.

24.0 - 24.8'; GRANITE, fresh, light pink, grades to gneiss at bottom. Badly fractured.

24.8 - 38.0'; GRANITE GNEISS, fresh, 24.8 - 30.5'; joints covered with iron oxide. Joint dips vary from 35° to 65° foliation dips 60° to 70°, numerous healed fractures. 30.5 - 32.3'; badly fractured along 90° foliation. 32.3 - 38.0'; finer grained toward bottom. Joints dip from 60° to 75° and coated with white calcite.

38.0 - 41.2'; GRANITE, fresh, pink, coarse grained. Gneissic at top, small xenoliths of mica schist at bottom. Joints coated with calcite. Joint dips range from 60° to 75°.

41.2 - 44.5'; GRANITE GNEISS, fresh, foliated, dip approximately 0°. Joints slickensided and coated with thin chlorite and calcite. Joint dips range from 25° to 30° and crosscuts foliation.

44.5 - 45.0'; GRANITE, fresh, pink, gneissic towards bottom. Joints coated with thin calcite, joint dips range from 25° to 65°.

45.0 - 47.6'; GRANITE GNEISS, fresh, foliated, joints coated with thin chlorite and calcite. Joints dips vary from 25° to 35°, subparallel to foliation.

EXPLANATION

CORE LOSS / CORE RECOVERY

*All angles measured from perpendicular to core axis unless otherwise noted. Percent recovery and RQD are calculated for lithologic intervals.

Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

FEATURE South Bore — PROJECT Eisenhower Tunnel — STATE Colorado — SHEET 1 OF 2 — HOLE NO. 111A

GPO 778-4

Bureau of Reclamation GEOLOGIC LOG OF DRILL HOLE SHEET 2 OF 2

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado
HOLE NO 111A LOCATION Crown COORDS. N. E. GROUND ELEV DIP (ANGLE FROM HORIZ.) +60°
BEGUN FINISHED DEPTH OF OVERBURDEN 0 TOTAL DEPTH 93.5' BEARING
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Dry LOGGED BY W. Collins LOG REVIEWED BY M. McKeown

47.6 - 48.4'; QUARTZ VEIN, fresh, some granitic material included. Badly fractured, fractures coated with thin white calcite.

48.4 - 50.0'; GRANITIC GNEISS, fresh, foliated. Dip* approximately 20°. Joints coated with thin calcite and chlorite. Joint dips vary from 45° to 55°. Fractures dipping 90° are coated with calcite.

50.0 - 52.0'; GRANITE, fresh, grades to gneiss at bottom, chloritized. Several calcite healed fractures. Joint dips range from 45° to 55°. Joints slickensided and coated with thin calcite. Several joints dipping 90° are coated with calcite.

52.0 - 53.7'; GRANITE GNEISS, fresh, foliation dips range from 0° to 10°. Joints coated with thin calcite, talc and chlorite.

53.7 - 56.2'; BIOTITE GNEISS, fresh, foliation dips approximately 50°. Joints coated with thin calcite, talc and chlorite. Joint dips range from 40° to 60°. Subparallels and crosscuts foliation.

56.2 - 64.4'; GRANITE GNEISS, fresh, joints coated with thin calcite. Joints dip 60°, crosscuts foliation. 56.2 - 57.7' foliation dips 30°. 57.7 - 64.4', biotite gneiss foliation dips 50°.

64.4 - 71.9'; GRANITE, fresh, pink, joints coated with calcite. Joint dips range from 55° to 60°. Fractures dipping 90° coated with calcite.

71.9 - 74.9'; BIOTITE GNEISS, fresh, foliation dips 45°. Joint dips range from 40° to 50°, subparallel foliation. Joints coated with iron oxides.

74.9 - 76.2'; QUARTZ VEIN WITH GRANITE INCLUSIONS, highly fractured. Joints mottled with iron oxide coating.

76.2 - 78.6'; BIOTITE GNEISS, fresh, foliation dips 45°. Joint dips range from 40° to 50°, subparallel to foliation. Joints coated with iron oxide.

78.6 - 81.9'; GRANITE WITH QUARTZ VEINS, slightly weathered, highly fractured, stained with iron oxides. Joints slickensided and coated with thin chlorite, talc and iron oxide. Joint dips range from 55° to 65°. Contains several healed fractures and joints in quartz.

81.9 - 83.8'; GRANITE GNEISS, fresh, joints coated with thin chlorite and iron oxides. Joint dips range from 40° to 60°, subparalleling and cross-cutting foliation.

83.8 - 84.9'; QUARTZ VEIN, highly fractured. Joints mottled with iron oxide coating.

84.9 - 91.0'; GRANITE GNEISS WITH QUARTZ VEINS, slightly weathered, highly fractured, stained with iron oxides. Joints slickensided and coated with chlorite, talc, and iron oxide. Joint dips range from 55° to 65°

91.0 - 93.5'; GRANITE GNEISS, fresh, foliation dips range from 40° to 55°. Joints coated with iron oxides and calcite. Joint dip ranges from 20° to 70°, cross-cutting foliation.

Bottom of hole at 93.5'.

EXPLANATION

*All angles measured from perpendicular to core axis unless otherwise noted. Percent recovery and RQD are calculated for lithologic intervals.

FEATURE South Bore PROJECT Eisenhower Tunnel STATE Colorado SHEET 2 OF 2 HOLE NO. 111A

APPENDIX B

SUPPORT INSTRUMENTATION DATA

Station 111+75

Station 101+70

Table B-1. - Stresses, percent yield, and bending moment
Steel set 225 - station 111+75
(Tension is +, compression is -) (Type - Light 2 drift - USBR)
Eisenhower Tunnel

Plane	Stress K/in^2 Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
	Date: December 28, 1977			Time: 11:35			
1	2.37	2.38	2.48	2.58	2.59	7	17
2	4.08	4.15	4.70	5.25	5.31	14	93
3	5.19	5.16	4.90	4.64	4.61	14	-44
	Date: January 5, 1978			Time: 10:20			
1	3.27	3.31	3.58	3.86	3.89	10	46
2	0	0	0	0	0	0	0
3	8.14	8.00	6.87	5.74	5.61	22	-190
	Date: January 11, 1978			Time: 10:00			
1	3.65	3.68	3.94	4.21	4.24	11	44
2	5.90	5.95	6.34	6.73	6.77	18	66
3	6.00	6.03	6.26	6.50	6.52	18	39
	Date: January 23, 1978			Time: 10:05			
1	3.42	3.45	3.74	4.03	4.07	11	49
2	6.13	6.18	6.54	6.90	6.95	19	61
3	5.93	5.92	5.83	5.74	5.73	16	-15
	Date: March 22, 1978			Time: 11:40			
1	2.81	2.84	3.15	3.45	3.49	9	51
2	5.20	5.31	6.18	7.05	7.15	19	146
3	4.14	4.18	4.45	4.73	4.76	13	46

NOTE: 1 k/in^2 = 6.900 MPa

Table B-1. - Stresses, percent yield, and bending moment - Continued
Steel set 225 - station 111+75
(Tension is +, compression is -) (Type - Light 2 drift - USBR)
Eisenhower Tunnel

Plane	Stress K/in^2 Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
Date: April 20, 1978 Time: 10:20							
1	3.23	3.25	3.38	3.51	3.52	9	22
2	4.77	5.16	8.47	11.77	12.17	33	555
3	4.18	4.21	4.45	4.70	4.73	13	41
Date: May 10, 1978 Time: 11:35							
1	2.75	2.78	3.10	3.42	3.46	9	54
2	5.09	5.16	5.80	6.44	6.51	18	107
3	3.51	3.65	4.87	6.09	6.23	17	205
Date: June 8, 1978 Time: 11:30							
1	2.58	2.61	2.87	3.13	3.16	8	44
2	6.00	6.00	6.05	6.09	6.10	16	7
3	2.87	2.96	3.73	4.50	4.59	12	129
Date: September 7, 1978 Time: 9:35							
1	1.62	1.65	1.94	2.23	2.27	6	49
2	2.55	2.61	3.10	3.60	3.65	10	83
3	0.02	0.12	0.96	1.80	1.90	5	141
Date: February 2, 1979 Time: 10:40							
1	1.92	1.91	1.90	1.89	1.88	5	-2
2	0.43	0.46	0.75	1.04	1.08	2	49
3	-4.98	-4.76	-2.87	-0.99	-0.76	13	317

NOTE: 1 k/in^2 = 6.900 MPa

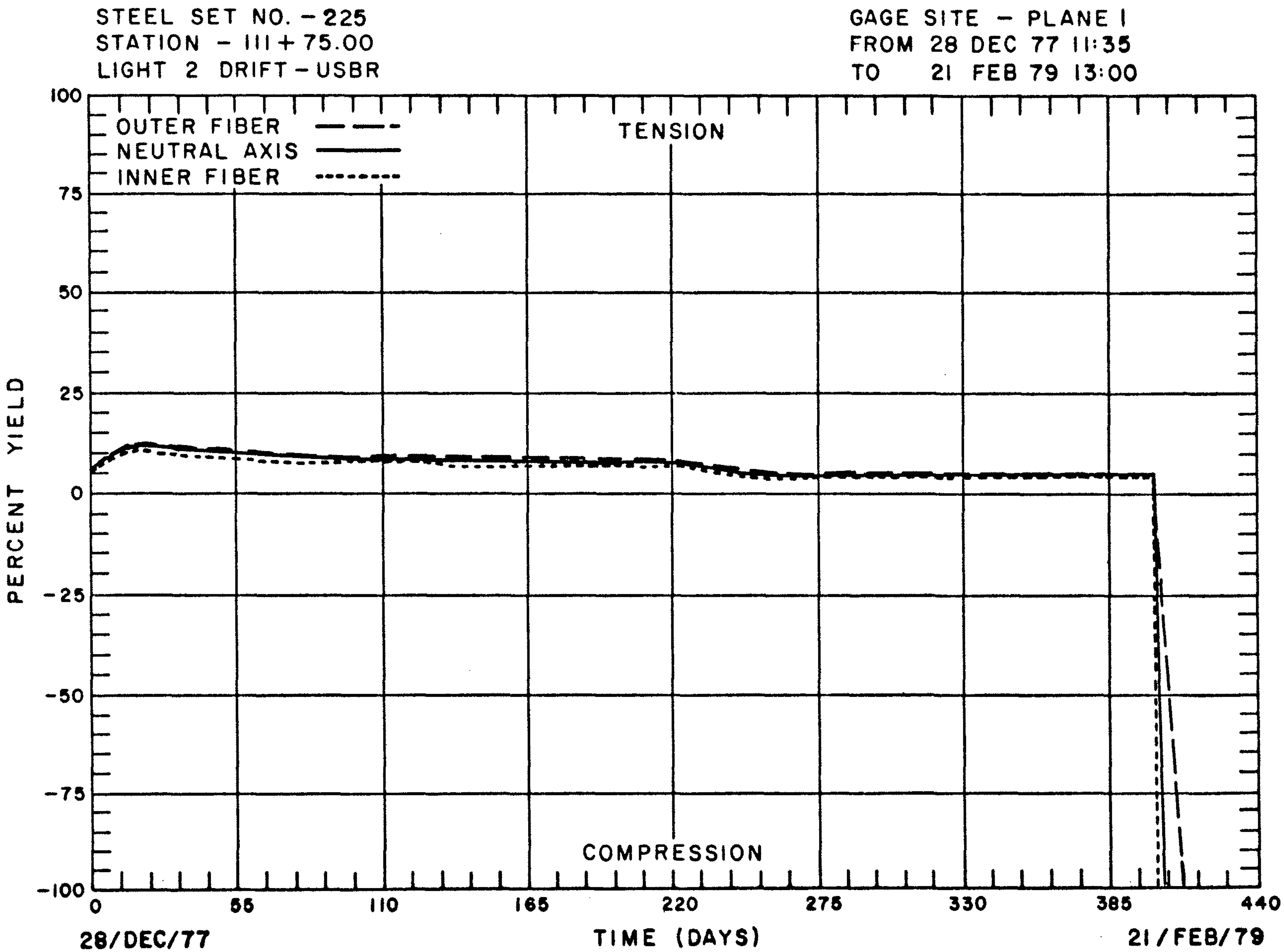


Figure B-1 Stresses--Plane 1, Steel Set No. 225

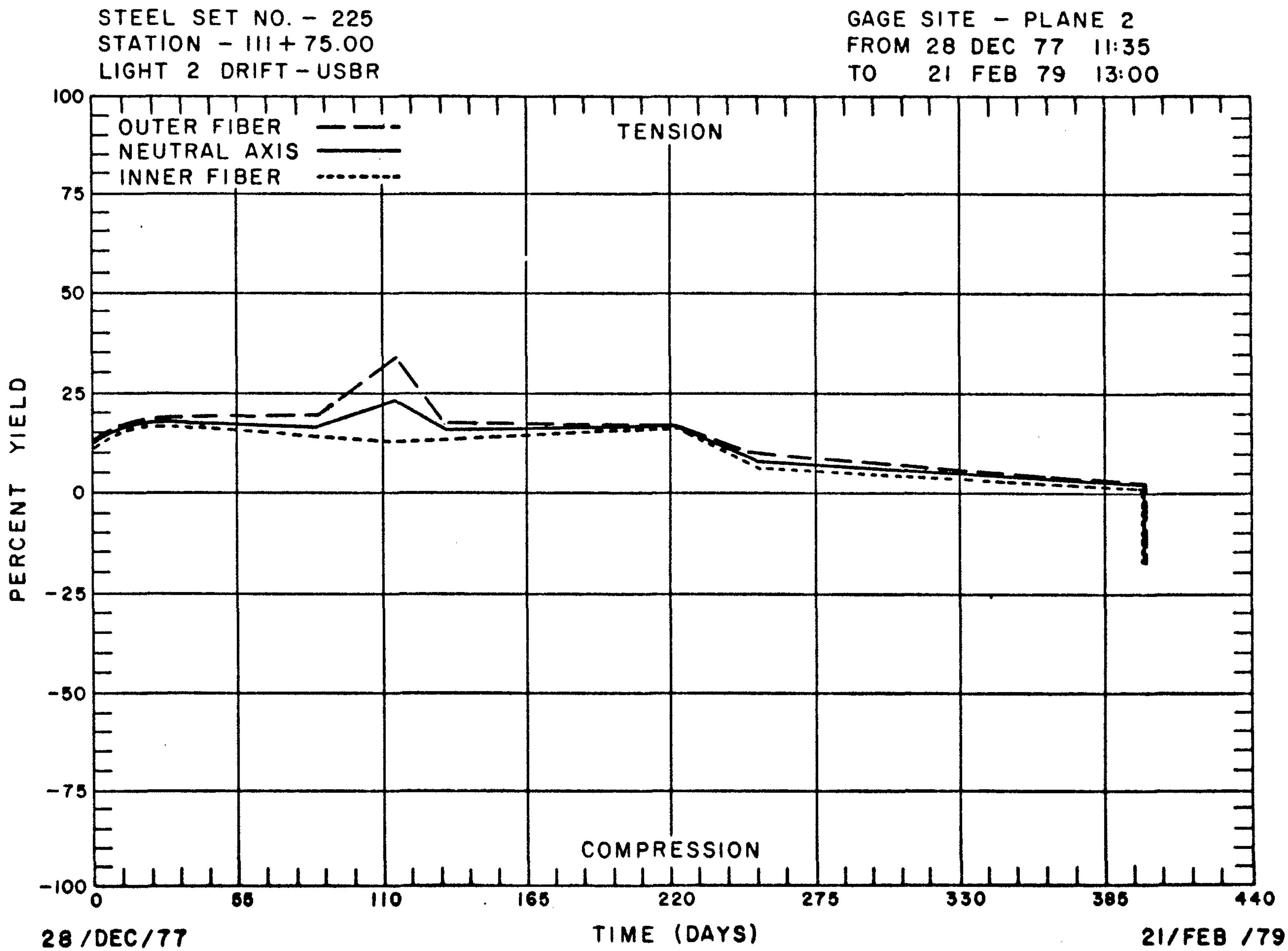


Figure B-2 Stresses--Plane 2, Steel Set No. 225

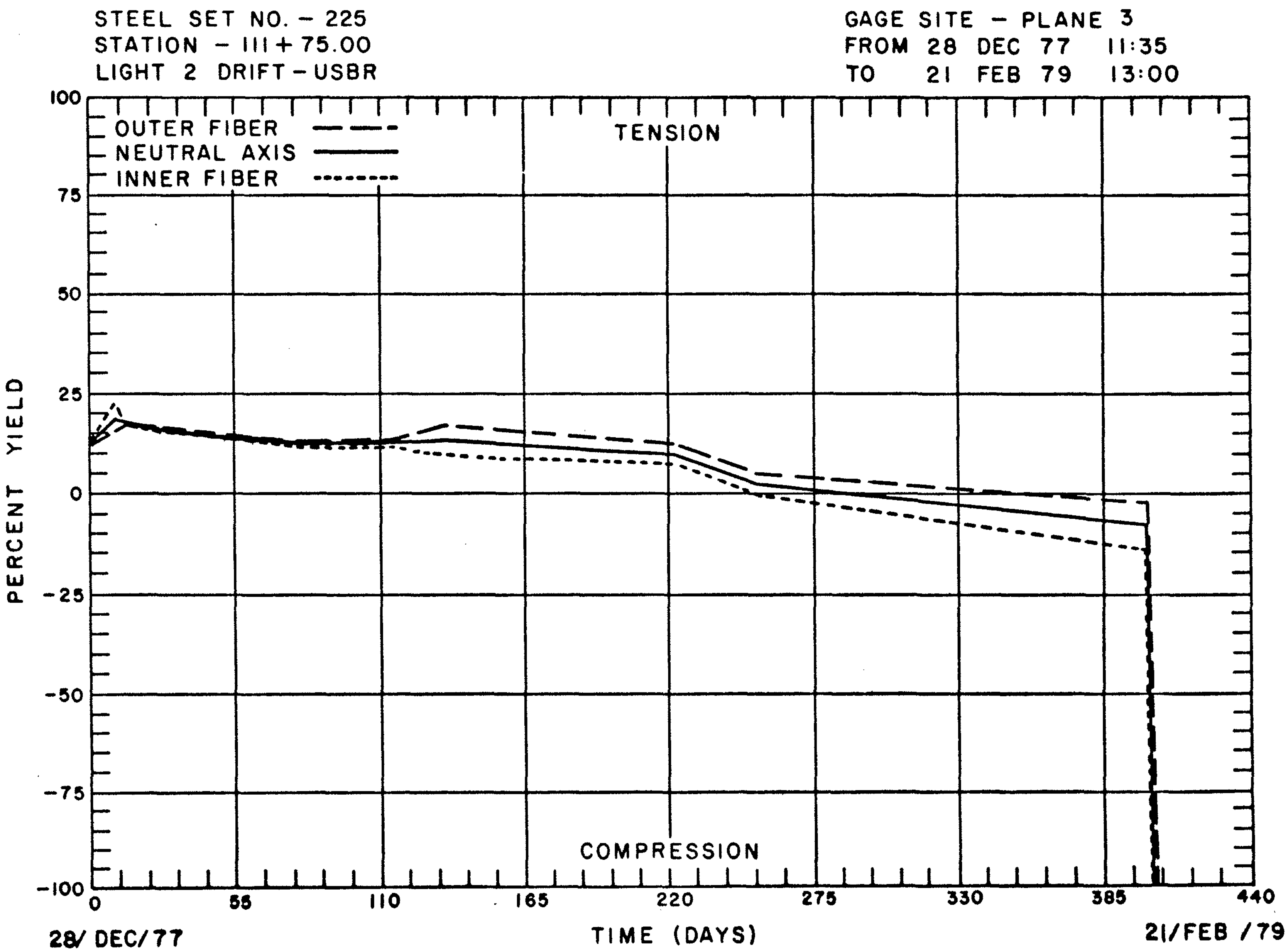


Figure B-3 Stresses--Plane 3, Steel Set NO. 225

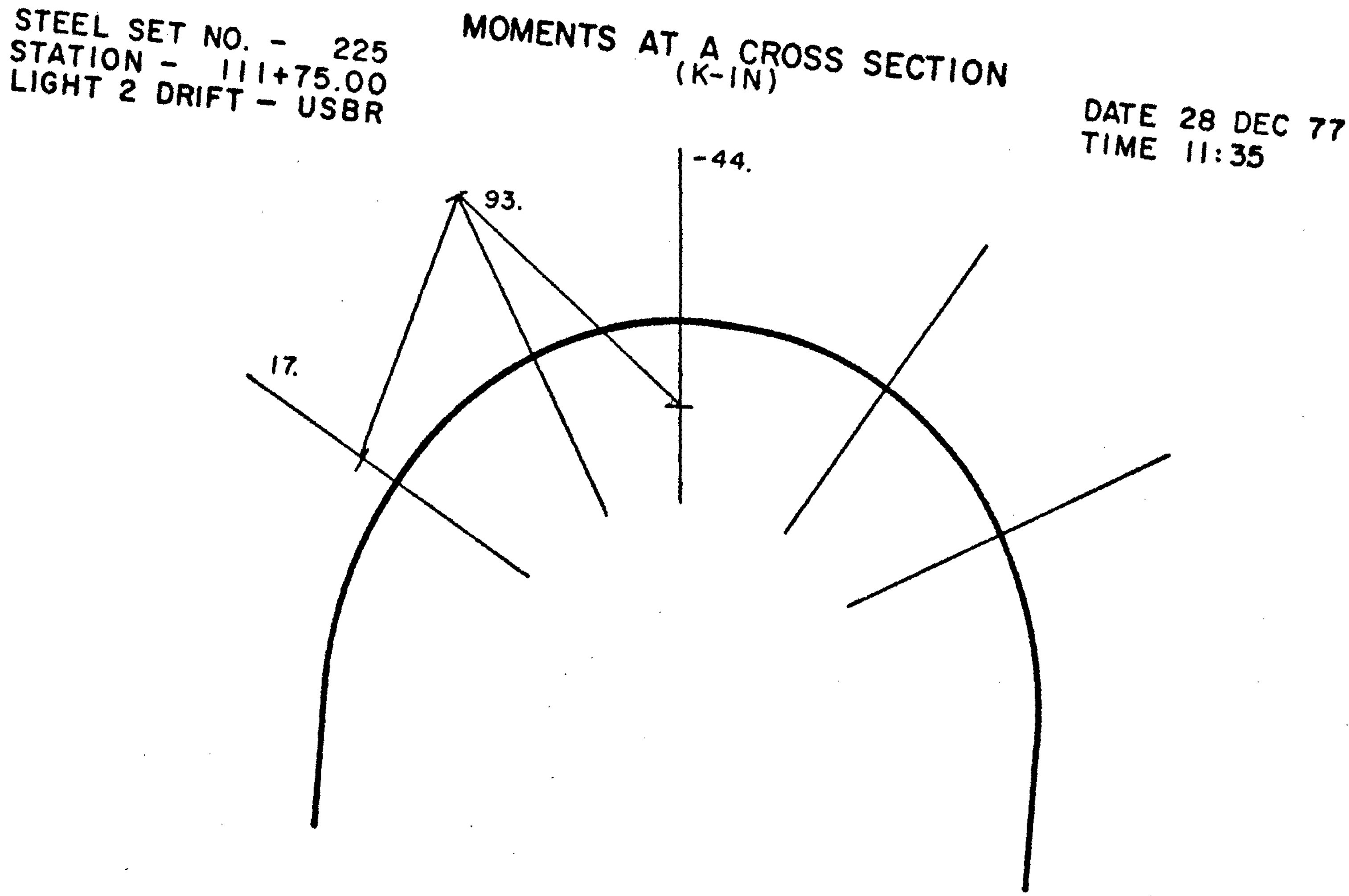


Figure B-4 Moments at Steel Set No. 225, December 1977.

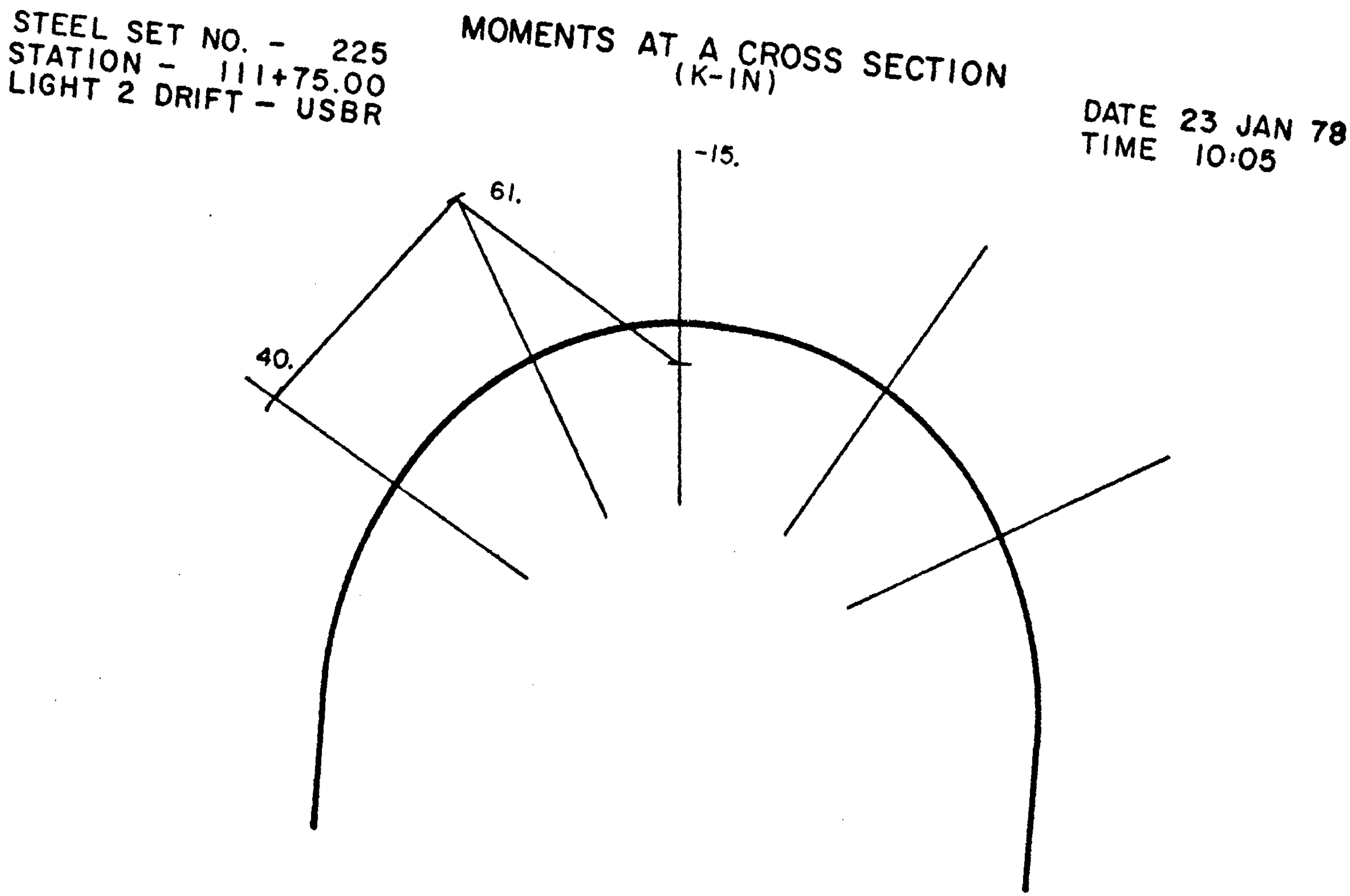


Figure B-5 Moments at Steel Set No. 225, January 1978

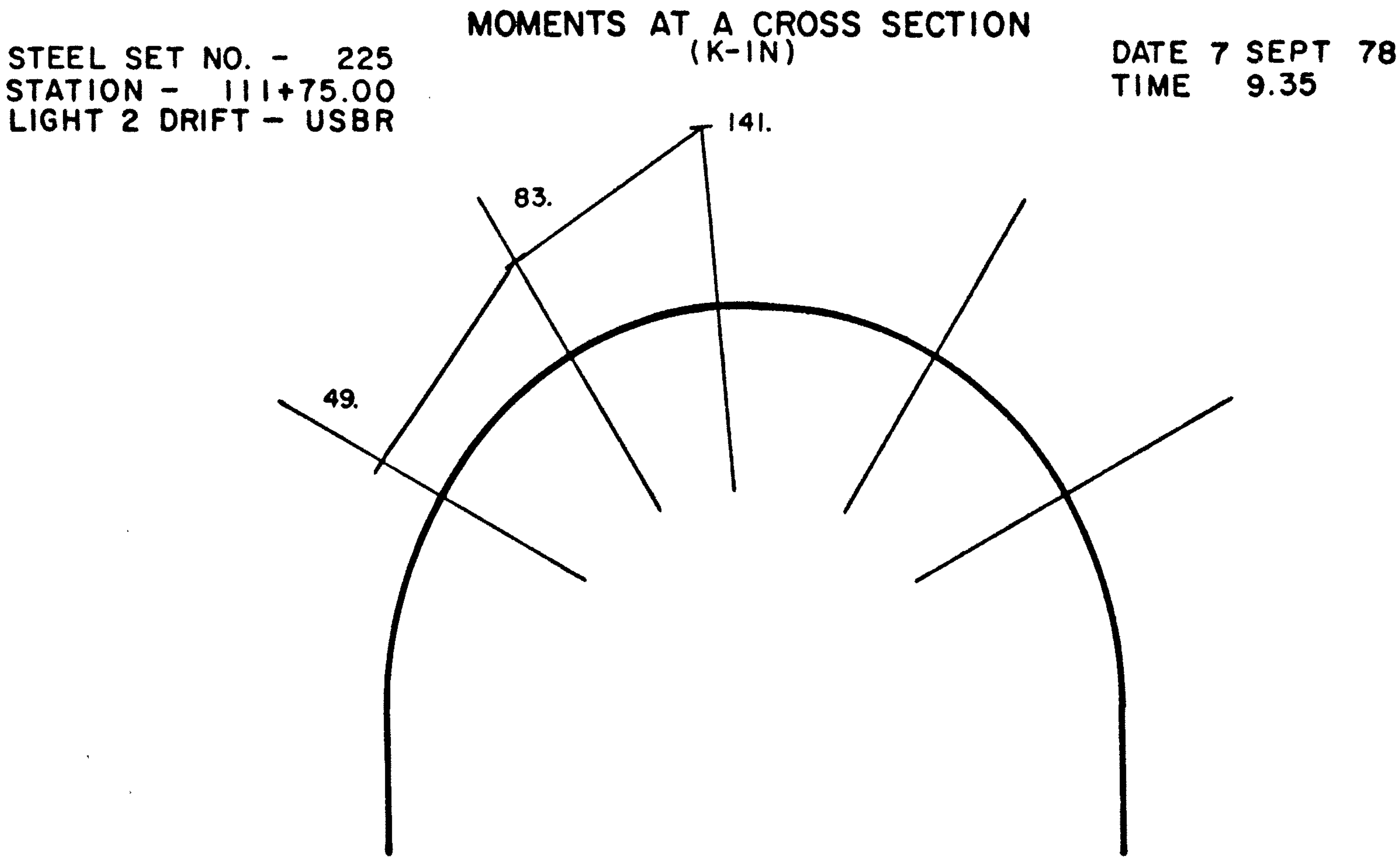


Figure B-6 Moments at Steel Set No. 225 September 1978

Table B-2. - Stresses, percent yield, and bending moment
Steel set 227 - station 111+75
(Tension is +, compression is -) (Type - Light 2 drift - USBR)
Eisenhower Tunnel

Plane	Stress K/in^2 Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
Date: December 28, 1977 Time: 11:20							
1	0.93	0.96	1.16	1.36	1.39	3	34
2	1.76	1.83	2.39	2.96	3.03	8	95
3	2.96	3.07	4.03	4.99	5.10	14	161
Date: January 5, 1978 Time: 10:10							
1	2.02	2.09	2.64	3.19	3.26	9	93
2	4.28	4.29	4.41	4.52	4.54	12	19
3	4.75	4.87	5.86	6.84	6.96	19	166
Date: January 10, 1978 Time: 10:10							
1	1.95	2.00	2.47	2.93	2.98	8	78
2	3.99	4.00	4.12	4.23	4.25	11	19
3	3.79	3.94	5.25	6.55	6.71	18	219
Date: January 23, 1978 Time: 9:55							
1	2.30	2.35	2.73	3.10	3.15	8	63
2	4.31	4.35	4.65	4.96	5.00	13	51
3	4.18	4.35	5.80	7.25	7.42	20	244
Date: March 22, 1978 Time: 11:40							
1	-2.86	-2.58	-0.20	2.18	2.46	7	399
2	4.55	4.50	4.06	3.63	3.57	12	-73
3	3.21	3.39	4.90	6.41	6.59	18	253
Date: April 20, 1978 Time: 10:30							
1	-3.69	-3.36	-0.58	2.20	2.53	10	468
2	3.09	3.25	4.61	5.97	6.14	17	229
3	3.25	3.42	4.87	6.32	6.49	18	244

NOTE: 1 k/in^2 = 6.900 MPa

Table B-2. - Stresses, percent yield, and bending moment - Continued
Steel set 227 - station 111+75
(Tension is +, compression is -) (Type - Light 2 drift - USBR)
Eisenhower Tunnel

Plane	Stress K/in² Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
	Date: May 10, 1978			Time: 11:43			
1	-3.67	-3.36	-0.78	1.80	2.10	10	434
2	2.79	2.84	3.28	3.71	3.76	10	73
3	2.44	2.64	4.35	6.06	6.26	17	287
	Date: June 8, 1978			Time: 11:35			
1	-2.98	-2.76	-0.90	0.96	1.18	8	312
2	2.43	2.55	3.18	3.80	3.87	10	105
3	2.56	2.76	4.36	5.97	6.17	17	270
	Date: September 7, 1978			Time: 10:00			
1	-4.94	-4.67	-2.35	-0.03	0.25	13	390
2	0.49	0.52	0.78	1.04	1.08	2	44
3	-0.87	-0.58	1.86	4.29	4.58	12	409
	Date: February 2, 1979			Time: 10:30			
1	-5.63	-5.34	-2.90	-0.46	-0.17	15	409
2	-0.19	-0.29	-1.16	-2.03	-2.13	5	-146
3	-8.17	-7.66	-3.29	1.07	1.59	22	733
	Date: February 21, 1979			Time: 12:55			
1	-5.32	-5.05	-2.73	-0.41	-0.13	14	390
2	0.00	0.00	0.00	-3.05	0.00	0	0
3	-9.13	-8.76	-5.60	-2.44	-2.06	25	531
	Date: April 5, 1979			Time: 9:10			
1	-3.94	-3.71	-1.77	0.17	0.40	10	326
2	1.65	1.51	0.26	-0.96	-1.10	4	-207
3	-7.02	-6.50	-2.06	2.38	2.91	19	745

NOTE: 1 k/in^2 = 6.900 MPa

Table B-2. - Stresses, percent yield, and bending moment - Continued
Steel set 227 - station 111+75
(Tension is +, compression is -) (Type - Light 2 drift - USBR)
Eisenhower Tunnel

Plane	Stress K/in^2 Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
Date: June 22, 1979 Time: 10:00							
1	-4.97	-4.76	-2.96	-1.16	-0.95	13	302
2	-0.16	-0.32	-1.65	-2.99	-3.15	8	-224
3	-9.52	-8.93	-3.94	1.04	1.64	26	838
Date: August 8, 1979 Time: 10:00							
1	-4.02	-3.89	-2.73	-1.57	-1.43	11	195
2	-0.91	-1.02	-1.90	-2.78	-2.89	8	-149
3	-10.12	-9.54	-4.67	0.20	0.78	28	818
Date: September 26, 1979 Time: 9:39							
1	-5.10	-4.87	-2.93	-0.99	-0.76	14	325
2	-0.71	-0.78	-1.39	-2.00	-2.07	5	-102
3	-10.17	-9.57	-4.55	0.46	1.06	28	843
Date: February 13, 1980 Time: 10:15							
1	-4.59	-4.35	-2.29	-0.23	0.01	12	346
2	-0.33	-0.35	-0.48	-0.61	-0.62	1	-22
3	-9.85	-9.22	-3.96	1.31	1.93	27	884

NOTE: 1 k/in^2 = 6.900 MPa

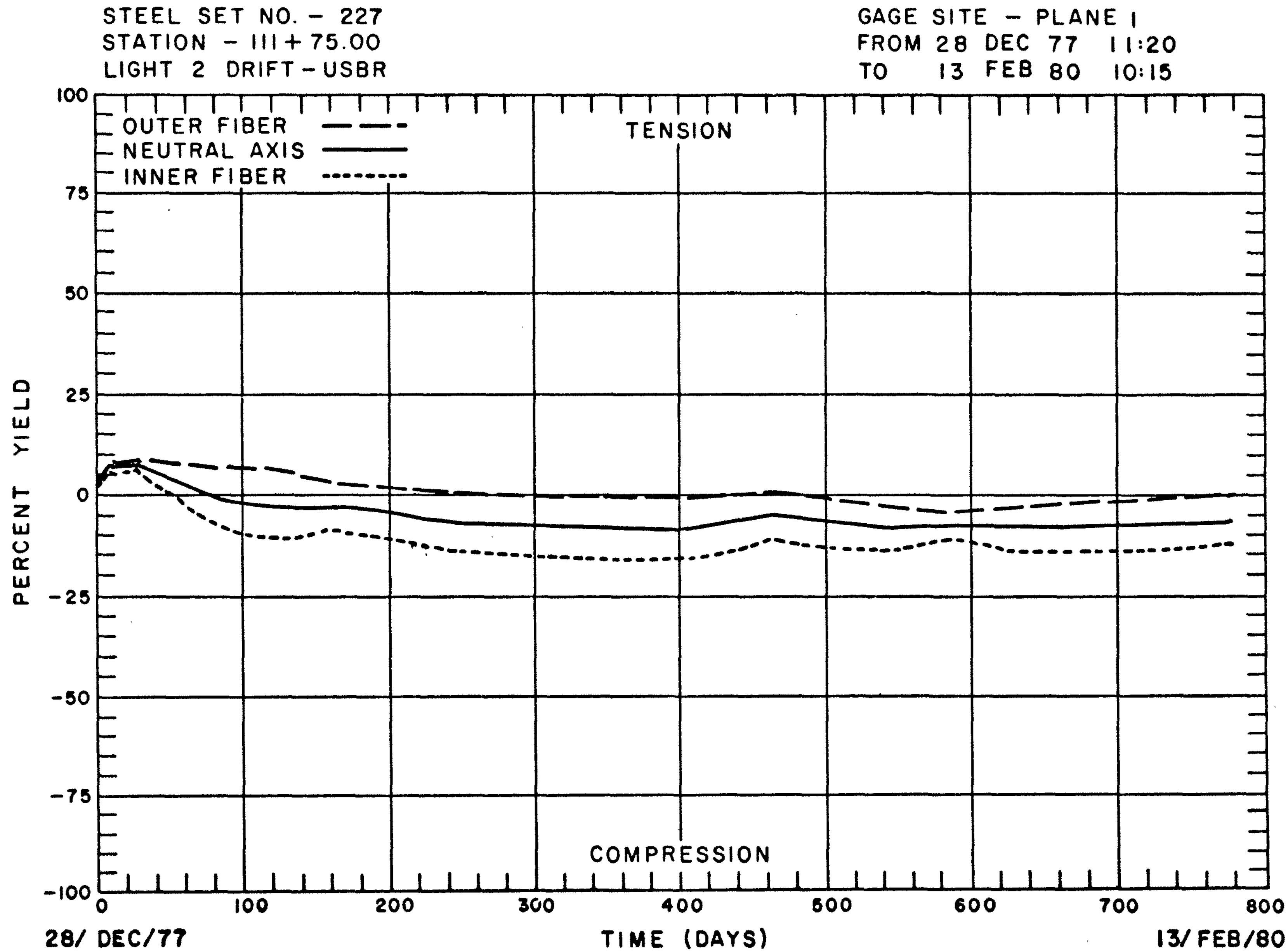


Figure B-7 Stress--Plane 1, Steel Set No. 227

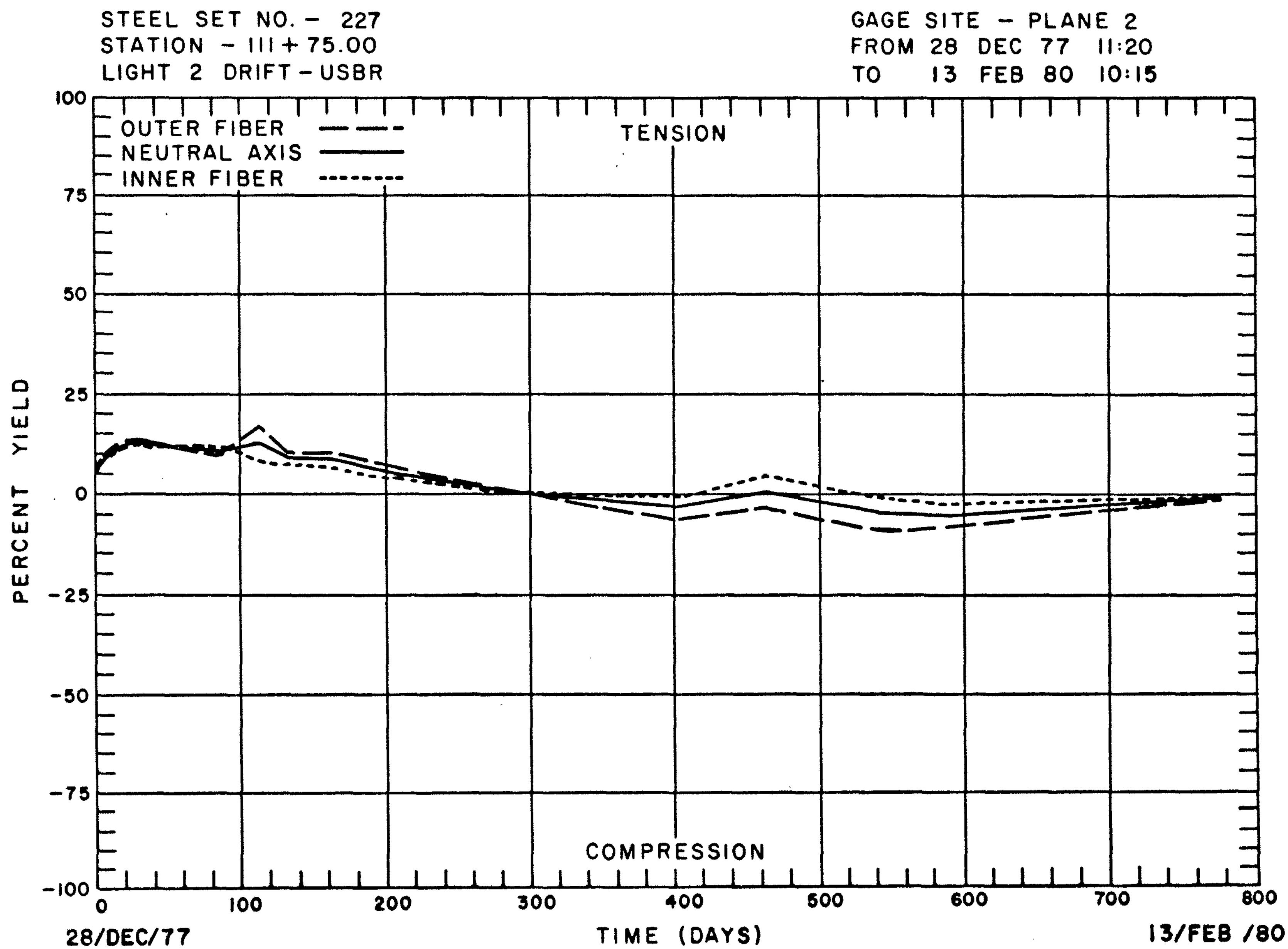


Figure B-8 Stresses--Plane 2, Steel Set No. 227

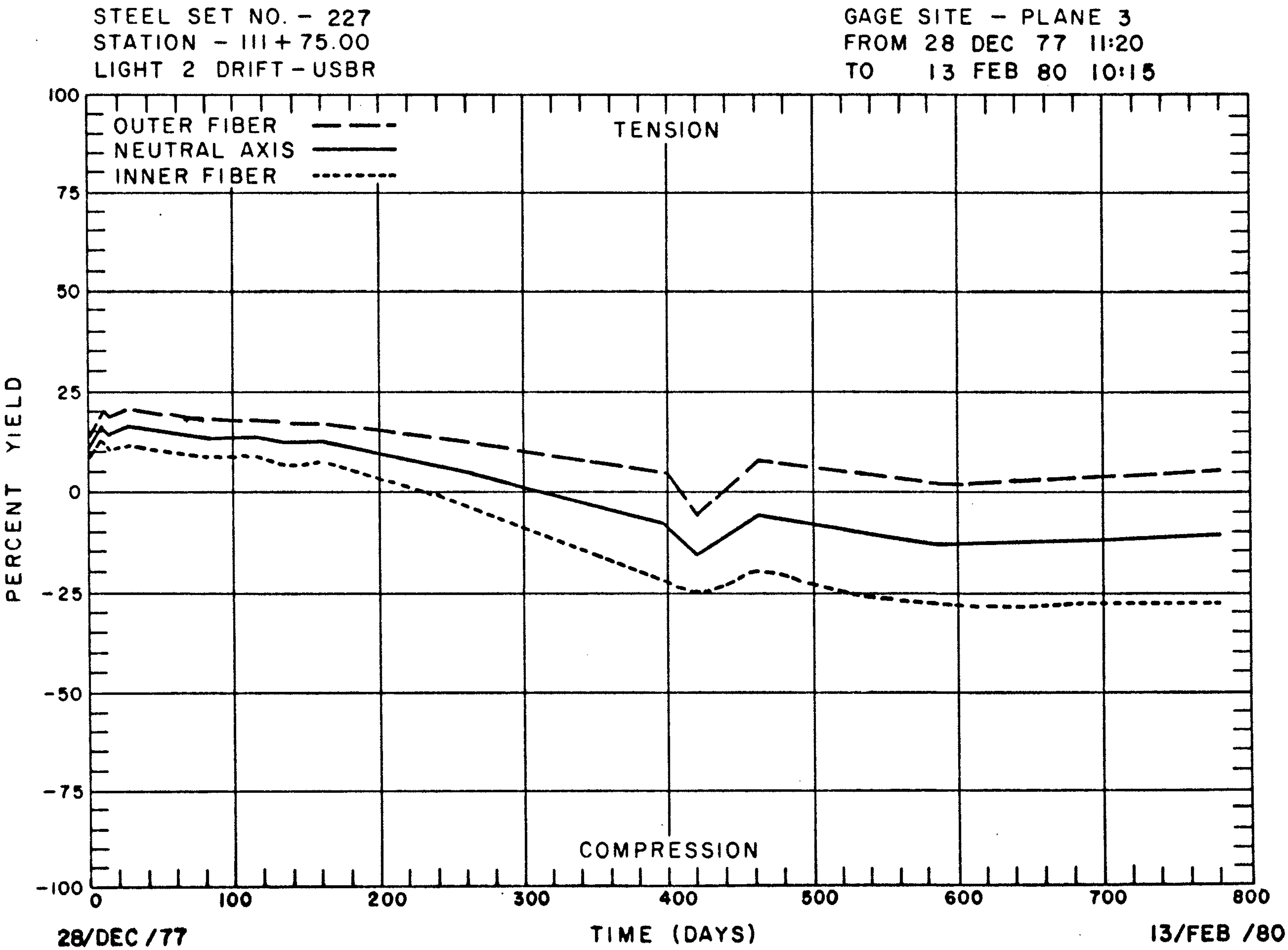


Figure B-9 Stresses - Plane 3 Steel Set No. 227

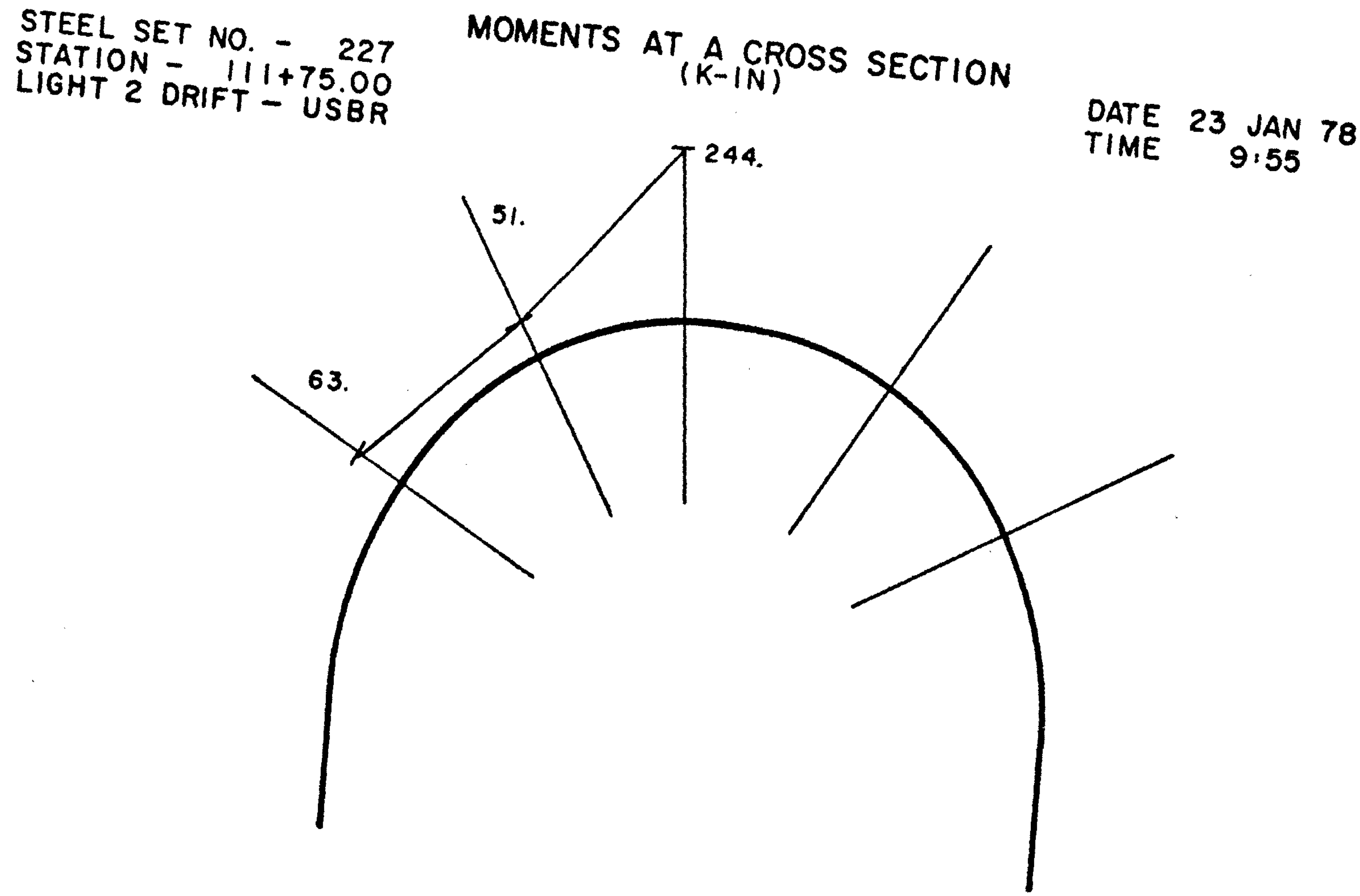


Figure B-10 Moments at Steel Set No. 227, January 1978

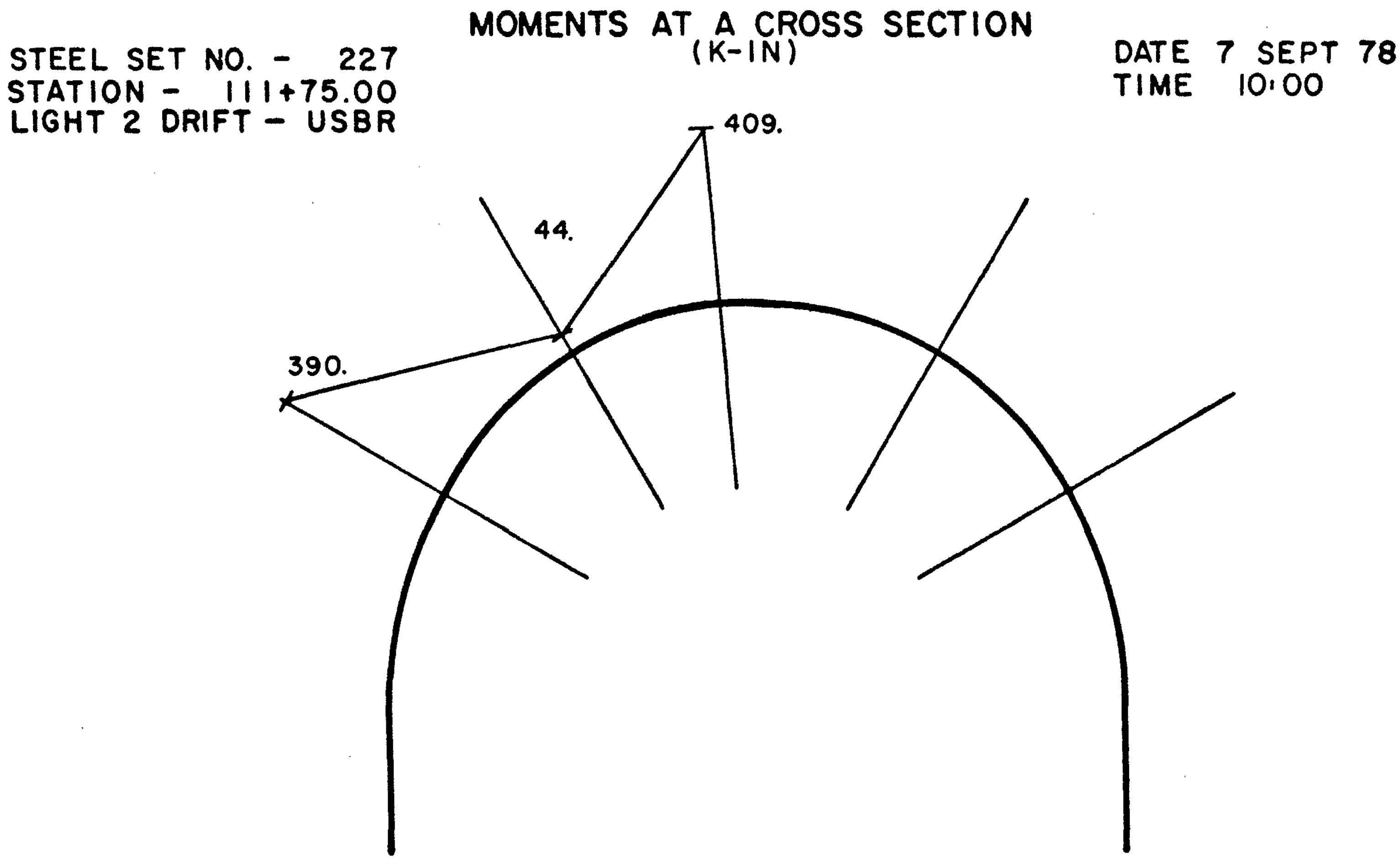


Figure B-11 Moments at Steel Set No. 227, September 1978

Table B-3. - Stresses, percent yield, and bending moment
Steel set 229 - station 111+75
(Tension is +, compression is -) (Type - Light 2 drift - USBR)
Eisenhower Tunnel

Plane	Stress K/in^2 Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
	Date: December 28, 1977 Time: 11:15						
1	1.01	1.04	1.32	1.60	1.63	4	46
2	1.97	2.06	2.83	3.60	3.69	10	129
3	2.58	2.70	3.71	4.73	4.85	13	171
	Date: January 5, 1978 Time: 10:00						
1	2.80	2.84	3.22	3.60	3.64	10	63
2	5.48	5.51	5.73	5.95	5.97	16	37
3	4.12	4.21	4.93	5.66	5.74	15	122
	Date: January 10, 1978 Time: 10:15						
1	2.32	2.35	2.62	2.90	2.93	8	46
2	3.47	3.54	4.13	4.73	4.80	13	100
3	3.30	3.39	4.18	4.96	5.05	14	132
	Date: January 23, 1978 Time: 10:05						
1	2.43	2.47	2.74	3.02	3.05	8	46
2	3.29	3.39	4.28	5.16	5.27	14	149
3	3.16	3.28	4.28	5.28	5.40	14	168
	Date: March 22, 1978 Time: 11:35						
1	1.61	1.68	2.26	2.84	2.91	8	97
2	3.10	3.19	3.94	4.70	4.79	13	127
3	2.23	2.41	3.89	5.37	5.54	15	248

NOTE: 1 k/in^2 = 6.900 MPa

Table B-3. - Stresses, percent yield, and bending moment - Continued
Steel set 229 - station 111+75
(Tension is +, compression is -) (Type - Light 2 drift - USBR)
Eisenhower Tunnel

Plane	Stress K/in² Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
Date: April 20, 1978 Time: 10:35							
1	1.76	1.83	2.36	2.90	2.96	8	90
2	1.71	1.91	3.63	5.34	5.54	15	287
3	2.20	2.35	3.64	4.93	5.08	14	217
Date: May 10, 1978 Time: 11:48							
1	1.26	1.28	1.42	1.57	1.58	4	24
2	0.73	0.99	3.16	5.34	5.59	15	365
3	1.76	1.89	3.68	5.48	5.69	15	302
Date: June 8, 1978 Time: 11:40							
1	0.55	0.58	0.81	1.04	1.07	2	39
2	1.52	1.68	3.02	4.35	4.51	12	224
3	1.24	1.39	2.68	3.97	4.13	11	217
Date: September 7, 1978 Time: 10:00							
1	-0.88	-0.81	-0.20	0.41	0.48	2	102
2	-1.12	-0.93	0.70	2.32	2.51	6	273
3	-0.51	-0.38	0.71	1.80	1.93	5	183
Date: February 2, 1979 Time: 10:25							
1	-0.83	-0.73	0.19	1.10	1.21	3	153
2	-4.54	-4.23	-1.64	0.96	1.27	12	436
3	-5.01	-4.79	-2.93	-1.07	-0.85	13	312
Date: February 21, 1979 Time: 12:50							
1	-3.70	-3.89	-5.42	-6.96	-7.14	19	-258
2	-8.62	-8.24	-5.00	-1.77	-1.38	23	543
3	NO STRAIN GAGE DATA						

NOTE: 1 k/in² = 6.900 MPa

Table B-3. - Stresses, percent yield, and bending moment - Continued
Steel set 229 - station 111+75
(Tension is +, compression is -) (Type - Light 2 drift - USBR)
Eisenhower Tunnel

Plane	Stress K/in^2 Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
	Date: April 5, 1979			Time: 9:15			
1	0.46	0.49	0.75	1.02	1.05	2	44
2	-3.53	-3.42	-2.51	-1.60	-1.49	9	153
3	-4.18	-3.97	-2.26	-0.55	-0.35	11	287
	Date: June 22, 1979			Time: 10:05			
1	-0.74	-0.67	-0.07	-0.52	-0.59	2	100
2	-5.50	-5.60	-6.42	-7.25	-7.35	20	-139
3	-5.63	-5.48	-4.23	-2.99	-2.84	15	209
	Date: August 8, 1979			Time: 10:05			
1	-1.65	-1.54	-0.58	0.38	0.49	4	161
2	-8.09	-8.00	-7.31	-6.61	-6.53	22	117
3	-5.57	-5.48	-4.73	-3.97	-3.88	15	127
	Date: September 26, 1979			Time: 9:45			
1	-1.79	-1.65	-0.48	0.70	0.84	4	197
2	-5.72	-5.66	-5.10	-4.55	-4.49	15	93
3	-6.37	-6.18	-4.54	-2.90	-2.71	17	275
	Date: February 13, 1980			Time: 10:20			
1	-1.44	-1.31	-0.19	0.93	1.06	3	188
2	-4.93	-5.13	-6.80	-8.47	-8.67	25	-280
3	-6.24	-6.12	-5.08	-4.03	-3.91	17	175

NOTE: 1 k/in^2 = 6.900 MPa

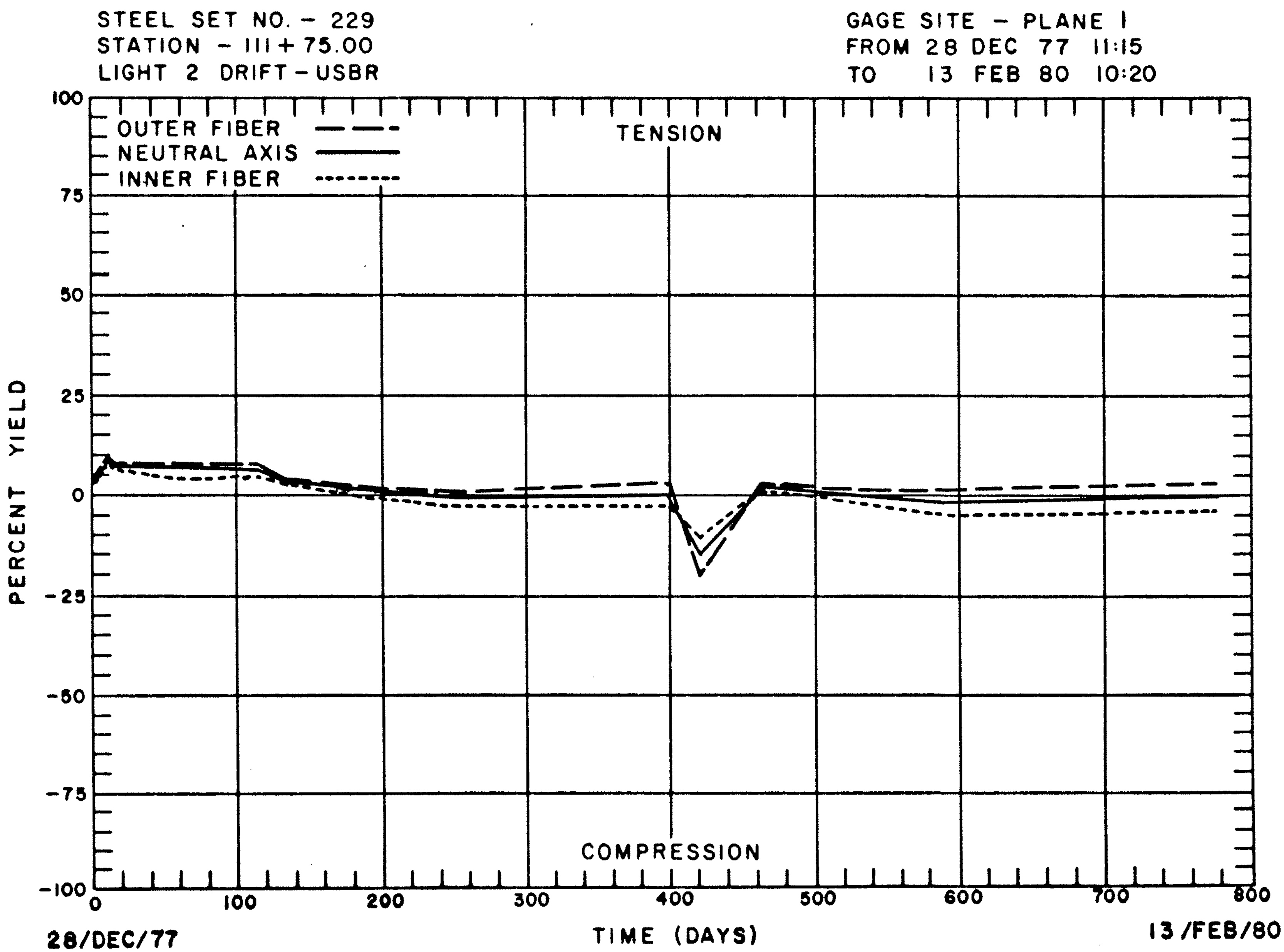


Figure B-12 Stresses--Plane 1, Steel Set No. 229

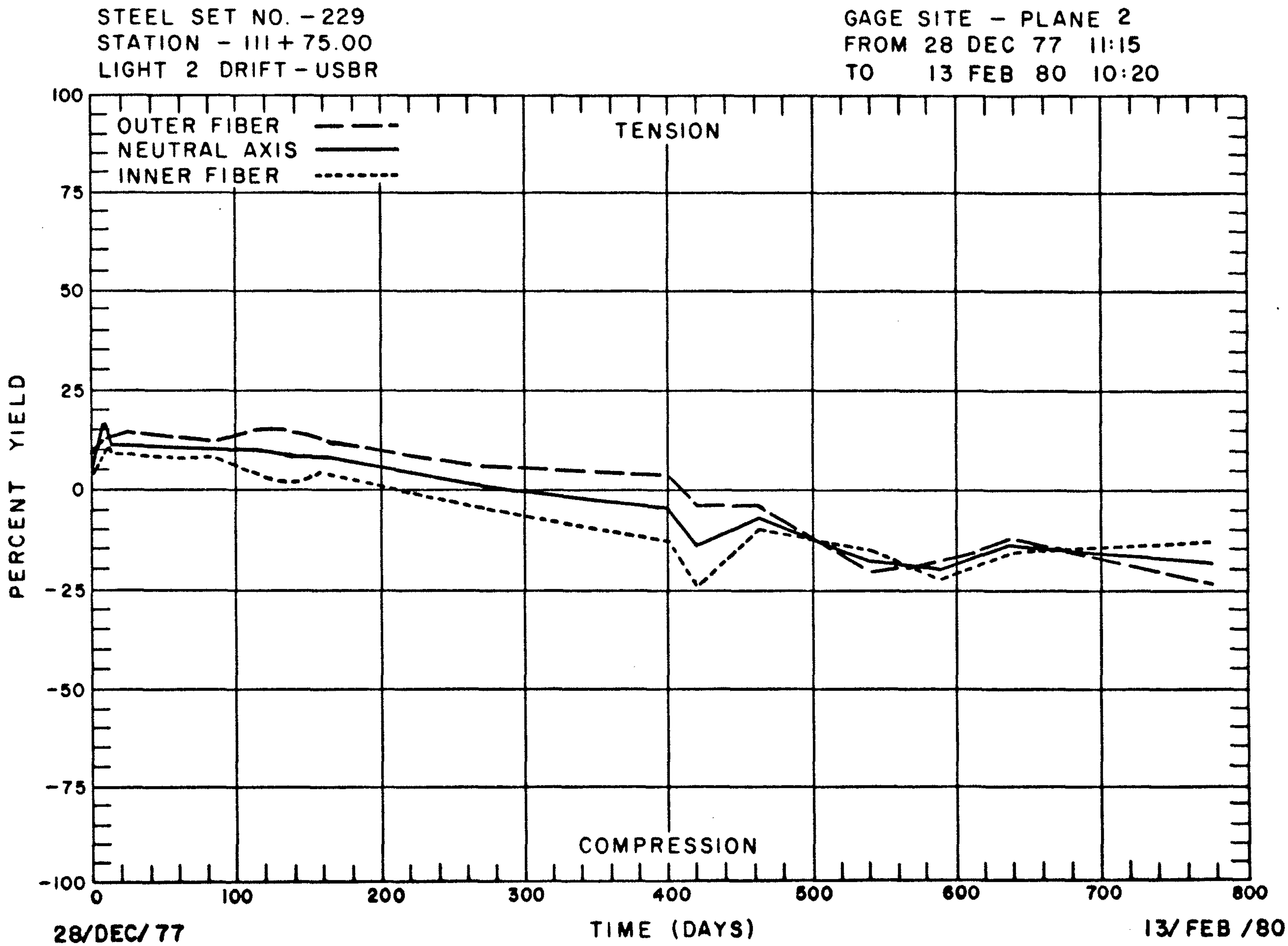


Figure B-13 Stresses--Plane 2, Steel Set No. 229

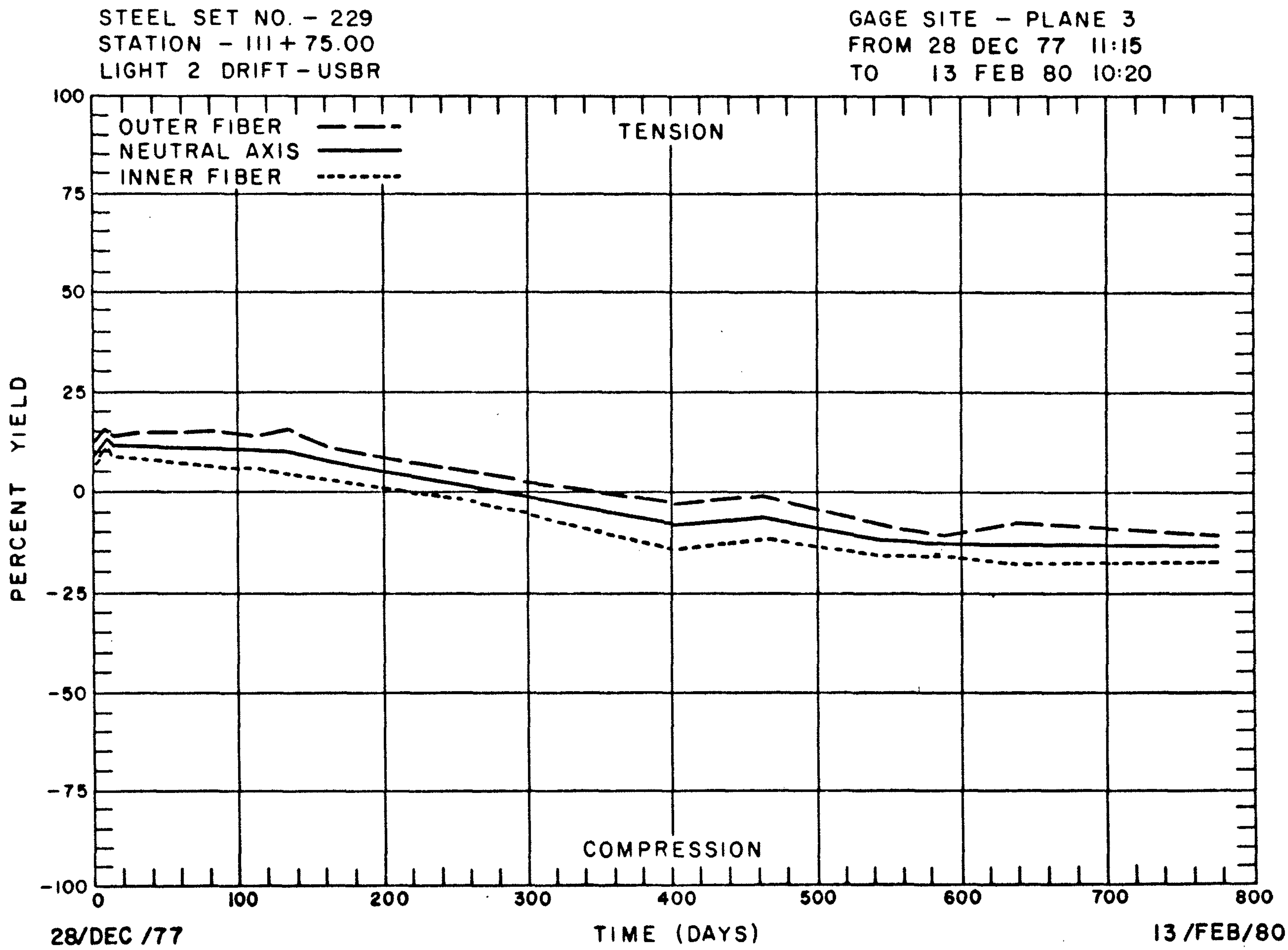


Figure B-14 Stresses - Plane 3, Steel Set No. 229

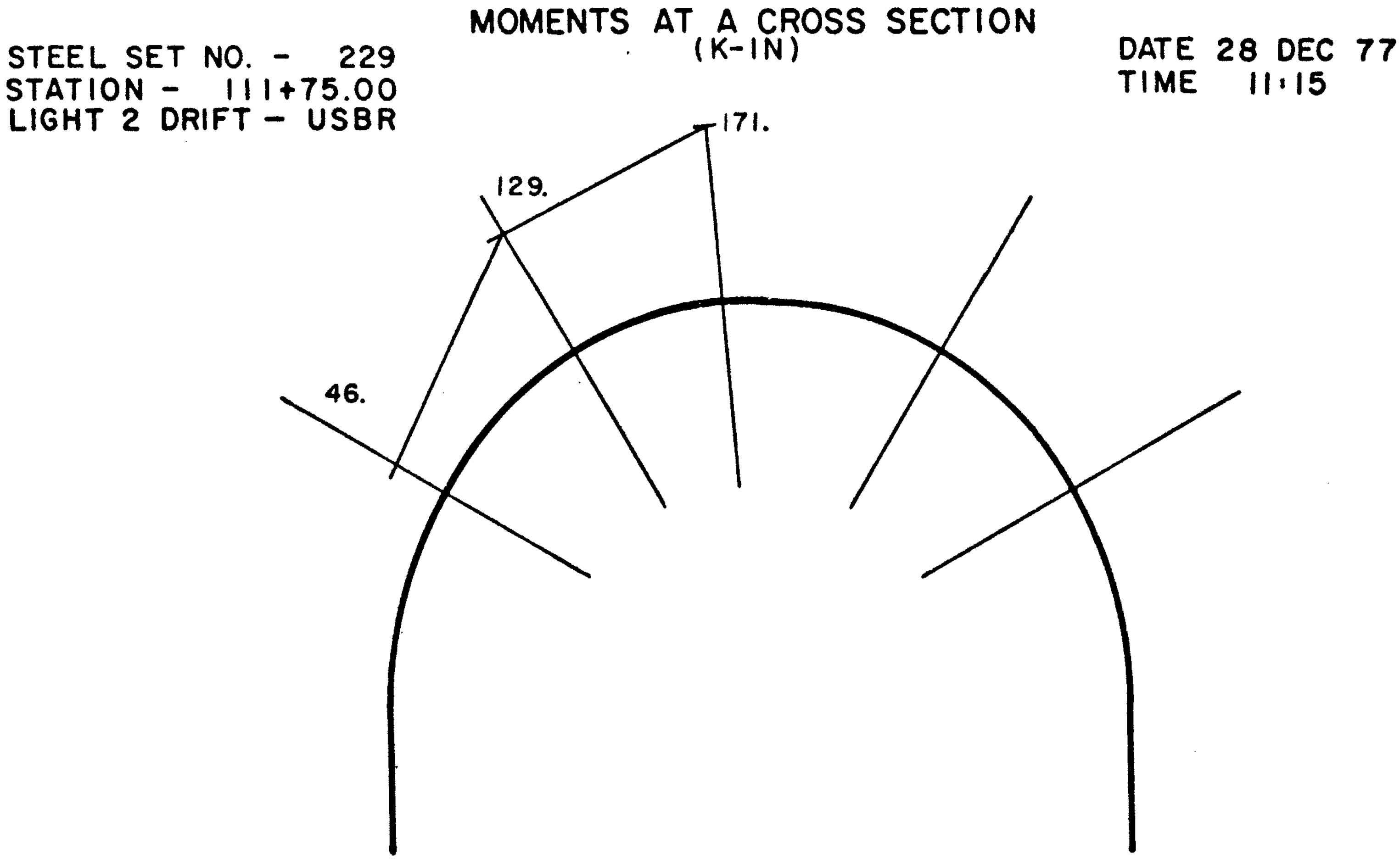


Figure B-15 Moments at Steel Set No. 229, December 1977

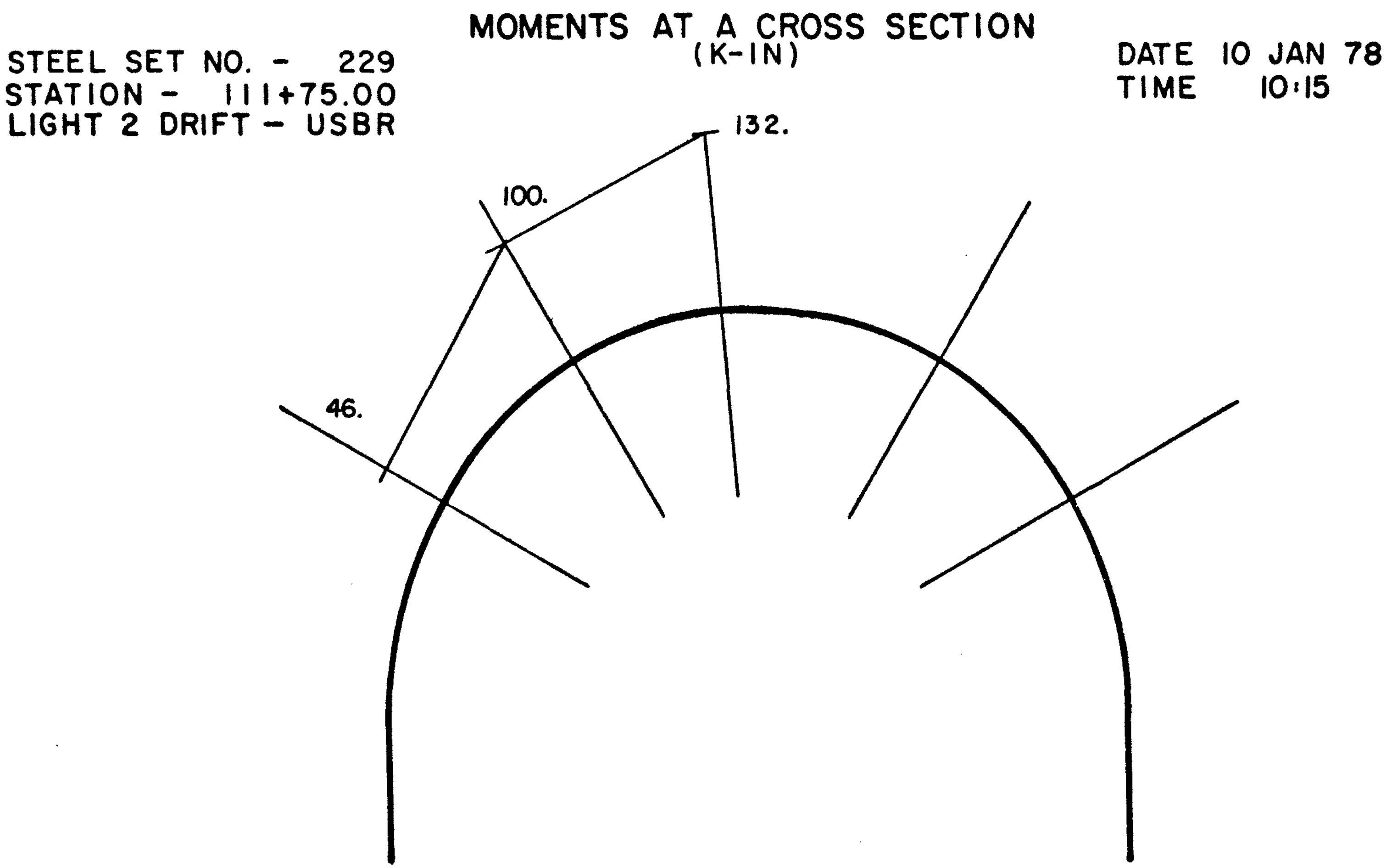


Figure B-16 Moments at Steel Set No. 229, January 1978

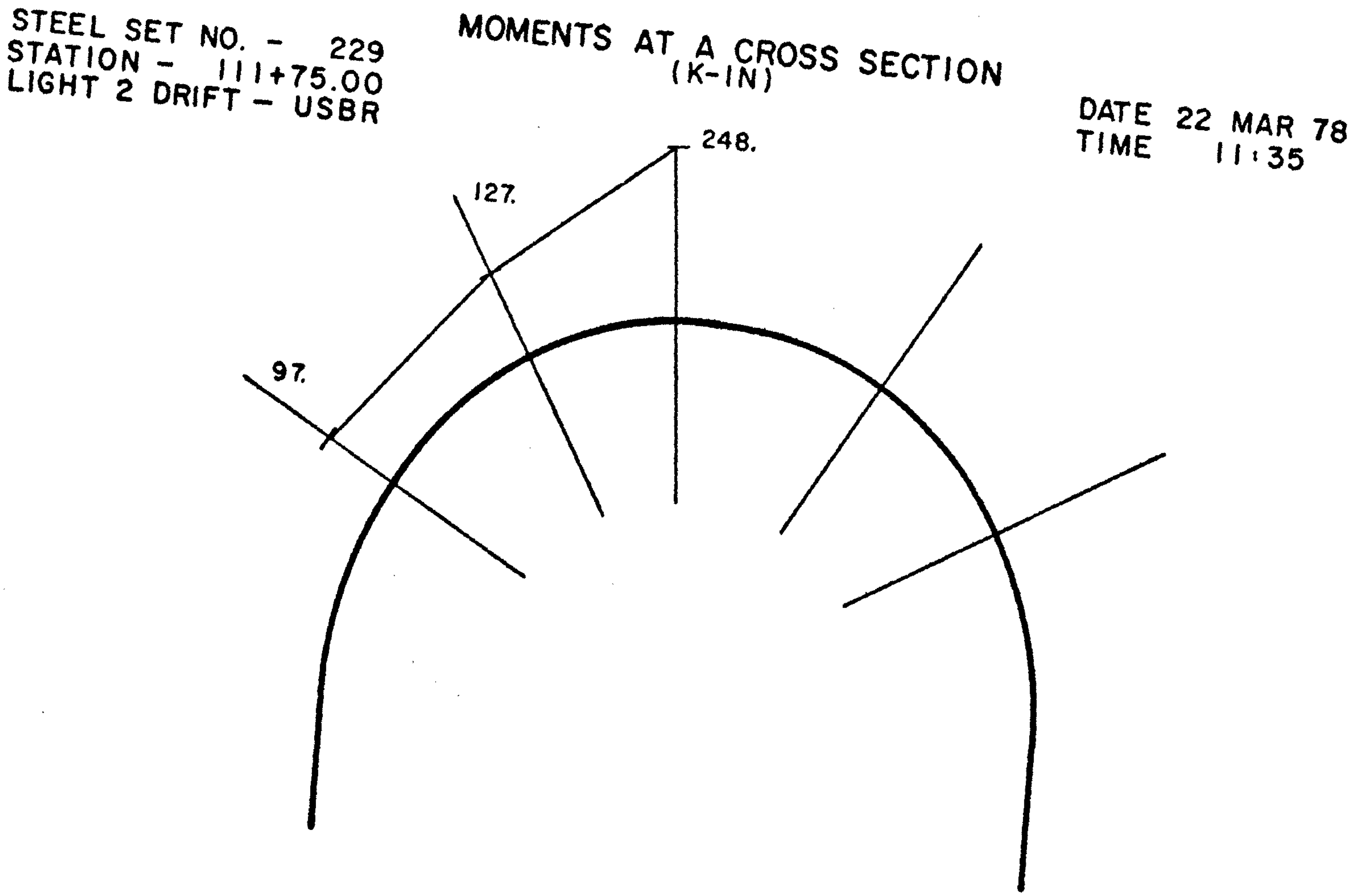


Figure B-17 Moments at Steel Set No.229, March 1978

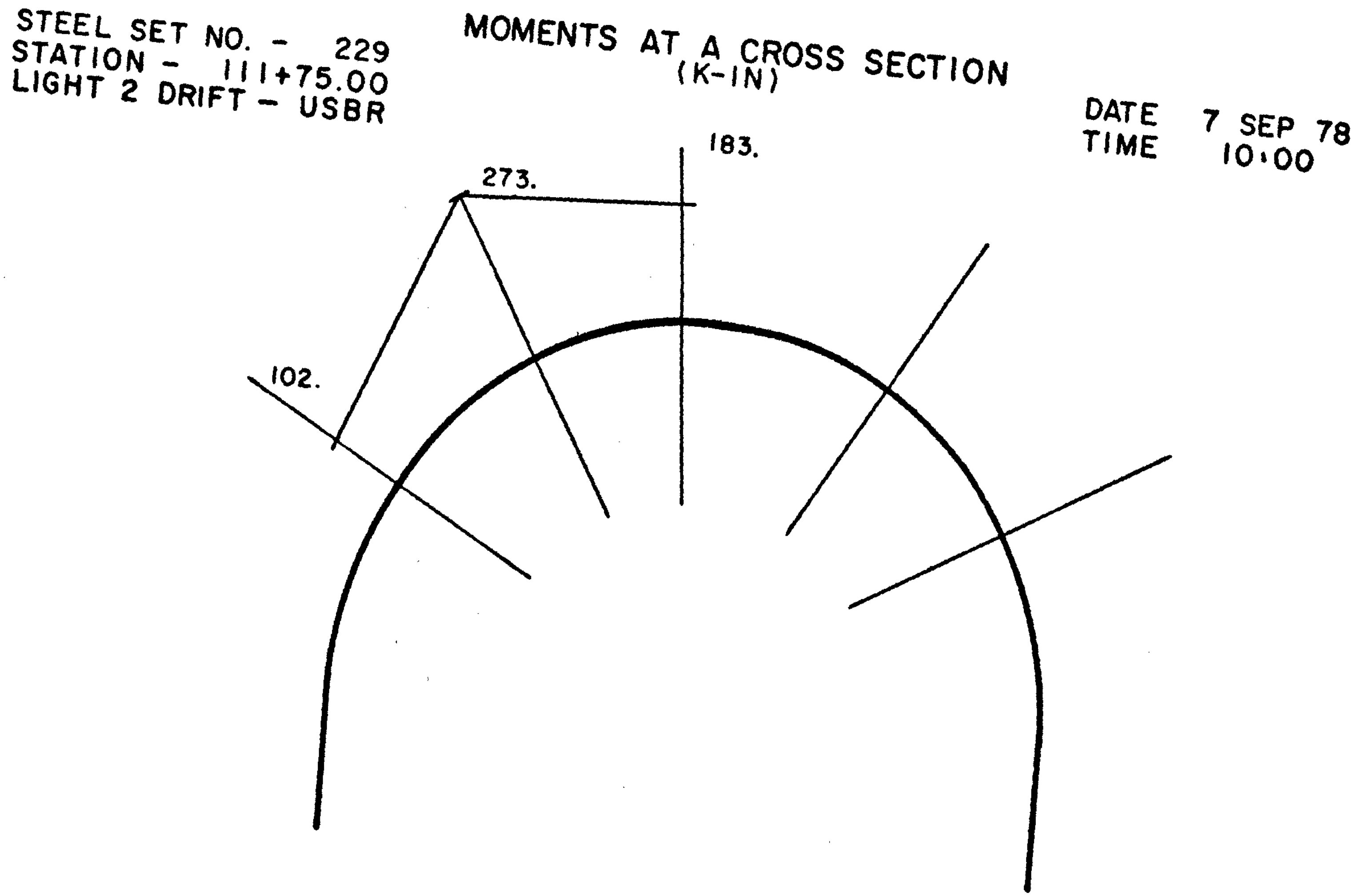


Figure B-18 Moments at Steel Set No, 229, September 1978

Table B-4. - Stresses, percent yield, and bending moment
Steel set 477 - station 101+70
(Tension is +, compression is -) (Type - East Cross - USBR)
Eisenhower Tunnel

Plane	Stress K/in^2 Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
	Date: May 2, 1978			Time: 13:00			
1	-10.86	-9.98	-4.79	0.41	1.29	19	1308
2	-7.31	-6.47	-1.51	3.45	4.29	13	1250
3	2.87	2.32	-0.90	-4.12	-4.66	8	-811
4	-12.59	-11.28	-3.55	4.18	5.49	22	1947
5	-13.07	-12.38	-8.32	-4.26	-3.57	23	1023
	Date: May 5, 1978			Time: 9:30			
1	-11.11	-10.21	-4.92	0.38	1.27	20	1334
2	-6.53	-6.06	-3.28	-0.49	-0.02	11	702
3	2.95	2.26	-1.78	-5.83	-6.52	11	-1019
4	-13.87	-12.53	-4.64	3.25	4.59	25	1988
5	-15.62	-14.73	-9.48	-4.23	-3.34	28	1323
	Date: May 9, 1978			Time: 10:19			
1	-11.30	-10.38	-4.99	0.41	1.32	20	1359
2	-6.36	-5.89	-3.10	-0.32	0.15	11	702
3	3.22	2.55	-1.39	-5.34	-6.00	10	-994
4	-13.80	-12.47	-4.61	3.25	4.58	25	1980
5	-13.74	-12.99	-8.58	-4.18	-3.43	24	1111
	Date: May 10, 1978			Time: 12:15			
1	-11.42	-10.50	-5.06	0.38	1.30	20	1370
2	-6.97	-6.44	-3.32	-0.20	0.33	12	786
3	3.47	2.81	-1.09	-4.99	-5.65	10	-983
4	-13.64	-12.35	-4.79	2.78	4.07	24	1907
5	-13.94	-13.17	-8.58	-4.00	-3.23	25	1155

NOTE: 1 k/in^2 = 6.900 MPa

Table B-4. - Stresses, percent yield, and bending moment - Continued
Steel set 477 - station 101+70
(Tension is +, compression is -) (Type - East Cross - USBR)
Eisenhower Tunnel

Plane	Stress K/in^2 Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
Date: May 16, 1978				Time: 9:40			
1	-12.15	-11.22	-5.77	-0.32	0.61	22	1374
2	-8.54	-7.86	-3.84	0.17	0.86	15	1012
3	2.54	1.91	-1.80	-5.51	-6.14	11	-935
4	-14.63	-13.31	-5.55	2.20	3.52	26	1955
5	-13.94	-13.25	-9.22	-5.19	-4.51	25	1016
Date May 17, 1978				Time: 11:20			
1	-12.15	-11.22	-5.77	-0.32	0.61	22	1374
2	-8.31	-7.77	-4.63	-1.48	-0.95	15	793
3	2.59	1.91	-2.06	-6.03	-6.71	12	-1001
4	-14.35	-13.05	-5.41	2.23	3.53	26	1926
5	-13.89	-13.17	-8.87	-4.58	-3.85	25	1082
Date: June 6, 1978				Time: 14:10			
1	-12.55	-11.60	-5.97	-0.35	0.61	22	1418
2	-8.14	-7.54	-3.99	-0.44	0.17	14	895
3	2.65	2.06	-1.44	-4.93	-5.52	10	-881
4	-14.48	-13.22	-5.81	1.60	2.85	26	1867
5	-5.89	-5.66	-4.26	-2.87	-2.63	10	351
Date: June 8, 1978				Time: 9:30			
1	-12.44	-11.48	-5.87	-0.26	0.69	22	1414
2	-7.66	-7.08	-3.61	-0.15	0.44	13	873
3	2.80	2.09	-2.09	-6.26	-6.97	12	-1052
4	-14.71	-13.46	-6.05	1.36	2.62	26	1867
5	-5.58	-5.39	-4.32	-3.25	-3.07	10	270
Date: July 26, 1978				Time: 10:00			
1	-7.62	-7.13	-4.26	-1.39	-0.91	13	723
2	0.00	0.00	0.00	-2.47	0.00	0	0
3	-22.01	-20.85	-14.02	-7.19	-6.03	40	1721
4	0.00	-15.63	0.00	0.00	0.00	0	0
5	-8.72	-8.35	-6.21	-4.06	-3.70	15	541

NOTE: 1 k/in^2 = 6.900 MPa

Table B-4. - Stresses, percent yield, and bending moment - Continued
Steel set 477 - station 101+70
(Tension is +, compression is -) (Type - East Cross - USBR)
Eisenhower Tunnel

Plane	Stress K/in² Inside fiber	Stress K/in² Inside gage	Stress K/in² Neutral axis	Stress K/in² Outer gage	Stress K/in² Outer fiber	% yield stress	Moment K-in
	Data after January 12 not used in analysis						
	Date: January 12, 1979			Time: 1:00			
1	0.00	0.00	0.00	-89.15	-86.80	216	3482
2	0.00	-32.31	0.00	0.00	0.00	0	0
3	0.00	0.00	-74.59	-45.47	-40.53	197	7337
4	-46.69	-49.71	-67.51	-85.32	-88.34	160	-4487
5	1.50	-1.25	-17.43	-33.61	-36.36	66	-4078
	Date: January 15, 1979			Time: 1:00			
1	-99.04	-93.67	-61.99	-30.31	-24.93	180	7983
2	0.00	-20.16	0.00	0.00	0.00	0	0
3	-70.42	-66.58	-43.94	-21.29	-17.45	128	5707
4	-17.03	-19.75	-35.80	-51.85	-54.57	99	-4045
5	-1.86	-2.38	-5.45	-8.53	-9.05	16	-775
	Date: February 21, 1979			Time: 12:30			
1	-68.07	-62.35	-28.62	5.10	10.82	123	8499
2	0.00	-15.40	0.00	0.00	0.00	0	0
3	-96.58	-90.94	-57.70	-24.45	-18.81	175	8378
4	0.00	-16.85	0.00	0.00	0.00	0	-1016
5	2.10	1.42	-2.61	-6.64	-7.32	13	
	Date: April 5, 1979			Time: 9:45			
1	0.00	0.00	-66.06	-10.64	-1.25	237	13965
2	0.00	-31.87	0.00	0.00	0.00	0	0
3	0.00	0.00	-82.46	-55.88	-51.38	206	6697
4	0.00	-24.62	0.00	0.00	0.00	0	0
5	106.16	95.79	34.60	-26.59	-36.97	193	0

NOTE: 1 k/in^2 = 6.900 MPa

Table B-4. - Stresses, percent yield, and bending moment - Continued
Steel set 477 - station 101+70
(Tension is +, compression is -) (Type - East Cross - USBR)
Eisenhower Tunnel

Plane	Stress K/in^2 Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
	Date: June 22, 1979			Time: 10:35			
1	-79.25	-72.70	-34.10	4.50	11.04	144	9726
2	0.00	-41.04	0.00	0.00	0.00	0	0
3	0.00	0.00	0.00	-68.88	-61.42	298	11071
4	0.00	-39.50	0.00	0.00	0.00	0	0
5	-1.29	-4.32	-22.19	-40.05	-43.08	78	-4501
	Date: August 8, 1979			Time: 10:45			
1	-71.80	-67.40	-41.44	-15.49	-11.08	130	6540
2	0.00	-45.62	0.00	0.00	0.00	0	0
3	0.00	0.00	0.00	-64.87	-58.03	277	10165
	Date: September 26, 1979			Time: 10:09			
1	-29.86	-34.39	-61.13	-87.87	-92.40	168	-6737
2	0.00	-51.91	0.00	0.00	0.00	0	0
3	0.00	-98.95	-80.75	-62.55	-59.47	185	4585
	Date: February 13, 1980			Time: 10:40			
1	-48.61	-51.53	-68.76	-85.98	-88.91	161	-4341
2	0.00	-42.83	0.00	0.00	0.00	0	0
3	0.00	0.00	0.00	-90.36	-88.36	210	2981

NOTE: 1 k/in^2 = 6.900 MPa

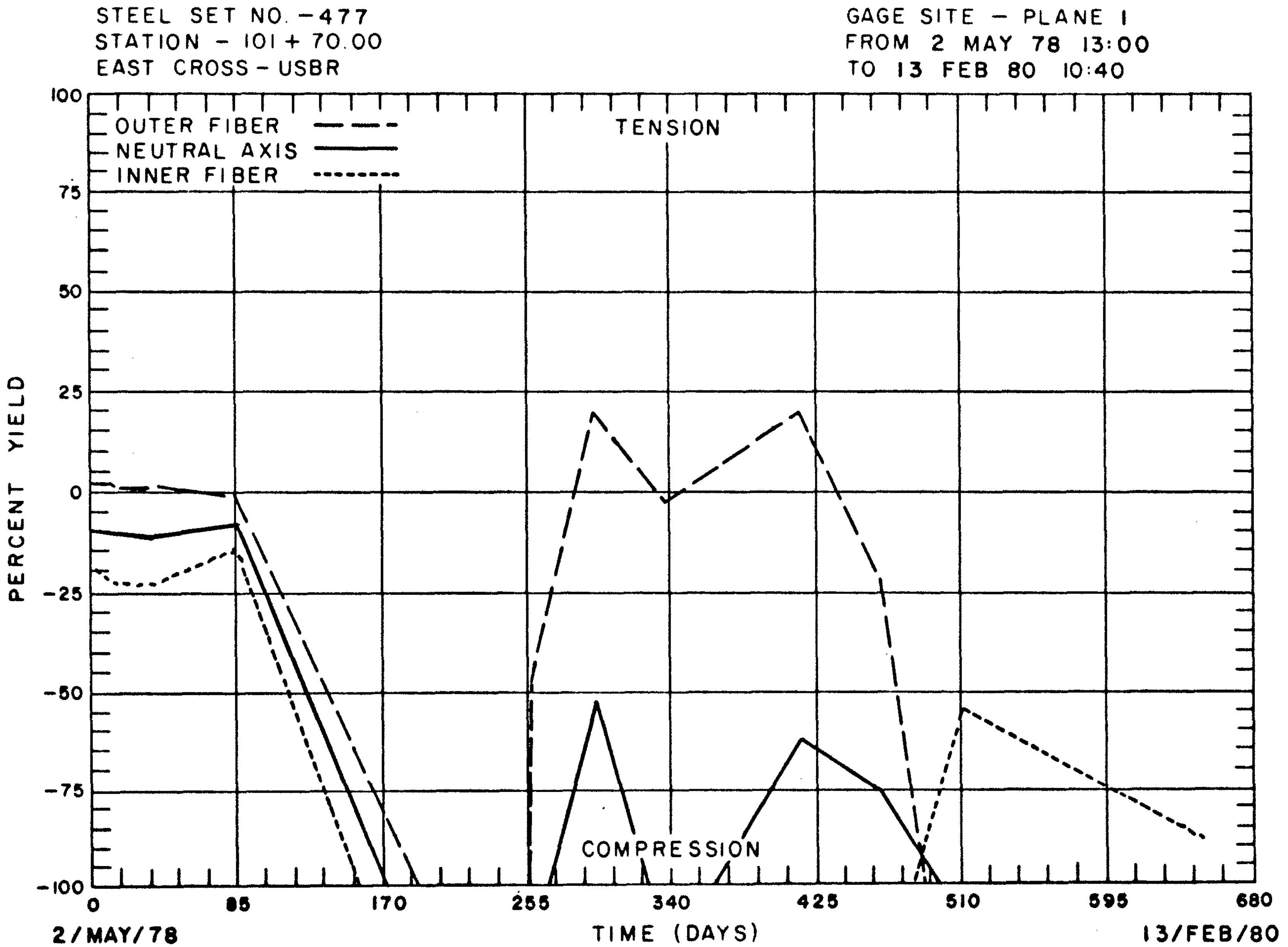


Figure B-19 Stresses--Planel, Steel No. 477

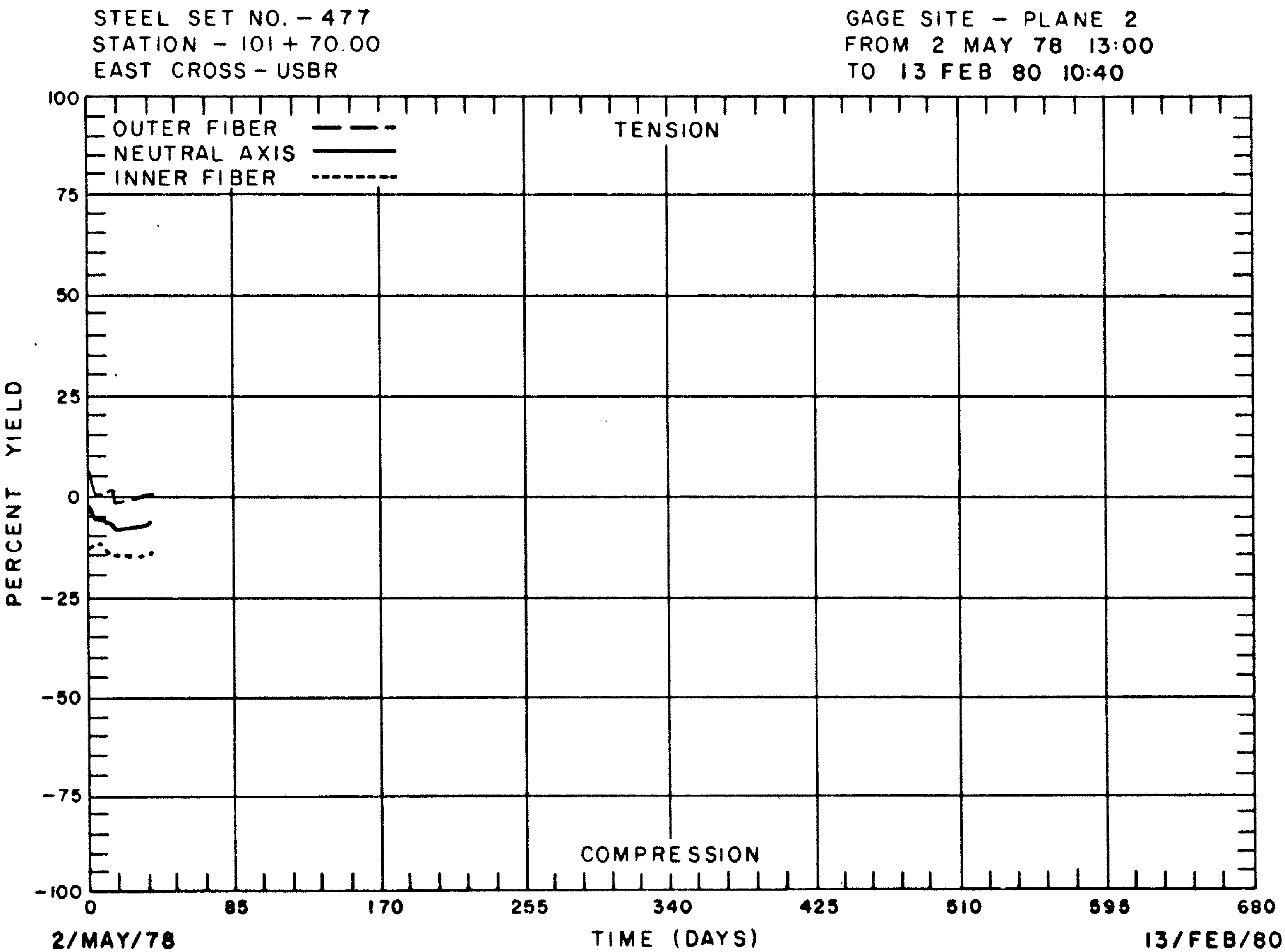


Figure B-20 Stresses--Plane 2, Steel Set No. 477

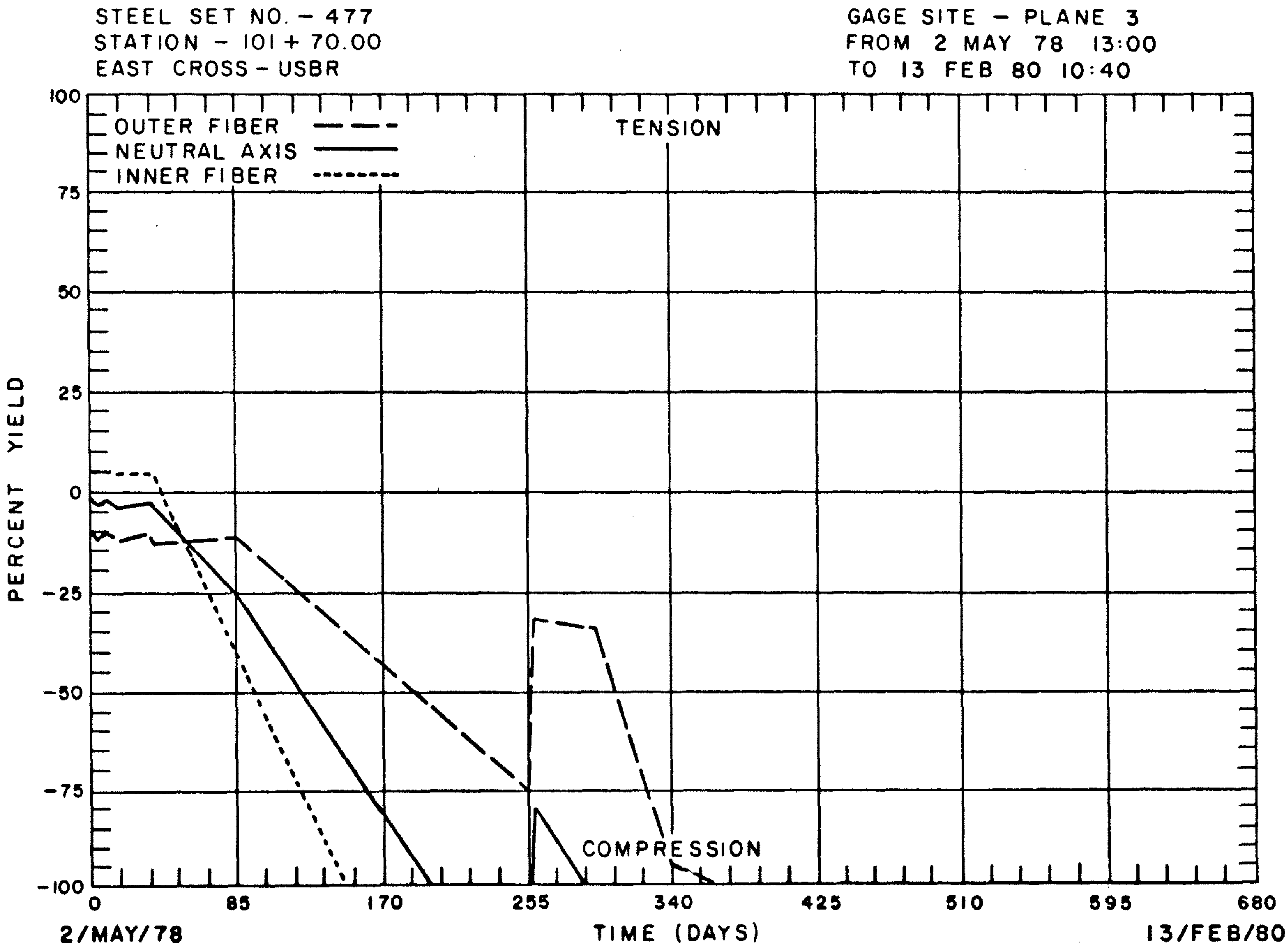


Figure B-21 Stresses--Plane 3, Steel Set No. 477

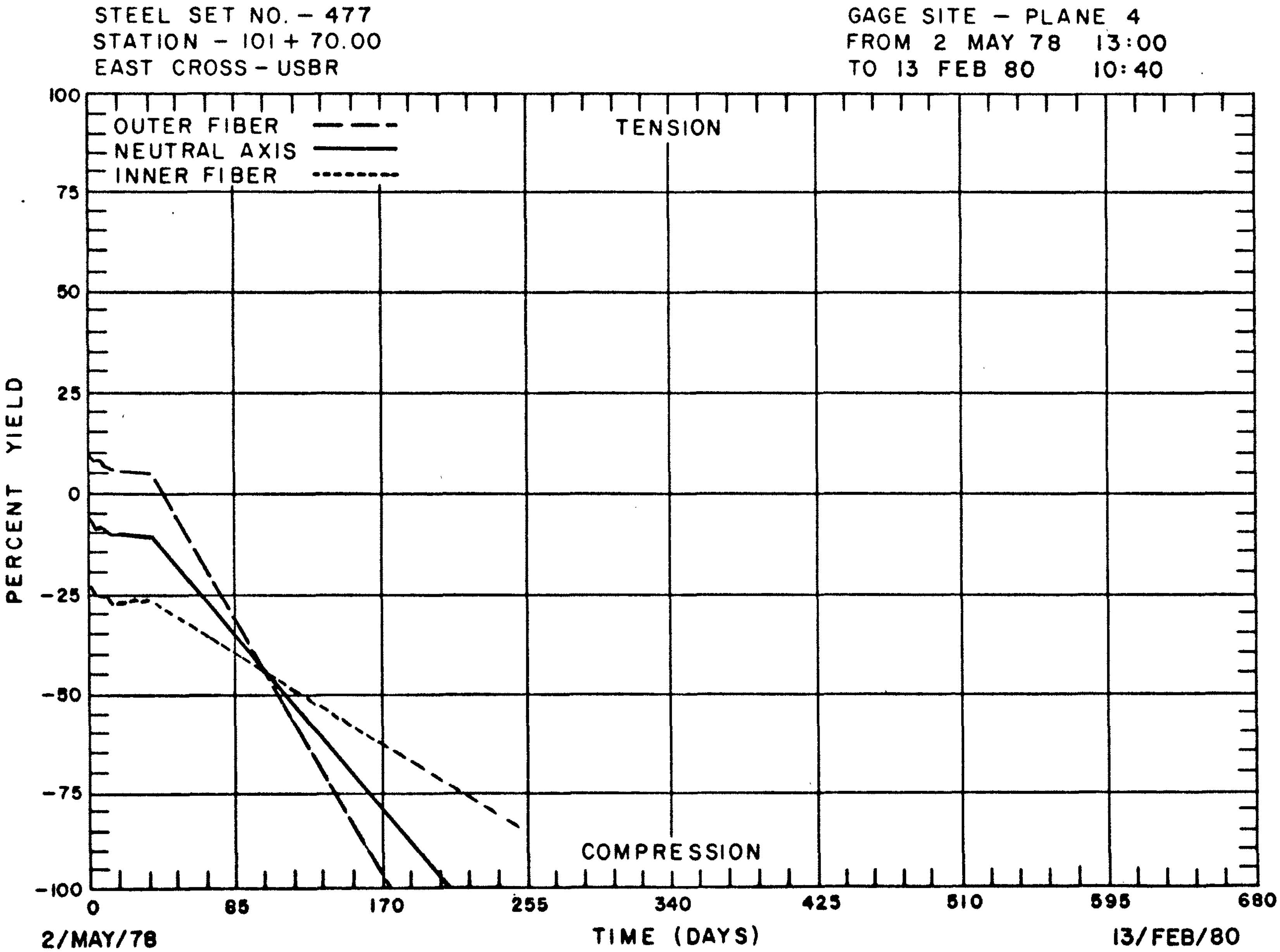


Figure B-22 Stresses--Plane Steel Set No. 477

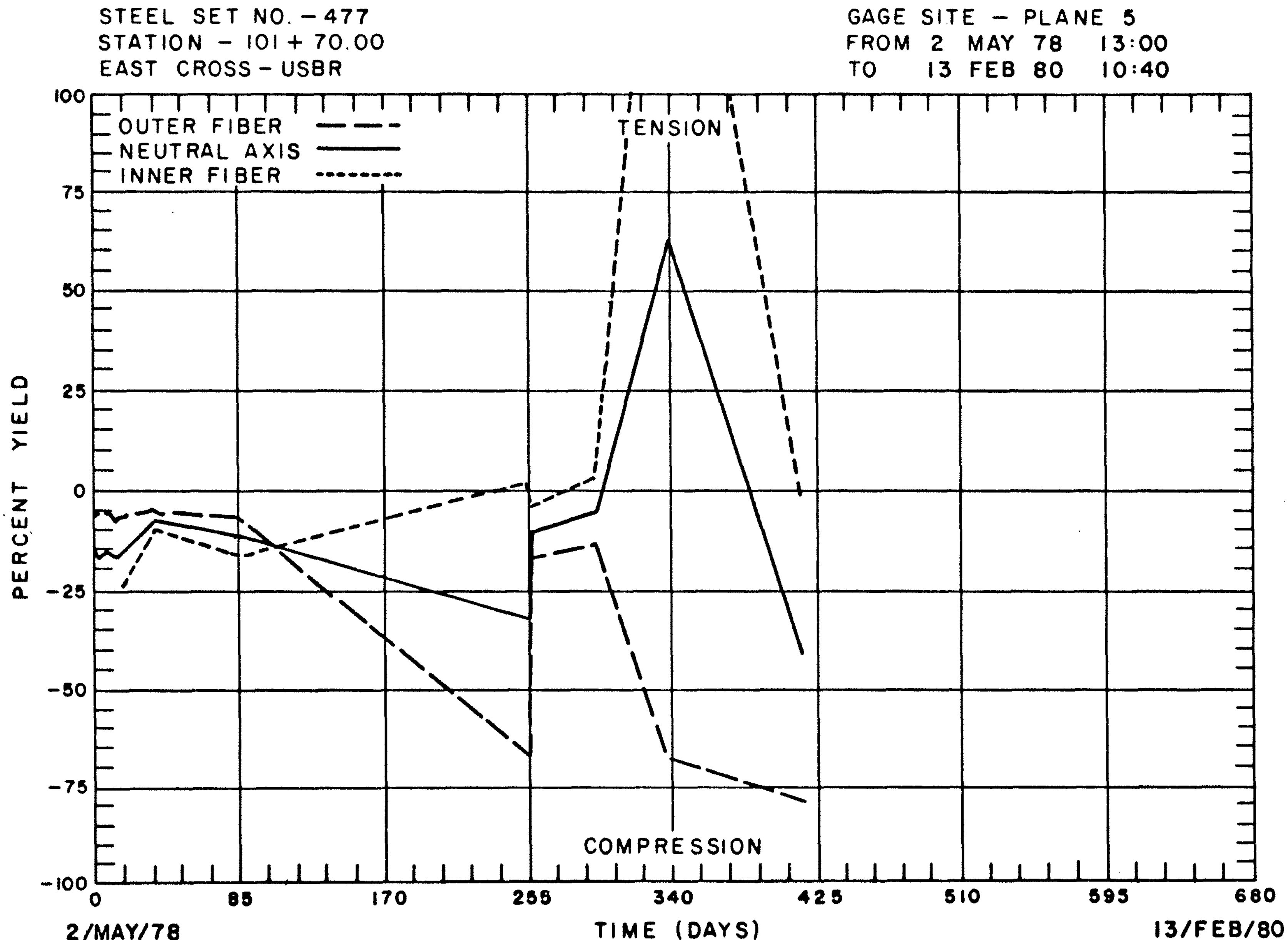


Figure B-23 Stresses--Plane 5, Steel Set No, 477

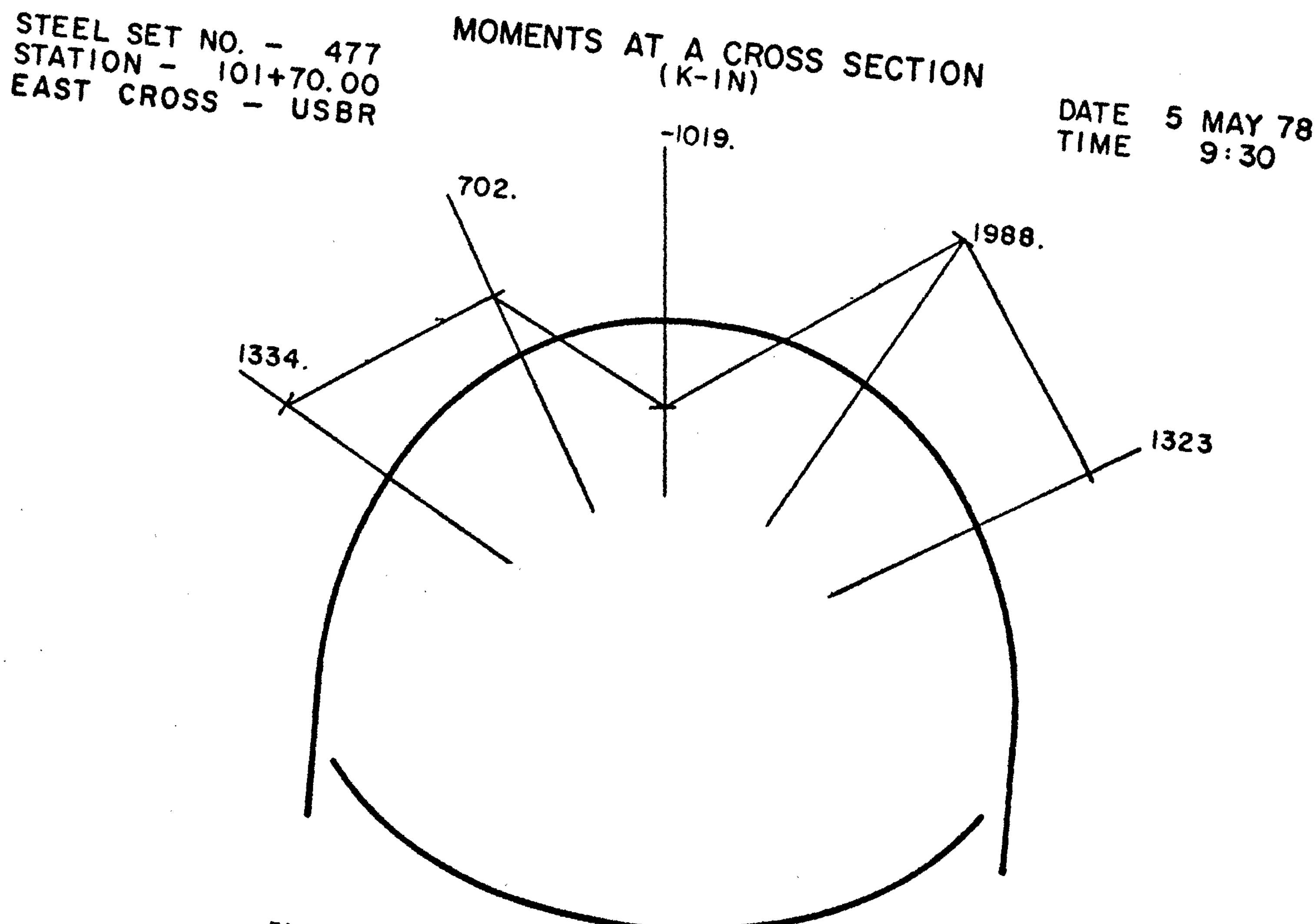


Figure B-24 Moments at Steel Set No.477, May 1978

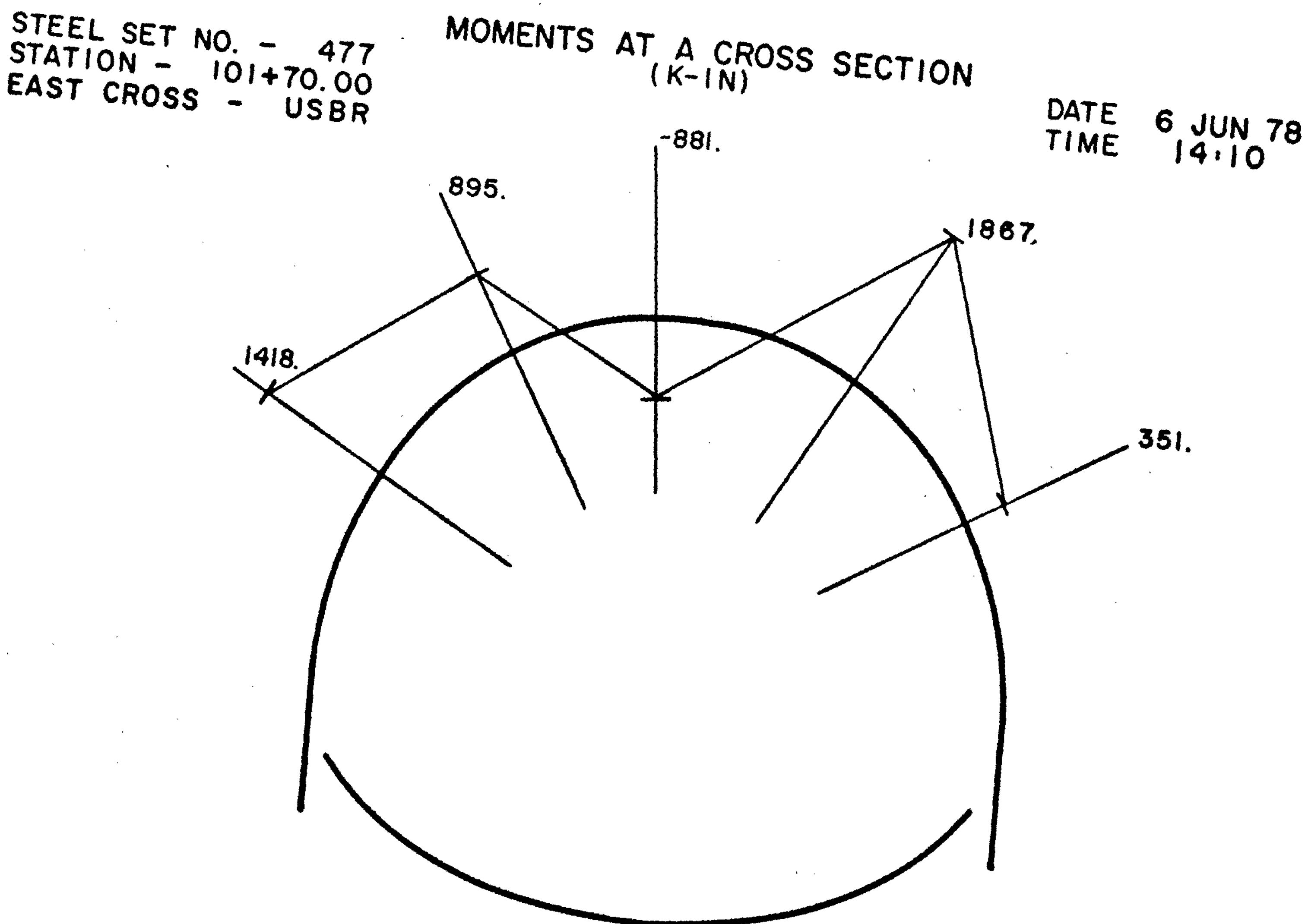


Figure B-25 Moments at Steel Set No.477, June 1978

Table B-5. - Stresses, percent yield, and bending moment
Steel set 478 - station 101+70
(Tension is +, compression is -) (Type - East Cross - USBR)
Eisenhower Tunnel

Plane	Stress K/in^2 Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
	Date: May 2, 1978			Time: 13:00			
1	0.00	0.00	0.00	0.00	0.00	0	0
2	0.00	-15.11	0.00	0.00	0.00	0	0
3	2.31	1.57	-2.84	-7.25	-8.00	14	-1111
4	6.75	2.84	-20.18	-43.21	-47.11	85	-5802
5	-1.50	-1.07	1.44	3.94	4.37	7	632
	Date: May 5, 1978			Time: 10:00			
1	-14.88	-13.43	-4.86	3.71	5.17	27	2159
2	0.00	-15.52	0.00	0.00	0.00	0	0
3	1.86	1.10	-3.39	-7.89	-8.65	15	-1133
4	6.67	2.81	-19.95	-42.72	-46.58	84	-5736
5	-1.69	-1.22	1.57	4.35	4.82	8	702
	Date: May 9, 1978			Time: 10:20			
1	0.00	0.00	0.00	0.00	0.00	0	0
2	0.00	-15.92	0.00	0.00	0.00	0	0
3	1.69	0.93	-3.57	-8.06	-8.82	16	-1133
4	5.06	1.33	-20.62	-42.57	-46.29	84	-5532
5	-2.91	-2.41	0.54	3.48	3.98	7	742
	Date: May 10, 1978			Time: 12:20			
1	-15.00	-13.51	-4.76	4.00	5.49	27	2207
2	0.00	-15.92	0.00	0.00	0.00	0	0
3	1.82	1.25	-2.12	-5.48	-6.05	11	-848
4	5.36	1.62	-20.42	-42.46	-46.19	83	-5554
5	-2.62	-2.09	1.04	4.18	4.71	8	789
	Date: May 16, 1978			Time: 9:50			
1	-15.96	-14.44	-5.48	3.48	5.00	29	2258
2	0.00	-16.53	0.00	0.00	0.00	0	0
3	1.48	0.67	-4.15	-8.96	-9.78	17	-1213
4	4.12	0.81	-18.68	-38.16	-41.47	75	-4911
5	-3.70	-3.13	0.20	3.54	4.10	7	840

NOTE: 1 k/in^2 = 6.900 MPa

Table B-5. - Stresses, percent yield, and bending moment - Continued
Steel set 478 - station 101+70
(Tension is +, compression is -) (Type - East Cross - USBR)
Eisenhower Tunnel

Plane	Stress K/in^2 Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
	Date: May 18, 1978			Time: 11:10			
1	-16.05	-14.53	-5.55	3.42	4.94	29	2262
2	0.00	-16.82	0.00	0.00	0.00	0	0
3	0.96	0.23	-4.07	-8.38	-9.11	16	-1085
4	4.46	0.75	-21.08	-42.92	-46.62	84	-5503
5	-3.88	-3.31	0.09	3.48	4.06	7	855
	Date: June 6, 1978			Time: 13:50			
1	-16.27	-14.76	-5.86	3.05	4.55	29	2243
2	0.00	-16.36	0.00	0.00	0.00	0	0
3	0.98	0.23	-4.16	-8.56	-9.30	16	-1107
4	0.00	0.75	0.00	0.00	0.00	0	0
	Date: June 8, 1978			Time: 12:20			
1	-16.28	-14.76	-5.83	3.10	4.62	29	2251
2	0.00	-16.97	0.00	0.00	0.00	0	0
3	0.76	-0.03	-4.68	-9.34	-10.13	18	-1173
4	0.00	0.09	0.00	0.00	0.00	0	0
	Date: July 26, 1978			Time: 10:00			
1	-19.19	-17.84	-9.85	-1.86	-0.50	34	2013
2	0.00	-13.86	0.00	0.00	0.00	0	0
3	-1.83	-2.47	-6.24	-10.01	-10.64	19	-950
4	0.00	-0.35	0.00	0.00	0.00	0	0
	Date: September 7, 1978			Time: 9:45			
1	-19.19	-17.72	-9.06	-0.41	1.06	34	2181
2	0.00	-18.94	0.00	0.00	0.00	0	0
3	-0.68	-1.42	-5.79	-10.15	-10.89	19	-1100
4	0.00	-0.70	0.00	0.00	0.00	0	0

NOTE: 1 k/in^2 = 6.900 MPa

Table B-5. - Stresses, percent yield, and bending moment - Continued
Steel set 478 - station 101+70
(Tension is +, compression is -) (Type - East Cross - USBR)
Eisenhower Tunnel

Plane	Stress K/in^2 Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
	Data after January 12 not used in analysis						
	Date: January 12, 1979			Time: 10.05			
1	-19.20	-19.23	-19.36	-19.49	-19.51	35	-33
2	0.00	-20.33	0.00	0.00	0.00	0	0
3	-0.81	-2.29	-11.03	-19.78	-21.26	38	-2203
4	0.00	-4.50	0.00	0.00	0.00	0	0
	Date: February 21, 1979			Time: 12:20			
1	-5.29	-11.92	-51.04	-90.16	-96.79	175	-9858
2	0.00	-13.95	0.00	0.00	0.00	0	0
3	0.44	-1.07	-10.01	-18.94	-20.45	37	-2251
4	-4.96	-7.02	-19.17	-31.32	-33.38	60	-3062
	Date: April 5, 1979			Time: 9:50			
1	0.00	-11.05	0.00	0.00	0.00	0	0
2	0.00	-12.82	0.00	0.00	0.00	0	0
3	0.15	-1.33	-10.06	-18.79	-20.27	36	-2200
4	-2.87	-5.37	-20.07	-34.77	-37.26	67	-3705

NOTE: 1 k/in^2 = 6.900 MPa

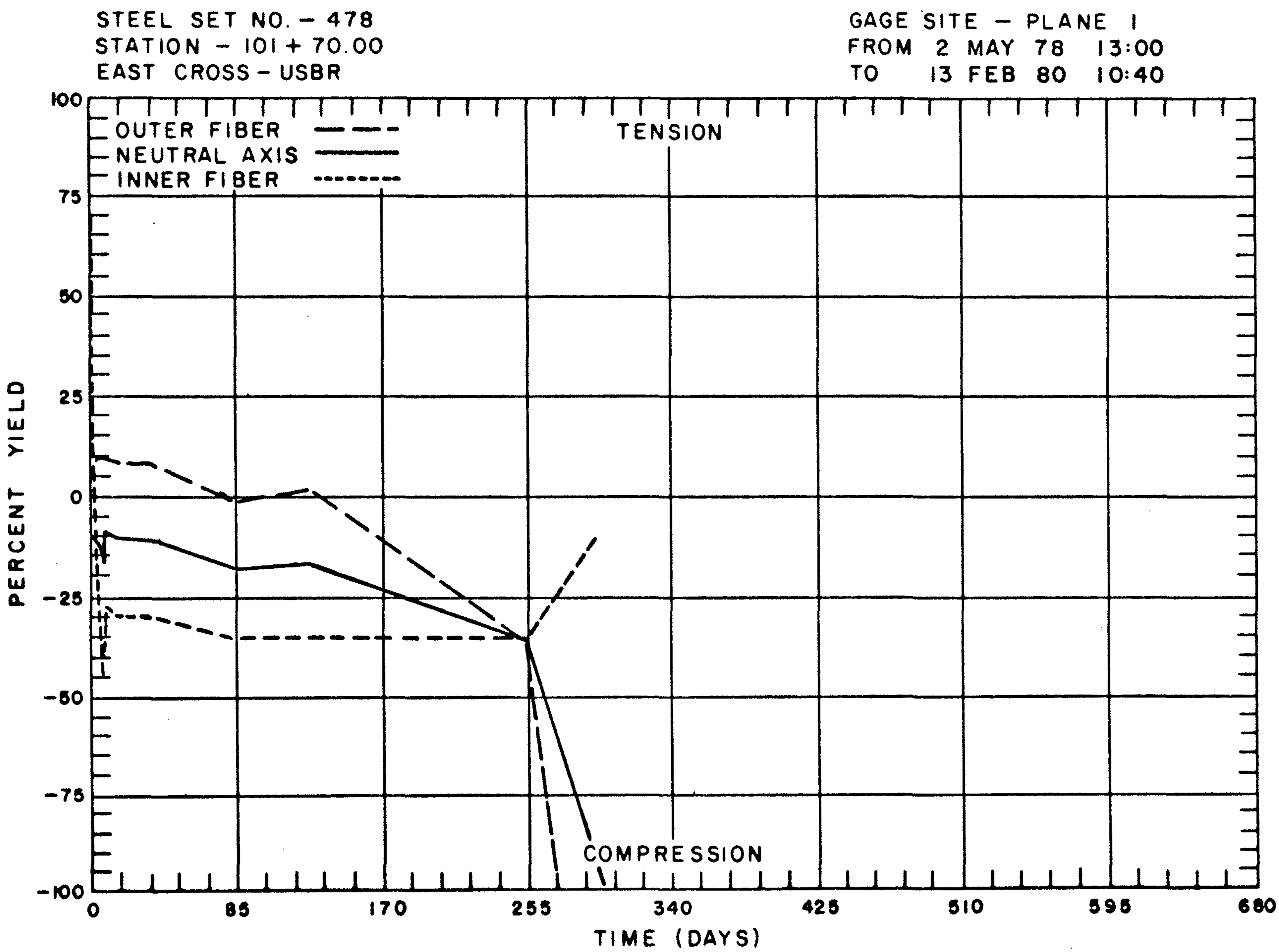


Figure B-26 Stresses--Plane 1, Steel Set No. 478

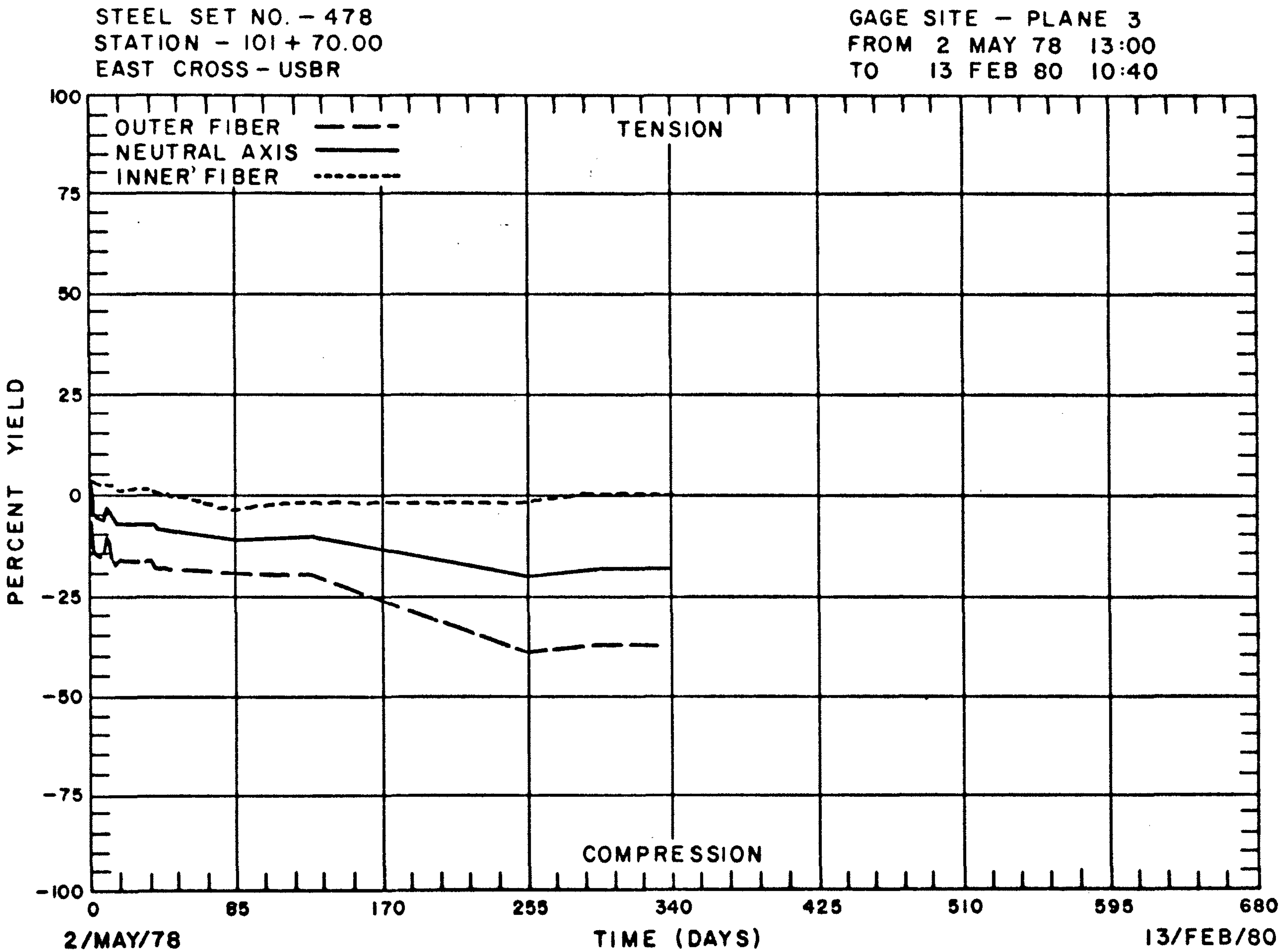


Figure B-27 Stresses--Plane 3, Steel Set No.478

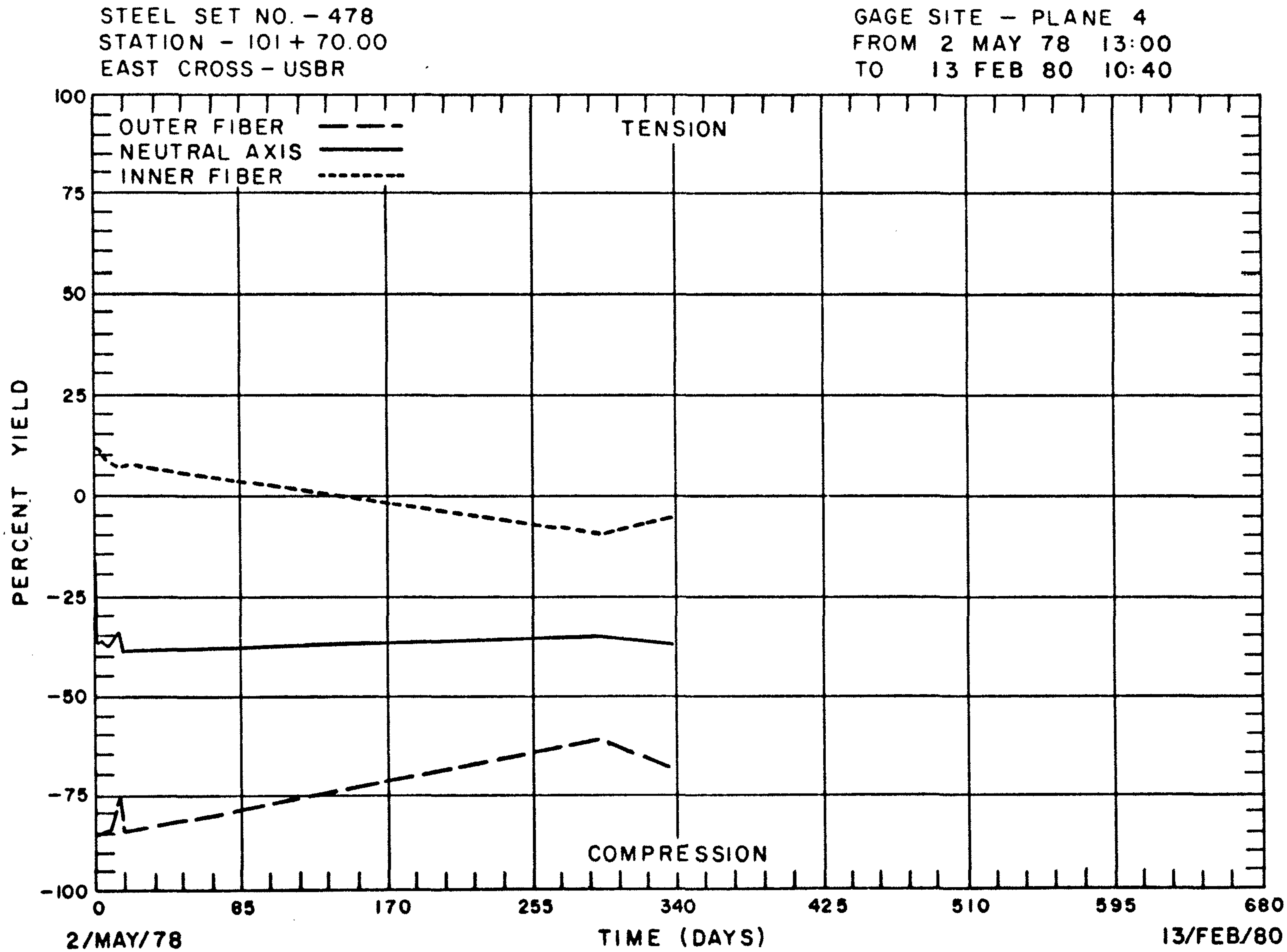


Figure B-29 Stresses--Plane 4, Steel Set No. 478

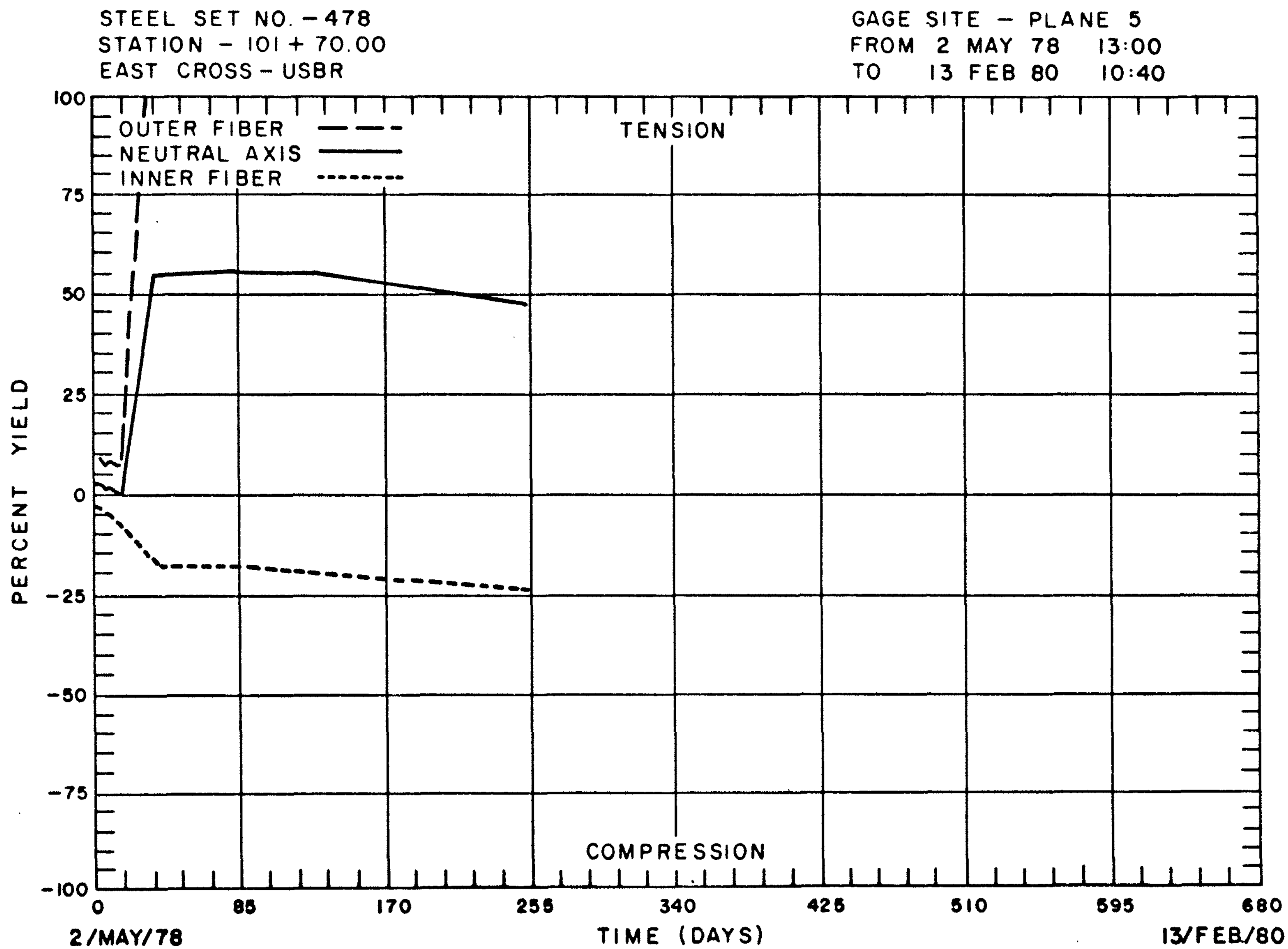


Figure B-29 Stresses--Plane 5, Steel Set No. 478

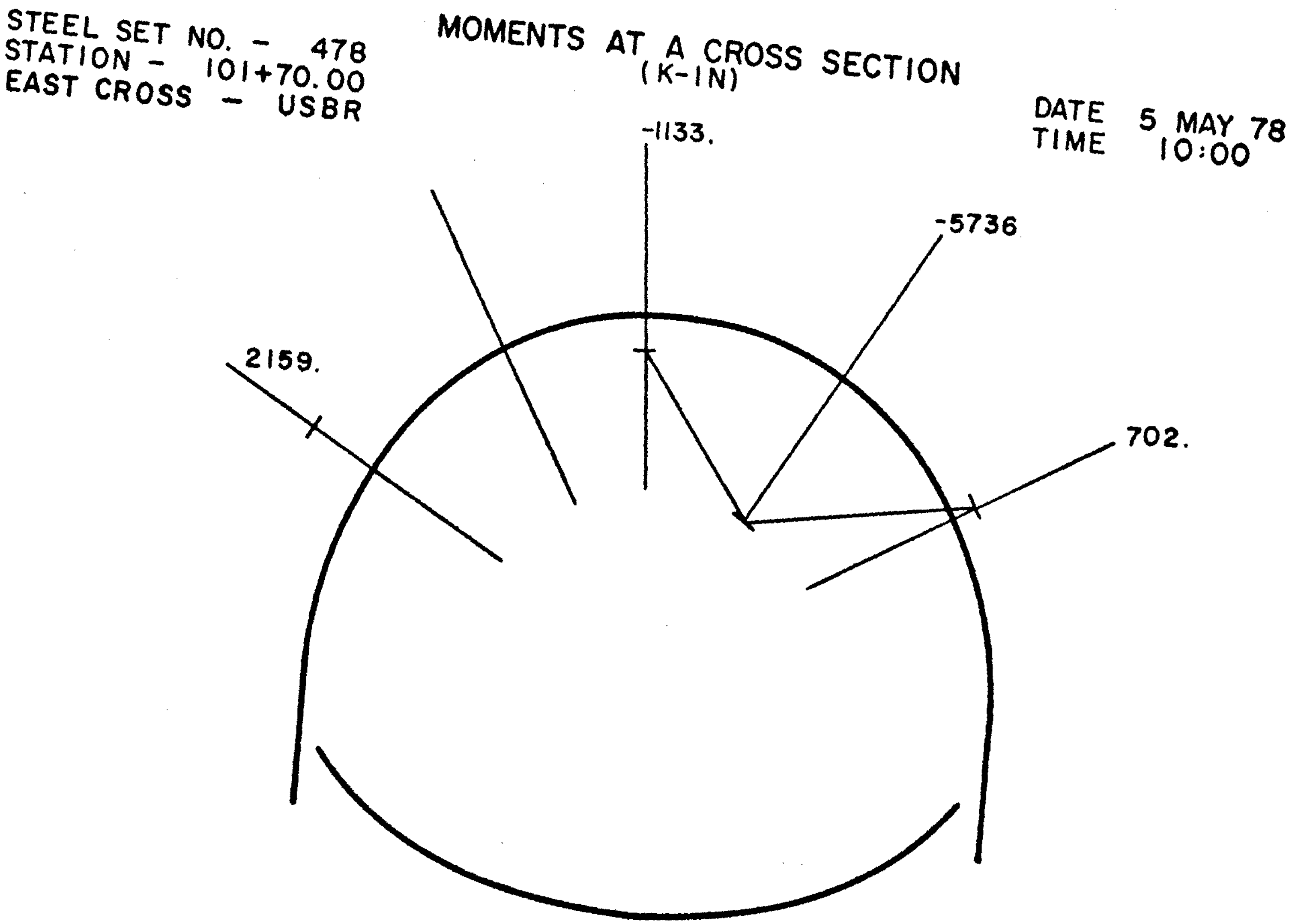


Figure B-30 Moments at Steel Set No. 478, May 1978

Table B-6. - Stresses, percent yield, and bending moment
Steel set 479 - station 101+70
(Tension is +, compression is -) (Type - Light 3 Drift - USBR)
Eisenhower Tunnel

Plane	Stress K/in^2 Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
Date: May 2, 1978				Time: 13:00			
1	-18.43	-17.17	-6.55	4.06	5.32	51	1783
2	-15.12	-14.38	-8.21	-2.03	-1.30	41	1038
3	8.77	7.19	-6.12	-19.43	-21.01	58	-2236
4	-0.55	-0.70	-1.91	-3.13	-3.28	9	-205
5	-10.06	-9.22	-2.19	4.84	5.68	27	1181
Date: May 4, 1978				Time: 10:15			
1	-18.73	-17.43	-6.50	4.44	5.74	52	1837
2	-14.78	-14.01	-7.48	-0.96	-0.18	41	1096
3	10.06	8.53	-4.35	-17.23	-18.76	52	-2163
4	0.80	0.58	-1.29	-3.16	-3.38	9	-314
5	-8.92	-8.09	-1.09	5.92	6.75	24	1176
Date: May 5, 1978				Time: 10:30			
1	-18.98	-17.66	-6.55	4.55	5.87	52	1866
2	-14.97	-14.21	-7.80	-1.39	-0.63	41	1077
3	8.97	7.51	-4.76	-17.02	-18.48	51	-2061
4	0.92	0.70	-1.16	-3.02	-3.24	8	-312
5	-9.06	-8.24	-1.28	5.68	6.51	25	1169
Date: May 9, 1978				Time: 10:30			
1	-20.20	-18.73	-6.44	5.86	7.32	56	2066
2	-15.18	-14.33	-7.11	0.12	0.97	42	1213
3	8.75	7.25	-5.37	-17.98	-19.48	54	-2119
4	0.32	0.12	-1.62	-3.36	-3.57	9	-292
5	-9.91	-9.08	-2.04	4.99	5.82	27	1181

NOTE: 1 k/in^2 = 6.900 MPa

Table B-6. - Stresses, percent yield, and bending moment - Continued
Steel set 479 - station 101+70
(Tension is +, compression is -) (Type - Light 3 Drift - USBR)
Eisenhower Tunnel

Plane	Stress K/in² Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
	Date: May 10, 1978			Time: 12:35			
1	-19.41	-18.04	-6.50	5.05	6.42	53	1939
2	-14.95	-14.21	-8.00	-1.80	-1.06	41	1043
3	9.16	7.66	-4.99	-17.63	-19.13	53	-2124
4	0.73	0.52	-1.20	-2.93	-3.13	8	-290
5	-9.38	-8.53	-1.36	5.80	6.65	26	1203
	Date: May 16, 1978			Time: 9:35			
1	-20.74	-19.31	-7.31	4.70	6.13	57	2017
2	-15.48	-14.62	-7.31	0.00	0.87	43	1228
3	8.70	7.16	-5.76	-18.68	-20.21	56	-2170
4	-0.51	-0.67	-1.99	-3.31	-3.46	9	-222
5	-9.97	-9.11	-1.87	5.37	6.23	27	1215
	Date: May 17, 1978			Time: 11:00			
1	-20.60	-19.05	-6.06	6.93	8.48	57	2182
2	0.00	-13.98	0.00	0.00	0.00	0	0
3	8.67	7.16	-5.52	-18.21	-19.72	54	-2131
4	-0.54	-0.70	-2.00	-3.31	-3.46	9	-219
5	-10.12	-9.25	-1.93	5.39	6.26	28	1230
	Date: June 6, 1978			Time: 13:40			
1	-20.86	-19.34	-6.55	6.24	7.76	57	2148
2	0.00	0.00	-8.12	0.00	0.00	0	0
3	8.53	7.02	-5.71	-18.44	-19.96	55	-2139
4	-0.89	-0.99	-1.78	-2.58	-2.68	7	-134
5	-10.41	-9.54	-2.22	5.10	5.97	28	1230

NOTE: 1 k/in^2 = 6.900 MPa

Table B-6. - Stresses, percent yield, and bending moment - Continued
Steel set 479 - station 101+70
(Tension is +, compression is -) (Type - Light 3 Drift - USBR)
Eisenhower Tunnel

Plane	Stress K/in^2 Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
Date: June 8, 1978				Time: 12:30			
1	-20.68	-19.20	-6.76	5.68	7.16	57	2090
2	0.00	0.00	-7.57	0.00	0.00	0	0
3	8.48	6.96	-5.83	-18.62	-20.14	55	-2148
4	-1.03	-1.13	-1.99	-2.84	-2.94	8	-144
5	-10.72	-9.83	-2.39	5.05	5.93	29	1250
Date: July 26, 1978				Time: 10:00			
1	0.00	0.00	-9.16	0.00	0.00	0	0
2	-16.91	-16.15	-9.74	-3.34	-2.57	46	1077
3	4.58	3.02	-10.16	-23.35	-24.91	69	-2214
4	-1.85	-1.86	-1.91	-1.97	-1.98	5	-10
5	-12.77	-12.01	-5.61	0.78	1.54	35	1074
Date: September 7, 1978				Time: 10:00			
1	-24.06	-22.36	-8.06	6.24	7.93	66	2402
2	-18.20	-17.52	-11.75	-5.97	-5.29	50	969
3	6.34	4.81	-8.02	-20.85	-22.38	62	-2156
4	-2.56	-2.58	-2.73	-2.87	-2.89	8	-24
5	-13.94	-12.96	-4.74	3.48	4.46	38	1381

NOTE: 1 k/in^2 = 6.900 MPa

Table B-6. - Stresses, percent yield, and bending moment - Continued
Steel set 479 - station 101+70
(Tension is +, compression is -) (Type - Light 3 Drift - USBR)
Eisenhower Tunnel

Plane	Stress K/in^2 Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in

Data after January 12 not used in analysis

Plane	Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
Date: January 12, 1979				Time: 10.15			
1	-26.70	-24.94	-10.12	4.70	6.46	74	2489
2	-20.84	-20.07	-13.57	-7.08	-6.30	57	1091
3	3.17	1.86	-9.22	-20.30	-21.62	60	-1861
4	-3.22	-3.65	-7.31	-10.96	-11.40	31	-614
5	0.00	0.00	-74.95	-2.87	5.70	432	12108
Date: February 21, 1979				Time: 12:15			
1	-27.90	-26.22	-12.01	2.20	3.89	77	2387
2	-23.40	-22.27	-12.79	-3.31	-2.18	64	1593
3	1.79	0.52	-10.18	-20.88	-22.15	61	-1798
4	-3.46	-4.90	-16.99	-29.09	-30.52	84	-2031
5	-33.69	-32.07	-18.49	-4.90	-3.29	93	2282
Date: April 5, 1979				Time: 9:55			
1	-27.96	-25.93	-8.82	8.29	10.33	77	2874
2	-22.98	-22.10	-14.65	-7.19	-6.31	63	1252
3	3.72	2.38	-8.93	-20.24	-21.59	59	-1900
4	-0.02	-2.29	-21.40	-40.51	-42.78	118	-3210
5	-39.13	-35.79	-7.69	20.42	23.76	108	4721
Date: June 22, 1979				Time: 11:50			
1	-31.67	-29.41	-10.38	8.64	10.90	87	3196
2	-22.12	-21.29	-14.24	-7.19	-6.35	61	1184
3	3.05	1.45	-12.09	-25.64	-27.25	75	-2275
4	5.05	2.70	-17.11	-36.92	-39.27	109	-3327
5	383.46	341.85	-8.24	0.00	0.00	0	0

NOTE: 1 k/in^2 = 6.900 MPa

Table B-6. - Stresses, percent yield, and bending moment - Continued
Steel set 479 - station 101+70
(Tension is +, compression is -) (Type - Light 3 Drift - USBR)
Eisenhower Tunnel

Plane	Stress K/in^2 Inside fiber	Inside gage	Neutral axis	Outer gage	Outer fiber	% yield stress	Moment K-in
			Data not Used - Continued				
		Date: August 8, 1979		Time: 10:50			
1	-32.62	-30.31	-10.79	8.73	11.05	90	3279
2	-22.39	-21.55	-14.47	-7.40	-6.55	62	1189
3	2.64	1.04	-12.35	-25.75	-27.34	75	-2251
4	41.49	35.24	-17.37	-69.98	-76.23	211	-8837
5	2.40	4.55	22.71	40.86	43.02	119	3050
		Date: September 26, 1979		Time: 10:25			
1	-33.19	-30.80	-10.67	9.45	11.85	92	3381
2	-21.13	-20.56	-15.75	-10.93	-10.36	58	809
3	2.24	0.81	-11.22	-23.26	-24.69	68	-2022
4	41.10	34.80	-18.24	-71.28	-77.59	215	-8910
5	1.99	4.15	22.27	40.40	42.55	118	3045
		Date: February 13, 1980		Time: 10:50			
1	-36.63	-33.90	-10.90	12.09	14.83	101	3863
2	-21.53	-20.82	-14.88	-8.93	-8.23	59	999
3	1.57	0.06	-12.64	-25.35	-26.86	74	-2134
4	-9.86	-10.76	-18.33	-25.90	-26.80	74	-1271

NOTE: 1 k/in^2 = 6.900 MPa

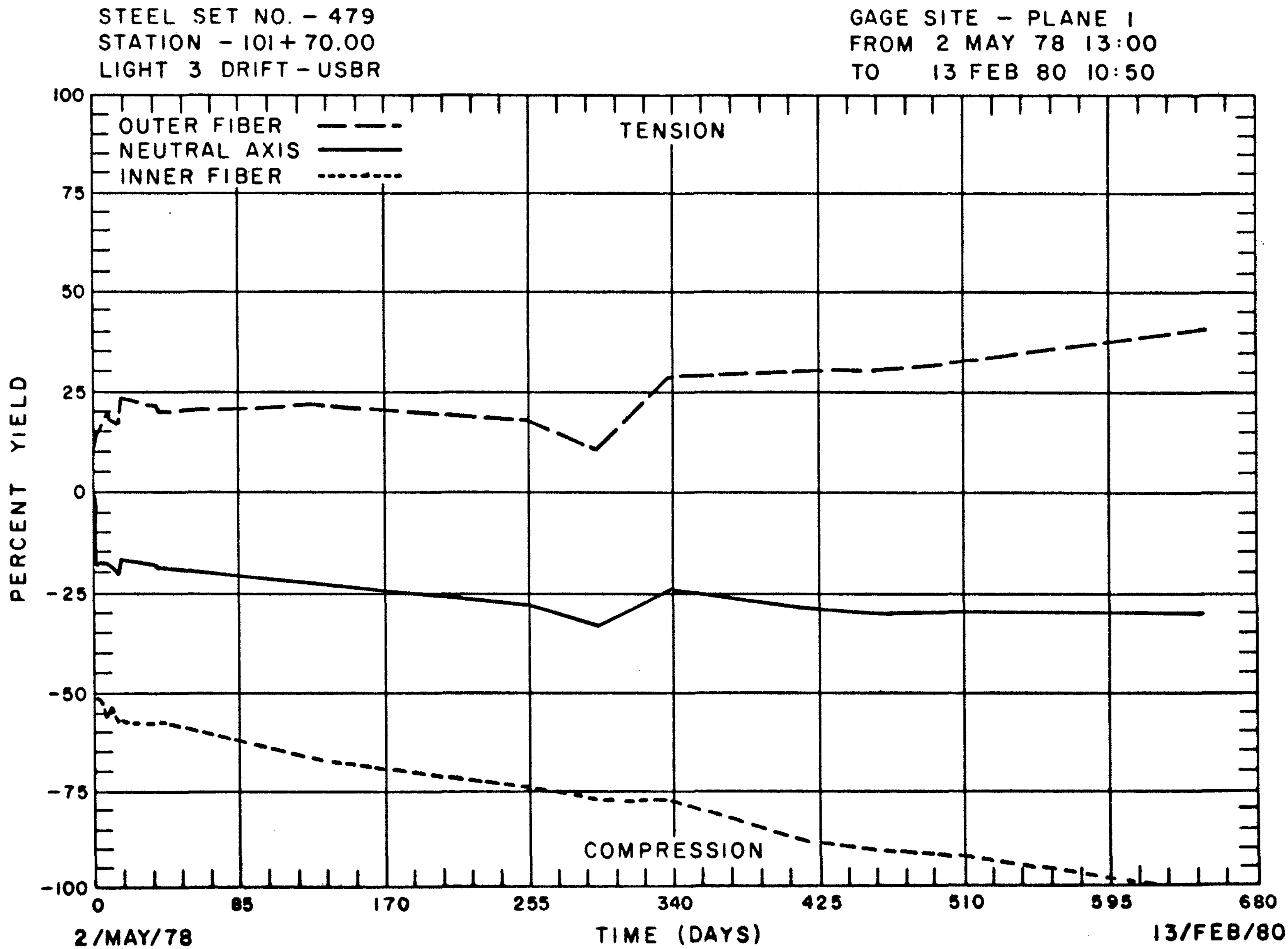


Figure B-31 Stresses--Plane 1, Steel Set No. 479

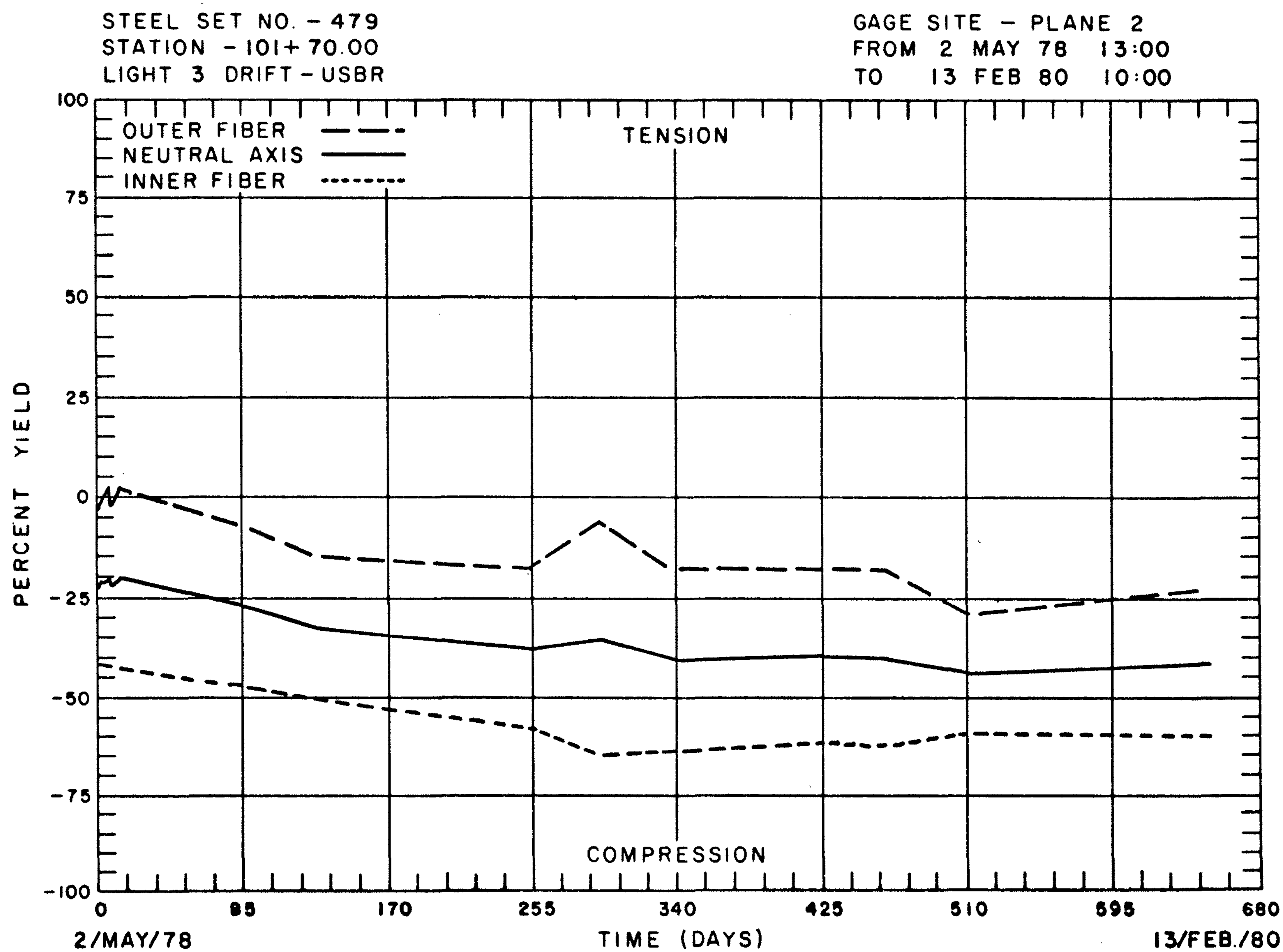


Figure B-32 Stresses--Plane 2, Steel Set No. 479

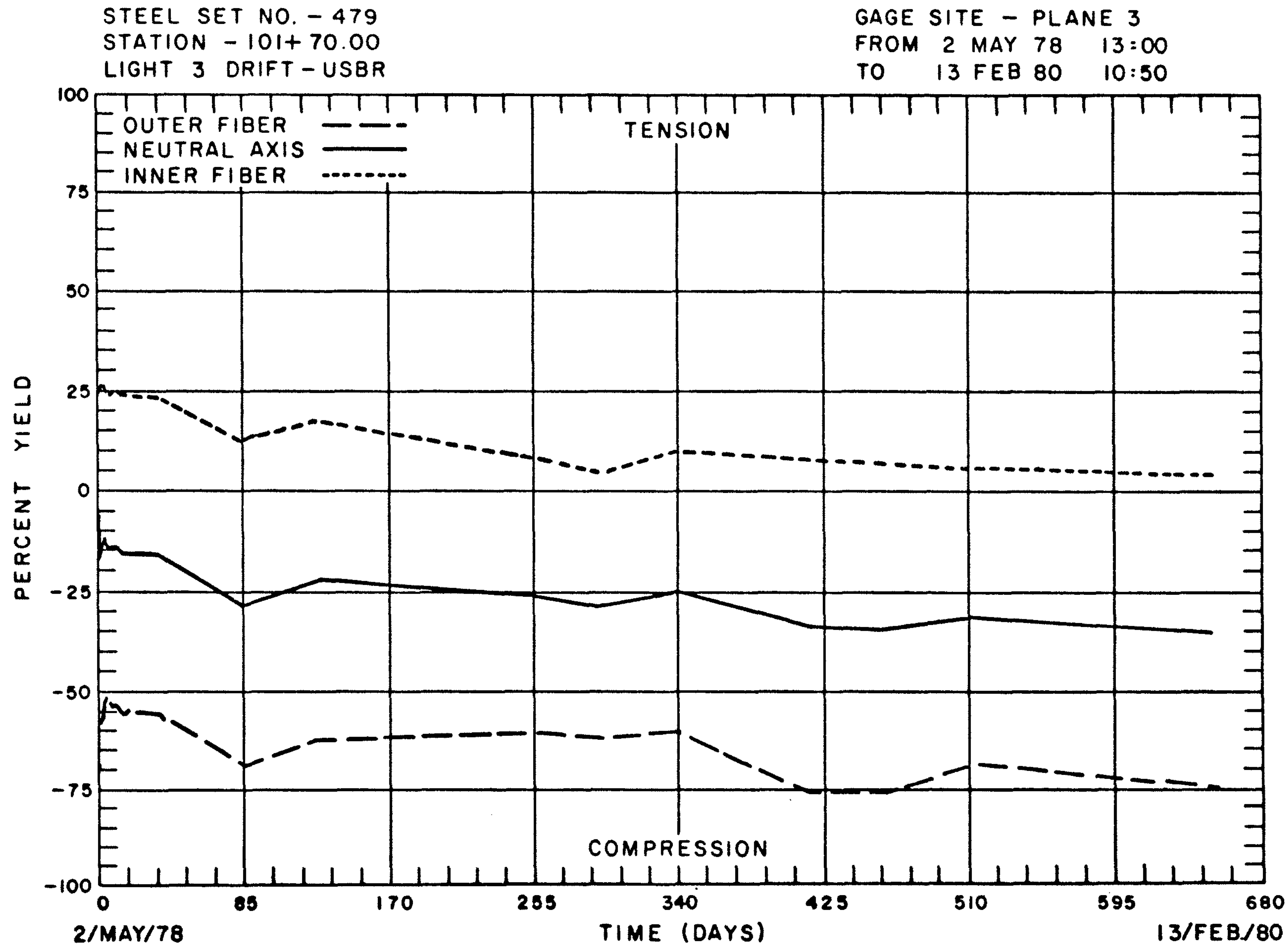


Figure B-33 Stresses--Plane 3, Steel Set No. 479

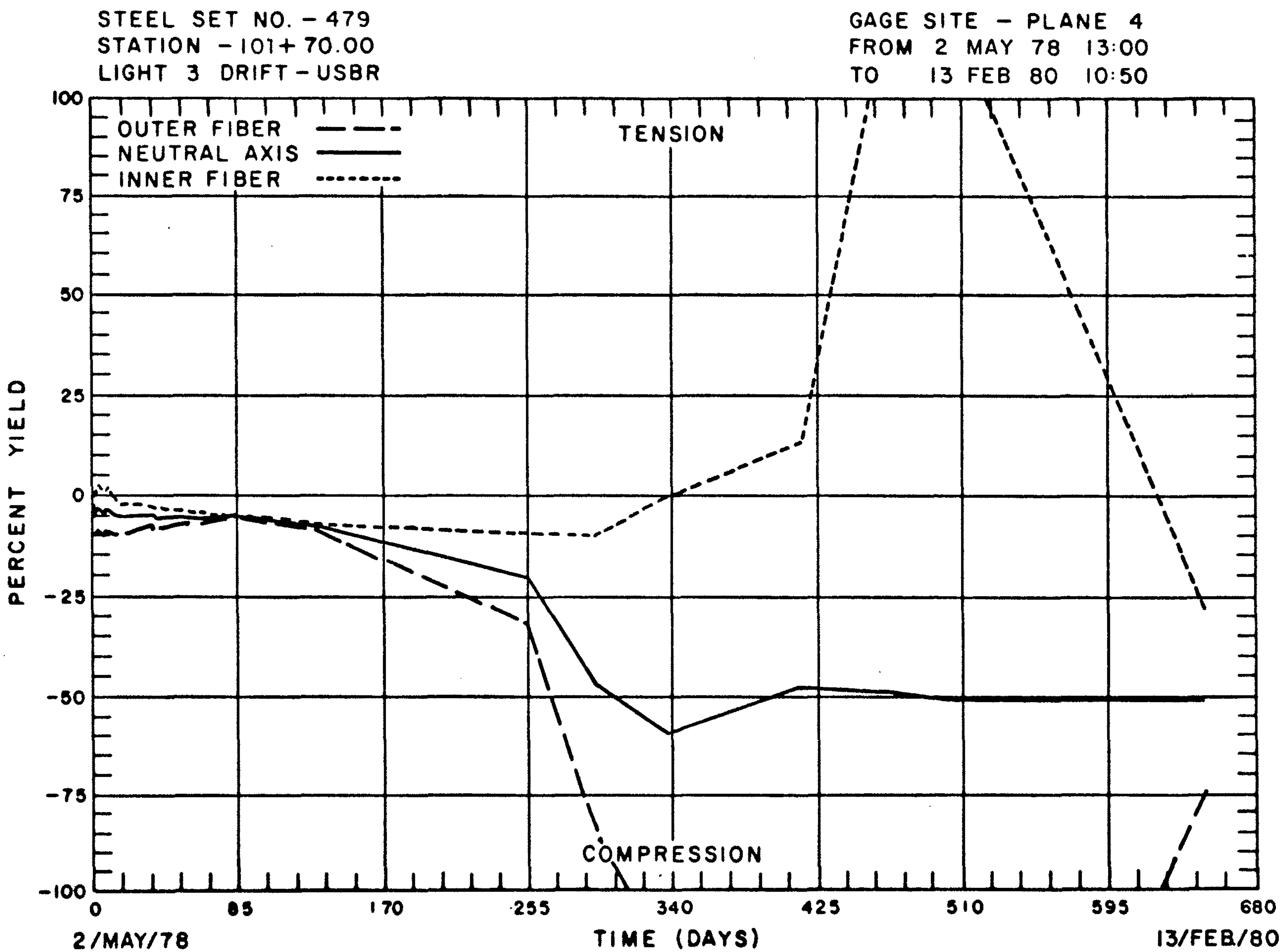


Figure B-34 Stresses--Plane 4, Steel Set No. 479

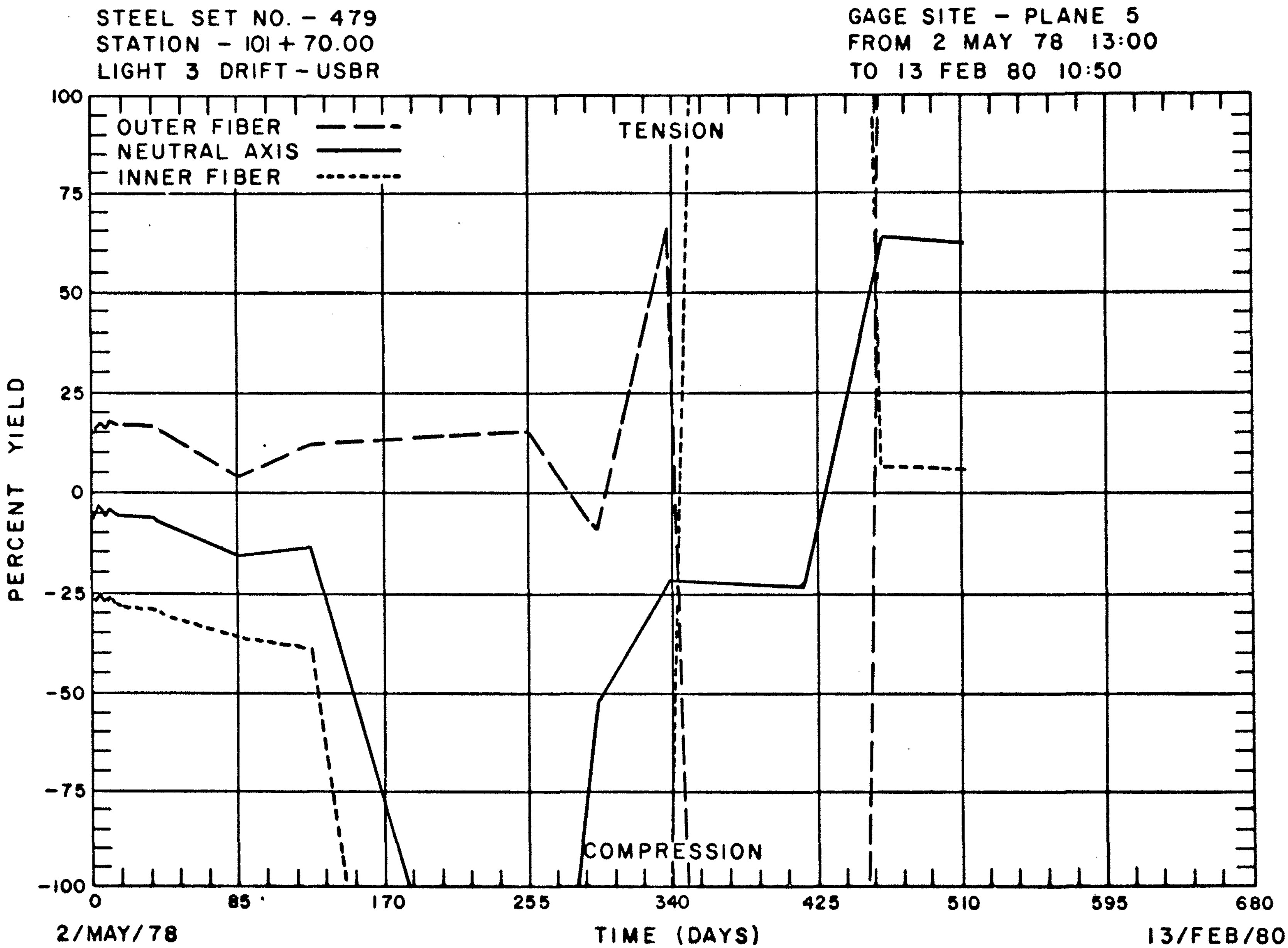


Figure B-35 Stress - Plane 5, Steel Set No. 479

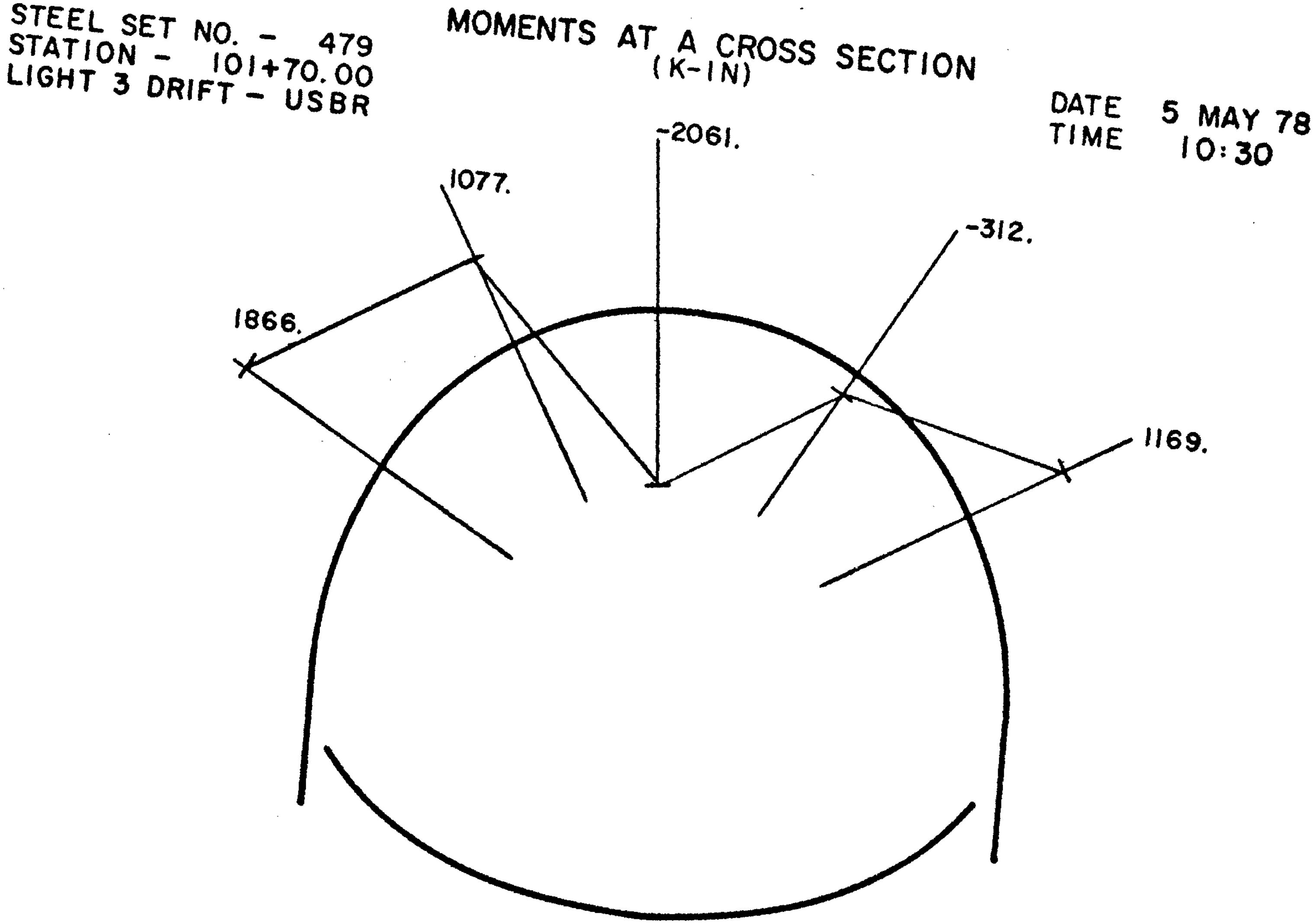


Figure B-36 Moments at Steel Set No. 479, May 1978

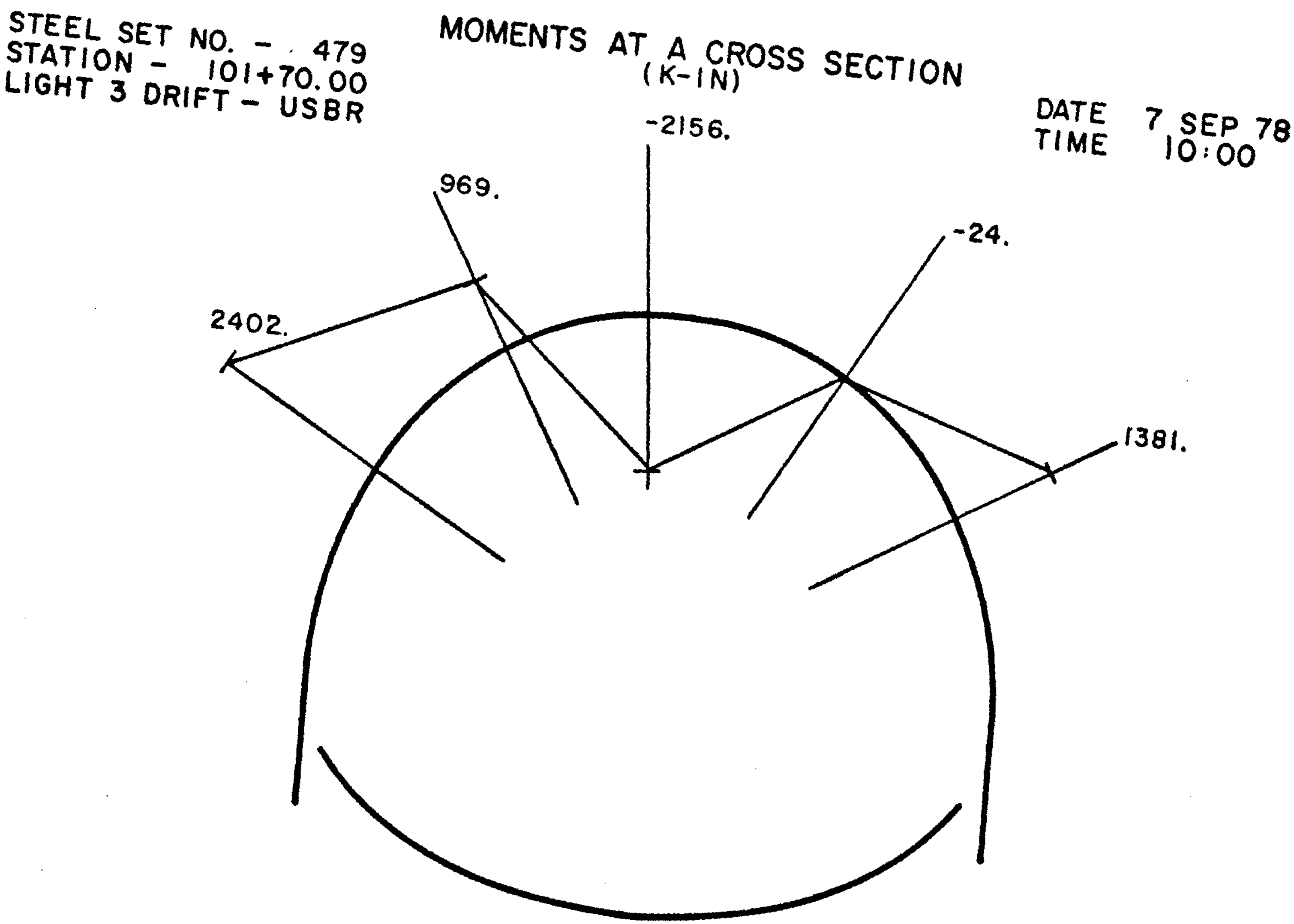


Figure 37 Moments at Steel Set No. 479, September 1978

APPENDIX C

LABORATORY CORE TEST DATA

Station 101+70

Station 111+75

Table C-1. - Laboratory core investigations
Eisenhower Tunnel
Specific gravity, absorption, and porosity - UJ1W, UJ1E

Specimen No.	Depth (ft)	Rock type (field)	Specific gravity	Percent absorption	Percent porosity
UJ1W	1.7	Biotite gneiss	2.56	2.11	5.40
UJ1W	13.4	Pegmatite dike	2.63	1.01	2.66
UJ1W	22.0	Biotite granite	2.60	1.52	3.95
UJ1E	5.3	Granite	2.57	1.79	4.60
UJ1E	7.2	Granite	2.55	1.05	2.68
UJ1E	20.9	Biotite gneiss	2.65	0.79	2.09
UJ1E	24.7	Biotite gneiss	2.69	2.22	5.97

Table C-2. - Laboratory core investigations
Eisenhower Tunnel
Specific gravity, absorption, and porosity - 101A

Specimen No.	Depth (ft)	Rock type (field)	Specific gravity	Percent absorption	Percent porosity
101A	6.2	Biotite gneiss	2.73	0.11	0.30
101A	7.7	Granite gneiss	2.73	0.43	1.17
101A	13.6	Granite gneiss	2.68	0.13	0.36
101A	18.3	Granite gneiss	2.60	0.92	2.39
101A	40.7	Granite gneiss	2.71	0.52	1.41
101A	62.9	Biotite gneiss	2.78	0.51	1.42
101A	70.6	Granite	2.59	0.26	0.68
101A	72.8	Granite	2.64	0.94	2.50
101A	76.3	Biotite gneiss	3.02	0.33	1.00
101A	81.2	Biotite gneiss	2.90	0.22	0.63
101A	87.6	Pegmatite dike	2.64	0.34	0.91
101A	97.4	Granite	2.63	0.33	0.87

NOTE: 1 ft = 0.348 m

Table C-3. - Laboratory core investigations
Eisenhower Tunnel
Specific gravity, absorption, and porosity - 101V

Specimen No.	Depth (ft)	Rock type (field)	Specific gravity	Percent abosrption	Percent porosity
101V	6.4	Biotite gneiss	2.69	0.28	0.75
101V	8.8	Biotite gneiss	2.70	0.20	0.54
101V	12.5	Biotite gneiss	2.68	0.29	0.77
101V	18.6	Biotite gneiss	2.70	0.34	0.91
101V	47.0	Granite gneiss	2.68	0.57	1.53
101V	59.5	Granite gneiss	2.76	1.14	3.15
101V	61.1	Granite gneiss	2.86	0.70	2.00
101V	71.8	Granite gneiss	2.66	0.40	1.06
101V	72.8	Granite gneiss	2.57	0.90	2.31
101V	73.5	Granite gneiss	2.67	0.34	0.90
101V	93.1	Biotite gneiss	2.61	0.94	6.55

NOTE: 1 ft = 0.348 m

Table C-4. - Laboratory core investigations
Eisenhower Tunnel
Ultrasonic, elastic, and strength properties, UJ1W, UJ1E

Specimen No.	Depth (ft)	Rock type (field)	Ultrasonic velocity ft/s	Poisson's ratio	Secant elasticity M lb/in^2	Compressive strength lb/in^2
UJ1W	1.7	Biotite gneiss	13,400	0.15	9.52	11,610
UJ1W	13.4	Pegmatite dike	15,900	0.13	8.00	20,890
UJ1W	22.0	Biotite granite	15,600	0.11	8.00	20,570
UJ1E	7.2	Granite	18,080	0.03	7.58	28,530
UJ1E	20.9	Biotite gneiss	15,700	0.03	7.14	24,920
UJ1E	24.7	Biotite gneiss	9,700	0.03	6.06	8,620

NOTE: 1 ft = 0.348 m
1 lb/in^2 = 6.900 kPa

Table C-5. - Laboratory core investigations
Eisenhower Tunnel
Ultrasonic, elastic, and strength properties, 101A

Specimen No.	Depth (ft)	Rock type (field)	Ultrasonic velocity ft/s	Poisson's ratio	Secant elasticity M lb/in^2	Compressive strength lb/in^2
101A	6.2	Biotite gneiss	17,900	0.13	10.64	29,600
101A	7.7	Granite gneiss	10,700	0.04	2.04	7,110
101A	13.6	Granite gneiss	16,000	0.13	10.42	21,800
101A	18.3	Granite gneiss	11,500	0.02	3.55	6,910
101A	40.7	Granite gneiss	13,800	0.15	8.70	10,500
101A	62.9	Biotite gneiss	14,500	0.06	5.85	11,500
101A	70.6	Granite	10,400	0.10	1.59	6,370
101A	72.8	Granite	16,500	0.15	6.17	-*
101A	76.3	Biotite gneiss	16,000	0.21	8.55	13,400
101A	81.2	Biotite gneiss	14,100	0.10	8.70	10,700
101A	87.6	Pegmatite dike	13,200	0.14	7.14	10,100
101A	97.4	Granite	14,600	0.14	6.90	9,100

* Was not tested for strength.
NOTE: 1 ft = 0.348 m
1 lb/in^2 = 6.900 kPA

Table C-6. - Laboratory core investigations
Eisenhower Tunnel
Ultrasonic, elastic, and strength properties, 101V

Specimen No.	Depth (ft)	Rock type (field)	Ultrasonic velocity ft/s	Poisson's ratio	Secant elasticity M lb/in^2	Compressive strength lb/in^2
101V	6.4	Biotite gneiss	15,650	0.12	8.93	10,100
101V	8.8	Biotite gneiss	18,700	0.02	14.08	19,000
101V	18.6	Biotite gneiss	16,600	0.13	7.94	10,600
101V	47.0	Granite gneiss	16,200	0.17	8.06	17,300
101V	59.5	Granite gneiss	12,400	0.14	2.99	6,810
101V	71.8	Granite gneiss	14,900	0.10	7.46	6,600
101V	72.8	Granite gneiss	16,100	0.18	7.58	19,500
101V	93.1	Biotite gneiss	13,100	0.07	2.58	7,150

NOTE: 1 ft = 0.348 m
1 lb/in^2 = 6.900 kPA

Table C-7. - Laboratory core investigations
Eisenhower Tunnel
Tensile strength, 101A

Specimen No.	Depth (ft)	Rock type (field)	Tensile strength lb/in^2
101A	40.7	Granite gneiss	2,010
101A	62.9	Biotite gneiss	1,430
101A	70.6	Granite	790
101A	71.6	Granite	300
101A	72.8	Granite	865
101A	76.3	Biotite gneiss	1,520
101A	87.6	Pegmatite dike	550

NOTE: 1 ft = 0.348 m
1 lb/in^2 = 6.900 kPA

Table C-8. - Laboratory core investigations
Eisenhower Tunnel
Tensile strength, 101V

Specimen No.	Depth (ft)	Rock type (field)	Tensile strength lb/in^2
101V	6.4	Biotite gneiss	1,920
101V	8.8	Biotite gneiss	1,770
101V	18.6	Biotite gneiss	2,015
101V	53.1	Granite	635
101V	61.1	Granite gneiss	1,040
101V	71.8	Granite gneiss	1,070
101V	72.8	Granite gneiss	1,765
101V	73.5	Granite gneiss	1,410

NOTE: 1 ft = 0.348 m
1 lb/in^2 = 6.900 kPA

Table C-9. - Laboratory core investigations
Eisenhower Tunnel
Shear properties, 101V, 101A

Specimen No.	Depth (ft)	Rock type (field)	Cohesion (lb/in^2) Linear regression	Cohesion (lb/in^2) Angle envelope	Phi (Ø) degrees Linear regression	Phi (Ø) degrees Angle envelope
101V	6.0	Biotite gneiss	1,700	1,300	18	45
101V	17.6	Biotite gneiss	1,290	820	66	72
101V	92.5	Biotite gneiss	3,410	3,140	30	46
101A	76.0	Biotite gneiss	3,010	2,930	29	34
101A	98.4	Granite	1,500	1,160	39	54

NOTE: 1 ft = 0.348 m
1 lb/in^2 = 6.900 kPA

Table C-10. - Laboratory core investigations
Eisenhower Tunnel
Sliding friction properties, 101V, 101A, UJ1W, UJ1E

Specimen No.	Depth (ft)	Rock type (field)	Cohesion (lb/in^2)		Phi (Ø) degrees	
			Linear regression	Angle envelope	Linear regression	Angle envelope
101V	1.3	Biotite gneiss	38	21	31	38
101V	9.5	Biotite gneiss	49	34	28	34
101V	46.3	Granite gneiss	72	57	34	40
101A	42.8	Granite gneiss	-9	6	27	20
UJ1W	12.0	Biotite gneiss	27	20	20	23
UJ1E	11.0	Granite	86	67	32	40
UJ1E	18.0	Biotite gneiss	67	9	11	38

NOTE: 1 ft = 0.348 m
$1\ lb/in^2$ = 6.900 kPA

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 101V - 6.0 ft
Area = 3.30 in^2

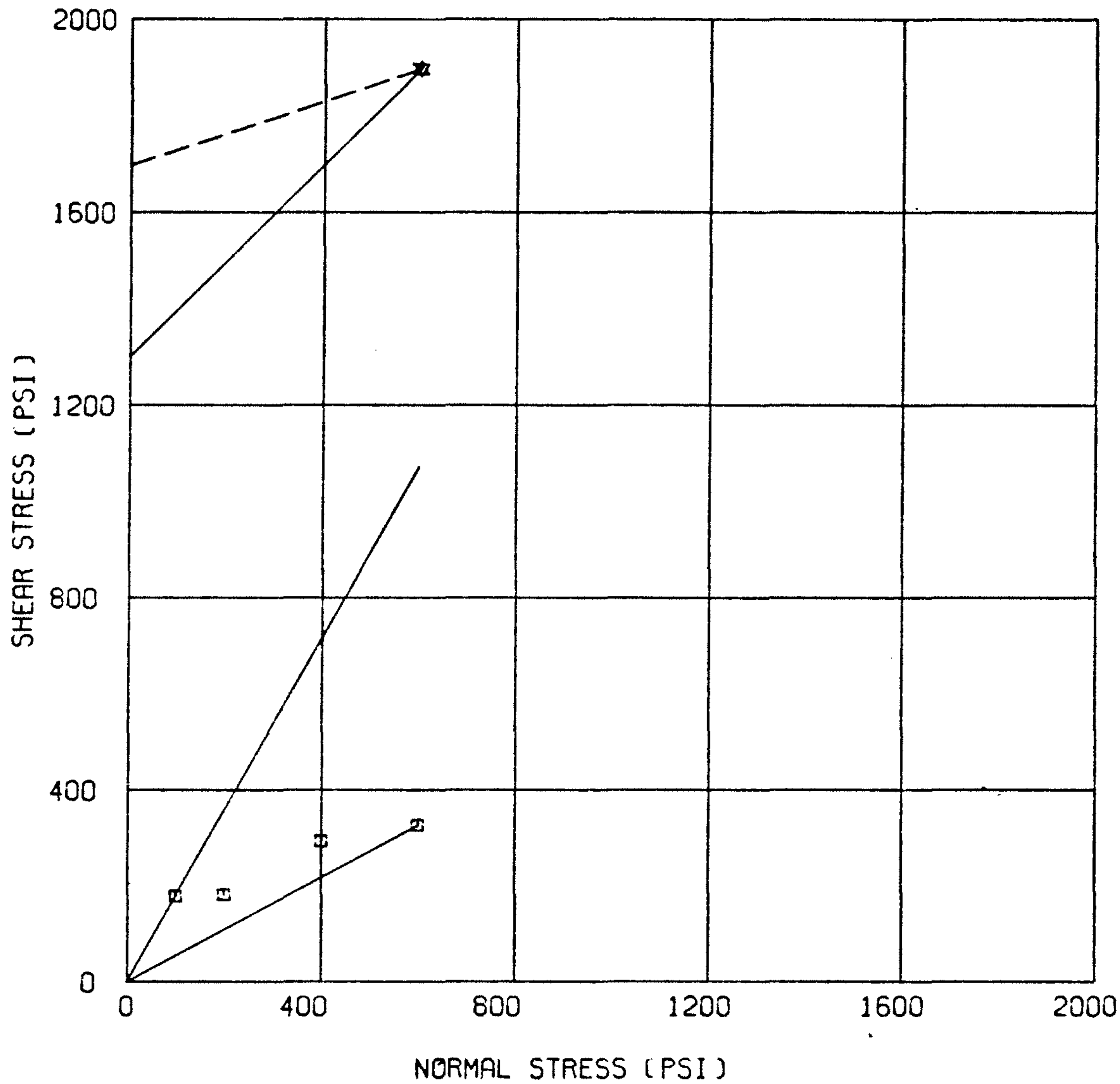
Run No.	N	S
1	600	1,897
2	100	179
3	200	182
4	400	294
5	600	327

Linear regression results:

S = 137.3 + 0.33282 (N)
Correlation = 0.9652
PHI = 18.4°
Cohesion = 1,697.3 lb/in^2

Angle envelope results:

PHI max. = 60.8° (1.78788)
PHI min. = 28.6° (0.54545)
PHI avg. = 44.8° (0.99432)
Cohesion (max. PHI) = 824.24 lb/in^2
Cohesion (min. PHI) = 1,569.70 lb/in^2
Cohesion (avg. PHI) = 1,300.38 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 101V 6.0

✡ INITIAL TEST

– – – – – – LINEAR REGRESSION

———————— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 101V - 17.6 ft
Area = 3.30 in^2

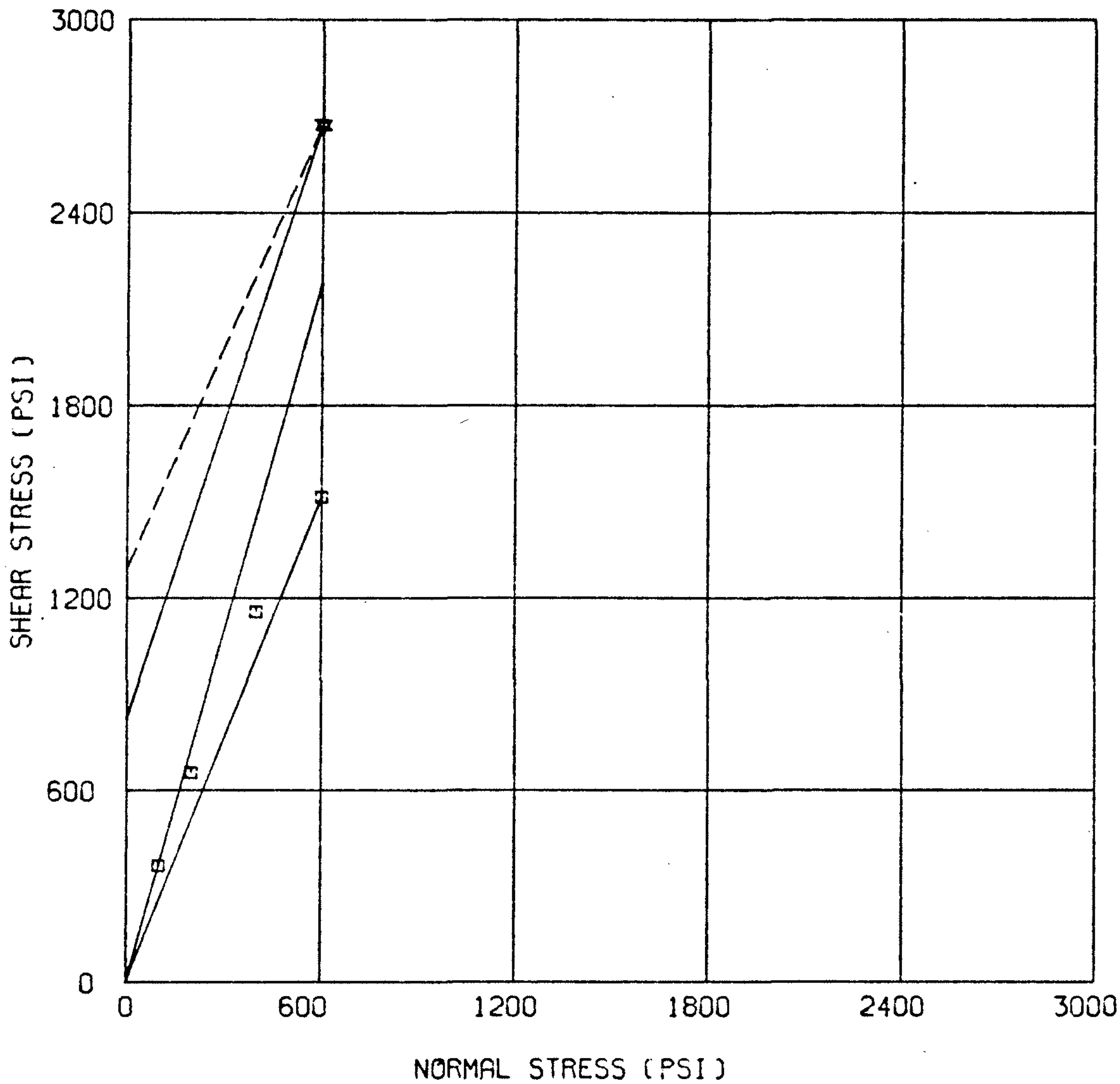
Run No.	N	S
1	600	2,673
2	100	364
3	200	655
4	400	1,158
5	600	1,515

Linear regression results:

S = 173.9 + 2.30406 (N)
Correlation = 0.9952
PHI = 66.5°
Cohesion = 1,290.3 lb/in^2

Angle envelope results:

PHI max. = 74.6° (3.63636)
PHI min. = 68.4° (2.52525)
PHI avg. = 72.0° (3.08207)
Cohesion (max. PHI) = 490.91 lb/in^2
Cohesion (min. PHI) = 1,157.58 lb/in^2
Cohesion (avg. PHI) = 823.48 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 101V 17.6

✡ INITIAL TEST

– – – – – – LINEAR REGRESSION

———— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 101V - 92.5 ft
Area = 3.30 in^2

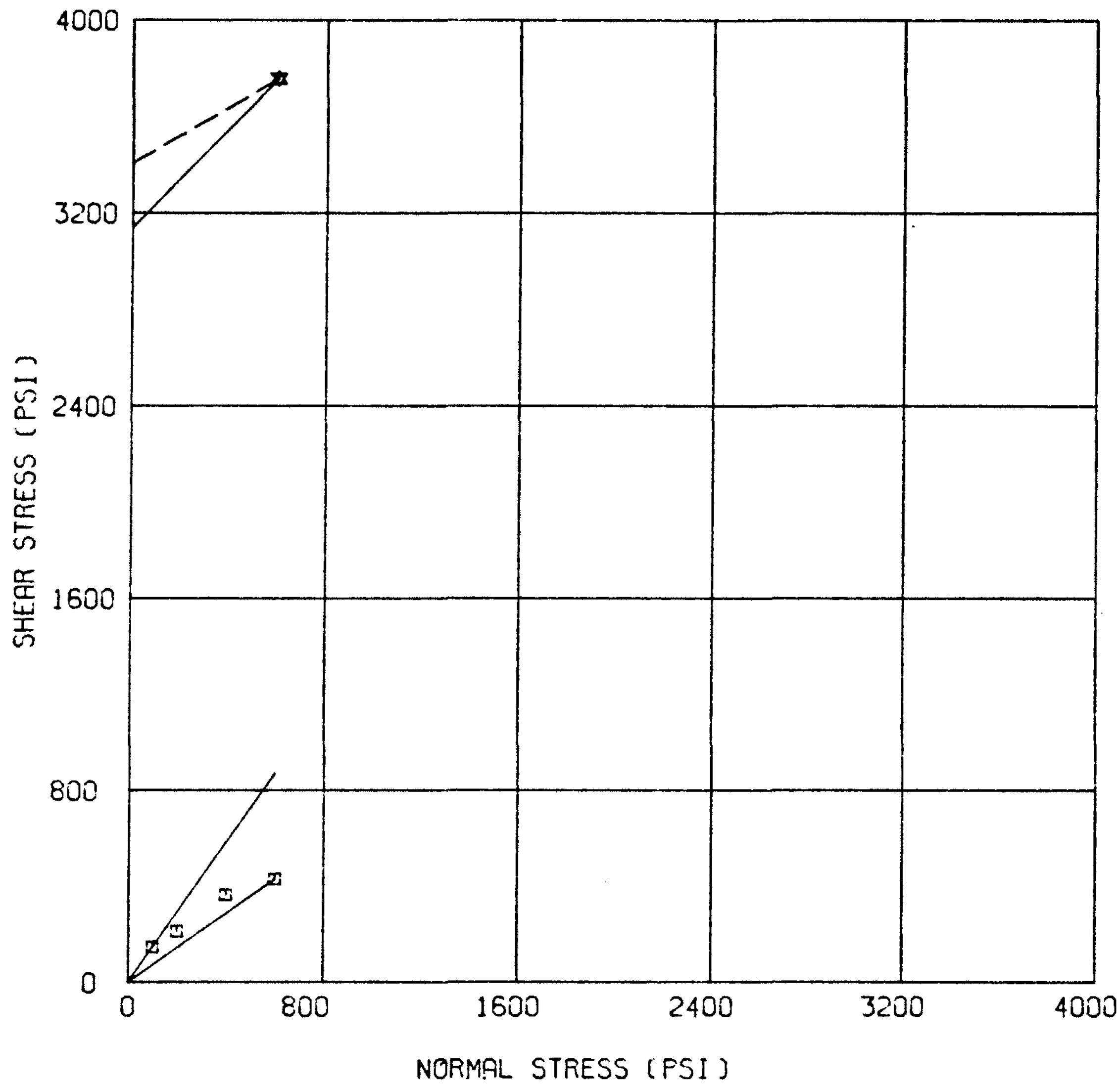
Run No.	N	S
1	600	3,758
2	100	145
3	200	212
4	400	364
5	600	430

Linear regression results:

S = 97.6 + 0.58552 (N)
Correlation = 0.9857
PHI = 30.3°
Cohesion = 3,406.3 lb/in^2

Angle envelope results:

PHI max. = 55.5° (1.45455)
PHI min. = 35.6° (0.71717)
PHI avg. = 46.0° (1.03535)
Cohesion (max. PHI) = 2,884.85 lb/in^2
Cohesion (min. PHI) = 3,327.27 lb/in^2
Cohesion (avg. PHI) = 3,136.36 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 101V 92.5

☆ INITIAL TEST

– – – – – – LINEAR REGRESSION

———— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 101A - 76.0 ft
Area = 3.30 in^2

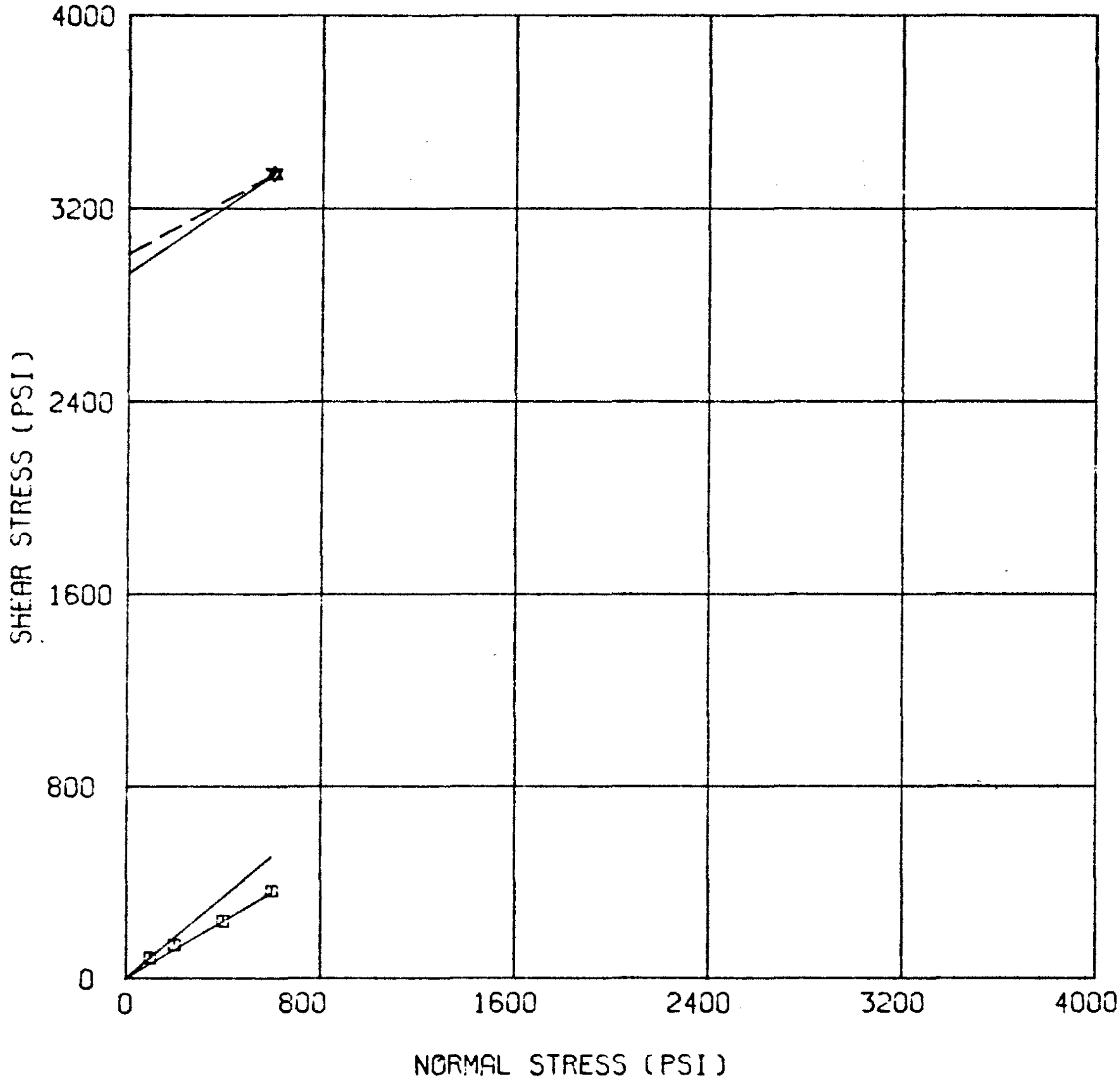
Run No.	N	S
1	600	3,342
2	100	85
3	200	139
4	400	239
5	600	364

Linear regression results:

S = 27.4 + 0.55213 (N)
Correlation = 0.9988
PHI = 28.9°
Cohesion = 3,011.1 lb/in^2

Angle envelope results:

PHI max. = 40.3° (0.84848)
PHI min. = 30.9° (0.59848)
PHI avg. = 34.5° (0.68750)
Cohesion (max. PHI) = 2,833.33 lb/in^2
Cohesion (min. PHI) = 2,983.33 lb/in^2
Cohesion (avg. PHI) = 2,929.92 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 101A 76.0

✡ INITIAL TEST

– – – – – – – LINEAR REGRESSION

———————— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 101A - 98.4 ft
Area = 3.30 in^2

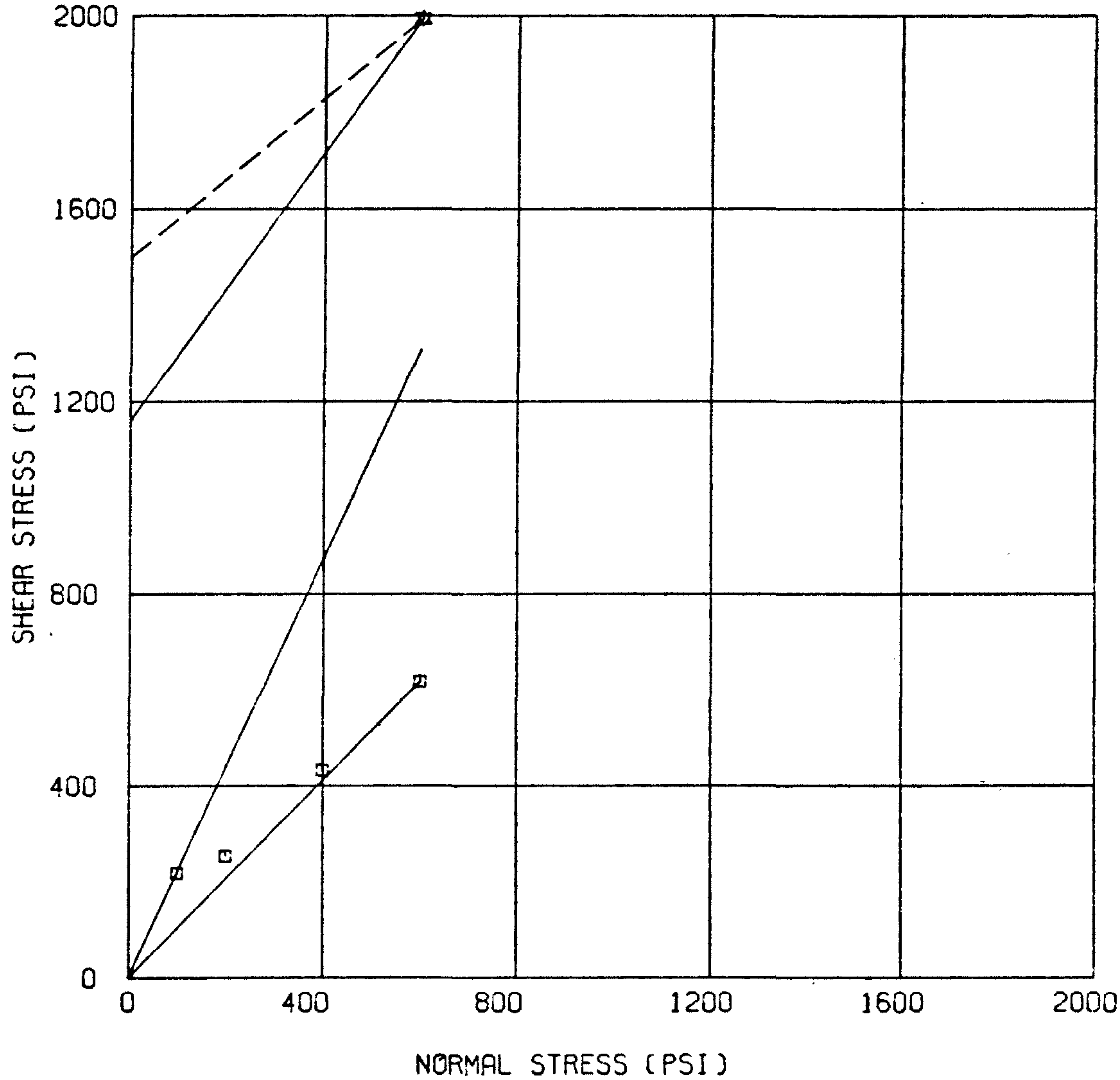
Run No.	N	S
1	600	1,994
2	100	218
3	200	255
4	400	433
5	600	618

Linear regression results:

S = 113.1 + 0.82435 (N)
Correlation = 0.9938
PHI = 39.5°
Cohesion = 1,499.3 lb/in^2

Angle envelope results:

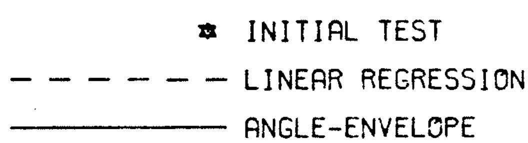
PHI max. = 65.4° (2.18182)
PHI min. = 45.9° (1.03030)
PHI avg. = 54.3° (1.39205)
Cohesion (max. PHI) = 684.85 lb/in^2
Cohesion (min. PHI) = 1,375.76 lb/in^2
Cohesion (avg. PHI) = 1,158.71 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 101A 98.4



Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 101V - 1.3 ft
Area = 3.98 in^2

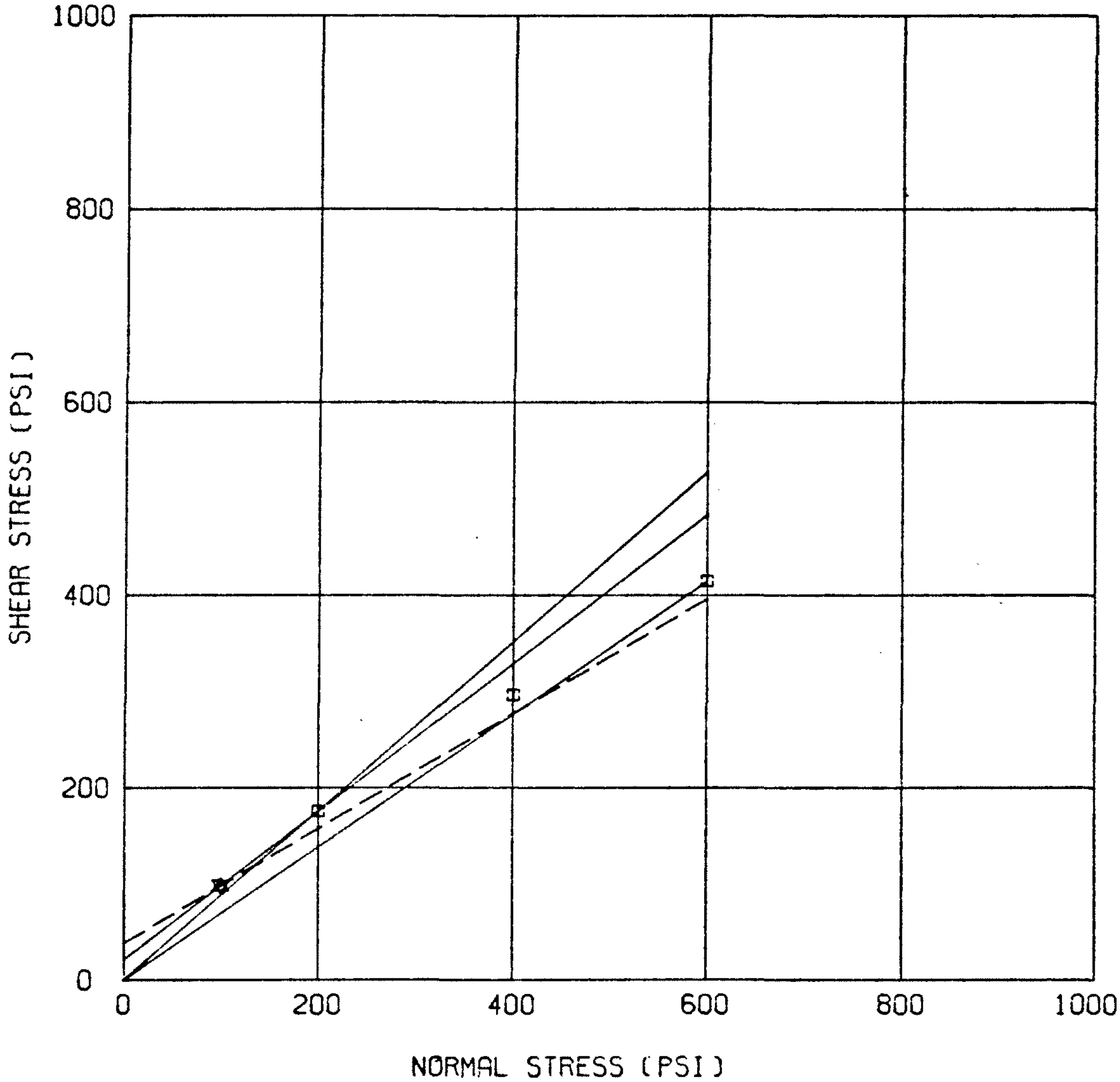
Run No.	N	S
1	100	98
2	200	176
3	400	296
4	600	415

Linear regression results:

S = 57.0 + 0.59673 (N)
Correlation = 1.0000
PHI = 30.8°
Cohesion = 38.3 lb/in^2

Angle envelope results:

PHI max. = 41.3° (0.87940)
PHI min. = 34.6° (0.69085)
PHI avg. = 37.6° (0.77052)
Cohesion (max. PHI) = 10.05 lb/in^2
Cohesion (min. PHI) = 28.89 lb/in^2
Cohesion (avg. PHI) = 20.94 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 101V 1.3

✡ INITIAL TEST

– – – – – – LINEAR REGRESSION

———— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 101V - 9.5 ft
Area = 5.03 in^2

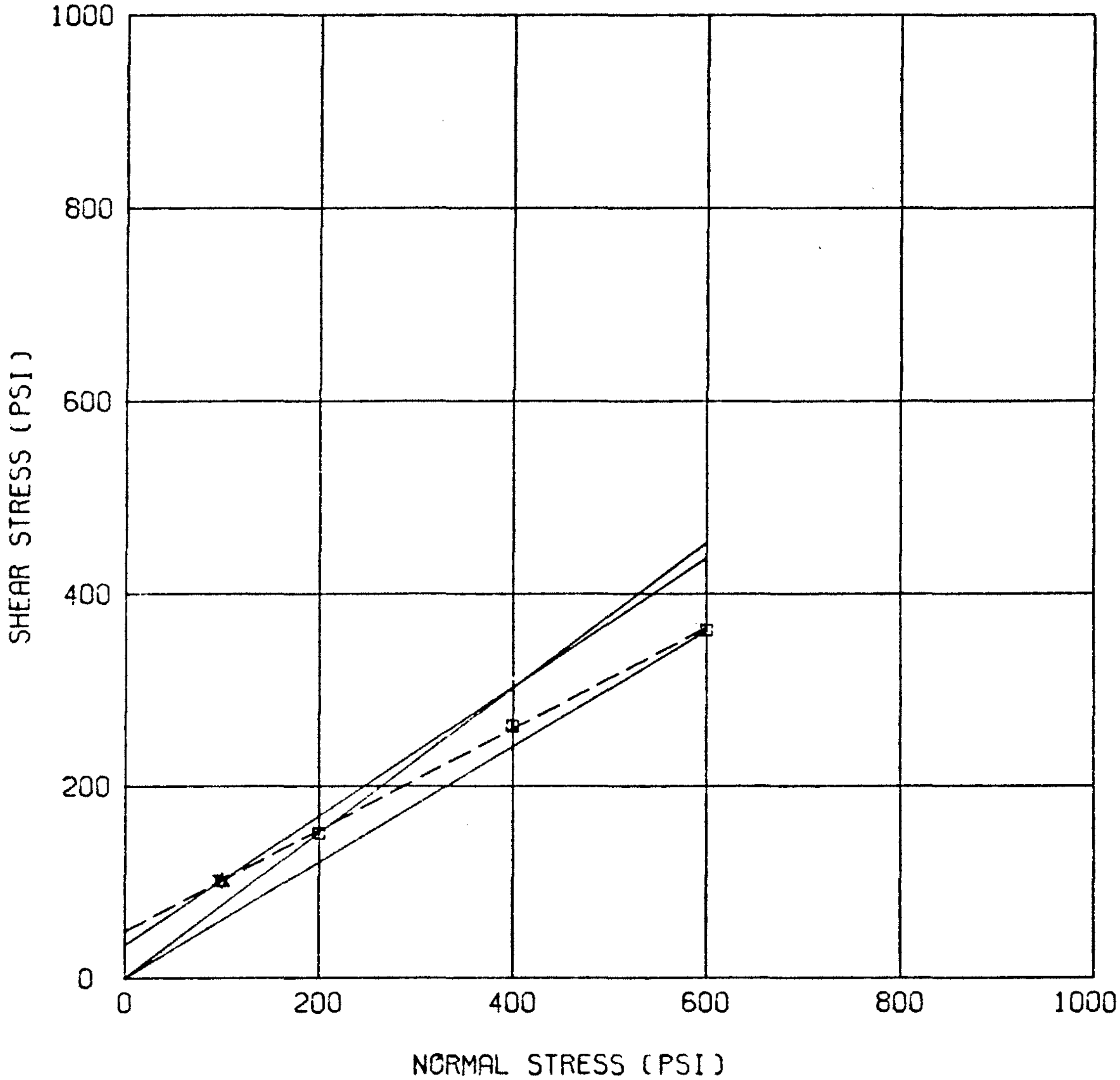
Run No.	N	S
1	100	101
2	200	151
3	400	262
4	600	362

Linear regression results:

S = 47.7 + 0.52684 (N)
Correlation = 0.9995
PHI = 27.8°
Cohesion = 48.7 lb/in^2

Angle envelope results:

PHI max. = 37.1° (0.75547)
PHI min. = 31.1° (0.60305)
PHI avg. = 33.9° (0.67153)
Cohesion (max. PHI) = 25.84 lb/in^2
Cohesion (min. PHI) = 41.09 lb/in^2
Cohesion (avg. PHI) = 34.24 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 101V 9.5

✡ INITIAL TEST

– – – – – – LINEAR REGRESSION

———— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 101V - 46.3 ft
Area = 5.03 in^2

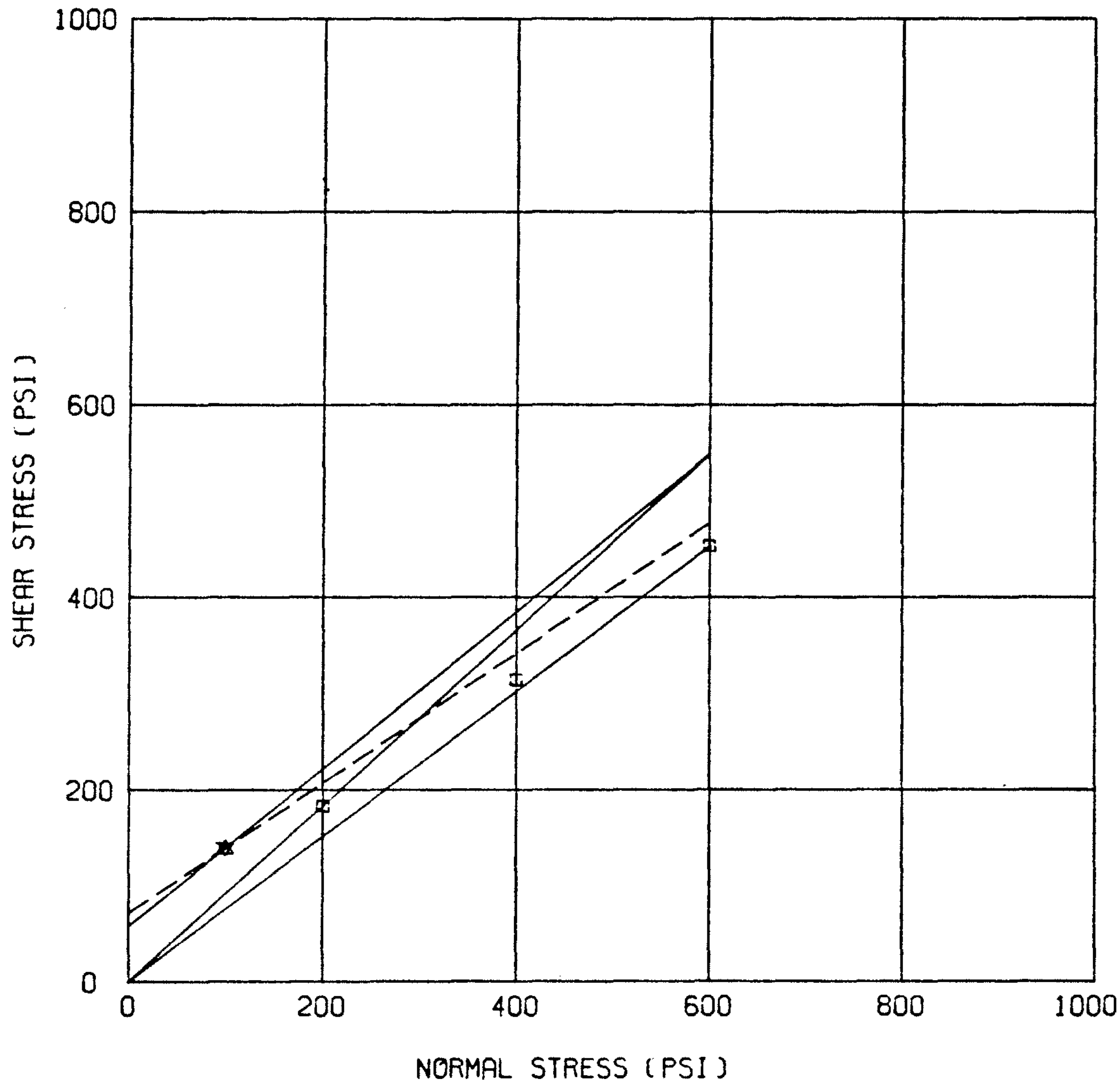
Run No.	N	S
1	100	139
2	200	183
3	400	314
4	600	453

Linear regression results:

S = 46.4 + 0.67594 (N)
Correlation = 0.9999
PHI = 34.1°
Cohesion = 71.6 lb/in^2

Angle envelope results:

PHI max. = 42.4° (0.91451)
PHI min. = 37.1° (0.75547)
PHI avg. = 39.3° (0.81842)
Cohesion (max. PHI) = 47.71 lb/in^2
Cohesion (min. PHI) = 63.62 lb/in^2
Cohesion (avg. PHI) = 57.32 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 101V 46.3

✡ INITIAL TEST
– – – – – – LINEAR REGRESSION
———— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 101A - 42.8 ft
Area = 5.75 in^2

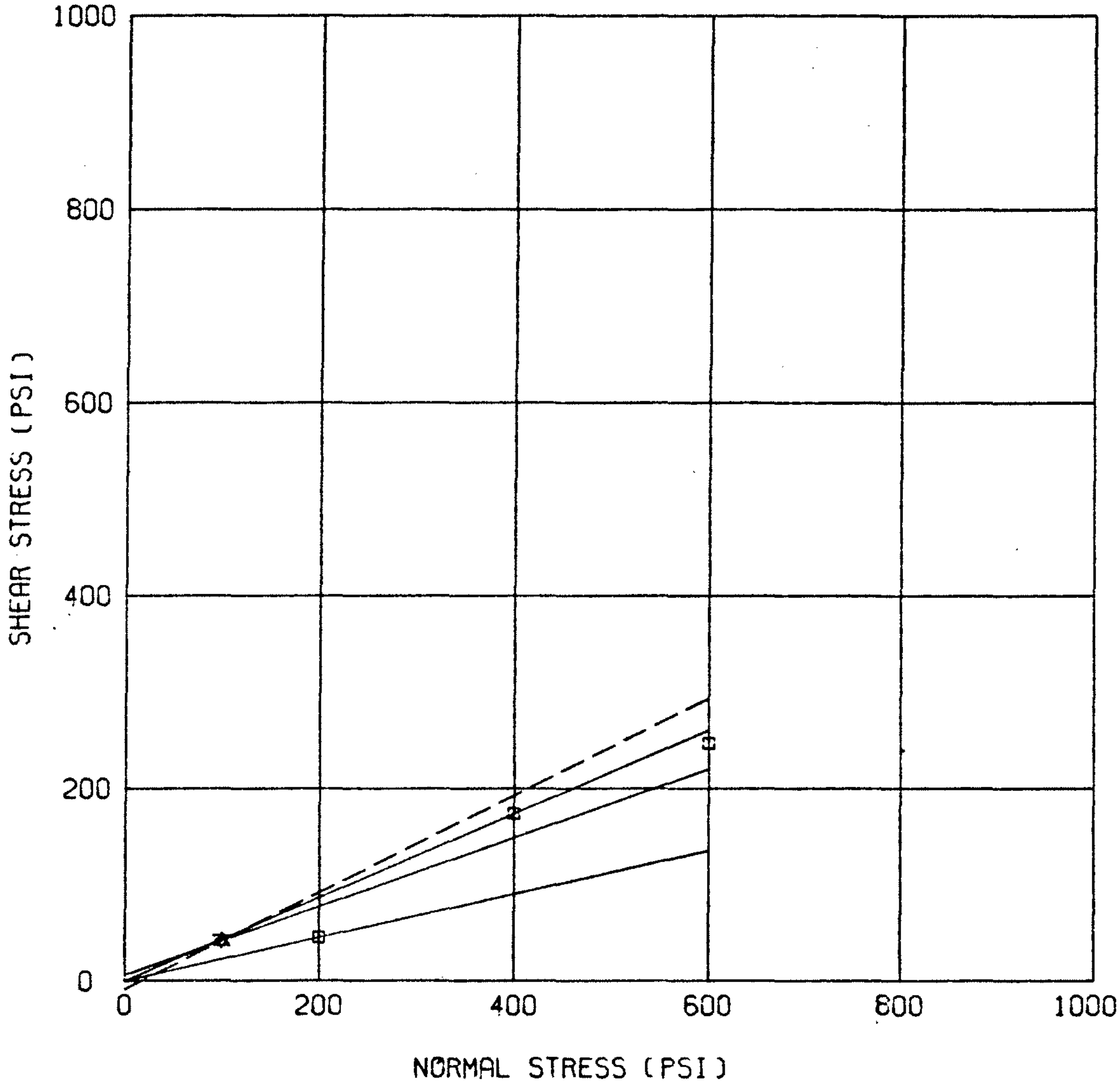
Run No.	N	S
1	100	42
2	200	45
3	400	174
4	600	247

Linear regression results:

S = -46.4 + 0.50435 (N)
Correlation = 0.9876
PHI = 26.8°
Cohesion = -8.7 lb/in^2

Angle envelope results:

PHI max. = 23.5° (0.43478)
PHI min. = 12.7° (0.22609)
PHI avg. = 19.7° (0.35749)
Cohesion (max. PHI) = 0.00 lb/in^2
Cohesion (min. PHI) = 19.13 lb/in^2
Cohesion (avg. PHI) = 5.99 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 101A 42.8

✡ INITIAL TEST

– – – – – – LINEAR REGRESSION

———— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. UJ1W - 12.0 ft
Area = 3.47 in^2

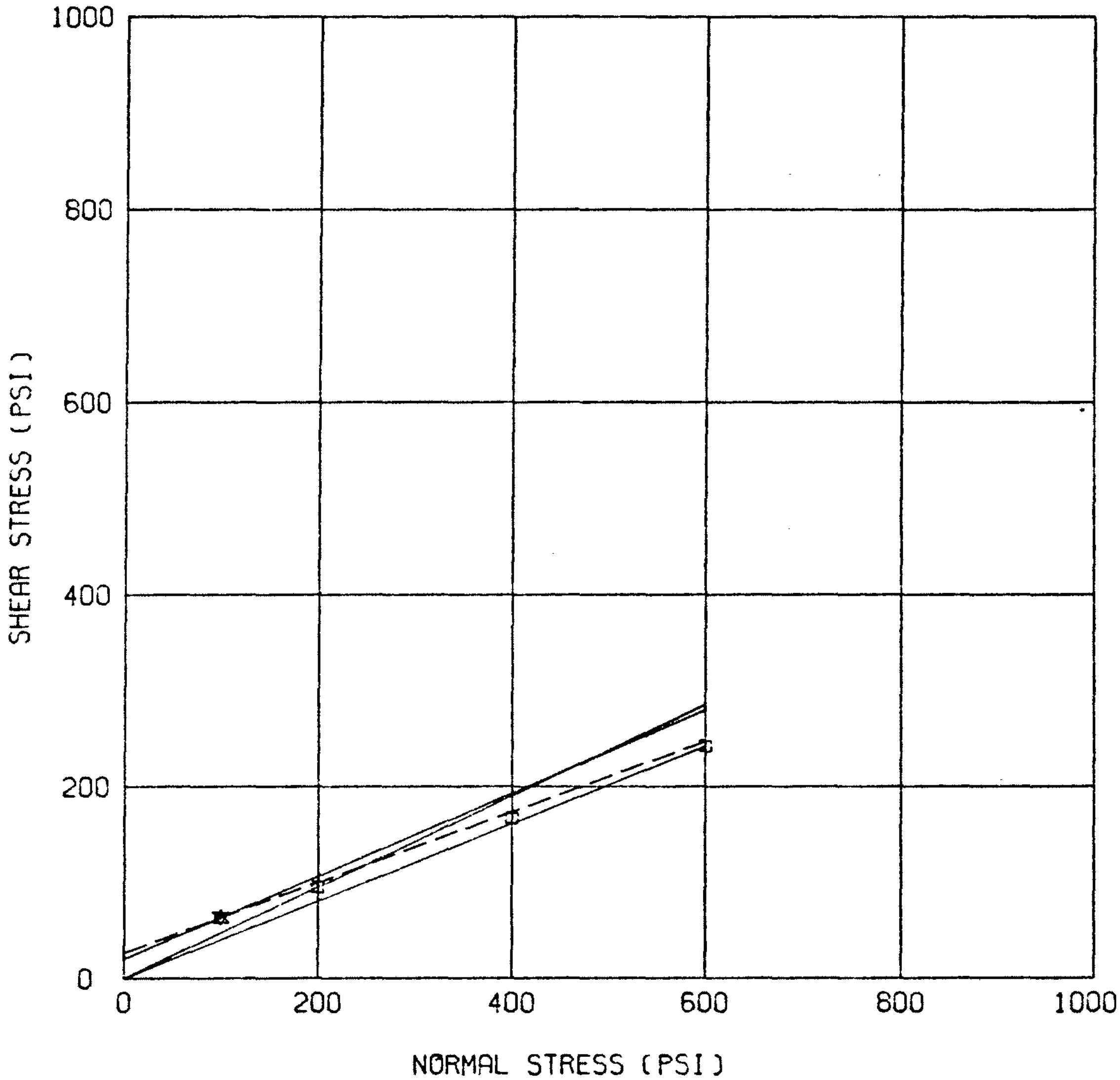
Run No.	N	S
1	100	63
2	200	95
3	400	167
4	600	242

Linear regression results:

S = 21.1 + 0.36744 (N)
Correlation = 0.9999
PHI = 20.2°
Cohesion = 26.7 lb/in^2

Angle envelope results:

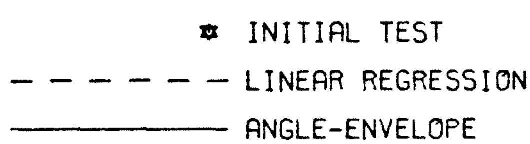
PHI max. = 25.4° (0.47550)
PHI min. = 22.0° (0.40346)
PHI avg. = 23.4° (0.43228)
Cohesion (max. PHI) = 15.85 lb/in^2
Cohesion (min. PHI) = 23.05 lb/in^2
Cohesion (avg. PHI) = 20.17 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. UJ1W 12.0



Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. UJ1E - 11.0 ft
Area = 3.74 in^2

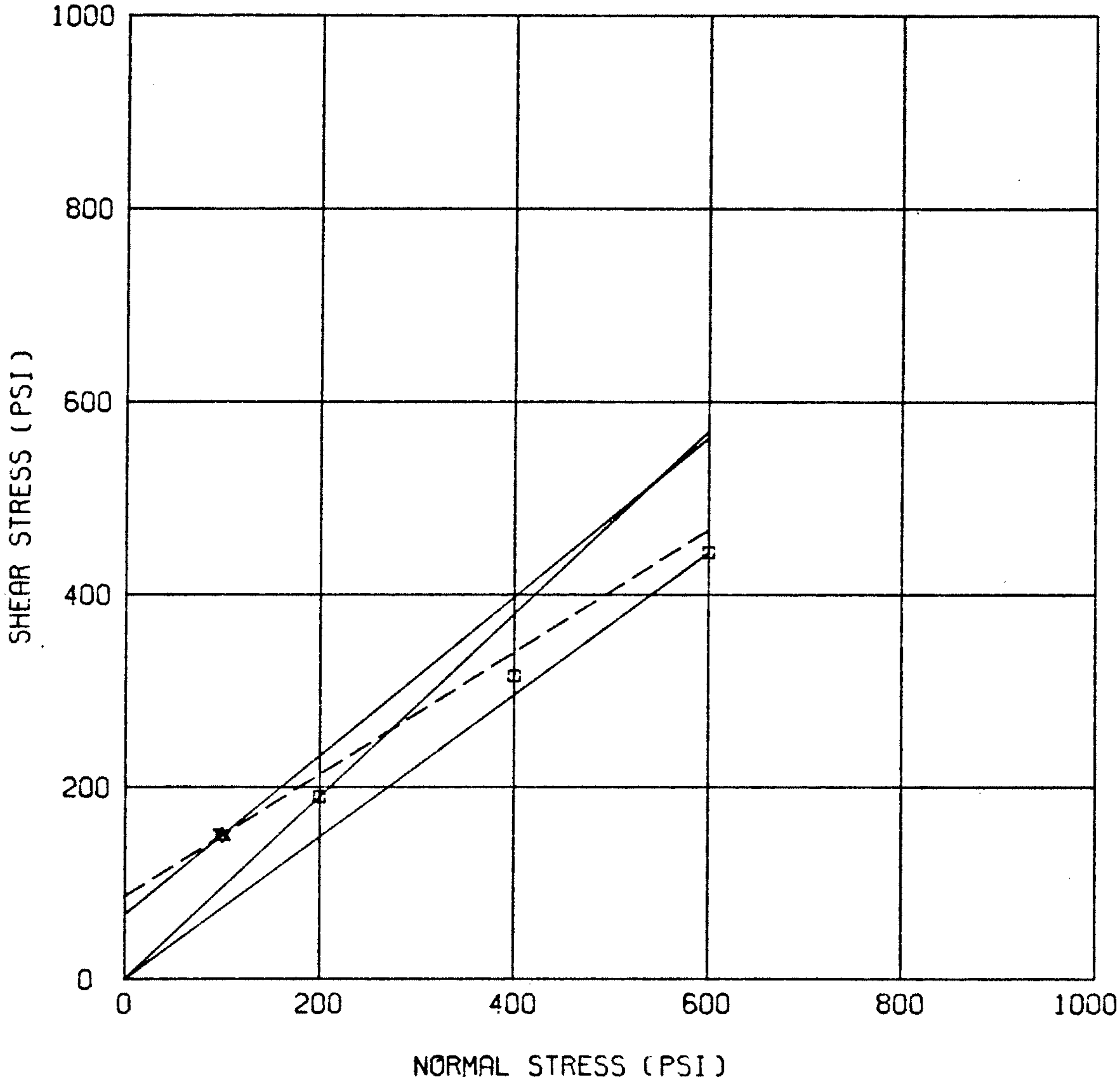
Run No.	N	S
1	100	150
2	200	190
3	400	316
4	600	444

Linear regression results:

S = 62.4 + 0.63503 (N)
Correlation = 1.0000
PHI = 32.4°
Cohesion = 86.2 lb/in^2

Angle envelope results:

PHI max. = 43.5° (0.94920)
PHI min. = 36.5° (0.73975)
PHI avg. = 39.6° (0.82591)
Cohesion (max. PHI) = 54.81 lb/in^2
Cohesion (min. PHI) = 75.76 lb/in^2
Cohesion (avg. PHI) = 67.14 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. UJ1E 11.0

✡ INITIAL TEST

– – – – – – – LINEAR REGRESSION

———————— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. UJ1E - 18.0 ft
Area = 3.67 in^2

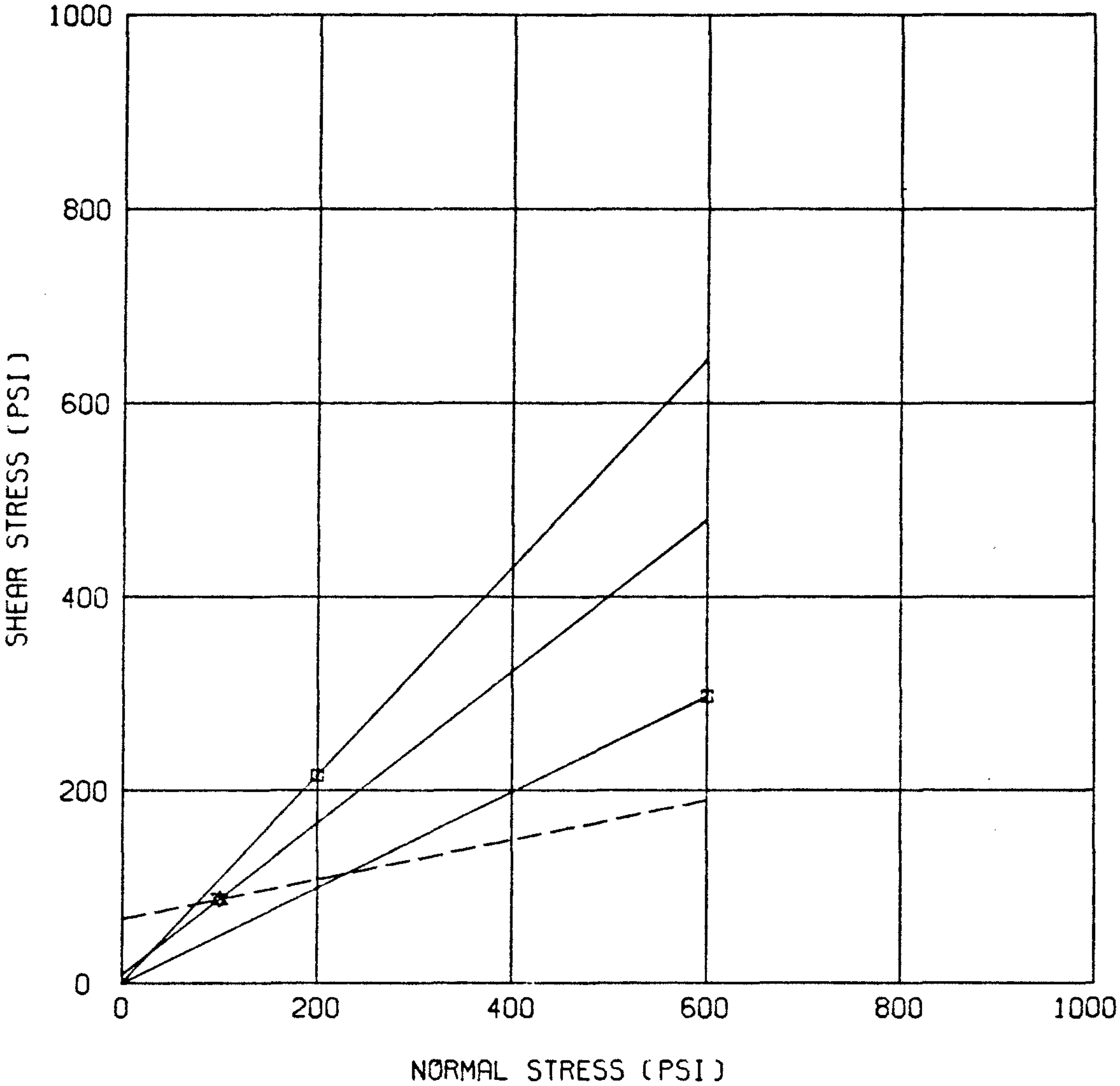
Run No.	N	S
1	100	87
2	200	215
3	600	297

Linear regression results:

S = 174.4 + 0.20436 (N)
Correlation = 1.0000
PHI = 11.5°
Cohesion = 66.8 lb/in^2

Angle envelope results:

PHI max. = 47.1° (1.07629)
PHI min. = 26.3° (0.49500)
PHI avg. = 38.2° (0.78565)
Cohesion (max. PHI) = 0.00 lb/in^2
Cohesion (min. PHI) = 37.69 lb/in^2
Cohesion (avg. PHI) = 8.63 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. UJ1E 18.0

✡ INITIAL TEST
– – – – – – LINEAR REGRESSION
———— ANGLE-ENVELOPE

Table C-11. - Laboratory core investigations
Eisenhower Tunnel
Specific gravity, absorption, and porosity - UJ2E, UJ2W, 111A, 111V

Specimen No.	Depth (ft)	Rock type (field)	Specific gravity	Percent absorption	Percent porosity
UJ2E	1.3	Biotite gneiss	2.80	0.08	0.22
UJ2E	13.5	Biotite gneiss	2.78	0.12	0.33
UJ2E	15.7	Pegmatite dike	2.76	0.24	0.66
UJ2E	17.5	Pegmatite dike	2.85	0.28	0.80
UJ2W	3.2	Pegmatite dike	2.64	0.28	0.74
UJ2W	5.1	Granite gneiss	2.73	0.31	0.85
UJ2W	12.5	Pegmatite dike	2.65	0.28	0.74
UJ2W	17.3	Biotite gneiss	2.72	0.14	0.38
111A	11.8	Biotite gneiss	2.77	0.13	0.36
111A	18.6	Granite gneiss	2.72	0.09	0.24
111A	22.0	Granite gneiss	2.74	0.16	0.44
111A	37.2	Granite gneiss	2.66	0.22	0.58
111A	56.4	Granite gneiss	2.65	0.14	0.37
111A	88.9	Granite gneiss	2.61	0.56	1.46
111A	93.5	Granite gneiss	2.66	0.73	1.94
111V	9.8	Granite gneiss	2.76	0.28	0.77
111V	13.0	Granite gneiss	2.62	0.56	1.47
111V	16.7	Granite gneiss	2.68	0.67	1.80
111V	34.3	Pegmatite dike	2.67	0.14	0.37
111V	64.6	Biotite gneiss	2.69	0.40	1.08
111V	80.4	Pegmatite dike	2.64	0.49	1.29

NOTE: 1 ft = 0.348 m

Table C-12. - Laboratory core investigations
Eisenhower Tunnel
Ultrasonic, elastic, and strength properties, UJ2E, UJ2W

Specimen No.	Depth (ft)	Rock type (field)	Ultrasonic velocity ft/s	Poisson's ratio	Secant elasticity M lb/in^2	Compressive strength lb/in^2
UJ2E	1.3	Biotite gneiss	18,900	0.24	7.30	22,500
UJ2E	13.5	Biotite gneiss	16,150	0.21	9.80	23,850
UJ2E	15.7	Pegmatite dike	14,650	0.07	3.40	15,450
UJ2E	17.5	Pegmatite dike	12,250	0.04	1.06	14,950
UJ2W	3.2	Pegmatite dike	15,050	0.14	5.75	17,250
UJ2W	5.1	Granite gneiss	16,550	0.26	11.63	19,100
UJ2W	12.5	Pegmatite dike	15,850	0.16	6.67	21,950
UJ2W	17.3	Biotite gneiss	17,700	0.21	9.62	23,650

NOTE: 1 ft = 0.348 m
1 lb/in^2 = 6.900 kPA

Table C-13. - Laboratory core investigations
Eisenhower Tunnel
Ultrasonic, elastic, and strength properties, 111A

Specimen No.	Depth (ft)	Rock type (field)	Ultrasonic velocity ft/s	Poisson's ratio	Secant elasticity M lb/in^2	Compressive strength lb/in^2
111A	11.8	Biotite gneiss	16,200	0.17	9.71	25,100
111A	18.6	Granite gneiss	16,950	0.19	8.47	17,050
111A	22.0	Granite gneiss	17,150	0.24	9.80	24,350
111A	37.2	Granite gneiss	16,600	0.14	7.25	14,900
111A	56.4	Granite gneiss	17,050	0.21	8.93	21,700
111A	88.9	Granite gneiss	16,100	0.04	7.81	16,450
111A	93.5	Granite gneiss	17,050	0.14	7.52	12,750

NOTE: 1 ft = 0.348 m
1 lb/in^2 = 6.900 kPA

Table C-14. - Laboratory core investigations
Eisenhower Tunnel
Ultrasonic, elastic, and strength properties, 111V

Specimen No.	Depth (ft)	Rock type (field)	Ultrasonic velocity ft/s	Poisson's ratio	Secant elasticity M lb/in^2	Compressive strength lb/in^2
111V	9.8	Granite gneiss	15,700	0.28	9.26	10,250
111V	13.0	Granite gneiss	17,300	0.15	9.52	16,350
111V	16.7	Granite gneiss	15,400	0.20	8.93	19,700
111V	34.3	Pegmatite dike	17,000	0.13	7.14	13,150
111V	64.6	Biotite gneiss	16,200	0.03	8.70	17,300
111V	80.4	Pegmatite dike	15,300	0.02	8.93	14,900

NOTE: 1 ft = 0.348 m
1 lb/in^2 = 6.900 kPA

Table C-15. - Laboratory core investigations
Eisenhower Tunnel
Tensile strength, UJ2E, UJ2W, 111V, 111A

Specimen No.	Depth (ft)	Rock type (field)	Tensile strength lb/in^2
UJ2E	1.3	Biotite gneiss	2,460
UJ2E	13.5	Biotite gneiss	1,900
UJ2E	15.7	Pegmatite dike	1,380
UJ2E	17.5	Pegmatite dike	1,480
UJ2W	3.2	Pegmatite dike	1,140
UJ2W	5.1	Granite gneiss	2,520
UJ2W	12.5	Pegmatite dike	1,480
UJ2W	17.3	Biotite gneiss	2,400
111V	9.8	Granite gneiss	1,280
111V	13.0	Granite gneiss	1,560
111V	16.7	Granite gneiss	1,740
111V	34.3	Pegmatite dike	1,740
111V	64.6	Biotite gneiss	1,520
111V	80.4	Pegmatite dike	800
111A	11.8	Biotite gneiss	2,040
111A	18.6	Granite gneiss	1,640
111A	22.0	Granite gneiss	2,120
111A	37.2	Granite gneiss	2,110
111A	56.4	Granite gneiss	1,820
111A	88.9	Granite gneiss	1,040
111A	93.5	Granite gneiss	1,700

NOTE: 1 ft = 0.348 m
1 lb/in^2 = 6.900 kPA

Table C-16. - Laboratory core investigations
Eisenhower Tunnel
Shear properties, 111A, 111V, and UJ2W

Specimen No.	Depth (ft)	Rock type (field)	Cohesion (lb/in^2) Linear regression	Cohesion (lb/in^2) Angle envelope	Phi (Ø) degrees Linear regression	Phi (Ø) degrees Angle envelope
111A	56.1	Biotite gneiss	2,200	1,890	34	55
111A	61.0	Granite gneiss	2,000	1 560	45	64
111A	64.8	Granite	1,820	1,520	46	61
111A	92.6	Granite gneiss	2,160	1,770	50	65
111V	23.5	Granite	2,930	2,700	42	56
111V	24.9	Granite	1,770	1,250	72	77
111V	75.7	Granite gneiss	1,450	1,040	68	74
UJ2W	12.8	Pegmatite dike	1,310	1,160	70	72
UJ2W	20.6	Biotite gneiss	1,520	1,050	66	74

NOTE: 1 ft = 0.348 m
$1\ lb/in^2 = 6.900$ kPA

Table C-17. - Laboratory core investigations
Eisenhower Tunnel
Sliding friction properties, 111A, and UJ2E

Specimen No.	Depth (ft)	Rock type (field)	Cohesion (lb/in^2)		Phi (Ø) degrees	
			Linear regression	Angle envelope	Linear regression	Angle envelope
111A	16.6	Granite gneiss	160	95	45	59
111A	69.7	Granite	34	24	33	37
111A	93.0	Granite gneiss	36	20	32	38
111A	93.2	Granite gneiss	60	48	42	45
UJ2E	18.0	Biotite gneiss	120	83	33	46
UJ2E	18.5	Biotite gneiss	148	91	47	59
UJ2E	19.0	Biotite gneiss	25	13	34	39

NOTE: 1 ft = 0.348 m
1 lb/in^2 = 6.900 kPA

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 111A - 56.1 ft
Area = 3.30 in^2

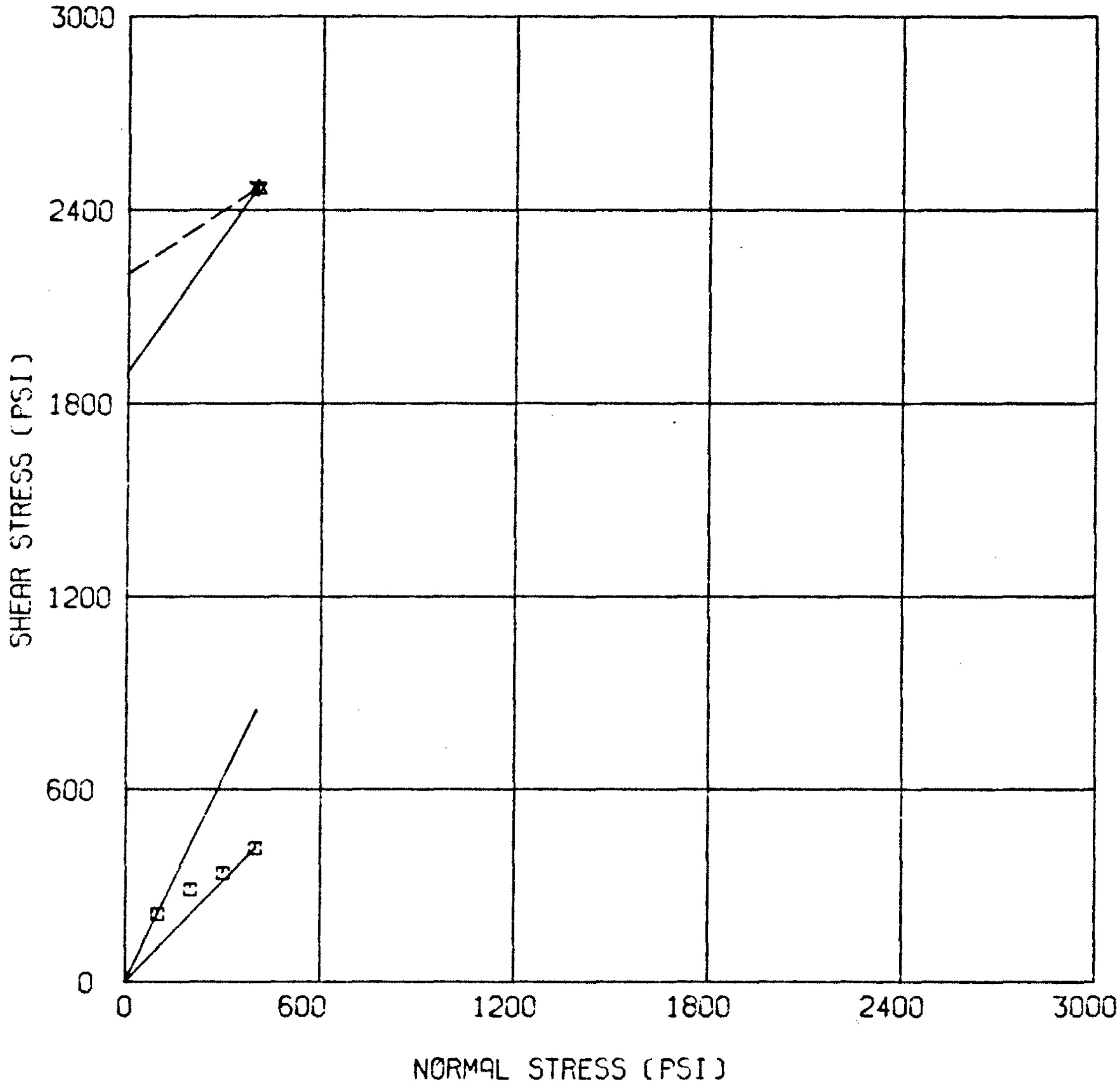
Run No.	N	S
1	400	2,470
2	100	212
3	200	288
4	300	339
5	400	418

Linear regression results:

S = 147.0 + 0.66970 (N)
Correlation = 0.9970
PHI = 33.8°
Cohesion = 2,201.8 lb/in^2

Angle envelope results:

PHI max. = 64.8° (2.12121)
PHI min. = 46.3° (1.04545)
PHI avg. = 55.1° (1.43434)
Cohesion (max. PHI) = 1,621.21 lb/in^2
Cohesion (min. PHI) = 2,051.52 lb/in^2
Cohesion (avg. PHI) = 1,895.96 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 111A56.1

✡ INITIAL TEST

– – – – – – LINEAR REGRESSION

———————— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 111A - 61.0 ft
Area = 3.30 in^2

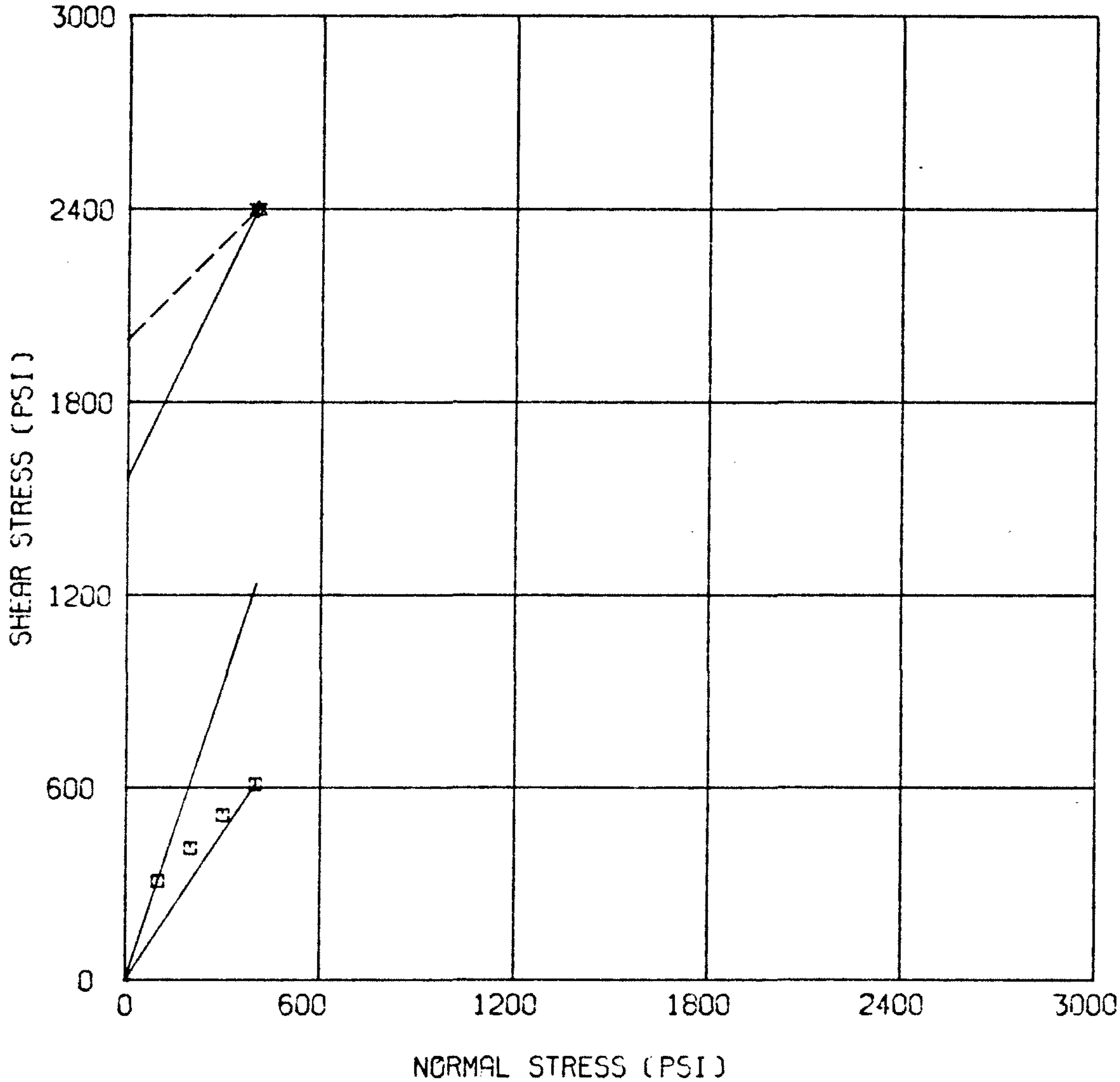
Run No.	N	S
1	400	2,400
2	100	309
3	200	412
4	300	515
5	400	612

Linear regression results:

S = 209.1 + 1.01212 (N)
Correlation = 0.9999
PHI = 45.3°
Cohesion = 1,995.2 lb/in^2

Angle envelope results:

PHI max. = 72.1° (3.09091)
PHI min. = 56.8° (1.53030)
PHI avg. = 64.5° (2.09975)
Cohesion (max. PHI) = 1,163.64 lb/in^2
Cohesion (min. PHI) = 1,787.88 lb/in^2
Cohesion (avg. PHI) = 1,560.10 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 111A61.0

✡ INITIAL TEST
– – – – – – LINEAR REGRESSION
———— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 111A - 64.8 ft
Area = 3.30 in^2

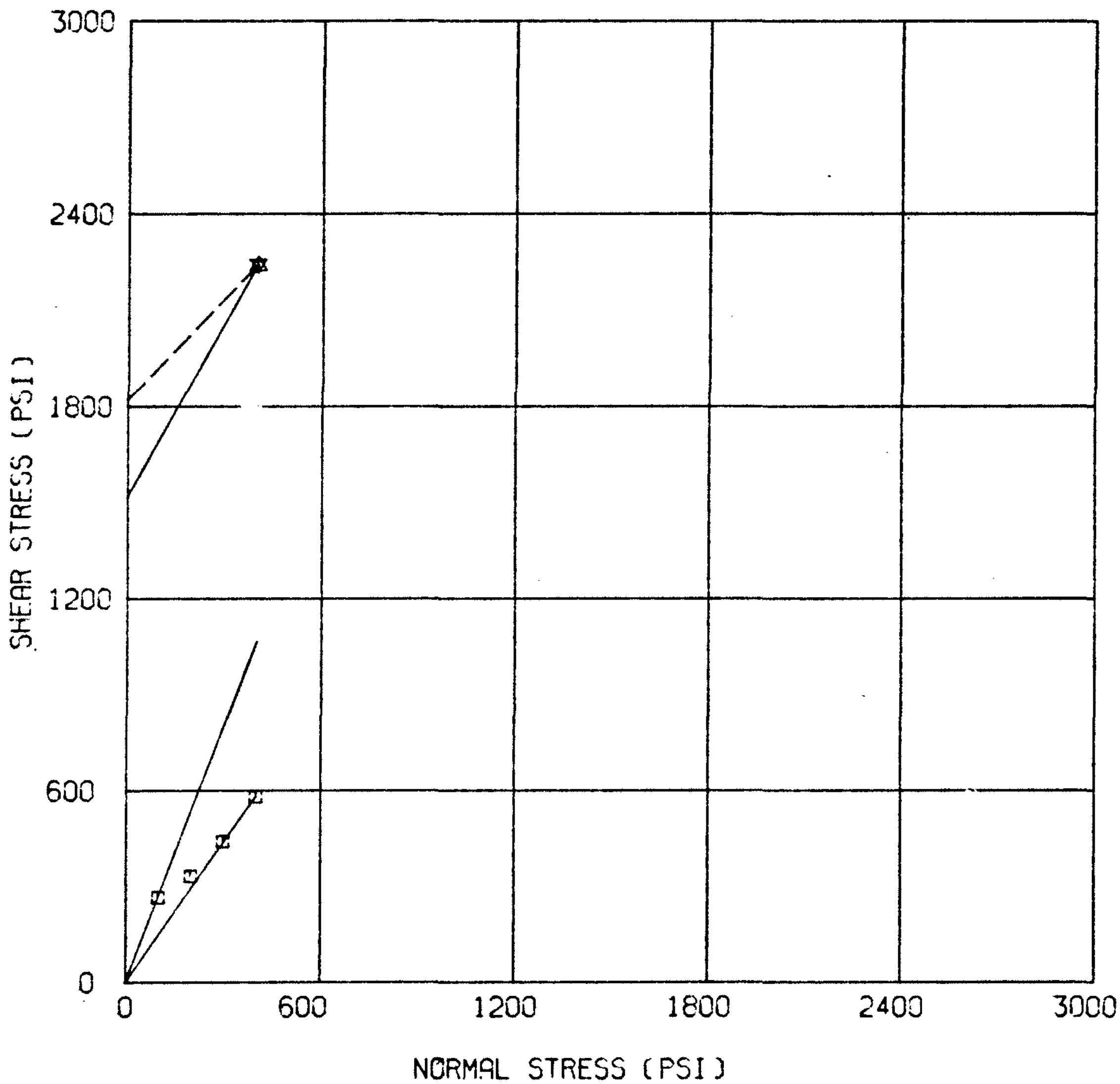
Run No.	N	S
1	400	2,242
2	100	267
3	200	333
4	300	442
5	400	582

Linear regression results:

S = 142.4 + 1.05455 (N)
Correlation = 0.9883
PHI = 46.5°
Cohesion = 1,820.6 lb/in^2

Angle envelope results:

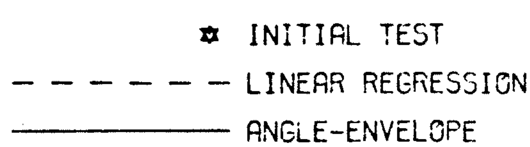
PHI max. = 69.4° (2.66667)
PHI min. = 55.5° (1.45455)
PHI avg. = 61.2° (1.81566)
Cohesion (max. PHI) = 1,175.76 lb/in^2
Cohesion (min. PHI) = 1,660.61 lb/in^2
Cohesion (avg. PHI) = 1,516.16 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 111A64.8



Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 111A - 92.6 ft
Area = 3.30 in^2

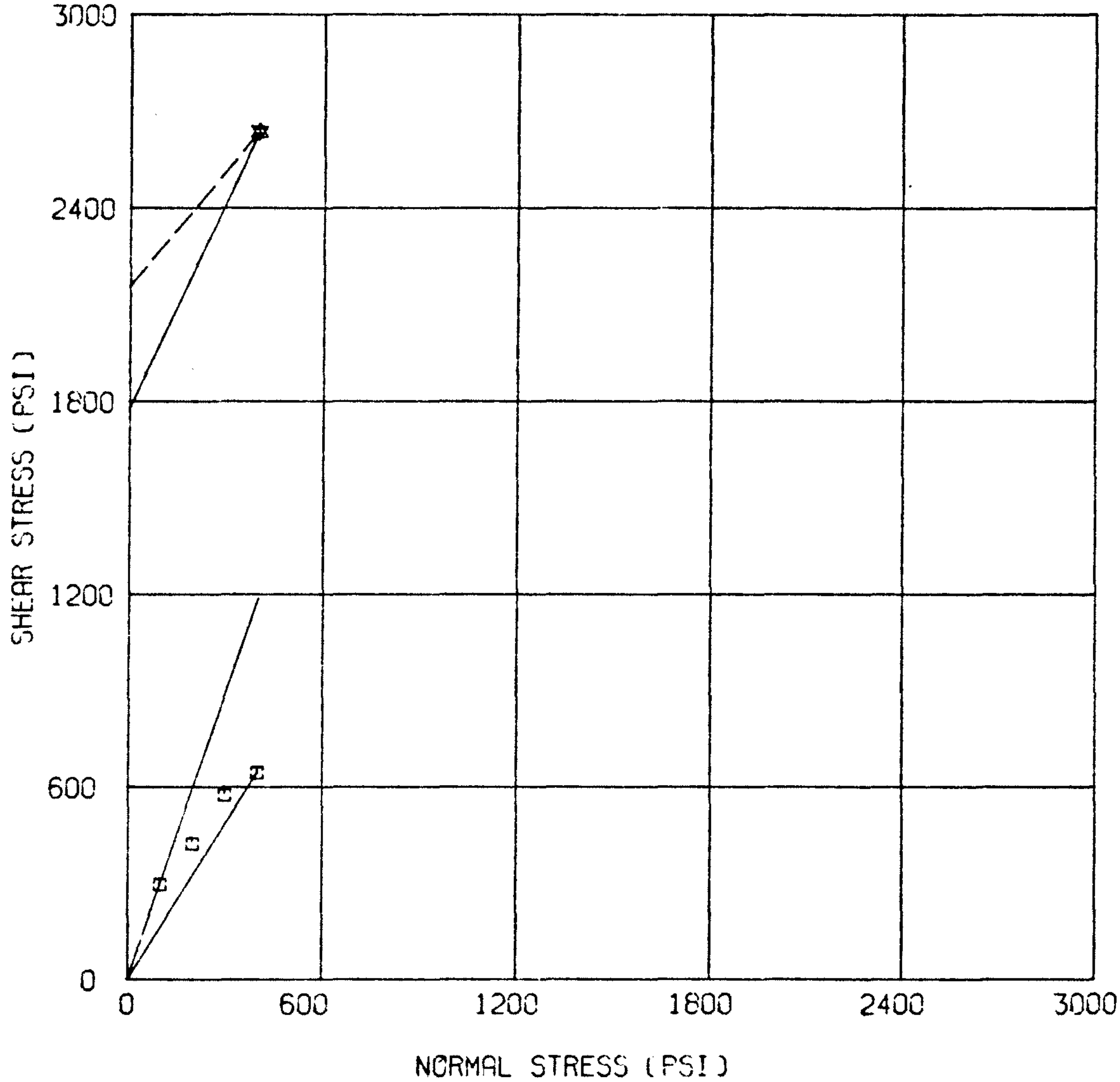
Run No.	N	S
1	400	2,636
2	100	297
3	200	424
4	300	576
5	400	645

Linear regression results:

S = 186.4 + 1.19697 (N)
Correlation = 0.9904
PHI = 50.1°
Cohesion = 2,157.6 lb/in^2

Angle envelope results:

PHI max. = 71.4° (2.96970)
PHI min. = 58.2° (1.61364)
PHI avg. = 65.1° (2.15593)
Cohesion (max. PHI) = 1,448.48 lb/in^2
Cohesion (min. PHI) = 1,990.91 lb/in^2
Cohesion (avg. PHI) = 1,773.99 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 111A95.6

✡ INITIAL TEST

– – – – – – LINEAR REGRESSION

——————— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 111V - 23.5 ft
Area = 3.30 in^2

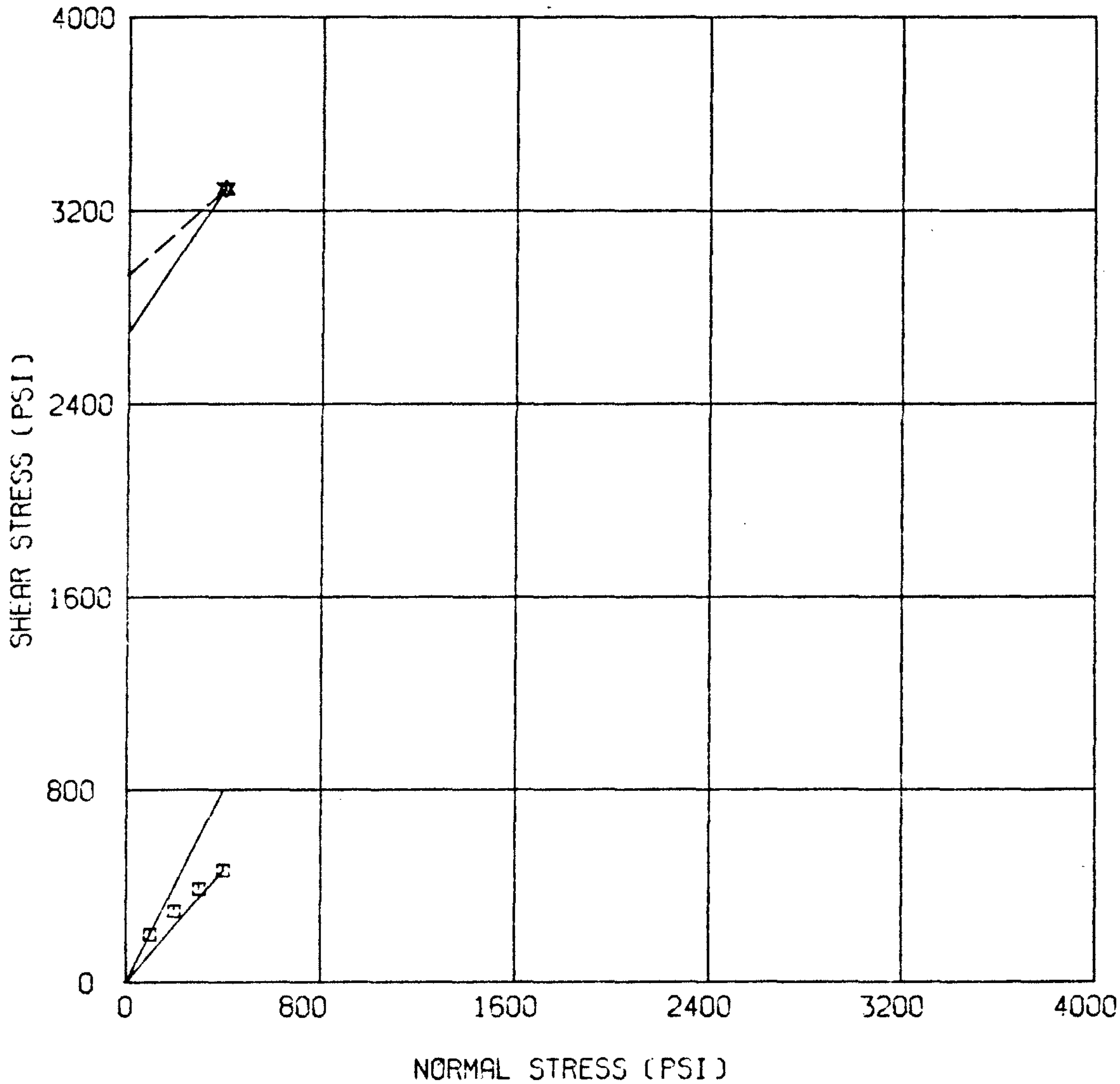
Run No.	N	S
1	400	3,291
2	100	200
3	200	297
4	300	388
5	400	467

Linear regression results:

S = 115.2 + 0.89091 (N)
Correlation = 0.9989
PHI = 41.7°
Cohesion = 2,934.5 lb/in^2

Angle envelope results:

PHI max. = 63.4° (2.00000)
PHI min. = 49.4° (1.16667)
PHI avg. = 56.1° (1.48611)
Cohesion (max. PHI) = 2,490.91 lb/in^2
Cohesion (min. PHI) = 2,824.24 lb/in^2
Cohesion (avg. PHI) = 2,696.46 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 111V23.5

✡ INITIAL TEST

– – – – – – LINEAR REGRESSION

———— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 111V - 24.9 ft
Area = 3.30 in^2

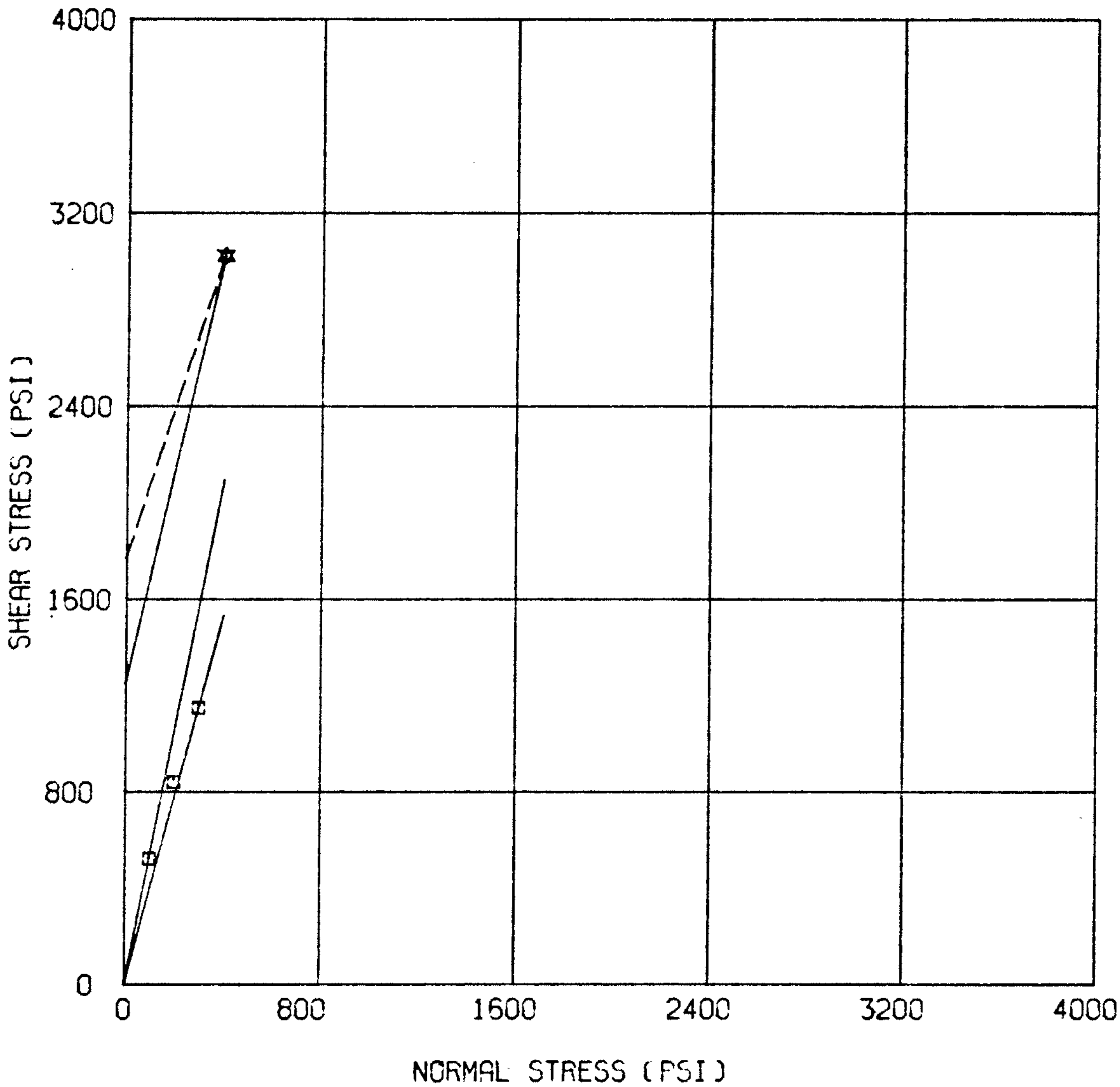
Run No.	N	S
1	400	3,024
2	100	524
3	200	842
4	300	1,152

Linear regression results:

S = 212.1 + 3.13636 (N)
Correlation = 1.0000
PHI = 72.3°
Cohesion = 1,769.7 lb/in^2

Angle envelope results:

PHI max. = 79.2° (5.24242)
PHI min. = 75.4° (3.83838)
PHI avg. = 77.3° (4.43098)
Cohesion (max. PHI) = 927.27 lb/in^2
Cohesion (min. PHI) = 1,488.89 lb/in^2
Cohesion (avg. PHI) = 1,251.85 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 111V24.9

☆ INITIAL TEST

– – – – – – LINEAR REGRESSION

———————— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 111V - 75.7 ft
Area = 3.30 in^2

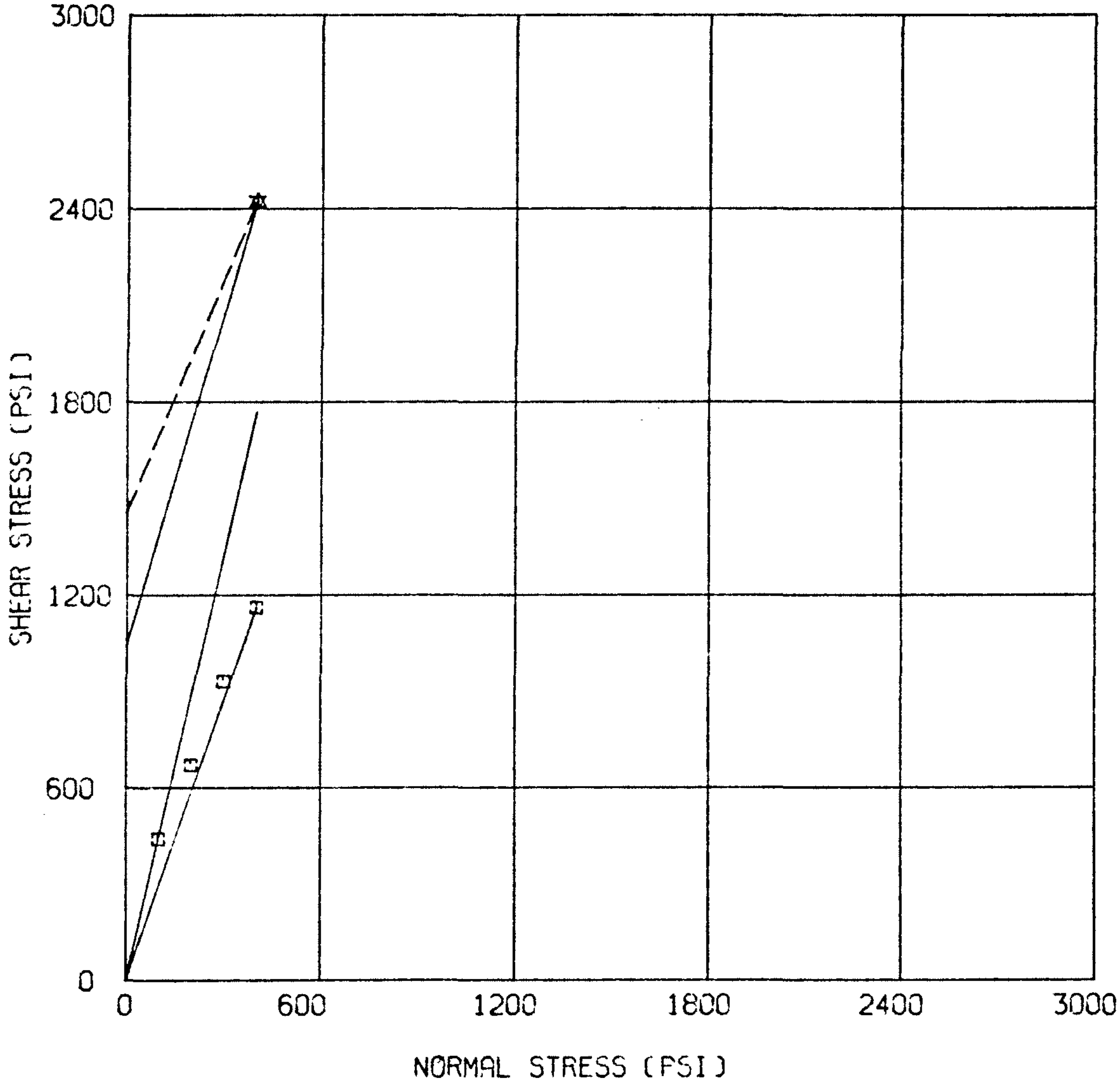
Run No.	N	S
1	400	2,424
2	100	442
3	200	673
4	300	933
5	400	1,164

Linear regression results:

S = 197.0 + 2.42424 (N)
Correlation = 0.9997
PHI = 67.6°
Cohesion = 1,454.5 lb/in^2

Angle envelope results:

PHI max. = 77.3° (4.42424)
PHI min. = 71.0° (2.90909)
PHI avg. = 73.8° (3.45202)
Cohesion (max. PHI) = 654.55 lb/in^2
Cohesion (min. PHI) = 1,260.61 lb/in^2
Cohesion (avg. PHI) = 1,043.43 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 111V75.7

✡ INITIAL TEST

– – – – – – LINEAR REGRESSION

———— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. UJ2W - 12.8 ft
Area = 3.30 in^2

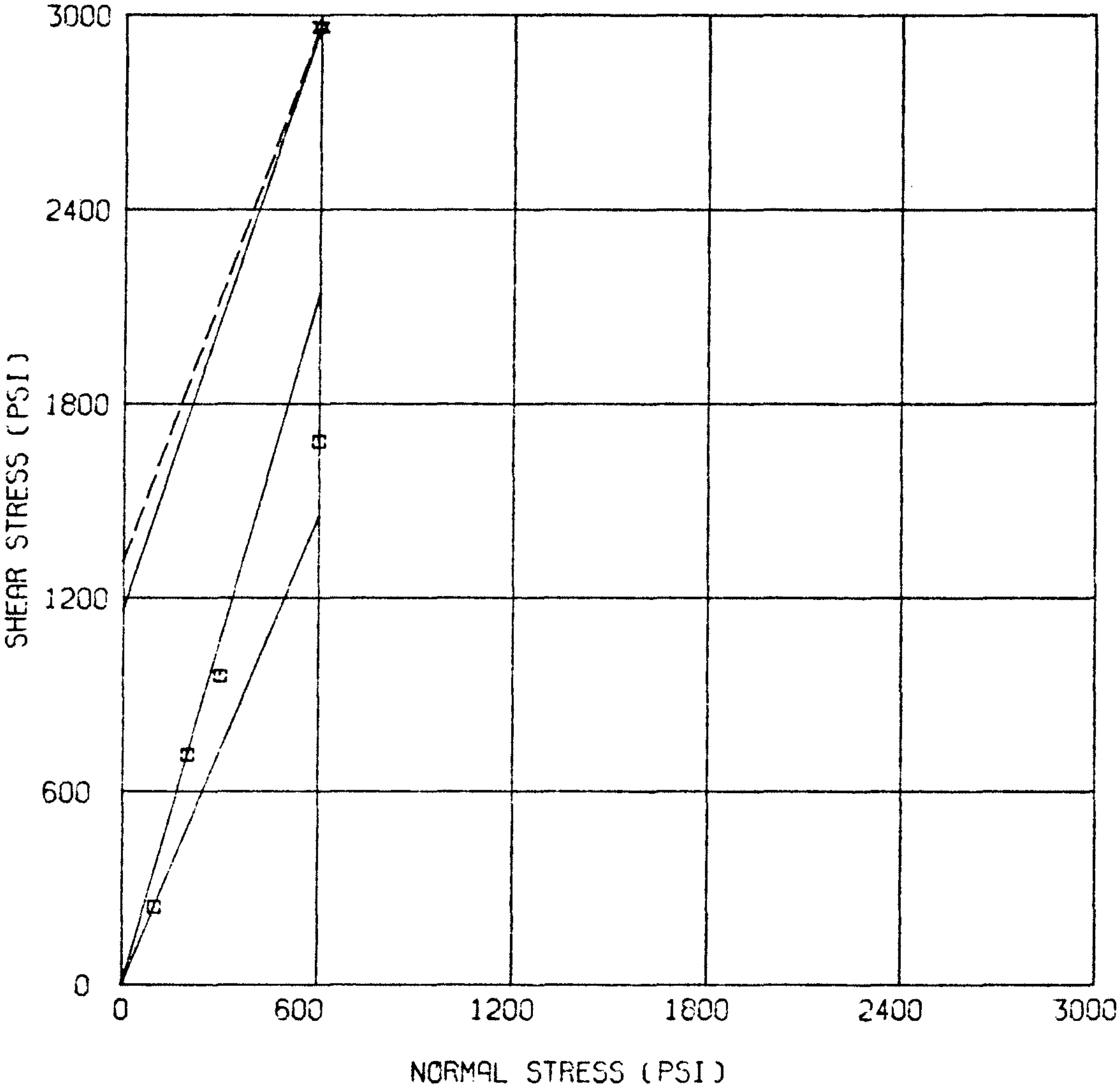
Run No.	N	S
1	600	2,964
2	100	242
3	200	715
4	300	961
5	600	1,685

Linear regression results:

S = 74.8 + 2.75325 (N)
Correlation = 0.9884
PHI = 70.0°
Cohesion = 1,311.7 lb/in^2

Angle envelope results:

PHI max. = 74.4° (3.57576)
PHI min. = 67.6° (2.42424)
PHI avg. = 71.6° (3.00253)
Cohesion (max. PHI) = 818.18 lb/in^2
Cohesion (min. PHI) = 1,509.09 lb/in^2
Cohesion (avg. PHI) = 1,162.12 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. UJ2W12.8

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. UJ2W - 20.6 ft
Area = 3.30 in^2

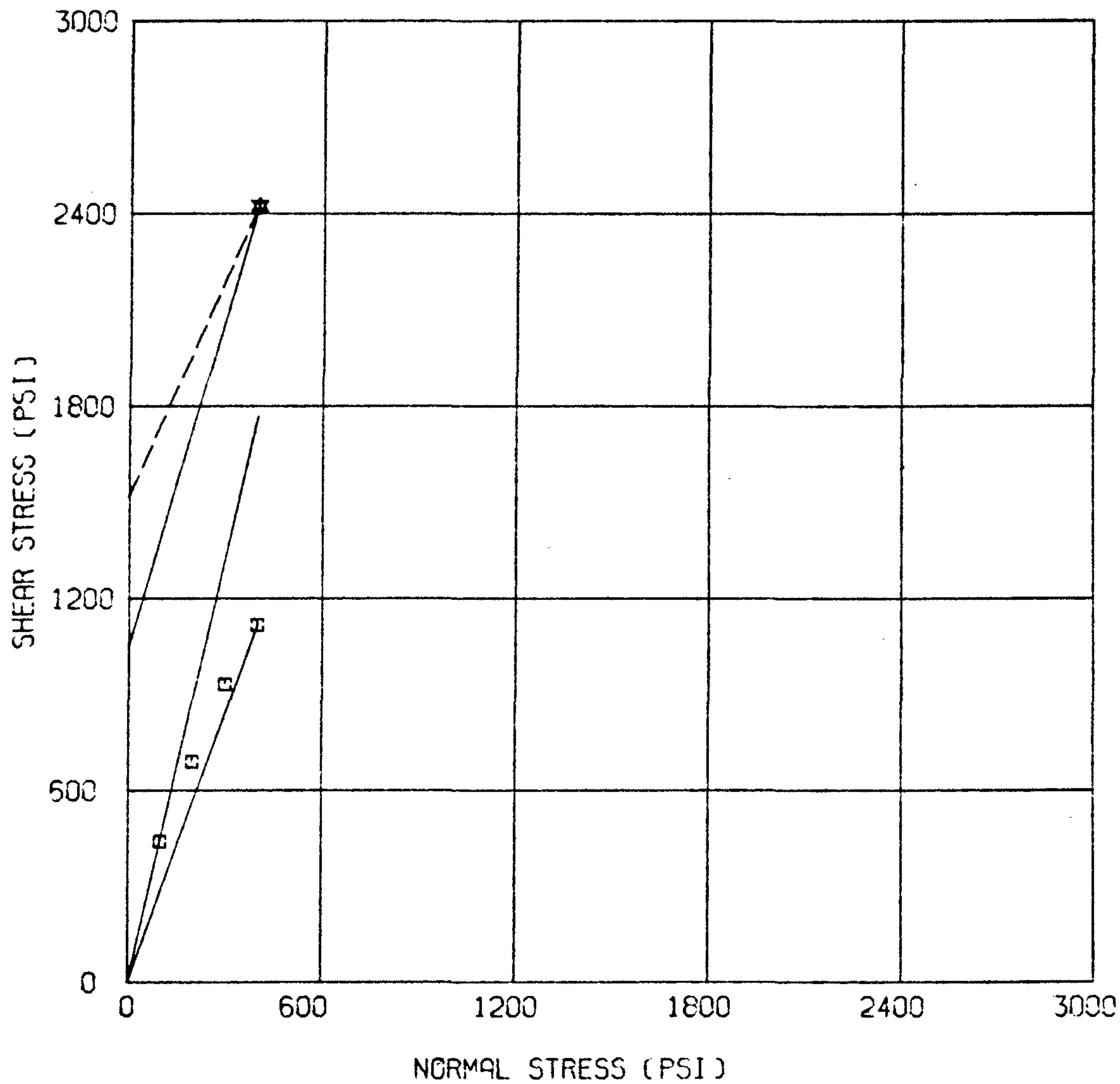
Run No.	N	S
1	400	2,424
2	100	442
3	200	691
4	300	933
5	400	1,118

Linear regression results:

S = 228.8 + 2.26970 (N)
Correlation = 0.9978
PHI = 66.2°
Cohesion = 1,516.4 lb/in^2

Angle envelope results:

PHI max. = 77.3° (4.42424)
PHI min. = 70.3° (2.79545)
PHI avg. = 73.8° (3.44634)
Cohesion (max. PHI) = 654.55 lb/in^2
Cohesion (min. PHI) = 1,306.06 lb/in^2
Cohesion (avg. PHI) = 1,045.71 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. UJ2W20.6

✡ INITIAL TEST

– – – – – – – LINEAR REGRESSION

———————— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 111A - 16.6 ft
Area = 4.18 in^2

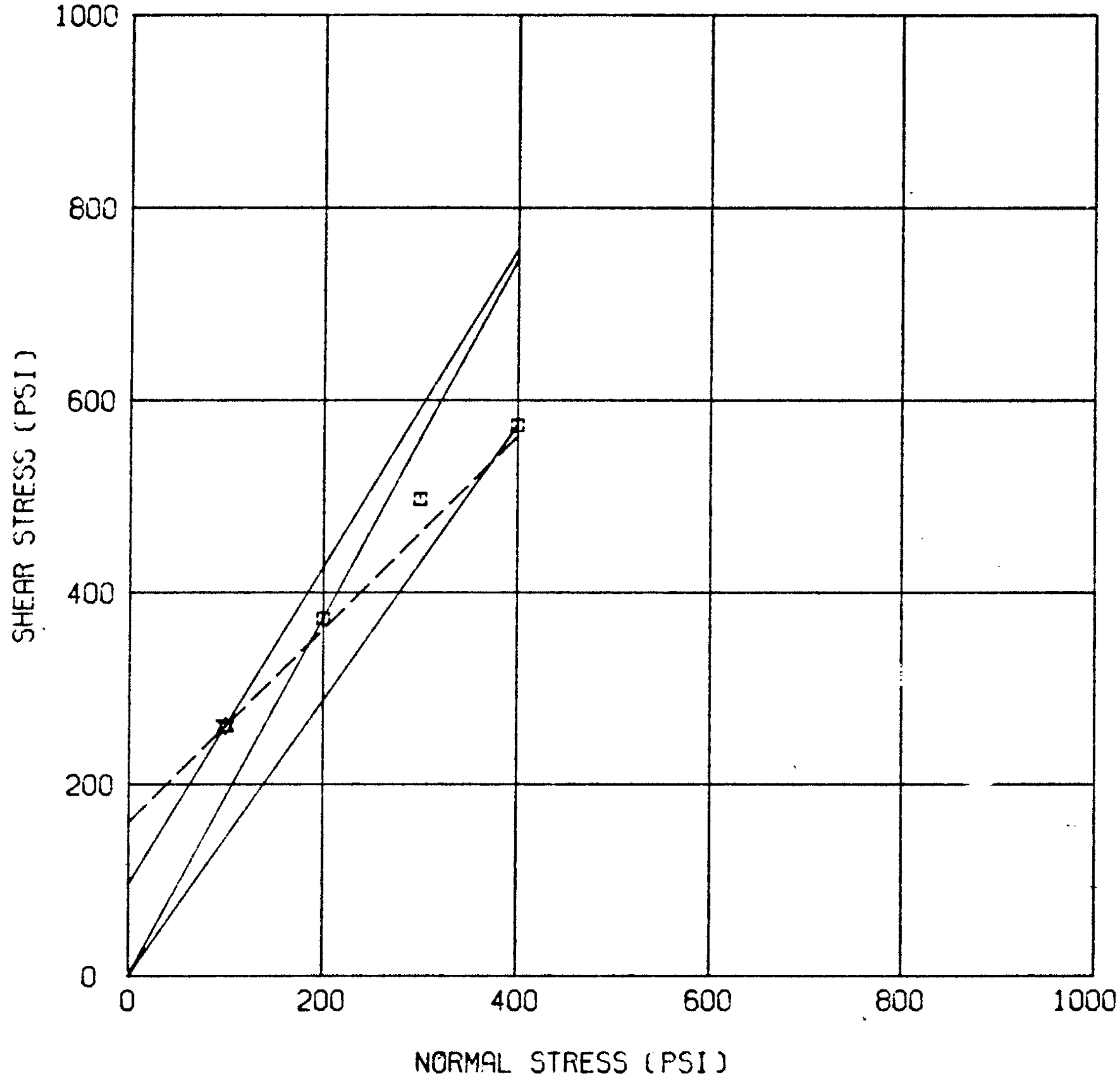
Run No.	N	S
1	100	261
2	200	373
3	300	498
4	400	574

Linear regression results:

S = 180.2 + 1.00478 (N)
Correlation = 0.9907
PHI = 45.1°
Cohesion = 160.3 lb/in^2

Angle envelope results:

PHI max. = 61.8° (1.86603)
PHI min. = 55.1° (1.43541)
PHI avg. = 58.8° (1.65338)
Cohesion (max. PHI) = 74.16 lb/in^2
Cohesion (min. PHI) = 117.22 lb/in^2
Cohesion (avg. PHI) = 95.43 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 111A16.6

✡ INITIAL TEST

– – – – – – LINEAR REGRESSION

———— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 111A - 69.7 ft
Area = 5.80 in^2

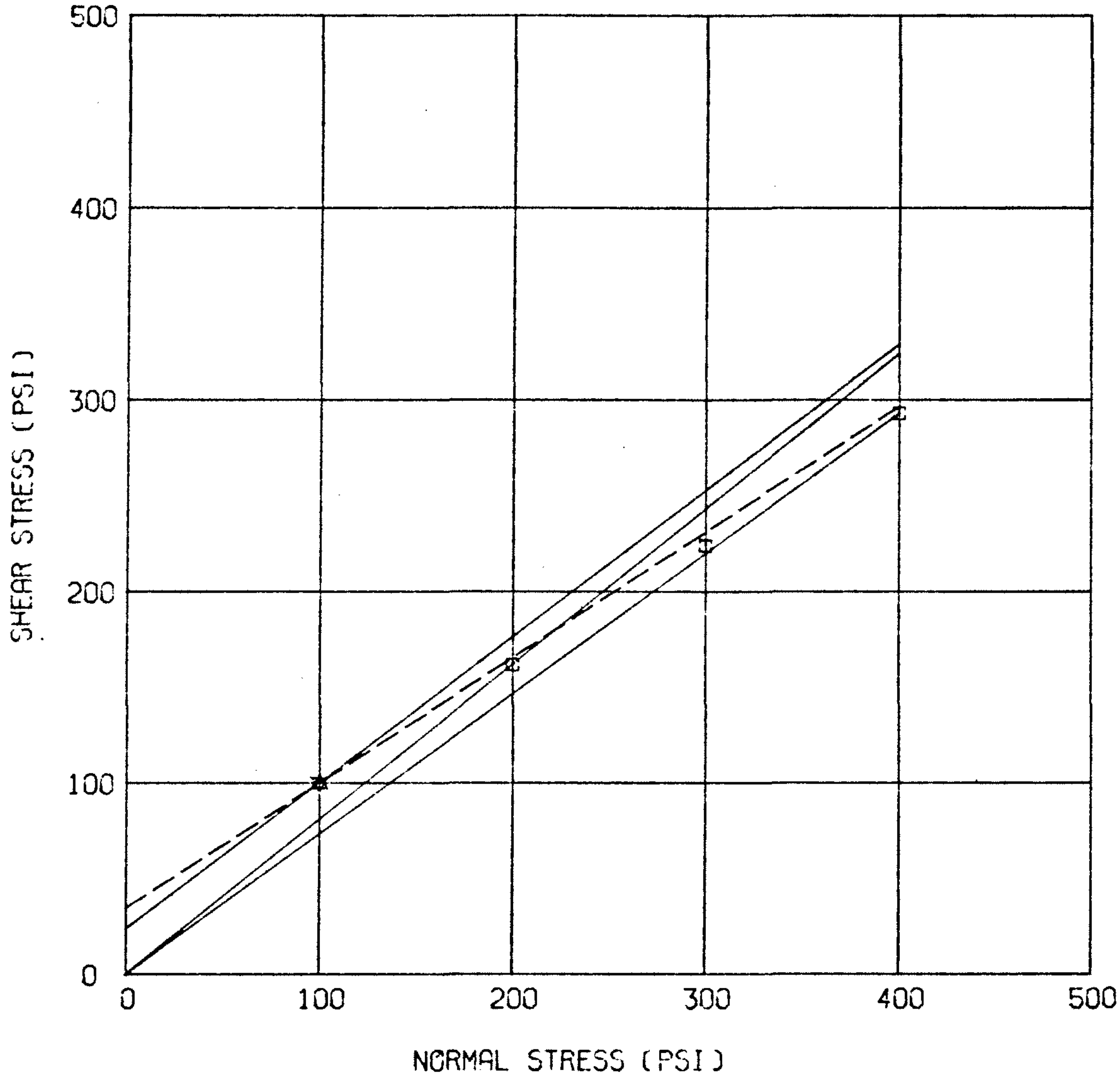
Run No.	N	S
1	100	100
2	200	162
3	300	224
4	400	293

Linear regression results:

S = 29.9 + 0.65517 (N)
Correlation = 0.9995
PHI = 33.2°
Cohesion = 34.5 lb/in^2

Angle envelope results:

PHI max. = 39.0° (0.81034)
PHI min. = 36.2° (0.73276)
PHI avg. = 37.4° (0.76341)
Cohesion (max. PHI) = 18.97 lb/in^2
Cohesion (min. PHI) = 26.72 lb/in^2
Cohesion (avg. PHI) = 23.66 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 111A69.7

✡ INITIAL TEST
– – – – – – LINEAR REGRESSION
———— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 111A - 93.0 ft
Area = 3.45 in^2

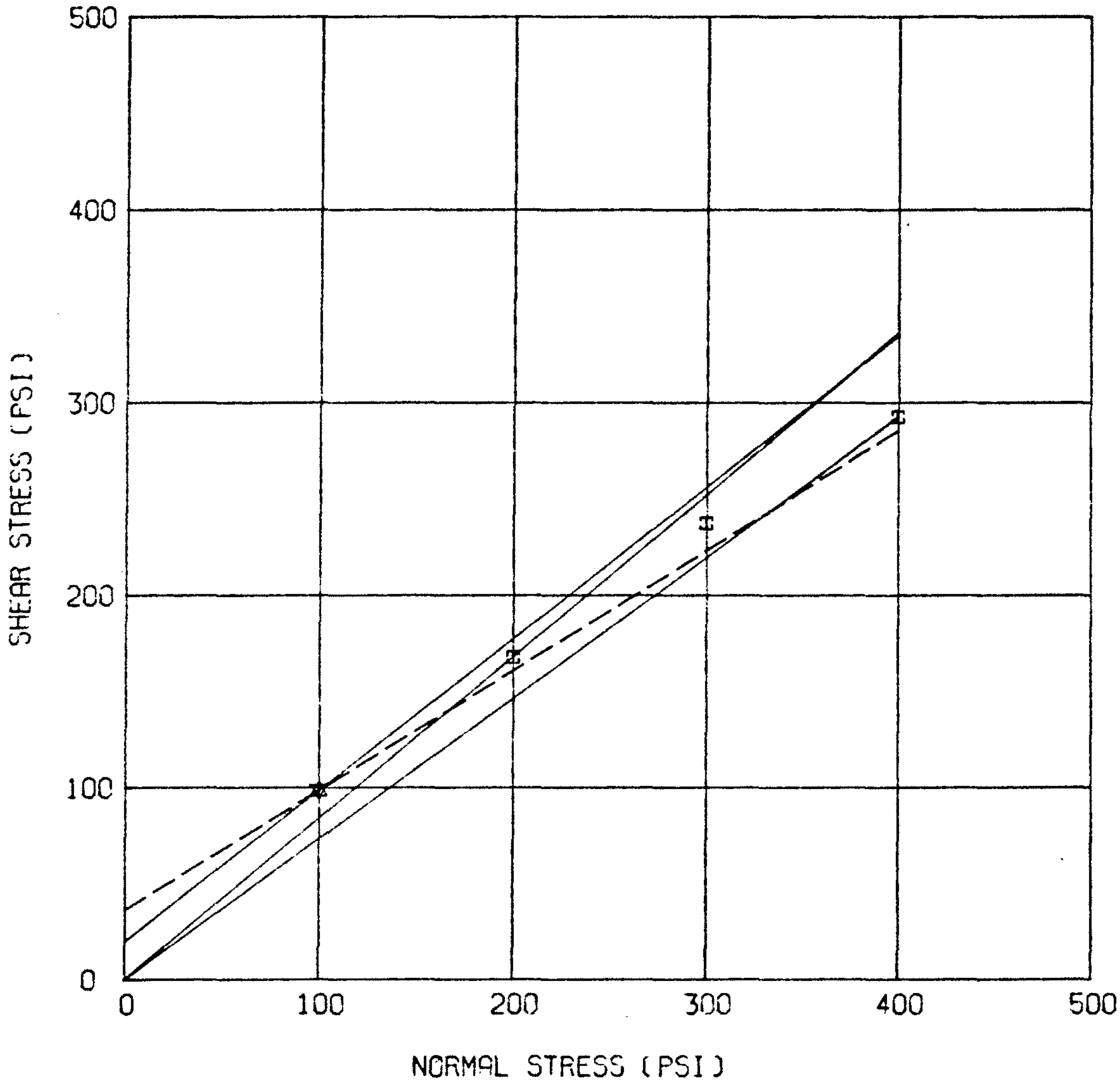
Run No.	N	S
1	100	99
2	200	168
3	300	238
4	400	293

Linear regression results:

S = 45.9 + 0.62319 (N)
Correlation = 0.9978
PHI = 31.9°
Cohesion = 36.2 lb/in^2

Angle envelope results:

PHI max. = 40.0° (0.84058)
PHI min. = 36.2° (0.73188)
PHI avg. = 38.2° (0.78824)
Cohesion (max. PHI) = 14.49 lb/in^2
Cohesion (min. PHI) = 25.36 lb/in^2
Cohesion (avg. PHI) = 19.73 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 111A93.0

✡ INITIAL TEST
– – – – – – LINEAR REGRESSION
———— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. 111A - 93.2 ft
Area = 3.70 in^2

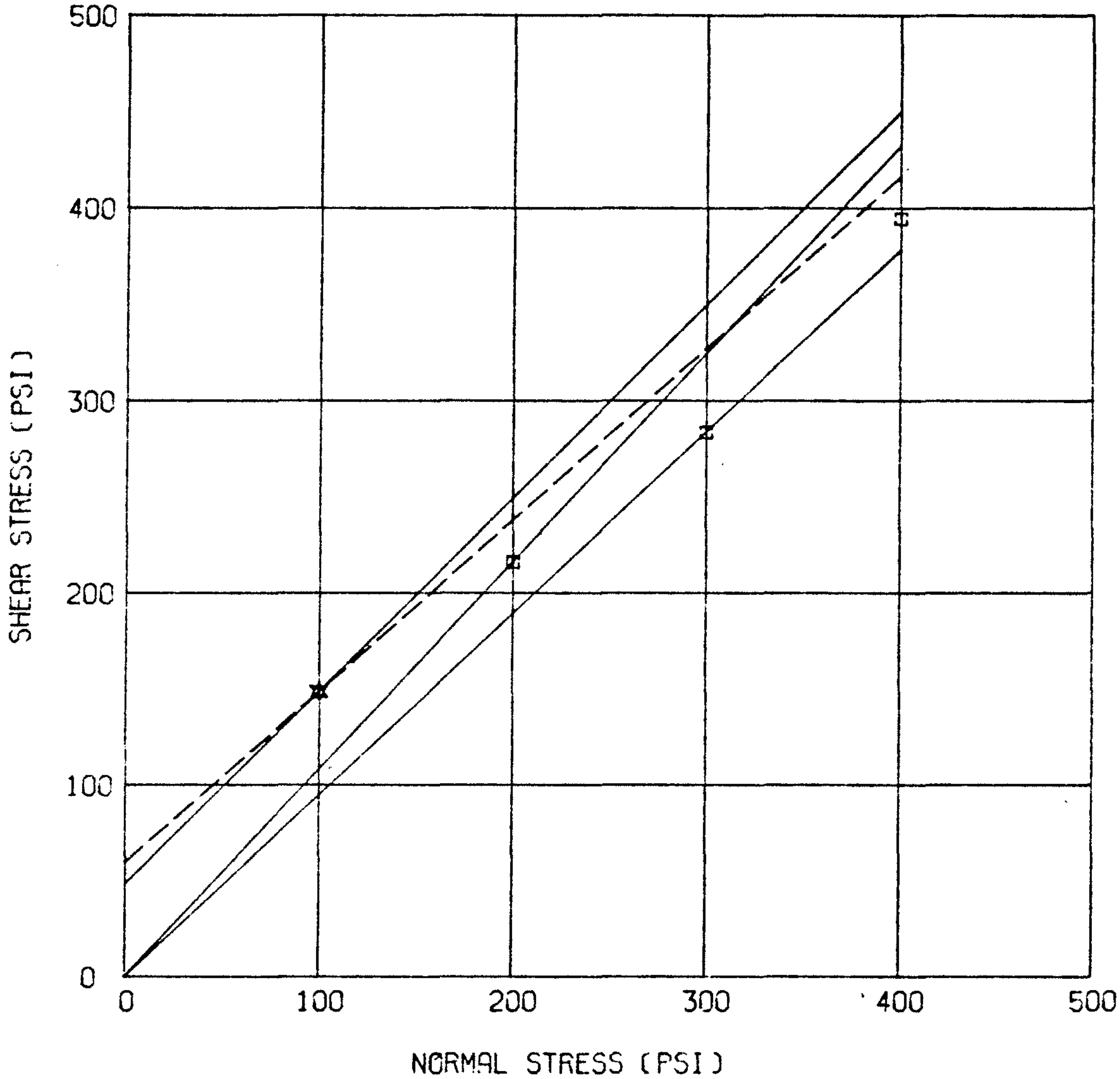
Run No.	N	S
1	100	149
2	200	216
3	300	284
4	400	395

Linear regression results:

S = 30.6 + 0.89189 (N)
Correlation = 0.9903
PHI = 41.7°
Cohesion = 59.5 lb/in^2

Angle envelope results:

PHI max. = 47.2° (1.08108)
PHI min. = 43.4° (0.94595)
PHI avg. = 45.1° (1.00450)
Cohesion (max. PHI) = 40.54 lb/in^2
Cohesion (min. PHI) = 54.05 lb/in^2
Cohesion (avg. PHI) = 48.20 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. 111A95.0

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. UJ2E - 18.0 ft
Area = 3.59 in^2

Run No.	N	S
1	100	187
2	200	240
3	300	295
4	400	370

Linear regression results:

S = 105.4 + 0.65460 (N)
Correlation = 0.9963
PHI = 33.2°
Cohesion = 121.2 lb/in^2

Angle envelope results:

PHI max. = 50.1° (1.19777)
PHI min. = 42.8° (0.92618)
PHI avg. = 46.0° (1.03606)
Cohesion (max. PHI) = 66.85 lb/in^2
Cohesion (min. PHI) = 94.01 lb/in^2
Cohesion (avg. PHI) = 83.02 lb/in^2

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. UJ2E - 19.0 ft
Area = 6.12 in^2

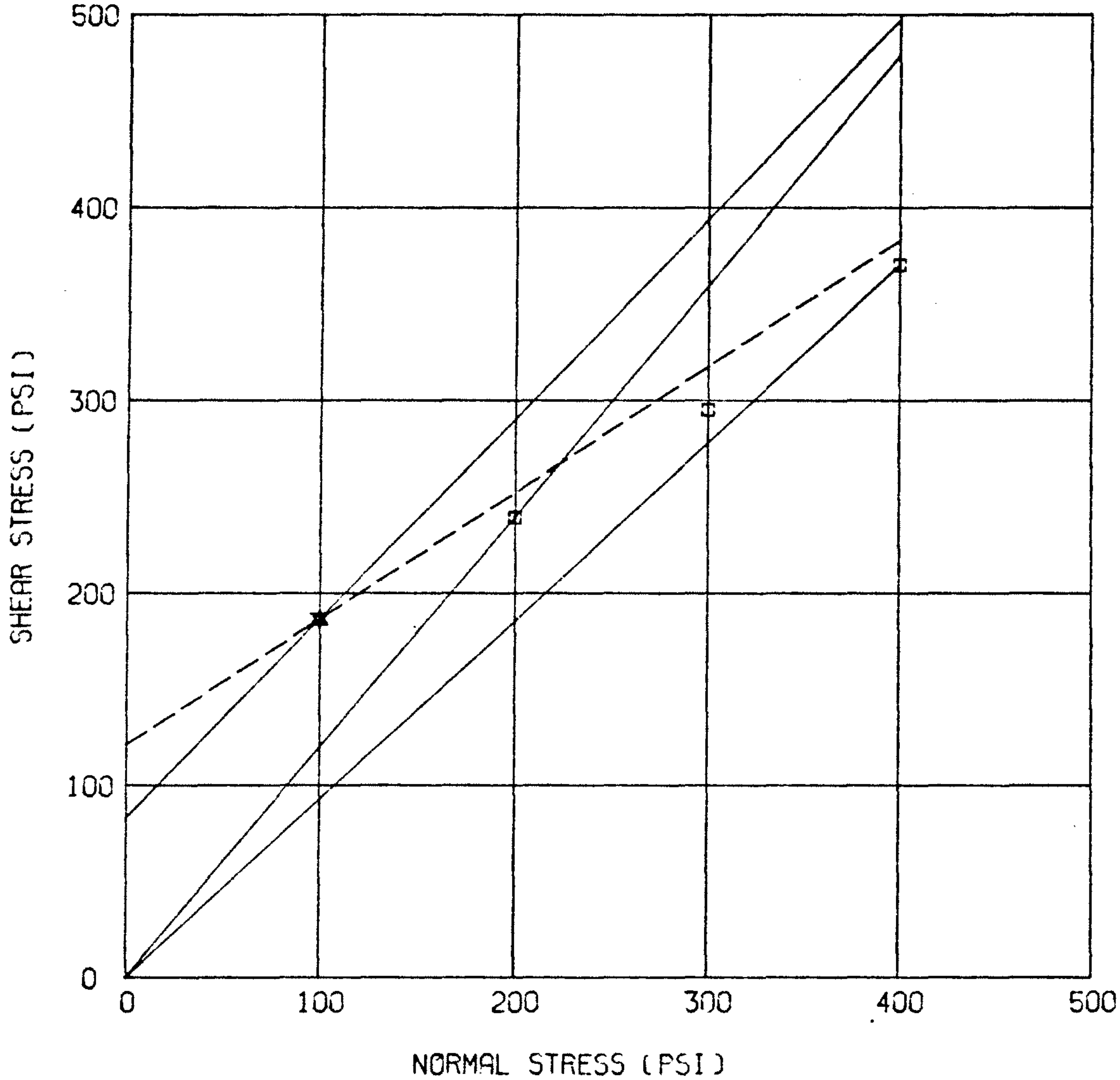
Run No.	N	S
1	100	93
2	200	167
3	300	243
4	400	304

Linear regression results:

S = 32.1 + 0.68627 (N)
Correlation = 0.9976
PHI = 34.5°
Cohesion = 24.5 lb/in^2

Angle envelope results:

PHI max. = 39.8° (0.83333)
PHI min. = 37.2° (0.75980)
PHI avg. = 38.7° (0.80156)
Cohesion (max. PHI) = 9.80 lb/in^2
Cohesion (min. PHI) = 17.16 lb/in^2
Cohesion (avg. PHI) = 12.98 lb/in^2



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. UJ2E18.0

✡ INITIAL TEST
— — — — — — LINEAR REGRESSION
———————— ANGLE-ENVELOPE

Shear Test Analysis
Angle envelope and linear regession results
Eisenhower Tunnel
Specimen No. UJ2E - 18.5 ft
Area = 3.85 in^2

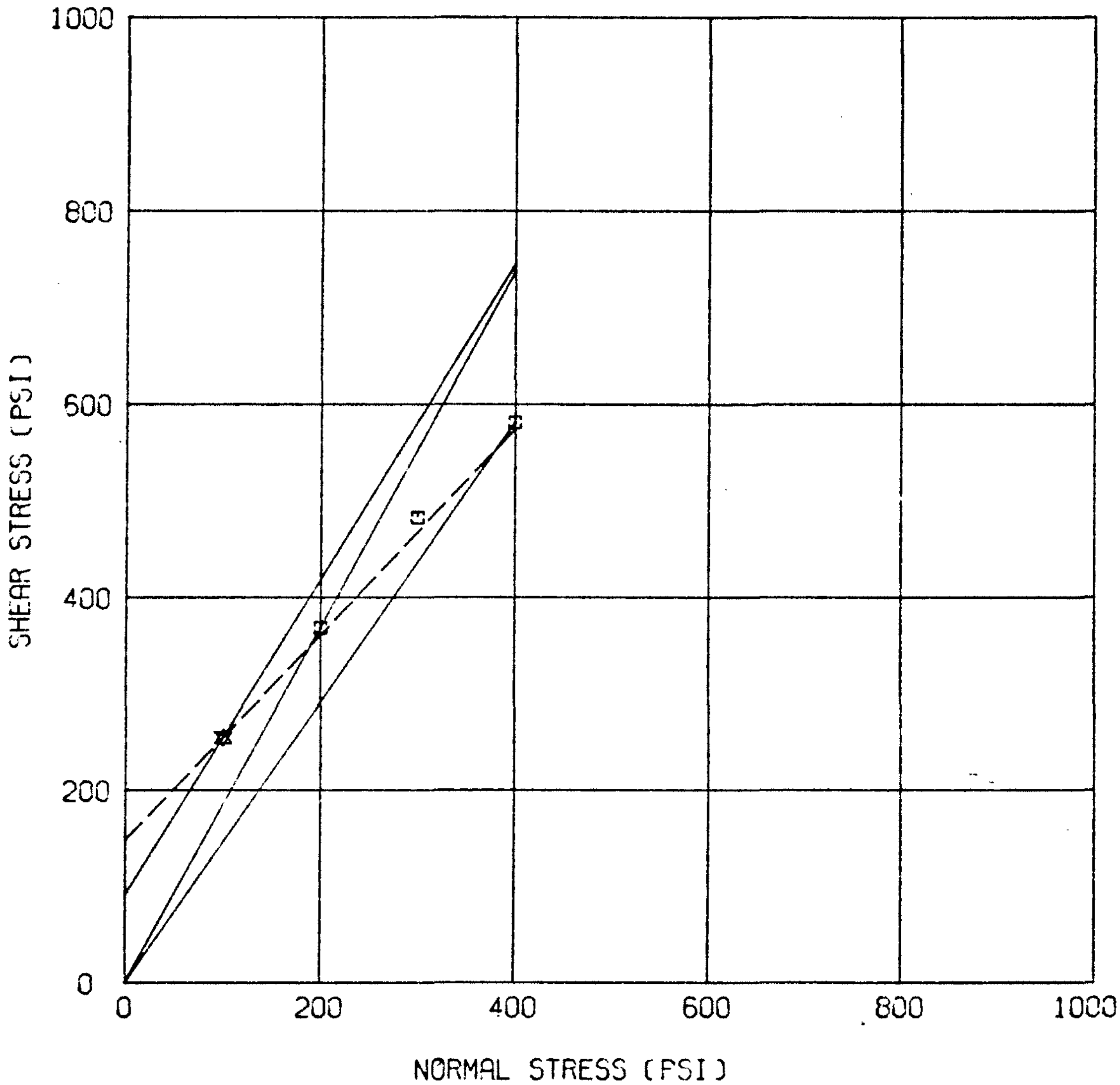
Run No.	N	S
1	100	255
2	200	369
3	300	483
4	400	582

Linear regression results:

S = 158.4 + 1.06494 (N)
Correlation = 0.9991
PHI = 46.8°
Cohesion = 148.1 lb/in^2

Angle envelope results:

PHI max. = 61.5° (1.84416)
PHI min. = 55.5° (1.45455)
PHI avg. = 58.6° (1.63636)
Cohesion (max. PHI) = 70.13 lb/in^2
Cohesion (min. PHI) = 109.09 lb/in^2
Cohesion (avg. PHI) = 90.91 lb/in^2



SHEAR TEST ANALYSIS

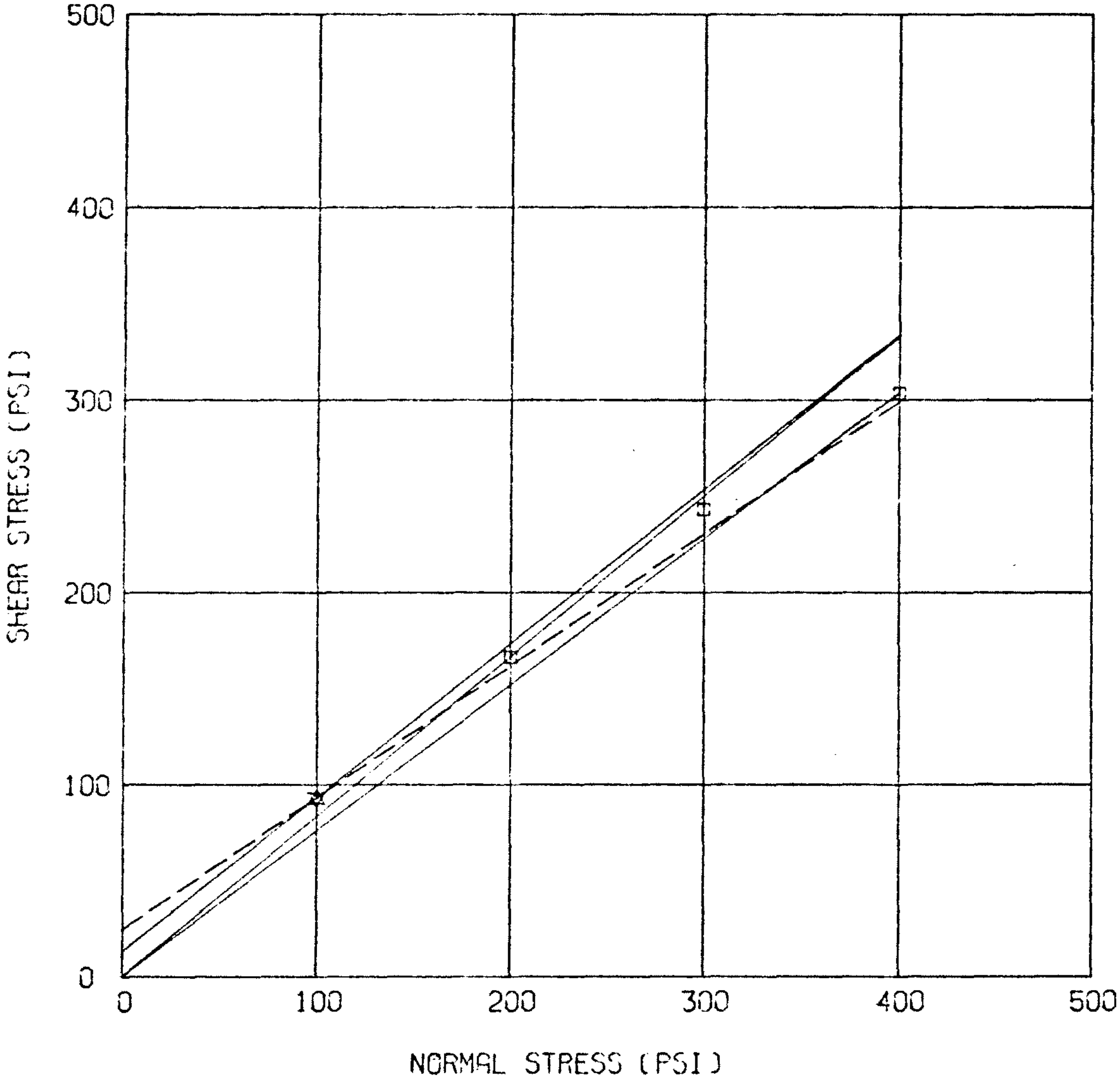
ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. UJ2E18.5

☆ INITIAL TEST

– – – – – – LINEAR REGRESSION

———— ANGLE-ENVELOPE



SHEAR TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

IKE TUNNEL SPECIMEN NO. UJ2E19.0

☆ INITIAL TEST

— — — — — — LINEAR REGRESSION

———————— ANGLE-ENVELOPE

APPENDIX D

PETROGRAHPIC DESCRIPTIONS

AND AFTERBREAK ANALYSIS

Petrographic Examination and Identification with Descriptions and Measurements of Afterbreak Specimens of Rock Core Tested for Unconfined Compressive Strength and Direct Shear Breakbond, and X-ray Diffraction Analyses of Rock Core Tested for Sliding Friction on Open Joints by the Rock Mechanics Section - South Bore - Eisenhower Tunnel, Colorado

Petrographic referral code: 79-17

INTRODUCTION

Eleven rock core were selected from drill holes UJ1W, UJ1E, 101A, 101V, 111A, and 111V, Eisenhower Tunnel, for thin section preparation and examination which were visually determined to be representative of four of the field rock types as shown in the Geologic Logs of Drill Holes, including biotite gneiss, biotite granite, granite, and granite gneiss. Thin sections were not prepared on the pegmatite or pegmatite granite because only a few crystals could be analyzed, due to the large grain size, and the rock types are quite diagnostic. Several thin sections of each of the biotite gneiss and granite gneiss were prepared and analyzed to show the variability of these rock types.

Petrographic descriptions and measurements were made on the unconfined compressive strength and direct shear breakbond specimens tested to failure as follows: Mode of failure; angles of foliation, fracturing, and jointing; and minerals associated with failure. The term "massive" denotes no structure was observed in the test specimen. The term "rock" denotes involving all the mineral assemblage for that particular rock type. The minerals associated with failure are listed in order of increasing percentages.

X-ray diffraction and microscopic analyses were performed on the open joints to identify those minerals associated with the sliding friction tests. The term "fresh rock" denotes the sliding friction tests were performed on previously produced mechanical breaks through intact rock and no joint minerals were present.

Attached are detailed hand specimen descriptions and thin section analyses of the four field rock types representative of the examined drill core. All thin sections were oriented normal, or near normal, to the observed structure or, if no structure was observed, normal to the long axis of the core. The afterbreak analyses are shown in tables D-1 and D-2 which include the drill hole, depth, field rock type, strength, mode of failure, angles of foliation, fracturing and jointing, and the material associated with failure. It should be noted that the field rock type and the description of the afterbreak analyses do not always indicate the same rock type. For example, the afterbreak analyses may show a granite to be foliated or a gneiss to be massive. This is due to local variations in structure and mineralogy within the metamorphic complex or facies, and does not indicate discrepancies in either the field rock type or afterbreak analyses. Table D-3 shows the miscroscopic and X-ray diffraction analyses of the open joint surfaces.

Table D-1. - Eisenhower Tunnel afterbreak analyses of unconfined compressive strength test specimens
Drill holes UJ1W, UJ1E, 101A, 101V, UJ2E, UJ2W, 111A, and 111V

Drill hole	Depth feet	Rock type field	Strength lb/in^2	Mode of failure	Angle of failed fractures and joints from core axis, degrees	Angle of foliation from core axis, degrees	Material associated with failure
UJ1W	1.7	Biotite gneiss	11,610	Failed generally along foliation	-	20	Rock-mica
	13.4	Biotite granite	20,890	Influenced somewhat by failure along joint and along gneiss-granite contact	55	Faint 5	Calcite-mica-rock
	22.0	Biotite granite	20,570	Influenced somewhat by failure along one continuous and two discontinuous joints	40-60-70	Massive	Calcite-rock
UJ1E	7.2	Granite	28,530	No apparent influencing factors	-	Massive	Rock
	20.9	Biotite gneiss	24,920	Influenced only slightly by partial failure along foliation and joints	60-65	45	Calcite-mica-rock
	24.7	Biotite gneiss	8,620	Failed chiefly along joints	20-30-35	Faint 10	Rock-calcite
101A	6.2	Biotite gneiss	29,600	Influenced only slightly by discontinuous joints	15-30	Faint 10	Calcite-rock
	7.7	Granite gneiss	7,110	Failed along foliation	-	35 to 45	Calcite-mica
	13.6	Granite gneiss	21,800	Influenced somewhat by partial failure along joints	35-35-45-50	Massive to 25	Calcite-rock
	18.3	Granite gneiss	6,910	Failed along joint	40	Massive	Calcite
	40.7	Granite gneiss	10,500	Failed chiefly along parallel joints and foliation	25-25	25	Rock-calcite-mica
	62.9	Biotite gneiss	11,500	No discernible influencing factors; appeared to fail along mica planes but no structure observed	-	Massive	Rock-mica
	70.6	Granite	6,370	No apparent influencing factors; joint did not appear to influence failure	5	Massive	Calcite-rock
	72.8	Granite	Specimen not tested for strength				
	76.3	Biotite gneiss	13,400	No apparent influencing factors	-	Faint 10	Mica-rock
	81.2	Biotite gneiss	10,700	No apparent influencing factors	-	Massive	Mica-rock
	87.6	Pegmatite	10,100	Failed along joint	15	Massive	Calcite-quartz
	97.4	Granite	9,100	Failed along hairline joint	10	Massive to 40	Rock-calcite
101V	6.4	Biotite gneiss	10,100	Failed chiefly along joint and somewhat along foliation	5	50	Mica-calcite
	8.8	Biotite gneiss	19,000	Influenced appreciably by joints	5-25-25	40	Calcite-rock
	18.6	Biotite gneiss	10,600	Failed along joint	15	35	Calcite
	47.0	Granite gneiss	17,300	Influenced somewhat by joints	40-40	Massive	Calcite-rock
	59.5	Granite gneiss	6,810	No apparent influencing factors	-	Faint 45 to massive	Rock
	61.1	Granite gneiss	-	Failed along joint	30	Faint 40	Calcite
	71.8	Granite gneiss	6,600	Failed chiefly along joints	15-20-40	50	Rock-chlorite(?)-clay(?)-calcite
	72.8	Granite gneiss	19,500	Influenced somewhat by failure along foliation and joint	25	35	Calcite-mica-rock
	93.1	Biotite gneiss	7,150	Failed along joint	20	Faint 15 to massive	Rock-calcite-clay

Table D-1. - Continued

Drill hole	Depth feet	Rock type field	Strength lb/in²	Mode of failure	Angle of failed fractures and joints from core axis, degrees	Angle of foliation from core axis, degrees	Material associated with failure
UJ2E	1.3	Biotite gneiss	22,500	No apparent influencing factors	-	25	Rock
	13.5	Biotite gneiss	23,850	No apparent influencing factors	-	15	Rock
	15.7	Pegmatite	15,450	Influenced somewhat by foliation	-	Massive to 35	Mica-rock
	17.5	Biotite gneiss	14,950	Influenced somewhat by foliation	-	Massive to 40	Mica-rock
UJ2W	3.2	Pegmatite	17,250	Influenced somewhat by foliation	-	Massive to 55	Mica-rock
	5.1	Granite gneiss	19,100	Influenced only slightly by joint	0	10	Iron oxide-calcite-rock
	12.5	Pegmatite	21,950	No apparent influencing factors	-	Massive to 10	Rock
	17.3	Biotite gneiss	23,650	No apparent influencing factors	-	15	Rock
111A	11.8	Biotite gneiss	25,100	No apparent influencing factors	-	85	Rock
	18.6	Granite gneiss	17,050	Influenced somewhat by failure along joint	20	Massive	Calcite-rock
	22.0	Granite gneiss	24,350	No apparent influencing factors	-	Faint 55	Rock
	37.2	Granite gneiss	14,900	No apparent influencing factors; failed almost through center of ends, parallel to the load, and about 15° from being normal to structure(?)	-	55	Rock
	56.4	Granite gneiss	21,700	Influenced by foliation	-	Variable 25 to 65	Rock-mica
	88.9	Granite gneiss	16,450	Failed along joints	15-35-35-40	Massive	Iron oxide-clay-calcite
	93.5	Granite gneiss	12,750	Failed along foliation	-	25	Mica
111V	9.8	Granite gneiss	10,250	Failed along joints	0-20-30	Faint 15	Calcite
	13.0	Granite gneiss	16,350	Influenced only slightly by joint	5	20	Calcite-rock
	16.7	Granite gneiss	19,700	No apparent influencing factors	-	15	Rock
	34.3	Pegmatite	13,150	Influenced by joints	30-30	Massive	Calcite-rock
	64.6	Biotite gneiss	17,300	Failed chiefly along joint	0	35 to 45	Rock-calcite
	80.4	Pegmatite	14,900	Influenced by joints	0-10	Massive	Calcite-rock

Table D-2. - Eisenhower Tunnel afterbreak analyses of direct shear breakbond test specimens
Drill holes 101V, 101A, 111A, 111V, and UJ2W

Drill hole	Depth feet	Rock type field	Linear regression Cohesion lb/in²	Linear regression Phi	Mode of failure	Material associated with failure
101V	6.0	Biotite gneiss	1,700	18	Failed generally across ostensibly nearly vertical structure	Mostly mica
	17.6	Biotite gneiss	1,290	66	Failed generally parallel to ostensibly nearly vertical structure, generally parallel to one joint at about 25° and across one joint at about 50° from the long axis of the core	Calcite-mostly mica
	92.5	Biotite gneiss	3,410	30	Failed generally across ostensibly nearly vertical structure	Mostly mica
101A	76.0	Biotite gneiss	3,010	29	Failed generally across ostensibly nearly vertical structure	Mostly mica
	98.4	Granite	1,500	39	Failed generally parallel to ostensibly nearly vertical structure	Quartz-feldspar-mica
111A	56.1	Granite gneiss	2,200	34	No apparent structure or joints	Mostly quartz
	61.0	Granite gneiss	2,000	45	No apparent structure or joints	Mostly mica
	64.8	Granite	1,800	46	No apparent structure or joints	Mica-quartz-feldspar
	92.6	Granite gneiss	2,160	50	Failed generally across ostensibly inclined vertical structure	Mostly mica
111V	23.5	Granite	2,930	42	No apparent structure or joints	Quartz-mica
	24.9	Granite	1,770	72	No apparent structure or joints	Mica-feldspar-quartz
	75.7	Granite gneiss	1,450	68	Failed across ostensibly inclined vertical structure	Feldspar-quartz-mica
UJ2W	12.8	Biotite gneiss	1,320	70	No apparent structure or joints	Quartz-feldspar-mica
	20.6	Biotite gneiss	1,520	66	Failed at angle of about 45° to ostensibly vertical structure	Quartz-feldspar-mica

Table D-3. - Eisenhower Tunnel
Microscope and X-ray diffraction analyses of open joint surfaces

Drill hole	Depth feet	Rock type field	Linear regression Cohesion lb/in^2	Linear regression Phi °	Major mineralogy	Minor mineralogy
101V	1.3	Biotite gneiss	38	31	Calcite-quartz*	Clay-iron oxide-feldspar*-mica*
	9.5	Biotite gneiss	9	28	Calcite-quartz*-feldspar*	Clay-iron oxide-mica*
	46.3	Granite gneiss	72	34	Calcite	Clay-iron oxide-quartz*-feldspar*
101A	42.8	Granite gneiss	-9	27	Calcite-quartz*	Clay-iron oxide-feldspar*
UJ1W	12.0	Biotite gneiss	27	20	Calcite-quartz*	Clay-iron oxide-feldspar* mica*
UJ1E	11.0	Granite	86	32	Calcite-quartz*-feldspar*	Clay-mica*
	18.0	Biotite gneiss	67	11	Calcite-clay-quartz*	Iron oxide-feldspar*
111A	16.6	Granite gneiss	160	45	Fresh rock**	
	69.7	Granite	34	33	Calcite	Clay-quartz*-feldspar*-mica*
	93.0	Granite gneiss	36	32	Iron oxide-quartz*-feldspar*	Calcite-clay-mica*
	93.2	Granite gneiss	60	42	Iron oxide-calcite*-quartz*	Clay-feldspar*-mica*
UJ2E	18.0	Biotite gneiss	120	33	Fresh rock**	
	18.5	Biotite gneiss	148	47	Fresh rock**	
	19.0	Biotite gneiss	25	35	Calcite-quartz*-feldspar*	Clay-iron oxide-mica*

* Host rock minerals and not joint filling material.
** Mechanical break through intact host rock - not an in situ joint.

PETROGRAPHIC EXAMINATION

Subject: Eisenhower Tunnel, South Bore, Colorado

Thin Section No. P-10,623

Field No. DH 101A, 6.2 ft

Hand specimen description: (Rock core diameter = 5.22 cm)

Streaked dark gray to black and white; finely crystalline; gneissic structure (25° from being parallel to long axis of core); one end piece exhibits a slickensided surface parallel to gneissosity; fairly hard; moderately dense; essentially nonporous and impermeable

Microscopic description:

Texture: Inequigranular and lamellar

Grain Size
Range: <0.01 mm to 2.2 mm
Mode: 0.5 mm

Structure: Gneissic to somewhat massive with a granitoid texture and well interlocked crystal grains

Mineralogy: (Percentages estimated from thin section)

40 to 45 percent feldspar - Chiefly albite with minor amounts of orthoclase, microcline, and oligoclase; colorless; transparent to translucent; essentially fresh and unaltered; a few crystal grains are incipiently altered; occurs randomly oriented as subhedral to chiefy anhedral crystal grains; grain size varies from about 0.01 mm to 2.2 mm in length and diameter with a mode of about 0.5 mm

30 percent quartz	- Colorless; transparent; randomly oriented anhedra; contains some dust-size mineral inclusions; some grains exhibit undulatory extinction under crossed nicols due to strain; grain size varies from about 0.01 mm to 2.2 mm in diameter with a mode of about 0.5 mm
20 to 25 percent boptote	- Light to dark brown; normal birefringence; strongly pleochroic; anhedral to euhedral, but chiefly subhedral; essentally fresh and unaltered; contains some minor inclusions of zircon, hematite, and dust-size magnetite; occurs randomly oriented to well alined parallel to gneissosity; grain or crystal sizes vary from about 0.01 mm to 1.0 mm in length and diameter with a mode of about 0.35 mm
5 percent minor and unidentifed	- Includes magnetite; zircon; apatite; pyrite; red iron oxide (hematite); calcite; some unidentified clays and clays-size minerals

Thin section orientation: Parallel to short axis of core (approximately normal to gneissosity)

Field classification: Biotite gneiss

Petrographic classification: Fine-grained, biotite-quartz-feldspar gneiss

PETROGRAPHIC EXAMINATION

Subject: Eisenhower Tunnel, South Bore, Colorado

Thin Section No. P-10,624

Field No. DH 101A, 7.7 ft

Hand specimen description: (Rock core diameter = 5.22 cm)

Streaked dark gray to black and white to light pink; fine to medium crystalline; gneissic structure (about 45° from being parallel to long axis of core); one end piece contains a few randomly oriented microfactures and one slickensided surface slightly coated with calcium carbonate (calcite); fairly hard; moderately dense; essentially nonporous and impermeable

Microscopic description:

Texture: Inequigranular and lamellar

Grain Size
Range: <0.01 mm to 3.0 mm
Mode: 0.7 mm

Structure: Gneissic to somewhat massive with a granitoid texture and well interlocked crystal grains

Mineralogy: (Percentages estimated from thin section)

40 to 45 percent feldspar - Chiefly microcline with minor amounts of orthoclase and albite; colorless; transparent to translucent; fresh to incipiently altered; randomly oriented subhedral to chiefly anhedral grains; a few grains contain microfractures filled to partially filled with kaolinite and some unidentified clay-size minerals; fresh and unaltered orthoclase; albite associated with quartz and feldspar as vermicular (myrmekite) intergrowths; grain or crystal sizes vary from about 0.05 mm to 3.0 mm in diameter

with a mode of about 0.7 mm; the rock core has a strong earthly odor when wetted with water indicating kaolinization of some of the feldspars

25 to 30 percent micas	- Chiefly biotite with about 2 to 3 percent muscovite; the biotite is light to dark brown, strongly pleochroic, has normal birefringence, and is essentially fresh and unaltered; the muscovite is colorless to pale green, nonpleochroic, has normal birefringence, and is essentially fresh and unaltered; the micas are chiefly anhedral, occur randomly oriented to well alined parallel to gneissosity, and vary from about 0.01 mm to 3.0 mm in length and diameter with a mode of about 1.0 mm
25 percent quartz	- Colorless; transparent to translucent; randomly oriented anhedra; contains some dust-size mineral inclusions; includes some myrmekitic and graphic intergrowths in the feldspars; some grains exhibit undulatory to flamboyant extinction under crossed nicols due to strain; some minor amounts of secondary quartz growths and exsolution cavities were observed along the boundary contacts with other minerals, especially feldspars and other quartz grains; grain sizes vary from about 0.01 mm to 2.5 mm in length and diameter with a mode of about 0.5 mm
5 percent minor and unidentifed	- Includes magnetite; pyrite; zircon; apatite; sillimanite; calcite; iron oxide (hematite); kaolinite; trace amounts of unidentified clays and clay-size minerals

Thin section orientation: Parallel to short axis of core and about 45° from being parallel to gneissosity

Field classification: Granite gneiss

Petrographic classification: Fine-grained, quartz-biotite-feldspar gneiss

PETROGRAPHIC EXAMINATION

Subject: Eisenhower Tunnel, South Bore, Colorado

Thin Section No. P-10,625

Field No. DH 101A, 76.3 ft

Hand specimen description: (Rock core diameter = 5.22 cm)

Dark gray to black with numerous, small white to light gray spots, splotches, and streaks; fine- to medium-grained; gneissic structures; no open joints or fractures observed; slight effervescence with cold dilute hydrochloric acid; fairly hard; moderately dense; essentially nonporous and impermeable

Microscopic description:

Texture: Inequigranular

Grain Size
Range: <0.01 mm to 2.0 mm
Mode: 0.75 mm

Structure: Gneissic to somewhat massive

Mineralogy: (Percentages estimated from thin section)

35 to 40 percent biotite - Light to dark brown; strongly pleochroic, normal birefringence; essentially fresh and unaltered; contains some dust-size mineral inclusions; chiefly anhedral to subhedral; occurs randomly oriented to fairly well alined parallel to gneissic structure; grain size varies from about 0.01 mm to 2.0 mm in length and diameter with a mode of about 0.75 mm

20 to 25 percent augite	- Colorless to very pale green; nonpleochroic; normal birefringence; essentially fresh and unaltered; anhedral to euhedral, but chiefly subhedral; occurs randomly oriented; grain size varies from about 0.02 mm to 0.75 mm in diameter with a mode of about 0.35 mm
15 to 20 percent quartz	- Colorless; some grains contain dust-size mineral inclusions; some grains exhibit undulatory and flamboyant extinction under crossed nicols due to strain; occurs as randomly oriented anhedra; grain size varies from about 0.01 mm to 1 mm in length and diameter with a mode of about 0.75 mm
15 to 20 percent feldspar	- Chiefly orthoclase with minor amounts of microcline and some unidentified plagioclase types; colorless; fresh to incipiently altered; contains a few microfractures filled to partially filled with kaolinite, calcite, and sericite; occurs as randomly oriented anhedra; grain size varies from about 0.05 mm to 1.5mm in length and diameter with a mode of about 0.5 mm
5 percent minor and unidentified	- Includes magnetite; pyrite; dust-size hematite; hornblende; sillimanite; zircon; apatite; calcite; muscovite; sericite; some unidentified clays and clay-size minerals

Thin section orientation: Parallel to short axis of core and about 5 to 10° from being normal to the gneissosity

Field classification: Biotite gneiss

Petrographic classification: Fine-grained, quartz-feldspar-augite-biotite gneiss

PETROGRAPHIC EXAMINATION

Subject: Eisenhower Tunnel, South Bore, Colorado

Thin Section No. P-10,626

Field No. DH 101A, 81.2 ft

Hand specimen description: (Rock core diameter = 5.22 cm)

Dark gray to black with numerous, small white to light gray spots, splotches, and streaks; fine-grained to aphanitics; gneissic structure; few thin calcite-filled microfractures; fairly hard; moderately dense; impervious

Microscopic description:

Texture: Inequigranular

Grain Size
Range: <0.01 mm to 3.2 mm
Mode: 0.75 mm

Structure: Gneissic to somewhat massive

Mineralogy: (Percentages estimated from thin section)

35 to 40 percent biotite - Light to dark brown; strongly pleochroic, normal birefringence; essentially fresh and unaltered; contains some dust-size mineral inclusions; chiefly anhedral to subhedral crystal fragments; occurs randomly oriented to fairly well alined parallel to gneissosity in some areas; grain or crystal sizes vary from about 0.01 mm to 3.0 mm in length and diameter with a mode of about 0.75 mm

10 to 15 percent hornblende	- Pale to dark green; moderately to strongly pleochroic; randomly oriented, poorly terminated anhedra; essentially fresh and unaltered; grain size varies from about 0.01 mm to 3.2 mm in length with a mode of about 0.5 mm
10 percent augite	- Colorless to pale green with a few pale brown grains; nonpleochroic, essentially fresh, a few grains exhibit some incipient alteration; randomly oriented, more or less, equidimensional anhedral to euhedral crystals; grain size varies from about 0.05 mm to 1 mm in diameter with a mode of about 0.35 mm
15 to 20 percent feldspar	- Chiefly orthoclase, but does not contain some unidentified albite twinned plagioclase types; colorless to white; transparent to translucent; fresh to incipiently to moderaly altered; contains some inclusions and intergrowths of quartz (graphic and myrmekitic); occurs randomly oriented in chiefly anhedral grains; grain size varies from about 0.01 mm to 1.0 mm in length and diameter with a mode of about 0.5 mm
15 to 20 percent quartz	- Colorless; anhedral; randomly oriented; contains some minute mineral inclusions; many grains exhibit undulatory extinction under crossed nicols due to strain; intergrown in part with the alkali and plagioclase feldspars; grain size varies from about 0.01 mm to 1.5 mm in diameter with a mode of about 0.5 mm
5 percent minor and unidentified	- Includes magnetite; pyrite; iron oxide (hematite); apatite; zircon; calcite; muscovite; sericite; kaolinite; some unidentified clays and clay-size minerals

P-10,626

Thin section orientation: Parallel to short axis of core and about 5 to 10° from being normal to gneissosity

Field classification: Biotite gneiss

Petrographic classification: Fine-grained, augite-hornblende-quartz-feldspar-biotite gneiss

PETROGRAPHIC EXAMINATION

Subject: Eisenhower Tunnel, South Bore, Colorado

Thin Section No. P-10,627

Field No. DH 101A, 97.4 ft

Hand specimen description: (Rock core diameter = 5.22 cm)

Mottled pink, gray, and black with a few thin black streak; medium- to coarse-grained; massive structure with a few gneissic streaks; few tight microfractures filled in part with calcite and chlorite; hard; dense; impervious

Microscopic description:

Texture: Inequigranular (granitic)

Grain Size
Range: <0.01 mm to 1.5 cm
Mode: 3 mm

Structure: Massive; contains a few discontinuous gneissic streaks of biotite; well interlocked grains; contains a few discontinuous microfractures

Mineralogy: (Percentages estimated from thin section)

60 to 65 percent feldspars - Chiefly microcline with minor amounts of orthoclase and albite; the microcline is pink and the albite and some minor amounts of the orthoclase are clear and colorless; the crystal grains vary from clear and colorless to cloudy and somewhat translucent; essentially fresh and unaltered, but a few grains are incipiently altered and some contain microfractures; some of the larger crystals contain smaller inclusions of the same and/or different feldspar types; minor amounts of quartz intergrowths are present, especially near their edge

contacts; anhedral to subhedral; randomly oriented crystal grains; grain sizes vary from about 0.1 mm to 1.5 cm in length and diameter with a mode of about 3 mm

20 to 25 percent quartz	- Colorless; randomly orented anhedral grains; some dust-size mineral inclusions; many grains exhibit undulatory extinction under crossed nicols due to strain; many grains contain highly sutured edges and some areas, especially the finer grained sizes, impart a coarsely mosaic texture; some graphic and vermicular (myrmekitic) intergrowths with the feldspars; grain sizes vary from about 0.05 mm to 4 mm in diameter with a mode of about 1 mm
10 percent biotite	- Light to dark brown; strongly pleochroic; normal birefringence, however, a few grains exhibit some anomalous "berlin-blue" birefringence due to slight alteration to a light greenish colored biotite and/or formation of chlorite and chloritic minerals; many grains contain minute inclusions of hematite, magnetite, pyrite, zircons, and some unidentified dust to caly-size minerals; some grains are composed of booklets that exhibit bending or flexuring to "kink-banding" in some grains; occurs chiefly as randomly oriented monomineralic anhedra; in some areas of the hand specimen, the biotite is segregated into fairly well alined streaks and thin layers that imparts a gneissic structure to the rock; grain size varies from about 0.01 mm to 2.0 mm in length and diameter with a mode of about 0.75 mm

5 percent minor and unidentified	- Includes magnetite; pyrite; hematitic iron oxide; apatite; zircon; kaolinite; muscovite; sericite; calcite; chlorite; trace amounts of unidentified clays and clay-size minerals

Thin section orientation: Normal to long axis of core

Field classification: Granite

Petrographic classification: Medium-grained granite

PETROGRAPHIC EXAMINATION

Subject: Eisenhower Tunnel, South Bore, Colorado

Thin Section No. P-10,628

Field No. DH 101V, 6.4 ft

Hand specimen description: (Rock core diameter = 5.22 cm)

Streaked dark gray to black and white; fine to medium grained; gneissic structure about 45° from being normal to long axis of core; no fractures or joints observed; very slightly effervescent in cold dilute hydrochloric acid; moderately hard; fairly dense; very slightly water absorptive, especially along some of the micaeous, gneissic planes

Microscopic description:

Texture: Inequigranular to fibro-lamellar

Grain Size
Range: <0.01 mm to 3.0 mm
Mode: 0.75 mm

Structure: Gneissic

Mineralogy: (Percentages estimated from thin section)

30 to 35 percent biotite - Light to dark brown; strongly pleochroic; normal birefringence; contains some dust-size mineral inclusions; some contorted and bent grains; occurs randomly oriented to well alined parallel to gneissosity; anhedral to subhedral crystal grains; grain size varies from about 0.05 mm to 2.0 mm is length and diameter with a mode of about 0.75 mm

30 to 35 percent feldspar	- Chiefly microcline with lesser amounts of orthoclase and minor amounts of albite; clear and colorless to cloudy, translucent, and white to pale green colored; fresh to incipiently to moderately weathered in some areas; some grains contain microfractures filled, in part, with kaolinite, calcite, sericite, and some unidentified clay-size minerals; occurs randomly oriented in anhedral grains; grain size varies from about 0.05 mm to 3.0 mm in length and diameter with a mode of about 0.75 mm
25 percent quartz	- Colorless; randomly oriented anhedra; many grains exhibit undulatory to flamboyant extinction under crossed nicols due to strain; many grains exhibit very irregular scalloped to sutured edges; some grains contain minute mineral inclusions; some grains are intergrown, in part, with the feldspars producing graphic and myrmekitic-type microstructures; grain sizes vary from less than 0.01 mm to 2.0 mm in diameter with a mode of about 0.75 mm
5 percent sillimanite	- Colorless; nonpleochroic; subhedral to euhedral; fibrous to elongate needle-shaped crystals; occurs in "bundle-like" aggregate structure closely associated with the biotite and alined more or less parallel to the gneissosity; grain or crystal size varies from less than 0.01 mm in diameter to 1.5 mm in length with a modal length of about 1 mm
5 percent minor and unidentified	- Includes magnetite; pyrite; red hematitic iron oxide; calcite; kaolinite; muscovite; sericite; zircon; apatite; some unidentified clays and clay-size minerals

Thin section orientation: Normal to gneissosity

Field classification: Biotite gneiss

Petrographic classification: Fine-grained, quartz-feldspar-biotite gneiss

PETROGRAPHIC EXAMINATION

Subject: Eisenhower Tunnel, South Bore, Colorado

Thin Section No. P-10,629

Field No. DH 101V, 18.6 ft

Hand specimen description: (Rock core diameter = 5.22 cm)

Finely streaked dark gray to black and white; fine to very finely crystalline; gneissic structure oriented about 25° to 45° from being parallel to short axis of core; few randomly oriented, tight, hairline fractures filled, in part, with secondary calcite, rust-brown iron oxide, kaolinite, and some unidentified clay-size minerals; strong earthy odor when wetted with water; fairly dense; moderately hard; impervious

Microscopic description:

Texture: Inequigranular

Grain Size
Range: <0.01 mm to 1.5 mm
Mode: 0.5 mm

Structure: Gneissic

Mineralogy: (Percentages estimated from thin section)

40 percent quartz - Colorless; randomly oriented anhedra; most grains exhibit undulatory extinction under crossed nicols due to strain; some grains contain minute mineral inclusions; many grains contain highly sutured and scalloped edges; minor amounts of graphic and myrmekitic intergrowths with the feldspar grains; grain size varies from about 0.01 mm to 1.5 mm in diameter and length with a mode of about 0.5 mm

40 percent feldspar	- About 20 percent microcline, 10 percent orthoclase, and 10 percent albite - twinned plagioclase types (probably albite-oligoclase); colorless, clear to light pink and transparent to translucent white to very pale green; the microcline is essentially fresh and unaltered; some of the orthoclase and plagioclase types are moderately to highly altered to a white to greasy greenish clay; occur randomly oriented in anhedral grains; grain or crystal size varies from about 0.05 mm to 1.5 mm in length and diameter with a mode of about 0.5 mm
15 percent biotite	- Light to dark brown; strongly pleochroic; normal birefringence; essentially fresh and unaltered; contains some rust-brown to red hematitic iron oxide and zircon crystal inclusions; some grains are associated with magnetite and muscovite; subhedral to chiefly anhedral grains; occurs randomly oriented to well alined parallel to gneissosity; grain size varies from about 0.01 mm to 1 mm in length and diameter with a mode of about 0.35 mm
5 percent minor and unidentified	- Includes magnetite; red to rust-brown hematitic iron oxide; pyrite; calcite; kaolinite; zircon; apatite; muscovite; sericite; some unidentified clays and clay-size minerals

Thin section orientation: Normal to gneissosity

Field Classification: Biotite gneiss

Petrographic classification: Fine-grained, biotite-quartz-feldspar gneiss

PETROGRAPHIC EXAMINATION

Subject: Eisenhower Tunnel, South Bore, Colorado

Thin Section No. P-10,630

Field No. DH 111A, 22.0 ft

Hand specimen description: (Rock core diameter = 5.22 cm)

Finely mottled dark gray to black and white with a few white to light pink spots and splotches; fine to medium crystalline; massive structure; no joints or fractures observed; fairly hard; moderately dense; impervious

Microscopic description:

Texture: Inequigranular (finely granitic)

Grain Size
Range: <0.01 mm to 3.5 mm
Mode: 1 mm

Structure: Massive (no structure observed)

Mineralogy: (Percentages estimated from thin section)

35 to 40 percent feldspar - About equal amounts of orthoclase and albite with only minor amounts of microcline; clear to pink to white; transparent to translucent; fresh to incipiently altered; randomly oriented anhedral to subhedral crystal grains; crystal sizes vary from about 0.05 mm to 3.5 mm in length and diameter with a mode of about 1 mm

30 to 35 percent biotite - Light to dark brown; strongly pleochroic; essentially fresh and unaltered; a few grains exhibit minor alteration to a green color exhibiting some anomalous "berlin-blue" birefringence under cross nicols [chlorite (?)]; contains some red to rust-brown hematitic iron oxide and zircon crystal

inclusions; closely associated with irregular grains of pyrite, magnetite, and muscovite; occurs as randomly oriented anhedral to subhedral grains; grain size varies from about 0.05 mm to 2.0 mm in length and diameter with a mode of about 0.75 mm

25 percent quartz - Colorless; randomly oriented anhedra; most grains exhibit undulatory extinction under crossed nicols due to strain; many grains contain dust-size mineral inclusions; most grains contain very irregular sutured and scalloped edges and, when closely packed, reveal a coarse mosaic texture; some small amounts of intergrowths (graphic and myrmekitic) with the feldspar grains; grain size varies from about 0.01 mm to 2.0 mm in diameter with a mode of about 1 mm

5 percent minor and unidentified - Includes magnetite; red to rust-brown hematitic iron oxide; pyrite; zircon; apatite; muscovite; sericite; chlorite(?); kaolinite; some unidentified clays and clay-size minerals

Thin section orientation: About 25° from being parallel to the long axis of the core

Field classification: Granite gneiss

Petrographic classification: Fine- to medium-grained, quartz-biotite-feldspar granite

PETROGRAPHIC EXAMINATION

Subject: Eisenhower Tunnel, South Bore, Colorado

Thin Section No. P-10,631

Field No. DH 111V, 13.0 ft

Hand specimen description: (Rock core diameter = 5.22 cm)

Dark gray to black with numerous white to light gray spots, splotches, and streaks; finely crystalline; gneissic structure; one tight fracture filled with calcite, kaolinite, rust-brown iron oxide, and some unidentified clay-size minerals; fairly hard; moderately dense; impervious

Microscopic description:

Texture: Inequigranular

Grain Size
Range: <0.01 mm to 2.0 mm
Mode: 0.35 mm

Structure: Gneissic

Mineralogy: (Percentages estimated from thin section)

30 to 35 percent feldspar - About equal amounts of orthoclase and microcline with minor amounts of albite; colorless to white; clear to translucent; fresh to incipiently altered; randomly oriented anhedral to subhedral crystal grains; grain size varies from about 0.05 mm to 1.5 mm in length and diameter with a mode of about 0.35 mm

30 percent quartz - Colorless; randomly oriented anhedra; most grains exhibit undulatory extinction under crossed nicols due to strain; some grains contain dust-size mineral inclusions; many grains exhibit highly

sutured and scalloped edges; minor amounts of graphic and myrmekitic intergrowths with the feldspar; grain size varies from about 0.01 mm to 2.0 mm in length and diameter with a mode of about 0.35 mm

25 to 30 percent biotite	- Light to dark brown; strongly pleochroic; normal birefringence; essentially fresh and unaltered; contains some rust-brown to red hematitic iron oxide and zircon crystal inclusions; subhedral to chiefly anhedral crystal grains; occurs randomly to fairly well alined parallel to gneissosity in some areas; grain size varies from about 0.01 mm to 2.0 mm in length and diameter with a mode of about 0.35 mm
5 percent sillimanite	- Colorless; nonpleochroic; subhedral to euhedral; fibrous to elongate needle-shaped crystals; occurs in bundles or "sheaf-like" masses closely associated with the biotite and alined more or less parallel to the gneissosity; grain or crystal sizes vary from less than 0.01 mm to 1.5 mm in length with a mode of about 0.5 mm
5 percent minor and unidentified	- Includes magnetite; pyrite; red to rust-brown hematitic iron oxides; zircon; apatite; kaolinite; muscovite; sericite; some unidentified clays and clay-size minerals

Thin section orientation: Normal to gneissosity and about 30° from being parallel to short axis of core

Field classification: Granite gneiss

Petrographic classification: Fine-grained, biotite-quartz-feldspar gneiss

PETROGRAPHIC EXAMINATION

Subject: Eisenhower Tunnel, South Bore, Colorado

Thin Section No. P-10,632

Field No. DH UJ1E, 20.9 ft

Hand specimen description: (Rock core diameter = 5.22 cm)

Dark gray to black with numerous white to gray to pink spots, splotches, and streaks; fine to medium crystalline; gneissic structure; few calcite-filled microfractures; fairly hard; moderately dense; essentially nonporous and impermeable

Microscopic description:

Texture: Inequigranular

Grain Size
Range: <0.01 mm to 3.7 mm
Mode: 1.0 mm

Structure: Gneissic to somewhat massive

Mineralogy: (Percentages estimated from thin section)

35 percent feldspar - Chiefly orthoclase and microcline with about 10 percent plagioclase types (albite, oligoclase); colorless to white; transparent to translucent; fresh to incipiently to moderately altered; chiefly anhedral to subhedral; randomly oriented; grain size varies from about 0.05 mm to 3.7 mm in length and diameter with a mode of about 1.0 mm

30 to 35 percent biotite - Light to dark brown; strongly pleochroic, normal birefringence; essentially fresh and unaltered; some grains contain mineral inclusions of magnetite, red to rust-brown iron oxides, and zircon crystals; chiefly anhedral grains; occurs randomly

oriented to fairly well alined parallel to gneissosity in some areas; grain size varies from about 0.05 mm to 2.0 mm in length and diameter with a mode of about 1.0 m

25 to 30 percent quartz - Colorless; randomly oriented anhedra; many grains exhibit undulatory extinction under crossed nicols due to strain; most grains contain highly scalloped and sutured edges; aggregates of finer sized materials exhibit a mosaic texture; some grains contain minute mineral inclusions; some graphic and myrmektic intergrowths with the feldspars; grain sizes vary from less than 0.01 mm to 3.0 mm in length and diameter with a mode of about 1.0 mm

5 percent minor and unidentified - Includes magnetite; red to rust-brown hematitic iron oxides; pyrite; zircon; apatite; muscovite; sericite; kaolinite; calcite; sillimanite; some unidentified clays and clay-size minerals

Thin section orientation: Normal to gneissosity and about 30° from being parallel to long axis of core

Field classification: Biotite gneiss

Petrographic classification: Fine- to medium-grained, quartz-biotite-feldspar gneiss

PETROGRAPHIC EXAMINATION

Subject: Eisenhower Tunnel, South Bore, Colorado

Thin Section No. P-10,633

Field No. DH UJ1W, 22.0 ft

Hand specimen description: (Rock core diameter = 5.22 cm)

Finely mottled black, gray, white, and pink with a few black streaks; fine to medium crystalline; massive structure with a few gneissic streaks; one fracture observed to be partially coated with kaolinite, calcite, chlorite, and trace amounts of rust-brown iron oxide; hard; fairly dense; essentially nonporous and impermeable

Microscopic description:

Texture: Inequigranular

Grain Size
Range: <0.01 mm to 6.0 mm
Mode: 1.5 mm

Structure: Massive with a few discontinuous gneissic streaks

Mineralogy: (Percentages estimated from thin section)

40 to 45 percent feldspar - Chiefly microcline with lesser amounts of orthoclase and some unidentified albite twinned plagioclases; colorless to pink to white; transparent to translucent; fresh to incipiently altered; randomly oriented anhedral to subhedral crystal grains; grain size varies from about 0.05 mm to 6.0 mm in length and diameter with a mode of about 1.5 mm

25 to 30 percent quartz - Colorless; randomly oriented anhedra grains; many grains exhibit undulatory extinction under cross nicols due to strain; most grains exhibit highly

sutured and scalloped edges; some grains contain minute mineral inclusions; some graphic and myrmekitic intergrowths with the feldspars were oberved; grain sizes vary from about 0.05 mm to 3.0 mm in length and diameter with a mode of about 1.5 mm

25 percent biotite - Light to dark brown; strongly pleochroic; normal birefringence; essentially fresh and unaltered; contains some minute mineral inclusions of magnetite, zircon, and red to rust-brown iron oxides; anhedral to subhedral; occurs chiefly randomly oriented, but also occurs in minor amounts fairly well alined parallel to some of the gneissic streaks; grain size varies from about 0.05 mm to 1.5 mm in length and diameter with a mode of about 0.75 mm

5 percent minor and unidentified - Includes dust-size magnetite; pyrite; red to rust-brown hematitic iron oxides; kaolinite; muscovite; sericite; calcite; zircon; apatite; chlorite; some unidentified clays and clay-size minerals

Thin section orientation: Normal to gneissic streaks and about 45° from being parallel to long axis of core

Field Classification: Biotite granite

Petrographic classification: Medium-grained, gneissic, biotite-quartz-feldspar granite