

STORAGE TANKS – SELECTION OF TYPE, DESIGN CODE AND TANK SIZING

Mahmoud N. Shatla and . Mokhtar El Hady
Enppi, Cairo, Egypt

ABSTRACT

The present work gives an insight into the proper selection of type, design code and sizing of storage tanks used in the Petroleum and Process industries. In this work, storage tanks are classified based on their design conditions. Suitable design codes and their limitations are discussed for each tank type.

The option of storage under high pressure and ambient temperature, in spherical and cigar tanks, is compared to the option of storage under low temperature and slight pressure (close to ambient) in low temperature and cryogenic tanks.

The discussion is extended to the types of low temperature and cryogenic tanks and recommendations are given to select their types. A study of pressurized tanks designed according to ASME code, conducted in the present work, reveals that tanks designed according to ASME Section VIII DIV 2 provides cost savings over tanks designed according to ASME Section VIII DIV 1.

The present work is extended to discuss the parameters that affect sizing of flat bottom cylindrical tanks. The analysis shows the effect of height-to-diameter ratio on tank instability and foundation loads.

1. INTRODUCTION

Tanks are classified based on their design internal pressure in the volume above the stored product (vapor space).

If the design internal pressure is atmospheric, tanks are usually designed and constructed according to API 650 code as flat bottom cylindrical tanks with cone roof. In this case, the maximum allowable internal pressure above the stored product is equal to the weight of the roof plates per unit area (0.004 barg) and the maximum allowable external pressure (vacuum pressure) is 0.0025 barg.

If the internal pressure is above 0.004 barg and below 0.17 barg, the tanks can still be designed according to API 650 as flat bottom cylindrical tanks but taking the provisions of Appendix F, in API 650, into consideration. If the internal design pressure exceeds 0.17 barg and is less than 1.03 barg, tanks are usually designed as flat bottom cylindrical tanks with dome roof as per API 620. In this case, the maximum allowable external pressure (vacuum pressure) as per API 620 is 0.0043 barg. Liquids (with vapor pressure > 1.5 psia) are stored in internal or external floating roof tanks designed according to API 650 code.

When, the design internal pressure exceeds 1.03 barg and/or the design external pressure exceed the API limitations mentioned above, tanks are designed according to ASME code section VIII DIV 1 or DIV 2 as spherical or cigar tanks. Instead of storing products at high pressure and ambient temperature in cigar or spherical tanks, products may be stored at low temperature corresponding to their boiling point at slight pressure (close to ambient) in cryogenic tanks which are more safe and can store larger amounts

of products specially liquefied gases. Storage in low temperature or cryogenic tanks requires refrigeration units and is cost effective only when it is required to store large amounts of products such as in liquefied gases export facilities.

2. LOW TEMPERATURE AND CRYOGENIC STORAGE TANKS

Flat bottom cylindrical tanks with dome roof are utilized to store liquefied gases at their boiling point and at a pressure close to atmospheric pressure. The advantages of that storage technique is the safety due to low pressure and the low unit cost of storage due to the large storage capacity. Low temperature storage covers the range from 0°C down to -101°C.

The Cryogenic range starts from -101°C down to -168°C. Some gases are stored in the low temperature range such as NGL (Natural Gas Liquids, its composition is mainly ETHANE+); others are stored in the cryogenic range such as LNG (Liquefied Natural Gas, its composition is mainly METHANE & ETHANE). There are many types of flat bottom tanks that are used to store gases at their boiling points such as the Single Wall Single Containment SWSC (Figure 1), Double Wall Single Containment DWSC (Figure 2), Double Wall Double Containment DWDC (Figure 3) and Full Containment FC tanks (Figure 4).

SWSC tank (Figure 1) consists of shell and bottom that are made of low temperature steel. The shell is covered with a layer of insulation such as polyurethane. Shell insulation is covered with thin metal sheets for weather protection. The shell and bottom rest on load bearing insulation. The shell supports the dome roof plates and structure that are made of regular inexpensive carbon steel because of the utilization of a suspended deck. As shown in the Figure, the suspended deck acts as a thermal barrier because of

the insulation layer that is spread over it. The space above the suspended deck is warm and has superheated vapors of the stored product. Under the deck, there is a cold vapor space that has saturated vapors of the stored product. The vapors above and below the deck are allowed to circulate through simple open pipe vents that are installed in the deck. The pipe vents help to eliminate any differential pressure across the deck that may cause left on the deck. The suspended deck plates, structure and hangers are made of low temperature material.

A concrete ring wall foundation with an interior filled with improved soil may be used if the soil condition is good. In this case, a foundation heating system must be used to prevent the soil from freezing which can result in upheaval and destruction of the brittle bottom insulation. Another type of foundation is the pile type foundation, used in poor soils. In pile type foundation, an elevated pile cap is used to eliminate the need of the tank foundation heating system because the elevated pile cap allows air circulation under the tank which prevents freezing of the soil and its upheaval.

Figure 2, shows the DWSC tank. If the outer shell and bottom are made of regular carbon steel and are designed only to protect the insulation, then the tank is DWSC. On the other hand, if the outer shell and bottom are made of low temperature steel and are designed to contain the stored product in case of failure of the inner shell and bottom, the tank is DWDC. The resilient blanket contracts or expands when the inner shell expands or contracts, respectively, due to thermal changes and/or due to hydrostatic stresses imposed during filling and emptying of the tank. Thus the resilient blanket helps to avoid settlement of the unsupported perlite insulation in the increased annular space when the inner shell contracts. Settlement of the perlite

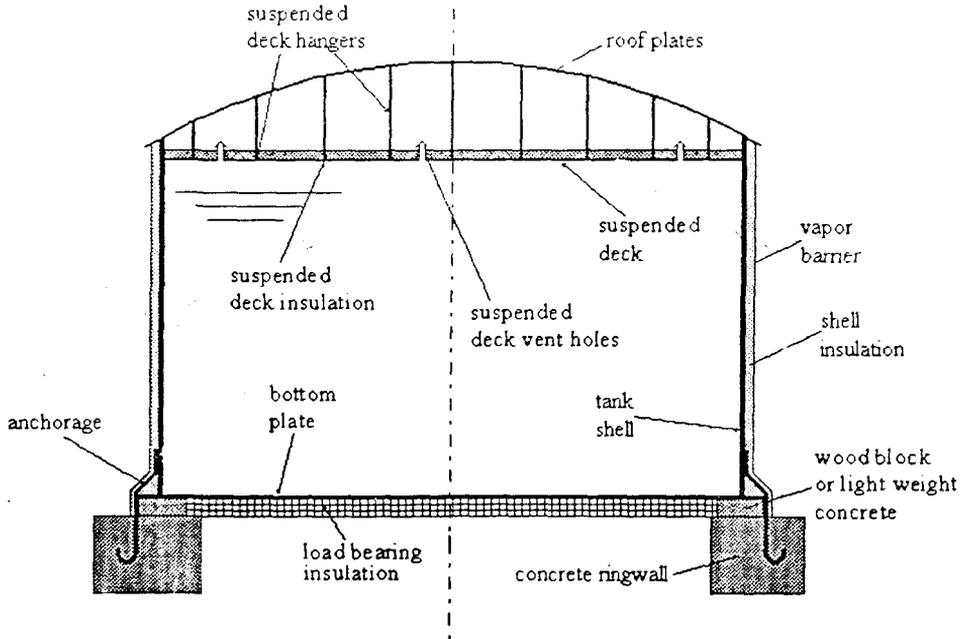
insulation will impose stresses when the annular space gets narrower due to re-expansion of the inner shell.

Another type of DWDC tank is shown in Figure 3 where the perlite insulation in the annular space is replaced by polyurethane insulation at the outside. In this case, the resilient blanket is not required. Moreover, the insulation is not destroyed in case of failure of the inner shell.

The FC tank is shown in Figure 4. For FC tank, the inner shell and bottom are made of low temperature steel. The outer shell and bottom are made of regular carbon steel because they act only as vapor barriers.

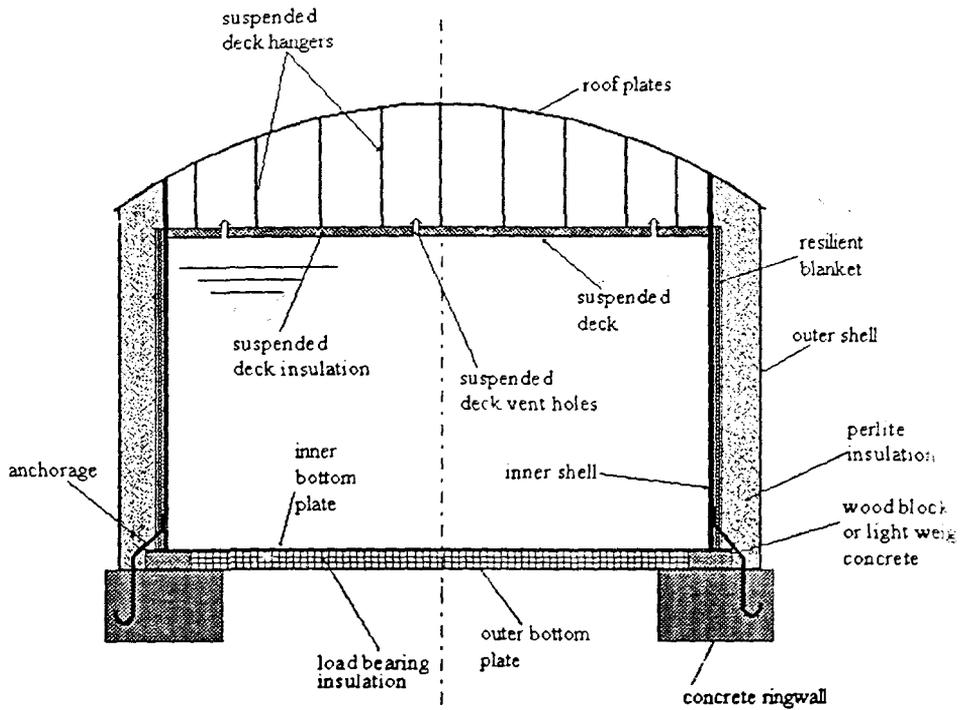
Low temperature and cryogenic tanks are designed using API 620 (App. Q and R) and/or BS 7777 (Parts 2 and 4) codes. The required low temperature steel varies with the temperature range. For example, in the range from 0 to -33°C , A 516 is used whereas A 537 is used in the range from -33 to -51°C . In the range from -51 to -168°C , A 645 (5% Nickel), A 353 and A 553 (9% Nickel), and A 240 type 304 Stainless Steel are used. The regular carbon steel used for the specific parts mentioned above can be A36 or A 283 Gr. C.

SW tanks may be used for less hazardous products at storage temperature higher than -50 deg C whereas FC tanks are strongly recommended for hazardous products such as ammonia and for products stored at temperatures below -100 deg C such as LNG. The outer concrete layer in the FC tank is very effective, in these situations, to resist fire and prevent emissions of the hazardous materials to the atmosphere.



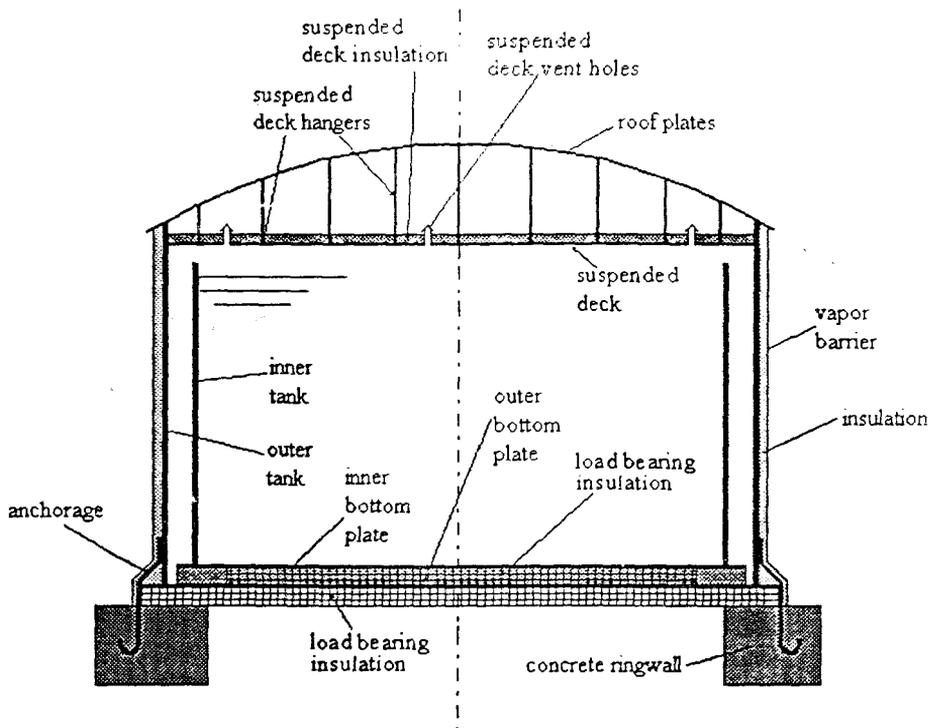
Component	Material
Shell	Low Temperature Material
Suspended Deck Plates and Framing	Low Temperature Material
Suspended Deck Hangers	Low Temperature Material
Bottom	Low Temperature Material
Annular Plate	Low Temperature Material
Anchor Straps	Low Temperature Material
Compression Ring	Low Temperature Material
Roof Plates & Structure	Common Carbon Steel Material

Figure 1: Single Wall Single Containment Tank



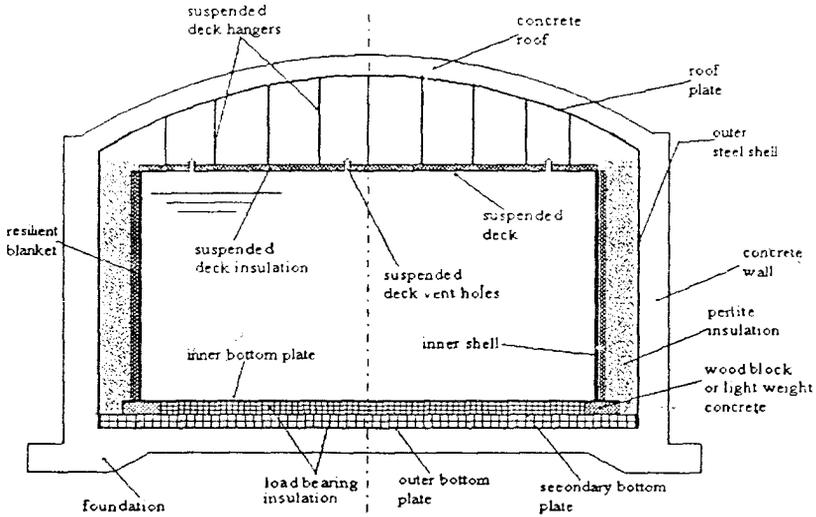
Component	Material
Inner Shell	Low Temperature Material
Outer Shell	Common Carbon Steel Material
Suspended Deck Plates and Framing	Low Temperature Material
Suspended Deck Hangers	Low Temperature Material
Inner Bottom Plate	Low Temperature Material
Outer Bottom Plate	Common Carbon Steel Material
Annular Plate	Low Temperature Material
Anchor Straps	Low Temperature Material
Compression Ring	Low Temperature Material
Roof Plates & Structure	Common Carbon Steel Material

Figure 2 : Double Wall Single Containment Tank



Component	Material
Inner Shell	Low Temperature Material
Outer Shell	Low Temperature Material
Suspended Deck Plates and Framing	Low Temperature Material
Suspended Deck Hangers	Low Temperature Material
Inner and Outer Bottom Plates	Low Temperature Material
Annular Plate	Low Temperature Material
Anchor Straps	Low Temperature Material
Compression Ring	Low Temperature Material
Roof Plates & Structure	Common Carbon Steel Material

Figure 3 : Double Wall Double Containment Tank



Component	Material
Inner Tank Shell	Low Temperature Material
Inner Tank Bottom Plate	Low Temperature Material
Inner Tank Annular Plate	Low Temperature Material
Outer steel Shell	Common Carbon Steel Material
Secondary Bottom Plate and annular Plate	Common Carbon Steel Material
Outer Bottom Plate	Common Carbon Steel Material
Roof Steel Skeleton	Common Carbon Steel Material
Roof Steel Plate	Common Carbon Steel Material
Concrete Outer Tank Shell	Pre-Stressed Concrete
Concrete Outer Tank Roof	Reinforced Concrete
Suspended Deck Plates and Framing	Low Temperature Material
Suspended Deck Hangers	Low Temperature Material

Figure 4: Full containment Tank

3. STORAGE UNDER HIGH PRESSURE IN CIGAR AND SPHERICAL TANKS

High pressure spherical and cigar tanks that are designed according to ASME code may be designed according to ASME code Section VIII DIV 1 (DIV 1) or Section VIII DIV 2 (DIV 2). DIV 1 requires more thickness but is less restrictive in terms of certification, testing and fabrication requirements compared to DIV 2.

An example of the more restrictive certification requirements is that, in DIV 2, the user's design specification and manufacturer's design report must be checked and certified by a professional engineer who is registered in the USA or Canada.

Moreover, an example of the more restrictive testing requirements is that the main longitudinal and circumferential welds, in tanks designed according to DIV 2, must be fully examined by radiography.

On the other hand, in DIV 1, partial or no radiography may be used provided that the service is not lethal and the thickness does not exceed certain upper limit that depend on material (30 mm for the common materials used in cigar and spherical tanks).

Furthermore, an example of the more restrictive fabrication requirements, is that, in DIV 2, double welded butt joints must be used for longitudinal welds and circumferential welds attaching heads to shells and single welded butt joints are used for other circumferential welds. Whereas, in DIV 1, less restrictions in the weld types can be found.

In the present work, a study is performed, as summarized in Figures 5 through 10, to investigate the savings in material when cigar and spherical tanks are designed according to DIV 2 instead of DIV 1. In this study, full RT

is used because it is mandatory for DIV 2 and mandatory for DIV 1 when the thickness of the materials used in this study exceeds 30 mm.

For spherical tanks, two different common materials are investigated which are SA-516-70 and SA 537 CL 1. For both materials, considerable savings in spherical tank weights are accomplished when using DIV 2 instead of DIV 1.

The savings in tank weights are increased with increasing design pressure and with increasing spherical tank diameter as shown in Figures 5 through 8. In Figure 8, the curves for the pressures 15 and 20 barg show severe nonlinearity due to the change in allowable stresses of SA 537 CL 1 with thickness.

Similar savings in cigar tanks weight per unit length are achieved when using DIV 2 instead of DIV 1 as shown in Figures 9 and 10. The material used in this study is SA 516-70 which is very common for manufacturing cigar tanks. The savings are increased with increasing pressure and with increasing cigar tank diameter.

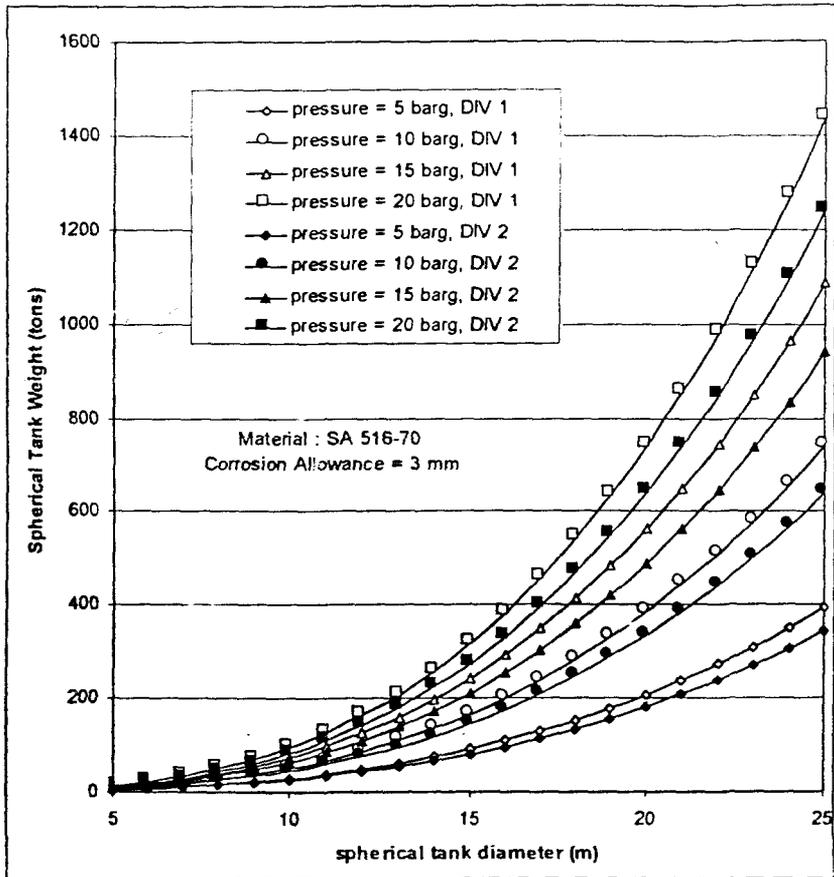


Figure 5: Comparison of the spherical tank weight as calculated by DIV 1 and DIV 2 for different internal pressures and diameters. Material is SA 516-70, corrosion allowance = 3 mm, full RT and ambient temperature are used in the analysis

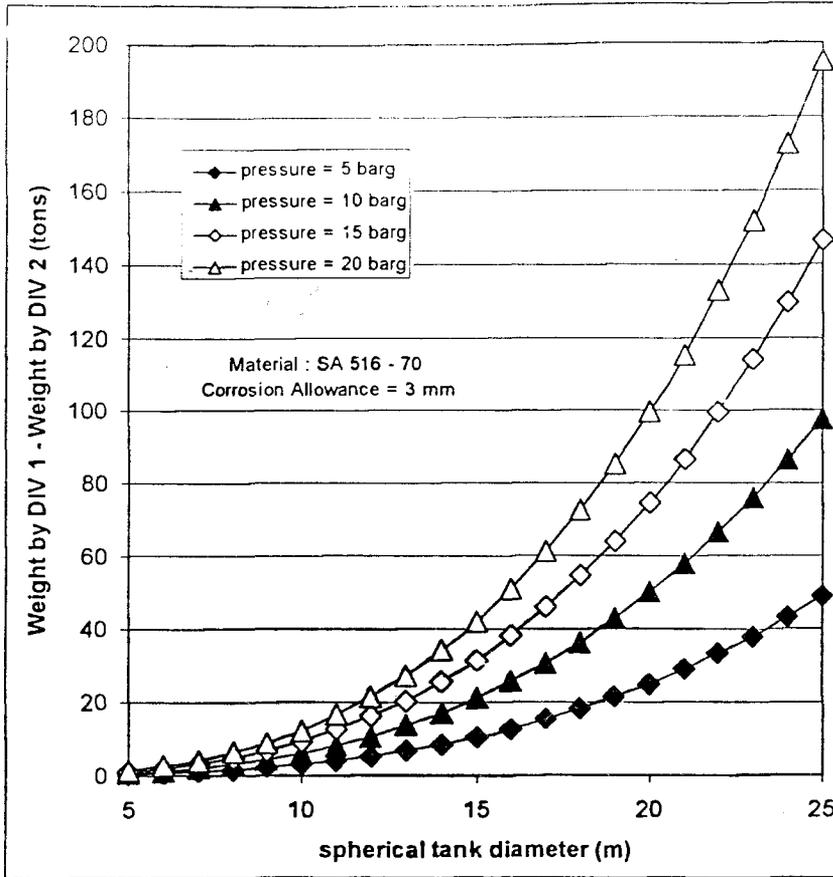


Figure 6: Difference in spherical tank weight calculated by DIV 1 and DIV 2 for different internal pressures and diameters. Material is SA 516-70, corrosion allowance = 3 mm, full RT and ambient temperature are used in the analysis

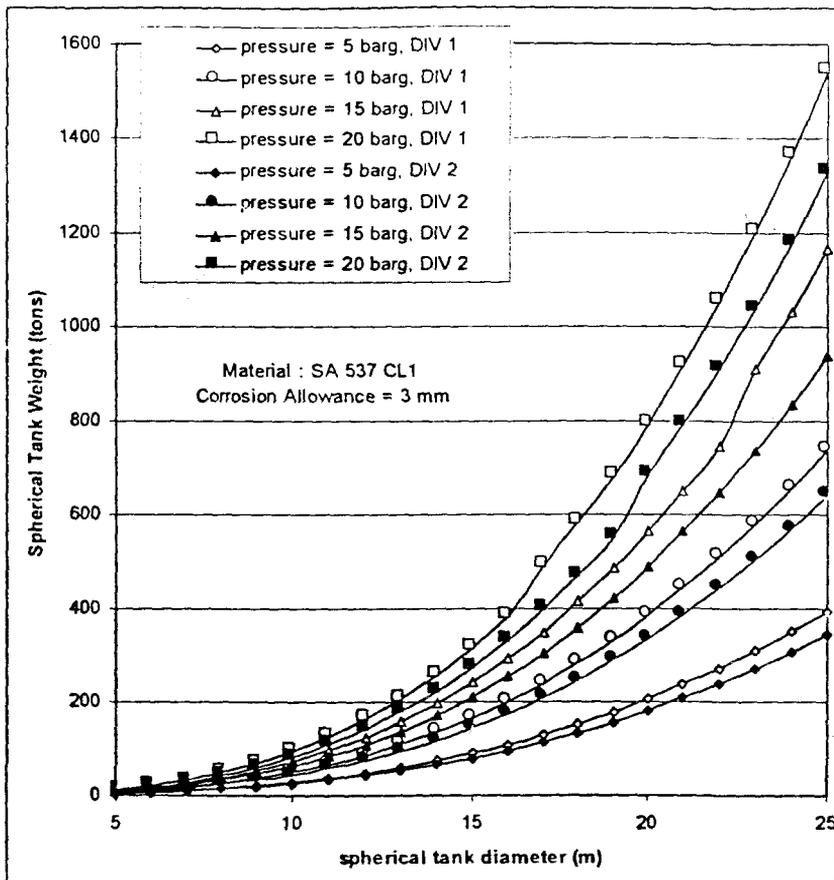


Figure 7: Comparison of the spherical tank weight as calculated by DIV 1 and DIV 2 for different internal pressures and diameters. Material is SA 537 CL 1, corrosion allowance = 3 mm, full RT and ambient temperature are used in the analysis

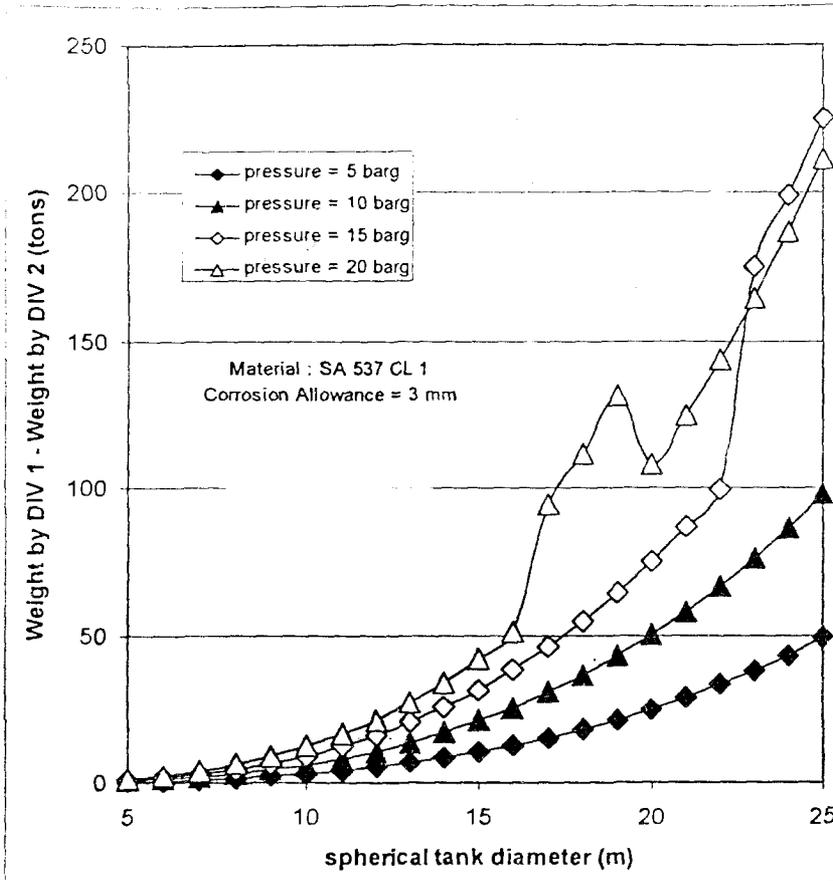


Figure 8: Difference in spherical tank weight calculated by DIV 1 and DIV 2 for different internal pressures and diameters. Material is SA 537 CL 1, corrosion allowance = 3 mm, full RT and ambient temperature are used in the analysis

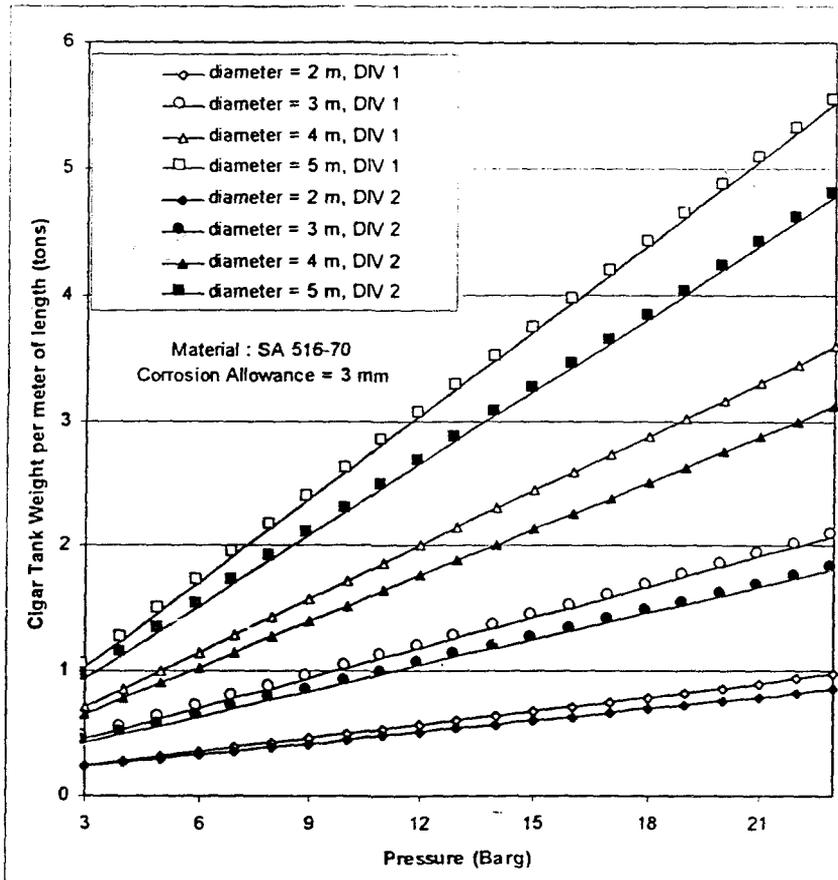


Figure 9: Comparison of the cigar tank weight per meter of cigar tank length as calculated by DIV 1 and DIV 2 for different internal pressures and diameters. Material is SA 516-70, corrosion allowance = 3 mm, full RT and ambient temperature are used in the analysis

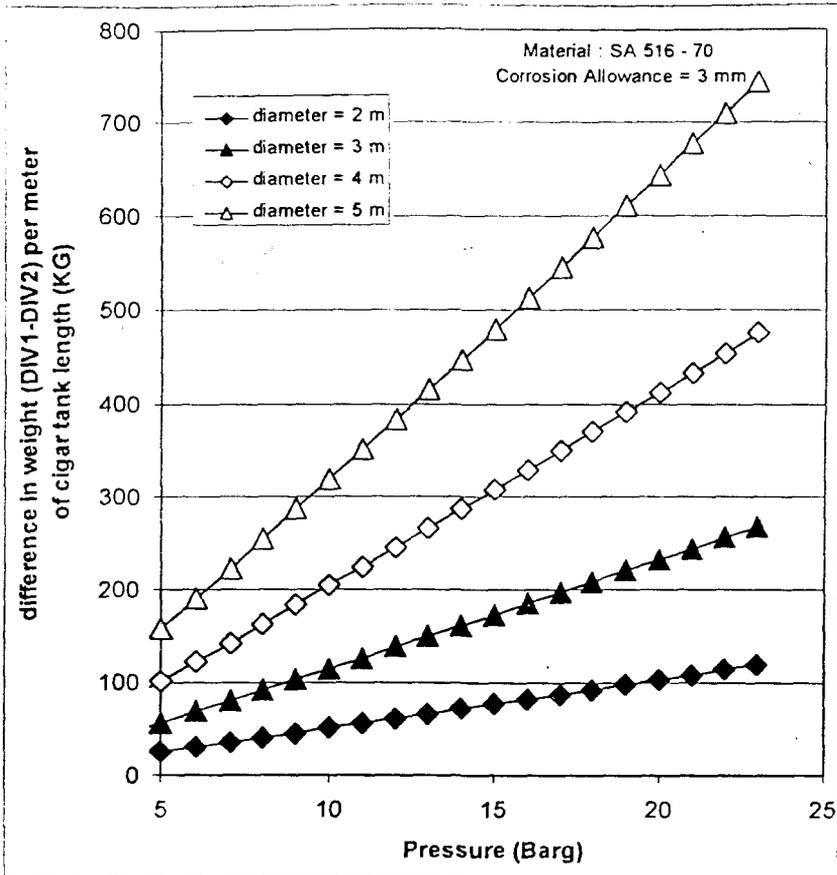


Figure 10: Difference in cigar tank weight per meter of unit length calculated by DIV 1 and DIV 2 for different internal pressures and diameters. Material is SA 516-70, corrosion allowance = 3 mm, full RT and ambient temperature are used in the analysis

4. SIZING OF FLAT BOTTOM CYLINDRICAL TANKS WITH CONE OR DOME ROOFS

The geometric or nominal capacity of the flat bottom cylindrical tank is its total volume without consideration of the dead zone below the Low Liquid Level (LLL) or the vapor space above the High Liquid Level (HLL). The net or working capacity of the tank is the volume between the LLL and the HLL. The tank is sized (diameter and height are selected) to contain the required net or working capacity.

There are many factors that influence the determination of the LLL such as the NPSH requirements of the pumps connected to the tank. Another factor is the allowed minimum distance between the centerline of the low tank nozzles and the bottom of the tank which is dependent on the nozzle size as per API 650. A third factor is the required margin between the LLLL and the LLL (usually 300 mm). Moreover, for floating roof tanks, the minimum allowed leg height for floating roof tanks (0.7-0.8 m) influences the LLL which should be at least 0.2 m above that leg height to prevent the legs from hitting the bottom when the LLL is reached, otherwise, the tank bottom may fail due to fatigue especially if the LLL is attained frequently.

Factors that determine the required vapor space are as follows:

1. Allowance for protrusion of the steel structure to prevent the steel structure from being immersed in the stored product. This allowance should be considered only for truss type roof structures and the protrusion depends on the tank diameter (usually between 0.5 m to 1 m) for diameters higher than 20 m.
2. Allowance for installation and foam application of the foam system for tanks that require foam fire extinguishing systems

3. Allowance for the sloshing distance of the liquid contents that is calculated in the seismic analysis (usually) not more than 300 mm.
4. Allowance for thermal expansion of the stored product.

The HLL is calculated by subtraction of the vapor space height and the margin between the HHLL and HLL (usually 300 mm) from the total tank shell height.

Tank height and diameter are selected to achieve the required net or working capacity defined as the volume between the LLL and HLL. As discussed above, the LLL and vapor space height must be determined to satisfy the factors discussed above. As the tank diameter is increased relative to the tank height, the dead volume of the stored product below the LLL and the volume above the HLL are increased. This will cause the tank nominal capacity to increase (more plates and roof structure members are required), the dead volume loss of the stored product to increase, the tank plot space to increase, and the tank piling requirements to increase. As the tank diameter is decreased relative to the tank height, the tank will be less stable for wind and seismic loading and the tank will most probably require anchorage.

In the present work, a study is conducted to investigate the influence of tank height-to-diameter (H/D) ratio on tank overturning due to wind loads. The wind equation in API 650 is manipulated as shown in Figure 11 to plot the weight stabilizing component $W/3D^2$ and the wind overturning component M/D^3 versus the tank H/D ratio using the parameters indicated in the Figure. As shown in Figure 11, stability (no need for anchorage) is achieved when the dotted line (tank weight stabilizing component) is higher than the solid line (wind overturning component). This is achieved for H/D ratios between 0.4 and 0.7 as shown in Figure 11 with the optimum value at

0.6. At H/D ratio higher than 0.7, the wind overturning component becomes dominant and causes instability (anchorage required). For H/D ratios below 0.4, the uplift due to internal pressure (0.015 barg) increases with increasing the diameter causing the weight stabilizing component to decrease because the uplift due to pressure is subtracted from it. The range of H/D ratios through which stability is achieved as indicated in Figure 11 is true only for the parameters indicated in the Figure.

The study, in the present work, is extended to investigate the effect of tank H/D ratio on seismic shear and moment exerted on the tank foundation. As shown in Figure 12, increasing the tank H/D ratio from 2/3 to 1 increases the seismic moment by 40%-50% depending on the tank nominal capacity. As shown in Figure 13, increasing the tank H/D ratio from 2/3 to 1 increases the seismic shear by 5%-10% depending on the tank nominal capacity.

From the above, we can conclude that the optimum tank height-to-diameter ratio for both wind and seismic loading is 2/3. However, further investigation on the influence on piling revealed that increasing the tank diameter to achieve the ratio of $H/D = 2/3$ has more influence on the required number of piles than decreasing the seismic shear and moment by 50% because of the increased weight of the pile cap and the maximum allowed spacing between piles as per the relevant codes. This suggests that, for tanks on piles, the prime concern is to reduce the diameter and increase the height. Although this may necessitate anchoring the tank, the cost saving in roof structure and piling will be much more than the cost of anchorage.

External floating roof tanks, however, can not work with D/H ratios less than 2.5 because of concerns related to the rolling ladder that is mounted at the top of the floating roof. Working with H/D ratios lower than 2.5 will

cause the rolling ladder angle with the horizontal line to exceed 60 deg which violate safety requirements. Moreover, lower D/H ratios will cause the rolling ladder to be long and heavy relative to the floating roof diameter which will cause the floating roof to be unstable.

Selection of tank heights and diameters should also take into consideration the standard plate dimensions (length X width) from which the tank will be manufactured. The diameter should be selected such that the circumference is equal to an integer multiplied by the standard plate length and the height should be an integer multiplied by the standard plate width. A minimum of half plate is allowed in the length and width direction.

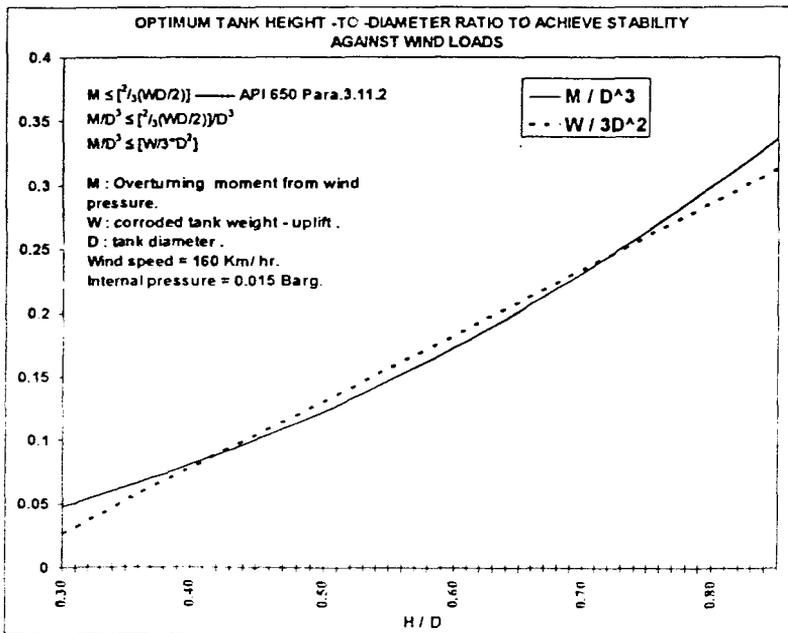


Figure 11 : Overturning due to wind load as a function of tank height-to-diameter ratio

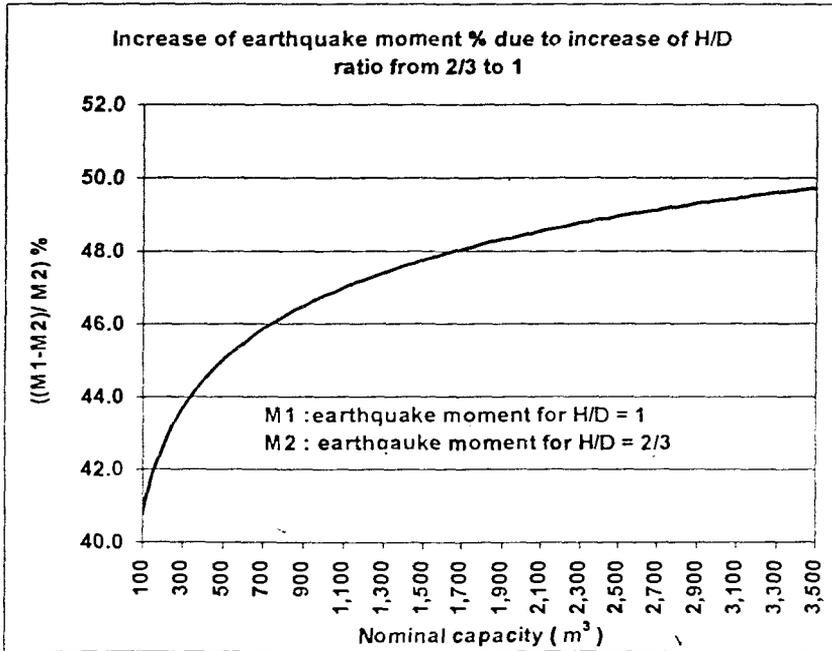
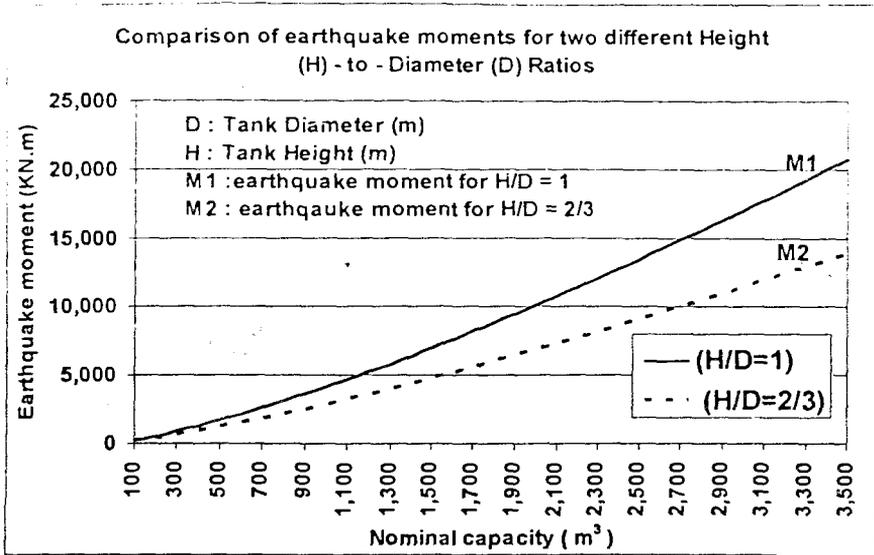


Figure 12 : Influence of increasing tank height-to-diameter ratio on increasing seismic moment

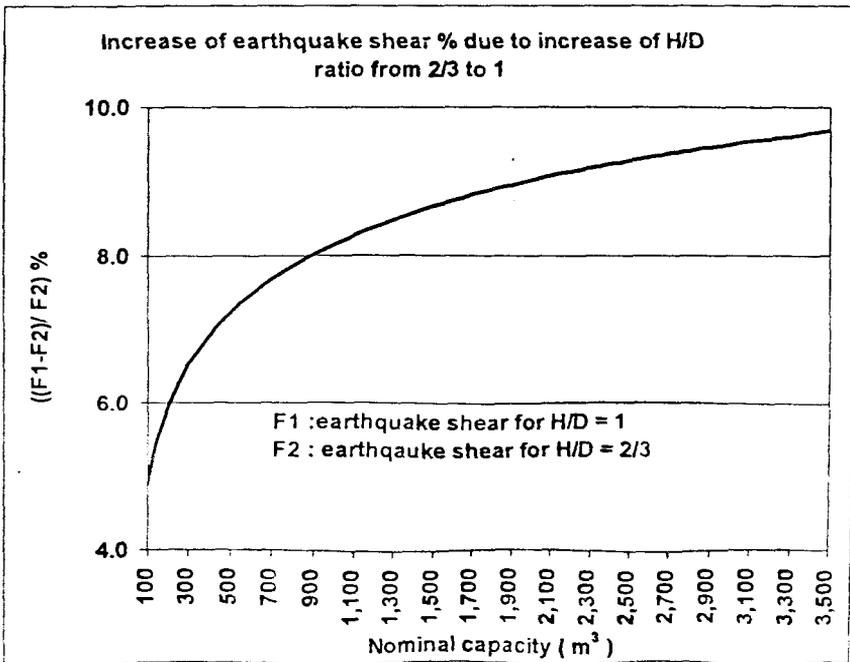
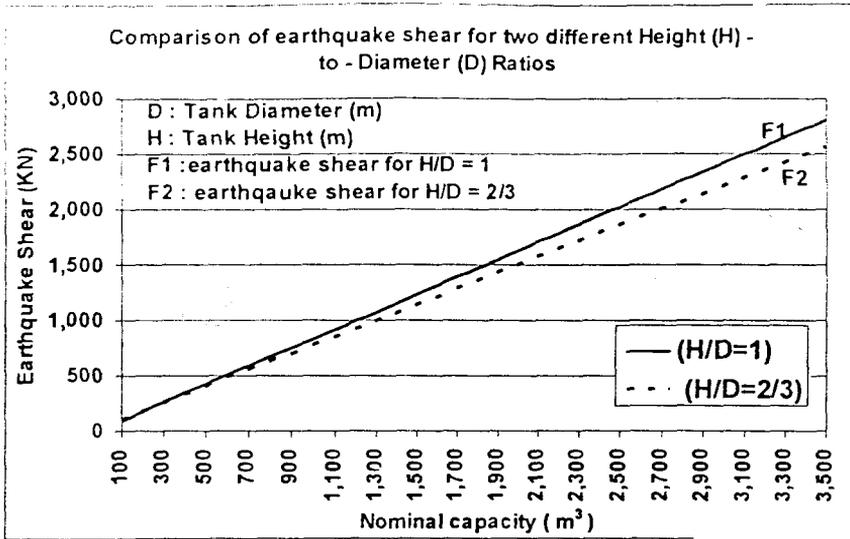


Figure 13 : Influence of increasing tank height-to-diameter ratio on increasing seismic shear

5. CONCLUSION

In the present work, storage tanks are classified based on their design conditions and their design codes are identified. It is shown that products can be stored at high pressure and ambient temperature in spherical or cigar tanks or can be stored at low temperature and slight pressure (close to ambient) in cryogenic tanks.

Types of cryogenic tanks are identified and it is concluded that single wall single containment tanks are suitable in the temperature range above -50 deg and non-toxic materials whereas the Full Containment tank is suitable for the low temperature range below -100 deg. C and/or toxic materials.

Moreover, a study conducted in the present work, proved that there are considerable savings when cigar and spherical tanks are designed according to ASME VIII DIV. 2 instead of ASME VIII DIV. 1 especially for large sized high pressure tanks.

Furthermore, a study conducted in the present work on the effect of tank sizing on foundation loads and instability revealed that the optimum ratio of height to diameter of flat bottom cylindrical tanks, except for external floating roof tanks, is 2/3. Floating roof tanks requires a diameter to height ratio of 2.5 for rolling ladder considerations.

6. REFERENCES

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