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EXPLOSION-INDUCED STRESS CHANGES ESTIMATED FROM VIBRATING-WIRE STRESSMETER MEASUREMENTS NEAR THE MIGHTY EPIC EVENT, NEVADA TEST SITE

By

W. L. Ellis and J. D. Kibler

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EXPLOSION-INDUCED STRESS CHANGES ESTIMATED FROM VIBRATING-WIRE STRESSMETER MEASUREMENTS NEAR THE MIGHTY EPIC EVENT, NEVADA TEST SITE

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ABSTRACT

Explosion-induced compressive stress increases near an underground nuclear explosion are believed to contribute significantly to the containment of high-pressure gases within the explosion-produced cavity. These induced compressive stresses are predicted by computer calculations, but have never been adequately confirmed by field measurements, owing primarily to the unique difficulties of obtaining such field data. Vibrating-wire stressmeter measurements made near the Mighty Epic nuclear detonation, however, qualitatively indicate that within 150 meters of the working point, permanent compressive stress increases of several megapascals were present 15 weeks after the event. Additionally, stress-change magnitudes interpreted from the stressmeter data between the 75- and 260-meter range from the working point compare favorably with calculational predictions of the stress changes believed to be present shortly after detonation of the event. The measurements and calculations differ, however, with regard to the pattern of stress change radial and transverse to the explosion source. For the range of the field measurements from the working point, computer models predict the largest compressive-stress increase to be radial to the explosion source, while the field data indicate the transverse component of stress change to be the most compressive. The significance of time-dependent modification of the initial explosion-induced stress distribution is, however, uncertain with regard to the comparison of the field measurements and theoretical predictions.

INTRODUCTION

The Mighty Epic event was a low-yield underground nuclear test conducted in Rainier Mesa, Nevada Test Site, (fig. 1) by the DNA (Defense Nuclear Agency) in May 1976. Mighty Epic was located in the U12n.10-drift complex, part of the N-tunnel complex (fig. 2) used for underground nuclear testing in Rainier Mesa.

The USGS (U.S. Geological Survey), in support of the DNA, conducted an experimental field investigation to collect data on permanent explosion-induced stress changes near the Mighty Epic event. Specifically, the investigation was fielded to examine the range of measurable induced stress

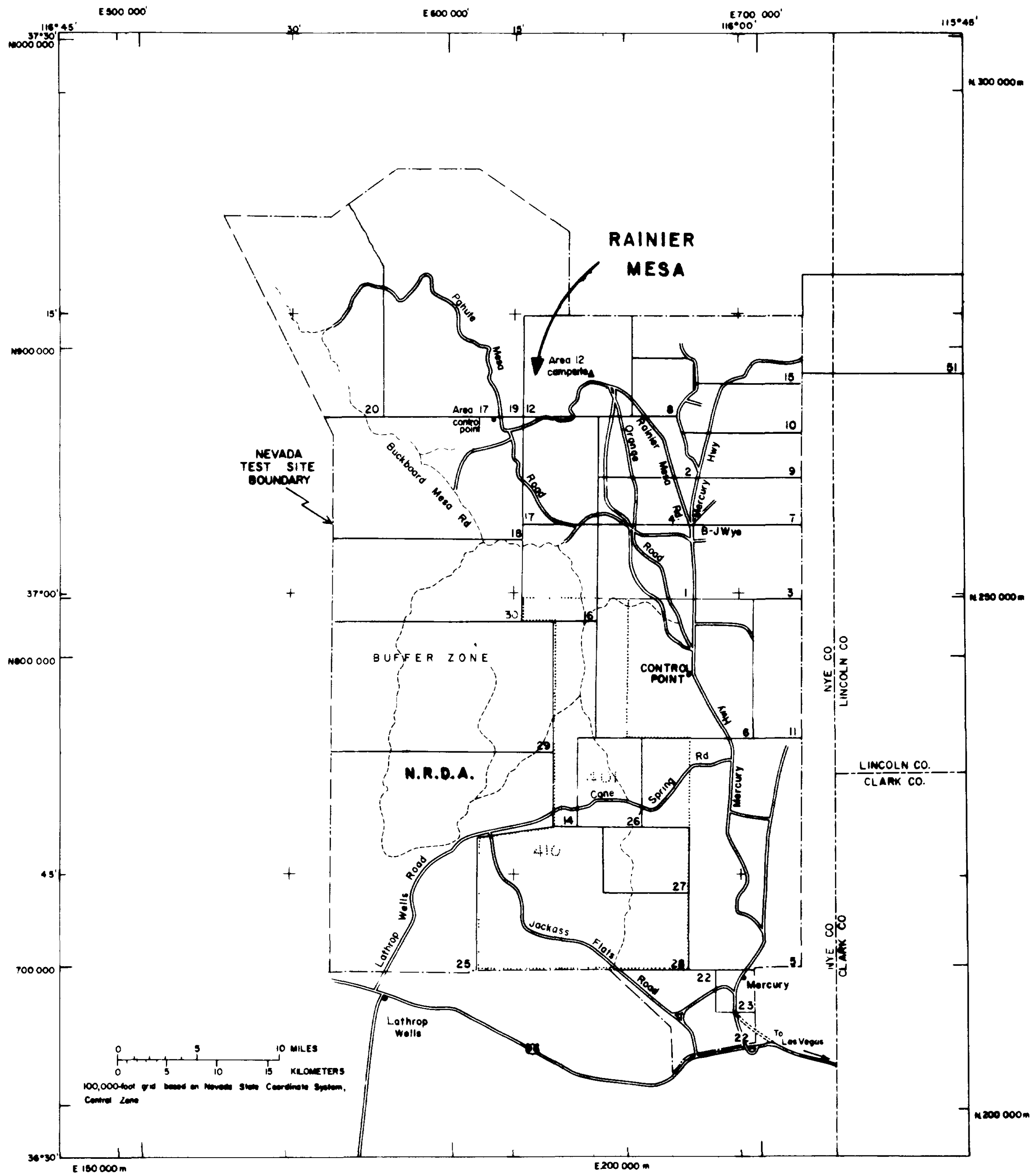

Figure 1.--Index map of the Nevada Test Site showing location of Rainier Mesa.

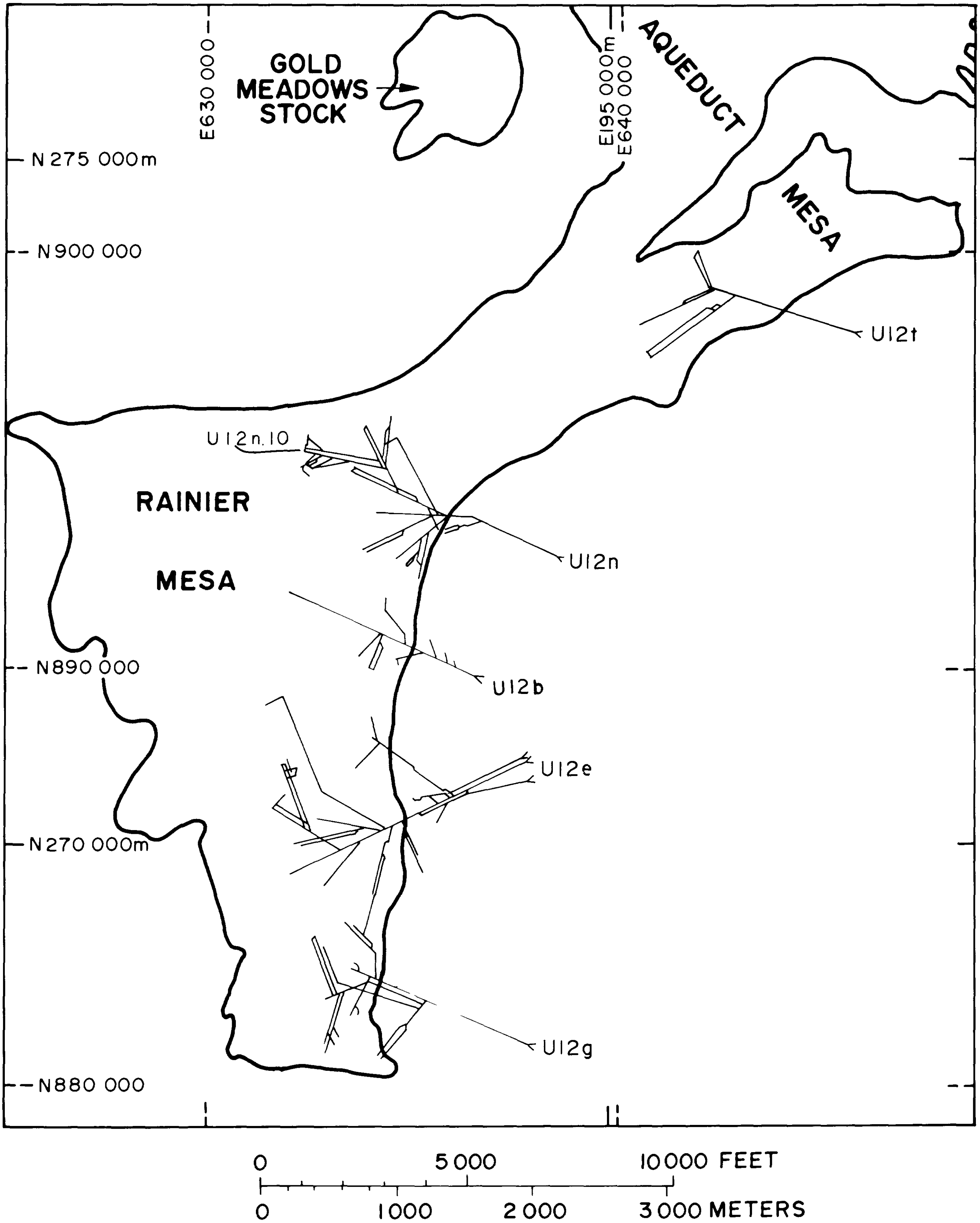

Figure 2.--Index map showing location of U12n.10-tunnel complex.

changes from the WP (working point), and to obtain data on the magnitude of stress change as a function of range from the WP. Instrumentation used in the investigation consisted of vibrating-wire stressmeters developed and manufactured by IRAD Gage, Inc., of Lebanon, N.H. Gages were emplaced at various ranges between 75 and 328 m from the WP several weeks before detonation of the event, and were monitored for several months after the event. The difference between the last pre-Mighty Epic detonation readings and the stable postdetonation readings of the stressmeters were interpreted to yield information concerning the explosion-induced stress changes. The results are judged to be qualitative because of uncertainties associated with interpretation of vibrating-wire stressmeter output, the unknown effects of shock loading on vibrating-wire stressmeter performance, and theoretical assumptions necessary for interpretation of stress changes in a triaxial stress field. Nonetheless, the data strongly suggest that within about 150 m of the Mighty Epic WP the explosion-induced static stress changes were compressive and perhaps several megapascals in magnitude. At distances greater than 150 m from the WP the data indicate relatively minor stress changes.

Acknowledgments

Mr. J. W. LaComb of the DNA provided constructive support for this investigation. Jerry Magner of the U.S. Geological Survey (USGS) assisted with stressmeter installation. In addition, Dean Townsend of Fenix & Scisson, Inc. (F&S), and Jerry Morrison and Tom Davies (formerly F&S) monitored and recorded the stressmeter readings for the several weeks required for the investigation.

GEOLOGY

Rainier Mesa is composed of horizontal to gently dipping beds of ash flows, beds of ash fall, reworked ash-fall tuff, and tuffaceous sandstones. The general stratigraphy of Rainier Mesa is shown on figure 3. Detailed geology in the area of the U12n.10-drift complex and the Mighty Epic event is reported by Fairer and Townsend (1979).

The U12n.10-drift complex penetrated zeolitized tuffs of tunnel-bed units 2-4 and the Tub Spring Member of the Belted Range Tuff. Bedding of the tuff units in the U12n.10-drift area dips 12°-20° toward the southeast. Tunnel-level geology of the U12n.10-drift complex is shown on figure 4 (Fairer and Townsend, 1979).

Eon/Era	System	Series	Formation	Member or unit and symbol
Cenozoic Era	Tertiary	Miocene	Timber Mountain Tuff	Rainier Mesa Member Tmr
			Paintbrush Tuff	Tiva Canyon Member Tpc — Tp
			Stockade Wash Tuff	Tsw — Trab
			Bedded and ash-flow tuffs of Area 20	Trab
			Bedded tuff of Dead Horse Flat Tdhb	
			Belted Range Tuff	Grouse Canyon Member Tbg
			Tunnel beds	Unit 5 Tt5
				Unit 4 Tt4 Subunits AB, CD, E, F, G, H, J, K[1]
				Unit 3 Tt3 Subunits A, BC, D[2]
			Belted Range Tuff	Tub Spring Member Tbt
			Tunnel beds	Unit 2 — Tt2
			Crater Flat Tuff	Tcf — Tt2
			Tunnel beds	Unit 1 Tt1
			Redrock Valley Tuff	Trv
			Older tuffs	Tot
			Paleocolluvium	Tc
Mesozoic Era	Cretaceous		Quartz monzonite of Gold Meadows stock	Kqm
Paleozoic Era	Devonian Silurian Ordovician Cambrian		Paleozoic rocks, undivided	Pz[3]
			Wood Canyon Formation	Є₽w
Proterozoic Eon			Stirling Quartzite	₽ — ₽[3]

[1]K is the youngest.
[2]D is the youngest.
[3]In some drill holes, paleocolluvium of Tertiary age (Tc) rests on Paleozoic or Precambrian rocks.

Figure 3.--General stratigraphy of Rainier Mesa area, Nevada Test Site.

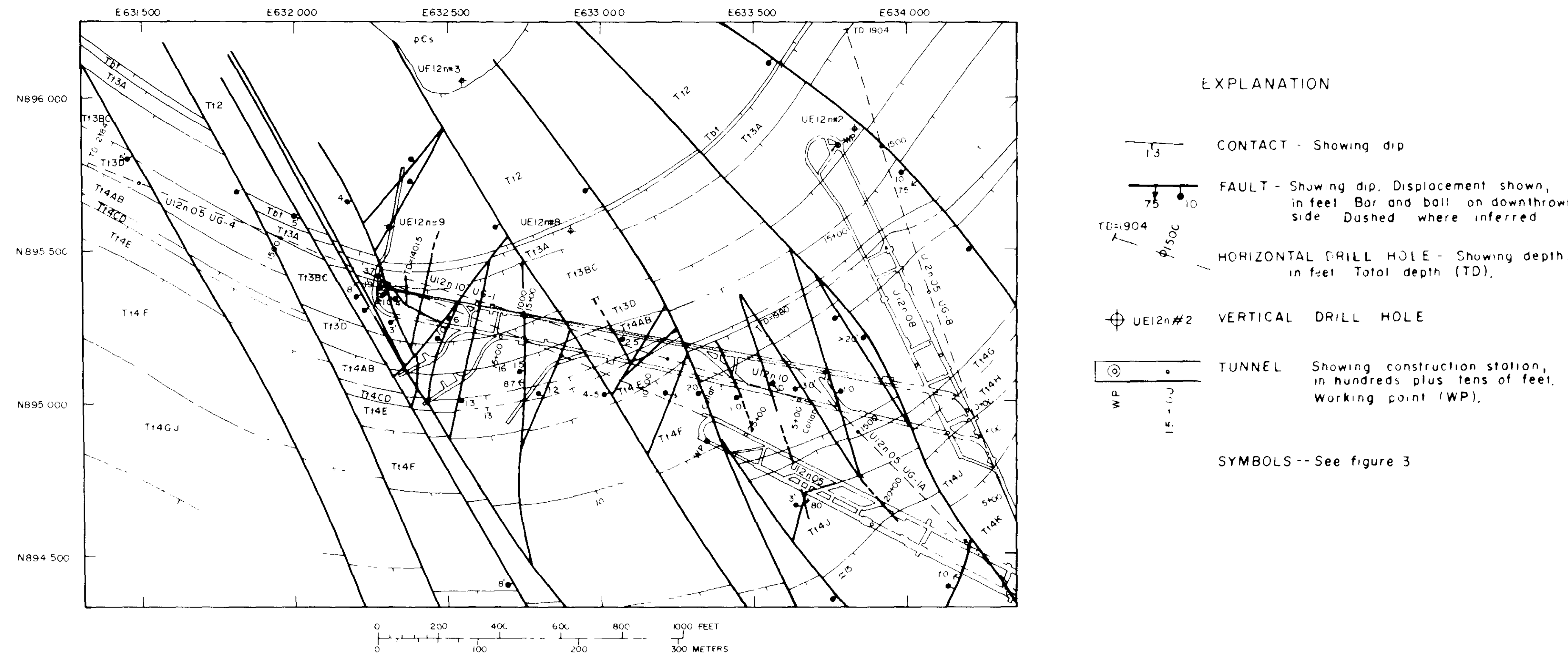

Figure 4.--Tunnel-level areal geology of the U12n.10 (Mighty Epic) drift complex.
(Modified from Fairer and Townsend, 1979.)

INSTRUMENTATION

Instrumentation utilized in this investigation consisted of vibrating-wire stressmeters and the associated emplacement and readout equipment manufactured by IRAD Gage, Inc., of Lebannon, N.H. The decision to utilize these gages was based on their apparent durability, relatively low cost, ease of installation, and commercial availability. Also, because the gages approximate a solid-inclusion stressmeter, an accurate knowledge of the Young's modulus of the rock at each installation site was theoretically not required for data interpretation.

Details of the construction and theory of operation of the IRAD Gage vibrating-wire stressmeter is published in the literature (Hawkes and Bailey, 1973; Hawkes and Hooker, 1974; Sellers, 1977). Briefly, the vibrating-wire stressmeter is a hollow, steel cylindrical gage about 3.8 cm long by 2.86 cm in diameter. One side of the cylindrical gage is machined flat such that it can be emplaced and preloaded in a 3.8-cm-diameter drill hole by means of a sliding wedge and platen assembly. Inside the gage a high-tension steel wire is stretched diametrically across the gage body coincident with the direction of loading from the wedge. The wire can be caused to vibrate at its natural frequency by means of an electromagnetic coil located near the wire inside the gage case, the frequency of vibration of the wire being a function of its tension. The electromagnetic coil also serves as an electronic pick up to monitor the frequency of the vibrating wire. A special readout box, connected to the stressmeter through electrical cable, is used to induce the wire vibration, count the vibrations, and digitally display the period of vibration of the wire.

When wedged into the emplacement hole, a change in rock stress induces a flexure in the gage body via the wedge and platen assembly. This flexure in turn causes a change in the tension of the steel wire, and thus, a change in its period of vibration. This change of period of vibration is therefore related to the magnitude of rock stress change.

For uniaxial plane-stress loading conditions, the manufacturer's empirically derived relationship between stress change and the stressmeter response for the wedge and platen assembly used in this investigation is given by (Hawkes and Bailey, 1973; Hawkes and Hooker, 1974):

$$\sigma_r = \frac{\left(\frac{422400}{To}\right)^2 \left[1-\left(\frac{To}{T}\right)^2\right]}{11.4-0.66X10^{-6}Er} \qquad (1)$$

where

T_o=initial meter reading
T=later meter reading
Er=Young's modulus of the rock (in lb/in^2)
σ_r=change in stress (lb/in^2)

Note: T is the four-digit meter reading; the period is $T \times 10^{-7}$ s.
145.04 lb/in^2 = 1 MPa

It is important to note that this relationship was derived from calibration of the stressmeter in slabs of rock under uniaxial plane-stress conditions. Thus, σ_r calculated by equation 1 for one stressmeter in a single drill hole cannot be interpreted as a change in the in situ rock stress where biaxial or triaxial stress changes have occurred. Interpretation of the stressmeter data in terms of biaxial or triaxial stress field changes requires multiple gage installation in rosette configuration in one or more boreholes, or that simplifying assumptions be made regarding the nature of the stress change. The method used to evaluate the stressmeter data for the triaxial stress changes induced by the Mighty Epic event will be discussed in the section on Data Interpretation.

Another important consideration of equation 1 is the relative insensitivity of σ_r to changes in Er for small values of Er. For example, a change of Er from 1.0 GPa to 7.0 GPa only results in about a 5 percent change in the calculated σ_r for a given meter reading change. For this investigation, a value of Er of 2.75 GPa for the rock was assumed in all calculations. This value is quite representative of the zeolitized tuffs in which the gages were emplaced. Any reasonable variations in the Young's modulus from site to site within the study area would therefore not be significant with respect to the calculations of σ_r using equation 1.

EVALUATION OF STRESSMETER DATA

Interpretation of IRAD Gage vibrating-wire stressmeter data has conventionally depended on the manufacturer's uniaxial calibrations, as discussed in the previous section. In recent years, however, studies by other investigators have shown that the stressmeter response is more complex than indicated by these original calibrations. The complexities arise from theoretical considerations in analyzing the gage response, and from practical considerations regarding application of the instrument in the field.

The most serious problem in analysis of the stressmeter response concerns the relationship between a change in rock stress and the corresponding change of stress in the vibrating-wire element. This relationship is defined as the uniaxial stress sensitivity factor, and no precise mathematical relationship for it has yet been developed. The uniaxial calibrations conducted by the manufacturer were used to derive this factor empirically. The denominator in equation 1 represents the uniaxial stress sensitivity factor determined by the manufacturer for the gage assembly used in this investigation.

Note that the original calibrations by the manufacturer indicate that the stress sensitivity factor is a linear function of the Young's modulus of the material in which the gage is emplaced. Fossum and others (1977), however, have since demonstrated that the stress sensitivity factor of the gage is not a linear function of Young's modulus. This was verified by Swolfs and the authors (U.S. Geological Survey, unpub. data, 1981) during testing of the vibrating-wire stressmeter in hollow cylinders subjected to uniform radial loading. Additionally, these hollow cylinder tests indicated that the stressmeter response varies with initial gage zero and preload setting in the emplacement hole. Some of the complexities associated with the stressmeter arise from the fact that the gage sensitivity varies with the area of contact between the gage assembly and the borehole wall, which to some degree is dependent on the Young's modulus of the rock and the preload setting.

In field applications, other potential sources of uncertainty can affect reliability of the stressmeter data. Conditions at the point of gage emplacement, including the rock elastic properties, borehole-wall roughness, borehole size and shape, rock fabric, micro and macrofractures, and anisotropy, can all have an effect on a contact area, and thus gage sensitivity. Also, any misalinement of the wedge and platen assembly with the gage body, which could result from nonideal borehole conditions or faulty installation, would cause nonuniform loading of the gage and adversely affect gage sensitivity.

Confidence in vibrating-wire stressmeter data can be increased somewhat by calibration of the gages in material in which they are to be used. This, however, is oftentimes not practical or possible. Even with detailed calibrations, there is no means to verify that the in situ response of a gage in the field matches the calibration response under known and controlled laboratory conditions. Because an exact analytical solution for the complex rock/stressmeter interaction is not available, and because of potential uncertainties associated with field applications, the vibrating-wire stressmeter should only be considered a qualitative tool for indicating rock stress change.

Several factors unique to this investigation have a bearing on the reliability of the data. The low Young's modulus of the rock (approximately 2.75 MPa), and the large stress changes near an underground nuclear detonation, contribute to providing a better approximation of the actual stress change. On the other hand, the potential effects of shock loading produce an additional unknown. Shock loading probably does not affect the functioning of the gage itself, but it could have an effect on the link between the gage and borehole wall via the wedge and platen assembly. Any shock-loading effects, however, would likely result in a decrease in gage sensitivity. Thus, any significant increase in gage readings probably indicates a significant increase in compressive stress, although the magnitude may be uncertain.

DATA INTERPRETATION

For this investigation, the manufacturer's uniaxial calibration (equation 1) is used in the data reduction scheme. However, measurements from a single stressmeter in a borehole are not sufficient to interpret a stress change in cases where a biaxial or triaxial stress change has occurred. If, however, the directions of the three principal stress changes can be assumed, and three vibrating-wire stressmeters are deployed to monitor in these three orthogonal directions, then an approximation of the triaxial stress-field change is possible. The basis for the procedure, using plain strain equations, is as follows.

The radial displacement U_r, at the boundary of a cylindrical hole of radius $\underline{a}$ in an infinite medium subsected to the three principal stress changes of S_x, S_y, and S_z is:

$$U_r = \frac{a}{Er}[(S_x + S_y) + 2(1-\nu^2)(S_x - S_y)\cos 2\theta - \nu S_z] \qquad (2)$$

where Er is the rock Young's modulus and ν is Poisson's ratio. Positive θ is measured counter clockwise from the X direction when viewing into the hole along the negative Z axis. Likewise, the radial displacement for a hole along the X axis would be:

$$U_r = \frac{a}{Er}[(S_y + S_z) + 2(1 - \nu^2)(S_y - S_z)\cos 2\theta - \nu S_x] \qquad (3)$$

where positive θ is measured counter clockwise from the y axis when viewing into the hole along the negative X axis.

Three measurements of S' (σ_r calculated from equation 1) made in the three assumed principal stress change directions result in three equations of the form:

$$U_x = \frac{a}{Er} 3S_x', \quad U_y = \frac{a}{Er} 3S_y', \quad U_z = \frac{a}{Er} 3S_z' \qquad (4)$$

If S_x' and S_y' are measured in a borehole along the Z axis and S_z' is measured in a borehole along the X axis, substitution of equation 4 into equations 2 and 3 gives:

$$3S_x' = (3-2\nu^2)S_x - (1-2\nu^2)S_y - \nu S_z$$

$$3S_y' = -(1-2\nu^2)S_x + (3-2\nu^2)S_y - \nu S_z$$

$$3S_z' = -\nu S_x - (1-2\nu^2)S_y + (3-2\nu^2)S_z \qquad (5)$$

These three equations can be solved simultaneously for the unknowns S_x, S_y, S_z, which are the three assumed principal stress-change magnitudes.

STRESSMETER DEPLOYMENT

A total of nine vibrating-wire stressmeter stations were established along a length of the U12n.10 bypass drift between ranges of 75 and 328 m from the Mighty Epic WP (fig. 5). In order to evaluate the stressmeter data in terms of triaxial stress change at each station using the procedure previously discribed, it was assumed that the directions of Mighty Epic induced principal stress changes would be radial to the working point, vertical, and transverse (horizontal and perpendicular to a radial from the WP) fig. 6.

In order to emplace the stressmeters consistent with the above assumption, each stressmeter station consisted of two emplacement holes 3.1 m deep; one oriented horizontal and perpendicular to a radial from the WP and one oriented vertically. Two stressmeters were emplaced in the horizontal hole such that one monitored in a direction radial to the WP and the other monitored in the vertical direction. In the vertical hole one stressmeter was emplaced such that it monitored in the horizontal transverse direction. Figure 7 is a diagram showing the emplacement and orientation of the stressmeters at a typical station and the numbering scheme used in identifying each stressmeter. Table 1 lists detailed information regarding the location and emplacement of the stressmeters. It is noted that at some stations the horizontal hole was drilled into the left rib and at others it was drilled into the right rib. Also, at some locations the vertical hole was drilled upward.

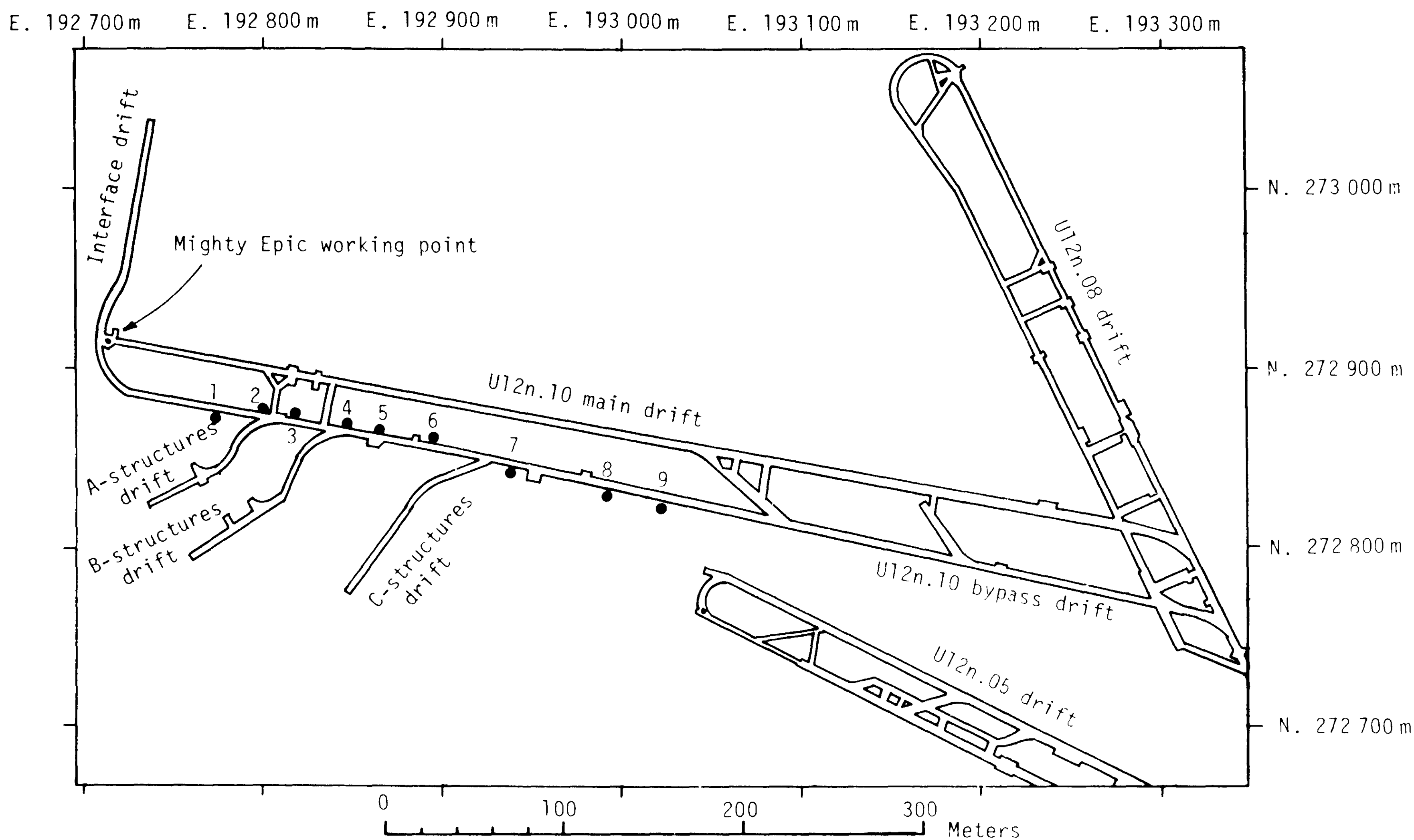

Figure 5.--Location of vibrating-wire stressmeter stations 1 through 9 along the U12n.10 bypass drift.

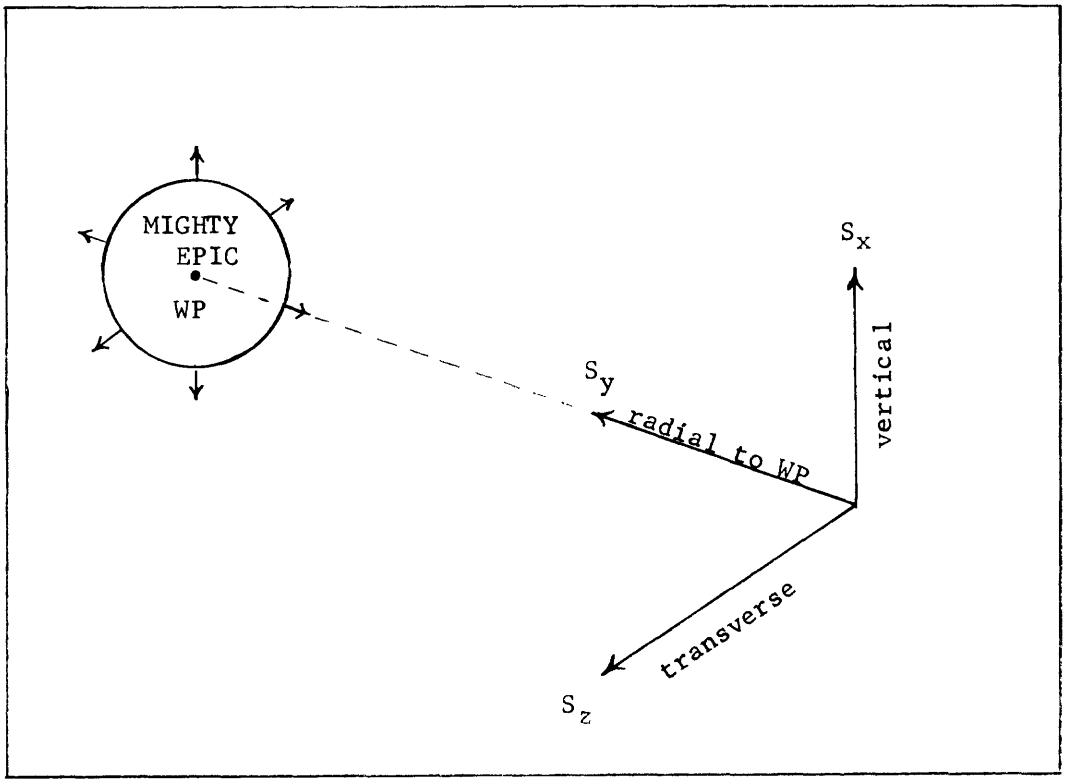

Figure 6.--Directions of assumed principal stress changes (S_x, S_y, S_z) induced by the Mighty Epic explosion.

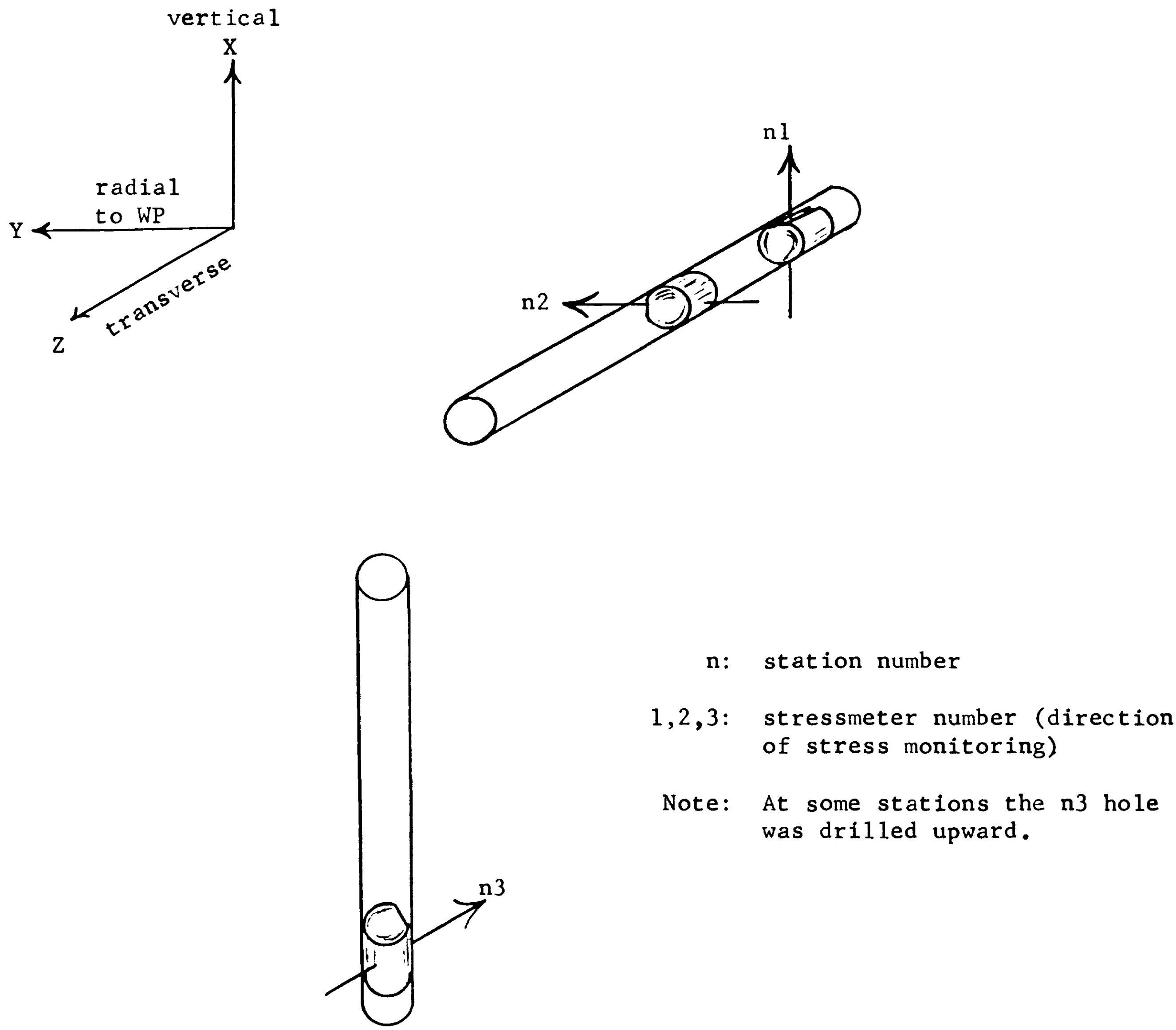

Figure 7.--Configuration of drill holes and vibrating-wire stressmeters at typical stressmeter station. Stressmeter numbering scheme also shown.

Table 1.--Location and emplacement information for vibrating-wire stressmeters in U12n.10 bypass drift

Stressmeter station No.	Hole No.	Stress-meter No.	Emplace-ment depth (m)	Construction station (CS) location[1]	Range from working point (m)
1	1 horizontal	11	2.90	17+08	74.7
		12	2.59		
	1 vertical	13	2.74		
2	2 horizontal	21	2.90	16+50	89.9
		22	2.74		
	2 vertical	23	2.90		
3	3 horizontal	31	2.90	15+95	106.1
		32	2.74		
	3 vertical	33	2.90		
4	4 horizontal	41	2.90	15.05	132.6
		42	2.74		
	4 vertical	([2])			
5	5 horizontal	51	2.90	14+15	160.0
		52	2.74		
	5 vertical	53	2.90		
6	6 horizontal	61	2.90	13+45	181.4
		62	2.74		
	6 vertical	63	2.90		
7	7 horizontal	71	2.90	11+95	227.1
		72	2.74		
	7 vertical	([2])			
8	8 horizontal	81	2.90	10+15	282.9
		82	2.74		
	8 vertical	83	2.90		
9	9 horizontal	91	2.90	8+70	327.7
		92	2.74		
	9 vertical	93	2.90		

[1]CS 17+08 refers to construction stations in the drift complex in accordance with surveying practice, and is measured in English units. Multiply 1708 by 0.3048 to convert to meters.

[2]Stressmeter not installed owing to construction activities or operational difficulties.

After emplacement of the stressmeters, and prior to detonation of the Mighty Epic event, the U12n.10 bypass drift was stemmed with grout from the WP to about CS 13+80[1]. Stations 1 through 5 were therefore within the stemmed portion of the drift. Stemming is standard procedure to insure containment of the underground nuclear explosion.

POST-MIGHTY EPIC STRESSMETER RECOVERY

The vibrating-wire stressmeters were emplaced and monitored for 3-4 weeks prior to the time that access to the U12n.10 bypass drift was restricted. Readings of all of the stressmeters had stabilized within about 1 week after installation. After detonation of the Mighty Epic event on May 12, 1976, the stressmeters were read as access to each station became available during reentry operations. Access to stations 6-9 occurred within 17 to 20 days after the last predetonation readings were made. Access to stations 3-5, in the stemmed portion of the bypass drift, and stations 1 and 2, nearest the WP, were not accessed until about 10 and 15 weeks, respectively, after the last predetonation readings.

The data from stations 6-9 did not indicate any significant changes after their first postdetonation readings. Readings at station 3 on the other hand, changed significantly for about 5 weeks after the station was accessed. Station 3 was located near a fault (fig. 4) which underwent approximately 0.5 m of shock-induced displacement from the Mighty Epic explosion. The postdetonation changes in stressmeter readings may have been the result of readjustments along the fault after the Mighty Epic event. Other changes were related to nearby mining activity, but were not significant compared to the total pre- and post-Mighty Epic change.

In order to compare the results from all stations for a common point in time, it was necessary to select a time at which all post-Mighty Epic readings had stabilized. Because of the changes that occurred at station 3, this time was approximately 15 weeks after the Mighty Epic detonation.

Not all of the stressmeters emplaced for this investigation remained operable. Several gages ceased to function prior to detonation of the Mighty Epic event, and at stations 3 and 7 the vertical hole stressmeters could not be emplaced due to construction activities and operational difficulties.

---

[1]Refers to construction stations in the drift complex in accordance with surveying practice and is measured in English units. To convert to meters multiply 1380 by 0.3048.

Survivability of the stressmeters from the Mighty Epic ground shock was quite good. Only at stations 1 and 2 nearest the WP were any gages lost, apparently due to ground shock damage to signal cables. Of the nine stressmeter stations originally established, four produced sufficient data (measurements from all three stressmeters) to make a triaxial interpretation of the stress changes. At six of the stations, there was sufficient data to infer radial and vertical stress changes assuming no change in the horizontal transverse direction. The pattern of stress change by either interpretation was very similar.

RESULTS

Table 2 lists the pre- and post-Mighty Epic vibrating-wire stressmeter readings, the change in readings, and the measurement direction according to the coordinate system shown on figures 6 and 7. From this data equation 1 was used to calculate S_x', S_y', and S_z'($S'=\sigma_r$ in equation 1) for the appropriate stressmeters at each station. In turn, for stations where values of S' were available from all three stressmeters, the values of S_x' S_y' and S_z' were used to calculate the principal stress changes S_x, S_y, and S_z using the simultaneous equations 5. The results of these calculations are shown in table 3.

Unfortunately, neither station 1 or 2 provided enough data to enable a triaxial interpretation of stress changes. Examination of the intermediate calculated values of S' for these two stations indicate that at station 1 the vertical stress change is apparently less than at stations 3 and 4. Also, station 2 S' values indicate a very high radial stress increase and a relative decrease in the transverse stress change as compared to station 3. The S' values at stations 1 and 2 therefore suggest that the relative magnitudes of the stress change components differ from the pattern indicated by stations 3, 5, and 6. In order to provide an indication of the stress change in the vicinity of stations 1 and 2, the data was combined with the assumption that the actual stress changes at these two stations were similar in character. The principal stress changes calculated from the stations 1 and 2 combined data are also included in table 3. Figure 8 is a plot of the calculated stress change components versus range from the Mighty Epic WP.

As stated previously, it was possible to infer biaxial stress change components (vertical and radial) at six of the nine original stressmeter stations. This was done using the horizontal hole stressmeters and assuming no stress change in the transverse direction. In this case it was also assumed that the principal stress changes were vertical and radial. This biaxial interpretation allows data from stations 4 and 7 to be evaluated, as well as the combined data of stations 1 and 2. Figure 9 shows the results of the biaxial evaluation as a function of range from the Mighty Epic WP. As can

Table 2.--Pre- and post-Mighty Epic stressmeter readings and change in readings

[Leaders (----) indicate no data]

Stressmeter station No.	Stressmeter No.[1]	Postshot reading[2]	Preshot reading[2]	Change
1	11	2215	2030	+185
	12	----	----	----
	13	----	----	----
2	21	----	2120	----
	22	2575	2025	+550
	23	2125	1975	+150
3	31	2845	2005	+840
	32	1735	2035	-100
	33	2685	1980	+705
4	41	2295	2040	+255
	42	1900	1970	-70
	43	----	----	----
5	51	2255	2265	-10
	52	1960	2005	-45
	53	2060	2005	+55
6	61	2130	2135	-5
	62	2090	2165	-75
	63	2280	2235	+45
7	71	2135	2140	-5
	72	1780	1990	-10
	73	----	----	----
8	81	1920	1895	+25
	82	2000	2000	0
	83	2010	2015	-5
9	91	2325	2140	+185
	92	----	----	----
	93	2010	1975	+35

[1]First digit refers to station number; second digit refers to direction of measurement in accordance with figure 7.

[2]Reading is period of vibration of wire X10^{-7} s. It is displayed as a four-digit reading by the readout unit.

Table 3.--Stress changes calculated from stressmeter data, triaxial interpretation

[Leaders (----) indicate no data available]

Stressmeter station No.	S_x' (vertical)[1] (MPa)	S_y' (radial)[1] (MPa)	S_z' (transverse)[1] (MPa)	S_x[2] (MPa)	S_y[2] (MPa)	S_z[2] (MPa)
1	4.3	----	----	[3]9.5	[3]14.2	[3]9.1
2	----	10.3	3.9			
3	13.9	-2.8	12.8	16.4	3.3	15.3
4	5.6	-2.1	----	----	----	----
5	-0.2	-1.3	1.4	-0.6	-1.5	0.9
6	-0.1	-1.7	0.9	-0.7	-1.9	0.3
7	-0.1	-0.3	----	----	----	----
8	0.8	0	-0.1	0.9	0.3	0.1
9	3.7	----	10	----	----	----

[1] $S'_{x,y,z}$ are intermediate values calculated using equation 1.

[2] $S_{x,y,z}$ are the calculated triaxial stress-change components using equation 5.

[3] Values calculated using combined data from stations 1 and 2.

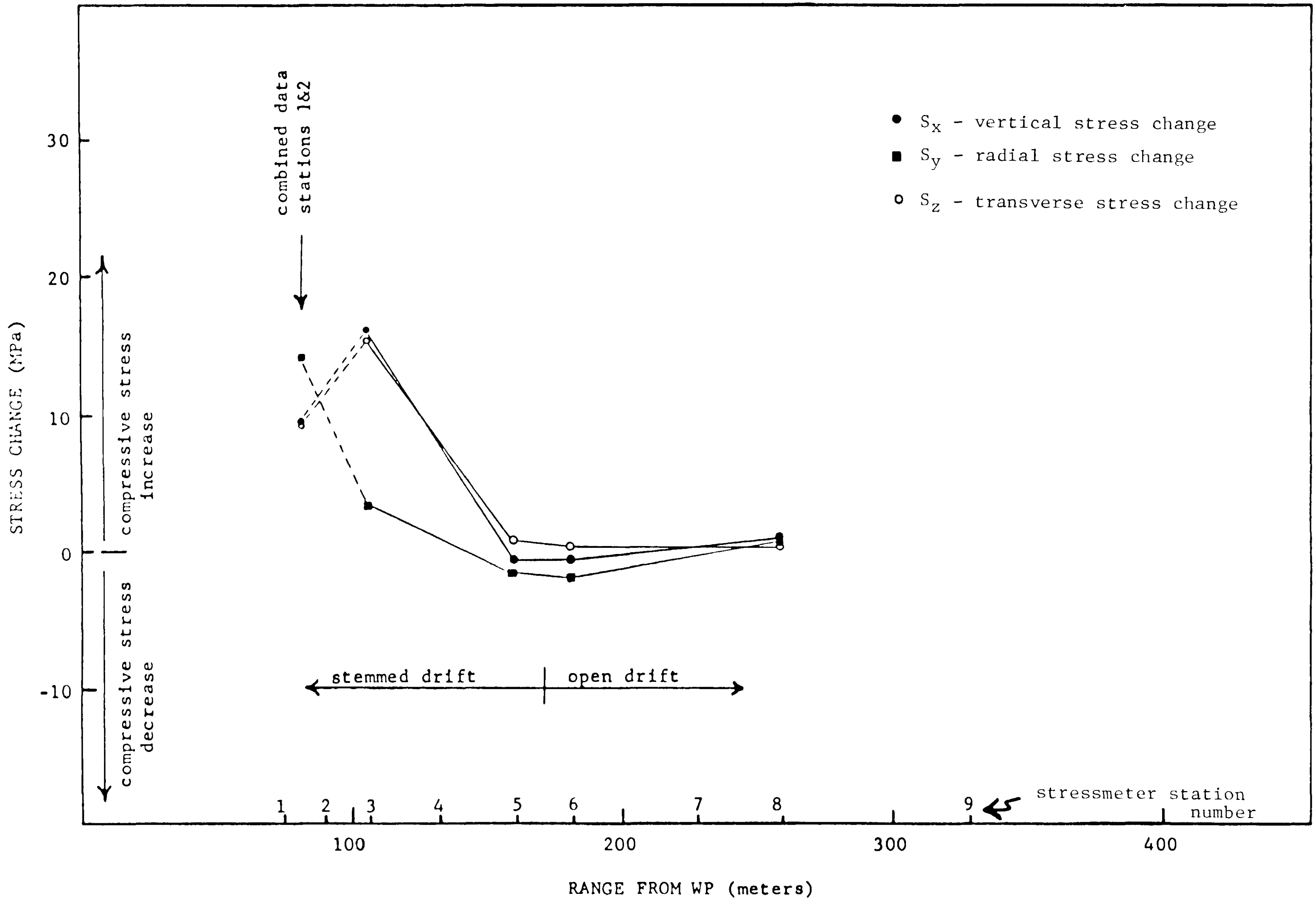

Figure 8.--Stress change versus range from Mighty Epic WP, triaxial interpretation of stressmeter data.

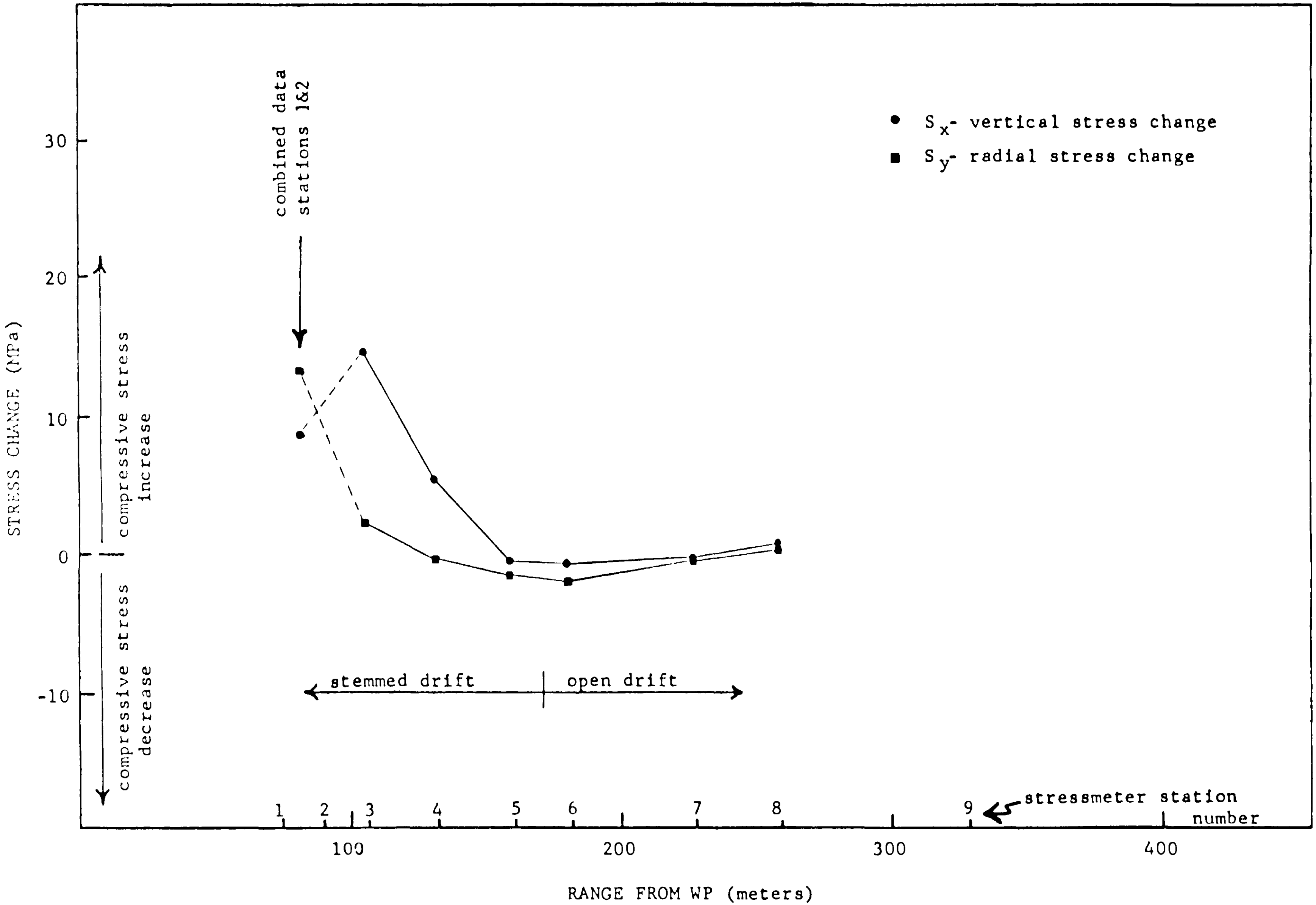

Figure 9.--Stress change versus range from Mighty Epic WP, biaxial interpretation of stressmeter data.

be seen, the biaxial interpretation of the radial and vertical stress changes is nearly identical to the triaxial interpretation. The significance of the biaxial interpretation is that data from stations 4 and 7 conform very well with the pattern of stress change indicated by the other stations, and thus substantiate the pattern of stress change indicated by the triaxial interpretation.

DISCUSSION OF RESULTS

Figures 8 and 9 indicate that a zone of significant compressive stress increase occurred within 150-m range of the Mighty Epic WP as a result of the Mighty Epic explosion. Between about 150- and 250-m range from the WP the data generally indicate a slight decrease in compression. Station 8, located at about 260-m range showed only insignificant change. An obvious feature of the pattern of stress change is that beyond about 100-m range from the WP the vertical and transverse stress change components are more compressive than the radial component. This pattern appears to reverse in the vicinity of stations 1 and 2. Note also that at each station the vertical and transverse stress change magnitudes are very similar. Considering the spherical symmetry of the situation (i.e., a spherical explosion source), it is expected that the vertical and transverse components of stress change should be approximately equal.

A comparison of the stress changes inferred from the stressmeter data with the theoretically predicted stress changes from computer modeling of the Mighty Epic event (Rimer, 1977) is shown on figure 10. The theoretically predicted value of σ_θ is the stress change in any direction tangential to the explosion source, and as such, is comparable to the vertical and transverse (S_x and S_z) components from the stressmeter data. The theoretical value of σ_r is the radial stress change component and is comparable to S_y from the stressmeter data.

It is noted that the stressmeter results are interpreted to represent stress changes present approximately 15 weeks after the Mighty Epic detonation, while the theoretically predicted stress changes are postulated to occur soon after the detonation. The effects of creep and other time-dependent phenomena on the amount and rate of degradation of nuclear explosion-induced stresses are not well known but may be significant, especially near the explosion cavity where the calculated stress gradients are large and the rock is subjected to maximum shock loading. Figure 10, therefore, compares the stress changes inferred to be present several weeks after the event to those theoretically predicted for shortly after the event.

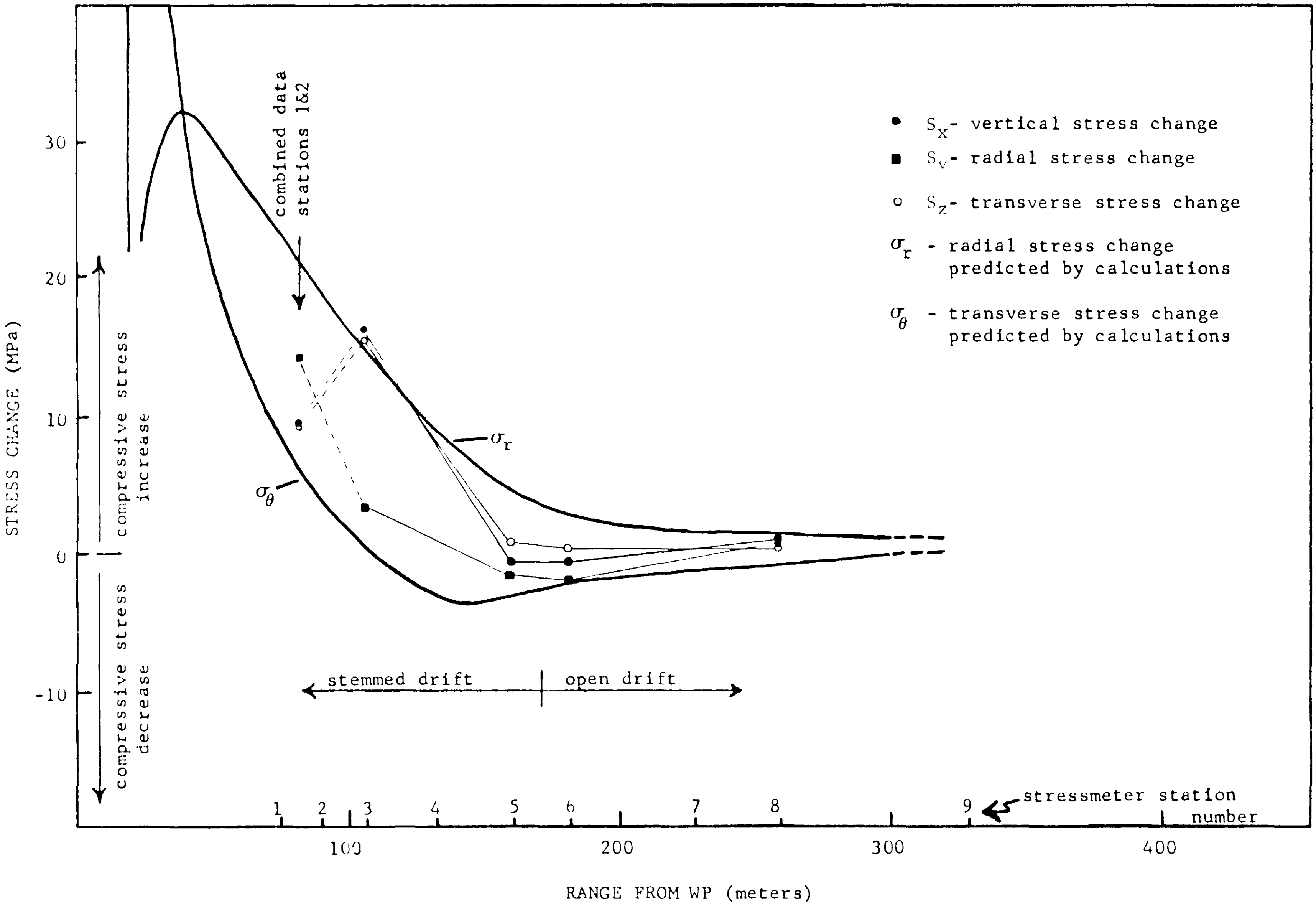

Figure 10.--Comparison of stressmeter results to theoretically predicted stress changes.

As depicted in figure 10, there are general similarities between the field results and the theoretical predictions. Both indicate compressive-stress increases nearer the WP and, on the average, both display a similar trend of stress-change magnitude versus range from the WP. There is, however, one obvious difference between the theoretical predictions and the field results. The field data indicate that, beyond about 100-m range from the WP, the transverse components of stress change (S_x and S_z) are more compressive than the radial component (S_y). The theoretical model, on the other hand, predicts that the radial component of stress change should be the most compressive. The results of this investigation therefore suggest that, 15 weeks after the event, the induced-stress changes within about 100 m of Mighty Epic were qualitatively similar in magnitude to the stress changes predicted to occur shortly after the event, but that the pattern of actual stress change may have been somewhat different than indicated by the numerical model.

CONCLUDING REMARKS

Explosion-induced compressive-stress increases in the rock surrounding an underground nuclear detonation are considered to be a key element in the containment of high pressure gases within the explosion-produced cavity. A considerable amount of theoretical and laboratory work has been conducted within the nuclear testing community to characterize and understand this "stress cage," but little has been done to try and measure it in the field, largely because of the unique difficulties imposed by the near-explosion environment.

This experimental field investigation is encouraging in that field data were obtained from which explosion-induced stresses could be inferred. How well the data quantitatively represent the actual induced stress-change magnitudes is at this time uncertain. However, the observations (1) that data obtained beyond the 100-m range from the WP indicate a consistent pattern of stress change, and (2) that at all stressmeter stations the transverse components of stress change are approximately equal, as theoretically expected, increase confidence in the qualitative value of the results.

The apparent discrepancy between the field measurements and the numerical model with regard to the relative magnitudes of the radial and transverse stress-change components suggests that perhaps the numerical model was not entirely representative of the actual induced-stress changes. Because of the potential importance of explosion-induced stresses to nuclear containment, it is recommended that additional field studies be conducted to determine if the Mighty Epic observations are repeatable. Future studies should include attempts to verify the stressmeter results by an independent stress determination method, perhaps by predetonation and postdetonation measurements utilizing an overcoring technique. Such studies would contribute significantly to establishing the reliability of vibrating-wire stressmeter data in this unique application, and provide a much needed data base for verification of the numerical models used in predicting nuclear explosion-induced stresses.

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