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DEPARTMENT OF THE INTERIOR
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DETERMINATION OF IN SITU STRESS IN U12g TUNNEL, RAINIER MESA, NEVADA TEST SITE, NEVADA

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DETERMINATION OF IN SITU STRESS IN U12g TUNNEL, RAINIER MESA, NEVADA TEST SITE, NEVADA

By

W. L. Ellis and J. R. Ege

ABSTRACT

Stress relief borehole-deformation measurements using the U.S. Bureau of Mines overcore technique were made at a depth of 442 m below Rainier Mesa, Nevada Test Site. The measurements, made in three noncoplaner boreholes drilled in low-modulus, low-density, volcanic rocks, were used to calculate the three-dimensional stress field. All stresses were found to be compressive. The calculated vertical stress component of 67 bars is consistent with the estimated vertical stress attributed to overburden. The maximum principal stress (85 bars) trends N. 21° E. and the minimum principal stress (26 bars) trends N. 68° W.; both are nearly horizontal. Synthesis of geologic and geophysical data by other workers indicates a similar orientation of the maximum and minimum horizontal stresses on a regional scale.

INTRODUCTION

The USGS (U.S. Geological Survey) in cooperation with DNA (Defense Nuclear Agency) and Sandia Laboratories, is currently conducting a program of determination and analysis of in situ stress in Rainier Mesa, NTS (Nevada Test Site). Information obtained from the program is used in containment evaluation for underground nuclear explosions and in the design and engineering of underground excavations at NTS. It is anticipated that this program will also lead to a better understanding of stress in Rainier Mesa and its relation to the geologic environment.

This report presents results of a stress determination made in the U12g tunnel main drift bypass under Rainier Mesa (fig. 1), using the USBM (U.S. Bureau of Mines) overcore method.

Stress relief borehole-deformation measurements in three noncoplaner boreholes were taken at depths greater than one tunnel diameter into rock surrounding the tunnel. Calculated stress should, therefore, be representative of the stress field, which is defined as the preexisting, or medium stress, present in the rock before mining (Obert and Duvall, 1967).

Appreciation is expressed to W. C. Vollendorf of Sandia Laboratories for his support and assistance in this investigation. V. E. Hooker, J. R. Aggson, and D. L. Bickel of the USBM are acknowledged for their cooperation in providing valuable technical assistance and advice to the USGS concerning overcoring stress determinations.

INSTRUMENTATION AND METHOD

The stress relief borehole-deformation measurements were made with a USBM three-component borehole-deformation gage (Merrill, 1967) following procedures developed by the USBM (Hooker and Bickel, 1974). The gage measures the diametral deformation across three diameters of a 3.8-cm- (1.5-in.-) diameter pilot hole as it is being overcored (stress relieved) by means of a 15.2-cm- (6-in.-) diameter core barrel. Each of the three diametral components of the gage is monitored continuously during overcoring so that a complete record of stress relief can be obtained--a necessary requirement for proper interpretation of the borehole-deformation data.

To determine the state of stress by the borehole-deformation method it is necessary to obtain measurements from at

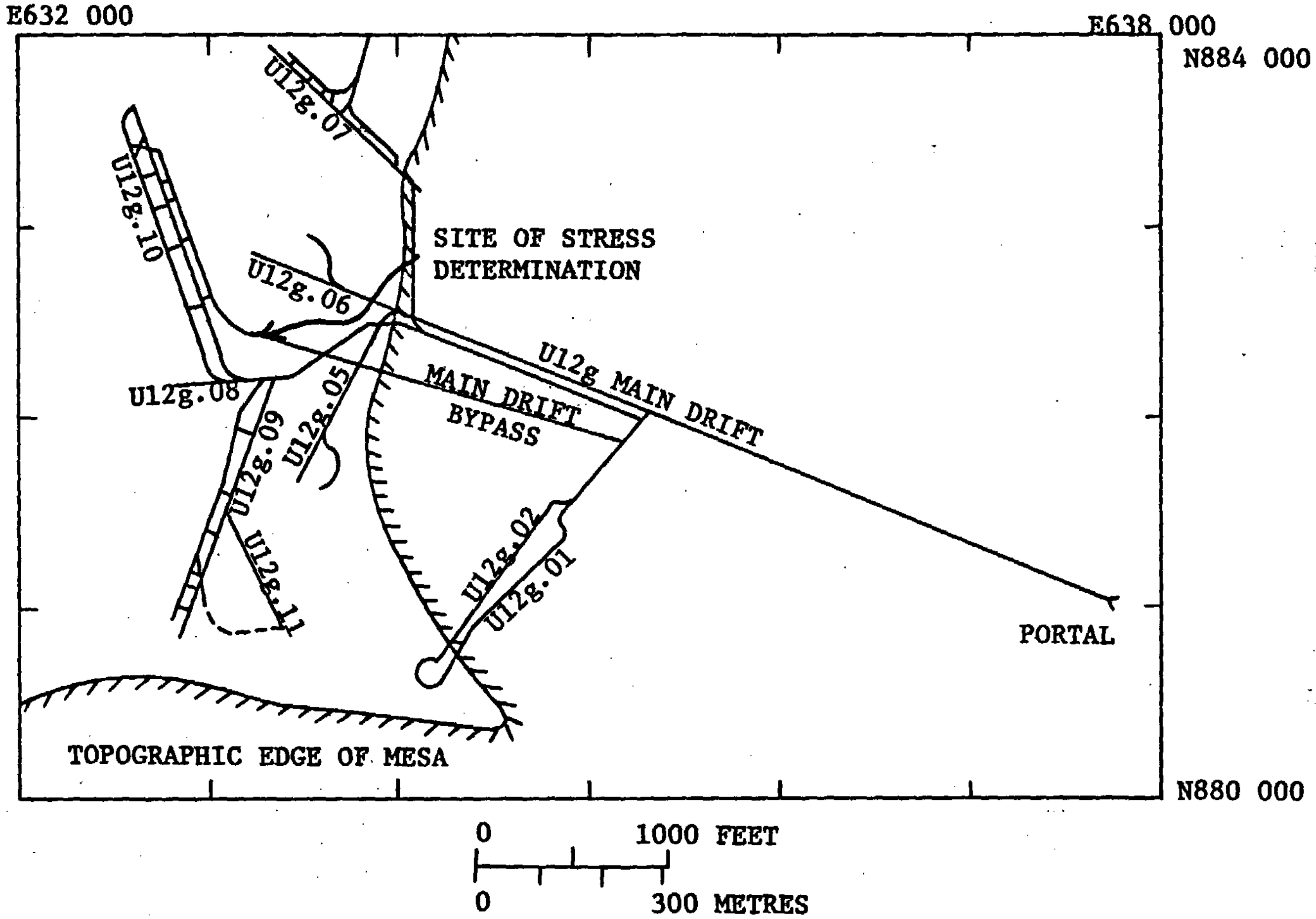

Figure 1.--Map of part of Rainier Mesa showing U12g tunnel complex and site of stress determination.

least three noncoplaner boreholes. The three boreholes used in this report (OCH #2, OCH #4, and OCH #5) and their configurations are shown on figure 2.

GEOLOGY AND ROCK PHYSICAL PROPERTIES

Rainier Mesa is composed of horizontal to gently dipping ash flows and beds of ash-fall and reworked ash-fall tuff and tuffaceous sandstones. The stratigraphic unit in which this stress determination was made is tunnel bed subunit 4K of Tertiary age (J. R. Ege and W. H. Lee, written commun., 1971). Figure 3 is a tunnel-level map showing the geology around the measurement site.

The ash-fall tuff at the measurement site is a very low strength, average modulus ratio rock. Deere and Miller (1966) define very low strength as uniaxial compressive strength less than 280 bars (4,000 psi), and average modulus ratio, which ranges between 200 and 500, as the quotient of the tangent modulus at 50 percent ultimate strength divided by uniaxial compressive strength.

The borehole-deformation measurements from OCH #2 and OCH #4 were made in reddish-brown tuff that contains white pumice fragments ranging from a few millimetres to about 2.5 cm in diameter. These fragments are relatively small compared to the 15-cm-diameter overcores and should not have had an effect on the borehole-deformation measurements. In OCH #5 the borehole-deformation measurements were made in a well-cemented fine- to medium-grained reddish-brown tuffaceous sandstone that occurs near the top of the 4K subunit.

No major faults occur in the vicinity of the stress determination site, and no faults or fractures were encountered in the overcore drilling. Apparently no physical or structural geologic conditions were present at the site that could cause

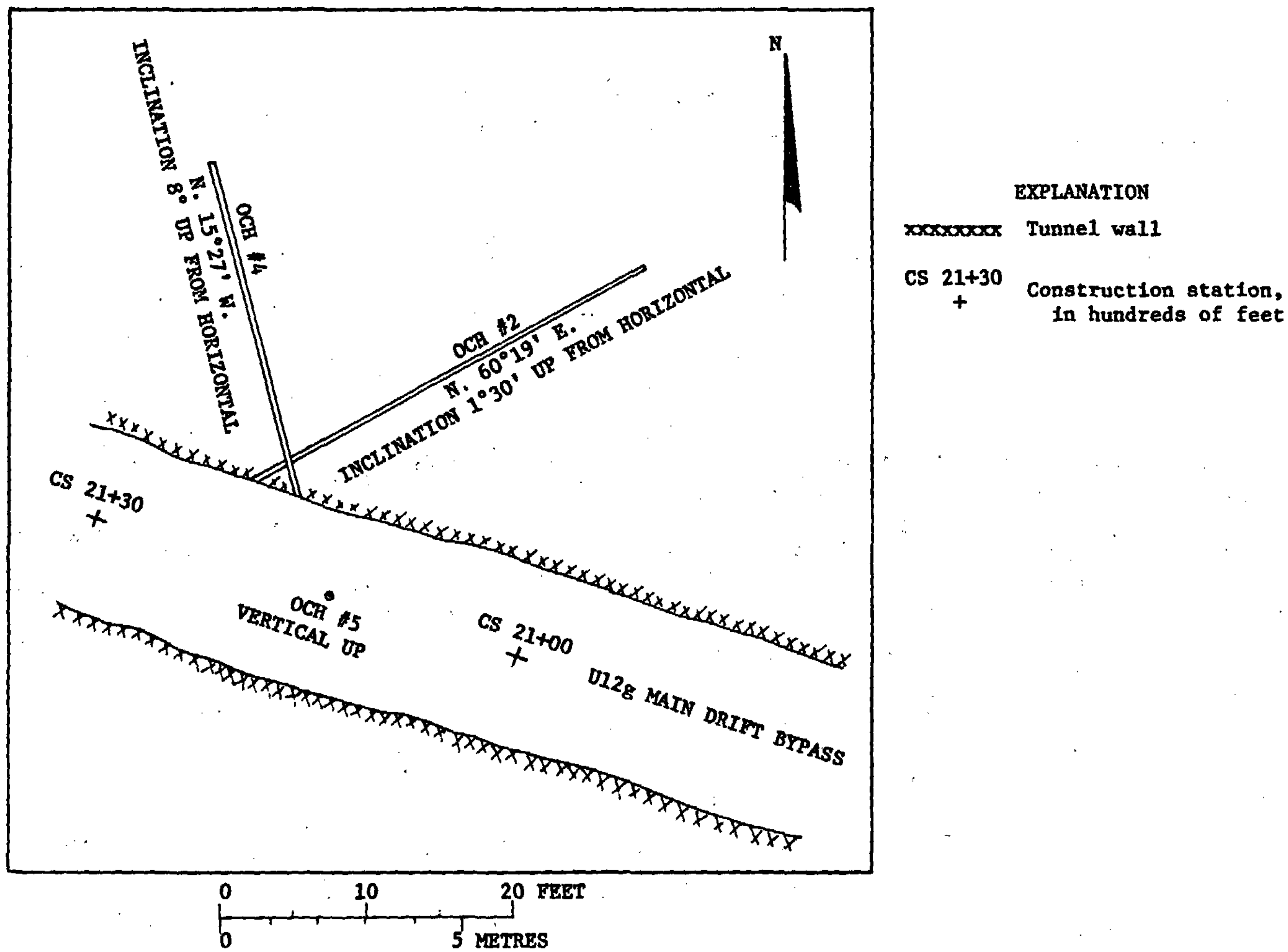

Figure 2.--Map of tunnel section showing location and configuration of overcore holes OCH #2, OCH #4, and OCH #5.

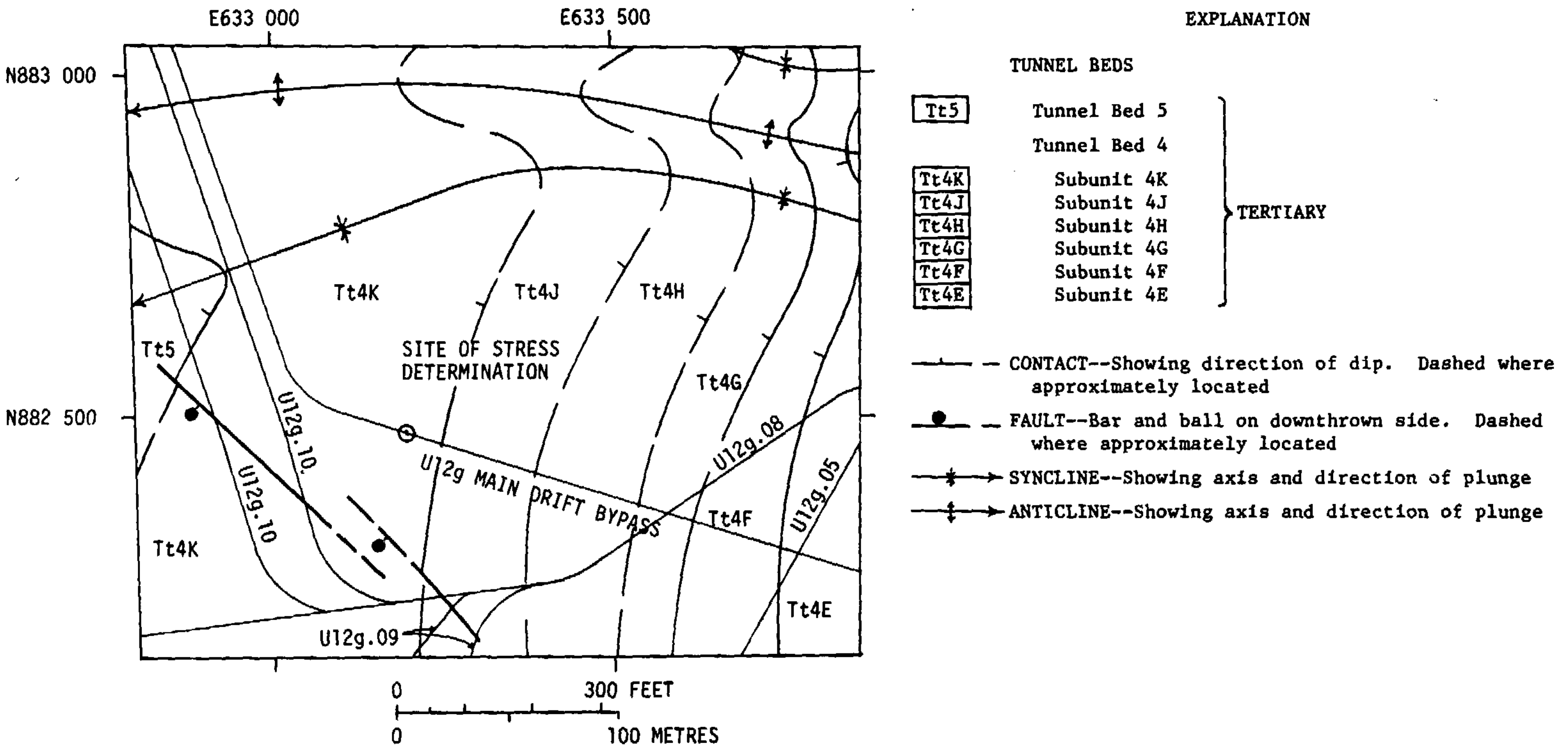

Figure 3.--Tunnel-level map showing geology around stress-determination site in U12g main drift bypass.

local perturbations in the in situ stress field or adversely affect the borehole-deformation measurements.

A biaxial loading device (Fitzpatrick, 1962) was used to determine the elastic modulus of selected 15-cm- (6-in.-) diameter overcores from each drill hole. Selected cores were also submitted to the Holmes and Narver Materials Testing Laboratory at NTS for triaxial testing. Elastic modulus values of the triaxially tested samples were generally higher than those determined by the biaxial method. This is probably due in part to the confining pressures in the triaxial tests and the smaller size of the samples tested. Secant elastic modulus values derived from the biaxial tests were used in the stress calculations, as these values best represent conditions during overcoring. Representative values of Poisson's ratio were determined from the triaxial tests.

The physical property values used in the stress calculations are listed in table 1; also listed are natural-state densities. As the biaxial tests did not indicate significant anisotropic conditions in the rock, isotropic conditions were assumed in the calculations.

RESULTS

A computer program developed by the USBM was used to calculate the state of stress using the borehole-deformation and physical-property data from the three boreholes. Results of the calculations are given in table 2, along with the standard deviation of the calculated stress values. Rock mechanics sign convention, where compressive stress is designated positive and tensile stress negative, is used in this report. A negative sign on shear stress indicates the direction of shear with respect to the designated coordinate system. Positive normal and shear stress components for the

Table 1.--*Representative physical-property values for rock from each drill hole*

Hole No.	Secant elastic modulus (E) (bars)	Secant elastic modulus (E) (psi x 10^6)	Poisson's ratio (ν)	Natural state density (g/cm^3)
OCH #2	48,952	0.71	0.20	1.82
OCH #4	32,405	.47	.20	1.89
OCH #5	44,126	.64	.20	1.99

Table 2.--*Calculated stresses, U12g tunnel main drift bypass*
[---, not applicable]

	Stress magnitude		Standard deviation		Bearing	Inclination
	bars	psi	bars	psi		+ degrees above horizontal - degrees below horizontal
Principal stresses						
	(+, compression)					
S_1 (minimum)	+25.8	+374	±3.9	±56	N. 68° W.	-7°
S_2 (maximum)	+85.0	+1,233	±5.2	±76	N. 21° E.	2°
S_3 (intermediate)	+68.0	+986	±2.9	±42	N. 83° W.	+82°
Normal stress components in X, Y, Z (east, north, vertical) coordinate system						
	(+, compression)					
σ_x	+34.5	+500	±3.1	±45	East	Horizontal
σ_y	+76.9	+1,116	±5.0	±72	North	Horizontal
σ_z	+67.3	+976	±2.8	±41	---	Vertical
Shear stress components in X, Y, Z coordinate system						
τ_{xy}	[1]+20.1	+292	±3.1	±45	---	---
τ_{yz}	[1]+2.6	+37	±3.4	±50	---	---
τ_{zx}	[1]-4.6	-70	±1.9	±27	---	---

[1]Positive or negative sign on shear stress magnitude indicates direction of shear stress with respect to X, Y, Z coordinate system.

X, Y, Z (east, north, vertical) coordinate system, using rock mechanics sign convention, are shown on figure 4.

The orientations of the principal stresses are given as a bearing and the associated inclination. The inclinations are referenced to the horizontal with a positive angle indicating degrees above horizontal, and a negative angle indicating degrees below horizontal. The principal stresses S_1, S_2, and S_3 are graphically represented on figure 5.

DISCUSSION OF RESULTS

The vertical stress component (σ_z in table 2) was calculated to be 67.3 bars (976 psi). Using average density values of the overlying rock the estimated vertical stress due to overburden is about 79 bars (1,145 psi), a difference of 15 percent. Considering the uncertainty in estimating the average density of the total overburden, the comparison of calculated and estimated vertical stress values is considered reasonably good.

The maximum principal stress of 85 bars (1,233 psi) is in the direction N. 21° E. and is almost horizontal (S_2 on fig. 5). The minimum principal stress (S_1 on fig. 5) of 25.8 bars (374 psi) is in the direction N. 68° W. and is also nearly horizontal. Stress determinations at several other sites in Rainier Mesa (V. E. Hooker and others, written commun., 1971; H. W. Dodge, Jr., unpub. data, 1971; Haimson and others, 1974; W. L. Ellis, unpub. data; C. H. Miller, unpub. data) also show stress in the northeast direction to be considerably higher than stress in the northwest direction, although the principal stress axes may deviate considerably from the horizontal and vertical.

The magnitude of the principal stress, S_2, is larger than what would be expected for a gravitational stress field in a horizontally confined elastic medium. Horizontal stresses for

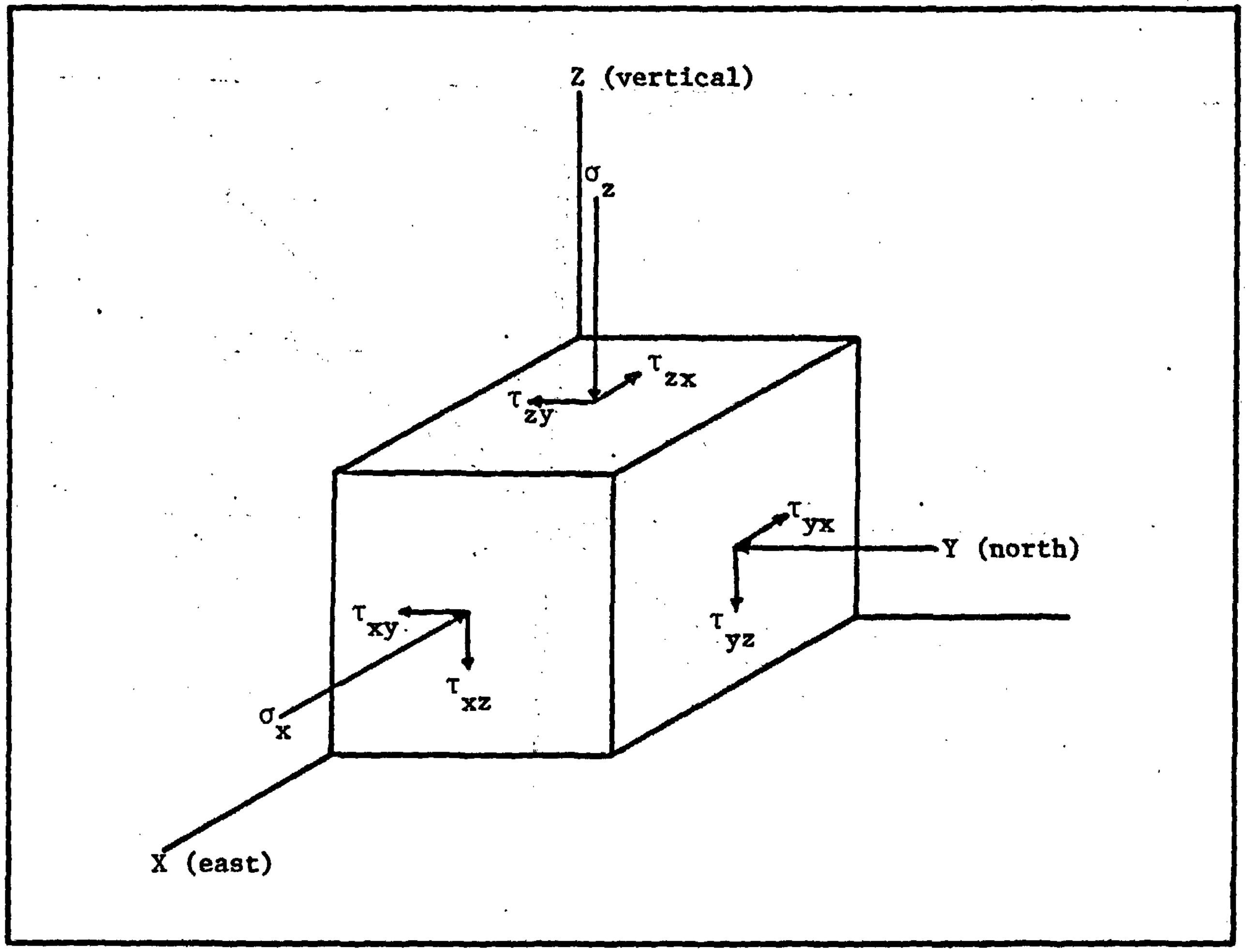

Figure 4.--Graphical representation of stress components in the X, Y, Z coordinate system. Rock mechanics sign convention.

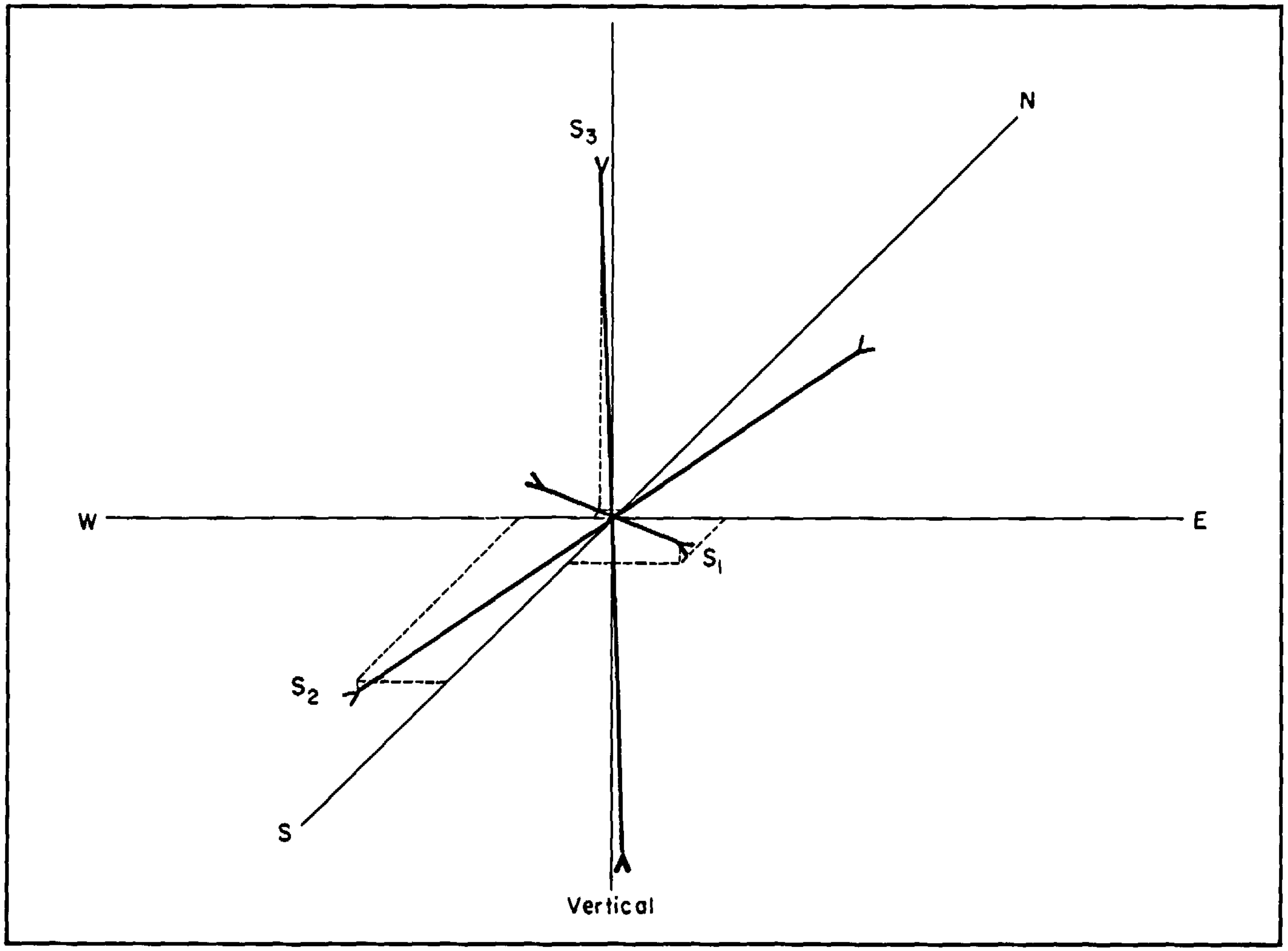

Figure 5.--Graphical representation of principal stresses S_1, S_2, and S_3. Not drawn to scale.

such a medium can be estimated from the relation:

$$\sigma_h = \frac{\nu}{1-\nu}\,\sigma_z$$

where ν equals Poisson's ratio and σ_z equals vertical stress. Using the above relation and associated assumptions the horizontal stresses in Rainier Mesa would thus be expected to range between 0.25 and 0.50 times the vertical stress. At this location in U12g tunnel the magnitude of stress S_2 is 1.26 times the vertical stress σ_z. This would give a so-called excess stress of at least 0.76 σ_z, or 51 bars (740 psi), in the N. 21° E. direction. Often, excess stress determined by this Poisson effect method is assumed to be of tectonic origin. However, as discussed by Bucknam (1973) the Poisson effect approach to analyses of in situ stress fields is overly simplified and may be misleading.

Excess horizontal stresses could be caused by several factors, either exclusive of, or in combination with, tectonic stress. Time-dependent inelastic creep in rocks at depth could result in horizontal stresses approaching the vertical stress in magnitude, particularly for low-modulus rocks. History of deposition and erosion is another factor which could cause in situ stress to deviate from that of a gravitational model. Brown and Goodman (1963) demonstrated that the final gravitational stresses in a body formed by progressive addition of material depend on the manner in which the material is deposited. Conversely, the final state of stress in a body could be affected by periods of erosion and unloading. The presence of intrusive bodies and faults could be a factor resulting in either high or low horizontal stresses, dependent upon the location of the intrusive or the nature of fault movement. Neither faults nor intrusive bodies appear to be a local factor at this location in U12g tunnel.

The topographic boundary of Rainier Mesa may have some influence on the principal stresses S_1 and S_2. The direction of the minimum stress, S_1, is roughly perpendicular to the mesa edge. As this is the direction of least horizontal confinement it is reasonable to expect it to be the direction of least compressive stress. As such it would have an effect on the orientation and relative magnitudes of principal stresses S_1 and S_2.

It is very probable that tectonic stresses do exist in Rainier Mesa. Evidence is present which strongly suggests that horizontal compressive stress in the NTS region is higher in the northeast-southwest direction than in the northwest-southeast direction. Carr (1974) cites considerable geologic and geophysical evidence from which he estimated the direction of maximum horizontal compressive stress for the region to be about N. 40° E. Presumably this stress is of a regional tectonic origin. The stress determined at this site in the U12g tunnel complex and stresses determined at other sites in Rainier Mesa exhibit a similar orientation and, as such, may reflect regional tectonic stress. However, to attribute the principal stress orientations and any excess stress magnitudes to tectonic stress alone could be misleading.

REFERENCES CITED

Brown, C. B., and Goodman, L. E., 1963, Gravitational stresses in accreted bodies: Royal Soc. London Proc., v. 276, ser. A, p. 571-576.

Bucknam, R. C., 1973, Some factors relevant to the determination of in situ stress by analysis of geological and geophysical data: U.S. Geol. Survey rept. USGS-474-168, 24 p.; available only from U.S. Dept. Commerce, Natl. Tech., Inf. Service, Springfield, VA 22161.

Carr, W. J., 1974, Summary of tectonic and structural evidence for stress orientation at the Nevada Test Site: U.S. Geol. Survey open-file report 74-176, 53 p.

Deere, D. U., and Miller, R. P., 1966, Engineering classification and index properties for intact rock: Air Force Weapons Laboratory Tech. Rept. AFWL-TR-65-116, 300 p.; available as AD 646-610 from Defense Documentation Center, Cameron Station, Alexandria, VA 22314.

Fitzpatrick, John, 1962, Biaxial device for determining the modulus of elasticity of stress-relief cores: U.S. Bur. Mines Rept. Inv. 6128, 13 p.

Haimson, B. C., LaComb, Joseph, Jones, A. H., and Green, S. J., 1974, Deep stress measurements in tuff at the Nevada Test Site, in Advances in Rock Mechanics: Third Cong. Internat. Soc. Rock Mechanics, Denver, CO, Sept. 1-7, 1974, Proc., v. 2, pt. A, p. 557-562.

Hooker, V. E., and Bickel, D. L., 1974, Overcoring equipment and techniques used in rock stress determination: U.S. Bur. Mines Inf. Circ. 8618, 32 p.

Merrill, R. H., 1967, Three-component borehole deformation gage for determining the stress in rock: U.S. Bur. Mines Rept. Inv. 7015, 38 p.

Obert, Leonard, and Duvall, W. I., 1967, Rock mechanics and the design of structures in rock: New York, John Wiley & Sons, Inc., 650 p.

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