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Some Tips for Shell Thickness Evaluations of In-Service Aboveground Atmospheric Storage Tanks – Part 1

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Work Highlights

General

The original required design thickness of an aboveground atmospheric storage tank shell is determined based on the hydrostatic head of liquid in the tank. The hydrostatic head produces circumferential and longitudinal stresses in the shell, and the shell thickness is selected to keep these stresses within safe, allowable limits. This approach is analogous to determining the minimum required thickness of a pipe or pressure vessel due to internal pressure.

Depending on the design philosophy of the owner/operator and the nature of the contained fluid, a corrosion allowance may also have been added to the shell thickness required for the hydrostatic head. In addition, the actual shell plates used may be slightly thicker than required in order to utilize standard plate thicknesses. API-650 also requires that the shell plates be at least a specified minimum thickness as a function of tank diameter in order to preclude mechanical damage during erection.

As corrosion occurs and the shell thins during operation, the remaining shell thicknesses may no longer be adequate for the maximum design fill height of the tank. In other words, the actual stress in the shell may exceed a safe level. In such cases, the allowable fill height must be reduced or shell repairs made to restore the thinned area. An API-653 evaluation of a storage tank shell requires that the minimum required thickness of each course be determined.

Minimum Required Shell Thickness per API-653

For tanks with diameter ≤ 200 ft. (60 m), the minimum acceptable thickness for an entire shell course is determined using Equation (1) below with H determined to the bottom of the course. This is the same basic philosophy as is used in API-650 with the One-Foot Equation. The result of this calculation is then used to determine if the tank shell course is suitable for continued service.

US Customary Units

$$t_{\min} = \frac{2.6(H-1)DG}{SE}$$

SI Units

$$t_{\min} = \frac{4.9(H-0.3)DG}{SE} \quad (1)$$

Mechanical Engineering

- Mechanical and materials engineering support was provided regarding replacement of a storage tank bottom. The existing bottom had experienced severe corrosion issues over several years, actually holing through in less than five years after previous major repairs were done. A technical specification was provided for a new double bottom design with a cathodic protection system, and an alternate approach that did not involve installing a double bottom.

Process, Operations & Safety

- Assisted a client to perform a crude unit startup test run on modifications recently implemented and report performance improvement vs. pre-mod baseline operations.
- Assisting a technology provider to update their lube processing design guides, including energy criteria.
- Provided consultation to an equipment vendor on specific technical safety issues and recommended resolutions.
- Providing safety assessment audit support for a confidential client at multiple locations.

If locally thinned areas are identified, or if specific areas of a shell course are being evaluated (e.g., the region near a shell nozzle), then Equation (2) is used with H determined for that particular location.

US Customary Units

$$t_{\min} = \frac{2.6D(H)G}{SE}$$

SI Units

$$t_{\min} = \frac{4.9D(H)G}{SE} \quad (2)$$

The parameters used in Equations (1) and (2) are defined below:

- t_{\min} = Minimum acceptable thickness for each course [not less than 0.1 in. (2.5 mm) regardless of the calculation results].
- D = Nominal tank diameter, ft. (m).
- H = For Equation (1) – Height from the bottom of the course being evaluated to the maximum design liquid level, ft. (m).
For Equation (2) – Height from the bottom of the locally thinned area to the maximum design liquid level, ft. (m).
- G = Highest specific gravity of the contents.
- S = Maximum allowable stress, psi (MPa).
- E = Original weld joint efficiency for the tank.

For a cylinder under internal pressure (hydrostatic head in the case of a storage tank), the circumferential stress just due to internal pressure is double the longitudinal stress. Thus, Equations 1 and 2 are based on the circumferential stress in the shell since this stress governs the required shell thickness.

Weld Joint Efficiency Considerations

Except for an API-650 Appendix A tank, the One-Foot Equation used to calculate the required shell thickness for a new tank in today's API-650 does not contain a weld joint efficiency parameter, E. So, why do the comparable API-653 equations contain E? This is because "older" tanks were designed using E as a parameter in determining required shell thickness, with the value of E based on the type of weld and level of inspection used.

Based on Table 4.2 of API-653, E can range between 0.35 (for a tank with single lap-welded construction) to 1.0 (for tanks built to API-650 7th Edition or later). If the year of construction is known, and it can be confirmed that the tank met the relevant API requirements at the time (e.g., by having an API nameplate), E will probably range between 0.7 and 1.0 depending on the type of weld joint used (i.e., butt or lap-welded) and weld inspection done. If the original E is unknown, use Table 4.2 to determine what value to use.

Since weld joint efficiency is an explicit parameter in the thickness calculation, the location of corroded regions with respect to vertical welds is important since it can determine whether the remaining shell thickness is acceptable or not. The weld joint efficiency does not need to be used if the corroded region is far enough away from vertical welds. Thus, use E = 1.0 when evaluating an area located away from vertical welds or joints by at least the greater of 1 in. (25 mm) or twice the plate thickness.



Allowable Shell Material Stress

Table 4.1 in API-653 lists the material allowable stresses to use when determining t_{min} . The allowable stress per API-653 is higher than that specified in API-650 in each case. In other words, API-653 uses lower safety factors with respect to the material's yield and tensile strengths than does API-650. However, these lower safety factors have proven to be acceptable for in-service storage tanks based on many years experience long before API-653 was first issued in January 1991.

Note also that unlike API-650, API-653 uses a slightly more conservative allowable stress basis for the bottom and second shell courses than for upper courses. This is due to the generally more complex stress distribution in these lower courses that is not being accounted for in the evaluation. In spite of this, the API-653 allowable stress basis is still slightly more liberal than API-650 in order not to be overly conservative, while still being safe, when evaluating existing tanks for continued operation.

In developing API-653, committee members recognized that there were many tanks whose documentation had been lost and the shell material was unknown. In order to still permit shell thickness evaluations for these tanks, assumptions were made of the material yield and tensile strengths, and these correspond in strength to ASTM A-283 Grade C or A-285 Grade C material. This was felt to be the weakest material that was most likely used in a storage tank, and thus safe to use for evaluation purposes if the material is unknown. This can have a significant impact on the evaluation if a stronger material was actually used but cannot be documented. In this case, the API-653 calculations could say that the tank was not good for the original design fill height even when new. If nothing else, this alone is enough to demonstrate the importance of maintaining complete records.

Vertical Location of Thinned Area Within a Shell Course

When shell thickness inspection results are initially reported for performing an engineering evaluation, it is commonly assumed in the calculations that the thinnest shell measurement in a given course is located at the bottom of the course, unless specifically noted otherwise in the inspection report. If the evaluation concludes that the tank shell thickness is acceptable (i.e., tank may be filled to its maximum design fill height), then there is no reason to proceed further. However, this approach is conservative if the corrosion is actually located higher in the course. Thus, obtaining better location data with respect to vertical position of the corrosion could improve the results and possibly avoid imposing a fill height restriction or making repairs.

Summary

This article introduced the basic equations used in API-653 to determine whether the shell thickness of in-service aboveground atmospheric storage tanks is acceptable. It highlighted several items that inspectors and engineers should be aware of and help avoid being overly conservative. A later article will continue on this subject and highlight several other items.

About the Author

Vincent Carucci, President of Carmagen Engineering, Inc., also provides mechanical engineering expertise in the areas of pressure vessels, heat exchangers, piping systems, and storage tanks to the process and power industries, insurance companies, and attorneys. If you would like more information, please contact Vince at vcarucci@carmagen.com.

