RECORD

DZ 6/9/96

DYNAMIC STUDY OF DRIFT STABILITY

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OBJECTIVES:

The specific objectives of this activity are:

- Evaluate the effects of drift stability in jointed rock mass under in situ and thermal stress fields for different amplitudes of repetitive seismic events.

- Identify a threshold amplitude if one exists

Technical Approach:

The technical approach for this study will be to utilize the discrete element code UDEC to conduct a series of numerical analyses to investigate drift stability under seismic events

The results from the project "Thermal-Mechanical (TM) Modeling of Emplacement Drift Stability" will be used as a starting point for the model. These results provide the drift geometry and the in situ and thermal stress fields. Two cases to be identified will provide a high

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and low thermal loading to analyze the thermal confining stress on drift stability during seismic loading.

The Yucca Mountain rock properties will be used in the analyses based on information available from borehole drilling. Rock joint orientations will be modeled based on the repository site.

The discrete element code UDEC 2.01 will be used to characterize the damage region around the emplacement drift & to evaluate the extent of rock fall which may impact the waste canister for assessments of long term canister performance.

COMPUTERS, COMPUTER CODES, and DATA FILES

The UDEC 2.01 Discrete Element Analysis code will be used for this study. The code is maintained under CNWRA configuration control (TOP-18).

Note: As of 1/1/97, Version 3.0 of UDEC is being used. Version 3.0 has many upgrades including more versatility in applying lateral free-field boundaries for dynamic analysis.

Source code is located in directory /ext1/mahola/earthquake on the SunSparc 10 workstation named sleepy. All input and output data files are also located in this directory. MA

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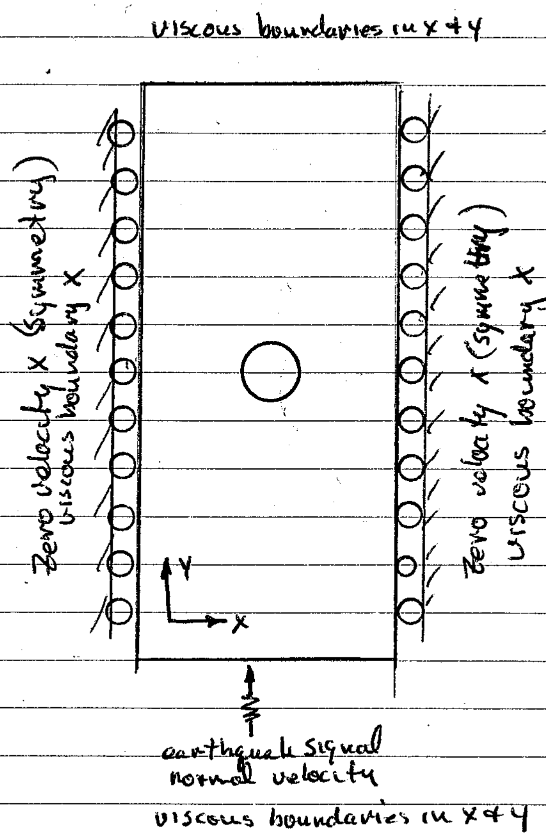
INITIAL MODEL: 6/14/96

This model is based on CASE 21 from the project "Thermal-Mechanical (TM) Modeling of Emplacement Drift Stability." The boundary conditions + thermal loading can be found in that report. The following geometry is from case 21. Thermical Mechanical analysis. This analysis provides the geometry, ~~and~~ thermal stress, and in situ stress for the drift.

The boundary conditions & loading are shown below (model not to scale)



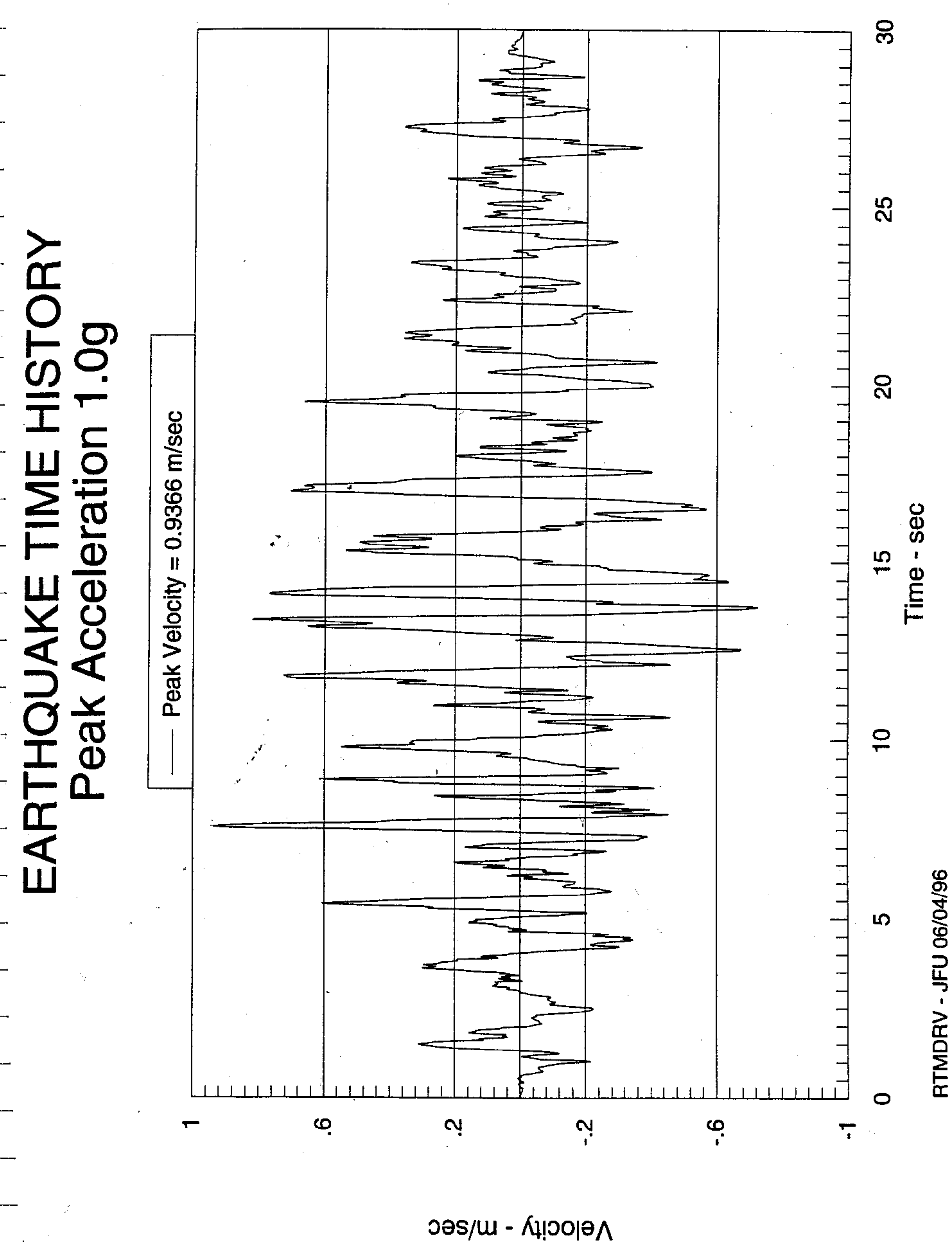
MATERIAL PROPERTIES 6/14/96

BULK MODULUS 9,195E3

SHEAR MODULUS 6.612E3

Density 2297.0 kg/m³

Earthquake History 6/14/96



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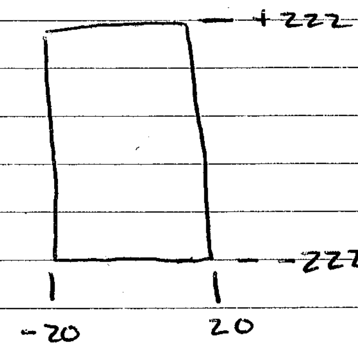
The earthquake history on the previous page is used as the base history. This history is scaled for the different amplitudes required for this study. The magnitude and corresponding input file name follows

0.4g	vel04.vel
0.6g	vel06.vel
0.8g	vel08.vel
1.0g	vel10.vel

Discrete Element Mesh for Case 1. 6/14/96

Case 1 is based on the Thermal-Mechanical analysis case 21. (i.e. thermal & in-situ stresses are from the TM case 21 analysis).

The problem domain is



Upper and lower boundaries are based on extent of thermal front at 100 years of heating

Vertical boundaries are located along symmetry lines assuming 40m drift spacings.

This symmetry condition is violated by the joint orientation. However this is not expected to influence the region of interest which is the area near the drift.

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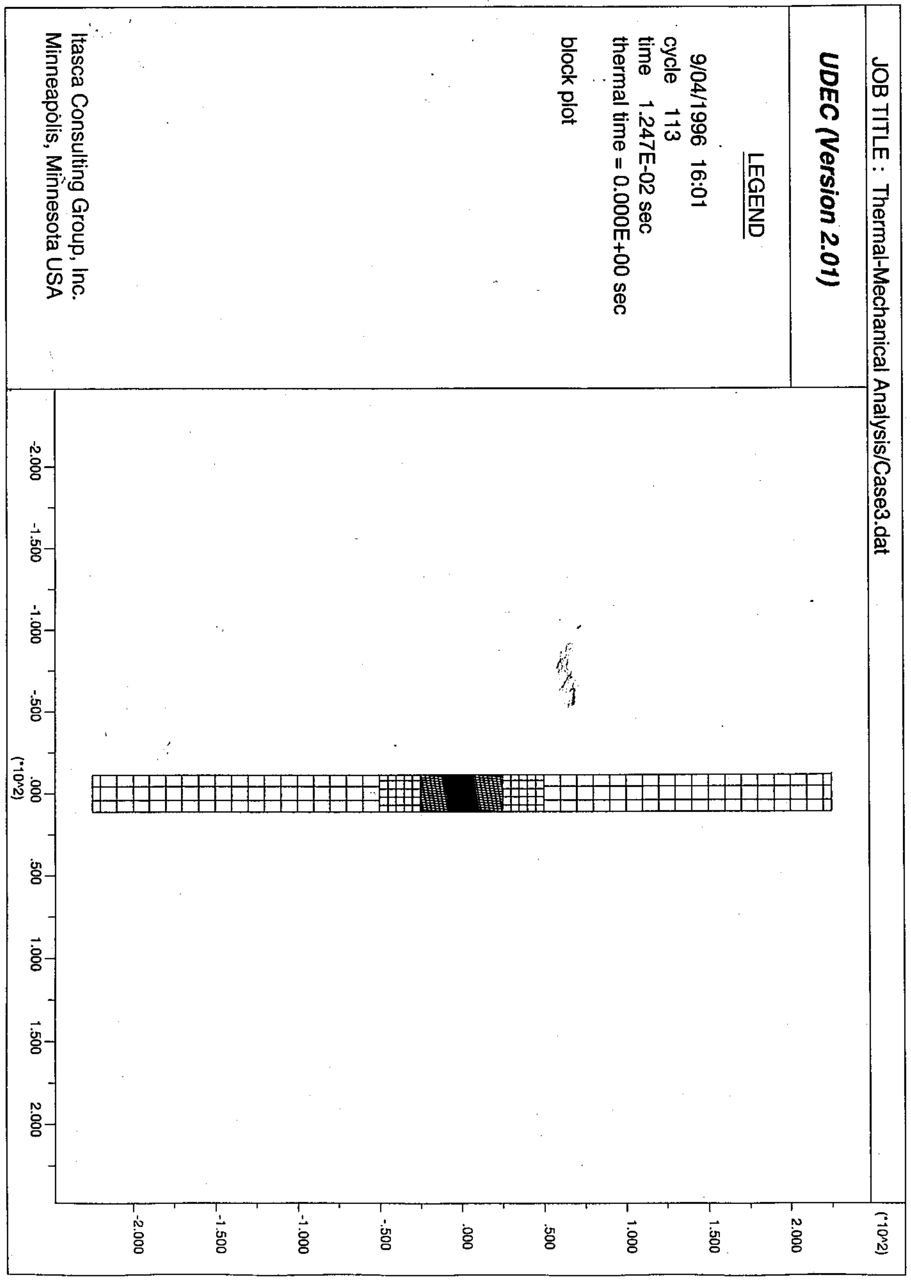
Mesh for Case 1



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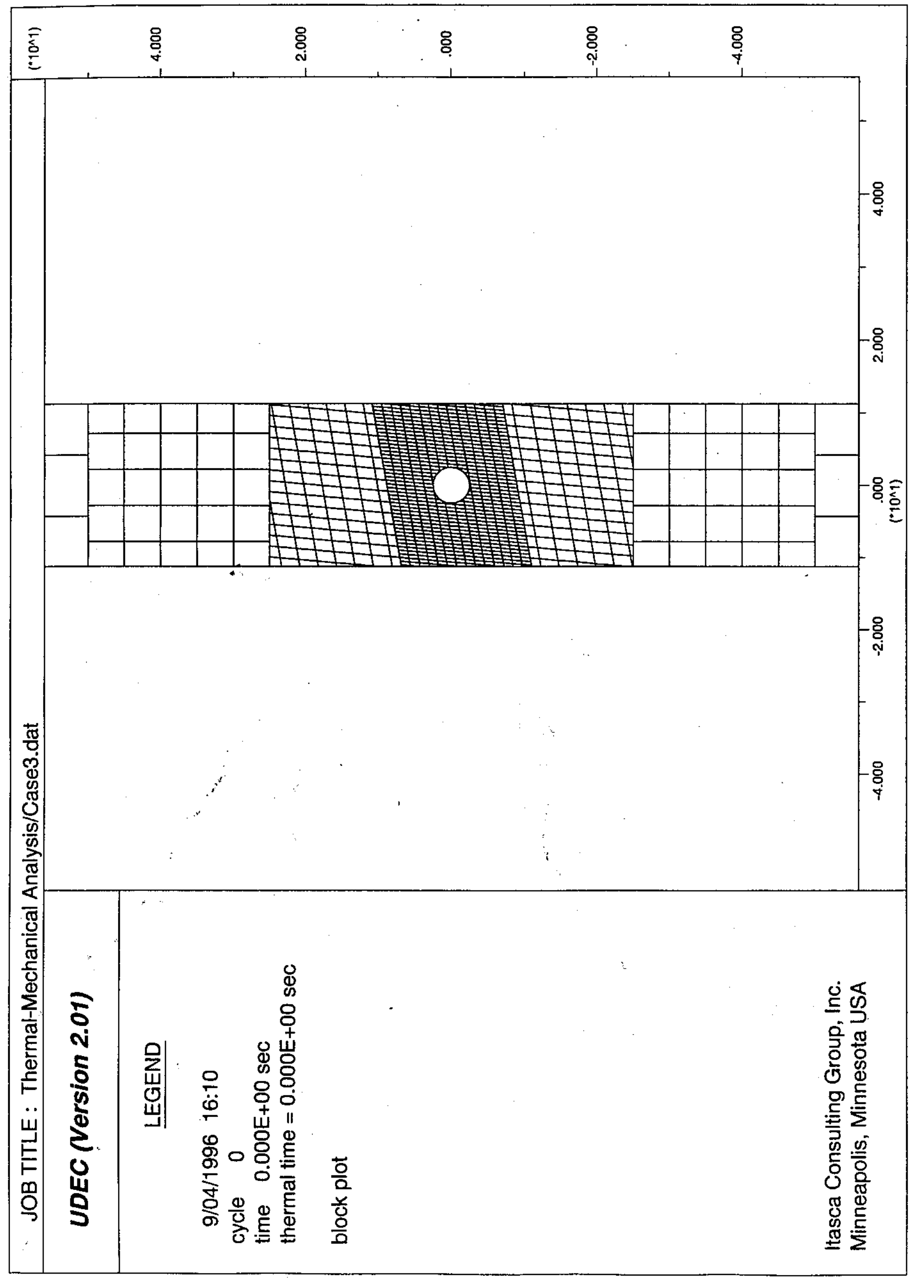
Mesh for case 1 showing jointing around excavation.



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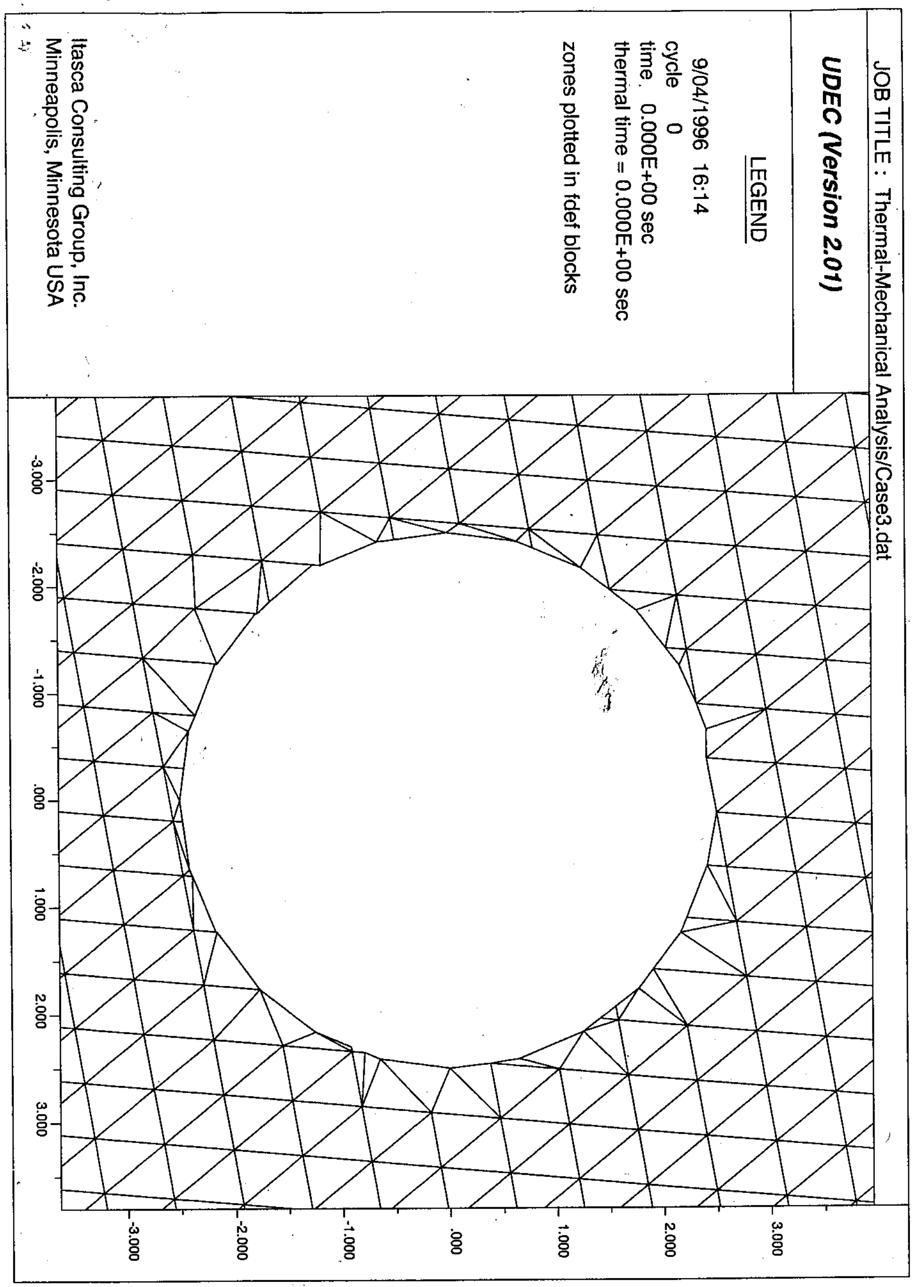
Mesh for Case 1 showing finite difference zones around drift.



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The zone sizes of the finite different mesh will dictate the timestep required for the solution. By inspecting the mesh, the smallest zones sizes are located near the tunnel. Mass ~~a~~ scaling ~~shot~~ should be used with caution size this will effect elements near the tunnel - the region we are interested in. ~~It was determine~~

RESULTS FOR CASE 1 — 9/20/96

Minimal rock fall occurred for the ~~three~~ four cases (.4g, .6g, .8g, 1.0g amplitude seismic loadings). No rock fall occurred for the .4 & .6g loadings. The results indicate that the motion of the drift due to seismic loading is very close to rigid body motion. This is from the slow nature of the ~~a~~ seismic history. However, based on model refinements suggested by L. Loris of Itasca, including reducing the vertical extent of dynamic model from the thermal-mechanical model (see Figure on page 16), and increasing, some ~~of~~ the size of far-field blocks, some numerical instabilities resulted. This is seen by comparing 2 Figs on pages 16 and 17 along the interface between the large and small discrete element blocks. Apparently, the code cannot handle numerous small blocks in contact w/ a single large block.

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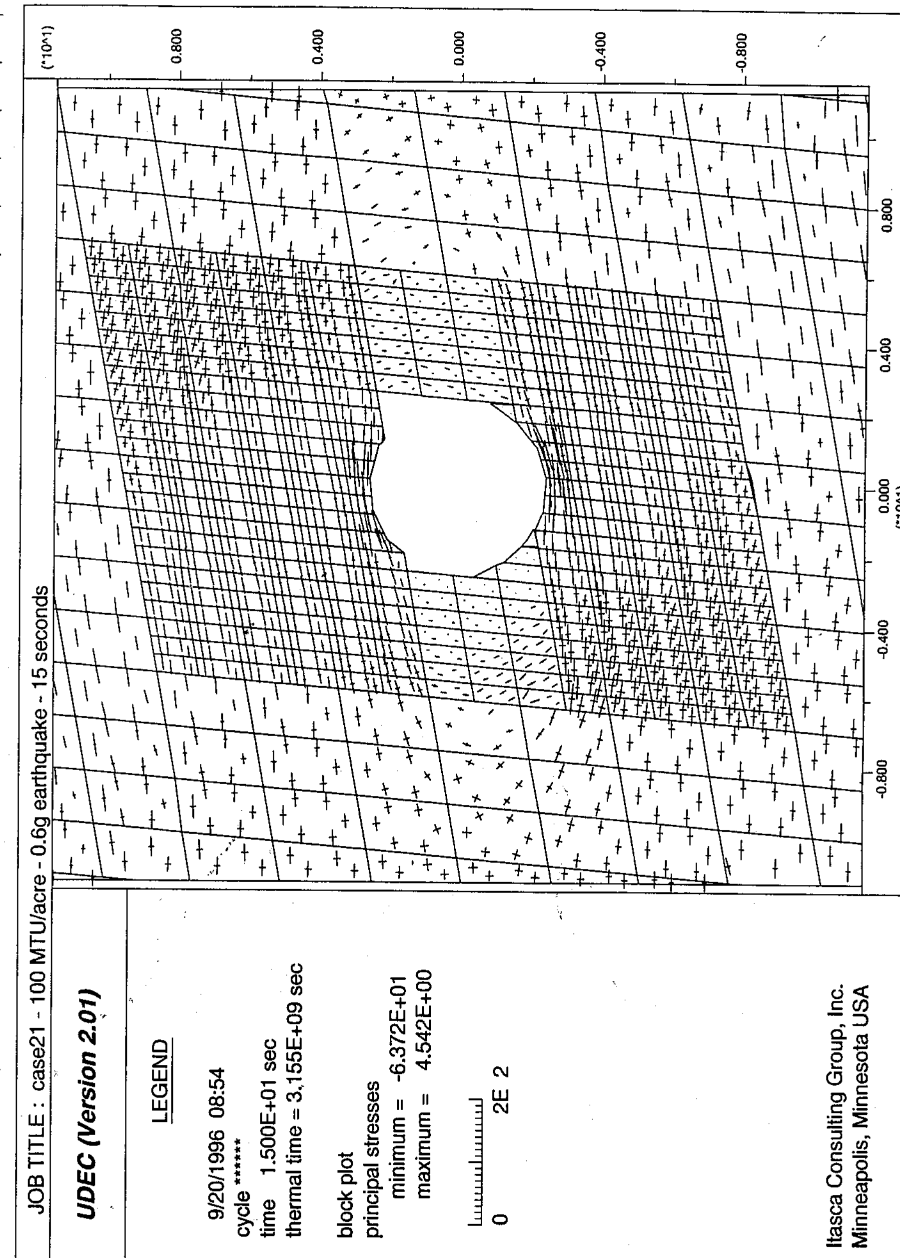

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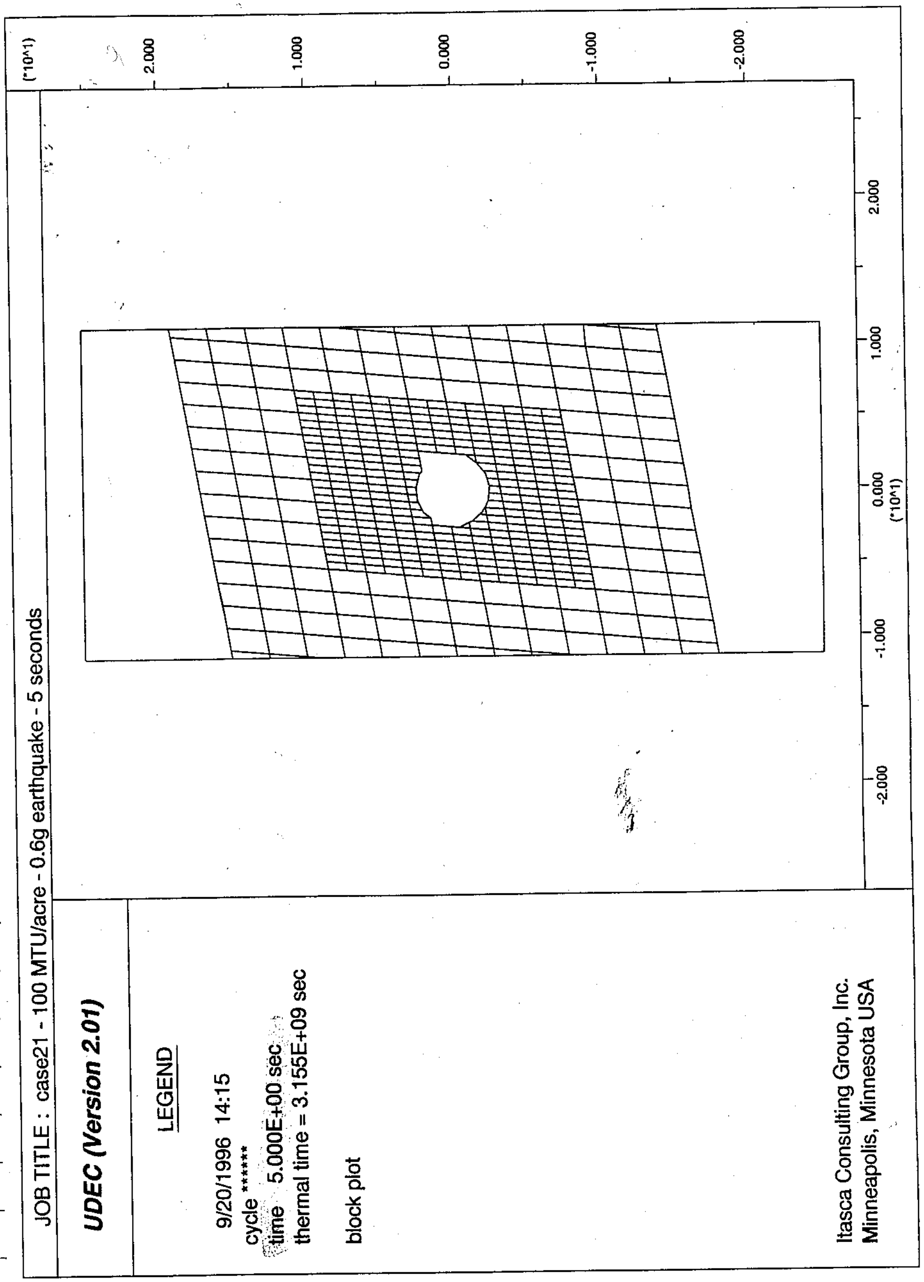
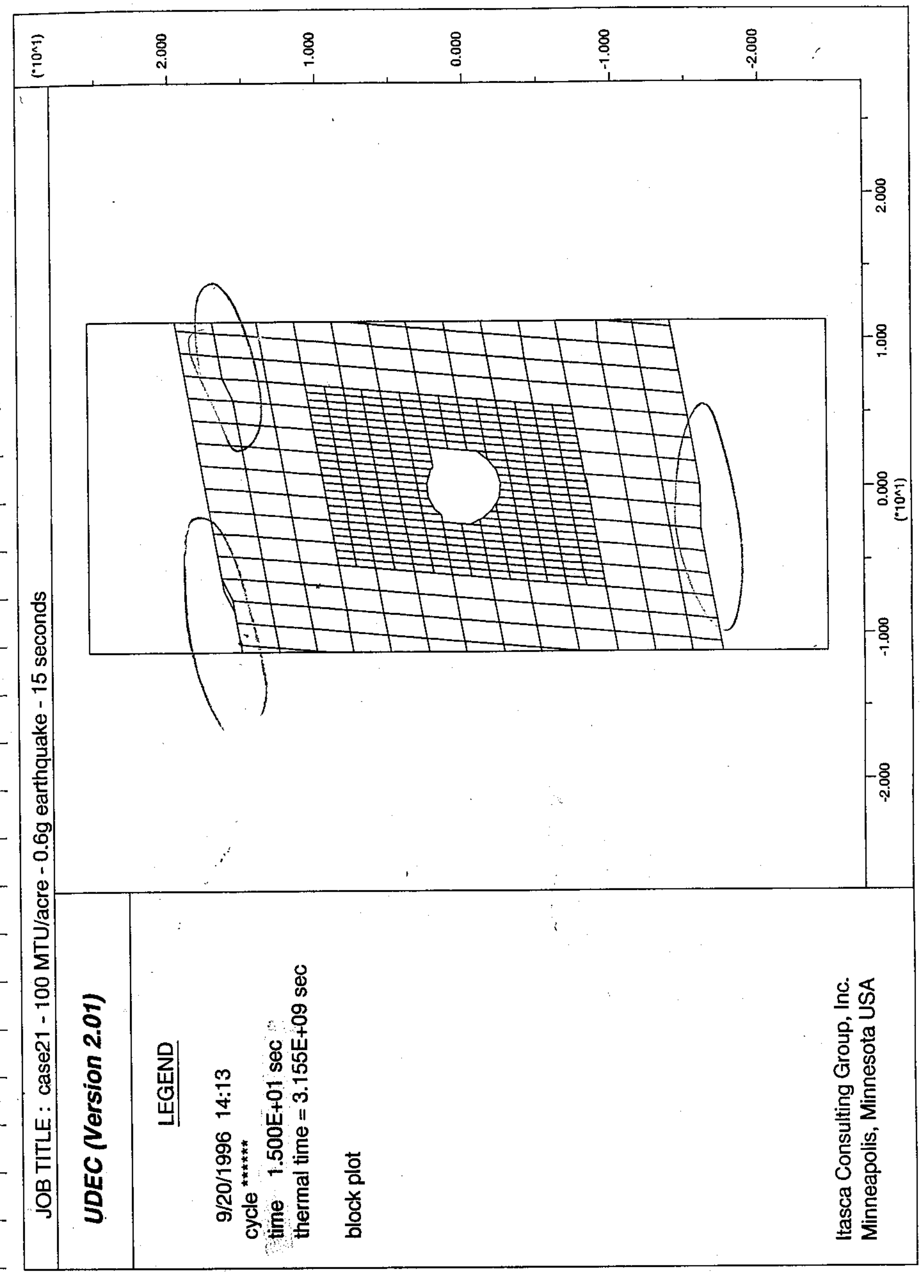


9/20/96 MA



9/6/96

As a result of these problems and the fact that the ~~small~~ reduced model did not run significantly faster than the original model (Fig on page 10), it was decided to go back to using the original model. Also, since the use of lateral free-field boundaries (per L. Lorig) were suggested for simulating a vertical propagating shear wave, the ~~model~~ free-field boundaries required that the model extend to the ground surface, 300 m above excavation. Since Case 25 from the TM parametric study had the largest amount of yielding, it was decided that Case 25 would be used as the input state (i.e. 100 year TM loading state) for the final dynamic analysis. The input material properties for Case 25 are listed on the next page.

9/20/96

Material Properties

Bulk Modulus K = 1.839e4 MPa
Shear Modulus G = 1.322e4 MPa
Young's Modulus E = 3.2e4 MPa
Poisson's Ratio = 0.21
Density ρ = 2297 kg/m³
Cohesion = 18.0 MPa
Internal Friction Angle = 20°
Tensile Strength = 5.0 MPa
Dilation Angle = 24 degrees

~~Them~~

Joint normal stiffness = 1.0e5 MPa/m
Joint Shear Stiffness = 1.0e5 MPa/m
Joint Dilation = 0
Joint Friction angle = 28 degrees
Joint Tensile Strength = 0.04 MPa

For the p-wave input at base of model, y-velocity time history was converted to a vertical (σ_{yy}) stress history. The reason for this was that viscous non-reflecting boundaries could then be used at the base.

Conversion from velocity to stress time history is as follows.

$$\sigma_{yy} = 2(\rho C_p) V_y$$

where

$$C_p = \sqrt{\frac{K + \frac{4}{3}G}{\rho}}$$

Using input data on page 19

$$C_p = 3960 \text{ m/sec}$$

$$\boxed{\sigma_{yy} = 18.2\, V_y} \quad \text{(in MPa units)}$$

The factor 18.2 is the multiplier used in UDEC input file.

Likewise for S-wave we have

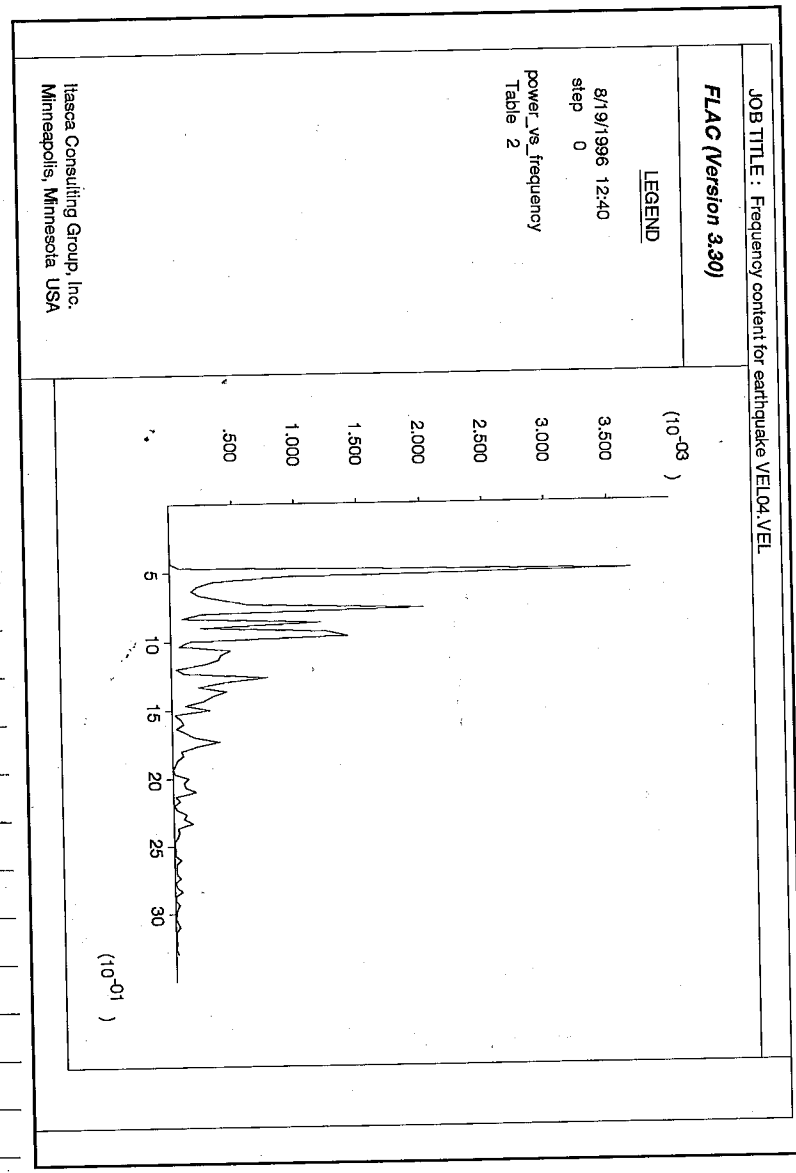
$$\sigma_{xy} = 2(\rho C_s) V_x$$

where $C_s = \left(\frac{G}{\rho}\right)^{1/2}$

$$C_s = 2399 \text{ m/s}$$

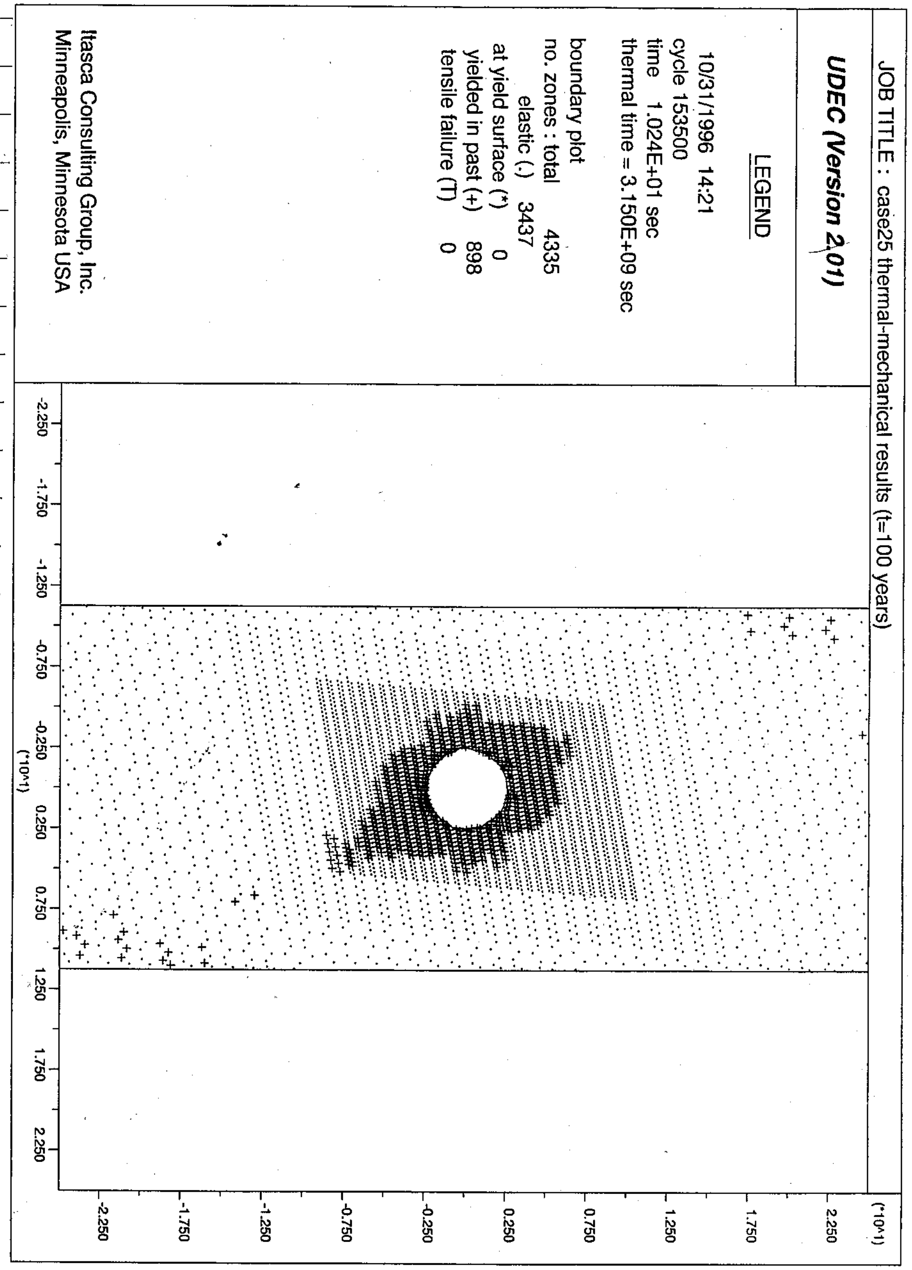
$$\boxed{\sigma_{xy} = 11.02\, V_x}$$

The seismic input will now be input as a stress history. ~~The input~~ seismic record can be used to determine the central frequency for Raleigh damping. The frequency content of the input record is shown below.



the dominant frequencies range between 0.5 to 1.5 Hz. For the analysis, damping at the central frequency ≈ 1 Hz was chosen. Stiffness damping was not used so as to increase the timestep. Preliminary analyses, comparing full Raleigh damping (mass + stiffness) with only that using mass damping did not differ appreciably. Also, a small amount of partial density scaling was utilized in the UDEC dynamic runs. Specifying a timestep of 1.5e-5 sec, in the model (using MSCALE part command) resulted in approximately 10 zones being scaled. The effect of this partial density scaling is expected to be small, but should be verified since the smallest zones to which the density scaling is applied, are located right around the tunnel.

For comparison purposes, the Figures on pages 23 - 26 contain a sample of results from the TM analysis for case 25.



Yield zone around Tunnel.

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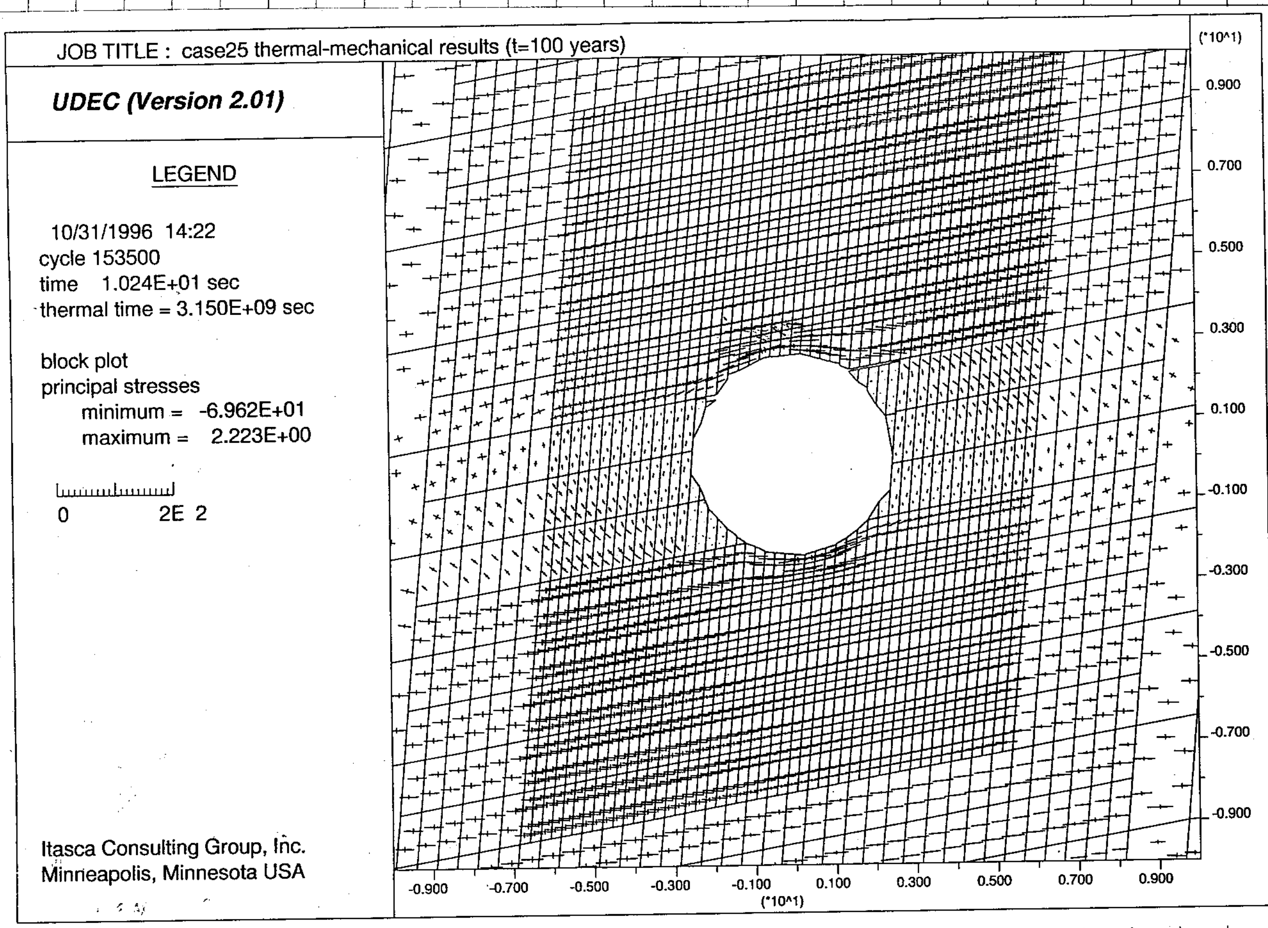
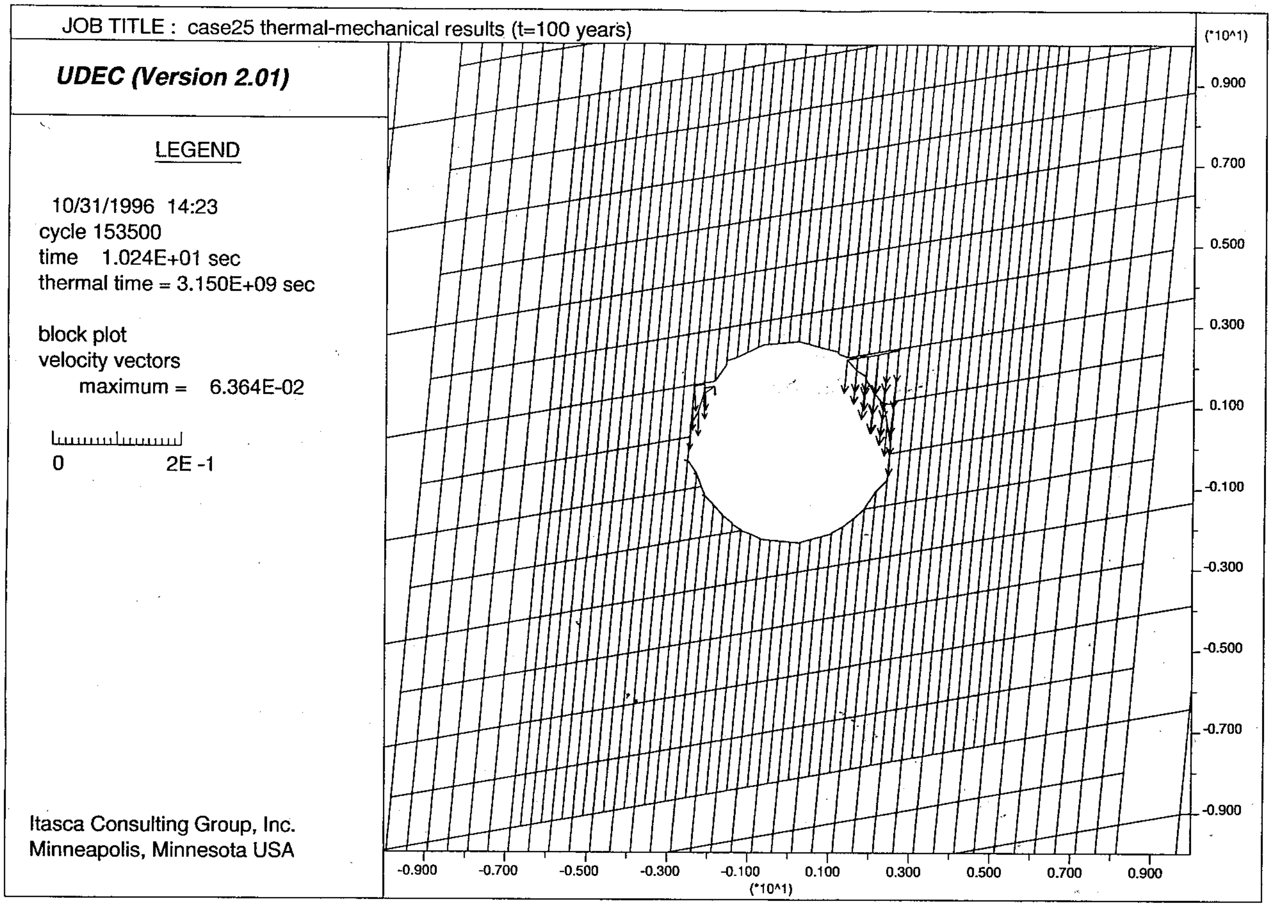


Principal Stress Plot. (Maximum = -69.6 MPa Comp.)

10/31/96



Block Plot showing unstable blocks in Roof.

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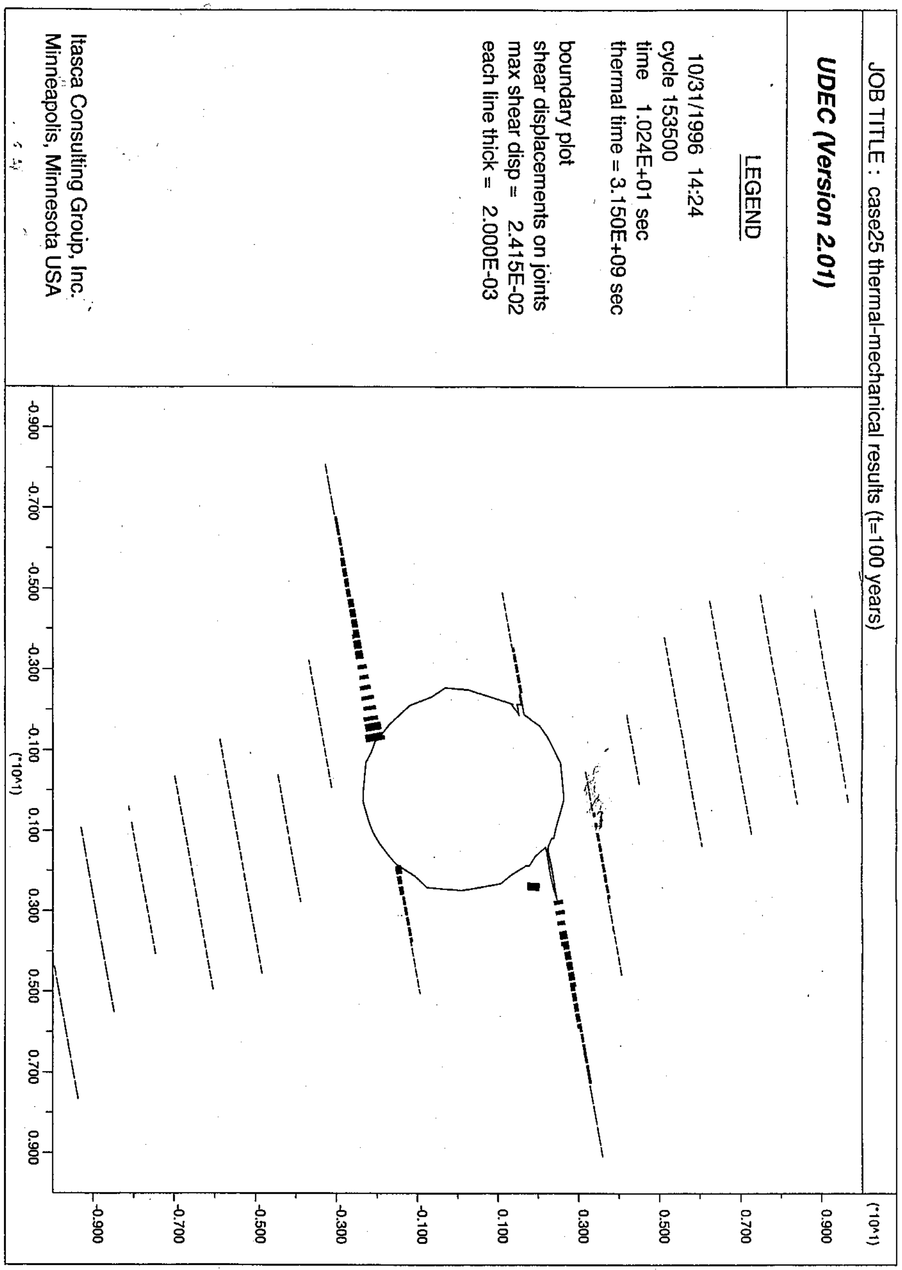

Total Shear Displacements

The first dynamic run for Case25 consisted of a vertical p-wave earthquake time history applied to base of model (30 sec. duration) (magnitude 0.6 g). The run took approximately 3 weeks on a Sun Sparc Station 10. Some of the results after completion of the 30 second earthquake are presented on the following pages followed by a discussion and comparison to the TM results on the previous 4 pages. Note: the unstable roof blocks (Figure page 25) were deleted prior to running the dynamic analysis.

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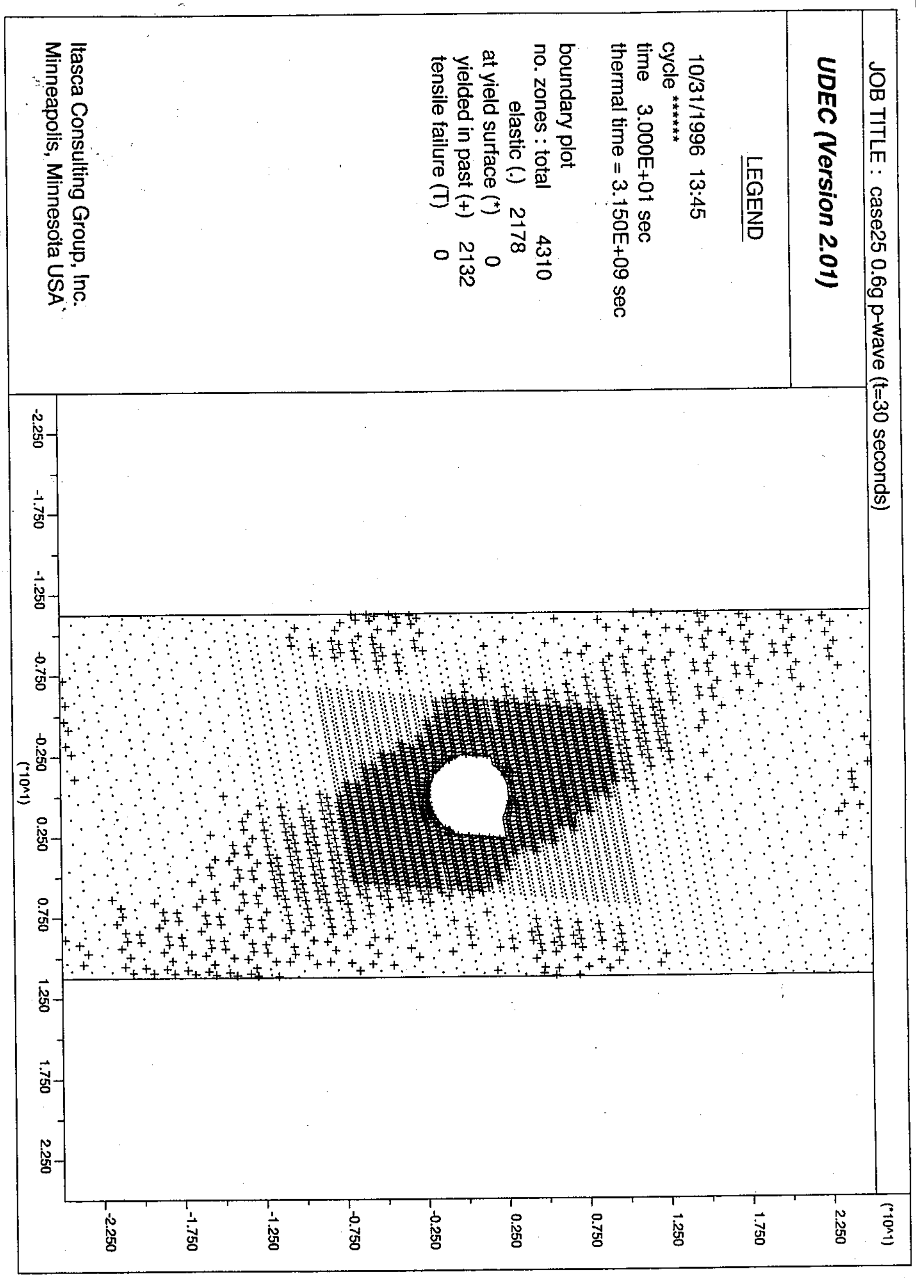
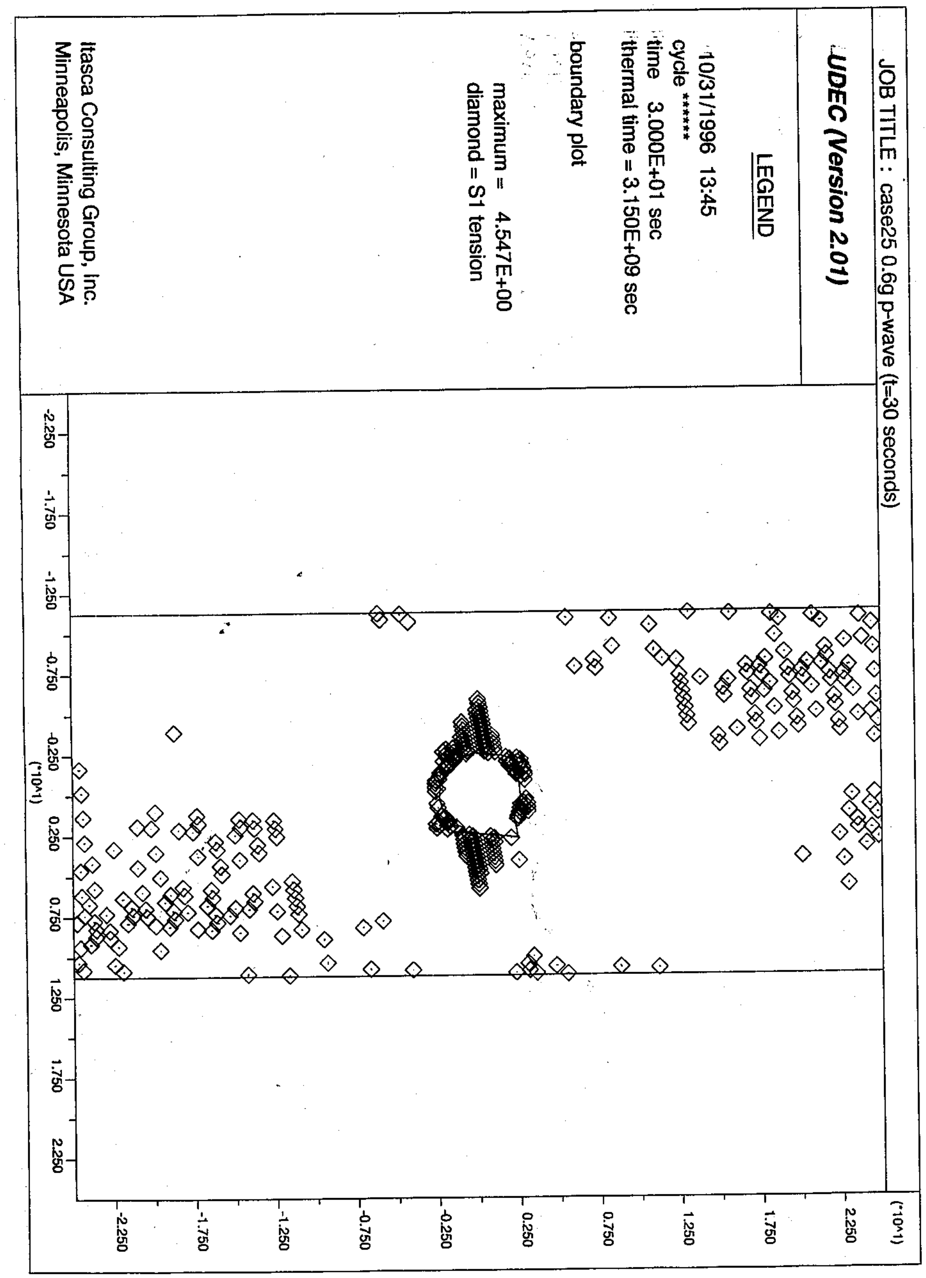
Yield Zone   10/31/96   ma



Tensile Stress Zone   10/31/96   ma



Block Plot.

mq
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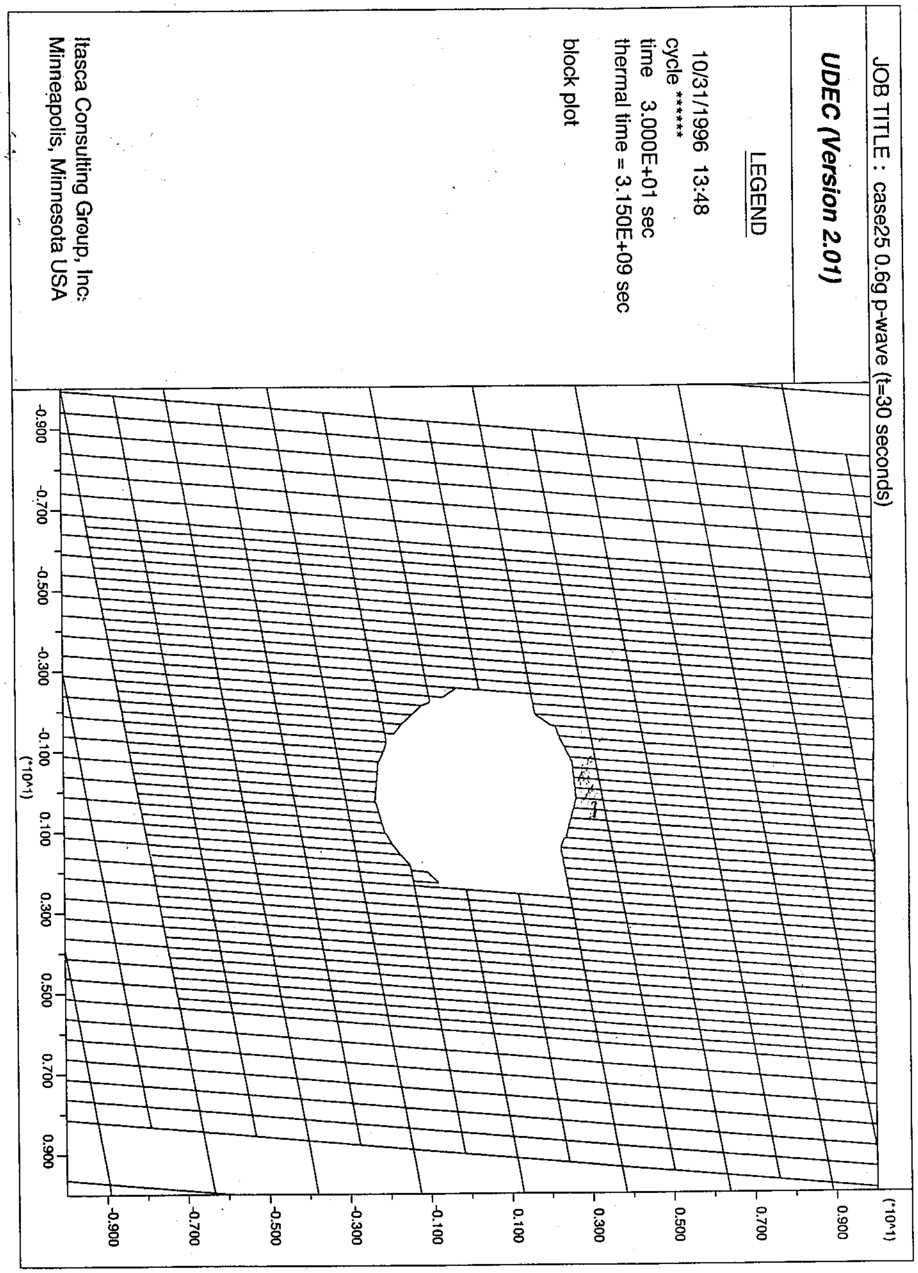

mq

Principal Stress Plot (Max = -49.5 MPa)
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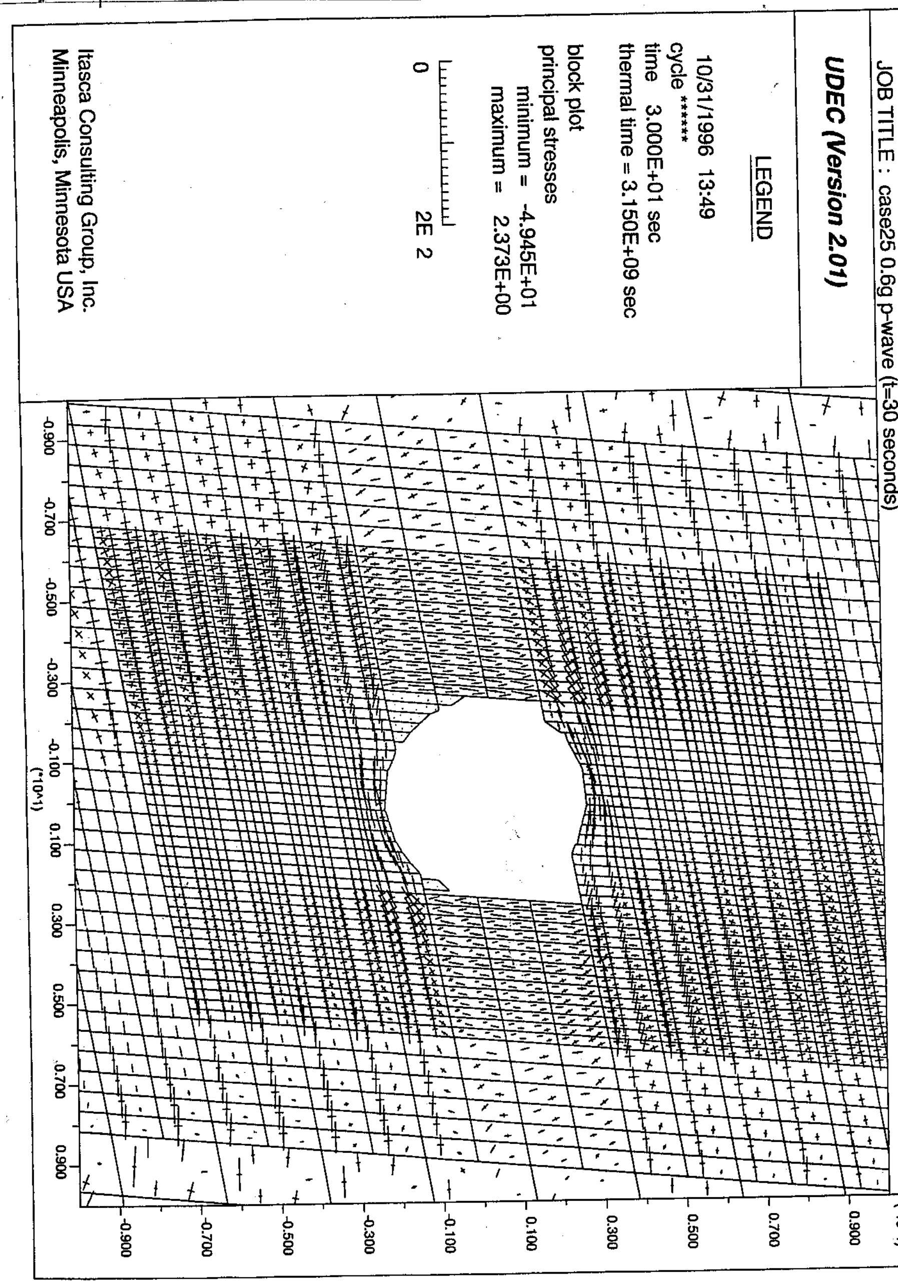
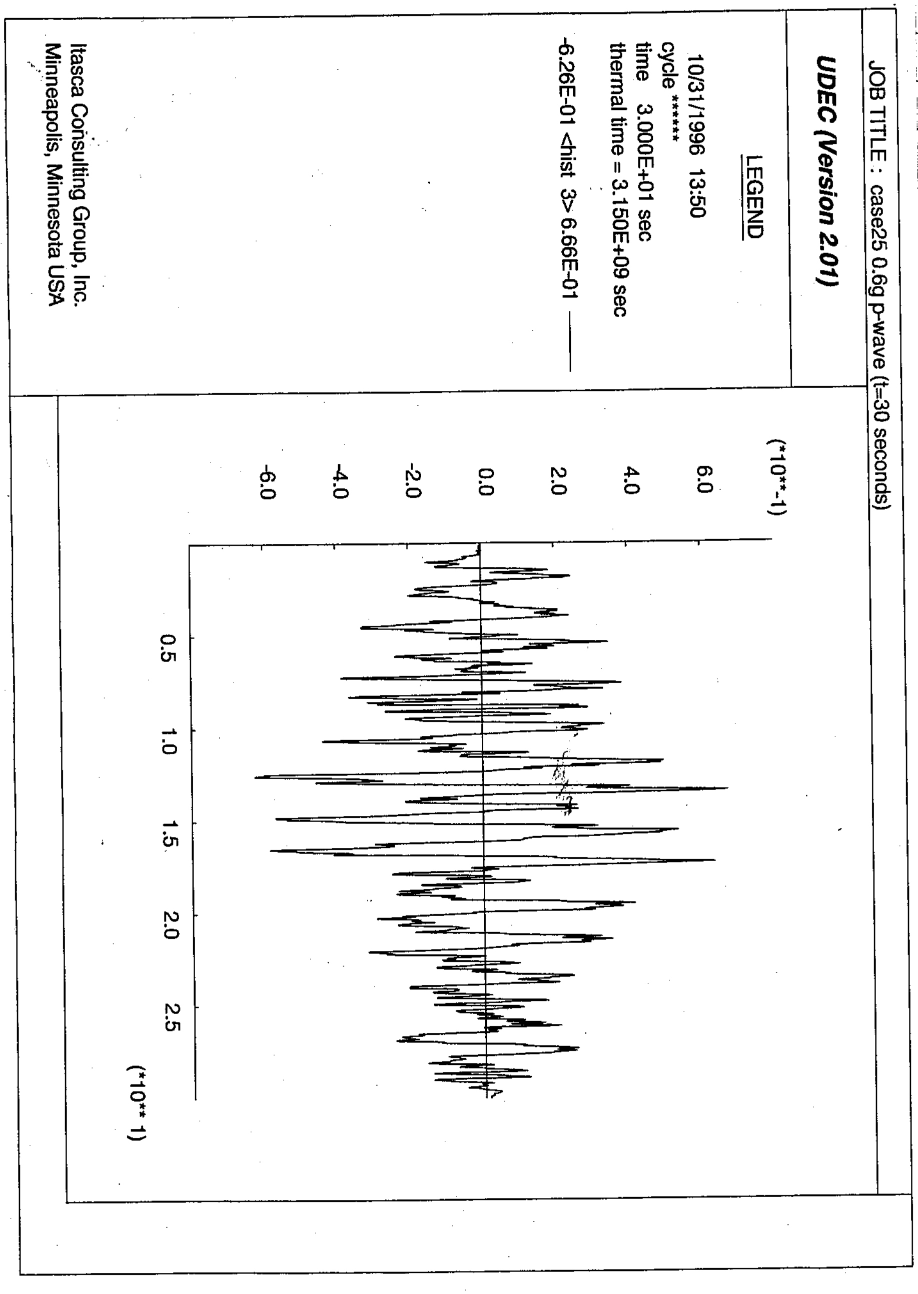


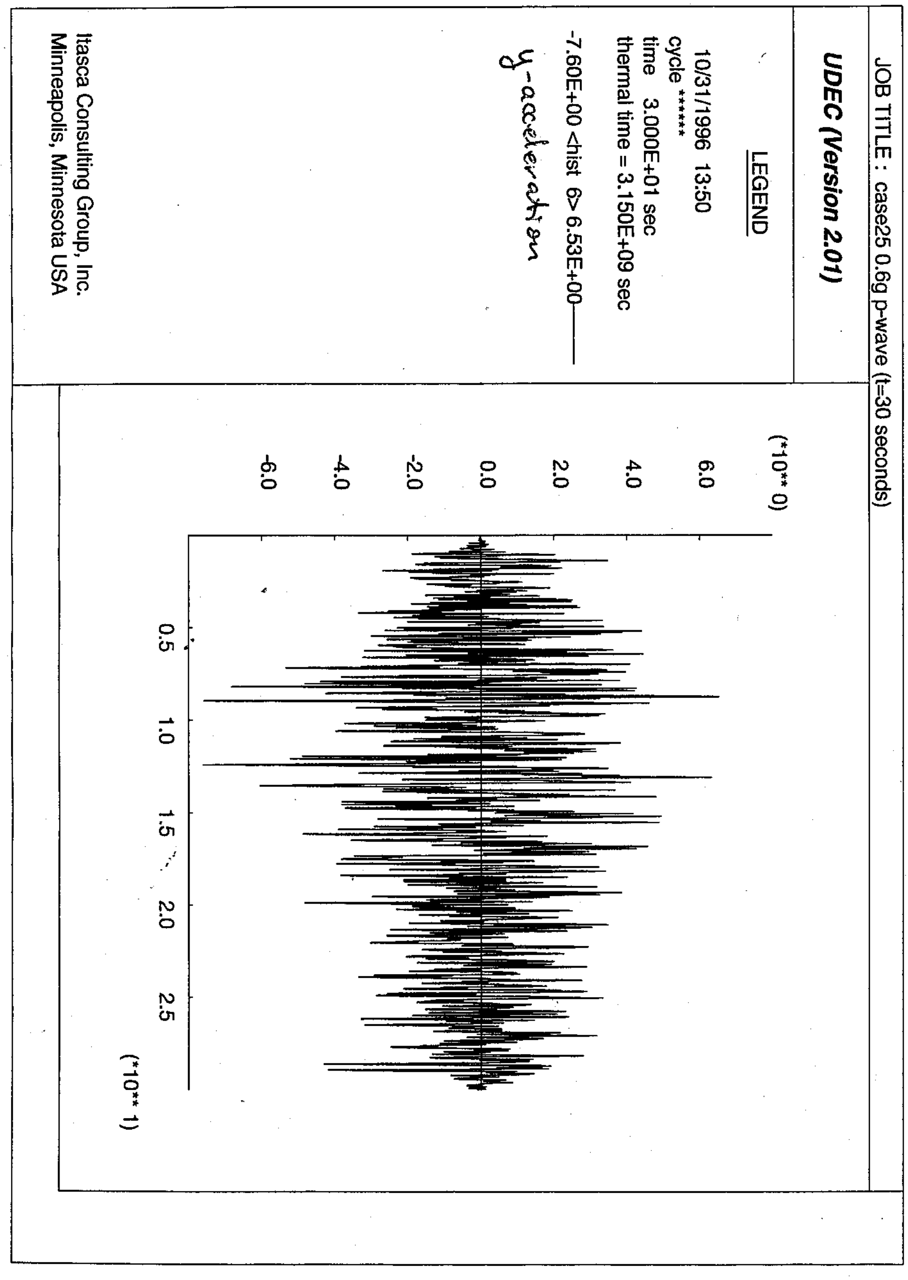
10/31/96 [illegible]

Input Velocity (Vy) at Base (m/s)



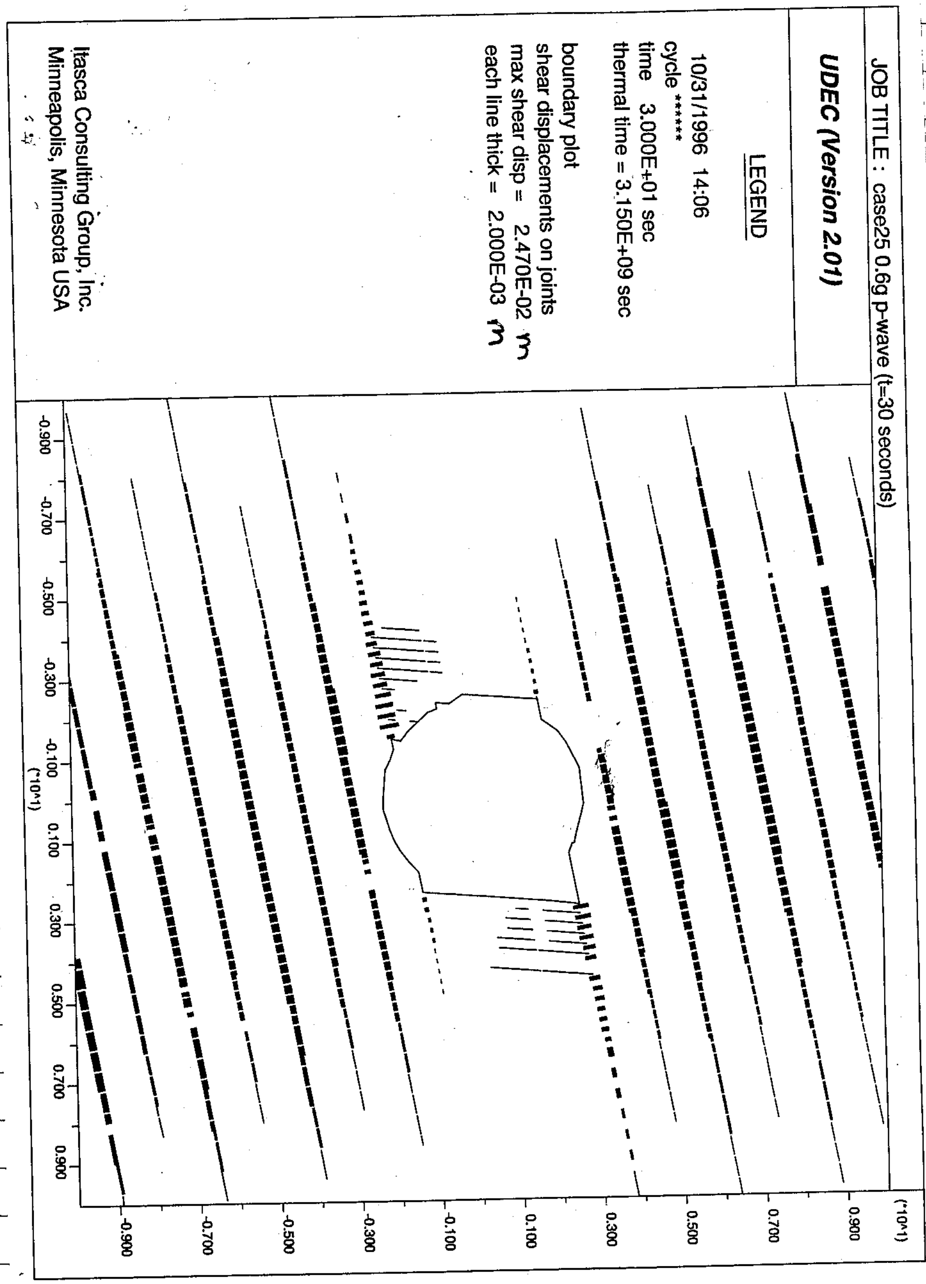
10/31/96 [illegible]

Input Acceleration (m/sec²)



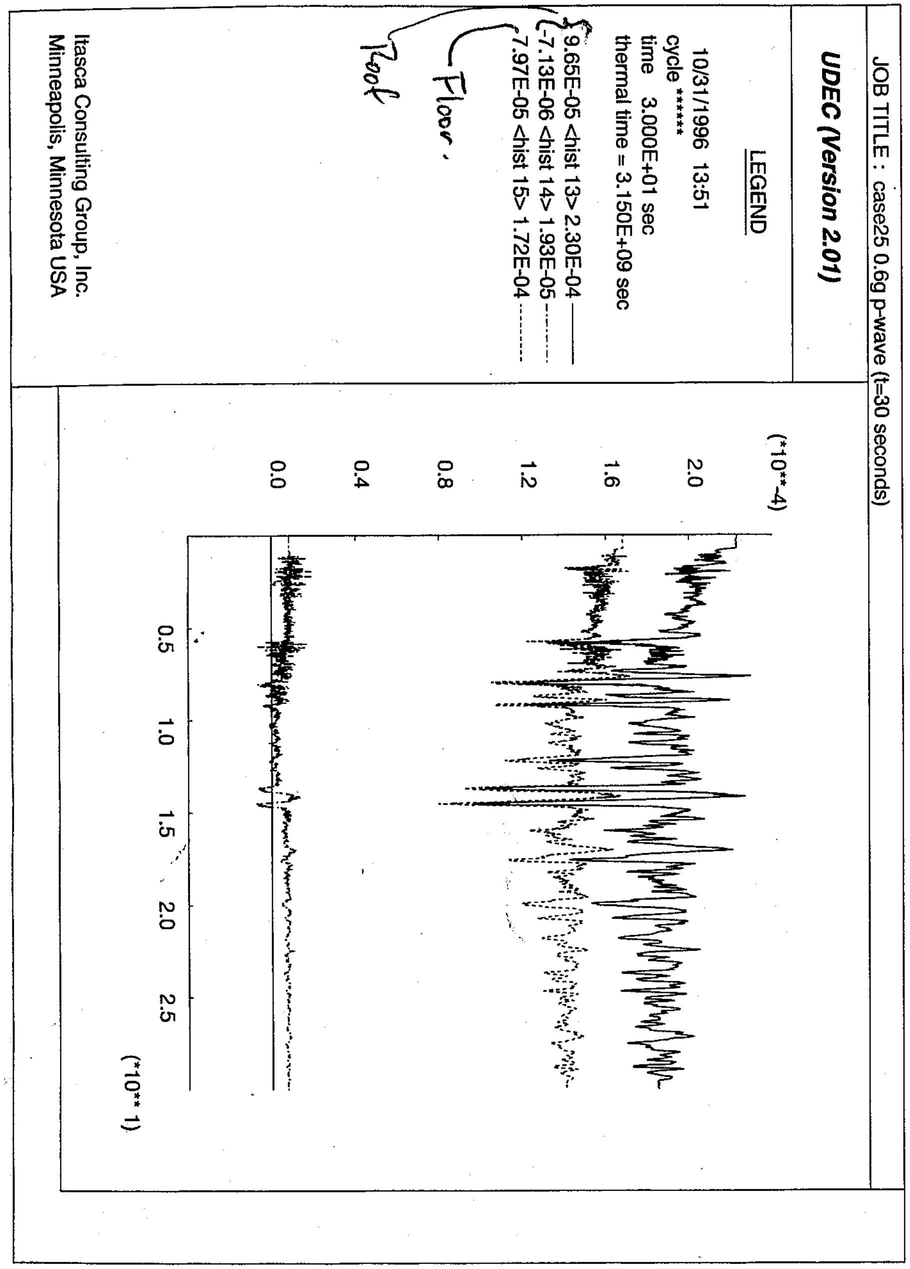
10/31/96 [initials]

Joint Shear Displacement



10/31/96 [initials]

Relative Joint shear displacement Histories in Roof and floor



In viewing the results from the dynamic analysis, both the extent of yielding and joint shear displacement have increased from the TM results. However, there is a drop in maximum principal compression from approx. 70 MPa to 50 MPa after dynamic shaking, most likely due to increased slip along joints and stress redistribution. The figure on Page 35 shows some relative offset (shearing) along joints in the roof, but little to none in the floor. Comparison of block plots (pg 25 and 30) shows some spalling of small blocks near the bottom of the tunnel after shaking. Note: Blocks that fell into the tunnel were deleted during the dynamic analysis since, ~~the~~ once becomming disconnected the code lost track of them,

12/20/96

Reflections of the dynamic wave from the surface were found to be fairly substantial in the model, particularily for the p-waves. This is partly due to the fact layering was not accounted for in the models.

It was felt that for the dynamic shear wave analysis that the lateral dimension of the model needed to be extended. A new model was developed that incorporated 3 tunnels. the lateral dimensions of the new model was 67.5 m versus 22.0 m in the previous model. The boundary conditions for the shear wave analysis are quite different than that for the p-wave analyses. For the p-wave analysis, rollers used to model symmetry for the thermal-mechanical analysis would also be used for the dynamic analysis.

the only changes were to convert the velocity input to a vertical stress wave input as described earlier in this notebook. Viscous boundary conditions are applied then at the base as well as at the top to eliminate unrealistic wave reflections.

For the shear wave analyses, the roller boundary conditions on both lateral boundaries were required to be removed. One cannot simply replace them with viscous boundary conditions in the (X) or lateral direction, since this would result in dampening of the shear wave as it propagates up the rock column. As a result, free-field boundaries as described in the UDEC User's manual were required to be attached the each lateral boundary to simulate the free field motion.

MA

1/6/97

Attempts at using the free-field boundaries in version 2.0 of UDEC were unsuccessful. Version 3.0 of UDEC which arrived 1/1/97 had much more capabilities in using the free field boundaries.

For a case run with no joints, the free-field boundaries worked perfectly. The approach to using them was to apply the in situ loading to the main model, cycling to equilibrium. The initial stresses were then applied to the free-field mesh and cycled to equilibrium. Once this was completed, the two meshes were linked together through the UDEC BOUNDARY condition command for the dynamic analysis.

MA

1/7/97

~~For the~~ Based on initial runs, it was found that a slight baseline correction to the velocity histories ~~was~~ shown on page 7 of this notebook. This was because although the velocity ~~record~~ [MA] went to zero at the end of the 30 second record, the integrated displacement showed a small offset on the order of 10^{-2} m (i.e. 1 cm). I talked with Jim Unruh (Div. 6) who provided the initial velocity records and he found a suitable approach to add a small term to the velocity so that the displacement would approach zero at the completion of the seismic input.

MA

1/7/97

For the thermal-mechanical-seismic analysis again with no joints, the free field mesh along the lateral boundaries apparently needs to be applied after the thermal loading stage and before the seismic loading. No guidance is given in the UDEC manuals. If the free-field boundaries are applied before the thermal loading (and replacing the roller boundaries), the thermal stress is not built up. Before linking the free-field mesh with the main mesh through the BOUND command, the ~~the~~ insitu loading is applied to the free field mesh. The free field mesh is then linked to the main mesh in which the TM analysis has been completed. One would think that once this is done the lateral stress in the free-field would build up but it doesn't. It remains at the insitu stress level.

Anyway, the approach appears to work in that the TM loads are held in the model, while the free-field boundaries allow vertical propagation of the shear wave. Again this is for the case with no joints, only an elastic media with 3 excavations. To speed up the dynamic analyse, especially when incorporating joints the upper and lower portions of the model were deleted (i.e. from -300 to -50m and 50m to 300m). When this is done, appropriate boundary stresses must be applied to the new upper and lower boundaries equivalent to before reducing the model. This is accomplished by setting the velocities (both x and y) to zero along ~~top~~ new top and bottom boundaries after deleting the upper and lower portions

of the model. A few cycles are then run to allow the appropriate stress to build up along those two boundaries. For the dynamic analysis, these two top and bottome boundaries are then replaced with viscous boundaries to eliminate seismic wave reflections

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Data file: dynza-tmjl.dat

Data file included in Scientific Notebook #206, page 4-13

The next step was to include joints in the TM + Seismic analysis. Since the realistic joint spacings are rather small, it was decided to start out with a coarse joint pattern and then gradually progress to the final analyses with fine joint spacings. Since, to achieve the final joint spacings, some mesh gradation is necessary. Some tests are required to see how the mesh gradation might affect the wave transmission as well as entrapment within the finer mesh zone. Entrapment was found to be severe for p-wave analysis. Jointing was only included in the near field zone (i.e. $-50m < y < 50m$) since the remainder of the model (i.e. $-300m < y < -50m$ and $50m < y < 300m$) was deleted for the seismic shear wave analyses.

** Both stiffness and mass damping with some

partial density scaling was applied. The analysis appeared to run sufficiently well for the 30 sec. seismic duration. Acceleration input was 0.2g, and the response measured at the base and top of model was consistent with input. No wave entrapment was seen as all velocities died of after shaking.

Data file: dyn2a-tmj1.dat

Dynamic timestep $\Delta t = 2.881 \times 10^{-5}$ sec.

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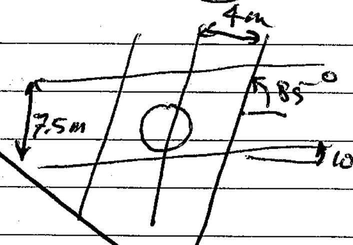
Nearfield joint Spacing

Subvertical 4.0 m @ 85°

Subhorizontal 7.5 m @ 10°



Run Time

Dynamic Analysis → 54 hours
(1 repetition corresponding to 30 s earthquake shaking).

Datafile included in Scientific Notebook #206 - page 14-22

A similar analysis to that described on pages 44 and 45 was conducted, but this time only mass damping along with partial density scaling was used. (i.e., full raleigh damping (mass + stiffness proportional damping) was not applied. Mass damping only normally gives a larger timestep especially when block and zone sizes ~~too a~~ become small (as a result of small joint spacings).

Data file: dyn2a_tmj1a.dat

Same as previous data file dyn2a_tmff.dat except stiffness damping removed!

Results were unacceptable due to large acceleration buildup around the tunnel most likely due to high frequencies generated there. Mass damping only damps low frequency. Thus, it is necessary to include full raleigh

damping in all the final dynamic analyses. Some partial density scaling is allowed.

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From this point forward all scientific notebook entries are transferred to a new and larger scientific notebook # 206

MA
2/6/97

I have reviewed this Scientific Notebook and find it in compliance with QAP-001.
[signature]
Element Manager, RDCO
2-7-97