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Accession #: D195063825

Document #: SD-WM-CAVR-003

Title/Desc:

BURIAL CONTAINER SUBSIDENCE LOAD & STRESS
CALCULATIONS

Pages: 22

NOV 28 1995

ENGINEERING DATA TRANSMITTAL

Page 1 of 1

1. EDT

604512

2. To: (Receiving Organization) Tony Miskho	3. From: (Originating Organization) Tank Systems Integration (74760)	4. Related EDT No.:
5. Proj./Prog./Dept./Div.: LLCE	6. Cog. Engr.: E. M. Veith (N1782)	7. Purchase Order No.:
8. Originator Remarks: This supporting document captures the analyses conducted to determine the LLCE burial containers structural integrity under different Trench closure scenarios. This analysis was conducted in support of the LLCE free liquid issue resolution.		9. Equip./Component No.:
		10. System/Bldg./Facility:
11. Receiver Remarks:		12. Major Assem. Dwg. No.:
		13. Permit/Permit Application No.:
		14. Required Response Date:

15. DATA TRANSMITTED					(F)	(G)	(H)	(I)
(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	Approval Designator	Reason for Transmittal	Originator Disposition	Receiver Disposition
1	WHC-SD-WM-CAVR-003	N/A	0	Burial Container Subsidence Load and Stress Calculations	N/A	1/2	1	1

16. KEY					
Approval Designator (F)		Reason for Transmittal (G)		Disposition (H) & (I)	
E, S, Q, D or N/A (see WHC-CM-3-5, Sec. 12.7)		1. Approval 2. Release 3. Information	4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment	4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged

17. SIGNATURE/DISTRIBUTION (See Approval Designator for required signatures)										(G)	(H)
Reason	Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN	(J) Name	(K) Signature	(L) Date	(M) MSIN	Reason	Disp.
1	1	Cog. Eng. EM Veith	<i>E. M. Veith</i>	11/21/95	15-68						
1	1	Cog. Mgr. RK Brown	<i>R. K. Brown</i>	11/21/95	15-68						
1	1	PA Titzler	<i>PA Titzler</i>	11/27/95	15-68						
1	1	Walter S. Josephson	<i>W. S. Josephson</i>	11/20/95	T3-04						

18. E. M. Veith Signature of EDT Originator Date 11/21/95	19. Authorized Representative for Receiving Organization Date	20. R. K. Brown See Blk 17K 11/21 Cognizant Manager Date 95	21. DOE APPROVAL (if required) Ctrl. No. ☐ Approved ☐ Approved w/comments ☐ Disapproved w/comments
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Burial Container Subsidence Load and Stress Calculations

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U.S. Department of Energy Contract DE-AC06-87RL10930

EDT/ECN: 604512

UC:502

Org Code: 74700

Charge Code: N1782

B&R Code: EW3130010

Total Pages: 20

Key Words: Burial Container, Subsidence Loads on Burial Container,
Burial Container Stress Calculations

Abstract: This document captures the supporting analyses conducted to
determine if the LLCE burial containers are structurally adequate under
different trench closure scenarios.

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James Bishop
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BURIAL CONTAINER SUBSIDENCE LOAD
AND STRESS CALCULATIONS

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1.0 INTRODUCTION

The Long-Length Contaminated Equipment (LLCE) program is designed to provide the equipment and infrastructure to recover contaminated equipment from the single- and double-shell tanks, and dispose of it into specially designed burial containers for burial in the mixed waste trenches. Burying this equipment within the mixed waste trenches could cause burial depths to reach 50 feet. This Supporting Document (SD) defines the analyses conducted to identify the loads and stresses on the burial containers associated with these burial depths. The structural integrity of each of the different burial containers was analyzed.

2.0 PURPOSE

Prior to the disposal of any LLCE items as mixed waste in the Low-Level Burial Grounds, the U.S. Department of Energy-Richland (DOE-RL) must ensure that hazardous debris macroencapsulated in accordance with Title 40 of the Code of Federal Regulations (CFR) Part 268.45, complies with free liquid requirements identified in Washington Administrative Code (WAC) 173-303-140(4)(b), and 40 CFR 264/265.314.

The LLCE is equipment that is, or was inside of tank farm tanks and extended down into the tank waste. Tank farm tanks, as used in this letter, includes tanks identified within the Single-Shell Tank and Double-Shell Tank System Part A, Form 3 Permit Applications. All LLCE items will be designated as mixed waste and will not be designated as state-only extremely hazardous waste. The LLCE items receive the following waste codes when they are generated as a waste: F001-F005, state-only D002, D004 D011, and state-only WT02, WP02, and WC02¹. It is possible given the Hanford Federal Facility Agreement and Consent Order milestones, that over 1,000 LLCE items may be removed from tank farm tanks over the next 20 or 30 years and buried within the mixed waste trenches. Therefore, it is critical to ensure structural integrity of the burial containers prior to the placement of the first macroencapsulated LLCE item in the Low-Level Burial Grounds.

The specification WHC-S-0402 for the design and fabrication of the burial containers identified in section 3.4.3.6 "The burial container structural integrity after loading and void filling shall have the compressive strength (vertical and horizontal) inherent to current land disposal environments (16 psi minimum on the exterior of the container surface."

3.0 DISCUSSION

The 16 psi specification requirement was developed from the NRC guidelines, based upon the burial container soil depth of 5 meters. Discussions at the October 1995 monthly meeting for the LLCE program identified that different closure scenarios for the trench could increase the soil depth and also identified the operational requirement for heavy earth

moving equipment to be working around the buried packages. The principal stress components acting on the disposed burial container are

- Self weight of soil (horizontal and Vertical)
- Concentrated Loads from construction equipment
- Distributed surface loads (snow and ash)

Equations for A. R. Junkins' Soil Mechanics were used. These horizontal and vertical loading equations were identified as shown in Attachment 1. The analysis did not consider cohesion since the soil within the land fill area is primarily sand. Internal friction was evaluated from Junkins and a soil density was taken from WHC-SD-WM-TI-665, Soil Load Above Hanford Waste Storage Tanks. The concentrated load was derived from a worst case 110 ton crane loading based upon four outriggers deployed for the heaviest 60 ton lift.

The burial depth was taken from Alternate Operational Backfill Material Study for W-025 Landfill utilizing a 10% slope design a 50 foot depth was found as the column of dirt above the first layer of burial container. The trench closure cover design of 10% is conservative when compared against EPA documentation and recommendations of a 3-5% slope for the closure covers. The burial containers physical dimensions were identified and calculations for all burial container types yielded a maximum load of 34 psi soil pressure load for the burial containers (see Attachment 1).

Upon completion of the disturbed load from the soil analysis an approximation of the stresses within the burial container was conducted. The stresses within the burial container from this soil loading on the void space (void assumed to be at top dead center) was conducted. The analyses looked at the void fill volume of 90% which is the minimum allowed.

See Attachment 1 for the detailed analyses. The result of Finite Element Model (FEM) analysis for all containers determined a nominal maximum stress of approximately 220-240 psi with maximum localized stresses of 389-410 psi, which are located at the void fill container interface. The use of 500 psi as a working stress limit was recommended by the supplier of the material for long term creep applications. Supplier data collected also can be found in Attachment 1. A confirmatory structural analysis was conducted by Eric M. Veith using a Roark pressure vessel analysis for the membrane stresses and a fixed curved beam analysis for the void fill interface. The simplified pressure vessel Roark analysis contains a conservative assumption on load supports as compared to the actual burial container conditions, but a less conservative replication of the true soil loading along the top quadrant of the container. The analysis yielded a longitudinal stress of 213 psi and radial stress of 3.75 psi for the largest container. The second independent analysis conducted by Eric M. Veith for the void fill interface utilized a concentrated load (derived from the pressure loads) and predicted stresses of 376 psi as compared to the range of FEM model stress of 389-410 psi. The close approximation for the burial container stresses in both cases provides the second independent check for the structural FEM analysis. This confirmatory structural analysis can also be found in Attachment 1.

4.0 CONCLUSION

4.1 The increases in soil depth to 50 feet and subsequent loading to 34 psi for the burial trench operation corresponds to approximately a 220 psi stress in the burial container over the void space. The factor of safety for creep loading is approximately 2.25. The new soil pressure loading and subsequent burial container stresses pose no structural integrity or long term creep concerns for the LLCE burial containers. The containers structural wall thickness are still driven by the lifting and handling loads associated with placement into the trench.

4.2 Three feet of soil cover is needed between the burial containers and the heavy equipment or cranes to allow for loads to be reduced to reasonable levels. This requirement will become an operational constraint for the trench and will be added to the Functions and Requirements document.

WHC-SD-WM-CAVR-003, REV. 0

ATTACHMENT NO. 1
SUPPORTING CALCULATIONS FOR PRESSURES AND STRESSES WITHIN THE LLCE BURIAL
CONTAINERS

Attachment 1: Burial Container Stress Analysis
By W. JOSEPHSON

1.0 Introduction

This study calculated the maximum material stresses in buried cylindrical containers. The material stress information developed by this study will be used to establish strength criteria for procurement of burial containers. The burial container procurement effort is being conducted in support of macroencapsulation treatment process development for Long-Length Contaminated Equipment (LLCE).

Stress analysis of the burial container was conducted using the ANSYS finite element code by developed by Swanson Analytical Systems, Inc. In order to properly model the burial container, ANSYS required the following information:

- burial container dimensions
- void fill level
- burial container and void fill material properties
- burial loads

2.0 Sketch

A sketch of a buried cylindrical container and a definition of the parameters of interest to this study are shown below:

pictured:

- h_0 = burial depth
- h = burial depth at point A
- D_{out} = container outer diameter
- b_z = vertical burial load at point A
- b_y = horizontal burial load at point A
- b_n = normal burial load at point A
- P = concentrated load
- S = distributed surface load

not pictured:

- L = container length
- K_a = vertical to horizontal stress ratio
- γ = soil density
- ϕ = angle of internal soil friction
- μ = coefficient of internal soil friction
- c = soil cohesion
- A = area of horizontal projection
- U = container circumference
- h_{max} = maximum burial depth
- H = maximum trench depth
- t = container thickness

3.0 Container Dimensions

Container dimensions were taken from WHC-S-0402 Commercial Specification for the Contaminated Equipment Burial Container. Container thickness data was taken from technical review of vendor proposals to WHC-S-0402. The dimensions for the seven burial container sizes are given by:

$$D_{out} := (26\text{-in } 26\text{-in } 36\text{-in } 36\text{-in } 54\text{-in } 63\text{-in } 63\text{-in})^T$$

$$t := (0.8\text{-in } 0.8\text{-in } 1.11\text{-in } 1.11\text{-in } 1.66\text{-in } 1.94\text{-in } 1.94\text{-in})^T$$

$$L := (52\text{-ft } 70\text{-ft } 52\text{-ft } 70\text{-ft } 70\text{-ft } 52\text{-ft } 70\text{-ft})^T$$

$$R_{out} := \frac{D_{out}}{2} \quad R_{out}^T = (13 \ 13 \ 18 \ 18 \ 27 \ 31.5 \ 31.5) \text{-in} \quad \text{outer radius}$$

$$R_{in} := R_{out} - t \quad R_{in}^T = (12.2 \ 12.2 \ 16.9 \ 16.9 \ 25.3 \ 29.6 \ 29.6) \text{-in} \quad \text{inner radius}$$

4.0 Void Fill Level

Void fill of the burial container is required to meet RCRA requirements set forth in 40 CFR 264.315 and 265.315. The standard set by EPA in these regulations is that containers shall be > 90% full when placed in the landfill. The volume of void fill material in a partially filled burial container would be given by:

$$dV_{fill} = 2 \cdot L \cdot \sqrt{R_{in}^2 - z^2} \cdot dz$$

$$V_{fill}(z) = \int_{-R_{in}}^z 2 \cdot L \cdot \sqrt{R_{in}^2 - z^2} \cdot dz$$

$$V_{fill}(z) = \left(\sqrt{R_{in}^2 - z^2} \cdot z + R_{in}^2 \cdot \arcsin\left(\frac{z}{R_{in}}\right) \right) \cdot L + \frac{1}{2} \cdot R_{in}^2 \cdot \pi \cdot L$$

Setting the void fill volume equal to 90% and solving for h_{void} yields:

$$i := 1, 2, \dots, 7 \quad z := 1 \text{-in}$$

$$V(z) := 90\% \cdot (R_{in,i})^2 \cdot \pi \cdot L_i - \left[\sqrt{(R_{in,i})^2 - z^2} \cdot z + (R_{in,i})^2 \cdot \arcsin\left(\frac{z}{R_{in,i}}\right) \right] \cdot L_i - \frac{1}{2} \cdot (R_{in,i})^2 \cdot \pi \cdot L_i$$

$$h_{void,i} := \text{root}(V(z), z)$$

$$h_{void}^T = (8.4 \ 8.4 \ 11.6 \ 11.6 \ 17.4 \ 20.3 \ 20.3) \text{-in}$$

5.0 Material Properties

The following material properties were used for ANSYS analysis in this study

$$E_{poly} := 1.3 \cdot 10^5 \text{ psi} \quad \text{Young's modulus for polyethylene}$$

$$E_{perlite} := 3 \cdot 10^6 \text{ psi} \quad \text{Young's modulus for perlite concrete}$$

6.0 Burial Loads

In this section, the equations required to calculate burial loads were developed, the applicable burial environment parameters were quantified, the worst-case burial depth was calculated, and the load distribution on the burial container was calculated at the worst-case burial depth.

6.1 Burial Load Equations

There are six principal load components acting on the disposed burial container pictured in Section 2.0.

- self-weight of soil: horizontal and vertical components
- concentrated load effects: horizontal and vertical components (e.g. construction equipment traffic)
- distributed surface load effects: horizontal and vertical components (e.g. snow, volcanic ash)

These load terms are discussed in order in the following sections.

6.1.1 Self-Weight of Soil

The equations for horizontal and vertical burial load due to self-weight of soil were taken from Soil Mechanics by A. R. Jumikis. They are valid for soils which exhibit internal friction and/or cohesion effects.

horizontal component:

$$b_{y\text{soil}} = \frac{\gamma \cdot h}{2} \cdot K_a - 2 \cdot c \cdot \sqrt{K_a}$$

vertical component:

$$b_{z\text{soil}} = \frac{1}{\mu \cdot K_a} \cdot \left(\gamma \cdot \frac{A}{U} - c \right) \cdot \left(1 - \exp \left(\frac{-\mu \cdot K_a \cdot U}{A} \cdot h \right) \right)$$

6.1.2 Concentrated Load

The equations for horizontal and vertical burial load due to concentrated loads were taken from Soil Mechanics by A. R. Jumikis. They are valid for soils which exhibit internal friction and/or cohesion effects.

horizontal component:

$$b_{y\text{load}} = \frac{3 \cdot P \cdot y^2}{2 \cdot \pi \cdot h^4} \cdot \left[1 + \left(\frac{y}{h} \right)^2 \right]^{\frac{5}{2}}$$

vertical component:

$$b_{z\text{load}} = \frac{3 \cdot P}{2 \cdot \pi \cdot h^2} \cdot \left[1 + \left(\frac{y}{h} \right)^2 \right]^{\frac{5}{2}}$$

6.1.3 Distributed Load

The distributed load was modeled as an additional increment of burial depth Δh such that:

$$\gamma \cdot \Delta h = S$$

This increment of burial depth was added to the self-weight of soil formula, but not the concentrated load formula.

6.1.4 Normal Load

Burial loads were modeled as stress terms. The formula for normal stress was derived from the following stress triangle:

$$b_n \cdot dA = b_z \cdot \cos(\theta) \cdot (dA \cdot \cos(\theta)) + b_y \cdot \sin(\theta) \cdot (dA \cdot \sin(\theta))$$

or:

$$b_n = b_z \cdot \cos^2(\theta) + b_y \cdot \sin^2(\theta)$$

The soil was assumed to be ineffective at applying shear loads to the burial container, therefore shear loads were not modeled.

6.1.5 Summary

Combining the results of Section 6.1.1 through 6.1.4 yields the following expressions for horizontal, vertical and normal stresses on the disposed burial container:

$$b_y = \frac{\gamma(h + \Delta h)}{2} K_a - 2 \cdot c \cdot \sqrt{K_a} + \frac{3 \cdot P \cdot y^2}{2 \cdot \pi \cdot h^4} \left[1 + \left(\frac{y}{h} \right)^2 \right]^{-\frac{5}{2}}$$

$$b_z = \frac{1}{\mu \cdot K_a} \cdot \left(\gamma \frac{A}{U} - c \right) \cdot \left[1 - \exp \left[\frac{-\mu \cdot K_a \cdot U}{A} \cdot (h + \Delta h) \right] \right] + \frac{3 \cdot P}{2 \cdot \pi \cdot h^2} \cdot \left[1 + \left(\frac{y}{h} \right)^2 \right]^{-\frac{5}{2}}$$

$$b_n = b_z \cdot \cos^2(\theta) + b_y \cdot \sin^2(\theta)$$

6.2 Burial Environment Parameters

6.2.1 Cohesion Factor

The Hanford disposal environment was assumed to be primarily sand, which is described in Jumikins as a frictional, non-cohesive material. As a result, the cohesion factor c was set to:

$$c = 0 \cdot \frac{\text{lb} \cdot \text{f}}{\text{ft}^2}$$

6.2.2 Soil Internal Friction

The angle of internal soil friction value was taken from Essentials of Soil Mechanics by McCarthy, who gives a range of $29 \text{ deg} < \phi < 32 \text{ deg}$ for sandy soil. Therefore ϕ was set to:

$$\phi = 30 \cdot \text{deg}$$

6.2.3 Soil Density

Soil density was taken from WHC-SD-WM-TI-665 Soil Load Above Hanford Waste Storage Tanks, which lists a worst-case soil density of $125 \text{ lb} \cdot \text{f} / \text{ft}^3$. Therefore γ was set to:

$$\gamma = 125 \cdot \frac{\text{lb} \cdot \text{f}}{\text{ft}^3}$$

6.2.4 Concentrated Load

The concentrated load term was derived from operation of a 110 Ton Grove crane lifting an 60 ton load above the disposed burial container. The crane weighs 132,270 lbf and has four outriggers to distribute the weight of the crane and the suspended load. Therefore P was set to:

$$P := \frac{60 \cdot 2000 \cdot \text{lbf} + 132270 \cdot \text{lbf}}{4}$$

6.2.5 Distributed Load

The distributed load term was taken from SDC 4.1 Hanford Plant Standards: Architectural - Civil Design Criteria - Design Loads for Facilities, which lists a standard worst-case value for snow and/or volcanic ash loading of 40 lbf/ft². Therefore S was set to:

$$S := 40 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

6.2.6 Maximum Trench Depth

Since the burial container will experience self-weight of soil loads, concentrated loads and distributed loads throughout the operational lifetime, a range of burial depths were investigated. The maximum trench depth value was taken from Alternative Operational Backfill Material Study for W-025 Landfill, which is a closure cover design study done by Golder and Associates for the RMW Landfill (Trench 31 and 34 in the LLW Burial Grounds). Closure cover designs of 10% and 25% maximum slope were investigated by Golder. Since EPA/530-SW- 89-047 Final Covers on Hazardous Waste Landfills and Surface Impoundments recommends a 3-5% slope, the 10% maximum slope design was used for this study. Based on the 10% slope design, the maximum trench depth was found to be approximately 50 feet. Therefore H was set to

$$H := 50 \cdot \text{ft}$$

6.2.7 Maximum Burial Depth

Since the maximum trench depth is fixed, smaller burial containers would be subjected to deeper burial depths. Maximum burial depths were rounded up to whole foot increments. The maximum burial depth for each container size is given by:

$$h_{\max} := \text{ceil}(H - D_{\text{out}})$$

$$h_{\max}^T = (48 \ 48 \ 47 \ 47 \ 46 \ 45 \ 45) \text{ ft}$$

6.2.8 Soil Cover

As discussed in Alternative Operational Backfill Material Study for W-025 Landfill, the standard soil cover depth planned for Trench 31 and 34 is 2 feet. Therefore, a minimum of 2 feet of soil cover was assumed to be provided for the burial container prior to application of distributed and/or concentrated loads.

6.3 Worst-Case Burial Depth

The limiting burial load was expected to be exerted at the top centerline position of the burial container, therefore stress at the top centerline position was used to determine the worst-case burial depth.

6.3.1 Derived Parameters

Given the fundamental disposal environment parameters listed in Section 6.2, the derived parameters required to complete the normal stress calculations are given by:

$$\mu := \tan(\phi) \quad K_a := \tan\left(\frac{\pi}{4} - \frac{\phi}{2}\right)^2 \quad \Delta h := \frac{S}{\gamma} \quad U := (\pi \cdot D_{out}) \quad A := (D_{out} \cdot L)$$

6.3.2 Worst-Case Burial Depth Calculation

This analysis determined the maximum stress on the burial container as a function of burial depth for each container size. The curves shown below were truncated at the maximum burial depth for each container size. The maximum stress as a function of burial depth is given by:

$$i := 1, 2 \dots 7$$

$$j := 2, 3 \dots \frac{H}{ft} \quad h_{0j} := (j \cdot ft)$$

$$b_{z_{i,j}} = \left[\frac{1}{\mu \cdot K_a} \cdot \left(\gamma \cdot \frac{A_i}{U_i} - c \right) \cdot \left[1 - \exp\left[\frac{-\mu \cdot K_a \cdot U_i}{A_i} (h_{0j} + \Delta h) \right] \right] + \frac{3 \cdot P}{2 \cdot \pi (h_{0j})^2} \right] \cdot (h_{0j} \leq h_{max,i})$$

Representative burial load vs. burial depth curves are shown below:

The plots above clearly show that at shallow burial depths, the concentrated load acts to create a large vertical load on the burial container. As burial depth increases, the load-spreading behavior of the soil cover acts to reduce burial load to a minimum value. Above the minimum point, the increasing weight of the soil column acts to again raise the burial load.

To avoid making the burial container design overly conservative, the burial load at maximum burial depth should be used to establish strength criteria, and operational controls should be used to ensure an adequate minimum soil cover. A listing of the burial load at maximum burial depth and at a soil cover of 3 feet are shown below:

C-1:	$b_{z_{1,48}} = 32.181 \cdot \text{psi}$	$b_{z_{1,3}} = 26.062 \cdot \text{psi}$	C-5:	$b_{z_{5,46}} = 33.237 \cdot \text{psi}$	$b_{z_{5,3}} = 26.076 \cdot \text{psi}$
C-2:	$b_{z_{2,48}} = 34.383 \cdot \text{psi}$	$b_{z_{2,3}} = 26.076 \cdot \text{psi}$	C-6:	$b_{z_{6,45}} = 30.683 \cdot \text{psi}$	$b_{z_{6,3}} = 26.062 \cdot \text{psi}$
C-3:	$b_{z_{3,47}} = 31.687 \cdot \text{psi}$	$b_{z_{3,3}} = 26.062 \cdot \text{psi}$	C-7:	$b_{z_{7,45}} = 32.657 \cdot \text{psi}$	$b_{z_{7,3}} = 26.076 \cdot \text{psi}$
C-4:	$b_{z_{4,47}} = 33.813 \cdot \text{psi}$	$b_{z_{4,3}} = 26.076 \cdot \text{psi}$			

As shown above, operationally restricting the minimum soil cover to 3 feet will ensure that maximum burial depth will be the limiting point for all container sizes.

6.4 Burial Load Distribution

This analysis determined the vertical, horizontal and normal burial load distribution at maximum burial depth. Burial loads were calculated at one degree increments along one quadrant of the burial container. From symmetry, the other quadrants would have identical stress distributions. The burial load distribution for each container size is given by:

$$i = 1, 2, \dots, 7$$

$$j = 1, 2, \dots, 91 \quad \theta_j = (j - 1) \cdot \text{deg} \quad h_{i,j} = h_{\max_i} + R_{\text{out}_i} \cdot (1 - \cos(\theta_j)) \quad y_j = R_{\text{out}_i} \cdot \sin(\theta_j)$$

$$b_{z_{i,j}} = \frac{1}{\mu \cdot K_a} \cdot \left(\gamma \frac{A_i}{U_i} - c \right) \cdot \left[1 - \exp \left[\frac{-\mu \cdot K_a \cdot U_i}{A_i} \cdot (h_{i,j} + \Delta h) \right] \right] + \frac{3 \cdot P}{2 \cdot \pi \cdot (h_{i,j})^2} \cdot \left[1 + \left(\frac{y_j}{h_{i,j}} \right)^2 \right]^{\frac{5}{2}}$$

$$b_{y_{i,j}} = \frac{\gamma \cdot (h_{i,j} + \Delta h)}{2} \cdot K_a - 2 \cdot c \cdot \sqrt{K_a} + \frac{3 \cdot P \cdot (y_j)^2}{2 \cdot \pi \cdot (h_{i,j})^4} \cdot \left[1 + \left(\frac{y_j}{h_{i,j}} \right)^2 \right]^{\frac{5}{2}}$$

$$b_{n_{i,j}} = b_{z_{i,j}} \cdot \cos^2(\theta_j) + b_{y_{i,j}} \cdot \sin^2(\theta_j)$$

A representative burial load distribution curve is shown below:

The maximum and minimum values for each container size are listed below:

C-1:	$b_{n_{1,1}} = 32.181 \cdot \text{psi}$	$b_{n_{1,91}} = 7.148 \cdot \text{psi}$	C-5:	$b_{n_{5,1}} = 33.237 \cdot \text{psi}$	$b_{n_{5,91}} = 7.027 \cdot \text{psi}$
C-2:	$b_{n_{2,1}} = 34.383 \cdot \text{psi}$	$b_{n_{2,91}} = 7.148 \cdot \text{psi}$	C-6:	$b_{n_{6,1}} = 30.683 \cdot \text{psi}$	$b_{n_{6,91}} = 6.937 \cdot \text{psi}$
C-3:	$b_{n_{3,1}} = 31.687 \cdot \text{psi}$	$b_{n_{3,91}} = 7.063 \cdot \text{psi}$	C-7:	$b_{n_{7,1}} = 32.657 \cdot \text{psi}$	$b_{n_{7,91}} = 6.937 \cdot \text{psi}$
C-4:	$b_{n_{4,1}} = 33.813 \cdot \text{psi}$	$b_{n_{4,91}} = 7.063 \cdot \text{psi}$			

From the above results, the burial load distribution may reasonably be approximated as a linear variation in θ from 7 psi to 34 psi. Therefore, the burial load input to the ANSYS 1/4 symmetry model was given by:

$$b_n(\theta) = 7 \cdot \text{psi} + \left(\frac{34 \cdot \text{psi} - 7 \cdot \text{psi}}{90 \cdot \text{deg}} \right) \cdot \theta \quad \text{or:} \quad b_n(\theta) = 7 \cdot \text{psi} + \left(0.3 \cdot \frac{\text{psi}}{\text{deg}} \right) \cdot \theta$$

7.0 ANSYS Results

The worst-case stress computed by ANSYS was for container C-1 and C-2, and occurred at the interface between the top of the void fill material and the burial container inner wall. The maximum computed stress was:

$$\sigma_{\max} = 410 \cdot \text{psi}$$

Since the creep stress limit was 500 psi, the container designs were considered acceptable.

A graphic representation of the stress distribution in container C-1 through C-7 have been included as Figure 1 through Figure 4.

Figure 1: Stress Distribution - Container C-1/C-2

ANSYS 5.0 ED56
 NOV 17 1995
 16:10:34
 PLOT NO. 1
 ELEMENT SOLUTION
 STEP=1
 SUB =1
 TIME=1
 SEQU (NOAUG)
 DMX =0.032208
 SMN =2.76
 SMNB=-69.592
 SMX =410.466
 SMXB=579.387
 2.76
 48.861
 93.361
 138.662
 183.963
 229.263
 274.564
 319.865
 365.165
 410.466

Figure 2: Stress Distribution - Container C-3/C-4

ANSYS 5.0 ED56
 NOV 17 1995
 16:13:50
 PLOT NO. 1
 ELEMENT SOLUTION
 STEP=1
 SUB =1
 TIME=1
 SEQU (NOAUG)
 DMX =0.044668
 SMN =2.686
 SMNB=-69.3
 SMX =398.377
 SMXB=558.8
 2.686
 46.652
 90.617
 134.583
 178.549
 222.514
 266.48
 310.446
 354.411
 398.377

Figure 3: Stress Distribution - Container C-5

ANSYS 5.0 ED56
 NOV 17 1995
 16:22:50
 PLOT NO. 1
 ELEMENT SOLUTION
 STEP=1
 SUB =1
 TIME=1
 SEQU (NOAUG)
 DMX =0.065215
 SMN =2.663
 SMNB=-64.508
 SMX =389.004
 SMXB=544.744
 2.663
 45.59
 88.517
 131.444
 174.37
 217.297
 260.224
 303.151
 346.078
 389.004

Figure 4: Stress Distribution - Container C-6/C-7

Evaluation of the Burial Containers for the Stresses Induced by the Burial ILoads
 Analytical Approach

An independent analysis of the FEM approach was conducted to verify the models output. This evaluation utilizes two first principle analyses. The first analysis utilized a first principle calculation for the stresses of a thin walled pressure vessel simply supported with a uniform load at top dead center. (Roark's 6th edition was used, Table 30, page 573) The analysis included herein utilized this first principle approach for calculating stresses in the longitudinal and radial direction.

Evaluate the largest container

$$\begin{aligned} v &:= .3 & r &:= 31.5 \\ L &:= 840 & t &:= 1.94 \quad 840 \text{ inches is } 70 \text{ feet} \\ P &:= 34 \end{aligned}$$

$$B := \left[12 \cdot (1 - v^2) \right]^{\frac{1}{8}}$$

Stress in longitudinal direction

Stress in radial direction

$$\sigma_1 := -.1188 \cdot B^3 \cdot P \cdot r^{\frac{1}{4}} \cdot L^{\frac{1}{2}} \cdot t^{\frac{7}{4}}$$

$$\sigma_2 := -.0492 \cdot B^8 \cdot P \cdot r^{\frac{3}{4}} \cdot L^{\frac{1}{2}} \cdot t^{\frac{5}{4}}$$

Examine stresses for largest container at 63 inches in diameter with a wall thickness minimum of 1.94 from SEG proposal

$$\sigma_1 = -213.154 \quad \text{Stress in psi} \quad \sigma_2 = -3.479$$

Evaluate for next largest container 54 inches

$$\begin{aligned} r &:= 27 \\ t &:= 1.66 \end{aligned}$$

$$\begin{aligned} \sigma_1 &:= -.1188 \cdot B^3 \cdot P \cdot r^{\frac{1}{4}} \cdot L^{\frac{1}{2}} \cdot t^{\frac{7}{4}} & \sigma_2 &:= -.0492 \cdot B^8 \cdot P \cdot r^{\frac{3}{4}} \cdot L^{\frac{1}{2}} \cdot t^{\frac{5}{4}} & \sigma_2 &= -3.479 \\ & & & & \sigma_1 &= -269.414 \end{aligned}$$

The finite element program calculated stresses of approximately 220 psi at the mid point from the fixed end conditions. This shows good agreement with the membrane stresses calculated and also provides excellent agreement with the FEM model. The next analysis will evaluate the end conditions.

This analysis is to confirm if the finite element analysis is predicting the stresses within the burial containers accurately. This analysis will evaluate the end conditions of the burial container and void fill by approximating a fixed-fixed end curved beam. The pressure load will be converted to a concentrated load to allow use of a first principle type of moment and stress calculations from Roark. The diameter of the largest container is 31.5 in., $b = a$ unit length. The pressure calculated by W. Josephson is 34 psi at top dead center falling off to 20 psi at 45 degrees.

$$r := 31.5 \text{ in} \quad b := 1 \text{ in}$$

$$p(\theta) := 20.5 \text{ psi} + (34 - 20.5) \cdot \text{psi} \cdot \frac{4}{\pi} \cdot \theta$$

$$\int_0^{\frac{\pi}{4}} 2 \cdot b \cdot r \cdot p(\theta) \, d\theta = 1348.332 \text{ lbf}$$

Load is equal to 1348 lbf at top dead center

Calculate A of void space, and find angle of void space

$$R := 31.5 \text{ in} \quad z := 1 \text{ in}$$

$$A(z) := 0.9 \cdot (\pi R^2) - \left[\left(z \cdot \sqrt{R^2 - z^2} + R^2 \cdot \arcsin\left(\frac{z}{R}\right) \right) + \frac{\pi R^2}{2} \right]$$

$$h_{90\%} := \text{root}(A(z), z) \quad h_{90\%} = 21.642 \text{ in}$$

$$\theta := \arctan\left(\frac{h_{90\%}}{R}\right) \quad \theta = 34.491 \text{ deg}$$

Case 5a, pg 294 Roark's 6th edition Formulas for Stress and Strain

$$\gamma := 0 \text{ deg} \quad W := 1348.332 \text{ lbf} \quad R := 31.5 \text{ in} \quad t := 1.94 \text{ in}$$

$$I := R^3 \cdot t \cdot \left(1 - \frac{3 \cdot t}{2 \cdot R} + \frac{t^2}{R^2} - \frac{t^3}{4 \cdot R^3} \right) \cdot \left(\theta + \sin(\theta) \cdot \cos(\theta) - \frac{2 \cdot \sin(\theta)^2}{\theta} \right) \quad A := \theta \cdot t \cdot (2 \cdot R - t) \quad \alpha := \frac{I}{A \cdot R^2}$$

$$I = 184.342 \text{ in}^4$$

$$F = \left(1 - \frac{3 \cdot t}{2 \cdot R} + \frac{t^2}{R^2} - \frac{t^3}{4 \cdot R^3} \right) \quad F = 0.911$$

$$k2 := 1 - \alpha$$

$$G = \left(\theta + \sin(\theta) \cdot \cos(\theta) - \frac{2 \cdot \sin(\theta)^2}{\theta} \right) \quad G = 0.003$$

Calculate for 1.94 in thick wall-from SEG proposal

$$M := W \cdot ((\theta + \gamma) \cdot \sin(\gamma) + k2 \cdot (\cos(\gamma) - \cos(\theta)))$$

in-lbf

$$M = 236.397 \text{ in-lbf}$$

$$\text{stress} := \frac{6 \cdot M}{t^2}$$

$$\text{stress} = 376.868 \text{ psi}$$

Maximum stresses in the first principle and finite element analysis were 376 psi and 410 psi respectively and provide excellent agreement.