Designing storage tanks

Software based on the latest international codes enables straightforward design of storage tanks in a range of load conditions

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The design and maintenance of atmospheric and low pressure vessels for oil storage is becoming ever more vital as crude oil storage capacity utilisation rises and oil storage capacity grows globally. The US Energy Information Administration shows crude oil storage capacity utilisation rising steadily.

Standards for tank design

From the perspective of the casual observer, these storage tanks just sit there doing their job day in, day out. And then in a spark of enlightenment, questions start to pop into the minds of the curious:
• How thick do the walls and floors of these structures have to be?
• Why are some tanks bolted down to the ground and others are not?
• What internal support structures are needed if the tank has a fixed roof?
• What happens to a tank during a hurricane or earthquake?

The answers to these questions are readily available. They ultimately lie in the pages of the following codes and standards:
• American Petroleum Institute (API) 650
• BS EN 14015:2004
• API 620.

Tank design codes reflect the culmination of decades of work by many dedicated individuals. Using these standards helps to ensure that tanks will be able to stand the rigours of the elements and conditions to which they are subjected.

API 650

The API 650 code is entitled *Welded Steel Tanks for Oil Storage*. At the time of this, the latest edition is the 12th, addendum 2, January 2016.

This code can be used for designs where the internal pressure is less than or equal to 2.5 psig. These tanks have historically been used to house petroleum for use by chemical plants and power production facilities, as well as basic and strategic reserves.

A group of dedicated individuals meet on a regular basis to maintain and update the 650 code. These sessions typically involve lengthy discussions of various agenda items that are important to the refinement and development of the code. As one would expect, all aspects of the code, both analytical and non-analytical, are addressed in the meetings.

But getting back to one of the previous questions, how do we decide how thick the wall of the tank should be? The answer can be found in section 5.6, Shell Design. In this section, there are two methods for consideration:
• 5.6.3 Calculation of Thickness by the 1-Foot Method
• 5.6.4 Calculation of Thickness by the Variable Point Method.

The 1-foot method computes the required plate thickness at a distance of one foot above the bottom of each shell course and is applicable to tanks 200ft (61m) and less in diameter. The basic equation in US customary units looks something like this:

$$thickness\ required = \frac{2.6D(H-1)G}{S} + CA$$

The variable point method is an alternative to the 1-foot method and can be used for tanks in excess of 200ft in diameter. The variable point equation in US units is as follows:

$$thickness\ required = \left(1.06 - \frac{0.463D}{H}\sqrt{\frac{H \times G}{S}}\right)\left(\frac{2.6H \times D \times G}{S}\right) + CA$$

Where:
H is the design fluid height in feet.
D is the nominal tank diameter in feet.
G is the specific gravity of the contents.
S is the tank wall material allowable tensile stress for the operating or test condition.
CA is the corrosion allowance, if any.

API 650 storage tanks are often designed to work at temperatures of up to 500ºF (260ºC). For these higher temperature designs, the allowable stress of the material decreases. As a result, the required wall thickness increases in a linear fashion when using the 1-foot method and in a slightly non-linear fashion when using the variable point method.

In addition to causing hoop stress and longitudinal stress in the tank wall, the slight internal pressure causes a tensile force (pressure × area) to be produced. This force pulls upward on the tank wall. This positive upward force is countered by the weight of the tank and roof (if not column-supported). If the net force is upward in any case or condition, the tank must be held down by anchor bolts.

The basic internal pressure case is just one example. There are several other uplift formulas in Tables 5.21a (metric) and 5.21b (imperial), which must also be considered.

The net uplift due to design

pressure formula from Table 5.21b in API 650 12th Edition, Addendum 2 is as follows:

$$= (Pi \times D^2 \times 4.08) - W1$$

Where:

Pi is the design internal pressure in inches of water.
D is the nominal diameter in feet.
W1 is the static weight of the tank components in pounds force, which resist the pressure/force uplift effect.

BS EN 14015:2004

BS EN 14015:2004 is the European design and analysis code for tanks. Its descriptive title is *Specification for the design and manufacture of site built, vertical, cylindrical, flat bottomed, above ground, welded, steel tanks for the storage of liquids at ambient temperature and above.*

This EN code shares some similarities with the API 650 code. Like API 650, EN 14015 computes the shell course required thickness via a fairly straightforward equation as shown here:

$$e = \frac{D}{20S}\{98W(H_c - 0.3) + p\} + c$$

Where:

c is the corrosion allowance in millimetres.
D is the tank diameter in metres.
e is the required thickness in millimetres.
H_c is the distance from the bottom of the shell course under consideration as defined in 9.2.1.
P is the design pressure at the top of the tank in mbar.
S is the allowable stress for the appropriate condition in N/mm².
W is the density of the liquid under consideration in kg/l.

It is interesting to note that the maximum design pressure for 14015 designs is 500 mbar or about 7.25 psig. This is well beyond the maximum of 2.5 psig allowed by API 650.

API 620

Now that we have a couple of answers to our questions, let us ask the next big one: what is API 620 and how does it differ from API 650?

The API 620 code is entitled

Design and Construction of Large, Welded, Low-Pressure Storage Tanks. After a quick review of this code, it is readily apparent that API 620 is a bit more technologically advanced than its close cousin API 650. The main difference, as mentioned earlier, is that this code has a higher range of design pressure (up to 15 psig).

API 620 is different from API 650 in a number of other ways. For example, API 620:
• Supports more varied types of geometries (not just flat bottomed tanks).
• Analyses a larger number of types of components (like elliptical heads and exchanger components).
• Accommodates a maximum design temperature of 250°F.
• Supports specific calculations for openings in shells.
• Offers different MDMT rules.
• Provides an explicit design methodology for the consideration of both tensile and compressive stresses on tank elements.

This final point really complicates matters. In the normal operation of a low pressure API 620 tank, it is easily conceivable that the stress in the hoop direction is tensile while the axial or longitudinal stress is compressive.

Another scenario might be that the tank is under a slight vacuum. This case would generate a compressive stress in both the hoop and longitudinal directions.

Because this represents a potentially more severe condition, the allowable compressive stress must be computed at each point of concern and compared to the actual compressive stress. Then the required thickness due to this condition can be determined.

So, depending on the mode in which the tank is operating, the wall could be fully under compression in both directions, fully under tension in both directions, or under a combination of tension and compression.

API 620 computes and labels these unit forces as T1 and T2. When T1 and T2 are both in tension, the required thickness is fairly straightforward to compute. It is just the maximum of the two

values, divided by the material allowable stress, multiplied by the joint efficiency. Of course, the corrosion allowance must be added to the final required thickness, if there is one.

When T1 and T2 are both compressive, the analysis quickly becomes complex. In this case, the tank wall is subject to buckling. The allowable buckling stress must be calculated and is a function of the thickness to radius ratio.

For API 620 designs, it is often required to determine the maximum allowable working pressure for both the internal and external pressure cases. This involves iteratively changing the pressure until the given wall thickness is insufficient. Not only do the shell courses and roof all have to be checked, but the roof to shell junction must be analysed as well. This process is tedious and time-consuming, not to mention error-prone if you are performing these calculations by hand.

But this is where Intergraph Tank comes in. Developed in the early 1990s, Tank is an analytical software solution that engineers and designers use to rate existing tanks and design new ones according to the design rules of international standards like API 650 and API 653. In July 2016, a new analysis code was added to Tank. This new code is API 620.

Data collection

The menu-driven interface of Tank enables the quick definition of input and functions for the accurate analysis of oil storage tanks to API standards.

Increased flexibility is provided by allowing users to select any unit combination for analyses or to produce reports. In addition, unit files are completely user-definable so engineers are not bound by program default settings. Even existing jobs can be converted to any existing unit format.

User interface

The user interface in Tank presents only what is needed at each point of information gathering. Therefore, users are not burdened with

'out-of-sequence' requirements for information required for analysis. You are asked for what is needed, when it is needed.

Analysis options and codes

Tank performs calculations in accordance with the latest API Standards 620, 650 and 653. Analysis can also take into account wind, seismic and settlement conditions plus calculate air venting requirements to API 2000 Section 4.3.

Output and reports

After completing an analysis, users can view the results in a tabular report or as a graphic diagram with associated data. For convenience in verifying the results, the output reports reference code sections used where applicable.

Material databases

Tank has many databases integral to the package, which make it easy to select standard data for accurate analysis. A number of US and international structural steel databases are provided. Tank is delivered with many material databases to choose from. Of course, the selections include those from the latest API 650 and 620 standards.

Tank design

The following describes how Intergraph Tank works for tank design.

Figure 1 shows the main Tank design window. From here, an engineer can select options and input the design data for a tank. Once sufficient information is submitted, the interactive 3D model is created and displayed.

Clicking on the icons in the Input panel (see **Figure 2**) switches the data input and allows information regarding the roof, seismic loads, grillage, external pressure and so on to be inputted. On some sections of the input there are tabs. Complete the data on each tab as necessary.

Tank analysis

After all of the tank data is submitted, press the Analyze button or F12 and TANK will error check,
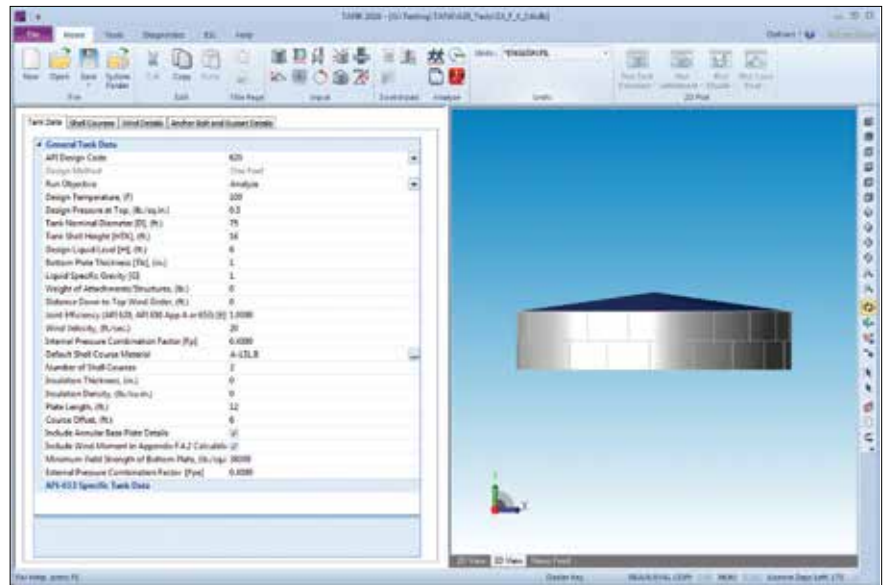

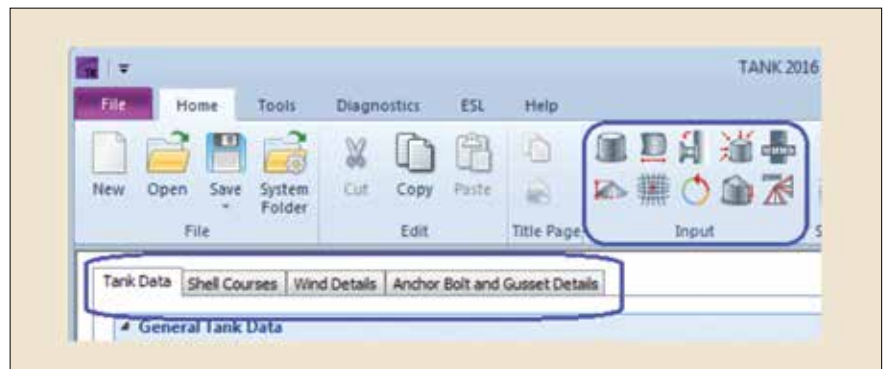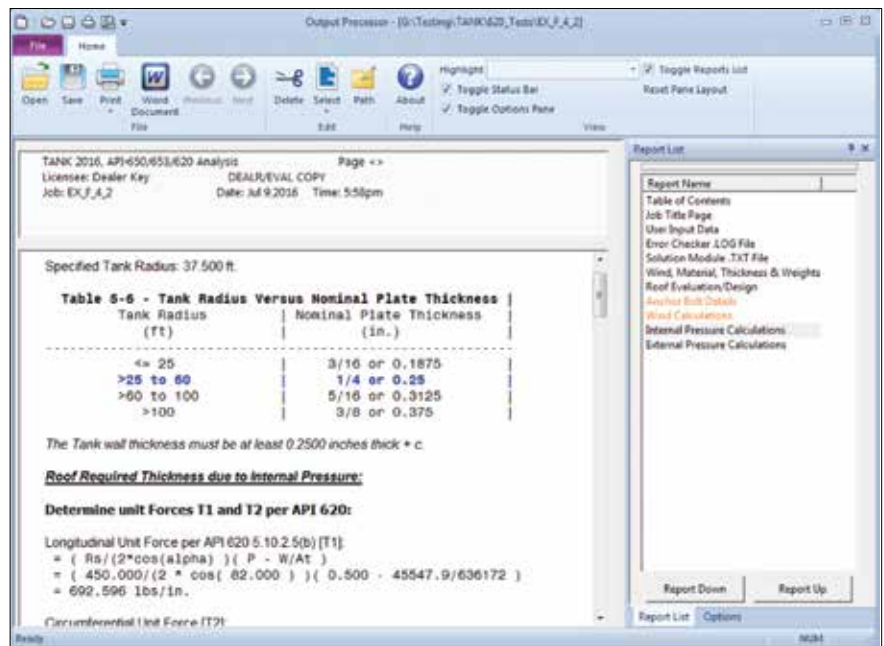Figure 1 Main design window of Tank software

Figure 2 Tank input panel

Figure 3 Tank output report

analyse the data and produce the output reports, which contain the results of the analysis. A typical output report is shown in **Figure 3**.

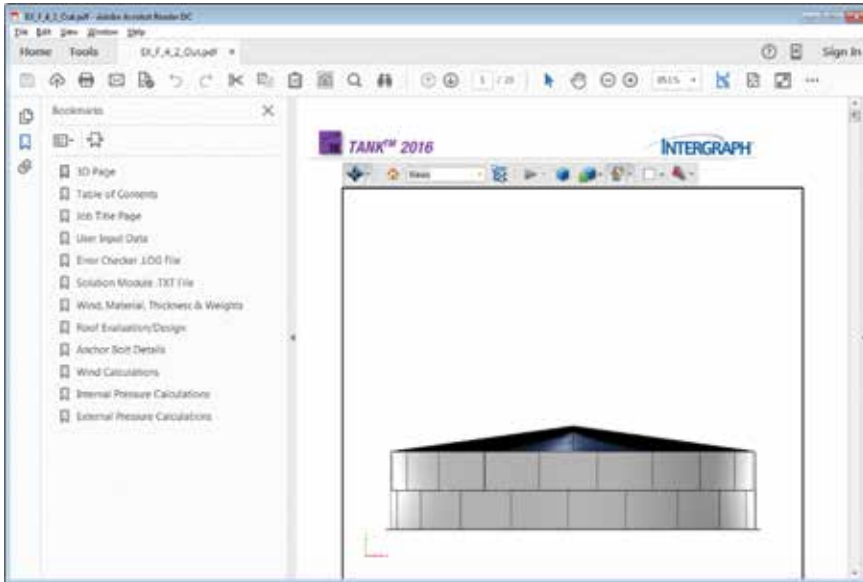Notice that the output contains tables and code formulas with

Figure 4 PDF record of a tank design

variable substitutions. This helps users to verify the software's results and figure out where all the numbers come from.

A PDF document can quickly be generated for records. Tank version 2015 and later can encapsulate and embed the 3D model directly into the PDF. You specifically need the Adobe Reader DC to interact with the 3D model. Non-Adobe PDF readers do have the ability to render and manipulate the 3D model.

The 3D PDF of the tank (see **Figure 4**) is available from the output report. A review of the analysis results provides all the information needed to proceed with the design or evaluation of the given geometry.

Conclusion

In this article, we have briefly discussed three different tank design codes, reviewed some basic equations for internal pressure design and done a little comparison and contrast.

Tank design is complex and can be confusing. Intergraph Tank helps engineers perform tank design easily and accurately to improve safety.

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