Stability and integrity check of a buckled storage tank through finite element analysis

- **Vu Cong Hoa**
- **Nguyen Hưu Tien**

Department of Enginneering Mechanics, Ho Chi Minh city University of Technology, VNU-HCM

(Manuscript Received on 30th Oct., 2015, Manuscript Revised 10th Nov., 2015)

ABSTRACT

This paper studies the stability of a latex storage tank by applied finite element analysis through buckling and stress analyses of the tank.

Storage tanks are containers that hold liquids, compressed gases (gas tank) or mediums that are used for short-term or long-term heat (cool) storage. There are usually many environmental rules applied to the design and operation of storage tanks, often depending on the nature of the fluid contained within.

The purpose of this paper is to check the stability and integrity of a buckled storage tank through Finite Element Analysis. The analysis is conducted for four cases, in which the tank bears loads that are Self- Weight Load, Platform Load, Wind load, and Seismic Load. The authors use standards such as API, ASME, IS for result evaluation, calculation, and design.

The results are compared with the standards in order to check the stability and the strength of the tank. The buckling and stress analysis is used for checking the stability and the integrity of the tank.

Key words: *Tank, stability, buckling, integrity, Platform load, Seismic load API, ASME, Indian Standard.*

1. INTRODUCTION

This project is being carried out on a buckled storage tank, to determine the suitability of this buckled storage tank for future operations, i.e. tank can be continued in service or shall be scrapped out.

During the maintenance operation, while the tank was being emptied, formation of vacuum occurred inside the tank. As a result, tank shell went under external pressure and suffered considerable inward deformation. [15], [16], [21], [23], [24].

Now, to analyze if the tank will sustain in designed service conditions, Finite Element Analysis will be performed with the application of various loading cases [1], [3], [4], [5], [6], [13], [14], [18], [20], and [21].

A finite element analysis is to be performed for buckled tank for various design conditions which are bound to occur during the life cycle of the tank, to check its stability and integrity.

Four cases of load will be applied for the model. The loads to be considered in analysis are as follows: Self-Weight, Platform Loads, Wind load [13], [15] [16], [17], [19], Seismic load [1], [3], [7],

This paper uses the standard calculation, design of ASME [10], IS to calculate and design models. After the design model and calculate the parameters given, the model will be taken to the finite element analysis.

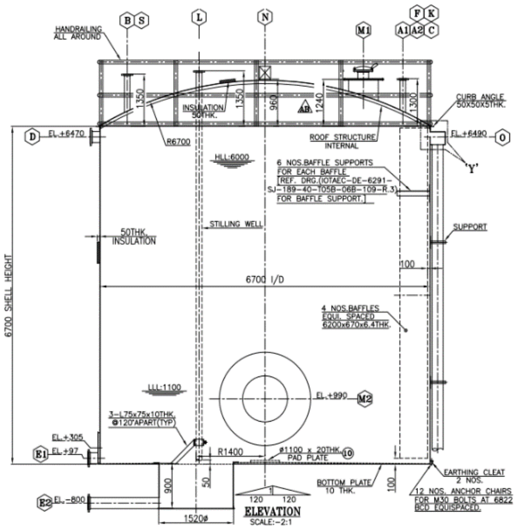
After the analysis is complete, the results will compare with the standards allows to check the stability and stress of the tank. The authors used three main criteria for the calculation and design were: ASME Section VIII, Division 2 Alternative Rules – Design and Fabrication of Pressure Vessels [10], IS-875 Part-3 [8], IS-1893 part-4 [9].

This paper used Ansys Workbench Software ver.15 for simulation. This help us simulation software more visual, more accurate, faster solutions.

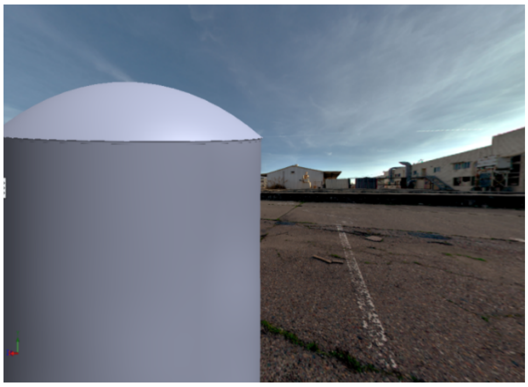
2. MODEL AND MATERIAL PROPERTIES

All Components of the Tanks are designed as per API-650 [4]. The location of the tank is Panipat, Haryana, India. Tank height: 6700 mm, radius: 3421 mm, thickness: 4.666 mm.

The material in this model follows by **IS: 2062 Gr.B** Specification of Structural Steel [25], [8], [9]. The chemical compositions and mechanical properties of the material are given in Tables 1 and 2, respectively.



(a)



(b)

Figure 1. 2D Drawing of Tank (a) and Geometry in SOLIDWORK (b)

Table 1. Chemical composition

Grade	C%	Mn%	S%	P%	Si	C.E%
B_{MAX}	0.22	1.5	0.045	0.045	0.04	0.41

*2T- Less than 25 mm.

*3T- More than 25 mm.

Table 2. Mechanical properties

Grade	UTS (Mpa)	Y.S(Mpa) Min.	EI.% Min	Bend
B	410	230	23	3T

3. METHODOLOGY

The aims of the research are to check the stability and integrity of a buckled storage tank through Finite Element Analysis. The model will be analyzed by a commercial finite element package, namely ANSYS Workbench [11]. After performing the finite element analysis, we will have the output parameters, which is the results we need. Based on these results, we carry out analysis again with the standard for comparison. If this value is greater than the one allowed by the standard, we will be reinforcing the shell and analyze each case the previous load. Assuming that storm and earthquake will not occur at the same time.

Hence there will be four cases of loading.

Case 1: Self-Weight (empty condition) + Platform Load + Wind load.

Case 2: Self-Weight (empty condition) + Platform Load+ Seismic load.

Case 3: Self-Weight (operating condition) + internal pressure including static head + Platform Load + Wind load.

Case 4: Self- Weight (operating condition) + internal pressure including static head + Platform Load + Seismic load.

All the above cases shall be applied and analyzed on the tank.

In order to check the stability and integrity, two types of analysis will be performed, viz. buckling analysis and stress analysis.

Stress Analysis: In order to check the integrity (reliability) of the tank, stress analysis needs to be performed. Stress analysis will be performed for various cases of loads as specified above. Stress distribution will be identified. More attention to be provided on the distribution of stress at deformed portion. Stress concentration will be checked. Stress distribution shall be in allowable limit specified in design codes and standards as per the material properties.

Buckling Analysis: In order to check the stability of the buckled tank, buckling analysis will be performed on the tank. Various cases of loads as specified above will be applied and tank will be analyzed for buckling. The critical load of buckling will be identified. The buckling load shall be below the allowable limit that mentioned in the buckling criteria. Various other parameters like ovality, deformations from the original position will be checked against allowable limits specified in applicable code.

4. THE CALCULATION FORMULA

4.1. Wind Load

These formulas are taken from Indian Standard (IS 875 part-3 wind load (1987)) [8], [9].

$$V_z = V_b * K_1 * K_2 * K_3 \tag{1}$$

$$P = 0.785D^2 * (P_i - C_{pe} * P_d) \tag{2}$$

$$P_z = 0.6 * V_z^2 \tag{3}$$

Where:

- $\mathbf{V_z}$ **=** design wind speed at any height z in m/s; V_b = regional basic wind speed;
- k_1= probability factor (risk coefficient) (see 5.3.1);
- k_2 = terrain, height and structure size factor (see 5.3.2);
- k_3 = topography factor (see 5.3.3);
- P_Z = design wind pressure in N/m^2 at height z (clause 5.4 IS 875 Part 3). [18]

- P = The total resultant load (at roofs of cylindrical) (clause 6.2.2.9 of IS 875 Part 3);
- D = diameter of cylinder;
- P_i = internal pressure;
- C_{pe} = external pressure coefficient;
- P_d = design wind pressure;

Therefore

- V_b = 47 m/s from threads.
- k_1 = 0.9 (clause 5.3.1 of IS 875 Part 3).
- k_2 =1, category 2, class A.
- k_3 = 1.
- Vz = 0.9*1*1*47 = 42.3 m/s.
- Pz = $0.6*V_z^2$ = 0.6*42.32= 1073.6 N/m2.

The total resultant load (at roofs of cylindrical) P:

$$P = 0.785D^2 * (P_i - C_{pe} * P_d) \quad (2)$$

Where:

C_{pe}= - 1 (clause 6.2.2.5 of IS 875 Part 3);

P_d = 1073.6 N/m2 (design wind pressure);

Empty condition: P_i = 0 internal pressure (apply to case 1);

P = 0.785*6.72*(0-(-1)*1073.6) = 37832.22 N.

Operating condition: Pi= 491Pa internal pressure (apply to case 3);

P = 0.785*6.72*(491-(-1)*1073.6)
= 55134.39 N.

4.2. Seismic Load

A_h Design horizontal seismic coefficient, shall be obtained by the following expression (clause 8.3 of IS 1893 part 4) [9].

$$A_h = \frac{Z}{2} * \frac{I}{R} * \frac{S_a}{g} \quad (4)$$

R = 5, response reduction factor to take into account the margins of safety, redundancy and ductility of the structure given in Table 3 IS 1893 part 4 [9].

Where:

Z = 0.24, Zone factor (Seismic Zone IV) given in ANNEX A of IS 1893 Part 4;

I =1.75, Importance factor (Table 2 IS 1893 part 4) [9]

S_a/g = spectral acceleration coefficient for rock and soil sites given in Annex B of IS 1893 Part 4[9]

This is in accordance with Fig. 1 of IS 1893 (Part 1) [2].

Accordance with clause 7.6.2 of IS 1893 (Part 1) [2], the approximate fundamental natural period of vibration (T), in seconds, of all other buildings, including moment-resisting frame buildings with brick infill panels, may be estimated by the empirical expression:

$$T = \frac{0.09h}{\sqrt{d}} \quad (5)$$

Where:

- h = 7.66(m): height of building
- d = 6.71(m), base dimension of the building at the plinth level, in m, along the considered direction of the lateral force.

$$T = \frac{0.09h}{\sqrt{d}} = \frac{0.09 * 7.66}{\sqrt{6.71}} = 0.266 \text{ (s)}$$

The building (tank) is located on Type II (medium soil). From Fig.2 of IS 1893 Part 1 [2], for T=0.266 (s), S_a/g = 2.5;

$$A_h = \frac{Z}{2} * \frac{I}{R} * \frac{S_a}{g} = \frac{0.24}{2} * \frac{1.75}{5} * 2.5 = 0.105$$

Vertical seismic coefficient = 0.105*2/3=0.07 (clause 8.4 IS 1893 part 4) [9].

5. ANALYSIS IN ANSYS WORKBENCH

This paper analyses four cases by using the same model.

Data analysis:

Table 3. Global Coordinate System

Coordinate System	Global Coordinate System
X Component	Horizontal acceleration coefficient*9.81 = 0.981 m/s² (ramped)
Y Component	Vertical acceleration coefficient*9.81 = 0.6867 m/s² (ramped)
Z Component	Horizontal acceleration coefficient*9.81 = 0.981 m/s² (ramped)

Case 1:

- Self- Weight (empty condition): Software automatic added vessel weight corresponding to material and geometry.
- Platform load: 29430 N
- Win load: Tan-tan 1073.6 Pa; Head 37832.22 N

Applied load:

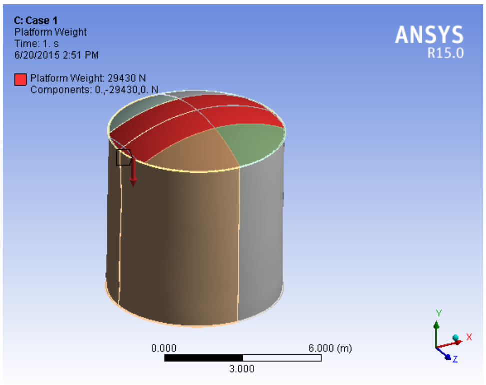


Figure 2. Applied platform weight

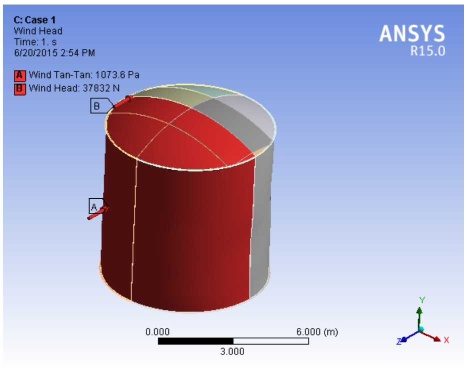


Figure 3. Applied wind load

Case 2:

- Self- Weight (empty condition): Software automatic added vessel weight corresponding to material and geometry.
- Platform load: 29430 N
- Seismic load: Horizontal acceleration coefficient 0.15; Vertical acceleration coefficient 0.07.
- Applied seismic load: Acceleration: 1.548 m/s^2

Case 3:

- Self- Weight (operating condition):

Self-Weight (empty condition) +944874.8Kg (Weight of liquid).

- Weight fluid operating condition: 96346 N.
- Platform Load: 29430 N
- Internal pressure including static head: 491 Pa.
- Wind load: Tan-tan 1073.6 Pa; Head 55134.39 N.

Case 4:

- Self- Weight (operating condition):
- Self-Weight (empty condition) +944874.8Kg (Weight of liquid).
- Platform Weight 29430 N
- Weight fluid operating condition: 96346 N

- Applied internal pressure including static head: 491 Pa
- Applied seismic load: 1.548 m/s^2

6. RESULT

6.1. Stress Analysis

The theory states that a particular combination of principal stresses causes failure if the maximum equivalent stress in a structure equals or exceeds a specific stress limit.

As stress ratio by FEA is greater than 1 hence s strength of case 1, case 2, case 3 is **fail; case 4 is pass** [11].

6.2. Buckling Analysis

The load multiplier is interpreted as the buckling factor of safety for the applied load.

$$F_{buckling} = F_{Applied} * \lambda \quad (6)$$

Where:

$F_{buckling}$: Buckling load.

$F_{Applied}$: Applied load.

λ: Load multiplier.

Table 4. Stress analysis results

Stress Ratio		Case 1	Case 2	Case 3	Case 4
Shear Stress Ratio (Pa)	Max	2.95E+08	1.92E+08	1.65 E+08	0.409
	Min	0	1.30E-09	190.96	0
Tensile Stress Ratio	Max	1.4371	1.0323	0.75967	0.24974
	Min	0	0	0	0
Equivalent Stress ratio	Max	2.1169	1.4111	1.1601	0.36757
	Min	0	9.35E-18	1.33 E-06	2.13E-06
Maximum shear Stress		2.95E+08	1.92E+08	1.65 E+08	5.12E+07

Each case can take many shape of deformation buckling.

Mode 1 more likely mode 2, mode 2 more likely mode 3.

Thus, $\lambda_{mode1} < \lambda_{mode2} < \lambda_{mode3}$.

Table 5. Buckling analysis results

Case	Load Multiplier		
	Mode 1	Mode 2	Mode 3
1	2.6961	2.766	4.5824
2	24.624	30.303	37.402
3	4.3213	4.438	7.6446
4	173.74	191.55	229.67
Case	**Max Total Deformation (m)**		
1	1.0995	1.0979	1.1059
2	1.0165	1.0001	1.022
3	1.0997	1.0976	1.1057
4	1.1373	1.1316	1.0327

Evaluation Criteria:

Accordance with clause 5.4.1 Part 5 ASME Sec.VIII Div.2, edition 2010 [10], [20], [21], [22], [24] for buckling analysis performed using an elastic stress analysis method [11], [17], [20] without geometric nonlinearities in solution to determine pre-stress in component, a minimum design factor of:

$$\phi_B = \frac{2}{\beta_{cr}} \quad (7)$$

β_{cr} : Capacity reduction factors; for unstiffened or ring stiffened cylinders and cones under external pressure $\frac{D_0}{t} = \frac{6.7}{0.005} = 1340$

$$\beta_{cr} = 0.207$$

$$\phi_B = \frac{2}{\beta_{cr}} = \frac{2}{0.207} = 9.66$$

For empty condition, the buckling load factor is calculated by FE analysis.

As buckling load factor by FEA is greater than minimum design load factor hence buckling strength is **PASS.**

As buckling load factor by FEA is lower than minimum design load factor hence buckling strength is **FAIL.**

Case 1: λ_{mode1} (of case 1) =2.6961 <9.66 :fail.

Case 2: λ_{mode1} (of case 2) = 24.624>9.66: pass.

Case 3: λ_{mode1} (of case 3) =4.3213 <9.66: fail.

Case 4: λ_{mode1} (of case 4) = 173.74>9.66: pass.

7. CONCLUSION

The numerical results obtained from the FEA result shows that in the analyzed condition, the stress ratio calculated by FEA is greater than 1. Hence tank is no safe in term of strength limit.

The FEA result also shows that for analyzed condition, the buckling load factor calculated by Eigenvalue liner buckling analysis is lower than the minimum design factor as required by per Part-5 of ASME Sec. VIII Div.2, Edition 2010, addenda 2011a [10]. Hence tank is no safe against buckling.

Kiểm tra tính ổn định và toàn vẹn của bể chứa bằng phân tích phần tử hữu hạn

- **Vũ Công Hòa**
- **Nguyễn Hữu Tiến**

Bộ môn Cơ kỹ thuật, Trường Đại học Bách khoa, ĐHQG-HCM

TÓM TẮT

Bài báo này nghiên cứu về sự ổn định của bể chứa mủ bằng phương pháp phần tử hữu hạn ứng dụng thông qua các phân tích buckling và ứng suất của bể chứa..

Bể chứa là bồn giữ chất lỏng, khí nén (bình ga) hoặc phương tiện được sử dụng để lưu trữ chất nóng (lạnh) ngắn hạn hoặc dài hạn. Thông thường có nhiều quy định về môi trường áp dụng cho việc thiết kế và các hoạt động của bể chứa, phụ thuộc vào bản chất của chất lỏng chứa bên trong.

Mục đích của bài báo này là để kiểm tra sự ổn định và tính toàn vẹn của một bể chứa vênh qua phân tích phần tử hữu hạn. Các phân tích được tiến hành cho bốn trường hợp, trong đó bể chứa chịu các tải trọng bản *thân, tải nền, tải trọng gió, và tải địa chấn. Các tiêu chuẩn như API, ASME, IS được sử dụng cho kết quả đánh giá, tính toán và thiết kế. Các kết quả được so sánh với các tiêu chuẩn để kiểm tra sự ổn định và độ bền của các bồn chứa. Các phân tích buckling và ứng suất được sử dụng để kiểm tra sự ổn định và tính toàn vẹn của các bồn chứa.*

Từ khóa: *Bồn, ổn định, oằn, tính toàn vẹn, tải nền, tải động đất, tiêu chuẩn API, tiêu chuẩn ASME, tiêu chuẩn Ấn Độ.*

REFERENCES

[1]. Fan Jiashen. *Dynamic stability of liquid storage cylindrical tanks subjected to horizontal seismic force excitation,* Applied Mathematical Modelling, Volume 18, Issue 7, p.373–383, July (1994).

[2]. Criteria for earthquake resistant design of structures, Indian Standard, part 1 general provisions and buildings, IS I1893, (1975).

[3]. K.Bandyopadhyay, A.Cornell, C.Costantino, R. Kennedy, C. Miller and A. Veletsos. *Seismic design and evaluation guidelines for the department of energy high-level waste storage tanks and appurtenances*, Engineering research and Applications Division Department of Advanced technology Brookhaven National Laboratory, Associated universities, Inc. Upton, New York 11973-5000.

[4]. Welded Tanks for Oil Storage, API STANDARD 650, American Petroleum Institute, API Publishing Services, 1220 L Street, NW, Washington, DC 20005, Twelfth edition, March, Copyright American Petroleum Institute.

[5]. Design and Construction of Large, Welded, Low – Pressure Storage Tanks, API STANDARD 620, American Petroleum Institute, API Publishing Services, 1220 L Street, NW, Washington, DC 20005, Ninth Edition, February (1996).

[6]. Design and Construction of Large, Welded, Low – Pressure Storage Tanks, API STANDARD 653, American Petroleum Institute, API Publishing Services, 1220 L Street, NW, Washington, DC 20005, Second EDITION, December (1995).

[7]. Seismic Design- Seismic design requirements for building structures, ASCE

[8]. Code of practice for design loads (other than earthquake) for buildings and structures, Indian Standard, Bureau of Indian standards manak having, 9 bahadur shah Zafar Marg new Delhi 110002, Second revision, Sixth reprint, November (1998).

[9]. Criteria for earthquake resistant design of structures, part 4, Industrial structures including stack-like structures, Indian Standard, Bureau of Indian standards manak bhavan, 9 bahadur shah zafar Marg new Delhi 110002, in 1893 (part 4) –(2005).

[10]. Design and Fabrication of Pressure Vessels, ASME Section VIII, Division 2 Alternative Rules.

[11]. ANSYS® Academic Research, Release 16.0, Help System, Stress Tool Guide, ANSYS, Inc.

[12]. G. Portela, L.A. Godoy. *Wind pressures and buckling of cylindrical steel with a dome roof*, Journal of Constructional Steel Research, Vols. 61, 808–824 (2005).

[13]. Godoy LA, Flores FG. *Imperfection sensitivity to elastic buckling of wind loaded open cylindrical tanks*, Structural Engineering and Mechanics, Vols 13(5), 533–542 (2002).

[14]. Godoy LA, Portela G, Sosa E, Suárez LE, Virella JC, Zapata RE. *Damage due to buckling in aboveground storage tanks*, In: P Castro, Editor. Proc. int. conf. on the behavior of structures with damage, Rio de Janeiro (Brazil): Universidade Federal Fluminense, (2002).

[15]. Greiner R. Cylindrical shells: Wind loading, in: Brown CJ, Nilssen L, Editors. Silos. London, EFN Spon, 378–99 (1998).

[16]. Greiner R, Derler P. *Effect of imperfections on wind loaded cylindrical shells*. Technical report, Institute for Steel and Shell Structures, Technical University of Graz, Austria, (1993).

[17]. Pircher M, Guggenberger W, Greiner R, Bridge R. *Stresses in elastic cylindrical shells under wind load*, University of Western Sydney, Nepean, 663–669 (1998).

[18]. Portela G. *Wind pressures and buckling of metal cantilever tank.* Ph.D. dissertation, University of Puerto Rico at Mayagüez, Puerto Rico, (2004).

[19]. Purdy DM, Maher PE, Frederick D. *Model studies of wind loads on flat-top cylinders*, Journal of the Structural Division, 93:379–95, ASCE 1967.

[20]. William L. Ko. *Thermo cryogenic Buckling and Stress Analyses of a Partially Filled Cryogenic Tank Subjected to Cylindrical Strip Heating*, NASA Technical Memorandum 4579, NASA Dryden Flight Research Center P.O. Box 273 Edwards, California 93523-0273.

[21]. Seung-Eock Kim, Chang-Sung Kim. *Buckling strength of the cylindrical shell and tank subjected to axially compressive loads*, Thin-Walled Structures, Vols. 40, 329–353 (2002)

[22]. Timoshenko SP, Gere JM. Theory of elastic stability, McGraw-Hill, New York (1983).

[23]. Timoshenko SP, Woinowsky-Krieger S. Theory of plate and shell, McGraw-Hill, New York, (1959).

[24]. Kim YS, Kardomateas GA. *Buckling of thick orthotropic cylindrical shells under torsion*, J Appl Mech, Vols. 66, 41–50 (1999).

[25]. Hot rolled medium and high tensile structural steel, Indian Standard, Specification ICS 77.140.01, Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg New Delhi 11002, September (2011).

[26]. ANSYS® Academic Research, Release 16.0, Help System, Linear Buckling Guide, ANSYS Inc.