Design, Analysis and Application of Moving Scaffold to the Maintenance for Spherical Structures

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Abstract

Spherical holders have spherical shape to prevent against high pressure and to save their construction materials. It is difficult to assemble the usual scaffold to maintain them. To overcome these problems, the moving scaffold, composed of several types of steel section, was proposed. The moving scaffold was composed of a lot of segments that was carried easily and was assembled at the construction site. Also, it was easy to reassemble after completion of the maintenance. To design such structure safely, the numerical evaluation was required. The moving scaffold was modeled by the space frame with semi-rigid joints at an end or both ends. The model was analyzed by use of Finite Element Method. In numerical analysis, the dead load, the moving load by the workers and maintenance equipments and the wind load were taken into account. From the numerical analysis, the safety of these structures was confirmed. Then, after the assembling of the scaffold system at the constructional site, the safety and the economical scaffold systems were confirmed. Then, the complete maintenance was performed.

Keywords: spherical holder, moving scaffold, FEM analysis

Introduction

A spherical storage holder is a popular structure for storing liquid and gas materials. In case of a gas holder, it grows over 30m diameter spherical steel shell. These are the important structure for industries and social infrastructure. To provide the safe infrastructure, the continuous maintenance is required. Therefore, the appropriate scaffolds are also required to complete the maintenance of these structures. However, in using the usual scaffold system, it will be quite difficult to cover such structures. Figure 1 shows the scaffold system plan for the spherical holder of the radius 11.25m.

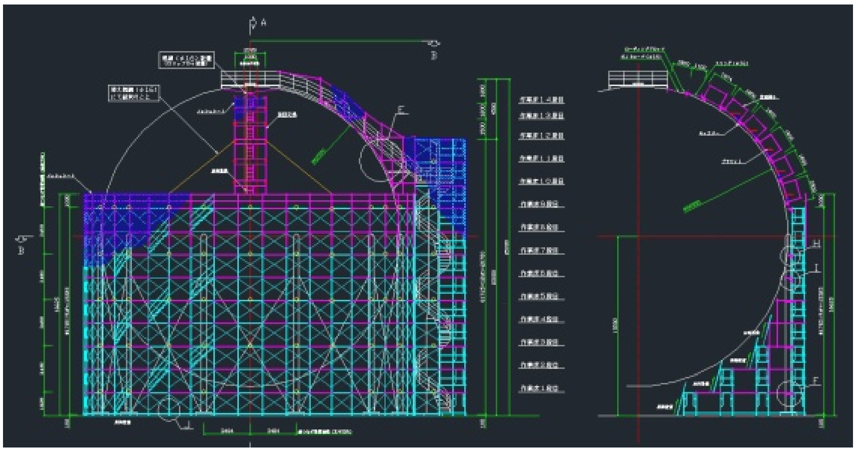

Figure 1 Typical spherical holder and scaffold

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If the usual scaffold is assembled on the upper half of the sphere, a lot of materials are required and the assembling work is also laborious. Based on the assemblage of the scaffold elements (Hara et al, 2010), the moving scaffold was designed and was used for a sufficient maintenance works for the oil tanks. It was confirmed to develop an easy and a sufficient scaffold system for managing the maintenance work.

In this paper, to overcome the assembling problems of scaffold for the spherical holder, the moving scaffolds composed of several types of steel section were proposed. The moving scaffold is composed of a lot of segments that can be carried easily and be assembled at the construction site. Also, it can be easy to reconstruct after completion of the maintenance. The systems were modeled by the space frame with semi-rigid joints at an end or both ends and were analyzed by use of Finite Element Method. In numerical analysis, the dead load, the moving load by the workers and maintenance equipments and the wind load were applied and the safety of the structure was confirmed to evaluate the displacements and the stresses.

Moving Scaffold

Dimensions and support

Figure 2 shows the proposed moving scaffold for spherical holder. The moving scaffold consists of 6 cages. The number of cage is changed depending on the size of holder.

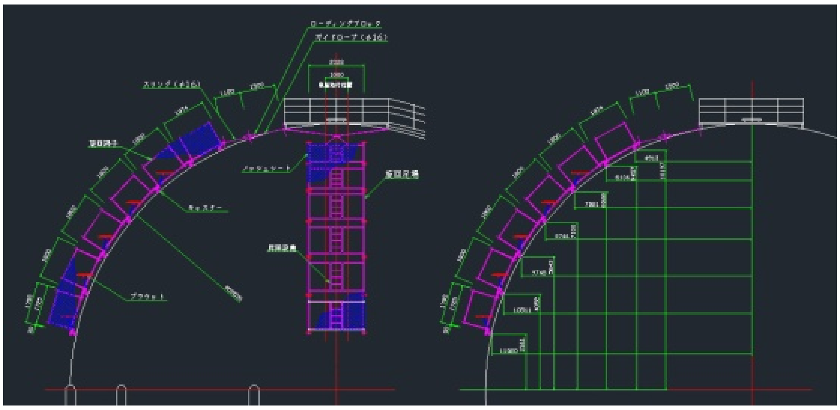


Figure 2 Moving scaffold

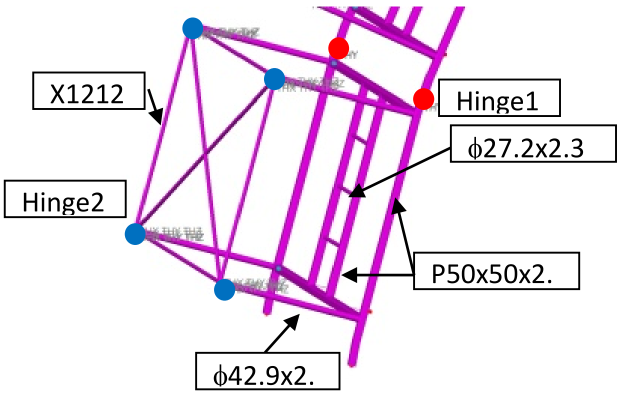


Figure 3 Structure of the cage

In this example, the diameter of the holder is 22.5m.

Each cage is shown in Figure 3. Cages are connected each other by two hinges, Hinge1. The base frame of the cage consists of P50x50x2.3mm box section shown in Figure 6 welded at ends. The length, the width and the height of the cage are 1400mm, 2320mm and 1280mm, respectively. Three radar steps are ϕ27.2x2.3mm pipes welded to the box section of the base frame. Four posts ϕ42.9x2.3mm are the spigot and socket connection to the base frame at one end. The other end is connected to the cover frame with hinges, Hinge 2. Cover frame consists of X1212 bars. Hinge 1 can only rotate around horizontal axis and Hinge 2 can rotate in any direction. On lower edge on the base frame, four touch rollers are placed for the top cage and two touch rollers are placed to the others. The touch roller can move easily only in vertical direction. Each cage is covered by the transparent mesh sheet to avoid the spreading the dust and the paint and to prevent the accidents of the falling of equipments as well.

Total moving scaffold is suspended by a pair of wires of diameter 16mm at the top of the holder. A pair of wire is squizzed at one point and hooked at the spherical top. Moving scaffold model is shown in Figure 4.

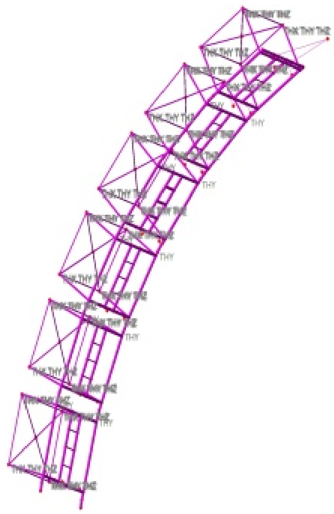


Figure 4 Total model

Loading conditions

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

Self weight

The self weight of cages is applied as the body force of the cage. Each member presented in Figure 4 is divided into four elements and the total load is distributed to the nodes depend on the self weight of the composing members.

Working load

Total six workers ride on each cage simultaneously. For each cage, 0.784kN and 0.196kN are estimated as the human weight and the materials, respectively.

Impact loading

The impact loading is considered as 20% of the self weight and the working loading.

Wind load
In this analysis, the wind pressure is applied to the tangential direction of the spherical holder surface and the design wind speed is defined as 10m/s.

$$p = 130.6 N / m^2 \tag{1}$$

The wind pressure is applied to the tangential direction of the spherical holder surface. The wind pressure applied area is 1400mmx1100mm. The transparent ratio of wind through the protection net is 50%. Also, the wind pressure on wind ward and lee word is 80% and -40% respectively (see Figure 5). The wind pressure on the surface of the cage is 104.5N and 52.3N in wind ward and lee word sides, respectively.

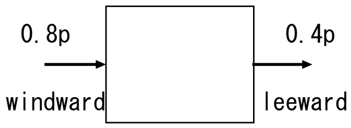


Figure 5 Wind pressure

Element properties

Figure 6 shows the several elements used in the moving scaffold. Cross section (a) is used for the top and the next to the top of the base frame to prevent the local buckling of the frame. Section (b) is used for all other portions of the base frame. Cross section (c) is used for the post to resist against the wind pressure. Also, element (d) is used for the step on the base frame. Element (e) is used for the bracing.

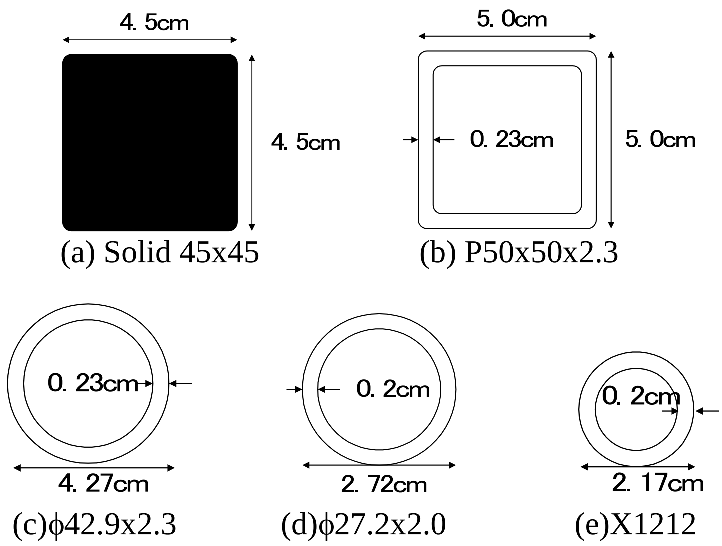


Figure 6 Cross section of the element

FEM analysis

Semi rigid connection

To represent the behaviour of the moving scaffold composed of several pipes shown in Figure 6, 3D bar elements with semi-rigid joints (see Figure 7) are adopted (IASS 2014 and Hara et al, 2009). In this model, two types of connections are introduced (see Figure 8).

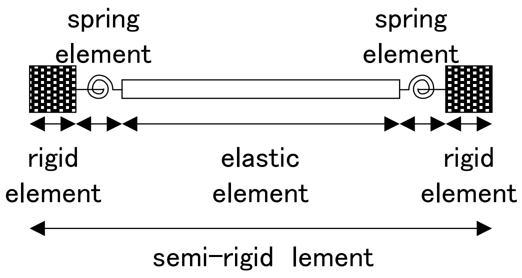


Figure 7 3D bar element with semi-rigid joints

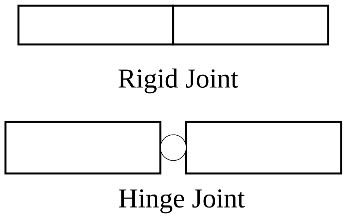


Figure 8 Connection type

The spring constant K_i at each node is represented as follows:

$$K_i = \frac{\lambda}{1-\lambda} K \quad (2)$$

where λ and K are the spring parameter and the beam flexural stiffness, respectively.

In this analysis, λ=1.00 and 0.00 are adopted to represent the stiffness of a welded and a hinge connections, respectively (see Figure 8).

Numerical Model

The moving scaffold for the spherical holder is modeled by use of several 3D elements. Considering the connection rigidities, numerical model is presented in Figure 9. Left and right figures show the upper three cages and the lower cages. The structure is modeled by 2012 nodes and 1044 elements.

Table 2 shows the material data used in this model. Young’s Modulus is evaluated as 205GPa from the material tests.

Table 1 Material Data

Steel	Tensile strength	Yield stress	Allowable stress
	410MPa	240MPa	140MPa
ϕ16wire	Tensile strength		Allowable load
	141kN		14.1kN

Combination of loading

To design the moving scaffold, three types of loading conditions are considered:

- Type I is the loading condition only under s self weight.
- Type II is the condition of a self and impact loadings under working.
- Type III is the loading condition under a self and impact loading as well as a wind loading.

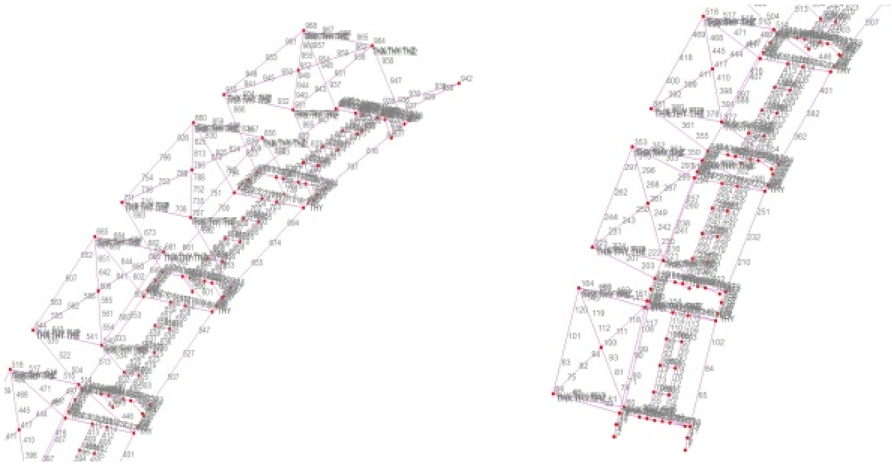
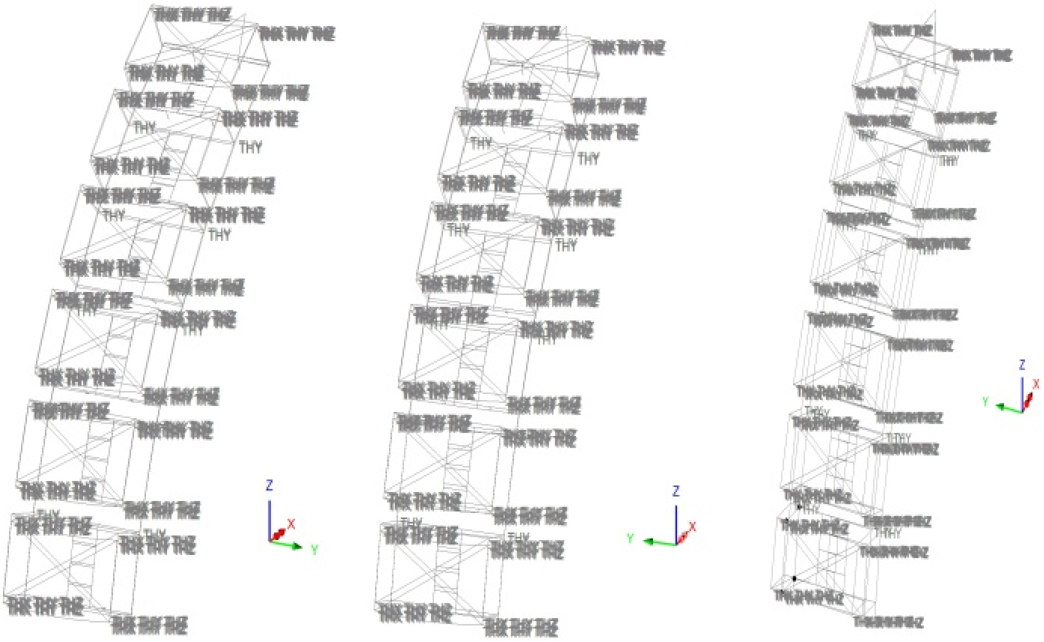


Figure 9 Numerical model

Numerical results

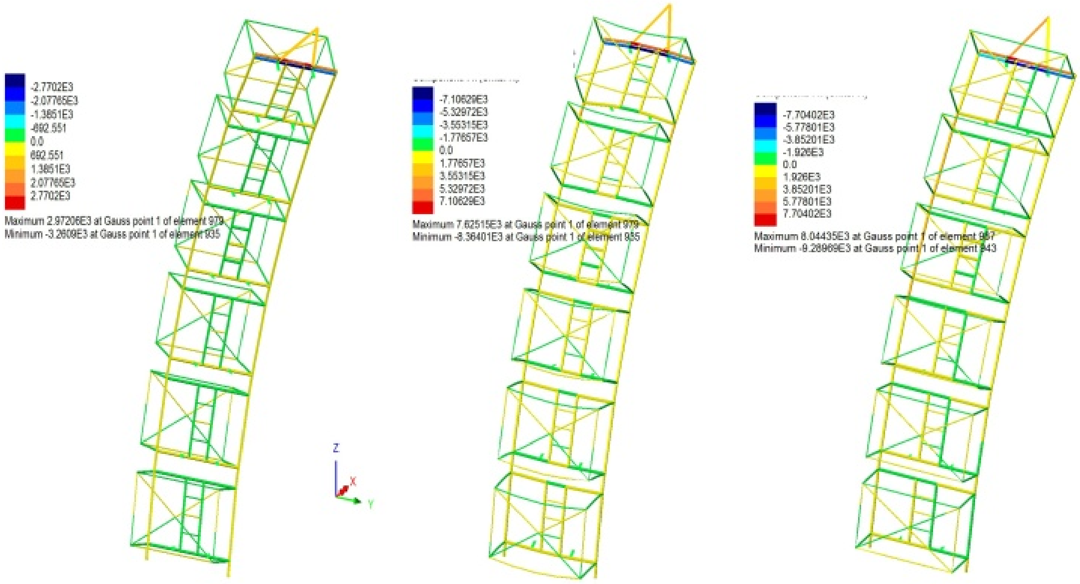
Deformation of the scaffold

Figure 10 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. Maximum displacements are 4.75mm and 5.06mm in vertical direction in Type I and Type II, respectively.



(a) Type I (b) Type II (c) Type III

Figure 10 Deformation under several loading



(a) Type I (b) Type II (c) Type III

Figure 11 Axial forces under several loading

In Type III lateral displacement shows the largest deformation of 115mm. These are the small displacement for the safety under design conditions.

Element forces of the scaffold

Figure 11 shows the axial force arisen in the scaffold elements under several conditions. In every loading case, forces in the elements are concentrated around the connection with wire rope at the top of the moving scaffold. The forces are 3.26kN, 8.36kN and 9.29kN for Type I, Type II and Type III, respectively. However, the stresses do not exceed the allowable stress limit shown in Table 1.

Stress in wire rope is 30.20N/mm^2 under Type III. It is equivalent to the tensile force 6.07kN.

Conclusions

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

- Usual working conditions, Type I and Type II, all the elements show the elastic status. Also the deformation is small. Therefore, the safety of these structures is confirmed.
- In the case of wind loading with usual working load, Type III, the moving scaffold is within the elastic condition and the deformation is not so large. The continuous working could be done under wind speed 10m/sec.
- Under the strong wind, exceeding the design wind pressure, the bottom of the moving scaffold should be fixed because of the stability and reducing the internal stresses.

After analyzing the safety of the structure, the scaffold system is assembled at the constructional site. Then, the safety and complete maintenance are actually performed.

References

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