ORNL/SUB-4269/1

THERMOELASTIC/PLASTIC ANALYSIS OF WASTE-CONTAINER SLEEVE:

II. INFLUENCE OF LARGE DISPLACEMENTS ON SLEEVE LOADING

Technical Memorandum Report (RSI-0017)

William G. Pariseau

March 21, 1975

This report was prepared by RE/SPEC, Inc. under Subcontract 4269 with Union Carbide Corporation, Nuclear Division. The subcontract was administered by Oak Ridge National Laboratory

UNION CARBIDE

OFFICE OF WASTE ISOLATION
OAK RIDGE, TENNESSEE

prepared for the **U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION**
under **U.S. GOVERNMENT** *Contract W-7405 eng 26*

ORNL-Sub-4269-1

SUBCONTRACT NO. 4269

THERMOELASTIC/PLASTIC ANALYSIS OF WASTE-CONTAINER SLEEVE:

II. INFLUENCE OF LARGE DISPLACEMENTS ON SLEEVE LOADING

TECHNICAL MEMORANDUM REPORT (RSI-0017)

Submitted To

Oak Ridge National Laboratory
Oak Ridge, Tennessee

operated by

Union Carbide Corporation
for the
U. S. Atomic Energy Commission

By

William G. Pariseau

of

RE/SPEC Inc.
Rapid City, South Dakota

March 21, 1975

REA

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FOREWORD

The work described in this report was completed by Dr. William G. Pariseau on July 29, 1974. The technical aspects of the work as presented herein were reviewed by Dr. Arlo F. Fossum.

RE/SPEC INC.

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March 21, 1975

TECHNICAL MEMORANDUM REPORT (RSI-0017)

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SUBJECT: Thermoelastic/Plastic Analysis of Waste-Container Sleeve: II. Influence of Large Displacement on Sleeve Loading (Union Carbide Corporation, Nuclear Division Subcontract No. 4269; RSI/001000/FY 75).

1. SUMMARY AND RECOMMENDATIONS

Modification of the thermoelastic/plastic finite element program to account for large displacements possibly associated with the development of an extensive plastic zone about a radioactive waste container emplaced in a typical repository room (SALT-4/T model) has been completed (a). Comparisons of radial stresses acting on the waste container and borehole wall displacements computed by the modified and conventional analyses techniques reveal little difference between the two sets of results over a 10 year heating period for salt strengths 25 percent of original values. Because no significant differences in results arise even under these exaggerated conditions, the more costly large displacement option need be used only sparingly as an occasional control check on the conventional procedure. As a consequent, economy of computer run time can be maintained without sacrifice of accuracy.

(a) The requisite modification is outlined in the Appendix A at the end of this report.

2. INTRODUCTORY REMARKS

The purpose of this report is to describe the results of estimates of waste-container sleeve loading obtained by axially symmetric thermoelastic/plastic analysis mofified to account for large displacements. In this analysis, the computer program simulates a sequence of operations that includes: (1) excavation of a typical repository room and borehole in the room floor, (2) emplacement of the waste container and (3) subsequent heating over a ten year period. In effect, the program excavates a circular repository room (axially symmetric) 18 ft in diameter containing a centrally located hole (18 ft. in length, 1 ft. radius) in the floor. Stress changes caused by the excavation are added to the initial gravity stresses to obtain the post-mining stress field. Waste-container emplacement follows the room excavation. The 10 ft. long container rests on the bottom of the hole. Its lateral surface is in intimate contact with the adjacent salt. No stemming of the upper 8 ft. of the hole is assumed.

TABLE 2.1

Material Properties of Salt and Waste Container/Sleeve Arrangement

	Elastic Moduli		Plastic Moduli		Other	
	$E\times10^6$psi	ν	$C_0\times10^3$psi	$T_0\times10^3$psi	γ pcf	$\alpha\times10^{-6}/{}^\circ F$
Salt	0.46	0.40	4.58	4.58	152	22.2
Waste-Container	0.8	0.38	60.0	60.0	152	6.5

Heating of the adjacent salt initiates a thermal loading sequence. Thermal loads or stresses are calculated periodically and used to update the post-mining stress field. Updates occur after six months of heating and also at the end of the first year and each year thereafter for a ten year period. Temperature fields at these times were obtained from the RSI/TRANCO finite element program. Figure 2.1 shows the main features of the SALT-4T model which contains 261 nodes and 445 elements. The repository floor in this model is located 2074 ft. below surface.

Table 2.1 shows the material properties for the salt and waste container used in previous work (b). In the present work, salt strengths were reduced to 25 percent of the full values shown in Table 2.1.

If a large displacement effect were to occur, it would be evident under greatly reduced strength conditions because of the additional displacement beyond the elastic range that occurs with extensive plastic flow. If a large displacement effect is not observed under these conditions, then the effect can be assumed to be negligible.

3. PRESENTATION AND DISCUSSION OF RESULTS

The main results of the study of the possible influence of large displacements on the SALT-4/T waste container analysis consist of comparisons of sleeve loadings and borehole wall displacements obtained by two methods: (1) the standard or conventional finite element technique used in previous work, and (2) a modified finite element formulation that accounts for the possible influence of large displacements. Both procedures were applied to the SALT-4/T model using salt strengths 25 percent of original value in order to exaggerate the potential influence of large displacements on the analyses.

3.1 INFLUENCE OF LARGE DISPLACEMENTS ON WASTE CONTAINER/SLEEVE LOADING

Horizontal (radial) loadings of the waste container caused by heating of the container and adjacent salt at various intervals during the ten year heating period obtained by the conventional finite element

(b) Pariseau, William A., "Thermoelastic/Plastic Analysis of Waste-Container Sleeve: I. Initial Estimates of Loading on the Sleeve", Technical Memorandum Report (RSI-0010), Prepared for the Oak Ridge National Laboratory under Subcontract No. 3706 with Union Carbide Corporation, Nuclear Division (May 1974), 14 pp.

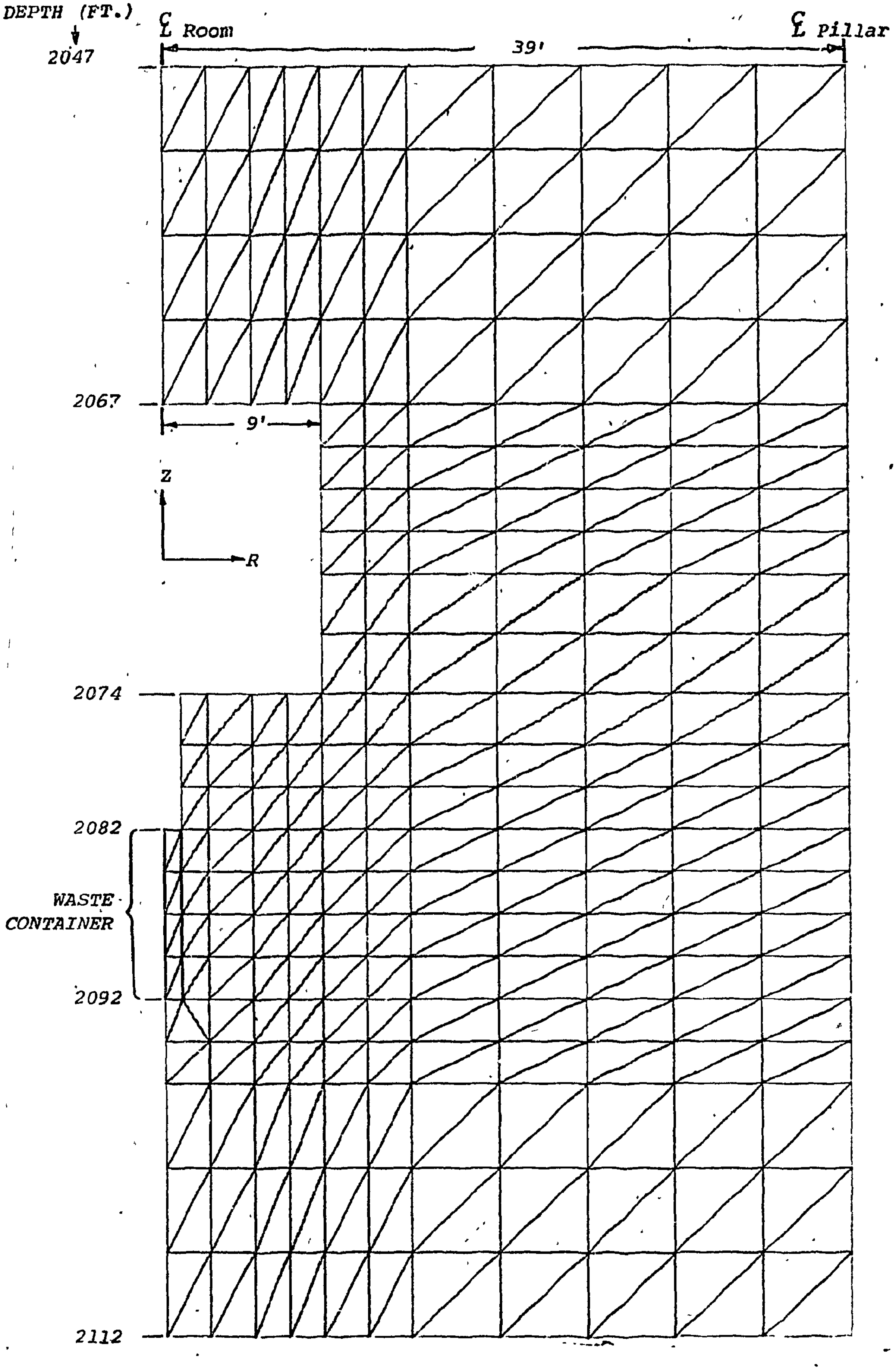


Figure 2.1. Finite-element grid for the room and pillar configuration at the New Mexico pilot-plant concept.

procedure are shown in Figure 3.1. Peak loadings and average loadings do not differ significantly. Also shown in Figure 3.1 are the 0.5 and 10.0 year loadings obtained with 100 percent salt strength values. Waste container loadings are similar over the lower one-half of the container, and are somewhat less over the upper half under reduced strength conditions as compared to full strength conditions. The load reduction is attributable to stress relief through plastic flow under reduced strength conditions. Under full strength conditions, plastic flow is not induced in the SALT-4/T model (b).

The horizontal loadings of the waste container obtained by the modified or large displacement finite element procedure differ very little from those obtained by the standard procedure. Table 3.1 shows the relative percent difference in loadings obtained by the two methods. The point by point comparison shown in Table 3.1 indicates that the differences in results obtained by the two methods are less than 1.3 percent.

The closeness of results obtained by the two methods is further illustrated in Figure 3.2 which shows the extent of the plastic zone that results in the reduced strength analyses. The extent of the plastic zone in both cases is, for practical purposes, the same.

3.2 INFLUENCE OF LARGE DISPLACEMENTS ON BOREHOLE CLOSURE

Borehole wall motion obtained by the conventional finite element procedure using 25 percent of original salt strengths is shown in Table 3.2. Vertical and horizontal (radial) displacements are greatest at the borehole collar labeled as point A. For comparison purposes, the displacement of point A calculated by the standard procedure using 100 percent salt strength is also shown in Table 3.2. The greater displacement at 25 percent strength is attributable to plastic flow. Upward motion of the borehole collar is less than 2.8 inches at 25 percent strength and less than 2.0 inches at full strength. Net borehole closure at the collar is slight, less than 0.15 inches at 25 percent strength.

Table 3.3 compares borehole wall displacements obtained by the standard procedure with that calculated by the modified or large displacement procedure. Generally the relative percent differences

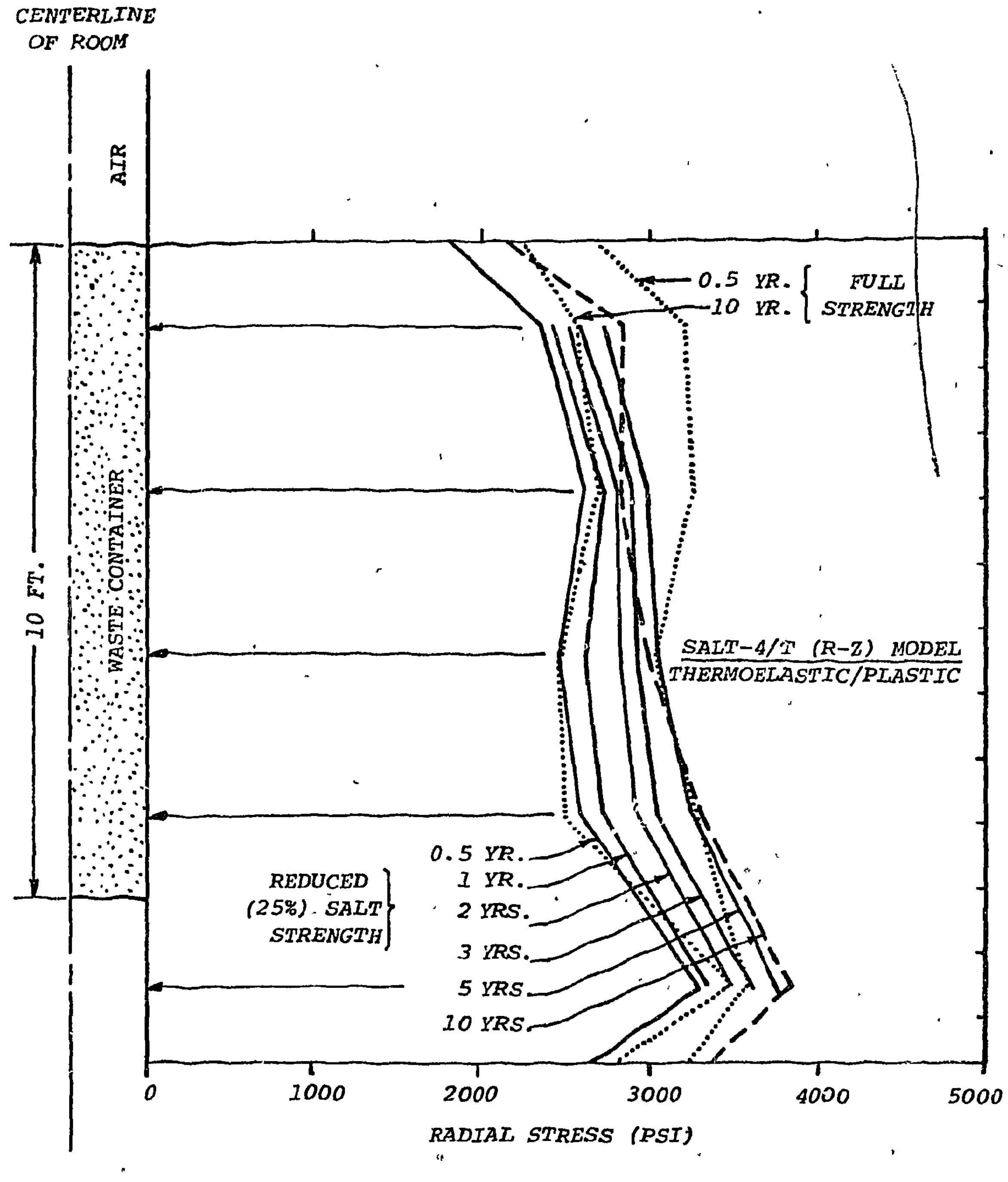


Figure 3.1. Radial stress loading on waste-container/sleeve over a 10 year heating period at 25% and 100% of full salt strength by conventional finite-element analysis.

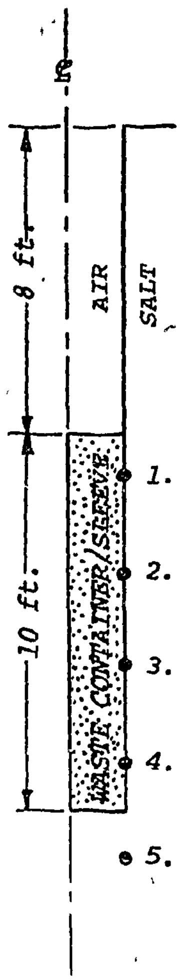


TABLE 3.1

Percent relative difference in radial stress loading on waste-container/sleeve (over a 10 yr. heating period, for 25% of original salt strength) between conventional and modified (finite-displacement) analyses.

$$\%\ \text{Relative Difference} = 100 \left[1.0 - \frac{\text{Modified Analysis}}{\text{Conventional Analysis}} \right]$$

PT. \ YR.	0.5	1.0	2.0	3.0	5.0	10.0
1.	0.6	1.5	-0.0	0.0	1.0	0.8
2.	0.0	1.1	-0.2	1.0	-0.2	-0.3
3.	-1.2	0.2	0.4	-0.3	0.3	0.3
4.	0.6	0.4	1.0	0.7	1.0	0.9
5.	-0.4	0.8	-0.4	-1.0	-1.8	1.4

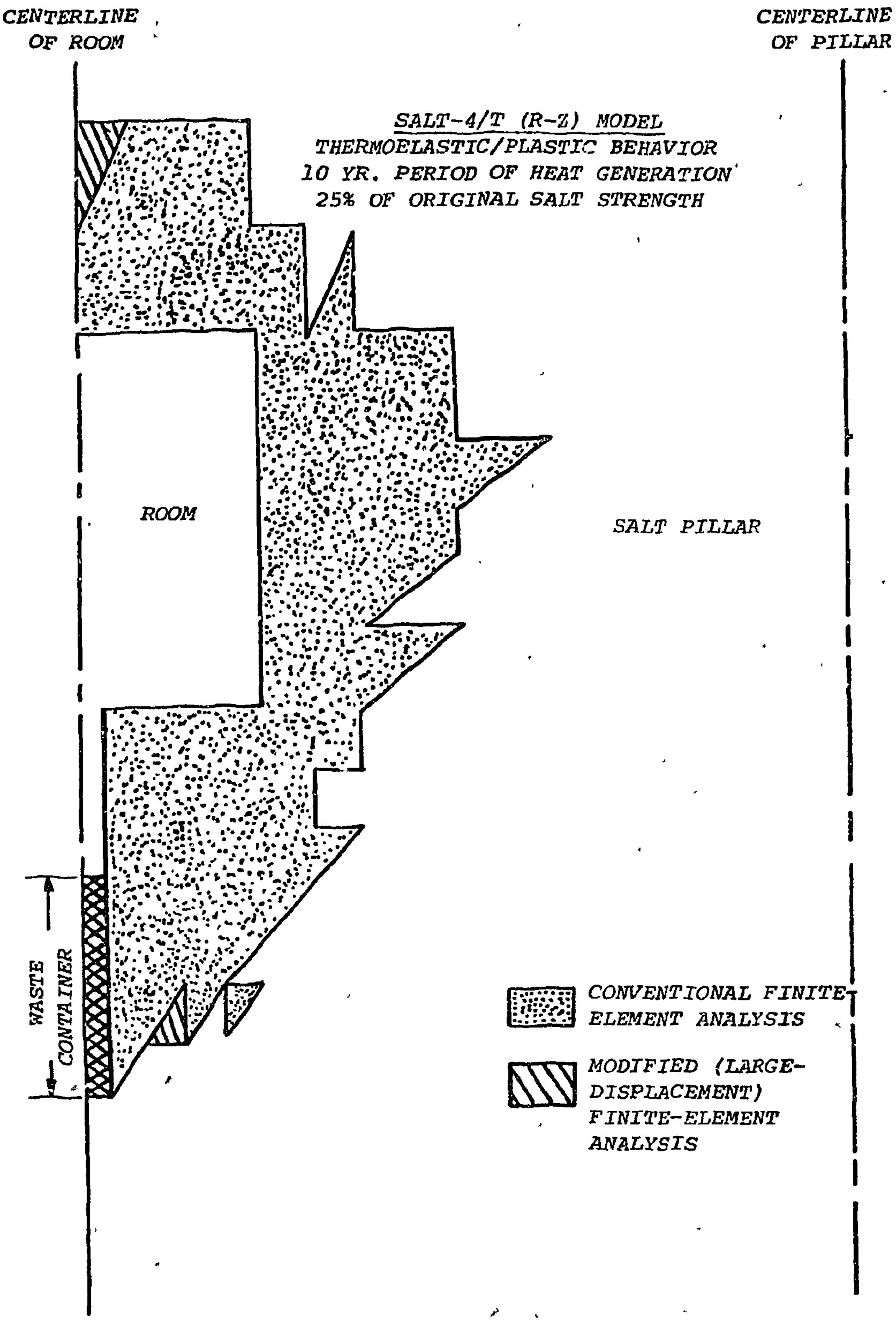
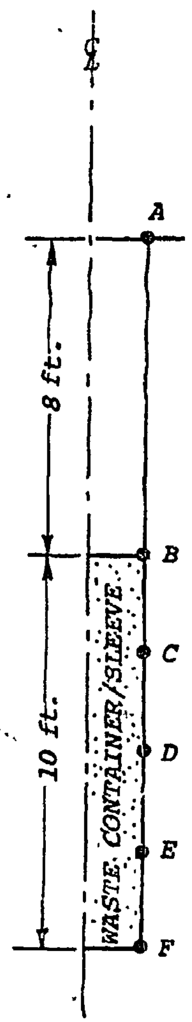


Figure 3.2. Development of zones of plastic yielding in the SALT-4/T model over a 10 year period of heating by conventional and modified (large-displacement) analyses, for salt at 25% of original strength.

TABLE 3.2

Vertical and radial displacements of the drillhole wall (over a 10 yr. heating period, for 25% of original salt strength) by conventional analysis (all displacements in inches; + sign indicates upwards/inwards movement).



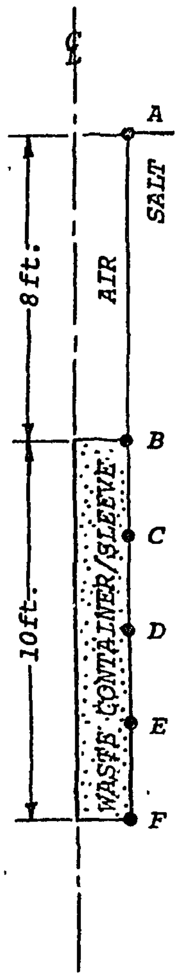
POINT	INITIAL 0.0 yr.	THERMAL ONLY (CUMULATIVE) 0.5	1	2	3	5	10 yr.	TOTAL (inches)
VERTICAL A* RADIAL	0.616 (0.528) (0.008) 0.023	0.497 (0.376) (-0.001) 0.000	0.729 (0.559) (0.008) 0.012	1.123 (0.830) (0.021) 0.037	1.440 (1.023) (0.030) 0.059	1.852 (1.259) (0.042) 0.092	2.157 (1.421) (0.053) 0.123	2.773 (1.960) (0.061) 0.146
VERTICAL B RADIAL	0.293 0.066	0.377 -0.030	0.543 -0.026	0.804 -0.018	1.006 -0.011	1.26 -0.001	1.435 0.008	1.728 0.074
VERTICAL C RADIAL	0.220 0.062	0.309 -0.021	0.457 -0.029	0.687 -0.025	0.861 -0.021	1.078 -0.015	1.229 -0.008	1.449 0.054
VERTICAL D RADIAL	0.165 0.058	0.229 -0.032	0.363 -0.030	0.570 -0.026	0.724 -0.022	0.915 -0.017	1.049 -0.011	1.214 -0.047
VERTICAL E RADIAL	0.123 0.052	0.143 -0.022	0.265 -0.020	0.451 -0.017	0.587 -0.014	0.754 -0.010	0.875 -0.004	0.998 0.048
VERTICAL F RADIAL	0.107 0.020	0.096 -0.014	0.205 -0.013	0.372 -0.010	0.493 -0.008	0.641 -0.004	0.749 -0.000	0.856 0.020

* Full strength data for point A shown in parenthesis. Differences are greatest at this point.

TABLE 3.3

Percent relative difference in drillhole wall displacements (over a 10 yr. heating period, for 25% of original salt strength) between conventional and modified (finite displacement) analyses. Maximum absolute difference is 0.048 inches which occurs at the end of the first heating year.

$$\% \text{ Relative Difference} = 100\left[1.0 - \frac{\text{Modified Analysis}}{\text{Conventional Analysis}}\right]$$



POINT \ YR.	(INITIAL) 0.0 yr.	10 yr. (THERMAL ONLY)	10 yr. (TOTAL)
A VERTICAL	-0.6%	1.9%	1.4%
A RADIAL	-17.4 [a]	2.4	-0.7
B VERTICAL	-2.4	-1.5	-1.6
B RADIAL	0.0	0.0	0.0
C VERTICAL	-1.8	-0.6	-0.6
C RADIAL	0.0	-33.0 [b]	-3.7
D VERTICAL	-1.8	-0.6	-0.7
D RADIAL	-1.7	0.0	-2.1
E VERTICAL	-1.6	-0.	-0.5
E RADIAL	-1.9	0.0	-2.1
F VERTICAL	-0.9	-0.1	-0.2
F RADIAL	0.0	c.	-5.0

a. Absolute difference is 0.004 inches.
b. Absolute difference is 0.002 inches.
c. Absolute difference is 0.001 inches. (percent calculation required division by zero and is therefore omitted).

in displacement are small, less than five percent. Where the relative percent differences are large, the absolute differences are less than 0.005 inches. A large percentage difference occurs whenever the conventionally calculated displacement is near zero and simply effects a division by a number near zero rather a large physical difference in displacement. The greatest absolute difference in displacements obtained by the two methods is 0.042 inches.

4.0 CONCLUDING REMARKS

Comparisons of waste container-sleeve loadings and borehole wall displacements obtained by conventional and modified (large displacement) finite element procedures show differences of only a few percent over a 10 year heating period using salt strengths 25 percent of original values. Thus, even under conditions designed to accentuate the influence of large displacements on the SALT-4/T analysis, no significant differences in results are obtained by the two methods. As a consequence, the economy of the conventional axially symmetric thermoelastic/plastic finite element procedure used in previous work can be maintained without sacrifice of accuracy.

APPENDIX A

LARGE DISPLACEMENT FINITE ELEMENT ANALYSIS

Conventional finite element analyses use the nodal point displacement to element strain transformation $\{e\} = [B]\{U_n\}$. In incremental form as required by elastic-plastic analyses using differential stress-strain relations, the transformation is $\{\Delta e\} = [B]\{\Delta U_n\}$ because B depends only on the nodal point coordinates. If the displacements are small, then the differences between the original nodal point coordinates and those following an increment of deformation are negligible. If this is not the case, then a reformulation is required.

If the displacements are large, then the B-matrix may be written as $[B] = [B_o] + [B_u]$ where $[B_o]$ is the original B-matrix and $[B_u]$ is the portion that changes with displacement. An increment in load $\{\Delta F_n\}$ is then related to an increment in displacement by

$$\{\Delta F_n\} = ((\int_V [B_o]^t[EP][B_o] + [B_o]^t[EP][B_u] + [B_u]^t[EP][B_o] + [B_u]^t[EP][B_u])dv)\{\Delta U_n\} + \int_V [\Delta B_u]\{\sigma_u\}dv$$

or

$$\{\Delta \overline{F}_n\} = [k_o]\{\Delta U_n\} + [k_u]\{\Delta U_n\}$$

where

$$[k_o] = \int_V [B_o]^t[EP][B_o]dv \quad \text{and} \quad \{\Delta \overline{F}_n\} = \{\Delta F_n\} - (\int_V [\Delta B_u]\{\sigma_u\}dv$$

$[k_o]$ is the usual element stiffness matrix computed in the conventional finite element analysis, and $[k_u]$ is the modification required for large displacements. $\{\sigma_u\}$ is the stress associated with the deformations.

In the present work, [B] was considered constant during a load step, so that $\{\Delta \overline{F}\} = \{\Delta F\}$. If the load steps are small, as required for valid results, then during an increment of constrained plastic flow the change in $[B_u]$ will be negligible and the assumption above will be justifiable. This is indeed the case in the work reported here.

APPENDIX B

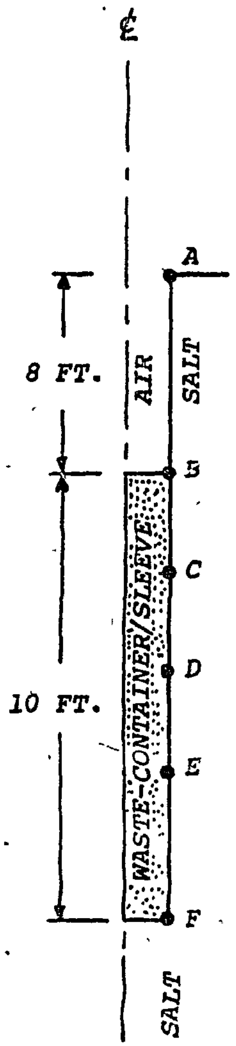
ERRATUM TO TECHNICAL MEMORANDUM REPORT (RSI-0010)

The radial displacements at the collar of the drillhole, as presented in Table 3.1 on page 9 of Technical Memorandum Report (RSI-0010)*, are incorrect. Table 3.1 is included on the following page, with the corrected time-dependent displacement at Point A inserted.

*See Ref. (b) on p. 3 of this report

TABLE 3.1

Vertical and Radial Displacements of Drillhole Wall Over a 10-Year Period of Heating (All displacements have units of inches; + sign indicates upwards/inwards movement)



POINT		INITIAL	THERMAL ONLY (CUMULATIVE)						TOTAL (inch)
		0.0 yr.	0.5	1	2	3	5	10 yr.	
A	VERTICAL	0.538	0.376	0.559	0.830	1.023	1.259	1.421	1.96
A	RADIAL	0.008	-0.001	0.008	0.021	0.030	0.042	0.053	0.061
B	VERTICAL	0.220	0.299	0.447	0.670	0.828	1.021	1.152	1.372
B	RADIAL	0.067	-0.028	-0.026	-0.023	-0.020	-0.016	-0.011	0.056
C	VERTICAL	0.157	0.244	0.383	0.592	0.740	0.921	1.047	1.204
C	RADIAL	0.060	-0.033	-0.031	-0.029	-0.027	-0.024	-0.019	0.041
D	VERTICAL	0.113	0.176	0.305	0.500	0.638	0.808	0.928	0.041
D	RADIAL	0.057	-0.033	-0.031	-0.028	-0.026	-0.023	-0.018	0.039
E	VERTICAL	0.081	0.103	0.222	0.401	0.529	0.687	0.802	0.883
E	RADIAL	0.051	-0.024	-0.022	-0.019	-0.017	-0.014	-0.009	0.042
F	VERTICAL	0.073	0.065	0.166	0.329	0.445	0.534	0.641	0.714
F	RADIAL	0.017	-0.016	-0.015	-0.014	-0.013	-0.011	-0.009	0.008