A METHOD FOR EVALUATING THE STRUCTURAL INTEGRITY OF BURIED LIQUID LOW LEVEL WASTE TANKS

J. H. Kincaid, M. R. Peet, and W. T. Thompson*
Central Engineering Services
Oak Ridge National Laboratory**

ABSTRACT

An analytical method for evaluating the structural integrity of buried (underground) tanks with specific emphasis on buckling collapse is presented. As an example, a typical tank which is part of the liquid low-level waste (LLLW) storage tank systems located at the Oak Ridge National Laboratory (ORNL) was evaluated and a margin of safety was computed. Codes associated with buried underground structure which could be used to establish design adequacy of underground storage tanks are identified.

A finite element model of the soil and tank with nonlinear interface elements with representative soil overburden loading was developed. The analysis was performed with the computer program ABAQUS using the arc length method for establishing buckling. The effects of soil properties and variations of tank thickness on buckling stability is presented for a typical tank.

INTRODUCTION

This paper presents a method for performing a structural assessment of buried (underground) tanks which are part of the liquid low-level waste (LLLW) storage tank systems located at the Oak Ridge National Laboratory (ORNL). Evaluation of the structural integrity of these tanks had been stipulated by the Federal Facility Agreement (FFA) between the Environmental Protection Agency (USEPA) - Region IV, the Tennessee Department of Environment and Conservation (TDEC), and the U.S. Department of Energy (DOE). The tanks have been categorized under the FFA as: "Category C- for Existing Tank Systems without Secondary Containment."

The overall objective of the study was to demonstrate that the LLLW tanks have sufficient structural strength to ensure that the tanks will not collapse from soil overburden pressure prior to removal from service. There were no specific codes identified on design documents applicable to these buried tanks when they were installed in 1963; however, the specification required design fabrication and inspection per Section VIII, Division 1, of the ASME Boiler and Pressure Vessel (B&PV) Code. The specific objectives of the study were:

1. identify and evaluate codes associated with underground structure which could be used to establish design adequacy,
2. define a soil/tank interface model,
3. establish an analytical method for identifying mode of failure,
4. evaluate overburden loads regarding structural stability (buckling) using site soil properties.

All objectives were achieved. The results of the evaluation showed that the design of buried LLLW tanks meet all requirements of applicable codes which were found to address buckling collapse of underground tanks or cylinders. The ASME requirement was considered by the inclusion of overburden buckling pressure as an externally applied load.

BURIED TANK DESIGN REQUIREMENTS

The most commonly referenced document for designing underground tanks is Underwriters Laboratory UL 58: "Standard for Steel Underground Tanks for Flammable and Combustible Liquids," Eighth Edition, April 15, 1986.

The current UL 58 code identified applicable requirements for design of steel (including stainless) underground tanks. The bases for the requirements in UL 58 were given without references as follows:

> "These requirements are based upon sound engineering principles, research, records of tests and field experience, and an appreciation of the problems of manufacture, installation, and use derived from consultation with and information obtained from manufacturer, users, inspection authorities, and others having specialized experience."

The underground LLLW tank used as an example met the current UL 58 design requirements.

The petroleum industry uses API Publication 1615, Par 1.4: "Installation of Underground Petroleum Storage Systems." API recommended Practice 1615 Fourth Edition, November 1987. API Publication 1615 refers to UL 58 for design of buried underground tanks.

The ASME B&PV, Section VIII, Division 1, Par UG-22, subparagraph (a), identified internal or external design pressure (as defined in UG-21) as loadings to be considered in designing a vessel. The external pressure was evaluated as a superimposed static reaction from the soil overburden weight. UG-28 requirements are applicable to tanks subjected to uniform external pressure and does not consider soil/tank interaction. The underground LLLW tank used as *an example* did <u>not</u> meet UG-28 external pressure requirements. Other loadings to be considered are also listed in Par UG-22 and were considered in ORNL LLLW tank design evaluation but were not included in this paper.

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TANK INSTALLATION

An example buried LLLW tank at ORNL is shown in Figs. 1 and 2. The physical data for the tank shown in Figs. 1 and 2 are listed as follows:

1. buried 15,000-gal horizontal tank,
2. constructed of 304L stainless steel,
3. tank designed for 30 psi internal pressure at 70$F,
4. tank installed on concrete pad and strapped into concrete saddles,
5. back-filled to centerline with gravel and then back-filled the rest of the way with earth,
6. the top of the tank is 6.5 ft below grade,
7. 120-in. outside diameter,
8. 27 ft 5 in, long,
9. 1/4-in. shell and 3/8-in. ASME head,
10. 11 nozzles located along the top of the tank axial centerline (not shown in Figs.).

ANALYSIS

A buckling and collapse analysis was performed with the computer program ABAQUS Version 4-8 (Copyright 1989 Hibbitt, Karlsson & Sorensen, Inc.) using the arc length (RIKS) method.

Soil Loading

The loading on the buried tank is the overburden soil pressure plus snow load acting on the top half of the tank due to the projected area over the tank. This condition has been simulated by applying a normal pressure with a sinusoidal distribution over the top half of the tank as shown in Fig. 3. This was required due to the limitation of the soil model which prevented soil separation and collapse as the tank deflected. The required pressure is developed from the overburden height plus snow load.

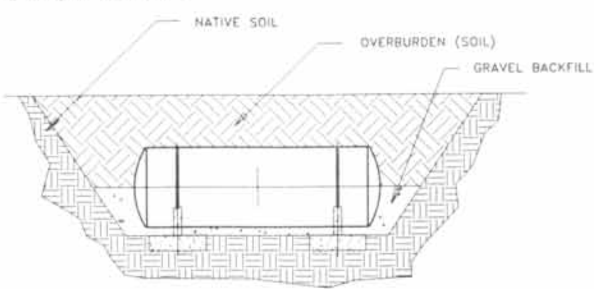

Fig. 1. Tank installation--elevation.

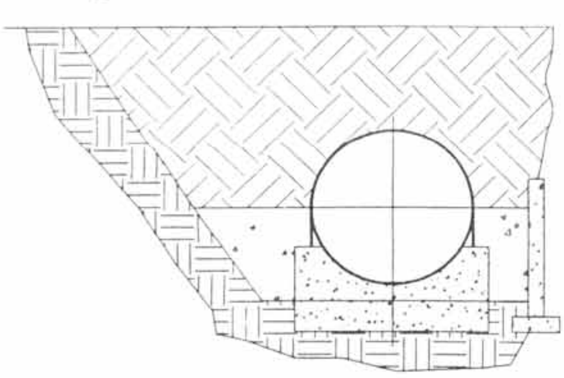

Fig. 2. Tank installation-mid section end view.

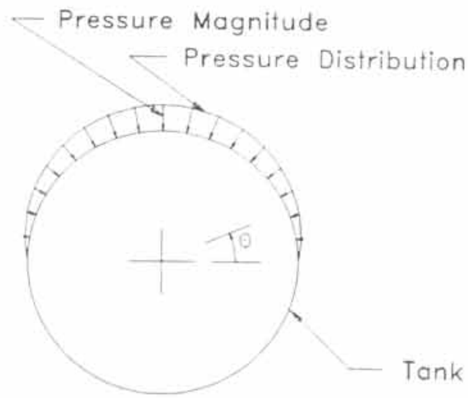

Fig. 3. Soil loading.

Soil/Tank Model

The soil/tank model was developed as a finite element model as shown in Fig. 4. The model of the soil and tank was developed with the following boundaries, a plane of symmetry along the axis of the tank, a slice 1-ft long at the center of the tank, the soil overburden height, the excavated depth to the top of the saddle slabs, and a tank radius from the tank as shown in Fig. 4. Interface elements were defined between the tank and the soil which could only transmit compressive loadings, i.e., the soil does not restrain the tank shell from buckling inward.

Tank Shell Model

A slice of the tank shell was modelled as a series of quadrilateral shell elements as shown in Fig. 5. This is considered a conservative model since the tank head contribution to buckling is neglected.

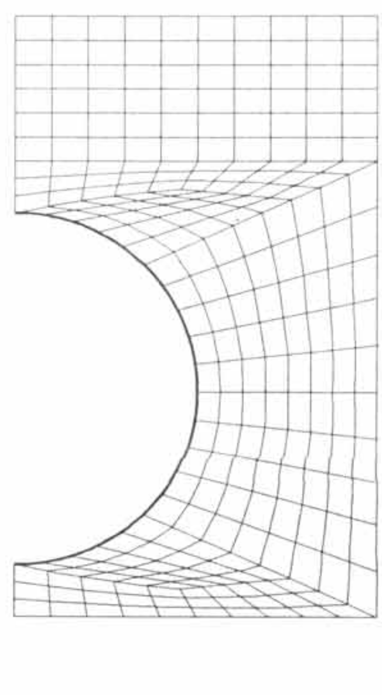

Fig. 4. Soil/tank model.

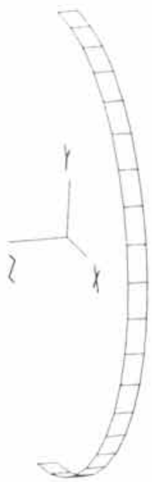

Fig. 5. Tank shell model.

Buckled Shape

The tank was loaded with increasing pressure until buckling was achieved. An exaggerated buckling shape of the tank is shown in Fig. 6 with the soil providing resistance and in Fig. 7 without considering soil resistance. These plot figures used representative properties only and do not represent a specific analysis. It can be seen that the soil reaction forces the buckling pattern into a more localized region with a reduced arc length. This reduced arc provides a substantial increase in the load which can be supported before buckling.

Effects of Soil Modulus

The soil modulus, Es, was parameterized to evaluate its effect. The effect of varying soil modulus on the maximum deflection versus the applied pressure loading is shown in Fig. 8.The buckling pressure established in Fig. 8 is cross plotted versus soil modulus in Fig. 9. It can be seen that there is strong logarithmic relationship which lends itself to interpolation.

Effects of Varying Shell Thickness

Tank thickness was parameterized to evaluate its effect. The effect of varying the tank thickness on the maximum deflection versus the applied pressure loading is shown in Fig. 10.

The buckling pressure established in Fig.10 is cross plotted versus shell thickness in Fig. 11. It can be seen that there is a linear relationship between the calculated buckling pressure and the shell thickness.

Hoop Stress Versus Pressure for Varying Soil Modulus

The hoop stress developed with the applied pressure for varying values of soil modulus are shown in Fig. 12. The results show that the primary membrane stress levels do not approach code limiting values based on comparison to a material yield stress of 25,000 psi. This indicates that design is limited by buckling.

Buckling Pressure for Actual Soil Condition

Soil properties were recommended by a geotechnical group as a range of lower bound values. A modulus of 800 psi was recommended for the soil back-fill and a modulus of 7000 psi was recommended for the gravel back-fill. A lower range was used because the materials have not been sampled or tested and compaction data for the earth and gravel back-fill

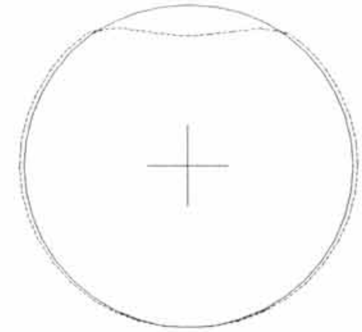

Fig. 6. Buckled shape with soil restraint.

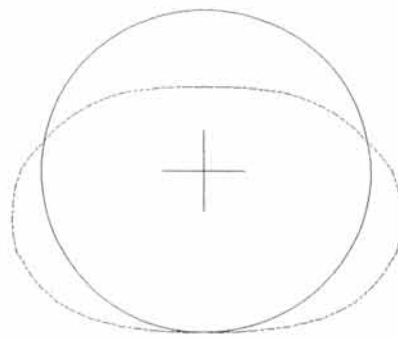

Fig. 7. Buckled shape without soil restraint.

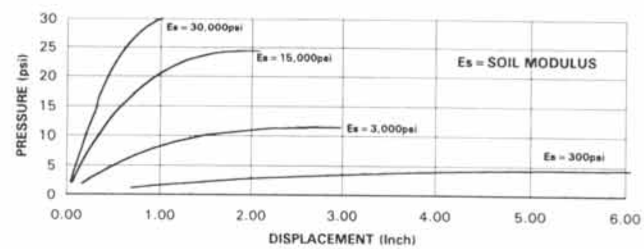

Fig. 8. Pressure vs displacement with varying soil modulus.

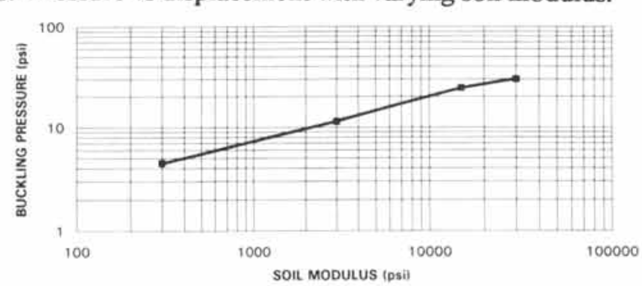

Fig. 9. Buckling pressure vs soil modulus.

were not available. The results of using the recommended values are summarized in Fig. 13. The required pressure of 5.42 psi reflects a 6.5-ft overburden height times the soil weight density converted to psi.

RESULTS AND CONCLUSIONS

The results show a comfortable margin between the capability required based on a 6.5-ft soil overburden and the tank capability. The margin of safety can be computed directly from data obtained from Fig. 13 as:

$$M.S. = \frac{9.5}{5.42} - 1 = .753$$

There are a number of conservatism built into the analysis approach which cannot be quantified due to modelling The

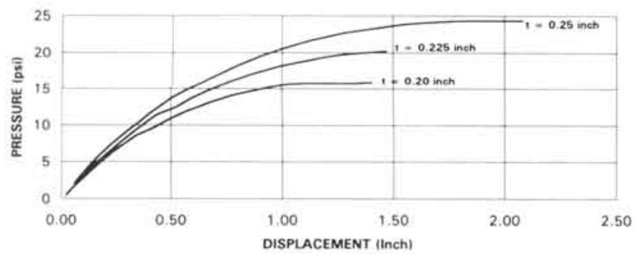

Fig. 10. Buckling pressure vs DISP with varying soil thickness.

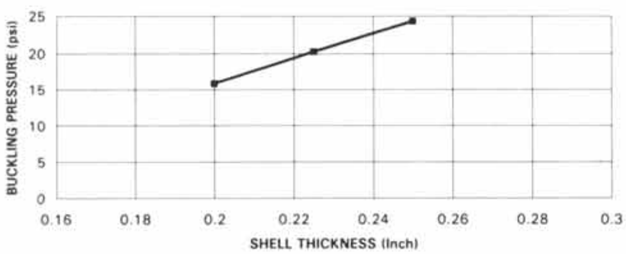

Fig. 11. Buckling pressure vs shell thickness.

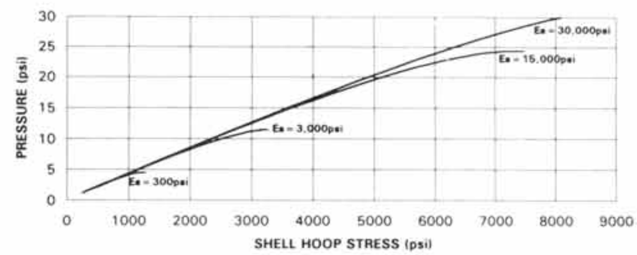

Fig. 12. Pressure vs shell hoop stress with varying soil MOD.

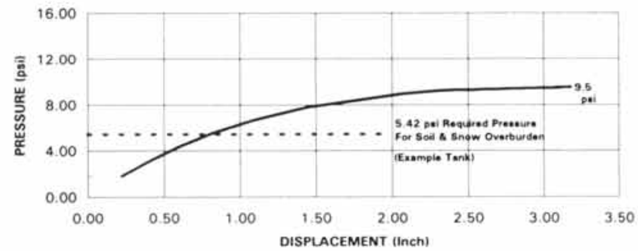

Fig. 13. Pressure vs displacement for actual soil conditions.

limitations. The results are consistent with codes used in design of underground storage tanks and equations used for culvert design. The method should be considered when computation of margin of safety is required and when a tank cannot meet the requirements of ASME B&PV, Section VIII, Division 1, Par UG-28. Any positive margin of safety computed by UG-28 rather than UG-22 would be overly conservative because soil reactions are not considered.