# The Dynamic Analysis of Desulfurization Tower With Large Opening under Earthquake in Different Direction

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**ABSTRACT :**

The safety of the desulfurization tower is critical to the power plants. This study is focusing on the dynamic responses of the desulfurization tower with large opening. By taking consideration of the dynamic behaviors of the structures during a significant earthquake, such as the dynamical displacements, internal force responses and the responses of fluid-solid coupling, finite element dynamic analysis on the whole desulfurization tower are made. The study concludes that the fluid-solid interaction has a significant impact on the desulfuration tower's safety and provides how the impact responding to the in-put directions of the earthquake wave. Some recommendations are provided for the future desulfurization tower design and construction in terms of improving its safety during earthquakes.

**KEYWORDS:** Desulfurization Tower; Dynamic Analysis; Liquid-solid Coupling; Major Earthquake

## 1. INTRODUCTION

General speaking, the structure of the desulfurization tower is like a large-diameter container with a large-opening and thin-wall. The rectangular air admission opening and the air outlet opening are considerably large comparing to the diameter of the tower (e.g., the largest extend could be more than 80% of tower diameter). Regarding the wind forces, earthquakes and other overhead forces, the structure strength and stability analysis is fairly complicated, especially the areas of the rectangular openings (i.e., the most possible areas for stress concentration). However, the design of this critical structure is typically based on the previous working experiences other than the theoretical analysis and scientific tests. Given that the most of power plants are located in seismic areas in China, the lack of researches and tests done for the desulfurization tower could cause serious damages potentially.

A numerous of studies on this topic have been completed for decades (Wang, 2002; Li and Sun, 2007; Ye *et al.*, 2007; Xu and Ma, 2005; Berrah and Kausel, 1992; Ye *et al*., 2008); however, these studies have not been adopted based on the local conditions. In the scientific point of view, the current design work for the desulfurization towers are either not following some criteria or consulting some guidelines which are not appropriate. In other words, most of the existing desulfaricaton tower designs have, more or less, shortcomings or are not cost-effective. Based on the previous researches, the liquid in a container changes the natural frequency of the container (Wang *et al.*, 2007). The 20th century, the cylindrical shell liquid-filled tank, according to static force design, damaged seriously in the earthquake in many countries (Rammer *et al.*, 1990). The flammable or toxic liquid media was leaked, and caused serious environmental pollution and disaster. In order to simulate the actual impacts caused by the liquid at the bottom of the tower, the fluid-solid coupling has been taken into consideration.

This study applies finite analysis method by using the finite program. The response of the structure is different in difference direction of the seismic wave. The 2-dimentional shock wave derived during a major earthquake (i.e., El-centro) is examined. In specifically, the shock wave are input through 2 directions, X wave (i.e., parallel to the gas opening) and the Y (i.e., perpendicular to the gas opening). The areas where the most shape-change and stress concentration happened caused by the waves are examined and analyzed. The quantified results are necessary for determining where and how to strength the structure if needed. Moreover, the results provide theoretical analysis for the future design optimization of the towers.

## 2. STRUCTURAL FINITE ELEMENT MODELING

This project takes the 300 MW units desulfurization tower as the background which is showed in Figure 1. In this project, the total volume of the desulfurization tower is 4958 $m^3$ with 36.306m tall and diameter of 13.1m. The wall thickness is variable from bottom to top, from 18mm at the bottom and 8mm at the top(Figure 2). The thickness of lid is 20mm. There is $CaCo_3$ solution under the elevation of 13.500m. The boundary conditions for setting up the analysis model are: the height and diameter of the tower, the dimension of the air-intake openings and some working platforms. This process of the modeling includes parameter estimation, modeling, Boolean operation, mesh generation, loading calculation, results analysis, etc. (Bai and Yu, 1995).

Given that the forces on the tower are not evenly distributed, the model is set as a lump model. The general methodology is: first, a geometric model is established and defines the critical parameters for the materials and the element property. Second, finite mesh is derived based on the geometric model. Because of the multi-openings on the tower, finite elements are not regular through the whole model (e.g., more elements may be required to define the surface boundary near the opening). Basically, the tower surface is divided carefully into different portions in order to minimize the irregular elements. More nodes are added till all the possible irregular elements are eliminated. Consequently, there are 14843 elements with 13481 nodes in finite mesh. The constraint conditions are nodes with fixed ends at the bottom of the tower.The method for this study is using the weak-coupling. The unit of Fluid80, 8 nodes in each unit, 3 degrees of freedom in each node is selected for the analysis. So, after this, the total numbers of the elements are 38627; numbers of nodes are 39281(Figure 3).

Fig. 1 Desulfurization tower

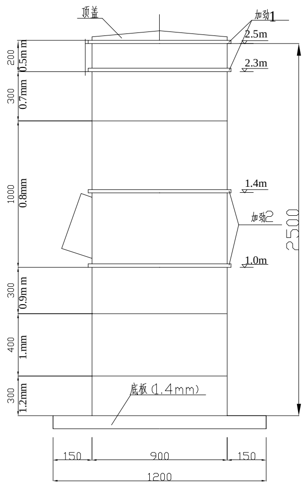


Fig. 2 Elevation drawing of desulfurization tower

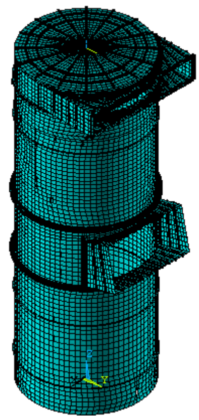

Fig. 3 Unit division of desulfurization tower

## 3. MODELING ANALYSIS

**Table 1** shows the first 10 natural frequency and vibration mode simulated using the modal.

The typical modals, demonstrated by No.1, 4, and 9 of the tower, are provided in **Figure 4**.

Based on the simulation results of the shaking modes, it can be found that the vibration occurred first on specific areas and then the entire structure, which means the integral rigidity distributed uneven. Theoretically, the local vibration always starts at the weakest parts then spreads to the whole structure. Taken the whole desulfurization tower into consideration, the first 3-vibration modes are typically the vibration of the beams because the beams are relatively long the structure for connecting the beams and supporting walls are not done properly. Hence, the beams become the weakest partial and vibrate firstly. The forth vibration mode is the whole-vibration of desulfurization tower structure (i.e., the main mode). The seventh vibration mode was the local vibration again; the main sites were air admission opening, air outlet opening and the site of beams connected with tower. Air admission and air outlet opening weaken the tower seriously, the rigidity of the tower is uneven, and the change is discontinuous. It is concluded that, the opening affects the tower structure dynamic characteristics significantly. Therefore, the opening structure needs to be strengthened.

Table 1 Natural Frequency and Cycle

| *Serial Number* | *Natural Frequency (Hz)* | *Cycle (s)* | *Modal characteristic* |
|---|---|---|---|
| 1 | 0.305 | 3.280 | spurting beam tower walls vibration |
| 2 | 0.367 | 2.720 | spurting beam tower walls vibration |
| 3 | 0.484 | 2.064 | spurting beam tower walls vibration |
| 4 | 3.932 | 0.254 | X direction whole vibration |
| 5 | 3.984 | 0.251 | Y direction whole vibration |
| 6 | 4.798 | 0.208 | spurting beam tower walls vibration |
| 7 | 5.111 | 0.196 | Air Admission Opening Co-Rotating vibration |
| 8 | 5.179 | 0.193 | Air Admission Opening reverse vibration |
| 9 | 5.400 | 0.185 | spurting beam tower walls vibration |
| 10 | 5.469 | 0.183 | spurting beam tower walls and Air Admission Opening vibration |

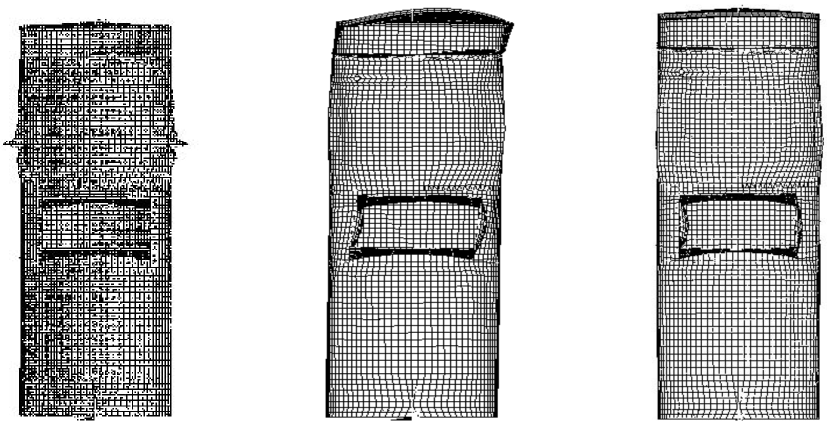

Fig. 4 Shaking modes of the first, the forth and the ninth modal of desulfurization tower

## 4. ANALYSIS OF EARTHQUAKE RESPONSE OF DESULFURIZATION TOWER

The main indexes of seismic analysis to the desulfurization tower structure are as following: strength, safety and stability. Therefore the main components in this study are focusing on the deformation of structure and the stress of steels.

### *4.1 Stress Analysis*

Selecting the two mutual perpendicular directions of the tower structure, X direction (parallel to the air admission and air outlet opening direction), Y direction (perpendicular to the air admission and air outlet opening direction), the seismic wave is input. To study the dynamic behaviors of the tower structure with large openings, earthquake response of the tower structure under the seismic waves with different directions were

made.
Through analyzing the stress of the tower under the seismic waves in different direction, it can be seen that the maximum stress value in X direction is 110MPa, on both sides of air admission opening; the maximum stress value in Y direction is 178MPa, on tower walls connection to the spurting beam.
**Figure 5** and **Figure 6** is the integral stress graph of the tower structure under the earthquake in X, Y direction.

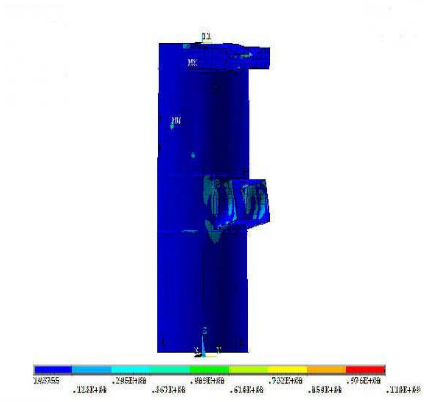

Fig.5 Stress pattern with seismic wave input in X direction

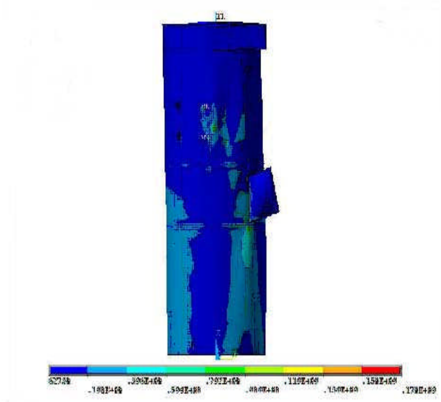

Fig.6 Stress pattern with seismic wave input in Y direction

It is showed that the seismic response of these locations, such as, air admission, air outlet opening and the tower walls connection to the spurting beam, is great than other locations, because of the big opening, stress concentration on the openings connection to the tower walls. The stress concentration destructed the stress status of the shell and affected the steady of the desulfurization tower structure seriously. The beams are the weak locations of the tower. So they are the mainly designed positions of the tower structures.

### *4.2 Deformation Analysis*

**Figure 7** showed the deformation of the desulfurization tower under earthquake in X direction. As the air admission opening outstand the tower, it is the weak position of the tower. It is the position that the maximum deformation occurred of the tower too. The maximum deformation value is 31.33mm. **Figure 8** showed the deformation of the desulfurization tower under earthquake in Y direction. The maximum deformation value is 49.9mm, occurred at the location of spurting beam.

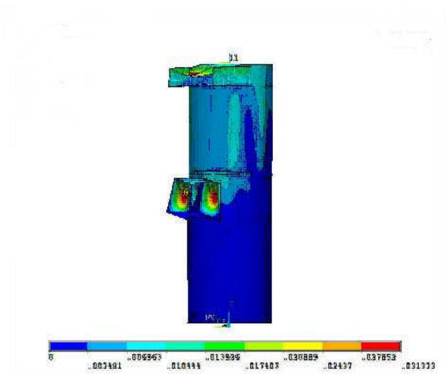

Fig.7 Structure deformation with seismic wave input in X direction

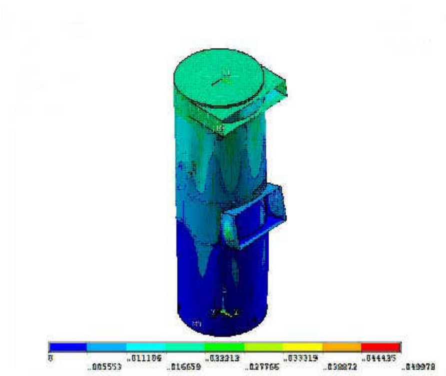

Fig.8 Structure deformation with seismic wave in Y direction

The results of the stress and the deformation show that the weak positions are the tower walls connection to the beams, the beams and air admission, air outlet opening. This result is consistent with the modeling analysis. The maximum value of the stress, deformation and their location are changed in different direction of seismic waves. The Y direction, perpendicular to the air admission and air outlet opening direction, is the weak direction to the desulfurization tower. So the method must be done to increase the stiffeners. The seismic performance of desulfurization tower can be improved.

## 5. ANALYSIS OF LIQUID-SOLID COUPLING OF DESULFURIZATION TOWER UNDER THE MAJOR EARTHQUAKE

The Liquid-solid Coupling is conducted based on the significant earthquakes. The degree of the earthquakes applied in this research is determined based on the dynamics characteristic, stress and deformation of structure. The structural performance during these earthquakes can be referenced for future tower design in the same areas.

### *5.1 Analysis of Earthquake Wave with Different Direction*

**Table 2** is the maximum value of stress and deformation and their location of the desulfurization tower structure in X (parallel to the gas opening), Y (perpendicular to the gas opening) both directions of earthquake wave.

Table 2 Maximum Value of Stress and Deformation and the Location

| | *Maximum Value of Stress（MPa）* | *Stress Location* | *Maximum Value of Deformation（cm）* | *Deformation Location* |
|---|---|---|---|---|
| X Direction | 239 | Both side of air outlet opening | 5.29 | Top of air outlet opening |
| Y Direction | 283 | spurting beam tower walls | 5.61 | middle of spurting beam |

The results of the analysis is as the following.

(1)Stress Analysis

**Table 2** shows that the direction of the earthquake waves is different. The maximum stress is also different. The maximum value of stress in Y direction is 283MPa, the time is 6.24s. The maximum value of stress in X direction is 239MPa, the time is 9.58s. The stress in Y direction is bigger than X direction. They exceed the yield strength of material all (235MPa). This is because of that the dynamic response of the structure was analyzed under the strong earthquakes in this article.

But the desulfurization tower structure was designed under the common earthquakes. So the results are reasonable that the desulfurization tower structure were yield under the strong earthquakes. The diameter-thickness ratio is one of the main factors of nonlinear buckling of the structure.

(2)Deformation Analysis

The result in the **Table 2** shows that the deformation in Y direction is bigger than in X direction, increased 0.32 cm with an increasing range of 6%. This is because of that the beams are the weakest areas of the structure under the dynamic direction earthquake waves, the different integral rigidity in both directions, and the constraints are very limited at the area of large opening and the beams themselves. So the deformation at those areas should be larger than the other areas. It verified the effect on dynamic characteristics of the different seismic wave input direction once again.

### *5.2 Analysis of Earthquake Wave of Liquid-solid Coupling with Different Direction*

There is 2000 tons $CaCo_3$ solution under the elevation of 13.500m. Compared with weight of the liquid itself, the weight of the desulfurization tower structure is miner (337t). The liquid and the tower will be interacted each other under the earthquakes. The liquid can absorb some energy, mitigating the impact caused by the earthquakes. On the other hand, the floating of the liquid can have some additional forces on the tower as well. Meanwhile, the deformation and the stress distribution will regulate, in some degree, the movement of the liquid. By inputting the earthquake waves in the same directions, the model simulates the maximum stress, deformation and the areas happened. **Table 3** summaries the simulation results.

Table 3 Maximum Value of Stress and Deformation and the Location

| | *Maximum Value of Stress (MPa)* | *Stress Location* | *Maximum Value of Deformation (cm)* | *Deformation Location* |
|---|---|---|---|---|
| Y Direction (no liquid) | 283 | spurting beam tower walls | 5.61 | middle of spurting beam |
| Y Direction | 380 | spurting beam tower walls | 9.25 | middle of spurting beam |

Based on the **Table 3**, it can be concluded that the liquid in the tower has a significant impact on the desulfurization tower structure. The maximum value increases 97MPa (34.3% increasing than previous), while the deformation increases 3.64cm (64.8% increasing) after considering fluid-solid coupling. This is because that the tower structure deformation caused by the earthquakes changes the fluid floating regimes (e.g., velocity and pressure) and these changes will swing back to the tower structure to make the impacts more serious, especially to the weakest areas (e.g., openings, beams and conjunctions). So we should increase the thickness of the bottom plate and increase the stiffener ring to improve the seismic performance. Hence, it is critical to complete an analysis on the dynamic response of fluid-solid coupling regarding the desulfurization tower design.

## 6. CONCLUSIONS

(1) Based on the analysis on the shaking models, the vibration starts from some weak areas (e.g., beams and openings) and spreads to the whole structure, while the strength and the stiffness are not distributed evenly. The large openings undermine the general structure performance significantly and need to be improved for the future designs.
(2) The direction of inputting earthquake wave has great impact on the stress and deformation of desulfurization tower structure. The maximum stress value in X direction is 110MPa, on both sides of air admission opening; the maximum stress value in Y direction is 178MPa, on tower walls connection to the spurting beam. The maximum deformation value is 31.33mm, occurred at the air admission opening. The maximum deformation value is 49.9mm in Y direction, occurred at the location of spurting beam. And Y direction is the weak direction of the tower structure. It shows that the directions of inputting seismic wave will have direct impact to the desulfurization tower structure. The stress concentration destructed the stress status of the shell and affected the steady of the desulfurization tower structure seriously.
(3) Based on the analysis on stress distribution and deformation with and without considering the liquid containing in the tower structure, it is concluded that the liquid in the structure causes the degradation of the structure strength, especially at the weak areas. The diameter-thickness ratio is one of the main factors of nonlinear buckling of the structure. Therefore, some measurements, such as increasing the thickness of the bottom plate and adding additional supports at the weak areas, need to be considered during the future designs. Hence, it is critical to complete an analysis on the dynamic response of fluid-solid coupling regarding the desulfurization tower design.

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