Design, analysis and application of moving scaffold to the structural maintenance

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Abstract

A liquid storage tank is a huge structure. In case of an oil storage tank, it shows 100m diameter and 30m height thin steel cylinder. Also, in case of a gas holder, it shows 30m diameter spherical steel shell. These are the important structure for industries and social infrastructures. Therefore, the continuous maintenance is required and the appropriate scaffolds are also required to do the complete maintenance of these structures. However, in using the usual scaffold system, it will be a huge structure due to the size of a repairing structure. In this paper, to reduce the scaffold work, the moving scaffold, which is composed of several types of steel section and is movable on the tank, is proposed. The moving scaffold is composed of a lot of segments that can be carried easily and are assembled at the construction site. Also, it must be easy to deconstruct after completion of the maintenance.

In numerical analysis, the moving scaffold systems are modelled by the space frame with semi-rigid joints at both ends and are analyzed by use of finite element method. In numerical computations, the dead load, the moving load by the workers and maintenance equipments and the wind load are considered. From the numerical analysis, the safety of these structures is confirmed. Then, after the assembling of the scaffold system at the constructional site, the safety of the maintenance is confirmed and the complete maintenance is performed.

Keywords: scaffold, semi-rigid joint, FEM analysis, maintenance

1 Introduction

Liquid storage tanks are often used for industrial and social purposes. In case of an oil storage tank, it is a huge and shows 100m diameter and 30m height thin steel cylinder. Also, in case of a gas holder, it shows 30m diameter spherical steel shell. These are the important structure for industries and social infrastructure. These structures have been constructed on the ground and have been prone to corrode. Therefore, the continuous maintenance is required for these structures. To maintain these structures, the appropriate scaffold systems are also required to do these works completely and safely. However, in using the usual scaffold system, it will be a quite laborious work to cover such a huge structure due to the huge size of repairing structure.

In this paper, to overcome these problems, the moving scaffold, which is composed of several types of steel section and is movable on the tank surface, is proposed. The moving scaffold is composed of a lot of segments that can be carried easily and are assembled at the construction site. Also, it must be easy to deconstruct after completion of the maintenance.
In the numerical analysis, the scaffold system is modelled by the space frame with semi-rigid joints at both ends and is analyzed by use of finite element method. In numerical computations, the dead load, the moving load by the workers and maintenance equipments and the wind load are considered.

2 Moving scaffold

2.1 Dimensions and supporting condition

Figure 1 shows the proposed scaffold. These structures mainly consist of knee brace frames, pipes and braces as well as spigots to connect them.

Figure 1 (a) shows the moving scaffolds for the oil tanks. The moving scaffold is hanged on the wind girder of a cylindrical tank and some touch rollers are placed between a cylindrical tank and the scaffold to avoid the collision of a scaffold and a tank. The scaffold has eleven working stages to hold the workers. The height and the width of this scaffold for the cylindrical tank of 26000mm are 20000mm and 1855mm, respectively. To analyze the scaffold, the dead, the moving and the working loads as well as the wind load are taken into account.

Figure 1 (b) shows the photo of the application of the moving scaffold. Also, Figure 1 (c) shows the working status. The scaffold has the driving system installed on the second wind girder from the top of the storage tank and can move along an oil tank surface.

![Diagram of scaffold and application](image-url)

(a) Cylindrical Tank
(b) Scaffold
(c) Working

Figure 1. Moving scaffold (unit:mm)

2.2 Loading conditions and element properties

To analyze the moving scaffold, the self weight, the working load including the impact load and the wind loading is considered.

<table>
<thead>
<tr>
<th>Element</th>
<th>Loading (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main truss</td>
<td>10.555</td>
</tr>
<tr>
<td>Upper cage</td>
<td>0.176x3= 0.529</td>
</tr>
<tr>
<td>Lower cage</td>
<td>0.216x8= 1.728</td>
</tr>
</tbody>
</table>
2.2.1 Self weight
Table 1 shows the self weight adopted in this analysis. The self weight of the upper and lower cages is calculated into the surface load of the main trusses and the total loads including the self weight of main trusses are distributed to each nodal load depend on the self weight of the composed members.

2.2.2 Working load
Total eleven workers ride on the moving scaffold in three upper and eight lower cages simultaneously. For each cage, 0.784kN and 0.196kN are estimated as the human weight, the maintenance equipments and the materials, respectively.

2.2.3 Impact loading
The impact load is considered as 20% of the working loading.

2.2.4 Wind load
In this analysis, the wind pressure is applied to the tangential (hoop) direction of the tank surface and the design wind speed is defined as 10m/s. Therefore, the fundamental wind load is defined as:

\[ q_{10} = \frac{v_{10}^2}{1.6} = \frac{10^2}{1.6} = 62.5 \text{ N/m}^2 \]  

(1)

The wind pressure applied to the moving scaffold is as follows:
- if height \( h \) is from 0 to 10m
  \[ p = C_s q_{10} = \left( \frac{h}{10} \right)^2 \times 62.5 = \left( \frac{10}{10} \right)^2 \times 62.5 = 62.5 \text{ N/m}^2 \]
- if height \( h \) exceeds 10m
  \[ p = C_s q_{10} = \left( \frac{h}{10} \right)^2 \times 62.5 = \left( \frac{20}{10} \right)^2 \times 62.5 = 70.6 \text{ N/m}^2 \]  

(2)

The wind pressure is applied to the tangential (hoop) direction of the tank surface.

2.2.5 Element properties
Figure 2 shows the several elements used in the moving scaffold. Cross sections (a)-(c) are used for the portion of the hanger at the wind girder of the tank. Cross section (d) is used for the arm lock placed to prevent the falling down the scaffolding. Also, elements (e)-(f) are for the truss around the upper portion of the scaffold. Elements (g)-(h) are elements for the truss around the lower portion of the scaffold. Finally, an element (i) is used for the bracing.

![Cross section of the element](image)
3 FEM analysis

3.1 Elements and connections

To represent the behaviour of the moving scaffold composed of several pipes shown in Figure 2, 3D bar element with semi-rigid joints (see Figure 3) is adopted (Hara et al, 2009). In this model, three types of connections are introduced (see Figure 4). The spring constant $K_i$ at each node is represented as follows:

$$K_i = \frac{\lambda}{1 - \lambda} K$$

where $\lambda$ and $K$ are the spring parameter and the beam flexural stiffness, respectively. In this analysis, $\lambda=1.00$, 0.47 and 0.00 are adopted to represent the stiffness of a welded, a spigot and a pin connections, respectively (see Figure 4).

![Figure 3. 3D bar element with semi-rigid joints](image1)

![Figure 4. Connections of joints](image2)

3.2 Numerical model

The moving scaffold is modelled by use of several 3D pipe elements. Considering the connection rigidities, numerical model is presented in Figure 5. Figures (a) through (d) represent the numerical model from top to bottom. The top of the scaffold is supported by the touch rollers and hanged at a wind girder of the cylindrical tank to avoid the collision of a tank and a scaffold.

The bottom end is also supported on the cylindrical tank surface by touch rollers. Table 2 shows the material data used in this model. Young’s Modulus is evaluated as 205GPa from the material tests.

<table>
<thead>
<tr>
<th>Steel</th>
<th>Tensile Strength(MPa)</th>
<th>Yield Stress(MPa)</th>
<th>Allow. Stress(MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUS304</td>
<td>410</td>
<td>240</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>2%Strain Strength(MPa)</td>
<td>Allow. Stress(MPa)</td>
<td>Allow. Stress (M12Bolt)</td>
</tr>
<tr>
<td></td>
<td>205</td>
<td>120</td>
<td>13.5kN</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wire</th>
<th>Ultimate Load(kN)</th>
<th>Allow. Load(kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-7</td>
<td>45</td>
<td>4.5</td>
</tr>
<tr>
<td>U-16</td>
<td>96</td>
<td>9.6</td>
</tr>
</tbody>
</table>
3.3 *Combination of loading condition*

To design the moving scaffold, four types of loading conditions are considered. Type I is the loading condition only under a self weight. Type II is the combination of a self weight and wind loading. Type III is the condition of a self weight and a working load including an impact loading under working. Finally, Type IV is the loading condition under a self weight and a working and an impact loads as well as a wind loading.
4 Numerical results

4.1 Deformation of the scaffold

Figure 6 shows the deformation of the moving scaffold under several loading conditions. The deformations are represented with large amplitude with magnifying factor. However, the deformation is small. For example, Type I shows the largest deformation of 150mm. This deformation is almost the same as the deformation after assembling on the constructional site.

Types II and IV show a large deformation. Therefore, scaffold must be fixed when the wind speed exceeds 10m/sec.

4.2 Element forces of the scaffold

Table 3 shows the maximum axial force arisen in the scaffold under several conditions. In the Table, “free” and “fix” represent under free and fix support conditions at the bottom of the moving scaffold. If the bottom edge of the scaffold is not fixed under loading Type II and IV, the element axial load exceeds allowable stress limit. Therefore, appropriate treatment is required on such conditions.

Table 3 Maximum element force (Unit: kN + tension – compression)

<table>
<thead>
<tr>
<th>Types</th>
<th>Upper portion</th>
<th>Lower portion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>outside</td>
<td>Tank side</td>
</tr>
<tr>
<td>Type I</td>
<td>-3.28</td>
<td>-3.32</td>
</tr>
<tr>
<td>Type II free</td>
<td>-11.34</td>
<td>4.74</td>
</tr>
<tr>
<td>Type II fix</td>
<td>-5.59</td>
<td>-1.01</td>
</tr>
<tr>
<td>Type III</td>
<td>-8.86</td>
<td>-8.89</td>
</tr>
<tr>
<td>Type IV free</td>
<td>-16.92</td>
<td>-0.85</td>
</tr>
<tr>
<td>Type IV fix</td>
<td>-11.18</td>
<td>-6.59</td>
</tr>
</tbody>
</table>

5 Conclusions

To support the safety and efficient maintenance working, the moving scaffold is designed and numerically analyzed. From the numerical analyses under several loading conditions, following conclusions are obtained

1. In usual working conditions, all the elements show the elastic stress and the stresses do not exceed the allowable stress. Therefore, the safety of these structures is confirmed.
2. Under the strong wind, the bottom of the moving scaffold should be fixed because of keeping the stability and reducing the internal stresses in the element.
3. In the case of wind load, a few element stresses exceed their allowable stress. However, in this analysis, the allowable stress relief is not considered. Therefore, it is possible to apply the moving scaffold to all the loading conditions.

After analysing the safety of the structure, the scaffold system is assembled at the constructional site. Then, the maintenance work is actually performed safely and completely (see Figure 1(c)).

References