INTERNATIONAL TECHNOLOGY CORPORATION

Memorandum

File

received

To: Carole Lojek, SNL/NM

Date: December 21, 1993

From: Kelley Peters, IT Corporation KLP

Subject: Department 9311 Archive Search of Luke Vortman Files

During an interview with ADS 1334 Technical Staff, Mr. Luke Vortman stated that his document files are housed in Department 9311 under the custody of Mr. Al Chabai, 9311. On Tuesday morning, December 21, 1993, Terry Cooper and Kelley Peters, IT Corporation, met Mr. Al Chabai, 9311, to review Mr. Vortman's files. There are 16 filing cabinets in the Department 9311 Archives containing documents and correspondence accumulated by Mr. Vortman. The files are extremely well-organized which facilitated the records search by IT personnel. The following indicate the contents of each cabinet searched:

1) University of California Radiation Laboratory, Livermore, California Technical Documents; Operation Plowshare information
2) Meteor impact crater technical papers; Operation Plowshare information; and Project Gnome/Gasbuggy documents
3) Technical papers on Projects Chariot, Churchill, Schooner, Gondola, Lost Creek, Essex, and Sphere; Nevada Test Site (NTS) cratering data; Waterways Experiment information
4) Proceedings of Nuclear Weapons Effects Conferences; instrumentation procedures; Non-SNL/NM cratering studies
5) Ground motion study documents; Department of the Army Technical Manuals on Explosives and instrumentation
6) Defense Nuclear Agency reports; NTS signal processing and ground motion reports
7) Technical Papers on NTS Operations Upshot-Knothole, Teapot, Plumbbob, Hardtack, Danny Boy, and Sun Beam Johnie Boy
8) U.S. Geological Survey (USGS) Technical Letters - NTS
9) USGS Technical Letters - NTS
10) USGS Technical Letters - NTS and Alaska
11) SAND Reports (Post-1970)
12) NTS Technical Documents; Sandia Technical Documents
13) NTS and Alaska Technical Reports
14) NTS and Alaska Technical Reports
15) USGS Topographic Maps; Blume Reports (Seismic Effects of Blasts at NTS)
16) Blume Reports

The majority of the documents in the files do not pertain to Sandia test activities. Documents authored by Mr. Vortman were located in Cabinet #12. These are the same reports requested from the Environmental Programs Records Center, therefore, IT staff did not make copies of these documents. IT staff obtained copies of the following as a result of the Department 9311 Archives search:

1) Memo from M. Merritt to L.J. Heilman listing report titles authored by potential ADS 1334 interviewees. These documents should be requested from the Environmental Programs Records Center.

2) "Preliminary Report on Measurement of Soil Stresses Caused by an Underground Explosion," SC-2278(Tr), William R. Perrett. Mr. Perrett is a potential interviewee. When Mr. Perrett is contacted, ask if this report is related to any test activities at Sandia.

3) Drawing No. BI-RB-25, Basic Information Boundary and Ownership, 1954. The locations of Areas X, Y, and Z as well as "blast centers" are identified on the drawing.

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SC-2278(Tr)

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Security Information ..

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PRELIMINARY REPORT ON MEASUREMENT OF SOIL STRESSES CAUSED BY AN UNDERGROUND EXPLOSION

William R. Perret, 5111

March 17, 1952

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PRELIMINARY REPORT ON MEASUREMENT OF SOIL STRESSES CAUSED BY AN UNDERGROUND EXPLOSION

Introduction

The significance of any measurement of subsurface soil pressures induced by blast loading depends, at least for general engineering purposes and for analysis of the stress condition in the soil mass, upon the extent to which the state of stress can be defined in terms of direction, as well as magnitude and time. Such measurements require that the instruments be directionally responsive.

All soils are elasto-plastic media -- the emphasis varying between elasticity and plasticity with the type and condition of the soil. These characteristics indicate that soils develop and support shear stresses when subject to mechanical loading. It is possible, therefore, to describe fully the state of stress in a soil mass in terms of either the distribution of normal and shear stresses or the distribution of the principal stresses. The latter stresses have, by definition, such orientation that shear stresses vanish in the principal planes which are normal to the principal stresses. No instruments have been developed for measuring shear stresses in soils satisfactorily. Consequently the state of stress may be fully determined if directionally responsive instruments for measuring normal stress are employed with such orientation that the magnitude and direction of the principal stresses at a specific point in the soil mass may be derived from the measurements.

Tests were made as a part of an HE test program to determine the feasibility of measurements which would yield data suitable for derivation of principal stress magnitudes and directions. Data for these tests, made in connection with the HE-1 and HE-3 shots, were recorded on several available channels of the Stanford Research Institute (SRI) blast line instrumentation

This preliminary report describes the procedures followed in placing the gauges and analysis of the data and indicates the type and reliability of the results which can be expected from such measurements. Only the data from the HE-3 test are discussed in detail. The HE-1 data were not considered suitable for analysis because of serious ringing of the gauges-- a condition which was partially remedied prior to the HE-3 test.

Instrumentation

The instruments used for stress-component measurements were Carlson-Wiancko earth-pressure gauges of 0-15-psi range. These gauges respond to pressures normal to the circular face plate and are insensitive to shears and accelerations within their working range. The relatively long protruding transducer housing at the rear of the Carlson-Wiancko gauges makes them less suitable for measurement of stresses developed within the soil mass than for measuring stresses exerted by soil on structures. Nevertheless, gauges of this type were used for the HE tests because they were available and the errors introduced by the geometry of the gauges were not considered sufficient to affect adversely the significance of the results for determining feasibility of stress-component measurements.

The techniques and methods of gauge placement and data analysis which have been used successfully by the Corps of Engineers for studies of static stress distribution in soils were adapted for dynamic stress-component measurement. An initial assumption of radial symmetry of the ground shock wave was made to simplify the installation and interpretation of data. The limited number of gauges and recording channels available also indicated advisability of limitation to a plane-stress condition. Instrumentation for determining stress distribution at a point in a radial plane passing through the charge center required the placement of the gauges in such orientation with respect to the charge that the data would be applicable to one of the normal stress rosette equations such as the 45°-90° equation for plane stress.

Placement of Gauges

One station at a radial distance of 58.8 feet from the center of the charge was instrumented for stress-component measurements adjacent to the SRI blast line for the HE-3 test. Four gauges were placed at a depth of 5 feet below the ground surface in a trench excavated perpendicular to the radial plane. The gauges were spaced 3 feet apart, the one nearest the SRI blast line instruments being 15 feet clockwise from the centerline of the blast line. Fig. 1 shows four gauges in place in the trench. The gauge at the top of the picture was placed to respond to the horizontal-radial component of stress, σ_h, and was nearest the blast-line instrumentation. The second gauge from the top was placed to respond to the vertical-stress component, σ_v; the third gauge responded to the radial-stress component directed downward away from the charge at 45° from horizontal, σ_{45} (away); the fourth gauge responded to the radial component directed downward toward the charge at 45° from horizontal, σ_{45} (toward). The photograph was taken after conclusion of the test and shows the gauges following excavation for their recovery.

Each gauge was placed in the trench after calibration on its assigned recorder channel. The gauges were carefully oriented and bedded in moist compacted sand tamped to a density slightly greater than the natural density of the surrounding soil. Moist soil was hand-tamped around and over the gauges to a depth of about 1 foot. The remainder of the backfill was dry random material compacted with a pneumatic tamper in 8-in. lifts to a density approximately equal to that of the surrounding material. The cables were carried through shallow trenches to the recording shelter, the first hundred or more feet of trench being loosely backfilled to minimize cable damage from fall-out material.

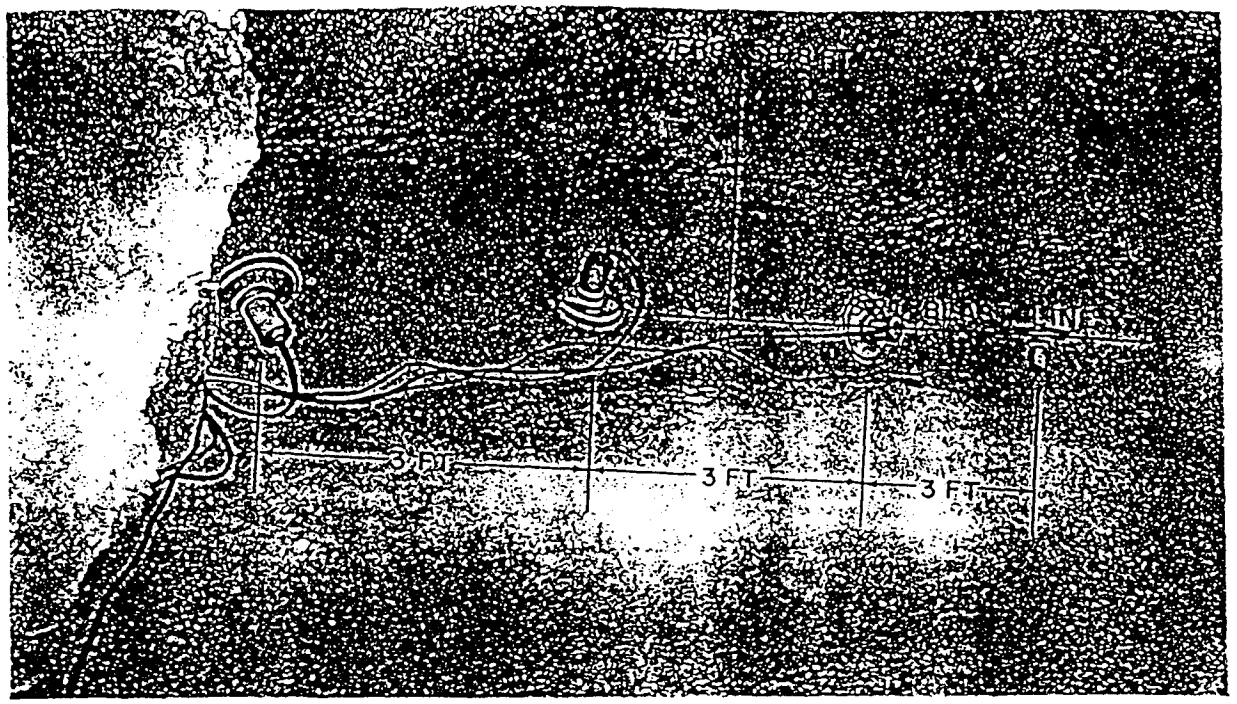

Fig. 1. -- Carlson-Wiancko earth-pressure gauges arranged to measure soil stress components

Methods of Analysis

The basic data derived from the stress-component gauges consisted of oscillograph records of the time-pressure response of each gauge. Tracings of these records, converted to uniform time and pressure scales, are presented in Fig. 2. The record from an 'oil bag' pressure gauge, which was a part of the SRI blast-line instrumentation at the same radial distance from the explosive, is included for comparison with the stress-component records. This gauge consisted of a pressure-sensitive Wiancko transducer placed in a neoprene bag filled air-free with oil. It was placed 5 feet below the surface in the bottom of a 6-in. diameter hole filled with drillers mud. There is evidence of some ringing or natural-frequency oscillation of the gauge in each of the stress-component records. This effect was relatively minor in the horizontal and vertical component records, but was of considerable magnitude in the two 45° component traces after the initial positive phase. Average curves were drawn, as shown in Fig. 2, through the recorded oscillations to give a reasonable approximation of the incident pressure function. The pressures indicated by these smoothed curves were read at 10-msec intervals from 0.03 to 0.20 sec after detonation of the explosive. These data were used to compute principal stress magnitudes and directions and maximum shear stresses at each 10-msec interval.

The 45°-90° rosette equations from which the principal stresses in a plane can be derived require knowledge of three normal stress components in the plane -- two mutually perpendicular and the third displaced 45° from each. These same data are applicable to graphic analysis by Mohr's stress circle. The measured stresses included a second 45° component

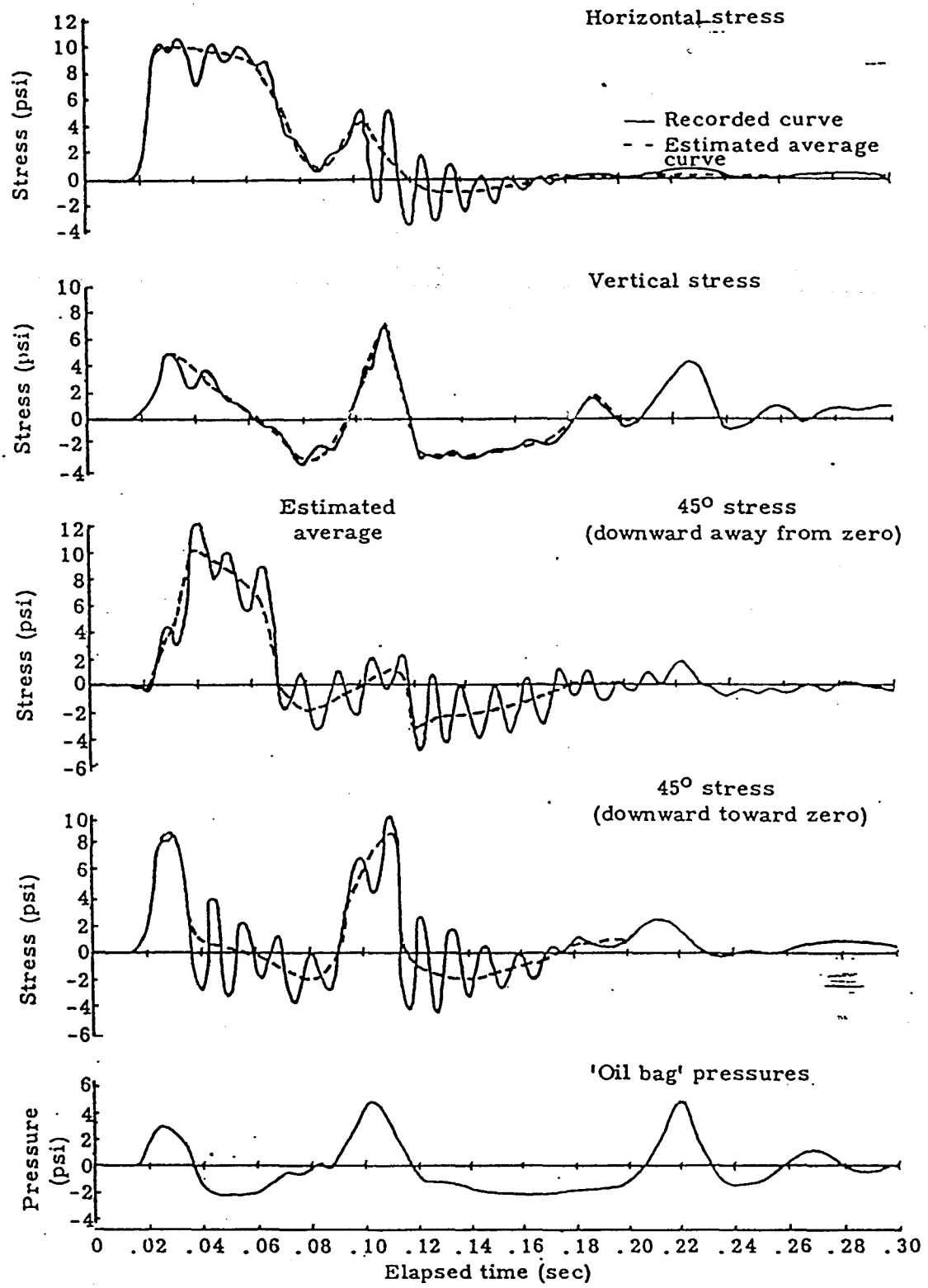

Fig. 2. -- Measured soil stress components (HE-3 test)

primarily for checking the instantaneous stress equilibrium, which requires that the sum of orthogonal stress pairs (vertical-horizontal and two 45° components) be equal. Both the rosette equations and Mohr's stress circle used for derivation of principal-stresses and other parameters are dependent only on equilibrium and continuity of stresses. Therefore the question of the degree to which elasticity and plasticity of the soil affect the propagation of the stresses is irrelevant to this phase of the study.

The rosette equations given by Taylor* in his discussion of earth-stress distribution provide a means for defining the state of stress within a medium independent of shearing stresses since they permit derivation of the principal stresses from certain measured normal stress components. These equations are important to the present problem since no practical instrument has been developed for measuring shear stresses in soils. The three equations given by Taylor are:

$$\sigma_1 - \sigma_3 = \sqrt{(\sigma_h + \sigma_v - 2\sigma_{45})^2 + (\sigma_h - \sigma_v)^2}$$

$$\sigma_1 + \sigma_3 = \sigma_h + \sigma_v$$

$$\tan 2\theta = (\sigma_h + \sigma_v - 2\sigma_{45})/(\sigma_h - \sigma_v)$$

The σ's represent normal stresses, and the subscripts define the directions of the stresses; 1 represents the major and 3 the minor principal stress direction; h, v, and 45 represent the horizontal, vertical, and 45° stress-component directions as measured. The angle θ represents orientation of the major principal stress with respect to a horizontal datum. The intermediate principal stress, σ_2, is defined here as the transverse or tangential component but is assumed to be negligible in this case. Measurements of the tangential stress component under static loading conditions have shown that when the stress condition is symmetrical, the tangential component of the stress is negligibly small.† The soil mechanics convention of representing compressive stresses as positive is used in this analysis. The maximum shear stress was also determined from the algebraic relation between it and the principal stresses for each 10-msec interval. The equation used was

$$\tau_{max} = \frac{1}{2}(\sigma_1 - \sigma_3)$$

where τ_{max} is the maximum shear stress.

The principal stresses, their orientation with respect to a horizontal datum, and the maximum shear stress may be derived graphically from data of the type obtained in the stress-component measurements by means of Mohr's stress circle. Mohr's stress circle for plane stress is based on the fact that the locus of the points representing the stress conditions on all planes through a point in a medium is a circle in an orthogonal coordinate system in which abscissae are normal stresses and ordinates are shear stresses. The axis of abscissae is a diameter of the circle, and by definition of principal stresses, the major and minor values of these parameters are at the two intersections of the circle with the axis of

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* Taylor, Donald W., Soil Mechanics Fact Finding Survey, Progress Report, Waterways Experiment Station, Vicksburg, Mississippi, April 1947, p 279

† Investigation of Pressures and Deflections for Flexible Pavements; Report No. 1 - Homogeneous Clayey-Silt Test Section, Technical Memorandum 3-323, Waterways Experiment Station, Vicksburg, Mississippi, March 1951

abscissae, where the shear stress is zero. The radius of the circle is equal to half the difference of the major and minor principal stresses. The center of the circle falls on the axis of abscissae at a distance from the ordinate axis equal to half the sum of the major and minor principal stresses. The maximum shear stress is numerically equal to the radius of the circle and is associated with a normal stress equal to half the sum of the principal stresses. Each point on the circle describes the associated normal and shear stresses which act on a plane whose direction with respect to the major principal plane is given by the angle between the axis of abscissae and a line joining the point to the major principal stress point. All these relations express graphically the same thing that the previously quoted equations express algebraically.

Construction of a Mohr stress circle for analysis of stress-component data such as that obtained in the HE-3 test follows the pattern described below and illustrated in Fig. 3. The data consist of the measured normal stresses at a specific instant at a point in the soil mass. The measured stresses act normal to planes which pass through the point in the soil mass and which are perpendicular to the radial plane containing the center of the explosive and the measurement point. The graphic representation of the measured normal stresses consists of three lines, the abscissae of which correspond to the measured values σ_h, σ_v, and σ_{45}, which are parallel to the ordinate axis. The points on these lines which represent the true stress condition are initially unknown in the absence of shear stress data. If, for purposes of construction, the plane of the graph is chosen to represent the radial plane in the soil mass, some point on the graph will correspond to the origin of stress planes (the measurement point in the soil). The trace of the vertical plane on which σ_h was measured will be the line on the graph representing σ_h, and the origin of stress planes will fall on that line. For convenience the position of this point is fixed arbitrarily, and the position of the axis of abscissae is left temporarily indeterminate. Two other lines, corresponding in direction to the traces of the planes on which σ_v and σ_{45} were measured, are plotted through the origin of planes and the intersection of these lines with the lines previously plotted at the abscissae for σ_v and σ_{45} are the points representing the true normal and shear stresses on the respective planes. Three points, the origin of planes and the two stress points (σ_v and σ_{45}) are thus known, and a circle determined by them is constructed. The center of this circle determines the position of the axis of abscissae, the intersections of which with the circle determine the major and minor principal stress magnitudes. The traces of the principal planes are represented by lines passing through the origin of planes and the principal stress points. The principal stress orientation is represented by the angle between the axis of abscissae and the normals to the principal planes. The point representing σ_h is the intersection of the circle with the line representing the trace of the vertical plane on which σ_h acts. This point will be on a common diameter with σ_v since the stresses are measured on orthogonal planes. Theoretically the two measured values of σ_{45} should also lie on a common diameter. However, because of measurement errors and other extraneous effects, this was not, in general, true, and since nothing in the data justified discrimination in favor of one of the 45° components, duplicate analyses were made for each time interval.

Discussion of Analyses

The results of both the algebraic and graphic analyses of the data from the HE-3 tests are presented in Table I. The second, third, fourth, and fifth columns contain the results derived from the rosette equations, and the remaining columns contain the corresponding graphically derived values. Duplicate values for each of the 10-msec time intervals are given because of the different σ_{45} values; the first set of data for each time interval is that determined

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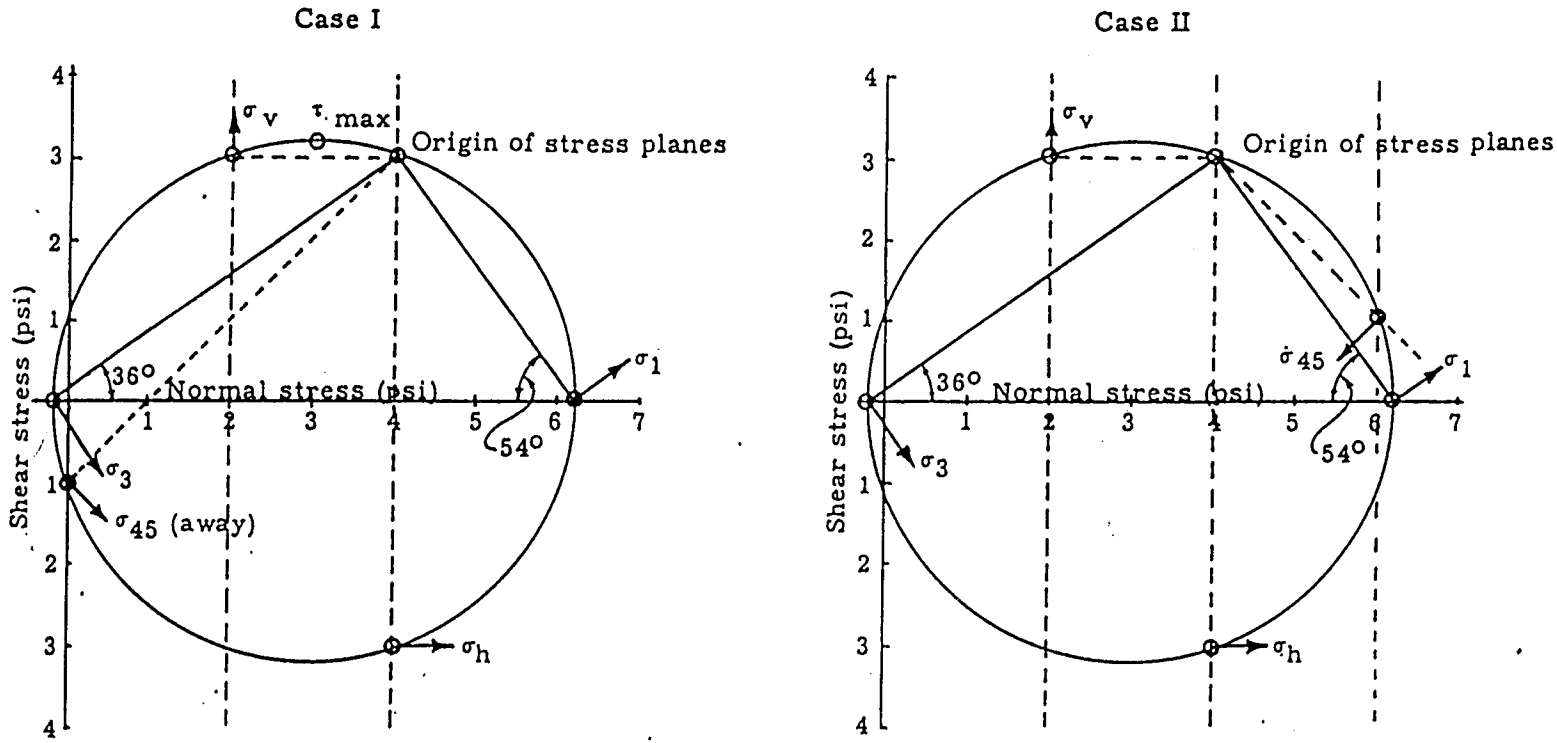

Data: Time: 0.10 sec
σ_h = 4.0 psi
σ_v = 2.0 psi
σ_{45} (away) = 0.0 psi (Case I)
σ_{45} (toward) = 6.0 psi (Case II)

Results: σ_1 = 6.2 psi at 36° counterclockwise
σ_3 = -0.2 psi at 54° clockwise
τ_{max} = 3.2 psi

Fig. 3. -- Graphic analysis of plane stress by Mohr circles as used for soil stress component measurements

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from the σ_{45} data measured in a direction downward away from zero, and the second set is for the σ_{45} data measured downward toward zero.

TABLE I

Results of HE-3 stress component measurements

Elapsed time* (sec)	Algebraic σ_1 (psi)	Algebraic σ_3 (psi)	Algebraic τ_{max}† (psi)	Algebraic $\theta_{\sigma 1}$‡ (°)	Graphical σ_1 (psi)	Graphical σ_3 (psi)	Graphical τ_{max} (psi)	Graphical $\theta_{\sigma 1}$ (°)
0.03	11.8	3.2	4.3	27.2	11.8	3.2	4.3	27 cc
	10.5	4.5	3.0	15.5	10.45	4.55	2.95	16 cc
0.04	11.3	2.8	4.25	22.5	11.25	2.75	4.25	22 c
	13.7	0.3	6.7	31.7	13.7	0.3	6.7	32 c
0.05	10.7	0.8	5.0	20.5	10.7	0.75	5.0	21 c
	12.2	-0.7	6.45	27.2	12.2	-0.7	6.45	27.5 c
0.06	9.7	-0.7	5.2	14.5	9.7	-0.7	5.2	14.5 c
	10.9	-1.9	6.4	22.5	10.9	-1.9	6.4	23 c
0.07	6.8	-1.8	4.3	17.8	6.8	-1.8	4.3	18 cc
	7.5	-2.4	5.0	22.5	7.5	-2.5	5.0	23 c
0.08	2.5	-3.5	3.0	15.5	2.4	-3.4	2.9	15 cc
	2.5	-3.5	3.0	15.5	2.4	-3.4	2.9	15 c
0.09	1.1	-2.1	1.6	9.2	1.1	-2.1	1.6	9 cc
	1.1	-2.1	1.6	9.2	1.1	-2.1	1.6	9 cc
0.10	6.1	-0.1	3.1	35.8	6.2	-0.2	3.2	36 cc
	6.1	-0.1	3.1	35.8	6.2	-0.2	3.2	36 cc
0.11	8.8	0.2	4.3	62.8	8.8	0.2	4.3	63 cc
	9.7	-0.7	5.2	59.5	9.7	-0.7	5.2	59 cc
0.12	3.0	-3.0	3.0	45.0	3.0	-3.0	3.0	45 cc
	1.0	-1.0	1.0	45.0	1.0	-1.0	1.0	45 c
0.13	-0.9	-3.1	1.1	13.3	-0.9	-3.1	1.1	13 cc
	-0.9	-3.1	1.1	13.3	-0.9	-3.1	1.1	13 cc
0.14	-0.9	-3.1	1.1	13.3	-0.9	-3.1	1.1	13 cc
	-1.0	-3.0	1.0	0.0	-1.0	-3.0	1.0	0
0.15	-0.4	-2.6	1.1	13.3	-0.4	-2.6	1.1	13 cc
	-0.4	-2.6	1.1	13.3	-0.4	-2.6	1.1	13 c
0.16	-0.4	-2.6	1.1	13.3	-0.4	-2.6	1.1	~~13~~ c
	-0.5	-2.5	1.0	0.0	-0.5	-2.5	1.0	0
0.17	0.1	-2.1	1.1	13.3	0.1	-2.1	1.1	13 c
	0.1	-2.1	1.1	13.3	0.1	-2.1	1.1	13 cc
0.18	0.1	-0.6	0.35	22.5	0.1	-0.6	0.35	23 cc
	0.5	-1.0	0.75	35.8	0.55	-1.05	0.8	36 cc
0.19	2.4	-0.4	1.4	67.5	2.4	-0.4	1.4	67.5 cc
	2.1	-0.1	1.1	76.7	2.1	-0.1	1.1	77 c
0.20	0.0	0.0	0.0	- - -	0.0	0.0	0.0	- - -
	1.0	-1.0	1.0	45.0	1.0	-1.0	1.0	45 cc

*Time elapsed after detonation

† τ_{max} = Maximum shear stress

‡ $\theta_{\sigma 1}$ = Orientation of major principal stress with respect to horizontal in direction away from explosion (c = clockwise, cc = counter clockwise)

Variation of the major and minor principal stresses, the orientation of the major principal stress, and the maximum shear stress as functions of time are plotted in Fig. 4. The duplicate values mentioned in the previous paragraph are plotted for each parameter. The orientations of the minor principal stress and maximum shear stress were not included in the table or graphs since by definition and construction they differ from the major principal stress orientation by 90° and 45°, respectively.

Comparison of appropriate columns of Table I indicates that the algebraic and graphic analyses give essentially identical results. This is, of course, to be expected since both methods are based on identical premises and follow similar channels of development. The agreement serves only as verification.

The differences found in the various parameters as a result of analysis using the two measured 45° components requires consideration of the precision of the measurements and of the significance of the stress equilibrium check previously mentioned. The gauges were designed for and used at a set maximum range of 15 psi. Static calibration data and characteristics of both the end instruments and recorder channels indicate that a precision of ± 2 per cent might be expected from those components. However, uncertainties and inhomogeneities involved in placement of the gauges within the soil mass, the assumption of equality of stress patterns for gauges separated laterally as necessitated by the finite size of gauges, and the assumption of an average curve through the 'ringing' portion of the records all indicate a much greater probable error. A reasonable estimate for the over-all precision of the measurement is probably 25 per cent. Some indication of the extent to which this estimate of precision is met by the measured stresses can be derived from the instantaneous stress equilibrium check. A study of the differences between the sums of the two pairs of orthogonal stresses measured shows that of the 18 sets of data read from the records, the differences were zero for 3 sets, less than 20 per cent of the larger sum for 9 sets, and 25 per cent or less of the larger sum for 11 sets. The differences between the sums of the orthogonal stress pairs for the seven sets of data not mentioned above varied from 50 to 200 per cent of the larger sum. In general agreement was poorer where the measured stresses were very small, and the error might be expected to be equal to or greater than the measured value. This evidence suggested that the estimates of error are reasonable and that in general the data fall within the limits of error.

The graphs of the principal stresses, orientation, and maximum shear stress (Fig. 4) indicate clearly the differences in computed parameters derived from the two 45° components. It is evident that for none of the data plotted are the duplicate values of stress different by more than 2.5 psi, and the average difference is less than 0.7 psi. The agreement between the values derived from the two 45° components for orientation of σ_1 with respect to the horizontal datum is not so close as for the principal stress. However, the major discrepancies are found to be associated with certain other features of the data which decrease their reliability. At the six points where duplicate data show wide differences in angle involving opposite signs the difference in the sums of the orthogonal stress pairs is very large; in most instances the difference is greater than 100 per cent of the larger sum. For all other points the angular values, although not so generally in exact agreement as the stress values, are sufficiently close to indicate a usable pattern of variation of the principal stress direction in a general stress analysis.

A consideration which is pertinent to the use of the data is the fact that for times after detonation greater than 0.12 sec the magnitudes of the principal stresses are sufficiently small to be considered negligible in terms of the magnitudes of the same stresses during the periods from 0.03 to 0.08 sec and from 0.10 to 0.12 sec. This means, from the practical viewpoint, if structures have not been damaged or seriously weakened by the 10-14-psi pressures during the peak-pressure period, they are not likely to be adversely affected by lower pressures later.

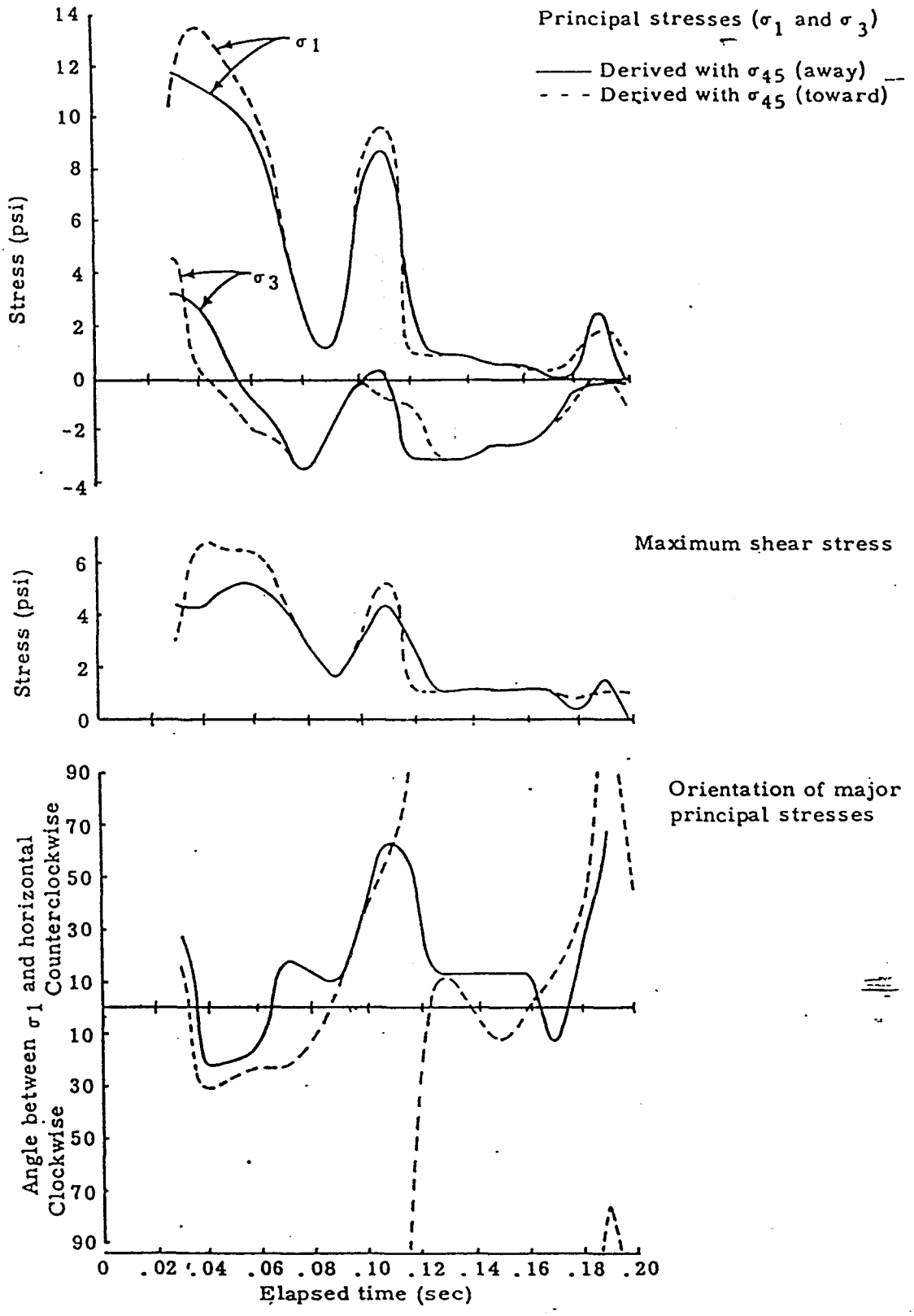

Fig. 4. -- Principal stresses and maximum shear stress (HE-3 test)

This, of course, refers to purely pressure effects on structures and does not consider the acceleration effects, which may be considerably different.

One characteristic of the data and results of these stress-component measurements which must be discussed in the light of soil characteristics is the negative values of measured normal stresses and derived principal stresses. According to the sign convention previously stated negative values of stress must correspond to tensile stresses. Ordinarily soils can support very little or no tensile stress. This is particularly true of dry, floury soils such as those involved in these tests. However, consideration of the placement of the gauges indicates that they are subjected to an initial pressure equal to the overburden load, or approximately 3.5 psi. Hence the static or dynamic-zero pressure indicated by the records acts on the gauges as an actual compressive stress of about 3.5 psi vertically and 1.5 psi horizontally. Thus all negative dynamic stresses numerically less than these static pressures are in reality dynamic reductions of the static stress and do not subject the soil to real tensile stresses. In the graphical analyses this means essentially that the ordinate axis, as plotted, is displaced by an amount of 3 psi more or less beyond the true zero for the total stress condition. These analyses are intended, however, to represent only the dynamic stresses produced by the underground explosion.

The significance of the factors discussed in the foregoing paragraph lies principally in the usefulness of the data for general stress analysis or for engineering studies of effects on structures. For the first of these the spatial distribution of the principal stresses for the total stress condition within the soil mass is desired. This requires the determination of the magnitudes and orientations of the total principal stresses attributable to both static and dynamic loading at a number of points within the soil mass. The total principal stress at a point may be derived by either of two methods -- addition of measured static and dynamic normal stress components prior to derivation of the principal stresses or addition of the static principal stresses and dynamic principal stresses with due regard for their differences in direction as well as magnitude. For engineering studies of effects on structures, knowledge of the distribution of total principal stresses or of the dynamic principal stresses will permit determination of the distribution of stress over the structure as a consequence of the underground explosion.

Conclusions

The data and results of the stress-component measurements made as a part of the HE-3 test have demonstrated the feasibility of measuring stress components in such manner as to permit derivation of principal stresses caused by underground explosions.

Precision of the data was evidently sufficient to give relevant results within the range of 5 to 15 psi. Increased precision would be desirable, but its attainment is somewhat doubtful because of the strong influence of natural inhomogeneities in the soil and the necessity for separating the gauges laterally.

The experiment established the feasibility of deriving curves representing the principal stresses, maximum shear stress, and directional variation of these parameters as functions of time by computation using data read from the oscillograph records of the stress components.

Recommendations

These recommendations are made as a result of this study of stress-component measurements:

Several similar tests involving one or two stations of stress-component measurement should be included in future test programs to establish further the validity and usefulness of such measurements.

Measurements of the type described should be made in connection with both underground and aerial explosive tests in sufficient number and with such lateral and depth distribution as to establish the pattern of stress distribution within the soil mass subject to the more serious effects of such explosions. It seems reasonable to expect that radial and depth distribution should be sufficient to define the stress pattern, but check points on several radii should be included in any test program to indicate possible influences of inhomogeneities in the soil mass.

It is suggested that a program for determination of stress distribution in soil could be satisfactorily accomplished using relatively large high-explosive charges.

Several tests should be made to determine the feasibility and pertinence of measuring stress components suitable for derivation of the three principal stresses.

The problem of instrumentation for stress-component measurement should be further studied from the standpoint of determining the necessary and sufficient instrument characteristics for such measurements and finding or developing instruments capable of meeting these required characteristics.

The feasibility of measuring soil-strain components in a manner similar to the soil-stress component measurements should be investigated as a means for determining the stress-strain phase relation in ground shock and to obtain information for establishing the validity of the elastic and plastic wave theory for ground-shock studies.

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57-66/110	AFSWP, Attn: Col. Blunda
67-68/110	Office, Chief of Engineers, US Army Asst. Chief of Engineers for Military Operations Asst. Chief of Engineers for Civil Works
69/110	Chief, Budocks, Attn: Lcdr. Rockefeller
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71/110	R. W. Carlson, Berkeley
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86/110	The Rand Corp., Attn: Dr. J. J. Gilvarry
87/110	Executive Secretary, Research and Development Board, Department of Defense, Washington, 25, D.C.
88/110	Office of Secretary of Defense, Weapons Systems Evaluation Group, Room 2E1006, Pentagon, Washington, ~~Dr~~C.
89/110	Col. Skidmore, Director of Waterways Experiment Station, PO Box 631, Vicksburg, Mississippi.
90/110	W. A. MacNair, 5000
91/110	R. P. Petersen, 5100
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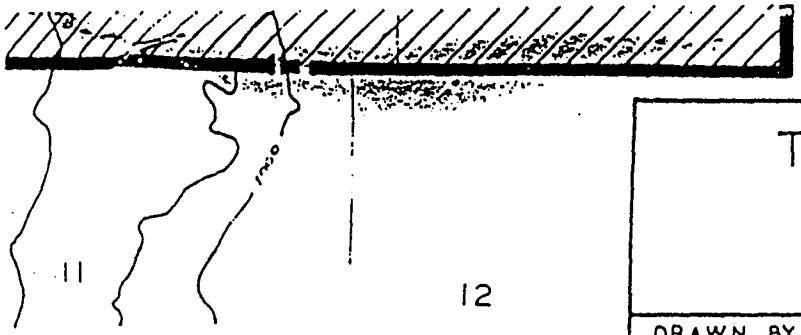
R. 6E



THE OFFICE OF THE BASE ENGINEER
SANDIA BASE
ALBUQUERQUE, NEW MEXICO

DRAWN BY	NJM
TRACED BY	NJM
CHECKED BY	RAR
SUBMITTED	[signature] ENGINEERING SECTION

BASIC INFORMATION

RESERVATION BOUNDARY AND OWNERSHIP

PLANT ENGINEERING SANDIA CORPORATION BY MBM	[signature]	RECOMMENDED [signature] BASE ENGINEER LT. COL. U.S.A.F.	SCALE 1 25,000	DATE 7 OCT. 1954
ENTS)	[signature]	APPROVED [signature] COL. ARMOR, COMMANDING	FILE NUMBER BI-RB-25	PLATE NUMBER 2
S THIS DATE	[signature]	DATE 7 OCT. 1954		
	[signature]			
CRIPTION	APP'D			

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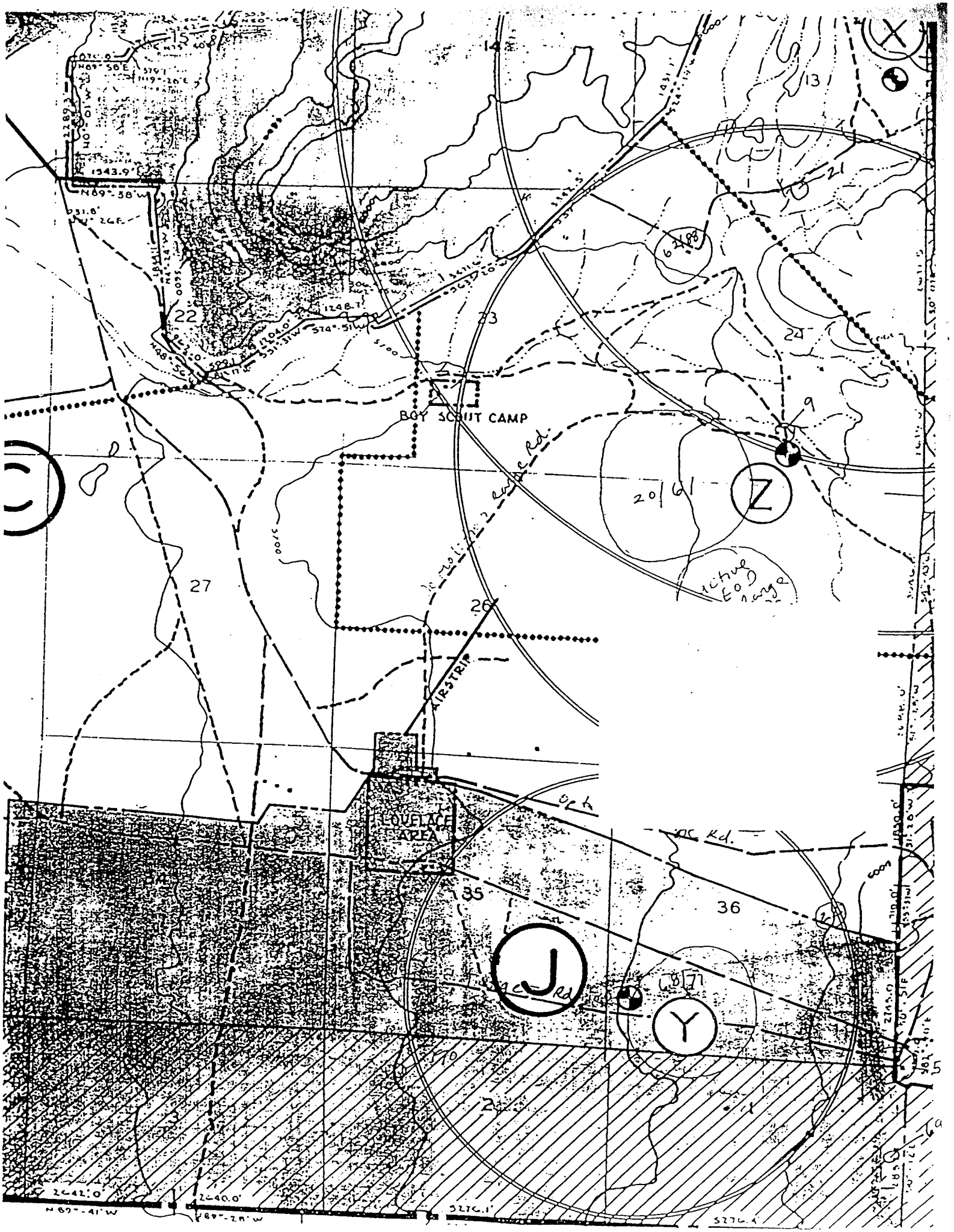

BOY SCOUT CAMP
AIRSTRIP
LOVELACE AREA
Z
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