Experimental and Theoretical Study of The Natural Frequency for Unanchored Fuel Storage Tank

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Abstract--- In this work, experimental and theoretical study are focused on calculation natural frequencies for empty tank and tanks with different filling ratio. A fuel storage tank which its diameter (0.2m) and the (H/R) ratio was three values and these values were (0.75, 1.0 and 1.25). The thickness of plate of were (1.5, 3 and 4) mm. Theoretically, The finite element model of the unanchored fuel storage tank used SHELL99 and SOLID187 Elements in order to described fluid and tank respectively. In this mode, the tank was divided into cylinder, base and roof and the cylinder was divided into several section depending on the thickness of tank and/or the level of liquid. SHELL99 element was used to mesh the liquid that was represented as a solid with certain modulus of elasticity and certain density. Experimentally, the vibration test used the roving hammer to calculate the fundamental natural frequency of the tank. Comparison between the experimental and theoretical results shows good agreement and the maximum absolute error percentage was (15.6%) when the thickness of plate was (4 mm) and the (H/R) ratio was (1.25).

Index Term--- Cylindrical tanks, natural frequency, finite element method, vibration test.

I- INTRODUCTION

The tank is one of the most important equipment of petroleum processing and storage, and its seismic performance must be good for safety production industry and processing of petroleum industry [1-4]. When the tank is destroyed under the action of earthquake, serious economic losses will be caused, in additional to other secondary disasters such as fire, environmental pollution and so on. Also, liquid storage tanks are one of the essential structures in industrial facilities. The tank structure is being utilized in a variety of configurations such as ground supported, elevated, or partly buried. Due to their vulnerability to earthquakes and their wide use, expectedly a substantial number of incidents of damage to tanks has occurred during past seismic events [5-8].

Several investigations are studied the evaluation of dynamic behavior of cylindrical tanks [9-12]. Marchaj [13] studied the tank behavior under vertical acceleration. He translated the dynamically applied forces into equivalent static forces and equated the work done by such forces to the stored elastic energy of the shell. He considered a horizontal strip of the tank wall in this study. Kumar [14] considered only the radial motion of partially-filled tanks and assumed that the effect of axial deformations.

II- FINITE ELEMENT MODEL

According to the theoretical work described by Marwa and Majid (under publishing) [20], the optimum dimensions of the tank were:

A. The diameter of the tank was 0.2 m.
B. The (H/R) ratio was three values and these values were (0.75, 1.0 and 1.25).
C. The thickness of plate were (1.5, 3 and 4) mm.

The finite element model of the unanchored fuel storage tank was similar to that used in [20]. This model used SHELL99 and SOLID187 Elements in order to described fluid and tank respectively. In this mode, the tank was divided into cylinder, base and roof and the cylinder was divided into several section depending on the thickness of tank and/or the level of liquid. SHELL99 element was used to mesh the liquid that was represented as a solid with certain modulus of elasticity and certain density [20].

III- EXPERIMENTAL WORK

The physical and mechanical properties of steel plate used for manufacturing the tank are density and modulus of the elasticity. The density of the plate measured using a classical way (the mass and the volume were measured) and the value of density was (7850 kg/m³). The modulus of elasticity of the...
plate was measured using the tensile test (according to ASTM (A370-2012)) and was (206 GPa). In other hand, the density of liquid used in vibration taste (Gasoline) was (680 kg/m³) and the modulus of elasticity was (1.2 GPa).

First of all, the reinforcement concrete foundation, with dimensions (1m*1m*15 cm) was built. The circular pit, with (0.2 m) diameter and (0.01 m) height, was done in the reinforcement concrete foundation. This pit is used as a support to prevent the tank to move in horizontal plane [see Fig.(2-a)].

The vibration test involves studying the fundamental natural frequency for empty tanks and tanks with different filling ratio of tanks and the dimensions of these tanks and the filling ratio using in this work can be illustrated in table I.

**TABLE I**

<table>
<thead>
<tr>
<th>N o</th>
<th>H/R</th>
<th>Diameter (m)</th>
<th>Height (m)</th>
<th>Thickness (mm)</th>
<th>Filling Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.75</td>
<td>0.2</td>
<td>0.075</td>
<td>3</td>
<td>Empty,0.166, 7, 0.3333, 0.5, 0.6667 and 0.8333</td>
</tr>
<tr>
<td>2</td>
<td>1.0</td>
<td>0.2</td>
<td>0.1</td>
<td>4</td>
<td>Empty,0.166, 7, 0.3333, 0.5, 0.6667 and 0.8333</td>
</tr>
<tr>
<td>3</td>
<td>1.25</td>
<td>0.2</td>
<td>0.125</td>
<td>3</td>
<td>Empty,0.166, 7, 0.3333, 0.5, 0.6667 and 0.8333</td>
</tr>
</tbody>
</table>

The rig used in vibration test consists of the following parts [see Fig. (2b)]:
A. The Reinforcement Concrete Foundation.
B. Impact Hammer Instrument (model:086C01-PCB Piezotronic vibration division)
D. The Amplifier (model 480E09).
E. Digital Storage Oscilloscope ( model ADS 1202CL+ and serial No.01020200300012):

The reinforcement foundation

The pit in the foundation

The rig used in this work.

To calculate the fundamental natural frequency of the tank, the impact hammer is used to generate the impulse force at a certain point on the tank and then the response from

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**Note:**
- Fig. 1. Tensile test according to ASTM number (A370-2012).
- Fig. 2. The rig used in this work.
- **a-** Tensile test machine used in this work.
- **b-** Dimensions of tensile test sample.

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**Table 1:** The Dimensions of Tanks and Height of Liquid Used in This Work.
accelerometer sensor will be measured using the amplifier and digital storage oscilloscope. The certain point, that the impact hammer hits the tank, was limited depending to the height of liquid in the tank. There are three ways can be measured the signal[1]. The method that used in this work used single accelerometer that can be fixed to one position and then impact our structure at several locations. This is known as a 'roving hammer' test. This uses the least resources, but takes longer to make several measurements. This is the most common form of hammer impact testing.

IV- RESULTS AND DISCUSSIONS

The experimental results of this work were divided into two groups. The first group are the experimental results of the empty tanks with thickness of plates (1.5, 3 and 4) mm and the second group are the experimental results of the tanks with different filling ratio and with thickness of plates (1.5, 3 and 4) mm. For the empty tanks, table (2) shows the comparison between the experimental results and two theoretical results.

From table (2), the maximum absolute error percentage are (4.67, 6.72 and 7.22) % when the (H/R) ratio are (0.75, 1.0 and 1.25) respectively. For the second mode, (8.2 and 10.6) % for the third mode, (54%) for the fourth mode. Also, the absolute minimum error percentage for the same (H/R) ratio are (0.7 %) for the first mode, (0.6 %) for the second mode, (1.3%) for the third mode and (0.48 %) for the fourth mode. For the same thickness of plate and when the (H/R) ratio is (1.0), the absolute error percentage range are (0.77-1.15)% for the first mode, (0.14-18.7) % for the second mode, (8.2-

| TABLE II | THE COMPARISON BETWEEN THE EXPERIMENTAL AND THEORETICAL RESULTS OF THE EMPTY TANKS FOR DIFFERENT (H/R) RATIO. |
|---|---|---|---|---|---|---|---|---|
| (1) The Thickness of Plate is (1.5) mm. |  |  |  |  |  |  |  |
| No. of Mode | Exp. Freq. (Hz) | Theo. Freq. (Hz) | Error % | Exp. Freq. (Hz) | Theo. Freq. (Hz) | Error % | Exp. Freq. (Hz) | Theo. Freq. (Hz) | Error % |
| 1 | 118.12 | - | - | 52.3 | - | - | 133.5 | - | - |
| 2 | 347.32 | 347.49 | 0.048 | 347.61 | 347.5 | -0.0316 | 347.73 | 347.51 | -0.06 |
| 3 | 700.2 | 724.47 | 3.350 | 702.91 | 724.34 | 2.9585 | 698.8 | 724.24 | 3.512 |
| 4 | 1140.5 | 1182 | 3.510 | 1139.7 | 1182.7 | 3.6340 | 1097.7 | 1183.2 | 7.226 |
| 5 | 1549.6 | 1480.4 | -4.674 | 1556.1 | 1458.1 | -6.7210 | 1434.5 | 1443.1 | 0.595 |
| (2) The Thickness of Plate is (3) mm. |  |  |  |  |  |  |  |
| No. of Mode | Exp. Freq. (Hz) | Theo. Freq. (Hz) | Error % | Exp. Freq. (Hz) | Theo. Freq. (Hz) | Error % | Exp. Freq. (Hz) | Theo. Freq. (Hz) | Error % |
| 1 | 77.4 | - | - | 49.11 | - | - | 73.3 | - | - |
| 2 | 674.3 | 672.59 | -2.54 | 674.62 | 671.83 | -0.4152 | 647.82 | 671.76 | 3.563 |
| 3 | 826.17 | 821.62 | -0.553 | 808.1 | 798.24 | -1.2352 | 793.2 | 780.83 | -1.58 |
| 4 | 1480.1 | 1470.6 | -0.645 | 1387.4 | 1444.5 | 3.9529 | 1528.3 | 1429.4 | -6.91 |
| 5 | 2713.2 | 2875 | 5.627 | 2860.2 | 2832.3 | -0.985 | 2610.7 | 2719.3 | 3.993 |
| (3) The Thickness of Plate is (4) mm. |  |  |  |  |  |  |  |
| No. of Mode | Exp. Freq. (Hz) | Theo. Freq. (Hz) | Error % | Exp. Freq. (Hz) | Theo. Freq. (Hz) | Error % | Exp. Freq. (Hz) | Theo. Freq. (Hz) | Error % |
| 1 | 317.1 | 1.3 | - | 61.27 | 1.12 | - | 40.33 | - | - |
| 2 | 880.7 | 881.18 | 0.054 | 880.33 | 879.93 | -0.045 | 887.89 | 879.4 | -0.96 |
| 3 | 1685 | 1834.8 | 8.164 | 1367 | 1831.9 | 25.378 | 1944.2 | 1829 | -6.29 |
| 4 | 2443.3 | 2930.5 | 16.62 | 2936 | 2937.6 | 0.0544 | 2477.5 | 2935.7 | 15.60 |
| 5 | 3816.5 | 3768.4 | -1.27 | 4028.8 | 3709.9 | -8.595 | 3203.5 | 3335.7 | 3.96 |
-27.2)% for the third mode and (1.6-33)% for the fourth mode. For the same thickness of plate and when the (H/R) ratio is (1.25), the absolute error percentage range are (0.19-0.34)% for the first mode, (2.1-10.35) % for the second mode, (0.515-25.15)% for the third mode and (2.1-33.8)% for the fourth mode.

B-For the thickness of plate is (3 mm) and when the (H/R) ratio is (0.75), the absolute error percentage range is (0.06-2.8)% for the first mode. The absolute error percentage increases when the mode increases and the maximum absolute error percentage reaches 80 % in the fourth mode. For the same thickness of plate and when the (H/R) ratio are (1.0) and (1.25), there is a very good agreement between experimental and theoretical results for the first mode and the absolute error percentage range increases with the number of mode. The maximum absolute error percentage are (0.3)% and (0.4)% for the (H/R) ratio are (1.0) and (1.25) respectively.

C-When the thickness of plate is (4 mm), there is a very good agreement between experimental and theoretical results for the first mode for the (H/R) ratio are (0.75, 1.0 and 1.25). The maximum absolute error percentage are (0.3, 0.35 and 19) % respectively. Also, the maximum absolute error percentage increases when the number of mode increases.

Fig. 3. The comparison between the experimental and theoretical natural frequencies of the first four modes for the filling ratio changes and when the (h/r) ratio is 0.75 and the thickness of plate is (1.5 mm).
Fig. 4. The comparison between the experimental and theoretical natural frequencies of the first four modes for the filling ratio changes and when the \((h/r)\) ratio is 1.0 and the thickness of plate is (1.5 mm).

c- The third mode.

d- The four mode.

Fig. 5. The comparison between the experimental and theoretical natural frequencies of the first four modes for the filling ratio changes and when the \((h/r)\) ratio is 1.25 and the thickness of plate is (1.5 mm).

c- The third mode.

d- The four mode.
Fig. 6. The comparison between the experimental and theoretical natural frequencies of the first four modes for the filling ratio changes and when the (h/r) ratio is 0.75 and the thickness of plate is (3 mm).

Fig. 7. The comparison between the experimental and theoretical natural frequencies of the first four modes for the filling ratio changes and when the (h/r) ratio is 1.0 and the thickness of plate is (3 mm).
The first mode.

The second mode.

The third mode.

The four mode.

Fig. 8. The comparison between the experimental and theoretical natural frequencies of the first four modes for the filling ratio changes and when the (h/r) ratio is 1.25 and the thickness of plate is (3 mm).

The first mode.

The second mode.

The third mode.

The four mode.

Fig. 9. The comparison between the experimental and theoretical natural frequencies of the first four modes for the filling ratio changes and when the (h/r) ratio is 0.75 and the thickness of plate is (4 mm).
V- CONCLUSION

The comparison between the experimental and ANSYS results of this work. From the results of empty tank, the maximum absolute error percentage increases when the \( (H/R) \) ratio increases and the maximum absolute error percentage increases when the thickness of plate increases. Generally,

Fig. 10. The comparison between the experimental and theoretical natural frequencies of the first four modes for the filling ratio changes and when the \( (h/r) \) ratio is 1.0 and the thickness of plate is (4 mm).

Fig. 11. The comparison between the experimental and theoretical natural frequencies of the first four modes for the filling ratio changes and when the \( (h/r) \) ratio is 1.25 and the thickness of plate is (4 mm).
there is a very good agreement between the experimental and theoretical results and the maximum absolute error percentage was (15.6%) when the thickness of plate was (4 mm) and the (H/R) ratio was (1.25). From the results of the tank with different filling ratio, there is a very good agreement between experimental and theoretical results for the first mode for different (H/R) ratio and different thickness of plate. But, the maximum absolute error percentage increases when the number of mode, thickness of plate and (H/R) ratio increase.

REFERENCES


