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MATERIAL RESPONSE CHARACTERIZATION

by

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Material response characterization is discussed from the viewpoint of its impact on the results obtained from free-field ground shock calculations. Selected field and laboratory test data are used in conjunction with calculational results to illustrate the influence of anisotropy, tension cutoff criteria, lithostatic stress fields, loading rate sensitivity, high pressure shear behavior, residual strength or post-failure response, and pore water

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20. ABSTRACT (Continued).

pressure. The pitfalls involved in overgeneralization of geologic material property test results, reliance on data of limited type and source, and failure to understand the basic mechanisms contributing to observed responses are emphasized.

PREFACE

This paper was prepared to document a presentation given during Session II--Weapons Effects Phenomenology--of the Defense Nuclear Agency (DNA) Strategic Structures Division Biennial Review Conference held at the Stanford Research Institute, Menlo Park, California, on 8-10 February 1977.

The purpose of the presentation was to point out some basic lessons learned from experience during the past few years about material response characterization, to identify some of the outstanding problem areas as brought into focus by recent efforts, and to highlight some of the relevant research currently being pursued for DNA by several laboratories.

The presentation was prepared by Dr. J. G. Jackson, Jr., following a series of discussions with colleagues at Terra Tek, Inc., Stanford Research Institute, the Air Force Weapons Laboratory, and his immediate associates in the Soil Dynamics Division of the Soils and Pavements Laboratory (S&PL), U. S. Army Engineer Waterways Experiment Station (WES). Their many contributions are gratefully acknowledged and very much appreciated.

Messrs. J. P. Sale and R. G. Ahlvin were Chief and Assistant Chief, respectively, of S&PL during the preparation of this paper. The Director of WES was COL J. L. Cannon, CE, and the Technical Director was Mr. F. R. Brown.

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
pounds (mass)	0.4535924	kilograms
tons (2000 lb, mass)	907.1847	kilograms
feet per second	0.3048	metres per second
pounds (force) per square inch	6894.757	pascals
kips (force) per square inch	6894.757	kilopascals
bars	100	kilopascals
kilobars	100	megapascals
degrees (angle)	0.01745329	radians

MATERIAL RESPONSE CHARACTERIZATION

Viewgraph 1

In 1969, I described the relatively low pressure uniaxial strain (UX) and triaxial shear (TX) test data then being obtained in the laboratory and the various assumptions and adjustments required to develop constitutive properties for the EIP models that were being used in ground shock calculations.[1] A typical application in those days involved an AI-only calculation of near-surface, superseismic motion.

Comparison of vertical particle velocity measurements from PRAIRIE FLAT with 2D code calculation results tends to indicate that this rather simplified material response characterization based primarily on vertically oriented UX tests is not too bad.[2] The 1D code result indicates why, i.e., the material at the gage location was essentially being subjected to a plane vertical stress wave.

But then we became interested in relatively stiff multi-layered soil/rock sites, craters and crater-induced effects, outrunning regions and deep motions.

Viewgraph 2

The solid lines show measured time of arrival contours and a vertical particle velocity wave form from the MIXED COMPANY III event. The preshot calculated arrivals (dashed lines) indicated that we had some material characterization problems--and the wave form comparisons proved it.[3,4]

If there is anything that we should have learned from the MIDDLE GUST/ MIXED COMPANY experience, it is the following:

a. We should not overly generalize or grossly extrapolate our data. The mechanisms or properties that dominate response in one problem simply cannot be trusted to dominate response in other problems--especially physically dissimilar ones.

b. We should not rely solely on data of any one type or from any one source. We need both laboratory tests and in situ tests; both have limitations that we should identify--and errors that we should quantify.

c. We should work as hard at analyzing our data as we do at collecting it--and just as hard at understanding why we get what appears to be a right answer as we do at what appears to be a wrong one.

The following viewgraphs should amplify these lessons as well as provide some relevant "material characterization" information with regard to the outstanding modeling problems previously listed by Dr. Sandler.[5]

Viewgraph 3

The solid lines show horizontal stress and displacement output from a postshot MIXED COMPANY calculation performed with isotropic models fit to vertical UX and TX data and a mean stress tension cutoff criterion. Because tests on the Kayenta sandstone materials had revealed a definite horizontal-to-vertical anisotropy,[6] a transverse isotropic version of the cap model was formulated and the horizontal stiffnesses were increased in accord with the available data trends[7] (e.g., hydrostatic $\varepsilon_r/\varepsilon_z = 0.6$ for the weathered rock). Vertical properties remained essentially the same as those for the isotropic model. The transverse isotropic calculation with the same mean stress tension cutoff (dashed line) clearly demonstrates, at least for this problem, that anisotropy is an important material characteristic.

The transverse isotropic calculation was then rerun, but with a principal stress, rather than a mean stress, tension cutoff. In the calculation with the mean stress cutoff criterion, whenever the mean stress at a point exceeded the specified cutoff value, it was corrected and the deviators were set to zero. In the calculation with the principal stress cutoff criterion, the principal stresses were monitored and corrected individually. From a purely physical sense, the principal stress cutoff criterion is more appealing than the simple mean stress cutoff. In any event, the dotted versus dashed line comparisons clearly demonstrate the impact that the somewhat arbitrary choice of a tension failure criterion can have on calculational events.

Viewgraph 4

Terra Tek has developed a set of transverse isotropic properties for MIXED COMPANY sandstone based on data obtained from both field and laboratory experiments. They coupled uphole and crosshole field seismic data with ultrasonic wave velocities measured in laboratory specimens at various angles to the bedding planes to determine the necessary five elastic moduli.[8] They used failure data from TX tests at different specimen angles to determine values for the five transverse isotropic failure surface parameters.[9] This data characterizing the anisotropic response of the upper 30 feet of Kayenta material should not just be filed away; it should be used in a MIXED COMPANY ground motion calculation.

Viewgraph 5

An isotropic cap model was recently fit to some WES data from vertically oriented specimens of Frenchman Flat silt. A plane strain CIST calculation with a -1 bar mean stress tension cutoff and one with a -1 bar principal stress cutoff gave essentially the same peak radial displacement versus range profile, even though at the 1/2-metre range in the p-cutoff calculation, the material was experiencing a totally unrealistic tangential tension of 167 bars, while p was still greater than -1 bar.

The hydrostat data indicated stiffer radial than vertical response, which was fit with the transverse isotropic cap model without changing the vertical properties from those specified for the isotropic model. A transverse isotropic calculation with a p-cutoff decreased the peak displacements significantly; shifting to a principal stress cutoff caused the displacements to increase. These trends are exactly opposite to those shown in Viewgraph 3. Results such as these should caution us in regard to iterative model fitting to be sure that we are iterating on the right properties.

Viewgraph 6

Assumptions regarding initial or lithostatic stress fields can also affect calculational results. The easiest thing to do is to assume a hydrostatic gravity condition, since the actual stresses are difficult, if not impossible, to measure. Terra Tek, however, conducted a series of large strain-relieved block experiments in a rock outcrop near the MIXED COMPANY site and concluded that the near-surface horizontal in situ stresses could be as high as 700 or 800 psi.[10]

In order to get a feel for the possible influence of such a stress field on a MIXED COMPANY-type problem, WES performed calculations for a 500-ton HE airblast sweeping over an elastic-ideally plastic half space.[11] Initial vertical stresses were purely gravitational, i.e., $\sigma_z = \gamma Z$; horizontal stresses were defined by $A\gamma Z + B$, where $A\gamma Z$ represents the gravitational component and B an "excess" lithostatic or "locked in" component. The solid lines depict tangential stress, radial stress, and radial displacement at the R = 110 ft/Z = 5 ft location for the hydrostatic gravity case (i.e., A = 1 and B = 0); first the tangential and then the radial stress hit the 5 psi tension limit. When an excess lithostatic stress of 750 psi was specified, the dashed line results were obtained.

It seems clear that lithostatic stresses could have significantly influenced the MIXED COMPANY results. And, if so, what could they do to a deep-basing problem? But we ought to avoid assuming that lithostatic stresses have to be large in order to cause problems. Small lithostatic stress reliefs can significantly alter the response of laboratory test specimens--and redistributions around CIST cavities and gage boreholes may be doing more to us than we realize.

Viewgraph 7

Laboratory/in situ property correlations may be influenced by loading rates. The dynamic and static UX test results reported for a low-modulus sandy clay stratum with about 10 percent air voids at MINUTEMAN Wing V Site D-1 are shown by the solid and short dashed lines, respectively.[12] The dynamic tests had rise times to peak stress of 7 and 9 msec; the static test comparison does not indicate much, if any, rate sensitivity.

AFWL conducted a CIST test at this site[13] and deduced properties from their gage measurements (long dashed lines) which compare favorably with the laboratory results.[14] They also made a stress measurement in the stratum which indicated a rise time to 1000 psi of about 3 msec, in reasonable agreement with the dynamic laboratory testing rates.

Viewgraph 8

There were three field tests in the clay stratum just below the groundwater table at the Pre-DICE THROW II site. SRI fired two 256-lb spherical charges at a depth of 3.7 m, and used their LASS technique to deduce peak radial stress/volumetric strain points.[15] Spherical loading behavior is essentially UX, and if the material is rate independent, the connected points define UX stress-strain relations. Loading times ranged from 10 to 24 μsec. AFWL conducted a CIST at the Pre-DICE THROW II site and deduced a UX relation for the 3.7-m depth.[16] They also had a stress gage at the 2.4-m range which indicated a rise time of about 0.1 msec to 0.29 kbar (cross).[17] WES conducted dynamic UX tests up to 3.5 kbars on specimens from two different borings and obtained another relation.[18] The laboratory loadings reached their peaks in 40 to 60 msec.

The data seem to be consistent and of good quality, with the only obvious difference being the loading rates. The key question then is "what are the loading rates in the event being calculated?" An SRI stress measurement at the 1.9-m range and 3.7-m depth in Pre-DICE THROW II Event 1 hit a peak of 8.9 kbars in 20 μsec (triangle),[19] in good agreement with the LASS data. A WES measurement at the 24.4-m range hit a peak of 0.24 kbar in about 0.3 msec (square),[20] in reasonable agreement with the CIST measurement. But the WES multi-millisecond laboratory loadings are definitely too slow for water-shocked soils. A UX device with a 1/10 msec rise time capability is currently being developed which should help. It would also help to have more data regarding the actual stress rates being experienced by the earth materials in various regions of interest during specific explosive events.

Viewgraph 9

High pressure shear failure also deserves attention. Our usual assumption that shear failure envelopes reach a von Mises-type limit at a pressure generally associated with air void closure does not fit the static TX data for MIXED COMPANY sandstone obtained by LLL.[21] Failure was defined by LLL as the maximum stress difference if that occurred before the axial strain reached 5 percent, or the stress difference at 5 percent axial strain. The solid circles indicate maximum stress differences obtained by Terra Tek which occurred at axial strains of 15 to 20 percent;[22] their stress difference values at 5 percent axial strain fall on the LLL envelope.[23]

The LLL data for MIDDLE GUST weathered shale show a dramatic increase in strength at pressures above a kilobar.[24] The stress difference values given for 5 percent and 10 percent axial strain illustrate how a failure envelope can vary with the definition of failure. The WES TX test data on unweathered MIDDLE GUST shale indicate a lot of "character" that cannot possibly be describe by a single point in $\sqrt{3J_2'}$ versus p space.[25] The dynamic test reached peak load in about 25 msec; SRI is currently developing an oblique plate impact technique which, hopefully, will provide some high pressure shear data for μsec loadings.[26]

Viewgraph 10

Post-failure response or residual strength is in vogue since AFWL indicated that their crater calculations correlated better with both KOA and MIXED COMPANY observations when, after an initial failure, the failure surface was lowered by eliminating the cohesive strength component.[27] The physical rationale for this is that some initial loading (such as an early airblast-induced pulse) fractured the material and that subsequent waves (direct induced or deep reflected) passed through broken rather than intact coral or sandstone.

WES has recently completed a series of residual strength tests for AFWL on HARD PAN sedimentary rocks. The sandstone specimen was failed under a confining pressure of 64 bars; then the failed specimen was dynamically retested under the same confining pressure. The three limestone tests show a continual degrading of strength with post-failure strain, which indicates that not only the magnitude of the initial failure load, but also its duration will affect response to a follow-on wave. The shale test was conducted on a specimen that already contained discontinuities in the form of horizontal bedding planes. To see what kind of strength the "fresh joint" could support, a multi-stage static TX test was run on the failed specimen and a residual strength envelope plotted. This type characterization may help with jointed rock, block motion and interface slip studies.

Viewgraph 11

Of more current concern to those developing constitutive models for MX is the residual strength of alluvial sands due to a breakdown of cementation. Dynamic UX tests and static TX failure data are available for a cemented, fine-to-coarse sand with gravel from Luke Bombing and Gunnery Range (LBGR). AFWL ran a CIST test at NTS Area 10 in a similar material[28] and deduced similar properties for use in their baseline MAP calculations.[29] After an initial failure, the MAP model failure envelope is dropped to a parallel line passing through the origin, to represent a loss of cohesion or breakdown of cementation. In this case cohesion is small, so the residual failure envelope in the model is essentially the same as the intact envelope.

WES just conducted a series of tests on the LBGR material after it had been thoroughly pulverized to remove the cementation and remolded to the in situ density. The results tend to confirm the relatively negligible effect on residual strength; but they also indicate that post-failure stress-strain behavior should be given some consideration by the modelers.

Viewgraph 12

And last, but not least, is pore fluid effects. Effective stress theory is a proven concept used in engineering practice to explain the mechanical response of saturated soils and rocks to low pressure loadings. It simply states that the total stress acting on an element of soil or rock with interconnecting pores is equal to the pore fluid pressure plus the intergranular or effective stress. In these recent tests on MIXED COMPANY sandstone, Terra Tek shows that the effective stress law holds for pressures up to 4 kbars during both hydrostatic and shear loadings.[30] "Dry" in this instance means an initial saturation of about 50 percent, so presumably the structure is lubricated as it would be in the conventional "saturated-drained" case.

Viewgraph 13

Having noted that in calculations of spherically symmetric wave propagation from an underground cavity that the strain response at some distance from the source is predominantly radial compression in UX followed by lateral extension at approximately constant axial strain (CX),[31] Terra Tek applied UX load-CX unload conditions to specimens of dry and saturated tuff and to dry and saturated MIXED COMPANY sandstone.[32] In both cases, they observed that upon initiation of CX unloading, the dry paths went up on a negative slope in accord with elastic theory until they reached and followed an apparent limiting failure surface. The saturated paths, on the other hand, unloaded on a positive slope, which elastically implies negative shear moduli, etc.

In terms of effective stress, however, the results are quite logical. The dashed line is the MIXED COMPANY sandstone effective stress failure envelope replotted from Viewgraph 12. The dry rock path indeed moves up until it reaches this envelope and then follows it. The saturated path never left it, i.e., the confining pressures being applied and released simply increased and decreased the pore pressures. An "elastic" analogy is just not adequate for this two-phase behavior.

Viewgraph 14

AFWL's CIST-deduced model for a sand stratum below the groundwater table at the Pre-DICE THROW II site has two failure surfaces,[16] but the physical rationale for intact-residual failure surfaces is not obvious for this case. Nevertheless, as indicated by the horizontal velocity wave forms calculated for the 25-ft range, using the two-surface model gave the best fit to the

CIST data.[33] As indicated by the Mohr stress circles, WES total stress TX data[18] tend to confirm the CIST-deduced initial failure surface.

The profile shows in situ stress conditions at the site. At gage depth, the total stress is approximately 1.5 bars, the pore water pressure 0.5 bar, and the intergranular or effective stress approximately 1.0 bar. A Mohr stress circle with a minor principal stress of 1.5 bars was constructed tangent to AFWL's initial failure surface. This circle was then translated to an effective minor principal stress of 1.0 bar and a postulated effective stress envelope drawn tangent to it and through the origin; the resulting effective Ø-angle of 35.6^{o} is quite reasonable for this material.

In order for this effective stress envelope to explain AFWL's observed loss of shear strength (i.e., down to something on the order of 0.6 bar), the intergranular stress must drop below its initial value of 1.0 bar. A reasonable postulate is that as the CIST pulse propagated out through the saturated sand, the overlying soils tended to move up and relieve the gravity-induced initial intergranular stress, thus causing the strength to drop and the sand to flow, i.e., blast-induced liquefaction.

If a stratum of this same sand were to be located at a depth of 300 ft and subjected to loadings from a nuclear burst, as is being assumed in the baseline MAP calculations,[29] it may or may not experience a similar flow. It might help us find out if we were able to perform effective stress calculations.

Viewgraph 15

The closing comment from the 1969 presentation is quoted;[1] it still seems to be an appropriate closing, even for 1977.

References

1. Jackson, J. G., Jr., "Analysis of Laboratory Data to Derive Soil Constitutive Properties," WES MP S-69-16, Apr 1969.

2. Zelasko, J. S., and Baladi, G. Y., "Free-Field Code Predictions Versus Field Measurements: A Comparative Analysis for the PRAIRIE FLAT Event," WES MP S-71-6, Mar 1971.

3. Bratton, J. L., "MIDDLE GUST-MIXED COMPANY Comparisons," Proceedings of the MIXED COMPANY/MIDDLE GUST Results Meeting 13-15 March 1973, Vol II, DASIAC DNA 3151P2, May 1973.

4. Sandler, I. S., et al, "Ground Motion Calculations for the MIXED COMPANY Event of the MIDDLE NORTH Series," WES CR S-74-4 by Weidlinger Associates, Oct 1974.

5. Sandler, I. S., "Material Models and Ground Shock," DNA (SPSS) Biennial Review Conference at SRI, 8-10 Feb 1977.

6. Ehrgott, J. Q., and Jackson, J. G., Jr., "Material Properties for Postshot MIXED COMPANY Analyses: Recommendations Based on Recent Laboratory and In Situ Test Data," WES MP S-74-1, Jan 1974.

7. Baladi, G. Y., "Transverse Isotropic Constitutive Model Equations and Fitting Parameter Values Used for Postshot MIXED COMPANY Calculations," WES report to DNA, Feb 1974.

8. Johnson, J. N., Lingle, R., and Swolfs, H. S., "The Determination of In Situ Anisotropic Elastic Moduli from Laboratory Ultrasonic and Field Seismic Measurements," Terra Tek DNA 3840T, Jun 1975.

9. Johnson, J. N., et al, "Anisotropic Mechanical Properties of Kayenta Sandstone (MIXED COMPANY Site) for Ground Motion Calculations," Terra Tek TR 74-61, Dec 1974.

10. Pratt, H. R., et al, "Experimental and Analytical Study of the Response of Earth Materials to Static and Dynamic Loads," AFWL TR-75-278 by Terra Tek, May 1976.

11. Baladi, G. Y., et al, "The Effects of Lithostatic Stress Fields on CIST and HE Surface Burst Code Calculations," WES report for DNA Material Properties Meeting, Salt Lake City, Utah, 21 Nov 1975.

12. Chisolm, E. E., et al, "Material Property Investigation of Wing V Site D-1: Subsurface Exploration and Laboratory Test Results (U)," WES TR S-75-18, Dec 1975.

13. Wooley, J. A., "MINUTEMAN Cylindrical In-Situ Test (CIST) Events Data," AFWL TR-76-44, Nov 1976.

14. Bratton, J. L., private communication of extracts from draft AFWL report on CIST 3 analysis to J. G. Jackson, Jr., 13 Jan 1977.

15. Rosenberg, J. T., LASS technique and results presentation, DNA Material Property/Ground Shock Meeting, 3 Aug 1976.

16. Ullrich, G. W., AFWL (DES-C) letter to WES dated 17 Jun 1976, subject: Transmittal of CIST-15 Calculation Results.

17. Wooley, J. A., "CIST 15 Experimental Data, White Sands Missile Range, DICE THROW Test Site, 16 July 1975," AFWL data package, Dec 1975.

18. Jackson, A. E., Jr., and Peterson, R. W., "Material Property Investigation for Pre-DICE THROW I and II: Results from the Laboratory Testing Programs," WES report to DNA, Nov 1976.

19. Murri, W. J., and Smith, C. W., "Stress Gage Measurements on Pre-DICE THROW II," draft SRI report to DNA, Aug 1976.

20. Murrell, D. W., private communication of WES stress gage records from Pre-DICE THROW II to J. G. Jackson, Jr., 25 Jan 1977.

21. Duba, A. G., et al, "High-Pressure Mechanical Properties of Kayenta Sandstone," LLL report UCRL-51526, 5 Feb 1974.

22. Green, S. J., et al, "The Stress-Strain and Failure Response of MIXED COMPANY Sandstone," Terra Tek TR-72-33, Nov 1972.

23. Swift, R. P., "Examination of the Mechanical Properties for a Kayenta Sandstone from the MIXED COMPANY Site," Physics International DNA 3683F, Jul 1975.

24. Bonner, B. P., et al, "High Pressure Mechanical Properties of Shales and Regolith from the MIDDLE GUST Site," LLL report UCID-16103, 1 Sep 1972.

25. Knott, R. A., "Effect of Loading Rate on the Stress-Strain Characteristics of a Clay Shale in Unconsolidated-Undrained Triaxial Compression," WES MP S-73-68, Dec 1973.

26. Gupta, Y. M., "Development of a Technique for Measuring Dynamic Shear Properties of Materials (Phase I)," SRI report to DNA, Dec 1976.

27. Ullrich, G. W., "The Mechanics of Central Peak Formation in Shock Wave Cratering Events," AFWL TR-75-88, May 1976.

28. Davis, S. E., "Nevada Test Site CIST Events Data," AFWL TR-74-131, May 1974.

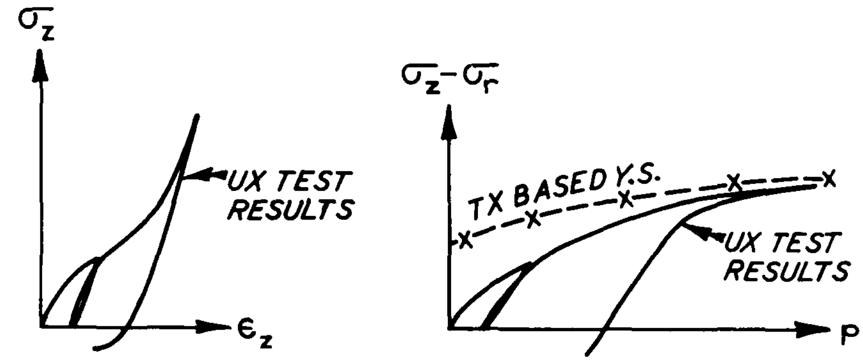
29. Ullrich, G. W., AFWL (DES-C) letter to DNA (SPSS) dated 27 Sep 1976, subject: Transmittal of MAP Material Model.

30. Dropek, R. K., "Data Summary for the Measurement of Failure Strength of Rock Under Conditions of Nonzero Pore Pressure," Terra Tek TR 76-53, Oct 1976.

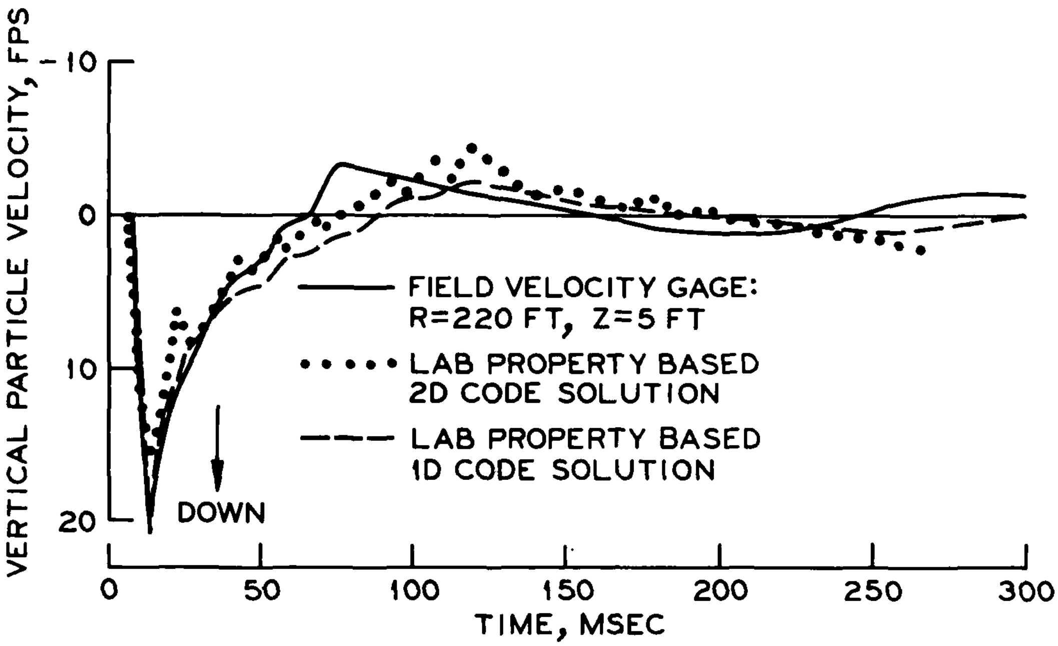
31. Johnson, J. N., and Schmitz, D. R., "Calculation of Stress and Strain Paths for Laboratory Testing of Geological Materials," Terra Tek TR 76-39, Jul 1976.

32. Johnson, J. N., and Dropek, R. K., "Measurement and Analysis of Pore Pressure Effects in the Inelastic Deformation of Rocks," Terra Tek DNA 3839T, Oct 1975.

33. Ullrich, G. W., AFWL CIST 15 calculation results (problem Nos. 1507 and 1508) telecopied to J. G. Jackson, Jr., 21 Jan 1977.

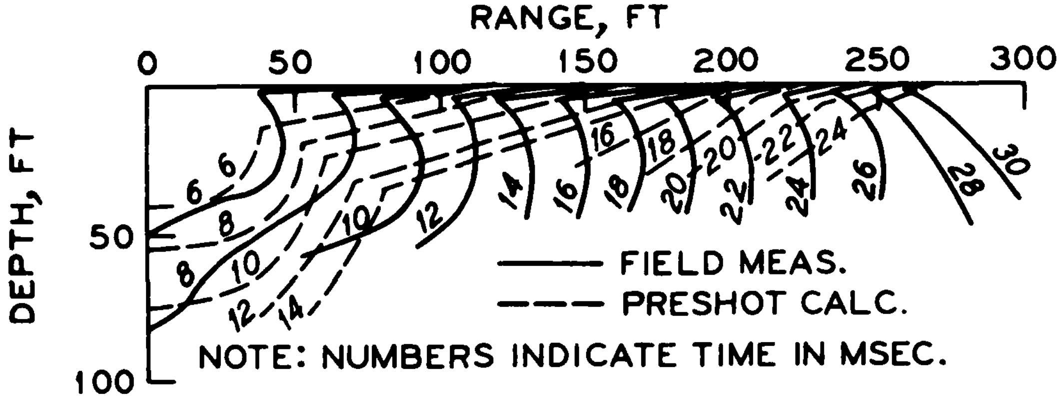


MATERIAL RESPONSE CHARACTERIZATION-1969

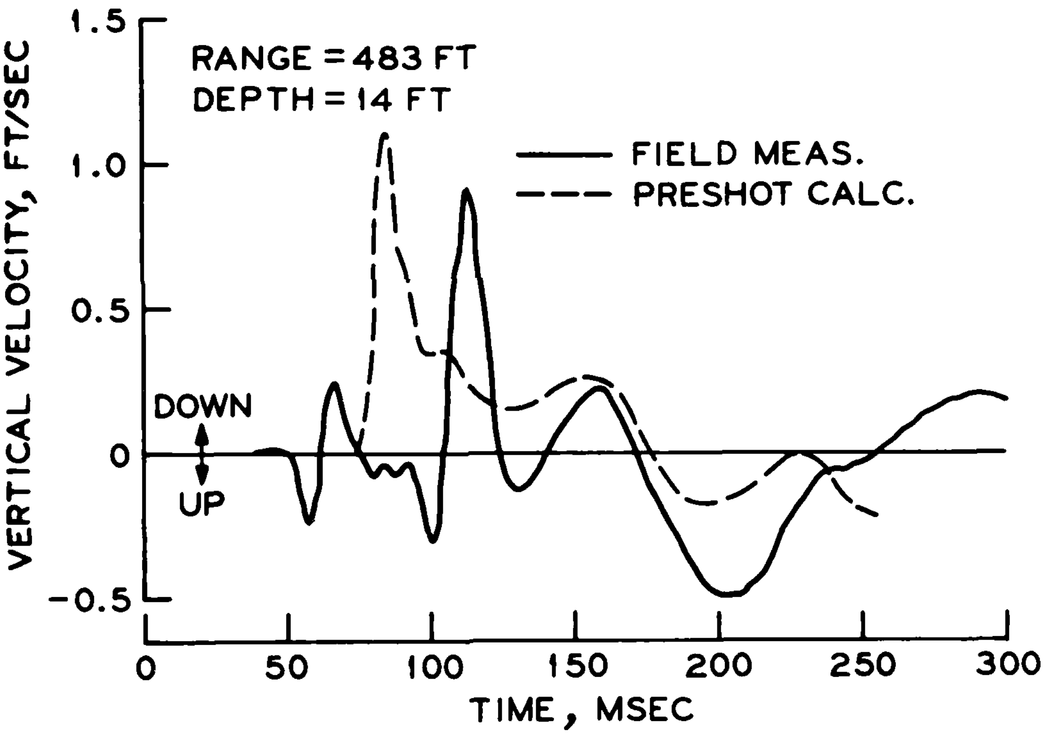


PRAIRIE FLAT AI-ONLY CODE CALCULATIONS-1970

VIEWGRAPH 1

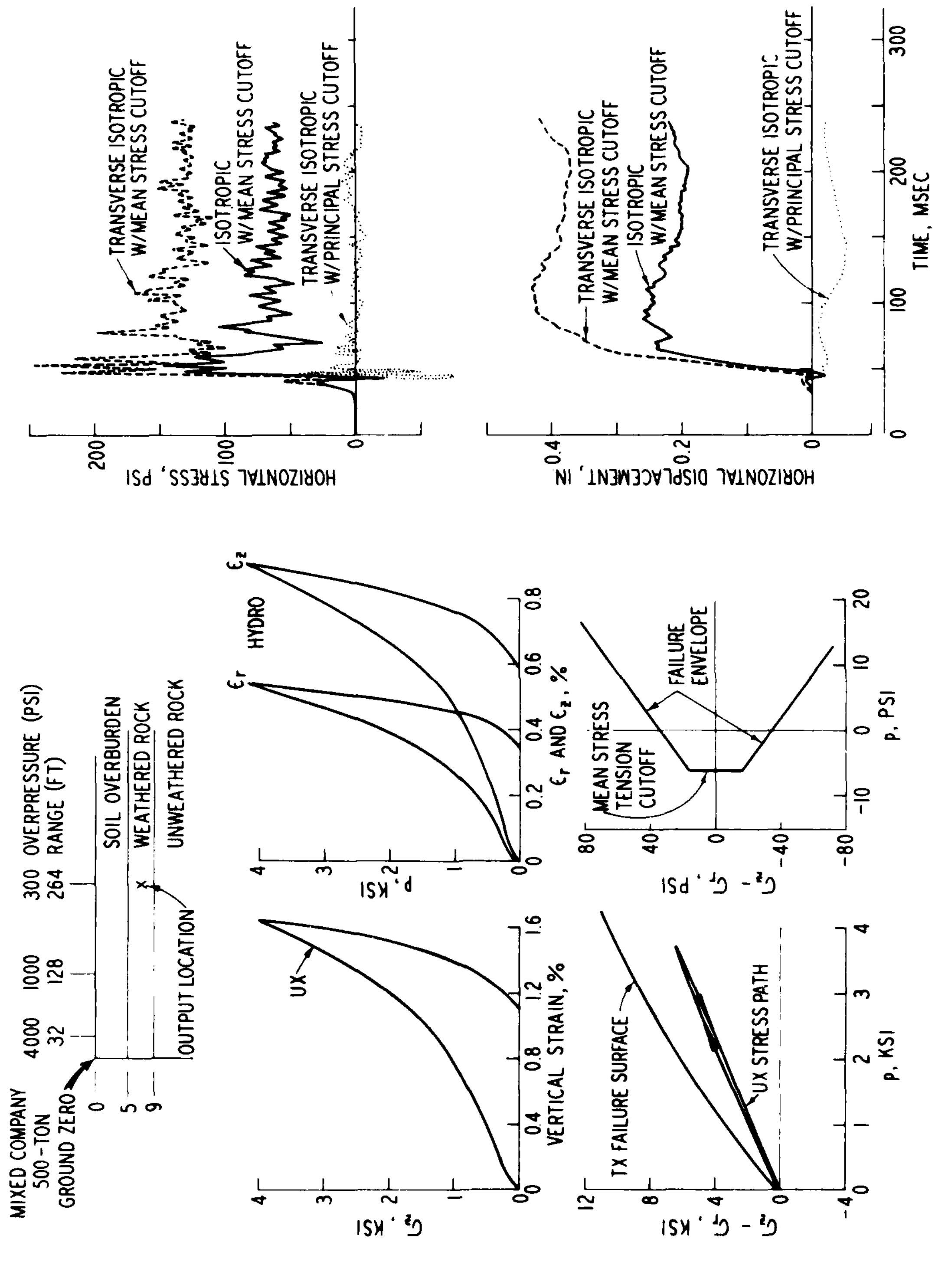


TIME OF ARRIVAL CONTOURS, MIXED COMPANY III



COMPARISON OF MIXED COMPANY CALCULATIONS WITH WES MEASURED FIELD RESPONSE

VIEWGRAPH 2



MIXED COMPANY
500-TON
GROUND ZERO
4000
32
1000
128
300
264
OVERPRESSURE (PSI)
RANGE (FT)
SOIL OVERBURDEN
WEATHERED ROCK
UNWEATHERED ROCK
OUTPUT LOCATION
0
5
9
UX
VERTICAL STRAIN, %
HYDRO
P, KSI
TX FAILURE SURFACE
UX STRESS PATH
p, KSI
MEAN STRESS TENSION CUTOFF
FAILURE ENVELOPE
p, PSI
TRANSVERSE ISOTROPIC W/MEAN STRESS CUTOFF
ISOTROPIC W/MEAN STRESS CUTOFF
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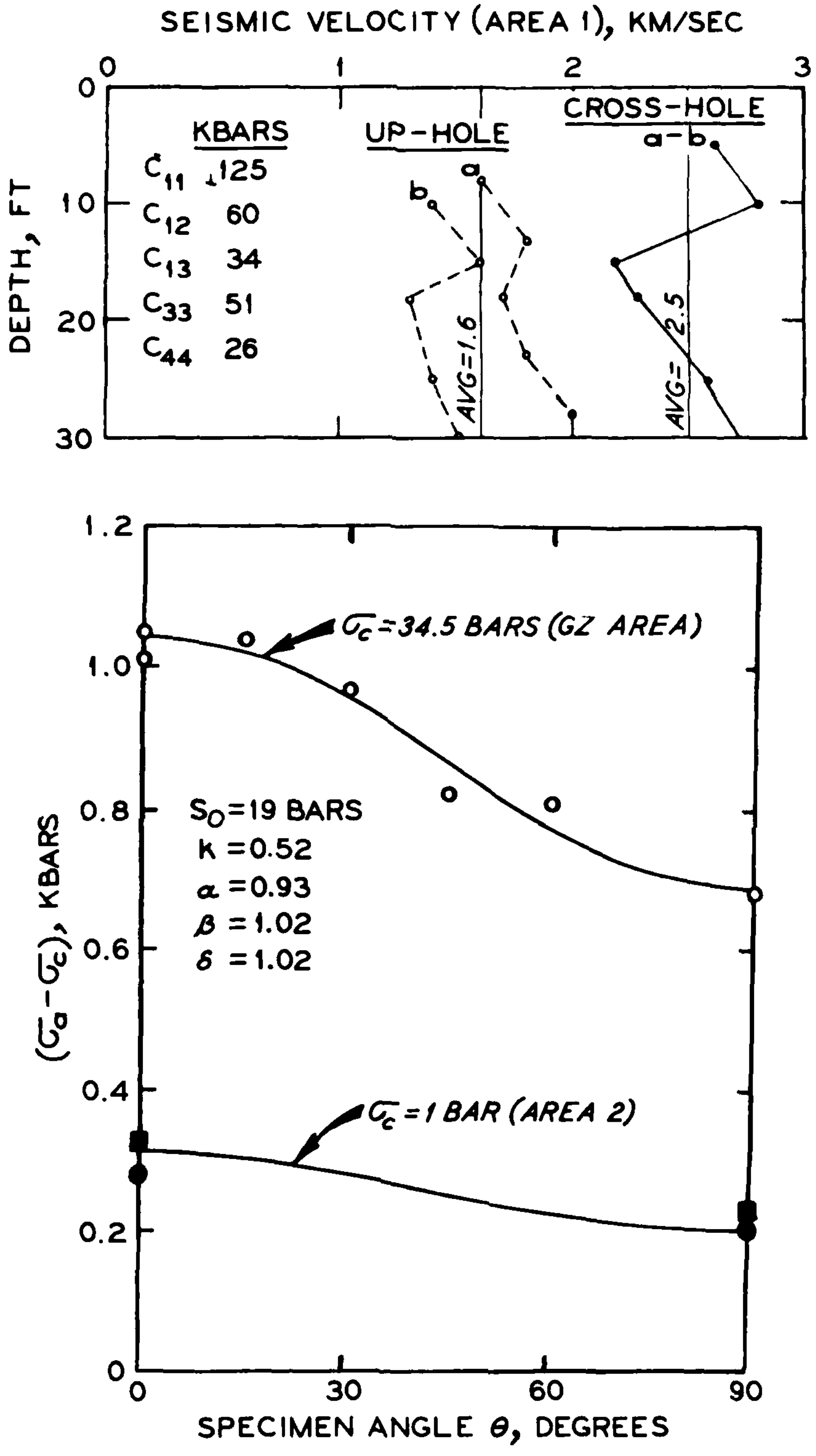
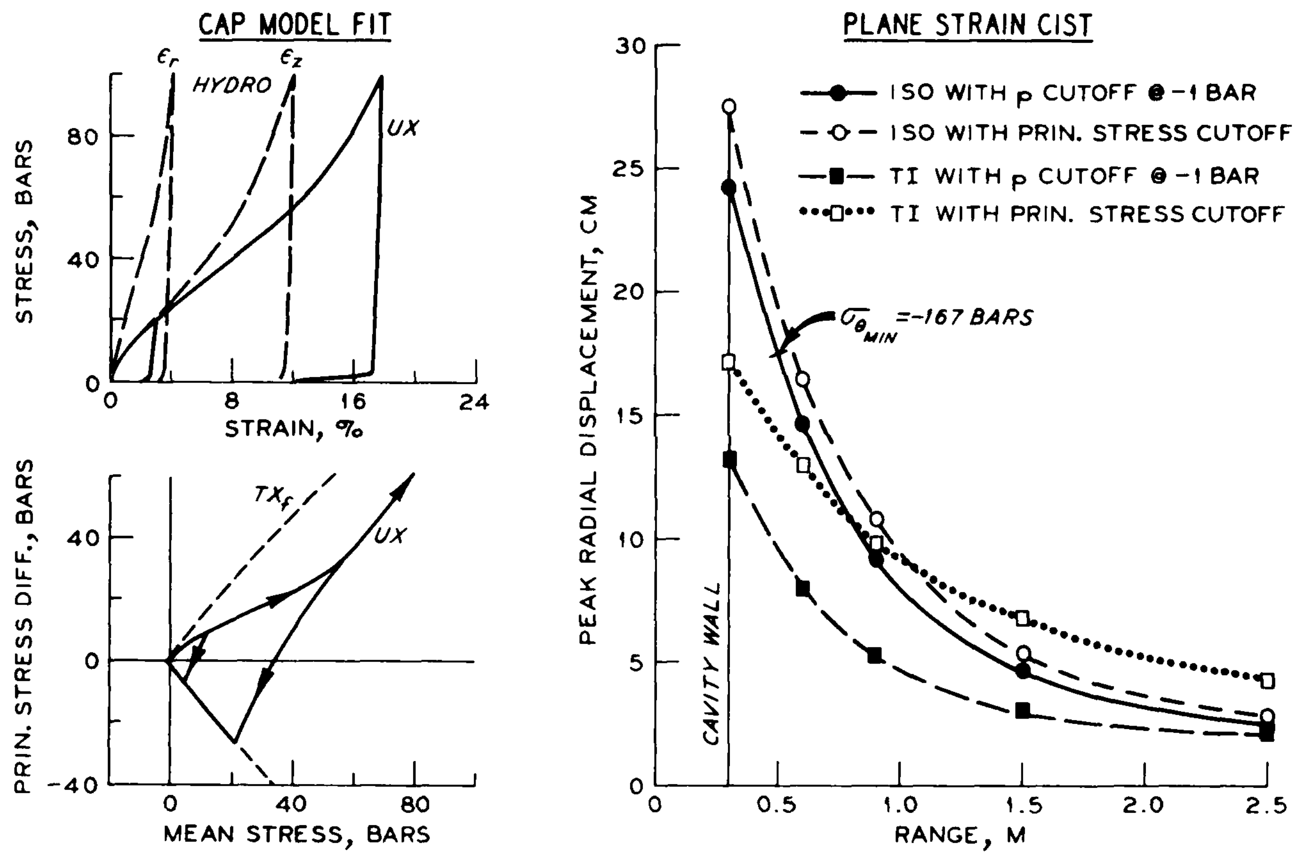
HORIZONTAL DISPLACEMENT, IN
TIME, MSEC

VIEWGRAPH 3



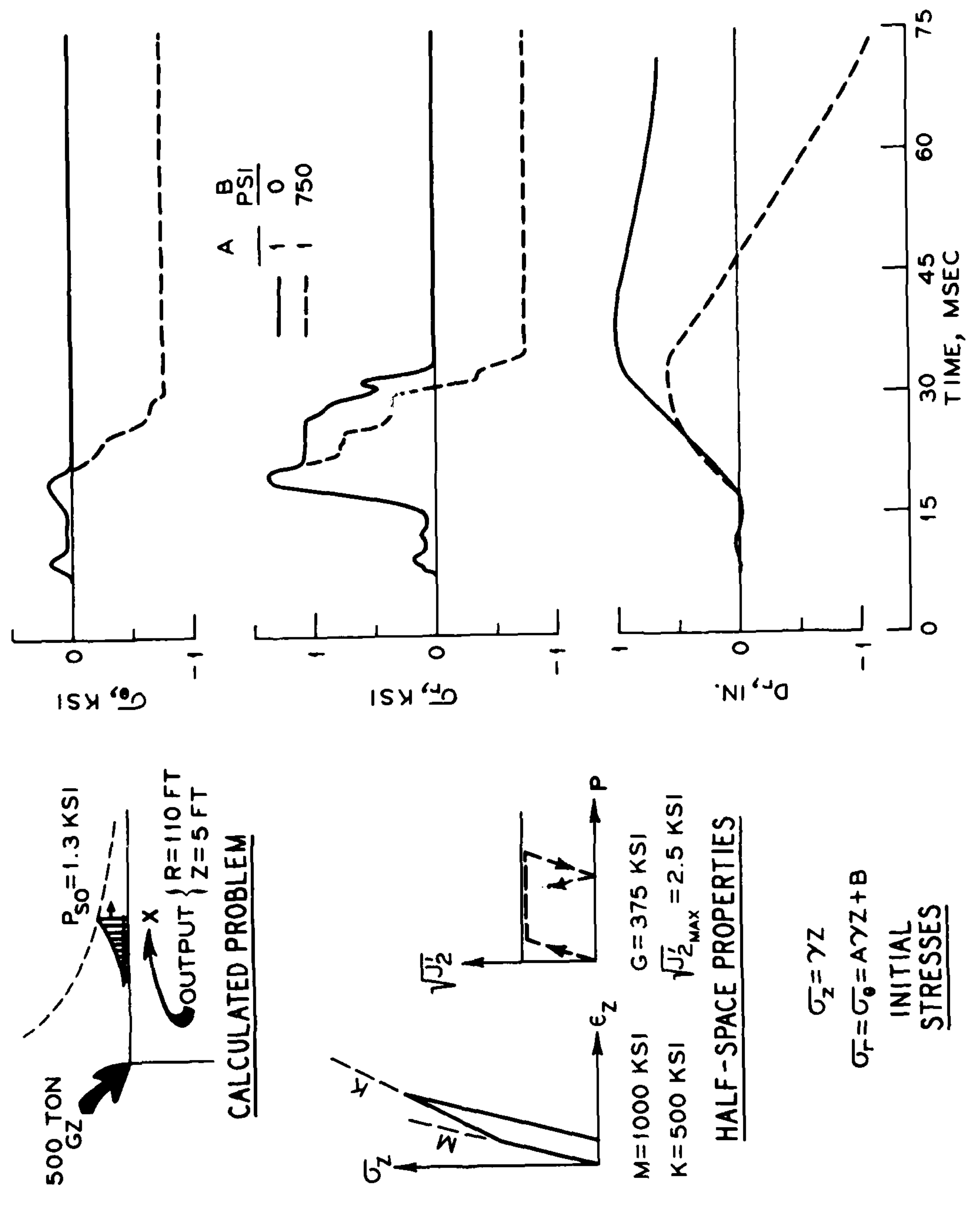
TRANSVERSE ISOTROPIC PROPERTIES FOR MIXED COMPANY SANDSTONE (TERRA TEK)

VIEWGRAPH 4



FRENCHMAN FLAT AT 5-M DEPTH

VIEWGRAPH 5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OUTPUT { R=110 FT Z=5 FT
CALCULATED PROBLEM
σZ
εZ
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K
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P
M=1000 KSI
K=500 KSI
G=375 KSI
√J2' MAX =2.5 KSI
HALF-SPACE PROPERTIES
σZ=γZ
σr=σθ=AγZ+B
INITIAL STRESSES
σθ, KSI
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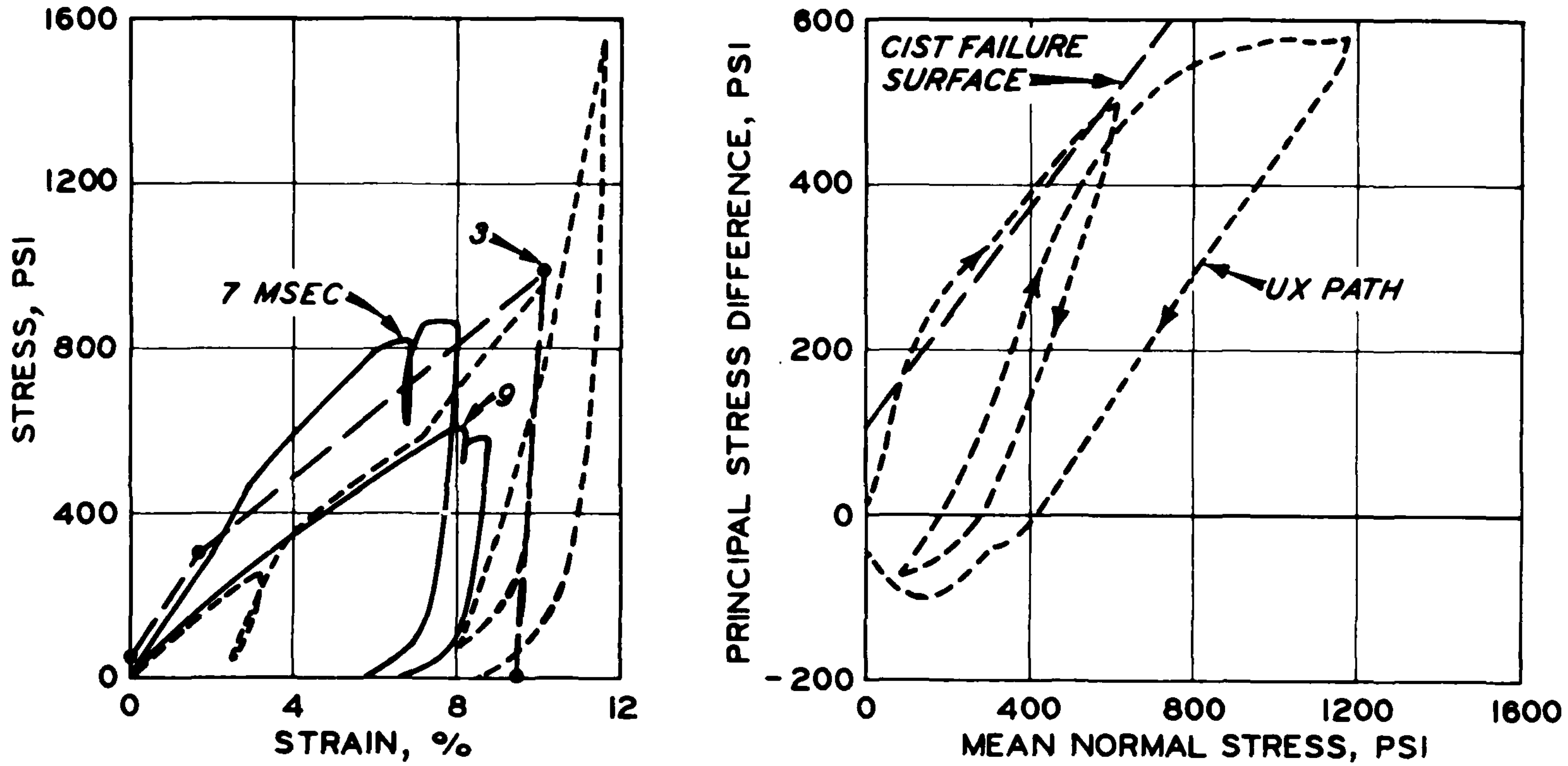
TIME, MSEC

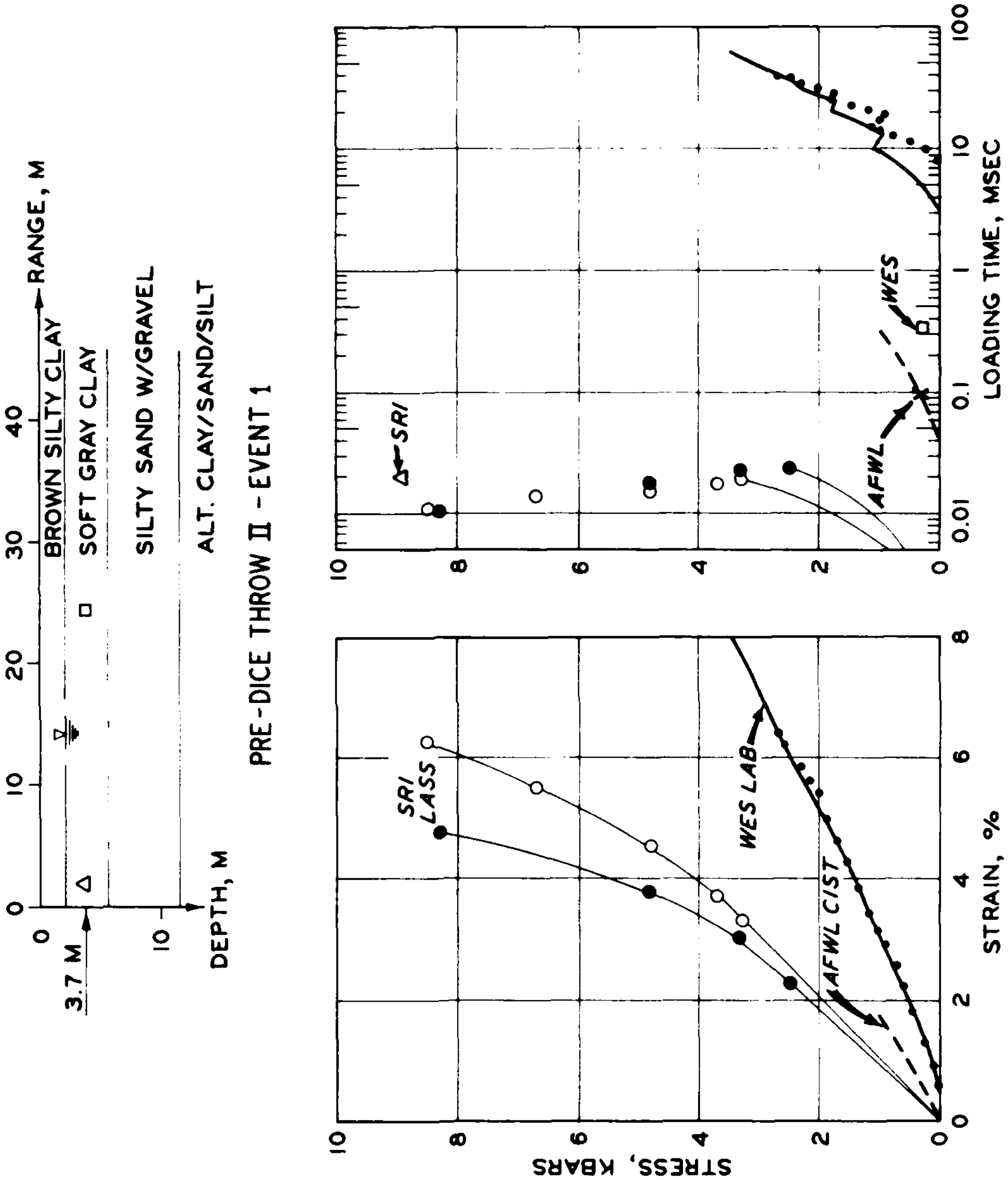
VIEWGRAPH 6



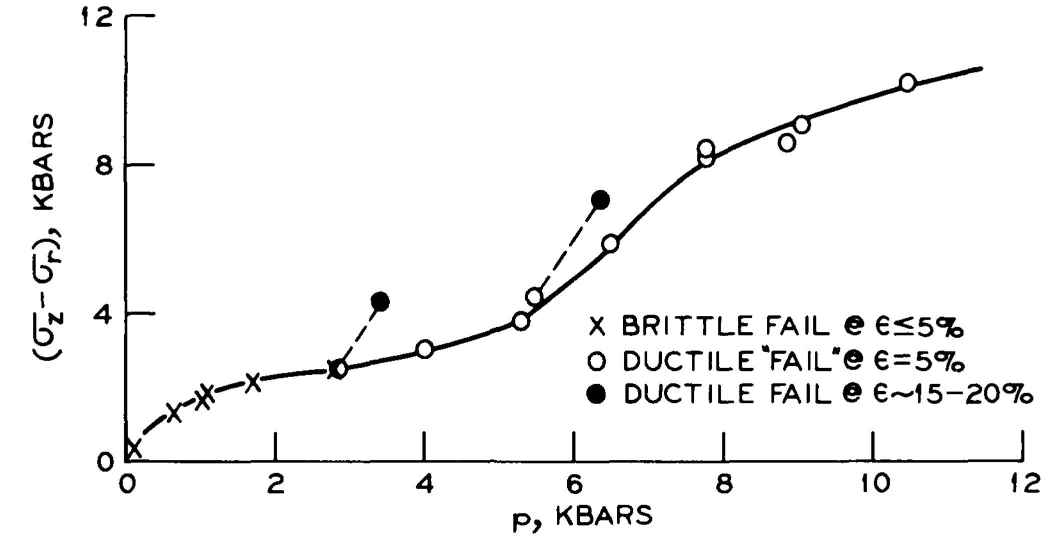
WES DYNAMIC UNIAXIAL STRAIN TESTS AT 18.1 AND 18.7 FT
WES STATIC UNIAXIAL STRAIN TEST AT 17.8 FT
AFWL MODEL DEDUCED FROM CIST 3 GAGES AT 17.5 FT

SANDY CLAY FROM MINUTEMAN SITE D-1, KIMBALL, NEB.

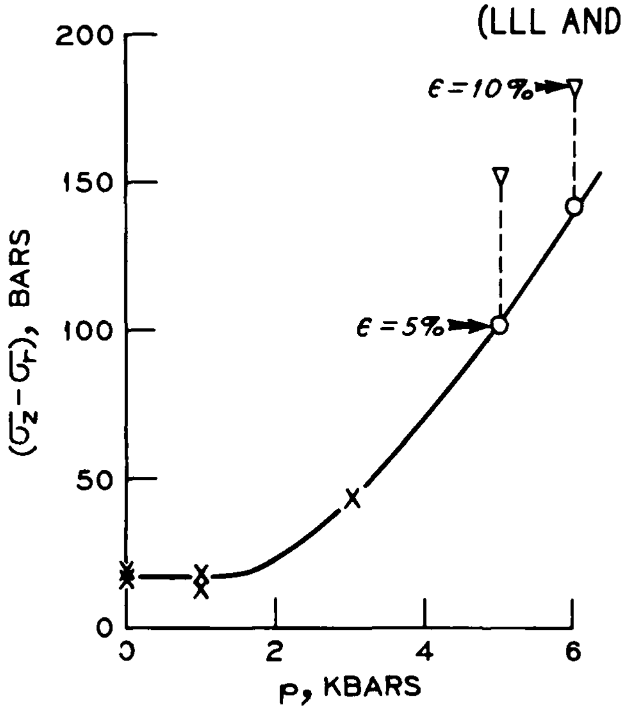
VIEWGRAPH 7


PRE-DICE THROW II - EVENT 1
RANGE, M
DEPTH, M
3.7 M
BROWN SILTY CLAY
SOFT GRAY CLAY
SILTY SAND W/GRAVEL
ALT. CLAY/SAND/SILT
STRESS, KBARS
STRAIN, %
SRI LASS
WES LAB
AFWL CIST
SRI
WES
AFWL
LOADING TIME, MSEC
UNIAXIAL STRAIN

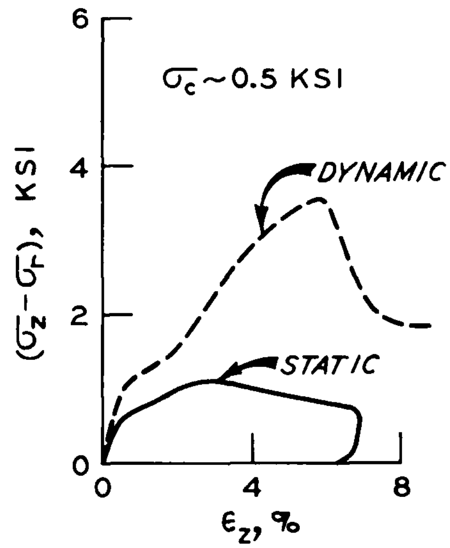
VIEWGRAPH 8



MIXED COMPANY SANDSTONE
(LLL AND TT)



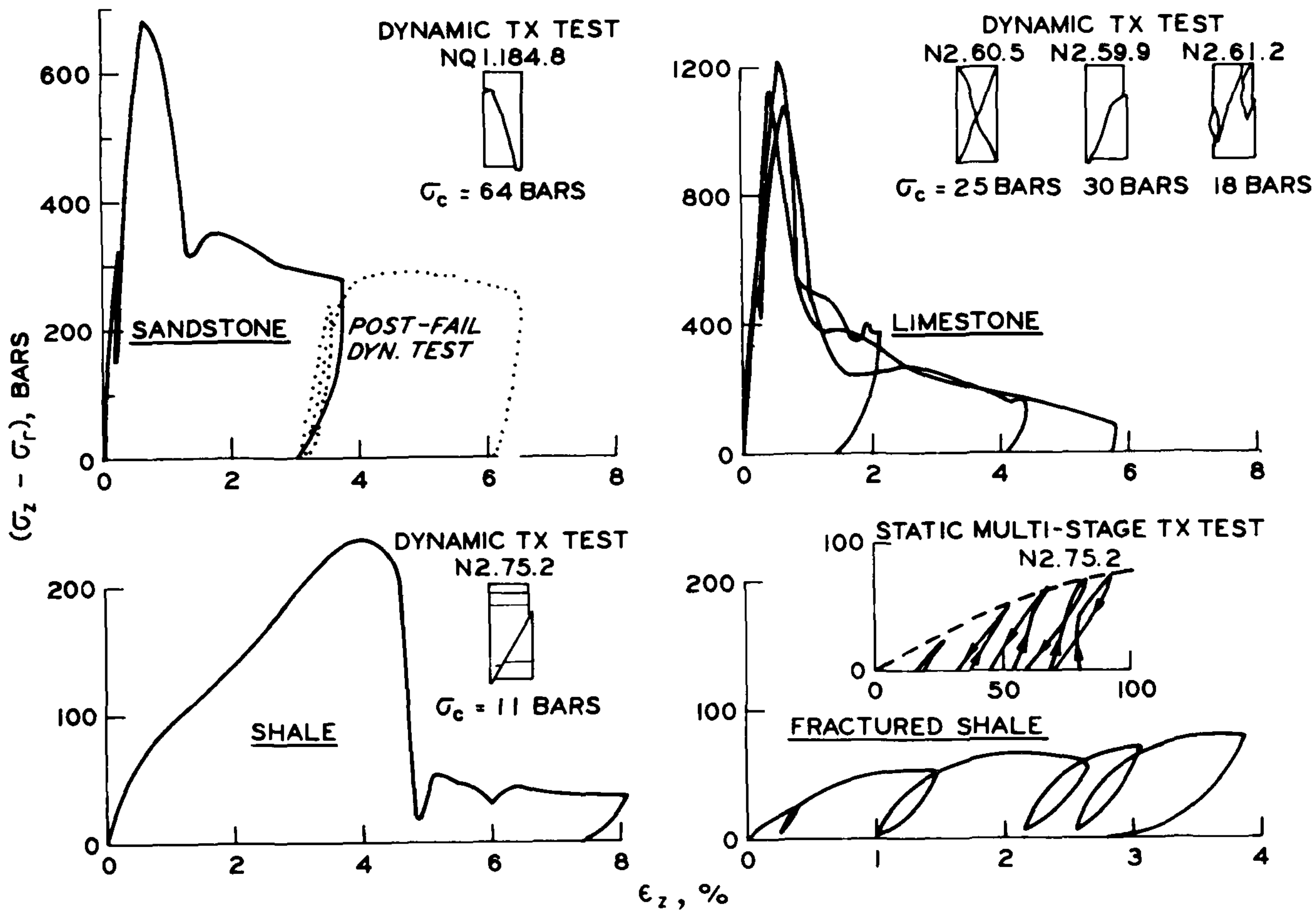
MIDDLE GUST
WEATHERED SHALE
(LLL)



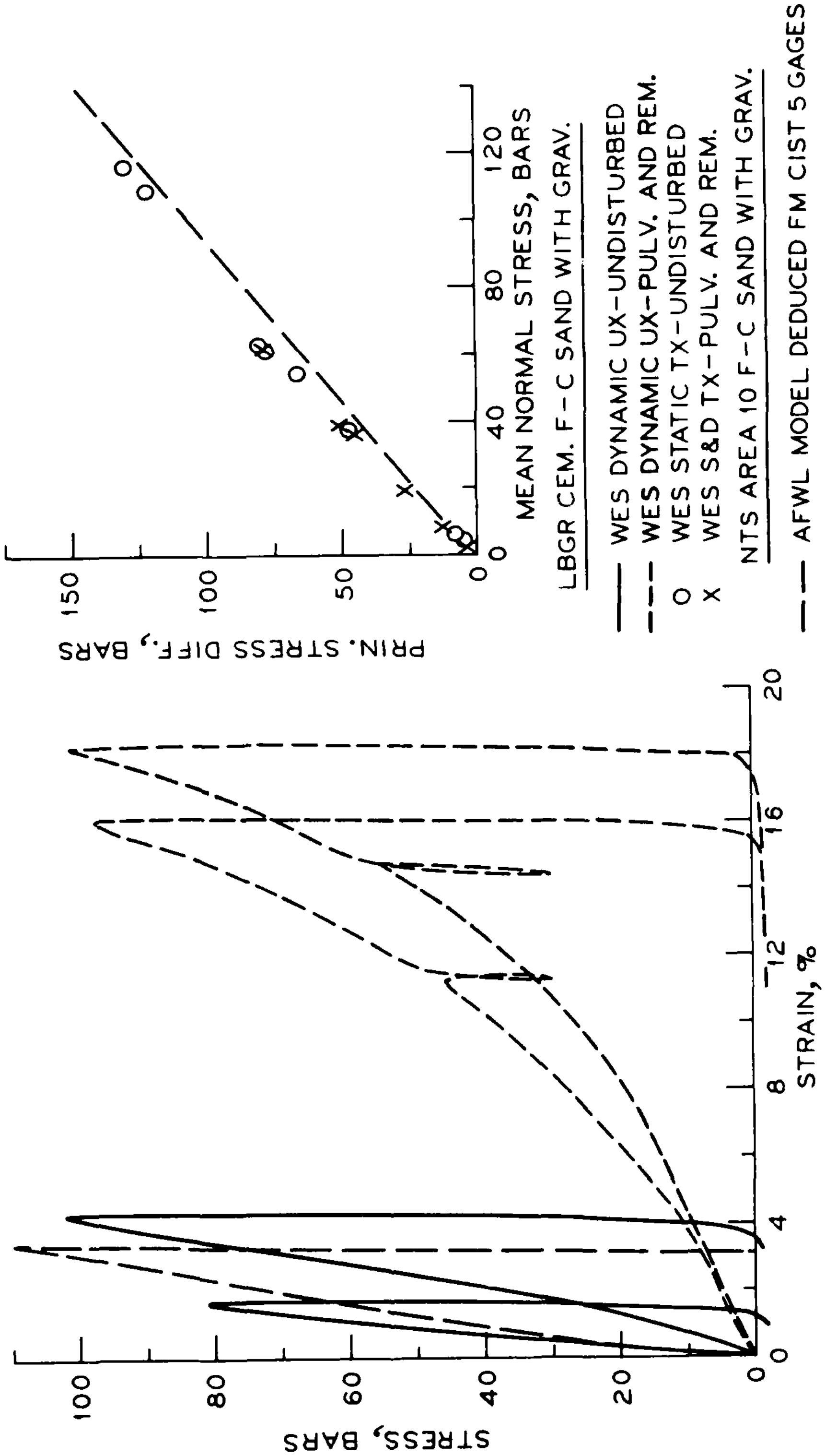
MIDDLE GUST
UNWEATHERED SHALE
(WES)

VIEWGRAPH 9

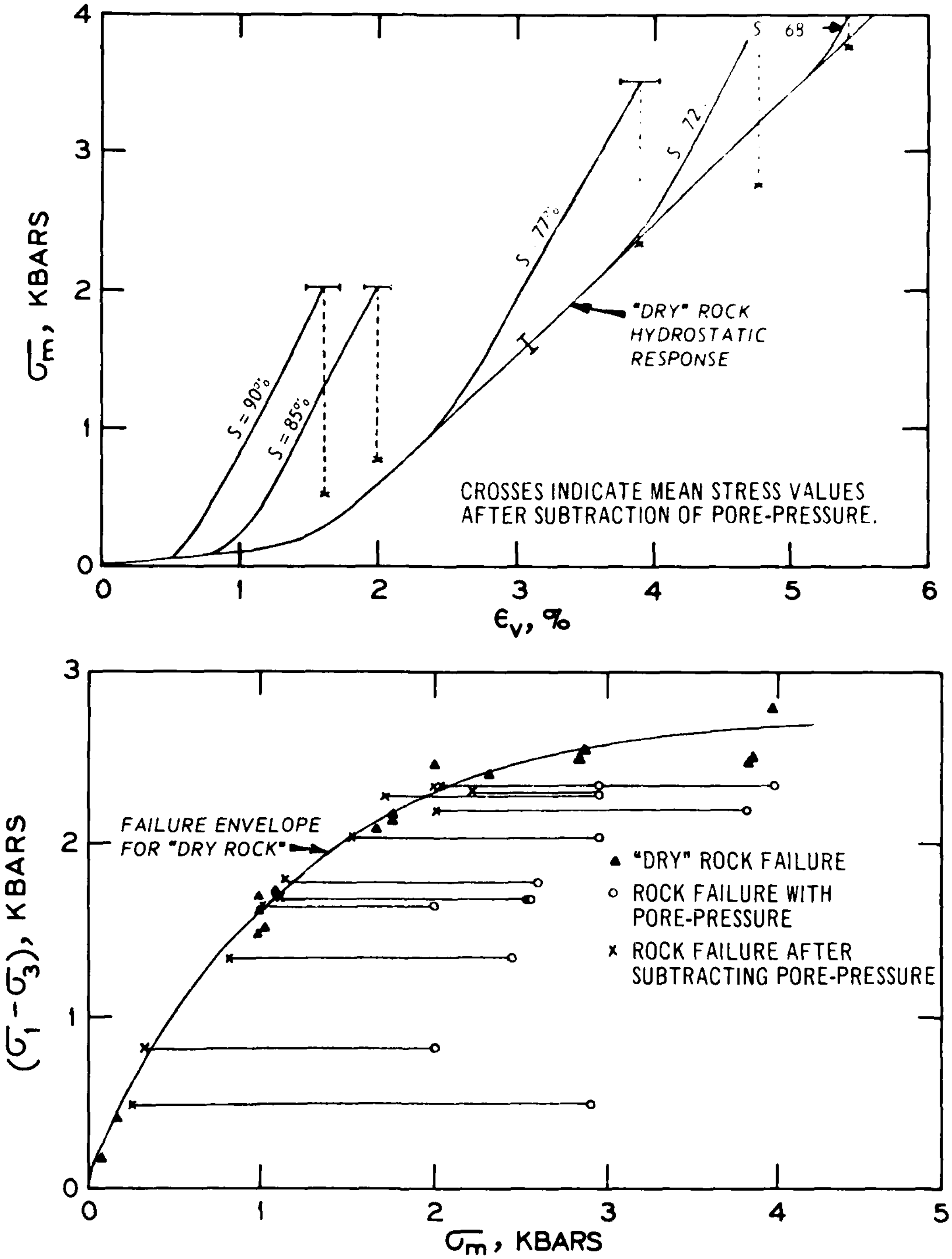
VIEWGRAPH 10



RESIDUAL STRENGTH OF HARD PAN SEDIMENTARY ROCKS

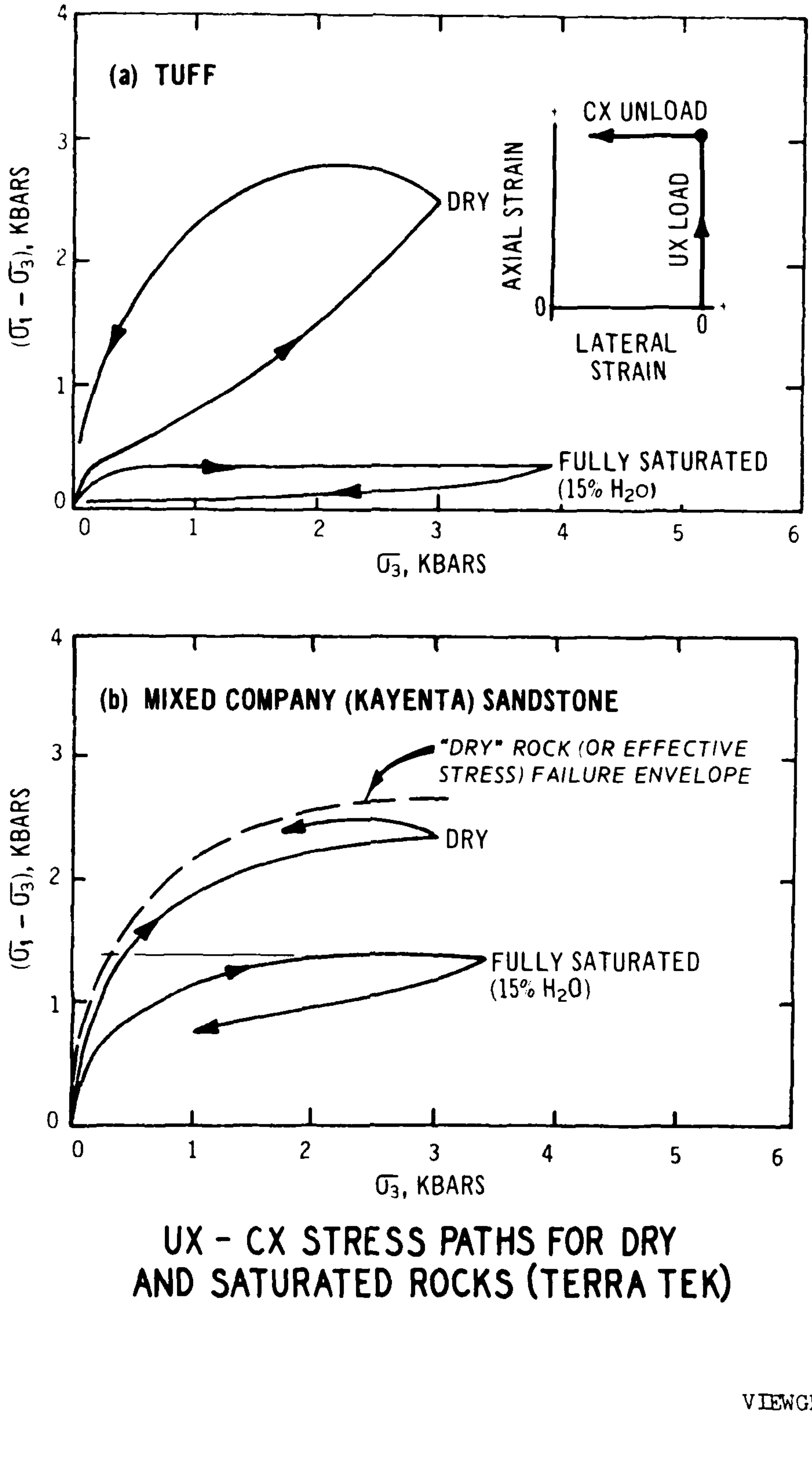


VIEWGRAPH 11



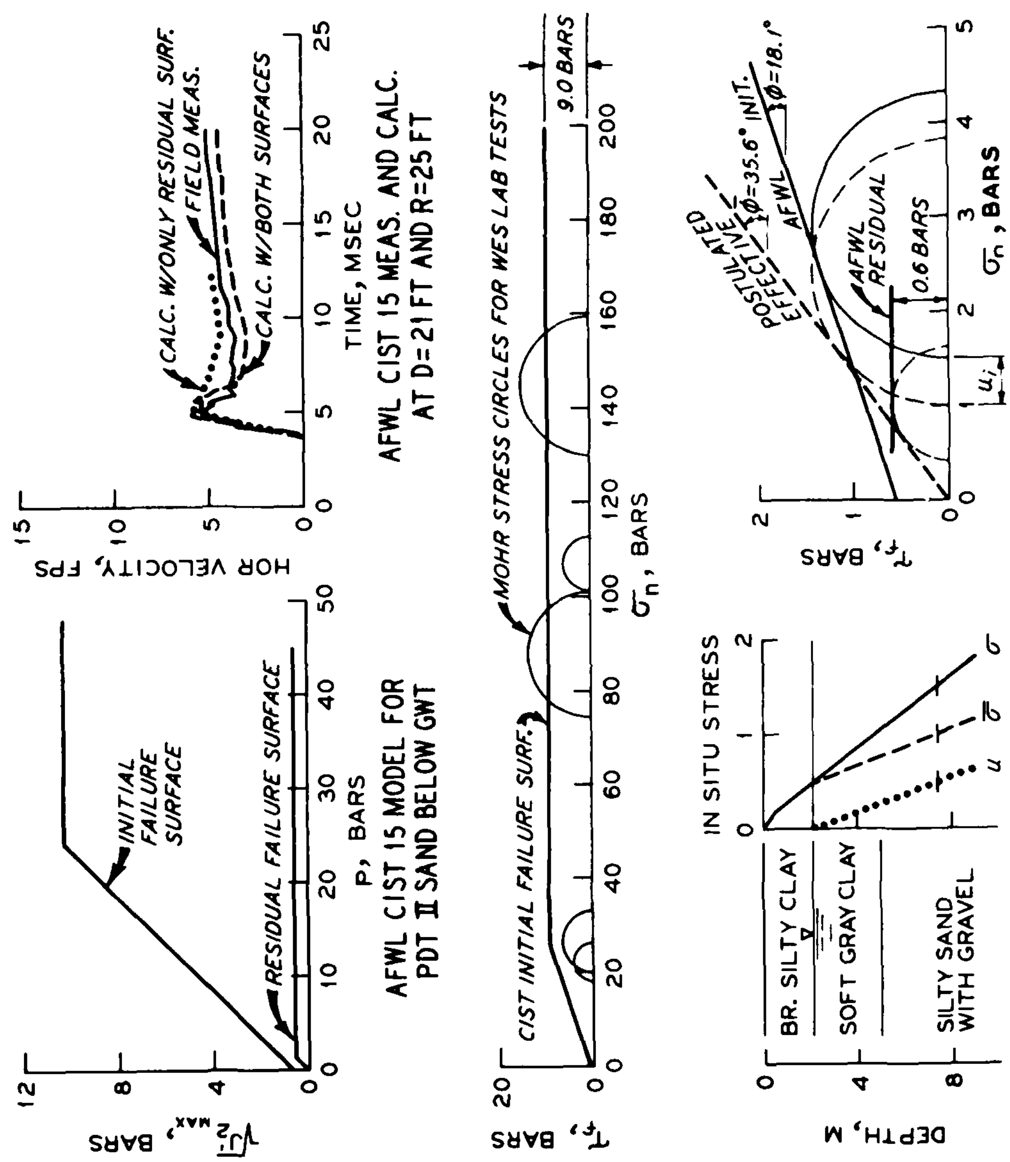
PORE PRESSURE EFFECTS ON MIXED COMPANY SANDSTONE (TERRA TEK)

VIEWGRAPH 12



UX - CX STRESS PATHS FOR DRY AND SATURATED ROCKS (TERRA TEK)

VIEWGRAPH 13



VIEWGRAPH 14

CLOSING COMMENT – ~~1969~~ 1977

"IT IS HOPED THAT THESE SUGGESTIONS FOR ADDITIONAL TESTS AND FOR PERHAPS SOME IMPROVEMENTS IN THE CONSTITUTIVE MODELS HAVE NOT LEFT THE IMPRESSION THAT SIMPLY HAVING MORE TEST DATA OF MORE DIFFERENT TYPES AND HAVING MORE GENERALIZED CONSTITUTIVE MODELS WILL SIMPLIFY THE JOB OF DEFINING CONSTITUTIVE PROPERTIES FOR CODE INPUT. JUST THE OPPOSITE WILL PROBABLY BE THE CASE; I.E., THE JOB WILL BE MUCH MORE COMPLICATED THAN IT IS ALREADY. THIS SHOULD NOT DETER SUCH EFFORTS, FOR IF THE SOILS ENGINEERS AND THE CALCULATORS WILL CONTINUE TO WORK TOGETHER, IT WILL LEAD TO MORE REALISTIC MODELS BASED ON MORE PHYSICAL FACTS, AND THAT CANNOT HELP BUT LEAD TO BETTER GROUND SHOCK CALCULATIONS."

VIEWGRAPH 15

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Jackson, John Guy
Material response characterization / by John G. Jackson, Jr. Vicksburg, Miss. : U. S. Waterways Experiment Station, 1977.
ii, 10, [15] p. ; 27 cm (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; S-77-11)
Prepared for Defense Nuclear Agency, Washington, D. C., under Subtask SB209, Work Unit 35.
References: p. 8-10.

1. Constitutive models. 2. Constitutive properties. 3. Dynamic properties. 4. Geologic materials. 5. Ground shock calculations. 6. Rock properties. 7. Soil properties. I. Defense Nuclear Agency. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; S-77-11.
TA7.W34m no.S-77-11