University of Thi_Qar Journal for Engineering Sciences ISSN 2075-9746
http://www.doi.org/10.31663/tqujes.10.1.217(2019)
Vol10 No.1 (May 2019) Available at http://jeng.utq.edu.iq
engjrnal@jeng.utq.edu.iq

Static and Time History Earthquake Analysis of LPG Spherical Steel Tanks in Iraq

Abbas Oda Dawood †

† Department of Civil Engineering/Engineering College//University of Misan/Amarah, Iraq

Abstract

Spherical storage tanks are widely used in Iraq for store hazardous liquid petroleum gas LPG which, thus it must be adequately designed for seismic actions. This paper present static and time history analysis of LPG tanks in Iraq using UBC97 code. The time history analysis accomplished by using three artificial earthquakes generated using SIMQKE_GR program in additional to El Centro earthquake records scaled according to PGA. The investigations were performed on the tank in Maysan province which was selected to be representative the other tanks in Iraq due to recently seismic activity in Maysan. The study comprised finite element modeling using STAAD Pro program for the estimation of the dynamic and static responses of the tank structure. The study is performed for both conditions of empty tank and at operating with 100% fill of LPG. The description of the properties and allowable stresses LPG tank used in Iraq is presented. Its concluded that time history analysis govern the tank behavior. The dynamic magnification factor of 1.4 for displacements and stresses was obtained which reflect the importance of dynamic analysis. The stresses of columns and sphere are within allowable limits except at sphere/column connection which slightly exceed the allowable limit, while the stresses in diagonal bracings are exceed the yielding limit thus double angle section is inadequate.

Keywords: LPG storage tank, spherical tank, static, time history, earthquake

1. Introduction

Spherical pressure vessels are widely used in the field of energy engineering, chemical and metallurgical industry as key large storage tanks for their large volume, small weight and strong load-bearing capacity [1]. Products which are gases at normal atmospheric temperatures and pressures, such as butadiene, butane, propylene and many other chemical and petrochemical products are stored most economically in spherical pressure tanks [2]. Spherical steel tanks usually used in Iraq for oil field especially for LPG store. Liquefied petroleum gas or liquid petroleum gas (LPG or LP gas), also referred to as simply propane or butane, are flammable mixtures of hydrocarbon gases used as fuel in heating appliances, cooking equipment, and vehicles. The Ministry of oil in Iraq have several spherical LPG steel tanks distributed mainly in large population provinces like Baghdad and Basra. In previous years the ministry put plans to build new spherical tank through all the country for storage oil products, in 2012 the ministry started to construct 18 new spherical LPG steel tanks of capacity of 3000 m3, distributed in Baghdad, Basra, Maysan, Muthana, Anbar, Najaf , Karbala, and Babylon provinces. The distribution of tanks number per province depends on populations density for example four tanks located in Baghdad while one tank in Maysan. Elevated spherical storage tanks are widely used in major industrial facilities worldwide for containing various types of liquids or gases, including hazardous content [3]. Thus, there should be attention to the seismic safety of these storage tanks and other industrial facilities (e.g. refineries, chemical plants, and other oil industries) located in seismic regions in Iraq, particularly on those critical structures that if failed during an earthquake can potentially endanger a large population, and may cause substantial financial losses. and retrofit for the industry and hazardous materials [4].

2. Description of spherical tanks in Iraq

In the present study the spherical tank in Maysan province is selected as a representative of other similar existing spheres in Iraqi provinces due to geometrically similarity and Maysan province consider the higher seismic hazard in comparison with above mentioned province in which an earthquake of magnitude of 6 degrees was recorded in 2014. In the present study the spherical tank in Maysan province is referred to as "reference tank". The reference tank is still in construction phase as shown in **Fig. (1)**. The reference sphere has an external diameter of 18 m with a volume capacity of 3000 m^3, and is supported on eleven steel columns made of circular 813 mm x 12.7 mm hollow sections, with conventional cross bracing double equal legs 2L200*20. The columns' height from base to sphere centre is 7.5 m. The sphere contains liquid hazardous LPG with a mass density of 580 kg/m^3, and is considered at 100% capacity, giving a total mass of 0.58*1*3000=1740 tons. The self-mass of the empty sphere, supporting columns and tie-rods is 535 tons. This gives a total seismic mass of 535 and 2275 tons for empty and operating conditions, respectively. The dimensions and geometry of LPG tank in Maysan (reference tank) is summarized in **Table (1).** The gas properties and pressures in the operating conditions are summarized in **Table (2).** Lateral seismic forces are primarily resisted by the supporting steel columns and by the existing cross braces between them. The Spherical Tank is composed by eleven column with the following parameters: Diameter single· column 813 mm, Thickness 12.7mm, the diameter on· which they are distributed is of 17.50 m; the height of the column is 7.50 m. The spherical tank has an external diameter of 18.00 m. The middle diameter of the sphere is 18 m, its thickness varies from 52 mm to 54 mm taking into account the corroded thickness. The sphere is supported by eleven cylindrical columns equidistant of 4.93 m. Each column has two parts: the higher part on which the sphere is welded and the lower part fixed on the foundation. All the columns of the steel structure are anchored to the foundations by means of base plates and anchor bolts.

Table (1): Dimensions and Geometry of reference LPG steel tank

No.	Item	Quantity	No.	Item	Quantity
1	Nominal Inside diameter Of Spherical Shell	17.9 m	5	height support	11 m
2	external diameter of tank	18 m	6	Geometrical Capacity	3003 m^3
3	Equatorial Height	11.5 m	7	Volume Of Product In Operating	3003 m^3
4	Number Of Support Columns	11			

Table (2): Operating conditions Data

No.	Item	Quantity	No.	Item	Quantity
1	Type of Substance In Operating:		6	Internal Design Pressure	1.88 MPa
2	Substance Density	580 kg/m^3	7	External Design Pressure	0.1020 MPa
3	Filling Rate.	100%	8	weight empty	5350 kN
4	Height of Product In Operating	17.9m	9	weight operating	22750 kN
5	Design Temperature	70 °C			

Fig.(1): Spherical LPG steel tank in Maysan during construction

3. Material properties and design criteria

The grade of steel of shell plates is SA 537 class 1 according to ASTM standards [5], this grade is commonly used in pressure vessel applications where low temperature resistance to notch sensitivity is needed and added strength levels are needed. For column, the steel grade is S275 according to European standards (a structural grade steel with a minimum yield strength of 275 N/mm²) which is equivalent to A570Gr40 US steel grade (36 ksi) [6]. Shell Plates Materials and Design Criteria according to ASME and AISC provisions [3,7] are summarized in **Table (3)**, in which working stress method is used for the design of thank.

4. Types of earthquakes analysis

There are many types of analysis techniques to take seismic effects into consideration when analyzing and designing structures. Static analysis or equivalent static procedure to compute equivalent lateral force of the earthquake is easier and require less computation as compared to the dynamic analyses. However, dynamic analyses in earthquake analyses are divided in parts: time history analysis and response spectrum analysis. Time histories usually express the ground motion as a record of acceleration with respect to time. Strong earthquake time histories are generated from one of three fundamental types of accelerograms [8]

1. Real Accelerograms: Selecting a suite of past recorded earthquake ground motions (real accelerograms)
2. Artificial Accelerograms: shall be generated so as to match the elastic response spectra (compatible with the design response spectrum)
3. Synthetic Accelerograms: Synthetically developing or modifying one or more ground motions (synthetic records obtained from seismological models)

In present study the first and second procedures are used to match or develop the acceleration time history for Maysan area

5. Fundamental period of the spherical tank

The storage tank analysis is accomplished for both empty and operating conditions. The tank full of LPG gas is the worst-case scenario. the fundamental period of the tank structure is determined for both empty and maximum filling. The evaluation of the natural frequencies and modal characteristics of all separate modes required in calculating the response of the structures to any loading. The free vibration analysis was accomplished using Staad Pro software, in which the output of free vibration analysis are frequencies (or time periods) and mode shapes for each mode of vibration. The fundamental period of LPG spherical tank is 0.142 sec and 0.371 sec for empty and operating conditions respectively, obtained from Staad Pro finite element model. The mode shapes for the first four modes are shown in **Fig. (2)** , in which the first and second modes have the same time period.

Table (3): Shell Plates and Columns Materials and Design Criteria [3,7]

No.	**Item**	**Material**	**Standards**	**Allowable stress, MPa**
1	Allowable Stress At Design Temperature for sphere shell	SA 537-1	ASME, [3]	201
2	Allowable Stress for columns	S275	AISC , [7]	180

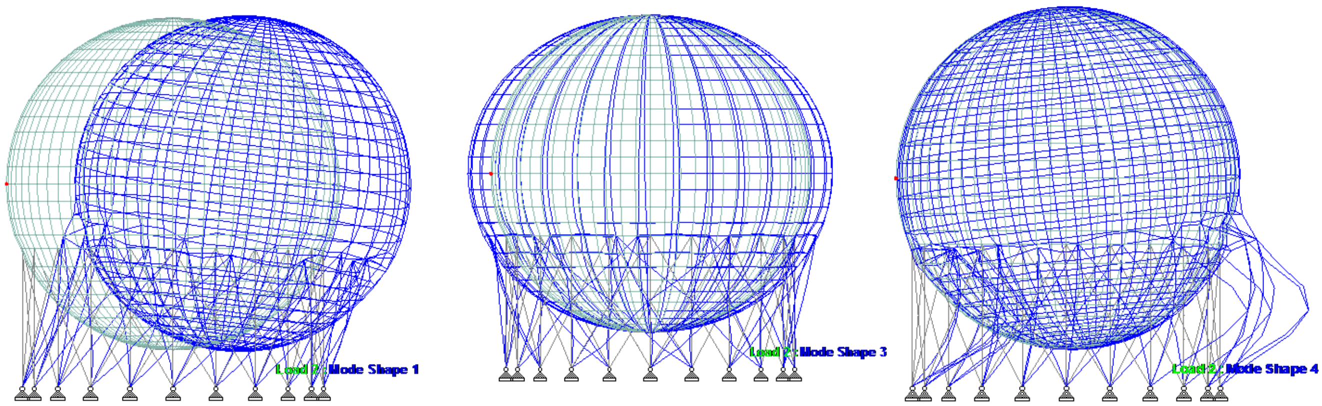


Fig.(2): Mode Shapes of LPG spherical Tank for First Four Modes

6. Seismological of Maysan province

Recent seismic activities especially in Maysan area which reached to magnitude of 6 degrees in 2014 emphasis on the seismic hazard consideration in these areas. Maysan province is located to the west of the Zagros belt, which is capable of producing strong earthquakes in which Maysan province is affected by all seismic sources along Iran-Iraq borders. Namely, Maysan province is located in a special seismotectonic conditions. Thus, Proper determination of the peak horizontal ground acceleration (PGA) for designing the earthquake-resistant structures in Maysan province which near active seismic belts at Iraq-Iran borders bears paramount importance. There is no available data for peak ground acceleration for Maysan Province, but due to Maysan province lies on the international Iraq-Iran borders, therefore the peak ground acceleration for Maysan province could be obtained from Iran peak ground acceleration maps that commonly in additional to Iranian borders it cover a strip inside Iraqi border included all Maysan province area, like that shown in **Fig.(3)**, [9]. The peak ground acceleration PGA for Amarah City from **Fig.(3)** is 2.4-3.0 m/s^2 or as a percent of gravity ground acceleration, (g = 9.81 m/s^2) is (0.244g-0.39g). In the present study the scaling of time histories is accomplished via PGA.

7. Design response spectrum of Maysan area

According to UBC 1997 [10] section 1653, Baghdad area is considered as Seismic Zone 3 while Basra as Zone 2. Due to Maysan province has seismic hazards in last years more than Baghdad, thus according to UBC classifications Maysan province is considered as Seismic Zone 3.According to UBC 1997 Table (16-J), the soil profile is defined by soil properties included shear wave velocity or standard penetration test or un-drained shear strength for top 100 ft (or 30.48 m) of soil profile. According to different soil investigations of site and region around the the standard penetration test results (SPT) for the top 100 ft (30.48m) of soil profile within the range of 15-50 so it is classified as type SD , namely stiff soil profile.Based on UBC 1997 procedure, the seismic coefficients C_a and C_v are determined firstly as in **Table (4)**. Then the design response spectrum for Maysan area is constructed based on UBC1997 graph shown in **Fig.(4)**.

8. Determination of static earthquake loading

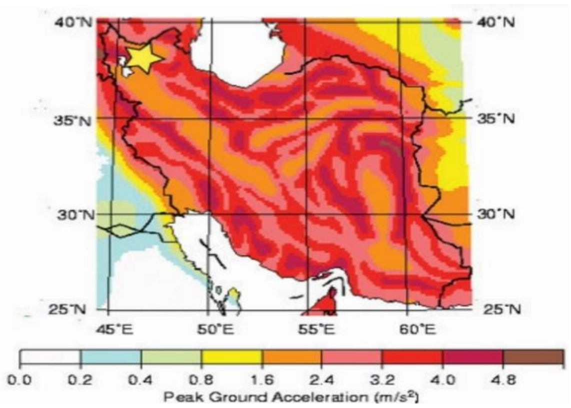
The determination of static seismic loadings on spherical LPG steel tanks according to UBC, can be accomplished by two methods depending on fundamental period of the tank, namely:

1- Rigid tank, if time period less than 0.06 second.
2- Flexible tank, if time period more than or equal to 0.06 second.

Load combinations for allowable stress analysis based on UBC code **[10]** in which worst case is (D+L+E/1.4) which is used in present study, where D, L and E is dead, live and earthquake loads respectively.

For rigid structures the base shear is determined according to UBC code section 1634.3 as

$$V = 0.7\, C_a\, I\, W \qquad For \quad T < 0.06\, sec \tag{1}$$



The flexible spherical tank is considered as non-building structure according to UBC code. The design base shear for non-building structures is calculated from the same expressions as for buildings (UBC, section 1630.2.1). In addition, non-building structures such as the vessel must also satisfy the requirements of UBC, section 1634.5, as following

$$V = \frac{C_v\, I}{R\, T}\, W \qquad \geq\; 0.56\, C_a\, I\, W \tag{2}$$

Where C_a, I, W, C_v, R and T are defined in **Table (4).** In the present study the fundamental time period as calculated in section 5 is 0.142. Thus the tank is considered flexible because the period is greater than 0.06 seconds. and the design parameters are listed in **Table (4)** .

9. Determination of time history of earthquake loading

El Centro strong-motions is selected as the real time-history records in which it scaled to fit with Maysan area characteristics. The scaling of acceleration time histories is based on PGA as derived in section 6, which is equals 0.244g. The maximum recorded of ground acceleration for El Centro is about 0.33g. Thus the scale factor is determined as 0.244g (Maysan Province/0.33 El centro =0.74). Three artificial time-history records for this study were generated by the program SIMQKE_GR [11] for peak ground acceleration of 0.244g and soil class S_D with a 5% viscous damping ratio (as commonly assumed for structural analysis [11]). The earthquake duration was set on 20 s. The ground motion records used in this study include three Spectrum-Compatible time histories EQ1, EQ2 and EQ3 generated using SIMQKE_GR program [11]. The spectrum adopted was that generated according to UBC code in **Fig (4).** After generating an initial three accelerograms, the corresponding spectra were computed and the degree to which they matched the target spectrum was assessed by eye until an acceptable fit was achieved [11]. The acceleration- time histories of ground motion records are shown in **Fig.(5)**.

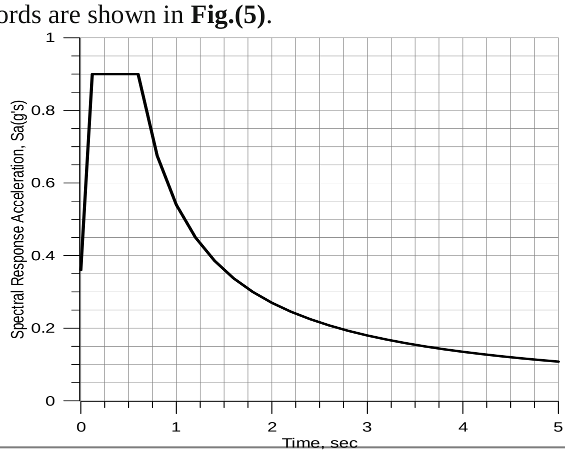


Fig.(3): Peak ground acceleration map of Iran and eastern of Iraq

Fig. (4): Design Response Spectrum of Tank Site according to UBC1997

10. Finite element analysis

A three-dimensional (3-D) finite element model representing the LPG spherical tank was constructed using STAAD Pro software [12]. In this model, the supporting columns and bracings were modeled using beam element, while sphere was meshed with shell elements. The model contains 11022 shell elements and 198 beam elements as shown in **Fig.(6)**. In determining the system mass matrix, lumped sum mass matrix is employed. The LPG is represented by lumped masses assigned to nodal points of the sphere. The sphere contains LPG filled to 100% capacity at operation condition. The steel pipe columns are fixed to the foundation via circular steel base plate of thickness 25 mm in addition to slide base plate of thickness 20 mm, thus the support of columns is considered as hinged support. In the present study the only externally applied load on tank is the weight of the content (tank full of LPG gas) and shell weight. Externally applied force on each of the leg is the sum of the weight of content (tank full of LPG gas) and shell divided by the number of legs. While there is base acceleration applied to the support due to seismic effect. According to the facility engineer, the spherical tank would be given to internal pressure and lower capacity level than that above mentioned should not be considered [4]. Hence, in the analysis, it was conservatively assumed that the whole contained material would act as an impulsive rigid mass which contributes to the dynamic response of the sphere structure.

Table (4): Design Base Shear Parameters According to UBC97 Code [10]

No.	Item	Value	Remarks
1	Seismic Zone	3	
2	Soil profile type	SD	Section 6
3	Seismic intensity coefficient, Z	0.3	Table 16-1 /UBC
4	Seismic coefficient , Ca	0.36	Table 16-O/UBC
5	Seismic coefficient , Cv	0.54	Table 16-R/UBC
6	Occupancy important fact, I	1.25	Table 16-K/UBC)
7	R-factor	2.2	Table 16-P/UBC
8	Time period for Empty Condition	0.142	Section 5
9	Time period for Operating Condition	0.371	Section 5
10	W, for empty case	5350 kN	
11	W, for operating (100% filing)	22750 kN	
12	Base Shear for Empty Condition	11,600 KN	Eq.(2)
13	Base Shear for Operating Condition	18,814 KN	Eq.(2)

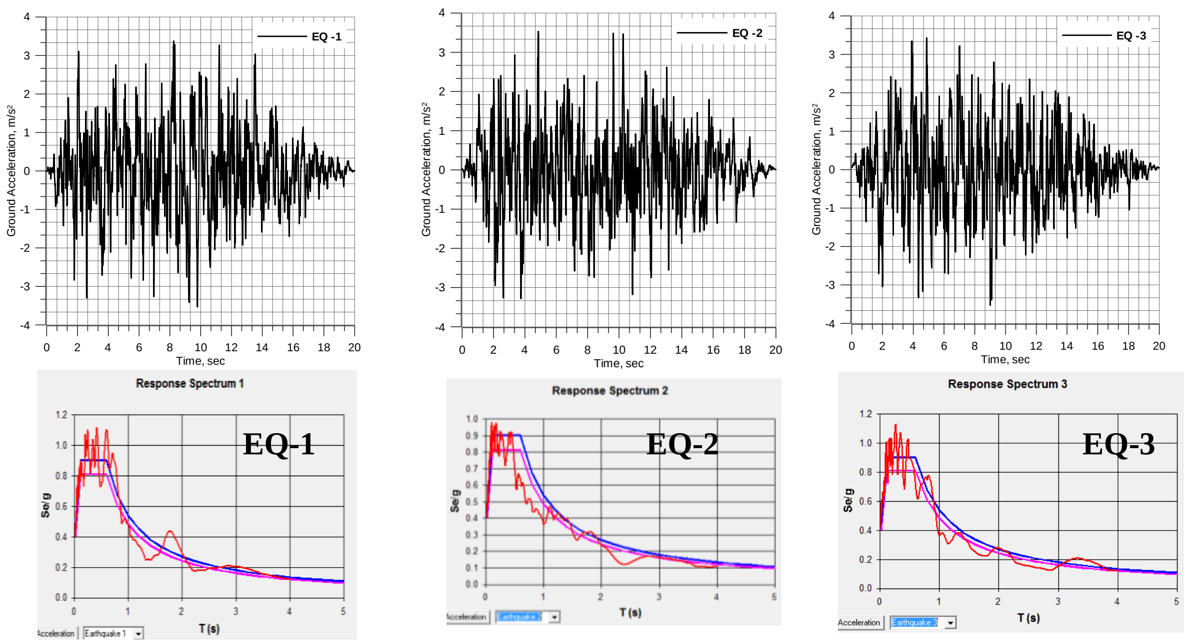


Fig.(5): Acceleration-Time Histories of Artificial Earthquakes Its Spectra

The finite element analysis considered the following load cases:

1- Empty Condition: which includes self-weight of structure (columns and sphere) only.

2- Operating Condition: which include in additional to self weight of structure, the weight of LPG gas for 100% filling conditions.

3-Earthquake loads: which combined with above two conditions separately statically and dynamically.

In the finite element model, the equivalent static seismic loads are applied as joint loads at the equator level only, while in dynamic analysis the earthquake loadings are applied as ground motion using Staad Pro commands.

The stress analysis was performed using a finite element model of the spherical tank for different load cases. The tank stresses were determined for columns, bracing and sphere, in addition stresses of the connection column-shell were determined in load direction and transverse to the load direction. The maximum stresses for different load combinations are investigated for columns and diagonal bracings as in **Table (5)** and for tank sphere as in **Table (6),** in which the worst scenario of stresses is due to artificial time history EQ3 at operating conditions. In comparison the stresses in worst conditions with that of the allowable limits in **Table (3),** it was observed that the column stresses are within allowable limit but the stresses in bracing are exceed the allowable limit especially the compressive stresses which highlight the buckling problems in bracing during earthquake loadings. The sphere shell stresses are less than allowable limits but they exceed the allowable limits at shell/column connections due to concentration of stresses which is commonly avoided by increasing that contact area between sphere and columns, the stress contour of shell

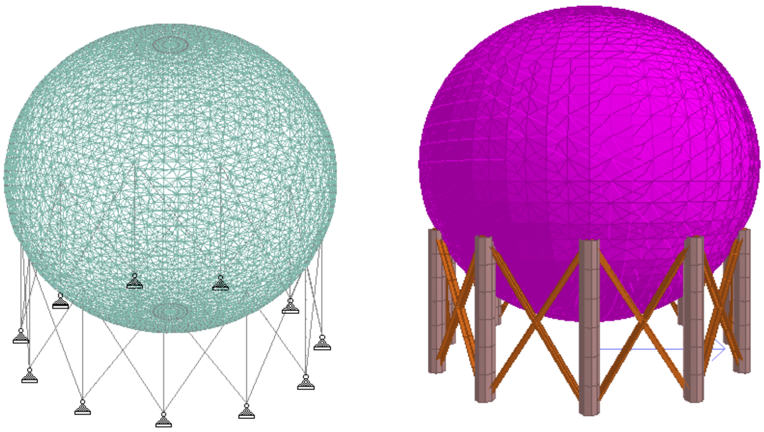


Fig.(6): Finite Element 3D Model Of LPG Spherical Tank

Table (5): Column Stresses, Axial Forces and Bracings Stresses

Analysis	**Load Case**	**Column**		**Bracing**		**Max. Comp. Support Reaction , KN**	**Max. Tensile Support Reaction , KN**
		Max. Comp. stress, MPa	**Max. Tensile stress, MPa**	**Max. Comp. stress, MPa**	**Max. Tensile stress, MPa**		
Equivalent Static UBC97	Empty	8.5	0	12.4	0	384	0
	Operation Empty +LPG	58.8	0	72.3	0	2,476	0
	Seismic +Empty	49.2	-37.3	114.6	-93.7	3,448	2,731
	Seismic +Operation	116.9	-37.9	223.9	-123.4	7,055	2,961
Time History	EQ1 +Empty	42.2	-27.3	90.0	-69.6	2752	1983
	EQ1 +Operation	143.4	-51.1	277.9	-165.4	8672	3723
	EQ2 +Empty	37.6	-23.1	82.3	-62.4	2407	1638
	EQ2 +Operation	135.0	-44.6	265.7	-154.1	8237	3291
	EQ3 +Empty	36.7	-23.6	80.8	-64.4	2433	1665
	EQ3 +Operation	**158.9**	**-63.2**	**288.9**	**-177.1**	**9638**	**4689**
	El Centro +Empty	24.8	-11.1	48.4	-30.2	1511	743
	El Centro + Operation	112.2	-20.1	206.2	-96.1	6317	1371

The comparison of stress results obtained from static and time history analyses is based on dynamic magnification factor which is equal to dynamic stress/static stress, in which the average magnification factor for different quantities (base shear, stresses, etc) is 1.4. This yield that dynamic earthquake analysis is necessary for analysis and design of spherical LPG tank. The base shear for different loads combinations are also shown in **Table (6).** The maximum base shear and vertical reactions is due to artificial time history earthquake in operating conditions is 22,383 KN (**Table 6**). The dynamic magnification factor for base shear is 22383/18814 = 1.19. The vertical compressive and tensile support reactions (as a conservative representation of the axial forces in columns) for different loads combinations are shown in **Table (5)**. The dynamic magnification factors for vertical reactions are 1.37 and 1.58 for compressive and tensile reactions respectively. The lateral and vertical deflections for sphere for different loads combinations are studied. The maximum lateral and vertical deflections are 43.2mm and 18.02mm respectively, due to artificial time history earthquake in operating conditions. The dynamic magnification factor for lateral displacements is 1.42 in which maximum static and dynamic lateral displacements are 30.5mm and 43.2mm, respectively. The maximum lateral displacement response versus time is shown in **Fig. (7)**

Table (6): Sphere Stresses and Base Shear

Analysis	Load Case	Sphere		Sphere/column connection		Base Shear, KN
		Max. Membrane stress, Sx MPa	Max. Membrane stress, Sy MPa	Max. Membrane stress, Sx MPa	Max.Membrane stress, Sy MPa	
Equivalent Static UBC97	Empty	2.61	1.31	14.3	9.45	0
	Operation Empty +LPG	25.3	17.2	97.8	72.9	0
	Seismic +Empty	28.3	20.0	47.6	37.6	11,600
	Seismic +Operation	41.2	26.6	152.9	117.3	18,814
Time History	EQ1 +Empty	10.1	5.6	44.5	30.4	7903 @ 9.41 sec
	EQ1 +Operation	47.4	32.3	197.9	138.0	21,772 @ 10.66 sec
	EQ2 +Empty	10.9	6.5	39.9	27.3	7198 @12.2 sec
	EQ2 +Operation	44.4	30.3	185.8	129.4	20,477 @3.89sec
	EQ3 +Empty	8.1	4.1	36.1	28.3	7550 @9.06sec
	EQ3 +Operation	**48.2**	**37.4**	**210.8**	**148.7**	**22,383** @ 4.03 sec
	El Centro +Empty	9.0	5.7	32.2	22.4	3711 @ 2.03 sec
	El Centro + Operation	38.6	36.5	150.1	116.5	14706 @ 2.65 sec

The following conclusions can be drawn from the present study:

1- The time history analysis govern the behavior of spherical LPG steel tanks subjected to earthquake forces in Maysan province, in comparison with results obtained from equivalent static analysis.

2- The stresses in columns are within allowable limit in under both equivalent static and time history analysis.

3- Stresses in diagonal bracings are exceeded the yield stress of steel under both static and time history analysis, which yield that double angle section (2L200*20) is inadequate to resist earthquake loadings.

4- Stresses in sphere are much less than allowable limits but they slightly exceed the allowable limits at sphere/column connections due to stresses concentration which can be reduced by increase the contact area between column and sphere at connection regions.

5- The dynamic magnification factor is 1.4 for both stresses and lateral displacement which yield that dynamic analysis are necessary for design and analysis of LPG spherical tanks' under earthquake loadings.

6- Base shear obtained by time history analysis for operating condition is larger than that computed by equivalent static by about 1.19, while for empty conditions always static analysis yield larger base shear than time history analysis

At the top of sphere (upper head)

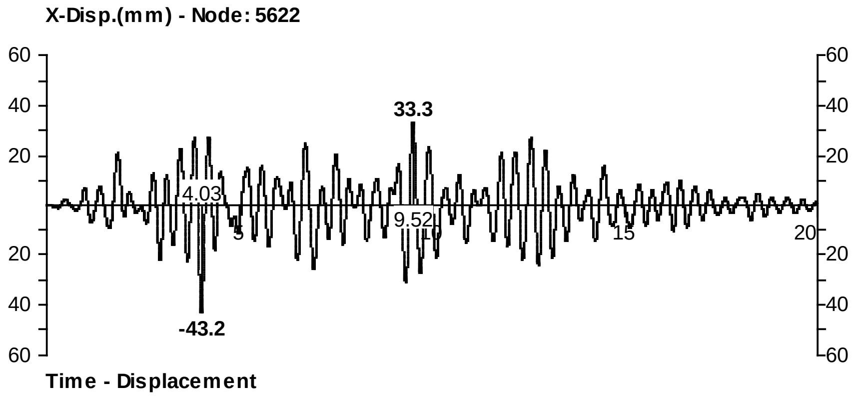


Fig.(7): Maximum Lateral Displacement Response versus Time

References

[1]- S. Zhang, Z. Wang , Y. Guo , J. Wang " FEM Simulation of the Hydroforming Process of Spherical Vessels from Combination Frustum Shells", Journal of Material Science Technology, 1993, Vol.9.

[2]- N. Teodorescu "Analysis of the Spherical Tanks Shell Stresses Concentration due to the Discontinuous Equatorial Supporting Solutions", REV. CHIM. (Bucuresti), 2010, 61, 1.

[3]- American Society of Mechanical Engineers ASME "Pressure Parts Material' Design Criteria " ASME, 2007, Viii -Div 2,.

[4]- E. Nsieri1, Y. Offir , A. Shohat " Seismic Retrofit Of Exiting Spherical Tank Using Non-Linear Viscous Dampers" Second European Conference on Earthquake Engineering and Seismology, Istanbul, 2014.

[5]- American Society for Testing and Materials (ASTM) " A537/A537M: Pressure Vessel Plates, Heat-Treated, Carbon-Manganese Silicon Steel", 2003.

[6]- N. Gilbert, "Structural Steel - S235, S275, S355 Chemical Composition, Mechanical Properties and Common Applications" Azom.com [online]. www.azom.com/article.aspx, 2012.

[7]- American Institute of Steel Construction, AISC "Steel Construction Manual"13 Edition, USA, 2006.

[8]- D. J. Chaudhari , V. M. Sapate "Generation Of Artificial Earthquake Time History" Proceedings of 9th IRF International Conference, Pune, India, 2014.

[9]- Seismoblog " Berkeley Seismological Laboratory" University of California at Berkeley [online], 2012.

[10]- Uniform Building Code, UBC97, " EARTHQUAKE DESIGN" California, USA, 1997.

[11]- P. Gelfi "SIMQKE_GR: SIMulation of earthQuaKE GRound motions " Version 2.7, University of Brescia, Italy, 2012.

[12]-STAAD PRO V8i "Structural Analysis And Design Computer Program" Bentley Company, USA, 2008.