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QUASI-STATIC ANALYSIS FOR SUBSIDENCE OF STACKED B-25 BOXES

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ABSTRACT

This paper presents a quasi-static technique to evaluate the structural deformation of the four stacked B-25 boxes subjected to the static loads of overlaying soil and to determine the effect of corrosion on the deformation. Although the boxes are subjected to a static load, the structural responses of the boxes vary with time. The analytical results indeed show that the deflection, buckling and post buckling of the components of the stacked boxes occur in sequence rather than simultaneously. Therefore, it is more appropriate to treat the problems considered as quasi-static rather than static; namely, the structural response of the stacked boxes are dynamic but with very long duration. Furthermore, the finite-element model has complex contact and slide conditions between the interfaces of the adjoining components, and thus its numerical solution is more tractable by using explicit time integration schemes.

The analysis covers the three corrosion scenarios following various time lengths of initial burial under an interim soil cover. The results qualitatively agree with expected differences in deformation for different degrees of corrosion subsidence potential reduction that can be achieved.

INTRODUCTION

The Savannah River Site (SRS) and other U.S. Department of Energy (DOE) sites use shallow land burial facilities (i.e., trenches) to dispose low-level radioactive waste. DOE Order 435.1, Radioactive Waste Management, and its companion manual and guide require that certain Performance Objectives be met over a 1,000-year period after closure in order to protect the public, environment, and workers. The requirement to achieve long-term stability, minimize waste material/container subsidence, and minimize the long-term active maintenance for cover systems is one such requirement.

However, at SRS and other DOE sites, waste containers with up to 90 percent void space are disposed in the shallow land burial facilities. Corrosion and degradation of these containers can result in significant subsidence over time, which can compromise the integrity of the long-term cover. This in turn can lead to increased water infiltration through the long-term cover into the waste and subsequent increased radionuclide transport into the environment. Understanding and predicting shallow-buried, low-level waste subsidence behavior is necessary for evaluating cost-effective and stable cover systems.

Although the stacked boxes are subjected to a static load, their structural responses vary with time. Therefore, it is more appropriate to treat the problem as quasi-static rather than static; namely, the structural responses of the stacked boxes are evaluated as dynamic transient with very long duration. In addition, the finite-element model accounts for the complex contact and slide conditions between the interfaces of the adjoining components, and thus its numerical solution is more tractable by using explicit time integration numerical schemes.

A quasi-static analysis for a stack of four B-25 boxes at various stags of corrosion and applied static surcharge has been conducted and is presented herein. The scenario modeled is static surcharge, where a 25-ft-thick soil cover is applied over an interim 6-ft-thick soil cover (plus bulldozer weight) to yield a total 3,986.63 pounds per square foot load.

ANALYSIS

Two scenarios of static loads are considered. The first scenario is to apply the load after the containers have been in the ground for about 25 years. The second scenario is to apply the load after the containers have been buried for a longer period of time. For both scenarios, the effect of steel-volume loss due to corrosion over time is accounted for, based on estimates from the three different methods presented in Jones and Phifer (2002).

Geometrical Configuration and Material Properties

The geometrical configurations of the B-25 boxes are given in Gong (2001). Figure 1 shows the configuration of the four stacked B-25 boxes.

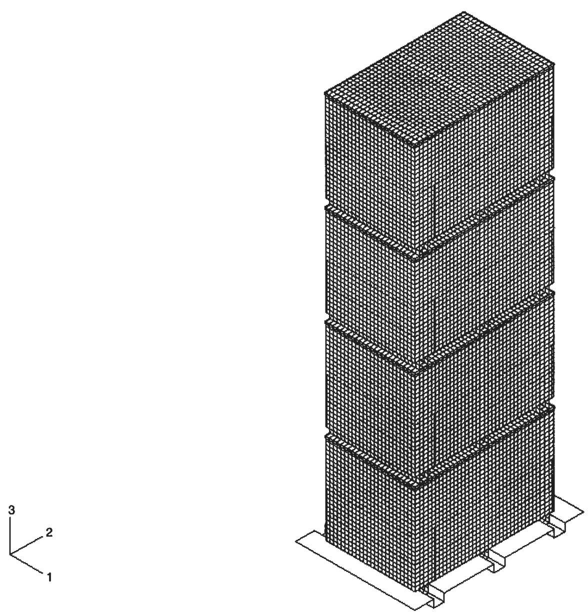


Figure 1. Configuration of Four Stacked B-25 Boxes

The stress-strain curve for the box material shown in Figure 2 is modified from the bi-linear curve given in Gong (2001) for a more accurate representation.

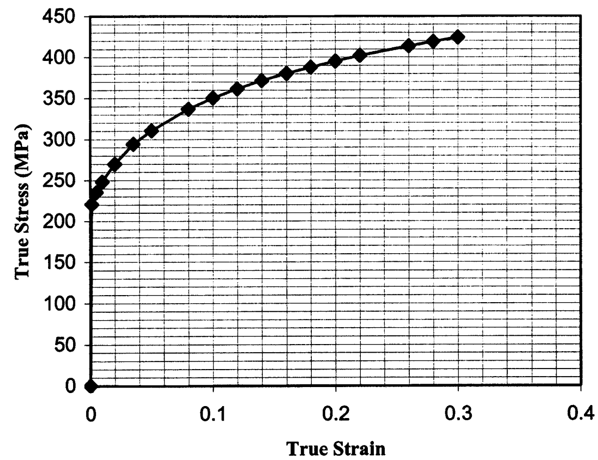


Figure 2. Carbon Steel Stress-Strain Curve (modified from Gong, 2001)

The contents of the B-25 boxes are low-level radioactive wastes, loosely disposed in the box with void ratio ranging from 10% to 90%. The equivalent mechanical properties of the waste are not available and highly variable. In the present analysis, the material properties of the contents are represented by the published values of a crushable foam as presented in Figure 3 (HKS, 1998). Other waste material properties used in the model of the contents are as follows.

Density = 305 kg/m^3
Young's Modulus = 0.129 GPa
Poisson's Ratio = 0

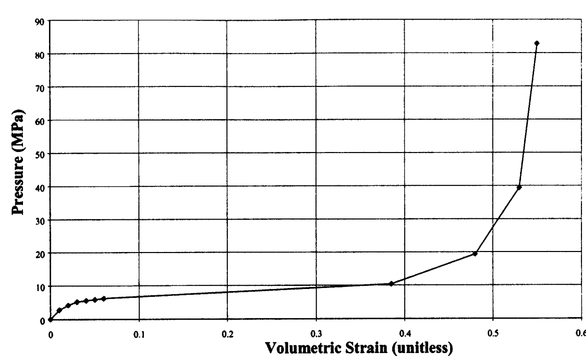


Figure 3, Pressure-Volumetric Strain Representation of Waste

Scenarios Analyzed

The estimated values of the wall thickness of the B-25 boxes after material loss due to corrosion are documented in Jones and Phifer (2002). Two scenarios are studied in the analysis.

Scenario One

Scenario One models the behavior of a stack of four B-25s under static surcharge, 25 years after placement of an interim 6-ft-thick soil cover. The total load includes both the interim soil cover and the static surcharge soil. The thicknesses of the lid, bottom, and sides of the B-25 box for the Constant Volume, Continuous Incipient Area, and Slowing Corrosion Methods at 25 years are provided in Table 1.

Scenario Two

Scenario Two models the behavior of a stack of four B-25 boxes under static surcharge at later years (150, 68, and 250 years since disposal for the Constant Volume, Continuous Incipient Area, and Slowing Corrosion Methods, respectively). Again, the total load includes both the interim soil cover and the static surcharge soil. These years were selected because they approach the time at which either the lid, the bottom, or the side wall would suffer 100 percent corrosion or zero thickness. The thicknesses of Scenario Two are presented in Table 2.

Assumptions

The following assumptions were made to keep the analysis tractable:

1. The overlaying soil is not modeled. The weight of soil over the lid of the uppermost box is treated as the distributed pressure load

2. Although the accumulation of the overlaying soil is a slow process, the equivalent pressure load is applied onto the lid of the uppermost box within 5 milliseconds (0.005 seconds).

3. The soil on which the stack of boxes rests is densely packaged so the soil can be represented by a rigid surface.

Finite-Element Model

The lid and the side wall of the uppermost B-25 box are separate components so that the interfaces of these two components undergo complicated contacting/separating conditions while the lid is being deformed and then pushed into the inside of the box by the soil weight. This scenario is described as follows.

The inner surface of the lid and the top edges and the outer surface of the walls are initially in contact. After the equivalent pressure load of the soil weight is applied onto the top surface of the lid, the center portion of the lid starts to deflect into the void inside the box. When the lid deflects further, the four edges of the lid will be bent outward and the walls of the box are no longer able to prevent the lateral motion of the lid edges. At this stage either the inner surface or the edge of the lid is in contact with the top edges of the box walls. Eventually the entire lid may be pushed into the inside of the box. When this happens, either of the edges of inside surface of the lid will be in contact with the inside surface of box.

The implicit numerical scheme cannot simulate the complicated interface-contacting conditions described above. Therefore, the explicit numerical scheme is used for the present analysis. Furthermore, the explicit numerical scheme involves the propagation of stress waves in the model, and thus the subsidence study of the stacked B-25 boxes must be treated as a dynamic problem, although the loading is static. Since the response of structure to the loading is very slow, the problem is categorized as “quasi-static.” A quasi-static problem is usually more difficult to analyze than the high-speed impact problems with short durations because of the long computing time, unless the mass scaling technique can be applied to increase the size of stable-time step by reducing the speed of the sonic waves traveling in the model. However, the structural response in the present analysis is due to a direct external load; thus increasing the densities of the model components will not only increase the size of the stable-time step, but also reduce the velocities of the components. In other words, mass scaling is not effective to the present problem.

The components of the B-25 Box, including the lid, walls, bottom plate, and the riser, are all comprised of 3D shell elements of Type S4R elements in the ABAQUS Computer Code, HKS (1998). The waste content is represented by 3D brick elements of Type C3D8R. The soil foundation is modeled by using a 3D rigid surface element of Type R3D4 to simulate the compact soil.

Pressure Load

The pressure loads applied on the lid of the uppermost box for both scenarios are equal to the sum of the weight of a 25-ft-thick static surcharge load of soil, plus the weight of a 6-ft-thick interim soil cover load, plus the weight of a bulldozer. The total loading is 3,986.63 lb/ft^2. Thus, the pressure load applied on the top surface of the lid of the uppermost box is:

$$P = 3{,}986.63 \ lb/ft^2 = 190{,}882.059 \ Pa(N/m^2)$$

The downward gravitational load acting at the boxes and waste contents is equal to 32.2 ft/sec^2 (9.815 m/sec^2).

Boundary Conditions

The reference nodes of the grid elements that represent the soil foundation are fixed. Thus, all three translations in the horizontal x and y directions and vertical z direction are equal to zero; the rotations about the x, y and z axes are also equal to zero.

Contact Conditions

The contact conditions on the interfaces of the model components are simulated using the contact surfaces and the contact pair options as well as the penalty method available in the ABAQUS Code.

Initial Conditions

The initial velocities of the all the nodes in the models of the box components are equal to zero.

Scenario One Modeling Results

Figure 4 displays the deformed shapes versus un-deformed shapes of the model for: (a) the Constant Volume, (b) Continuous Incipient Area, and (c) Slowing Corrosion Methods, respectively, after static surcharge following 25 years burial under an interim soil cover. As expected, after such a short number of years since burial, the results show similar amounts of displacements for the three methods considered, since relatively little difference exists in lid, bottom, and side wall thickness among the three methods.

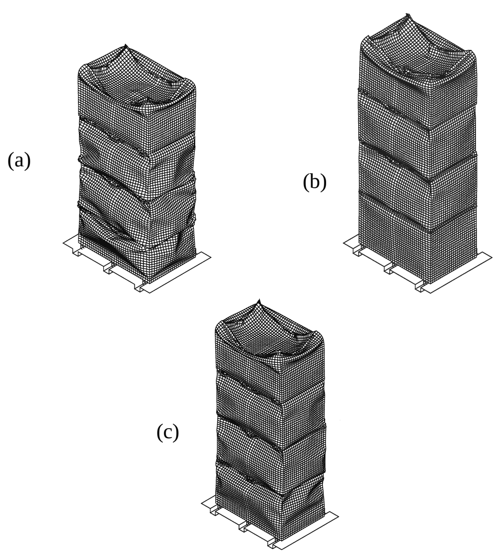


Figure 4. B-25 Deformation from Static Surcharge Loading after Twenty-Five Years beneath an Interim Soil Cover.

Scenario Two Modeling Results

Figure 5 displays the analytical results for:

a) Constant Volume Method after static surcharge following burial under an interim soil cover for 150 years.

b) Continuous Incipient Area Method after static surcharge following burial under an interim soil cover for 68 years.

c) Slowing-Corrosion Method under an interim soil cover for 250 years.

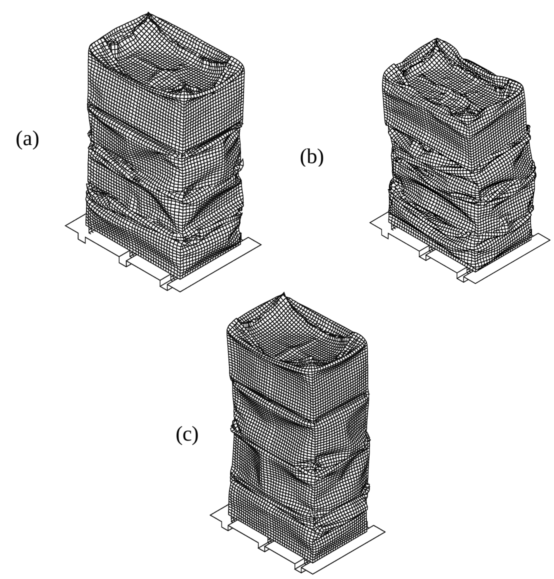
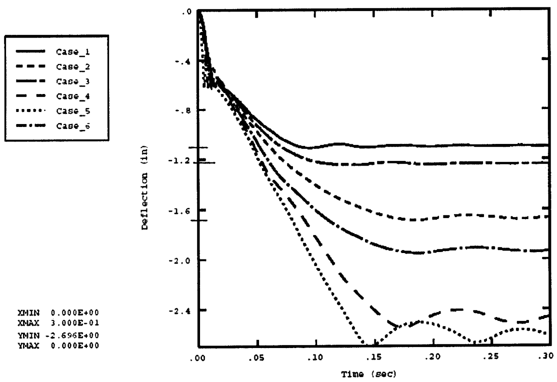


Figure 5. B-25 Deformation from Static Surcharge Loading after Various Years beneath an Interim Soil Cover Comparison of Scenarios

Differences are obvious in B-25 box displacement, especially between the Continuous Incipient Area Method at only 68 years and the Slowing Corrosion Method at 250 years.

The difference in B-25 box displacement (difference from original height of a stack of four B-25 boxes) for each of the six cases modeled is presented in Figure 6. The plots in Figure 6 show that the relatively greater displacement under the Continuous Incipient Area Method compared to the other two methods. The height of the stacked boxes is reduced by about 2.5m after 150 years under the Constant Volume Method, by about 2.7m after only 68 years under the Continuous Incipient Area Method, and by about 1.9 m after 250 years under the Slowing Corrosion Method.

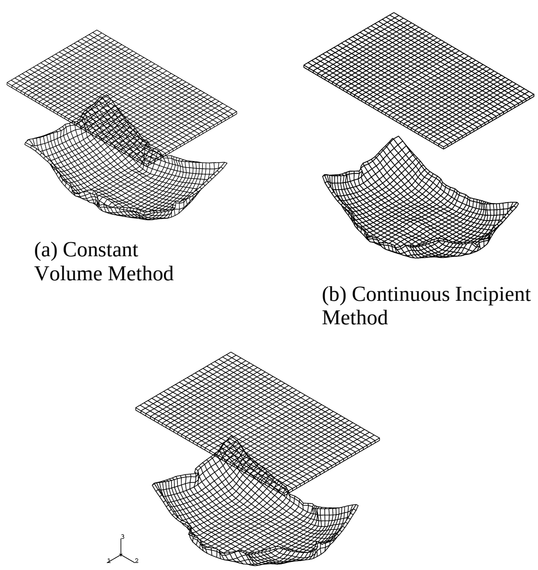


Case 1 - Constant Volume Method, static surcharge performed 25 years after initial burial
Case 2 - Continuous Incipient Area Method, static surcharge performed 25 years after initial burial
Case 3 - Slowing Corrosion Method, static surcharge performed 25 years after initial burial
Case 4 - Constant Volume Method, static surcharge performed 150 years after initial burial
Case 5 - Continuous Incipient Area Method, static surcharge performed 68 years after initial burial
Case 6 - Slowing Corrosion Method, static surcharge performed 250 years after initial burial

Figure 6. Net Deflection (Difference from Original Height) of Stack of Four B-25 Boxes for each Modeling Run

Comparison between Analytical Results and Field Observations

The analytical results indicate that the lid for the uppermost B-25 boxes will bow and be pushed down inside the container by the interim soil cover weight alone as shown in Figure 7. This is consistent with field observations for the B-25 boxes excavated in 2001 (Dunn, 2002; Jones and Li, 2001) and with earlier theoretical studies (Dames and Moore, 1987).



(a) Constant Volume Method

(b) Continuous Incipient Method

(c) Slowing Corrosion Method

Figure 7. Lid Deflection for Scenario One Cases -- Static Surcharge after 25 Years Burial

CONCLUSIONS

Quasi-static finite-element analysis provides the deformation results for a stack of four B-25 boxes under a static surcharge load applied to three corrosion scenarios following various time durations of initial burial under an interim soil cover. The results agree with expected differences in deformation for different degrees of corrosion. Additionally, the results demonstrate that the timing of static surcharge application relative to corrosion extent greatly impacts the degree of subsidence potential reduction that can be achieved.

REFERENCES

Jones, William E. and Phifer, Mark A. (2002), "Corrosion and Potential Subsidence Scenarios for Buried B-25 Waste Containers (U)," WSRC-TR-2002-00354, September 2002, Westinghouse Savannah River Company, Aiken, SC 29808.

Gong, Chung (2001), "Finite Element Analysis of Dynamic Compaction of a Stack of Four B-25 Containers (U)," WSRC-TR-2001-00320, August 2001, Westinghouse Savannah River Company, Aiken, SC 29808.

HKS (1998), ABAQUS/Explicit User's Manual Version 5.8, Hibbit, Karlsson & Sorensen, Inc., Pawtucket, RI 02860-4847.

Dunn, Kerry (2002), "B-25 Corrosion Evaluation Summary Report (U)," WSRC-TR-2001-00587, January 2002, Westinghouse Savannah River Company, Aiken, SC 29808.

Jones, William E. and Li, William (2001), "Long-Term Waste Stabilization Parameter Estimation (U)", Savannah River Site, Aiken, South Carolina, WSRC-TR-2001-00323, September 2001, Westinghouse Savannah River Company, Aiken, SC 29808.

Dames and Moore, Inc. (1987), "Subsidence Study of B-25 Metal Containers Mixed Waste Management Facility," DMSRP-97, March 4, 1997.

Table 1. Scenario One Modeling Input: Lid, Bottom, and Sides Thickness at 25 Years Since Disposal for the Three Steel-Volume Loss Methods

Steel Volume-Loss Method	Years Since Disposal	Lid Percent Loss	Lid Thickness (in.)	Bottom Percent Loss	Bottom Thickness (in.)	Sides Percent Loss	Sides Thickness (in.)
Constant Volume Method	25	8.9	0.0996	25	0.0821	5.95	0.1029
Continuous Incipient Corrosion Method	25	23.3	0.0839	25.2	0.0818	15.9	0.0920
Slowing Corrosion Method	25	3.9	0.1051	10.9	0.0974	2.7	0.1064

Table 2. Scenario Two Modeling Input: Lid, Bottom, and Sides Thickness at Later Years Since Disposal for the Three Steel-Volume Loss Methods

Steel Volume-Loss Method	Years Since Disposal	Lid Percent Loss	Lid Thickness (in.)	Bottom Percent Loss	Bottom Thickness (in.)	Sides Percent Loss	Sides Thickness (in.)
Constant Volume Method	150	49	0.0558	89	0.0120	36	0.0700
Continuous Incipient Corrosion Method	68	79.3	0.0226	53.8	0.0505	57.6	0.0464
Slowing Corrosion Method	250	29	0.0777	77	0.0252	20	0.0875