Structure load calculation for Essential ESW Intake Structure /CCW HX Building Chilled Water Compression Tank

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Abstract. Interest in studying of the shell arises from the fifties of twentieth century. Assemblies which contains thin shells, find wide use in the modern engineering especially in ships, aircraft and spacecraft industry. In today’s aerospace and aircraft industries, structural efficiency is the main concern. In this paper the shell vibrations and buckling modes are analyzed by means of numerical methods to clarify qualitatively critical loads and different buckling modes. In our study we focus on the experimental analysis of axial loading for static and buckling analysis for pressure vessel. The modeling and the analysis both are carried out in Ansys 15.0 solver. The analysis provides the stresses for the saddle support & shell near the saddle support due to upset (OBE) and faulted (SSE) seismic load conditions. Furthermore, the results from the simulation are then compared with the KEPIC (Korea Electric Power Industry Code) standards to find the structure integrity of particular unit. Finally, data collected from these simulations results, we conclude that it is safe to manufacture particular pressure vessel with current loading conditions.

1. Introduction

Pressure vessels are important because many liquids and gases are stored in it under high pressure [1]. Special emphasis is placed upon the strength of the vessel to prevent explosions as a result of rupture. Codes for the safety of such vessels have been developed that specify the design of the container for specified conditions. Most pressure vessels are required to carry only low pressures and thus are constructed of tubes and sheets rolled to form cylinders [2]. Some pressure vessels must carry high pressures; however the thickness of the vessel walls must increase in order to provide adequate strength [3]. Interest in studying of the shell arises from the fifties to twentieth century. The assemblies containing thin shells find wide use in the modern engineering especially in ships aircraft and spacecraft industry. The basic schematics of pressure vessel is shown in Figure 1.

Cylindrical shells such as thin-walled laminated composite unstiffened vessels like deep submarine exploration housings and autonomous underwater vehicles are subjected to combination of in plane, out of plane and shear loads due to the high external hydrostatic pressure during their application [4,5]. Due to the geometry of these structures, buckling is one of the most important failure criteria [6,7]. Buckling failure mode of a stiffened cylindrical shell can further subdivided into global buckling, local skin buckling and stiffener crippling. Global buckling is collapse of the whole structure, i.e. collapse of the stiffeners and the shell as one unit. Local skin buckling and the stiffeners crippling on the other hand are localized failure modes involving local failure of only the skin in the first case and the stiffeners in the second case [8].
2. Problem identification
In today’s aerospace and aircraft industries structural efficiency is the main concern. Due to their high specific strength and light weight, fiber reinforced composites find a wide range of applications [9]. Compression load carrying structures form part of all aircraft and space vehicle fuel tanks, air cylinders are some of the many applications. An analytical procedure is developed to design and predict the behaviour of Essential ESW Intake Structure/ CCW HX Building Chilled Water Compression Tank. Stress analysis has been carried out for Saddle supports and vessel shell near the saddle support and their effects on Chilled Water Compression Tank pressure vessel has been studied [2]. The shell vibrations and buckling modes are analysed by means of numerical methods, to clarify qualitatively the critical loads and different buckling modes.

3. Modelling of cylindrical pressure vessel
For the design data the weight of empty tank is consider 570 kg which is full of water the total weight is 1070 kg and the pressure is 80 pascals while the operating temperature is 65.5 °C. The modelling of the Cylindrical Pressure Vessel is done in ANSYS 12.1.

There are two type of seismic loads applied in study. One is equivalent static analysis used for the design of anchor bolt and BSLS (Building Structure Load Summary) calculation [10,11]. The other is dynamic analysis for the stress calculation of saddle support and shell near the saddle support due to seismic loads including sloshing effects. The following data shall be applied for the dynamic analysis. SSE seismic response spectra for 3% of damping for SSE and 1/2 SSE seismic response spectra for 2% of damping for OBE from Technical Specification. The load combinations for Equipment & supports shall be in accordance with the Table 1. The following loading combination and stress limits shall be applied for the Building Structure Load Summary and structure stress analysis in this paper.

Table 1. Stress limits for Equipment & supports

| Condition   | Loading Combination | Loading Combination | Strength Limits |
|-------------|---------------------|---------------------|----------------|
| Normal      | W +P + T + O        | (0.9)W+(1.7)P+(1.3)T+(1.4)O |               |
| Upset       | W +P + T + O + S(u) | (0.9)W+(1.7)P+(1.3)T+(1.4)O+(1.9)S(u) | ACI 349-01 |
| Faulted     | W +P + T + O + S(y) | (0.9)W+(1.0)P+(1.0)T+(1.0)O+S(y) |               |

Where W is Weight (operating weight), P is Pressure Load, T is Thermal Expansion, O is Equipment Operating Loads (Piping Loads), S(u) is Upset condition Dynamic Loads (operating basis earthquake load : 1/2 SSE with 2% damping) and S(y) is Faulted condition Dynamic Loads (safe shutdown earthquake load : SSE with 3% damping).

4. Finite element model
The finite element analysis code for this work is the ANSYS 12.1 ANSYS shell elements type SHELL181 (4-noded structural shell) were selected for modeling. Figure 2 is finite element model for

Figure 1. Chilled Water Compression Tank
analysis including applied boundary conditions. All nodes on the anchor chair in the skirt support were restrained vertically and laterally. ANSYS 'POST1' will categorize stress into membrane, bending, membrane + bending, peak, and total stresses at inside & outside surface and center of cut section.

Since the ANSYS program uses linear distribution of stress through the thickness of shell elements, intensity values of shell mid-surface, shell bottom and top surface present linearized results. The mid-wall stress is a shell membrane stress while the top and bottom surfaces are membrane plus bending stresses. Hence, the mid-wall stress can be compared directly with the KEPIC code for allowable stress of membrane stress and the two-surface membrane plus bending stresses.

**Figure 2.** Boundary conditions applied finite element model

5. **Building structure load calculation and modal analysis**

Building Structure Load calculation shall be summarized for the Operating load, Nozzle loads and seismic loads. Equivalent static seismic loads, which is 1.5 times maximum acceleration in the response spectra curves is applied for the anchor bolt design and the calculation of BSLS (Building Structure Load Summary) conservatively. The arrangement of anchor bolt and its dimensions are shown in Figure 3.

**Figure 3.** Anchor bolt arrangement

The five modal frequencies for the Essential ESW Intake Structure /CCW HX Building Chilled Water Compression Tank in cycles per second are listed in Table 2 and the first and 2th mode shapes (Figure 4 are attached).

**Table 2** Modal frequencies at different mode

| Mode sequence number | Frequency (Hz) |
|----------------------|----------------|
| 1                    | 53.2           |
| 2                    | 59.0           |
| 3                    | 123.3          |
| 4                    | 127.8          |
| 5                    | 131.4          |
1\textsuperscript{st} Mode – $f_n = 53.2$ Hz

2\textsuperscript{nd} Mode – $f_n = 59.0$ Hz

6. Seismic loading
The CCW HX Building Chilled Water Compression Tank behaves like as rigid body because the lowest fundamental frequency is higher than 33 Hz. Therefore, constant accelerations are applied to three directions as shown in Table 3.

| Spectrum Value (g) | Applied Value (g) |
|--------------------|-------------------|
| EW                 | 0.35              |
| NS                 | 0.40              |
| VT                 | 0.37              |
| OBE                | 0.175             |
| 0.2                |
| 0.185              |

7. Stress analysis
ANSYS is used for static, piping, seismic OBE and SSE in the load combination and combined stress shall be checked with the applicable stress limits for the following areas.

1) Saddle supports.

2) Vessel Shell near the saddle support

ANSYS output shows three kinds of stresses, which are stresses inside, outside and middle of each element. Stress in middle is membrane stress while stress those are inside and outside of vessel are called bending stress.

7.1. Saddle supports
The saddle supports are SA36, $S = 14.5$ ksi, $Sy = 36$ ksi, $Su=58$ ksi, the maximum stress intensity of saddle support is indicated through Table 4 and Figure 5,6 and 7.
## Table 4 Maximum Stress Intensity of Saddle supports

| Load            | Operating condition | Classification | Max. Stress Intensity | Refer to |
|-----------------|---------------------|----------------|-----------------------|----------|
| Static load     | Normal              | Pm             | 1.29                  |          |
|                 |                     | Pm + Pb        | 4.05                  |          |
|                 | Upset               | Pm             | 1.29                  | Fig.5    |
|                 |                     | Pm + Pb        | 4.05                  |          |
|                 | Faulted             | Pm             | 1.29                  |          |
|                 |                     | Pm + Pb        | 4.05                  |          |
| Piping load     | Normal              | Pm             | 10.22                 |          |
|                 |                     | Pm + Pb        | 15.28                 |          |
|                 | Upset               | Pm             | 10.22                 | Fig.6    |
|                 |                     | Pm + Pb        | 15.28                 |          |
|                 | Faulted             | Pm             | 16.18                 |          |
|                 |                     | Pm + Pb        | 24.14                 |          |
| Seismic load    | Normal              | Pm             | N/A                   |          |
|                 |                     | Pm + Pb        | N/A                   |          |
|                 | Upset               | Pm             | 0.70                  | Fig. 7   |
|                 |                     | Pm + Pb        | 1.06                  |          |
|                 | Faulted             | Pm             | 1.40                  |          |
|                 |                     | Pm + Pb        | 2.12                  |          |
|                 | Normal              | Pm             | 11.51                 | < F<sub>allow</sub> = 14.5 ksi OK |
|                 |                     | Pm + Pb        | 19.33                 | < 1.5F<sub>allow</sub> = 21.75 ksi |
|                 |                     | Pm             | 12.21                 |          |
|                 | Upset               | Pm             | 20.39                 | < F<sub>allow</sub> = 19.29 ksi OK |
|                 |                     | Pm + Pb        | 20.39                 |          |
|                 | Faulted             | Pm             | 18.87                 | < F<sub>allow</sub> = 40.6 ksi OK |
|                 |                     | Pm + Pb        | 30.31                 |          |
| Total           | Normal              | Pm             | < F<sub>allow</sub> = 14.5 ksi OK |
|                 | Upset               | Pm + Pb        | < 1.5F<sub>allow</sub> = 21.75 ksi |
|                 | Faulted             | Pm             | < F<sub>allow</sub> = 40.6 ksi OK |

### Figure 5. Distribution of Membrane stress intensity of saddle support (Static load)

### Figure 6. Distribution of Membrane stress intensity of saddle support (Piping load - Normal /Upset)
Figure 7. Distribution of Membrane+ Bending stress intensity of saddle support (Seismic load - SSE)

7.2. Vessel shell near the saddle support

The vessel shell stresses are calculated by ANSYS for the internal pressure, weight and SSE and piping loads. The piping stresses is combined using the square root of sum of squares (SRSS) method in the ANSYS program and added to the sum of pressure, weight and 1/2 SEE seismic event stresses for the upset condition. The piping stresses are combined using the SRSS method in the ANSYS program and added to the sum of pressure, weight and SSE seismic event stresses for the faulted condition.

The maximum principal stresses in the shell occur at the intersection of the piping and are largely due to the piping loads. The stresses in the supports and in the shell at the support pads are not as large. All the data is clearly shown in Table 5 and Figure 8, 9 and 10.

| Load          | Operating Condition | Classification | Max. Stress Intensity | Refer To |
|---------------|---------------------|----------------|-----------------------|---------|
| Static Load   | Normal              | Pm             | 2.44                  |         |
|               |                     | Pm + Pb        | 4.07                  | FIG. 8  |
|               | Upset               | Pm             | 2.44                  |         |
|               |                     | Pm + Pb        | 4.07                  |         |
|               | Faulted             | Pm             | 2.44                  |         |
|               |                     | Pm + Pb        | 4.07                  |         |
| Piping Load   | Normal              | Pm             | 3.09                  |         |
|               |                     | Pm + Pb        | 6.70                  | FIG.9   |
|               | Upset               | Pm             | 3.09                  |         |
|               |                     | Pm + Pb        | 6.70                  |         |
|               | Faulted             | Pm             | 5.02                  |         |
|               |                     | Pm + Pb        | 10.86                 |         |
| Seismic Load  | Normal              | Pm             | N/A                   |         |
|               |                     | Pm + Pb        | N/A                   |         |
|               | Upset               | Pm             | 0.16                  | FIG. 10 |
|               |                     | Pm + Pb        | 0.37                  |         |
|               | Faulted             | Pm             | 0.32                  |         |
|               |                     | Pm + Pb        | 0.74                  |         |
| Total         | Normal              | PM             | 5.53                  |         |
Unit : ksi

Figure 8. Distribution of Membrane stress intensity of shell near the saddle (Static load)

Figure 9. Distribution of Membrane+ Bending stress intensity of saddle support (Piping load - Normal /Upset)

Figure 10. Distribution of Membrane+ Bending stress intensity of shell near the saddle (Seismic load - OBE)

8. Allowable KEPIC stresses
According to KEPIC MDP, the allowable stress limits of components for Normal, upset and Faulted condition for primary Su plus secondary Sy stresses. The comparison between the resulting stresses and allowable stress limits are summarized in Table 6. According to this standard the ratio of maximum stress divide by allowable stress should be less than 1 for the structural integrity of Compression Tank during operation.

| Stress          | Material | Su (ksi) | Sy (ksi) |
|-----------------|----------|----------|----------|
| Shell, Head     | SA-516-70| 70       | 38       |
| Flange          | SA-105   | 70       | 36       |
| Nozzle          | SA-106-B | 60       | 35       |
| Fitting         | SA-105   | 70       | 36       |
| Base Plate      | SA-36    | 58       | 36       |
| Anchor bolt     | A-193-B7 | 125      | 105      |

Table 6 Stress Evaluation Results of KEPIC standards
9. Maximum stress intensities due to Hydrostatic test (MNC 3218)

Our model is subjected to each direction force and moment imposed simultaneously on the equipment nozzles, seismic loads and static loads. The analysis provides the stresses for the saddle support & shell near the saddle support due to upset (OBE) and faulted (SSE) seismic conditions. Actual test pressure shall not exceed the required test pressure by more than 6% as shown in table 7.

\[
\begin{align*}
S_y &= 38.0 \text{ ksi} \\
P_m < 0.9 S_y &= 34.2 \text{ ksi} \\
P_m + P_b < 1.35 S_y &= 51.3 \text{ ksi} & \text{ For } P_m < 0.67 S_y &= 25.46 \text{ ksi} \\
P_m + P_b < (2.15 S_y - 1.2 P_m) &= 51.3 \text{ ksi} & \text{ For } 0.67 S_y = 25.46 \text{ ksi} < P_m < 0.9 S_y &= 34.2 \text{ ksi}
\end{align*}
\]

### Table 7 Stress values for different load conditions

| Load       | Classification | Max. Stress Intensity | Refer to |
|------------|----------------|-----------------------|----------|
| Hydrostatic test | Pm     | 10.82                 | Fig. 11,12 |
|             | Pm + P_b | 15.13                 |          |

Pm = 10.82 ksi < Fallow = 34.2 ksi, ratio of Pm/Fallow < 1 OK

Pm + P_b = 15.213 ksi < Fallow = 51.3 ksi, ratio of Pm+Pb/Fallow < 1 OK

Since the ratio of (Pm/Fallow, Pm+Pb/Fallow) is less than 1.0, it is concluded that the structural integrity of Essential ESW Intake Structure CCW HX Building Chilled Water Compression Tank is maintained during operation as shown in Figure 11 and 12.

![Figure 11. Distribution of Membrane + Bending stress intensity (Hydrostatic test)](image1)

![Figure 12. Distribution of Membrane + Bending stress intensity (Hydrostatic test)](image2)

10. Conclusion

This study represents the results of a Dynamic Analysis (Seismic) of the proposed Essential ESW Intake Structure CCW HX Building Chilled Water Compression Tank. Dynamic analysis was performed using ANSYS computer program and the structure was modeled using finite element techniques.

The model was subjected to each direction force and moment imposed simultaneously on the equipment nozzles, seismic loads and static loads. The analysis provides the stresses for the saddle support & shell near the saddle support due to upset (OBE) and faulted (SSE) seismic conditions. The seismic analysis is performed based on the lowest fundamental frequency (53.2 Hz) of ESW Compression Tank, therefore it is considered as rigid. The constant seismic acceleration values which is shown in in Technical specification shall be applied for equivalent static analysis instead of spectrum analysis. The partial components for the x, y, and z directions were combined using the square root of the sum of the squares (SRSS) method. Finally, the results from the experiment are compare with KEPIC
standards to find the structure integrity of the pressure vessel. Form the result we conclude that it is safe to design the particular unit for given amount of static load, piping load and Seismic Loads.

11. References

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