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INVESTIGATION OF STRESS IN A CIRCULAR TUNNEL DUE TO OVERBURDEN AND THERMAL LOADING OF HORIZONTALLY PLACED 21 PWR MULTI PURPOSE CANISTERS

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ABSTRACT

The drift of a High Level Nuclear Waste (HLNW) Repository were subjected to 2-D thermal loading resulting from the horizontal emplacement of 125 Ton Multi-Purpose Canisters (MPC). Ten 2-D temperature profiles, resulting from 57 Kw/acre and 114 Kw/acre thermal loading conditions, were used in a finite element analysis of the drift; in which a quadrant of the drift and surrounding rock +/- 100m above and below the drift were modeled.

Our analysis shows that the 114 Kw/acre thermal loading results in compressive stresses around the drift, 60 years after emplacement, that exceed the unconfined compressive strength of the TSW_2 tuff analyzed. Stresses resulting from a 57 Kw/acre thermal loading are within the acceptable limit in tunnel rock. A parametric analysis of the invert backfill material showed that Young's modulus for the invert backfill *should closely* match that of the surrounding unconfined rock in the tunnel in order to prevent an unacceptable stress rise in both rock and backfill.

INTRODUCTION

Stress analysis due to overburden , gravity and 10 cases of thermal loading due to storage 21PWR capacity Multi-Purpose Canisters (MPC) with inner and outer barriers is presented. In this analysis the MPC are horizontally placed in the drifts of a High Level Nuclear Waste repository (HLNWR) in tuff. The MPC has 22 years old fuel, 42.2 GWd/MTU burnup. Thermal loadings of 114 KW/acre and 57 KW/acre were considered in the analysis since 2-D temperature distributions, due to average thermal loading, were available[3]. 2-D stress analysis using the finite element method were conducted.

In our previous studies[1,2], the canisters were stored in a vertical emplacement mode with the vertical holes spaced 20m, center to center and the parallel circular rock drifts 38m apart. Both the 2-D and the 3-D finite element models showed high thermal stress concentrations and local collapses around the sides of the vertical emplacement holes and in some of the circular tunnel walls areas.

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I. 2-D TEMPERATURE DISTRIBUTION

The two dimensional temperature distribution profiles, used in this paper to establish the 10 different cases of thermal loading, were provided by the CRWMS M&O Group[3], using finite element analysis in both the MPC and deep in the rock. In this paper the stress distribution in the tunnel wall and in a vertical section of the repository 200m long, ranging between -209m and -409m from the top of the repository, is presented. Maximum temperatures in the drift walls were reached at 10 years after the start of the horizontal emplacement for the 57kw/acre thermal loading and at 60 years after the start of the horizontal emplacement of the 114kw/acre thermal loading. Temperature decreases horizontally from the drift wall to the center line between two drifts ; and decreases vertically upward to 24°C at 100m above the tunnel and to 37°C at 100m below the tunnel, which corresponds to the geothermal gradient in the rock[4].

II. FINITE ELEMENT MODEL

Our finite element mesh uses triangular plane strain elements[5] having two degrees of freedom per node. The exact tunnel shape and emplacement of an MPC waste package are shown in Figure 1. The sizes of the element gradually increases away from the waste package (WP); with the smallest triangular elements having sides of approximately 0.17m and heights of 0.09m to 0.15m adjacent to the WP in the invert backfill, which is an engineered material. Similarly elements adjacent to the walls of the tunnel have side lengths of approximately 0.3m and heights of 0.10m to 0.25m. The model is a half quadrant including half of the tunnels of 7.8m diameter and having a drift spacing of 26m. The waste package spacing changes according to the heat load applied. A concrete seat was provided to support the MPC. The finite element model we present has a total of 4936 nodes, 9496 elements and 9852 degrees of freedom.

III. TEMPERATURE LOADING

Thermal loading is applied to the nodes of the elements by continuously varying their temperature values[3] which are specified at circular surfaces in the model having the center of the drift as their own center.

IV. MATERIAL CONSIDERATIONS

The material properties used in the analysis of the concrete[6] seat under the WP are : Young's Modulus, E_c=18.3GPa; Poisons' Ratio, Nu=0.26 ; Density, Rho=2.24g/cm^3; and the thermal expansion coefficient Alpha=1.1x10^{-6}/C°. The engineered material[7] properties used for the tunnel invert backfill, under the MPC seat, are Young's Modulus, E=6.89 GPa to E=28 GPa; Poisons' Ratio, Nu=0.2 ; Density, Rho=2.32g/cm^3. Thermal expansion coefficient Alpha is a function of temperature, as shown in table 1. The thermal and mechanical properties used in the model for the TSW2 tuff rock[8] are shown in table 1 & 2, with a rock density[9] Rho=2.32g/cm^3 at ambient temperature.

Young's and shear modulii at ambient temperature were reduced by approximately 10% at the high temperature regions above the 150°C[10].

V ANALYSIS

Our previous analysis [1,2] of the vertical emplacement mode showed rock failure and collapse in the vertical boreholes and some areas of tunnel walls. The present study analyzes the adequacy of horizontal emplacement of 125 Ton, 21PWR MPC/WP producing a thermal loading of 57 Kw/acre and 114 Kw/acre[3] . Similarly, a parametric study of the engineered material backfill, under the canisters, is shown for the 57 Kw/acre loading to determine a suitable material that produces thermal stress compatibility with the tunnel concrete lining, if a lining is deemed necessary, and with the rock tunnel walls.

A. Load case I. Gravity, overburden load and geothermal temperature: Principal stresses for this load case were quite low, 7MPa, compared to the allowable stresses in the rock.

B. Load case II. Thermal load of 57 Kw/acre:

1. Thermal Stress analysis for a load of 57 KW/acre at 1, 10, 60, 200, and 1000 years after horizontal emplacement of the MPC's was conducted. Material properties in different zones of the rock were changed along with changes in the temperature profiles within these zones. The invert backfill material constants were kept unchanged. Results show that the highest stresses in the tunnel walls were reached at 10 years after emplacement. Maximum stress values for Sigma-X of 41.3 MPa which occur at the tunnel crown, Point A Figure 1, are within the allowable stress limit for the TSW2 tuff, as shown in table 2.

2. Thermal stress analysis of the invert backfill for a load of 57 Kw/acre at 10 years after horizontal emplacement: A parametric study allowed the invert backfill materials to have different Young's modulii of E= 6880 MPa (B1), E= 14000 MPa (B2), E= 21000 MPa (B3), and E= 28000 MPa (B4). Results are shown for Point G in the invert backfill and Point F in the rock at +/- .50m respectively from the rock wall where the two materials meet. Results are shown in Figure 2. Sigma-X, Sigma-Y, and Sigma-Z are shown in the backfill material and the rock at Points G and F respectively. The bar gragh shows that the stress levels in both rock and invert backfill materials rise substantially as Young's modulus of the backfill material increases, Figure 2. the stresses in the rock.

C. Load case III. Thermal load of 114Kw/acre: Thermal stress analysis for a load of 114 Kw/acre at 1, 10, 60, 200, 1000 years after horizontal emplacements of MPC's was conducted. The highest stresses were produced after 60 years of emplacements. Figure 1 shows the vertical symmetry line 1, the horizontal line 2 and reference points A & B at the crown and 1m inside the rock respectively also points C & D are located at the bottom of the drift and 1m inside the rock. Figure 3 and 4 show the stress profiles of Sigma-X, Sigma-Y and Sigma-Z at points A, B, C, & D as functions of time after emplacement of MPC's. Figure 5 shows the horizontal stress Sigma-X along Line 1 for different times after emplacement of the MPC. Compressive stresses reache 94 MPa at point A, on the crest of the drift. The stress is beyond the allowable unconfined compressive strength for the rock mass at ambient temperature.

Figure 6 shows the spread of the high stress zone in the crown of the drift. Low tensile stresses occur at point E, on the drift mid point. The magnitude of the displacement resultant around the tunnel opening does not exceed 2cm. Figure 7 shows the effect of the biforcation in the linear thermal expansion coefficient, due to changes in temperature, on the stress values in the rock. At 5.1m, in the x direction, from the center of the tunnel (1.2m inside the rock the stress values for Sigma-y jumps from 30MPa to 50.2 MPa within a distance of 0.3m.

VI. CONCLUSIONS.

Drifts in a H.L.N.W. Repository in tuff were subjected to 10 cases of thermal loadings of 57 Kw/acre and 114 Kw/acre resulting from the horizontal emplacement of MPC's.

Results show that stresses in the tunnel go beyond the unconfined crushing strength of the TSW_2 tuff with worst stresses occurring after 60 years of emplacement under an average thermal load of 114Kw/acre. Stresses resulting from a 57Kw/acre loading are within the acceptable limit.

When the stiffness of the engineered backfill material as measured by its Young's modulus, exceeds the stiffnesses in both the invert backfill and the adjacent rock stresses in the rock and backfill rise to unacceptable values. The backfill material should be designed to have a modulus that closely matches the modulus of the rock.

ACKNOWLEDGEMENT

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REFERENCES

1. N. Kandalaft-Ladkany, R.V. Wyman,"Design Management and Stress Analysis of a Circular Rock Tunnel and Emplacement Holes for Storage of Spent Nuclear Fuel," High Level Radioactive Waste Management, Proceedings of the 3rd International Conference, Las Vegas, Nevada, (1992).

2. N. Kandalaft-Ladkany, R.V. Wyman and S.G. Ladkany,"Investigation in 3D of Stress Distribution in a Circular Tunnel and Vertical Emplacement Holes due to Thermal and Overburden Loading in Tuff," High Level Radioactive Waste Management, Proceedings of the 4th International Conference, Las Vegas, Nevada, (1993).

3. T. Doering and R. Bahney," Mined Geologic Disposal System - Multipurpose Canister - Design Considerations Report," TRW Environmental Safety Systems - Civilian Radioactive Waste Management System - Management and Operating Contractor, Preliminary Draft, B00000000-01717, August (1993).

4.Szabo, B. J. and Kyser, T.K.; "ages and Stable-Isotope Compositions of Secondary Calcite and Opal in Drill Cores From Tertiary Volcanic Rocks";Geological Society of American Bulletin, December 1990.

5. M. Lashkari, Cosmos/M User Guide, Volume II, release 1.65, Structural Research and Analysis Corp., California (1991).

6. American Concrete Institute,Behavior of Concrete Under Temperature Extremes, ACI Publication SP - 39, (1973).

7. J.A. Fernandez, J.B. Case and J.R. Tyburski, "Initial Field Testing Definition of Subsurface Sealing and Backfilling Tests in Unsaturated Tuff," SANDIA REPORT SAND92-0960, May (1993).

8. Yucca Mountain Project, The Reference Information Base, Released August 6th, 1990.

9. L.S. Costin and S.J. Bauer, "Thermal and Mechanical Codes; Part I : Thermal Analysis," SANDIA REPORT SAN88 - 1221 UC 814.

10. S.P. Clark, Jr., Handbook of Physical Constants, Geological Society of America, Memoit 97, 570 pp., (1966).

11. Office of Civilian Radioactive Waste Management; December 1988.

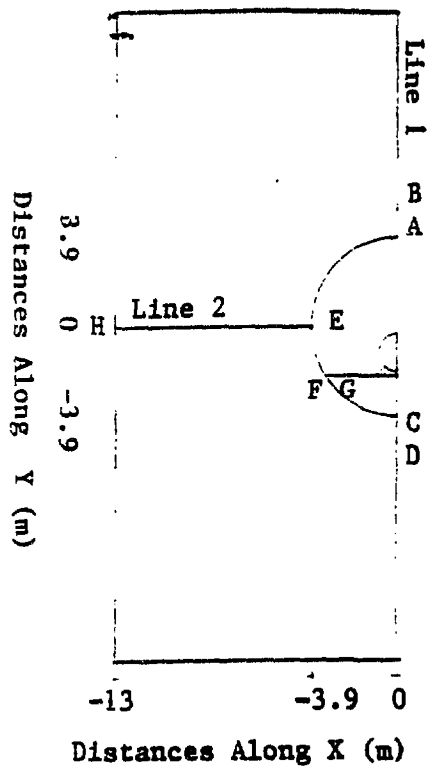


Figure 1. Schematic of Tunnel and the surrounding rock areas

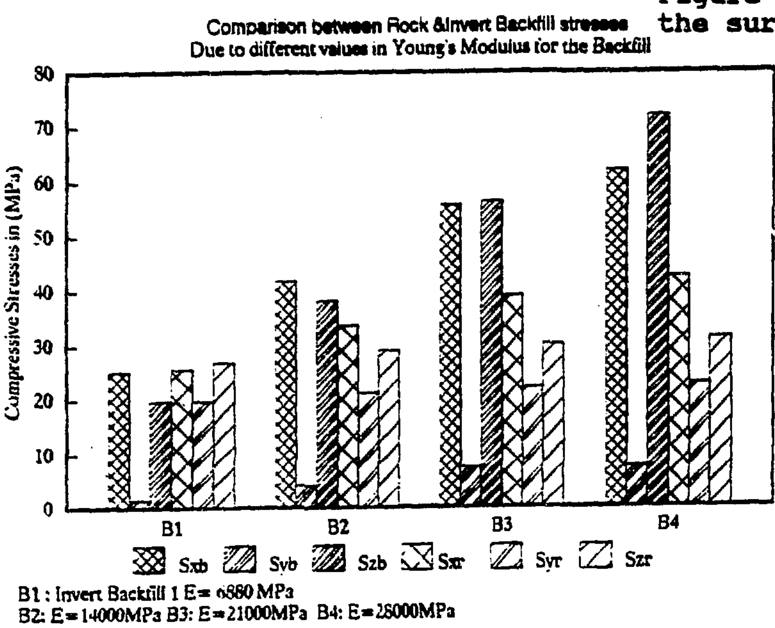


Figure 2. Invert Backfil Bar Chart Comparing Stresses @ Point G in Backfill & Point F in Rock.

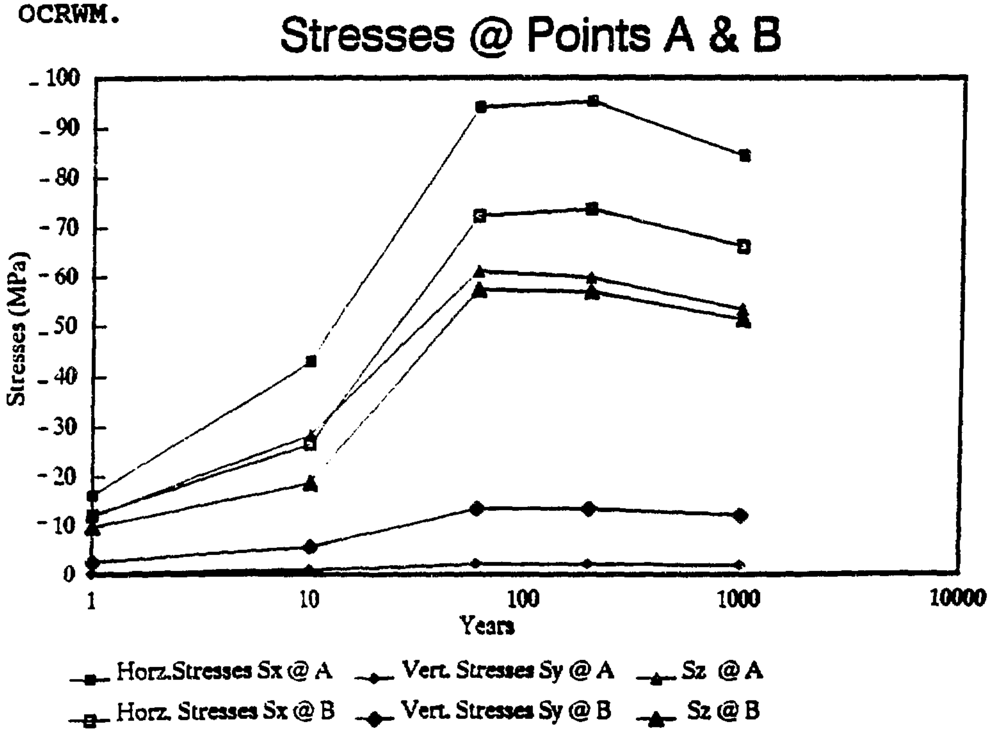
Linear Thermal Expansion Coeff.	25°- 50°	50° - 100°	100° -150°	150° -200°	200°-250°
TSW_2 for Very Near Field	5.40E-6	8.0E-6	9.8 E-6	17.0 E-6	25.0 E-6
TSW_2 Rock Mass Environment	9.1 E-6	8.2 E-6	6.8 E-6	9.7 E-6	No data

Table 1- Linear Thermal Expansion Coefficients for TSW_2 Rock @ Temperature Ranging from 25°C to 250°C, From Reference[8], YMP/RIB

	Unconfined Compressive Strength (MPa)	Young's Modulus (GPa)	Poison's Ratio
TSw_2 Intact Rock from wells USWG-1, USW GU-3, USW G-4	155 +/- 59	32.7 +/- 4.6	.22 +/- .03
TSw_2 ROCK MASS	75	15.2	.22

Table 2- TSW_2 rock, Mechanical Properties, Reference 8 & 11, YMP/RIB & OCRWM.

Figure 3.



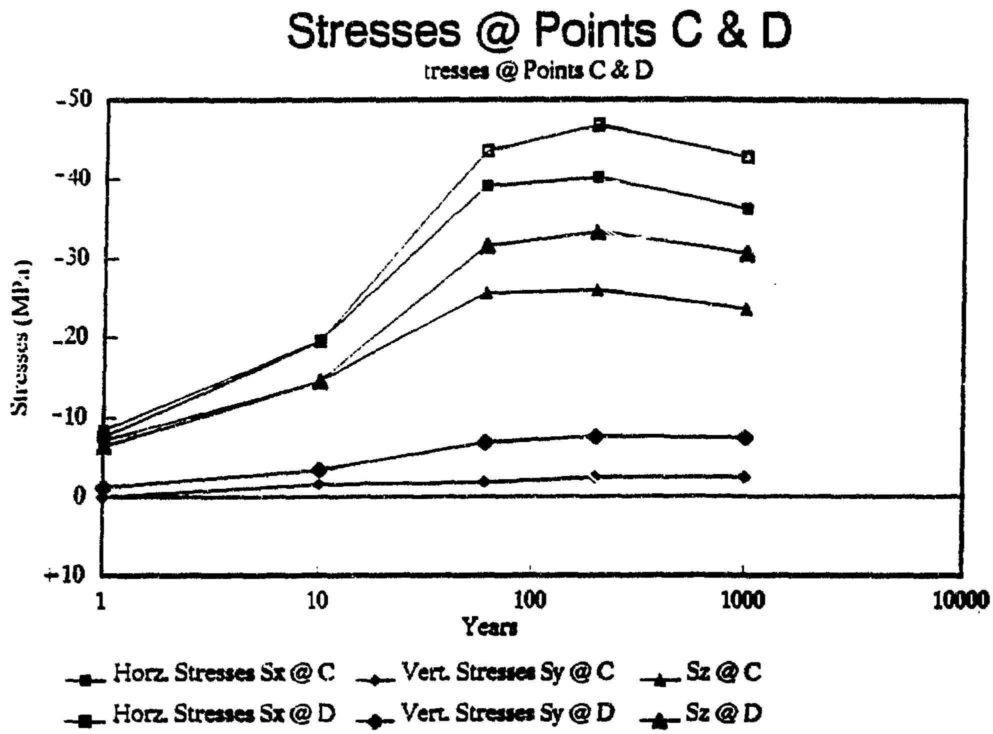


Figure 4.

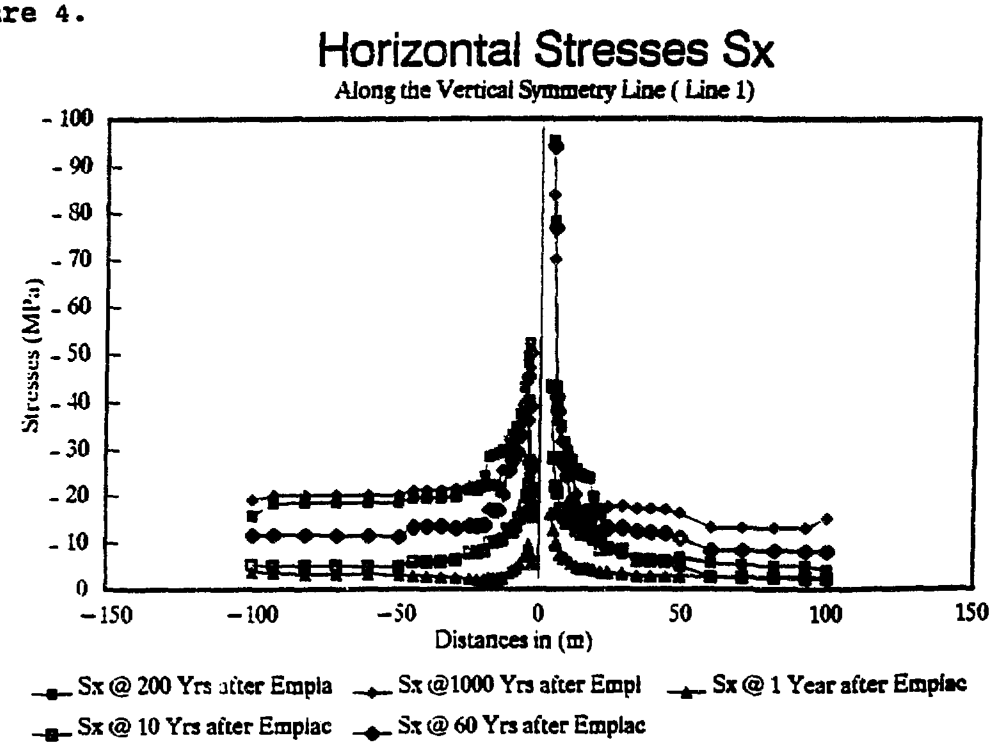


Figure 5.

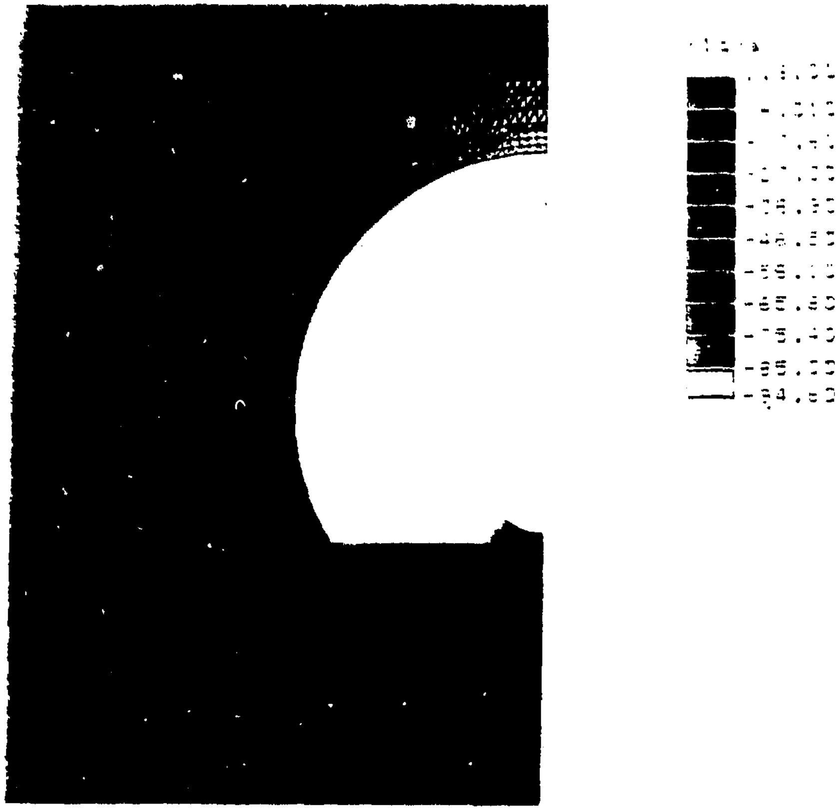


Figure 6. Horizontal Thermal Stress Plot of Sigma-X due to a Load of 114 Kw/acre @ 60 Years After Emplacement.

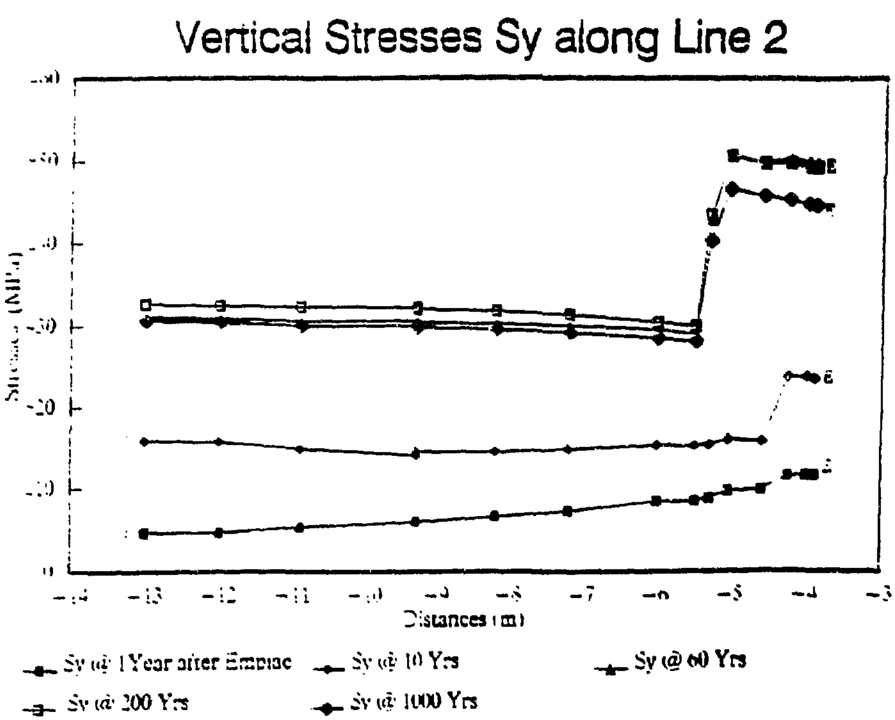


Figure 7.