Analysis on the Stability of double-fastener type Tubular Scaffold

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Abstract. The fastener type scaffold has the advantages of dismounting convenience, wide universality and good integral rigidity, which can bring convenience for construction. In this paper, the finite element software ANSYS10.0 has been used to construct a semi-rigid tubular scaffold model, on which certain concentrated load has been applied for numerical analysis. This paper mainly studies the effect of steel-tube thickness and the arrangement of connecting tubes on the stability of scaffold, so provide a theoretical basis for the practical construction and design of scaffold, and to reduce the incidence of accidents.

1. introduction
As construction needs a long time and bears complex forces, there exists many unstable factors and great risks during the application of scaffold. The analysis on the stability of semi-rigid scaffold aims to reduce accidents caused by scaffold.

The pipe thickness is required to be 3.6 mm and the allowable deviation is -0.6 mm in Standards, so the actual pipe thickness for this scaffold should lie between 3.0mm~3.6mm[1]. However, in order to reduce the material cost, the pipe wall thickness used in actual construction is only 2.5mm~3.0mm and even below 2.5mm[2], which is far from the requirement in the Standards. While, the scheme design is based on the condition with a pipe-wall thickness of 3.6mm. So, the big difference of the pipe-wall thickness in the Standards and actual construction will affect the stability of scaffold and may threaten the safety.

2. Stability calculation for the vertical pole of semi-rigid scaffold
The stability calculation formula has been specified in Technical code for safety of steel tubular scaffold with couplers in construction (JGJ130-2011) as below:

Without wind load:

\[ \frac{N}{\phi A} \leq f \]  

(1)

Where,
\( N \) –Design value for the axial force on the vertical bar (N);
\( \phi \) –Stability coefficient of axial compression members; It should be determined by Table A-0.6 in Appendix A according to the slenderness ratio \( \lambda \);
\( A \) –Cross-section area (m²) of vertical bar;
$f$ – Design value of steel strength.

The stability coefficient of axial compression members can only be obtained when its slenderness ratio $\lambda$ is computed. The formula for slenderness ratio $\lambda$ is as below:

$$\lambda = \frac{l_0}{i}$$

Where,

- $l_0$ – The length (mm);
- $i$ – Refers to the gyration radius (mm).

$l_0$ can be computed according to the following formula for slenderness ratio $\lambda$:

$$l_0 = k \mu h$$

Where,

- $k$ – Additional coefficient for the length of vertical pole. $k = 1.155$; When it is used to check the slenderness ratio, $k = 1$;
- $\mu$ – Length coefficient of single pole under the consideration of overall stability factor of single-double fastener scaffold;
- $h$ – Step distance.

The length coefficient of the vertical pole in the scaffold is shown in Table 1.

### 3. Establishment of scaffold model

The research object in this paper is a 6-span (X-direction) 4-step (Z-direction) (9m×7.2m) scaffold. The geometric parameters of the model include step distance (1.8m), vertical distance (1.5m), transverse distance (1.05m), and distance between the sweep rod and the ground (0.2m). Besides, the bridging is arranged reasonable, and a concentrated force ($F=4000$N) has been applied on the model in the vertical downward direction according to the self-weight of the personnel and materials specified in the Standards. The geometric characteristics of the steel pipe section are shown in table 2, and the steel pipe material parameters in Table 3.

#### Table 1. The length coefficient of the vertical pole in the scaffold.

| Type            | Horizontal Distance of Vertical Pole (m) | Arrangement of Connecting Bars |
|-----------------|-----------------------------------------|--------------------------------|
| Double Fastener | 1.05                                     | Two-step Three-span             |
|                 |                                         | 1.50                            |
|                 |                                         | 1.70                            |
| Single Fastener | 1.30                                     | Three-step Three-span           |
|                 |                                         | 1.55                            |
|                 |                                         | 1.75                            |
|                 |                                         | 1.55                            |
|                 |                                         | 1.60                            |
|                 |                                         | 1.80                            |

#### Table 2. The geometric characteristics of the steel pipe section.

| Outer Diameter (m) | Pipe-wall Thickness (m) | Area of Cross Section (m²) | Inertia Moment (m⁴) | Section Modulus (m³) | Gyration Radius (m) |
|--------------------|--------------------------|-----------------------------|---------------------|----------------------|---------------------|
| 4.83×10⁻²          | 3.6×10⁻³                 | 5.06×10⁻⁴                   | 1.271×10⁻³          | 5.26×10⁻⁸            | 1.59×10⁻³           |

#### Table 3. The steel pipe material parameters.

| Elastic Modulus (Pa) | Poisson's ratio | Yield Limit (Pa) | Density (kg/m³) |
|----------------------|-----------------|------------------|-----------------|
| 2.06×10¹¹            | 0.3             | 2.05×10⁸         | 7800            |
Establishment of module: The scaffold is hinged to the ground fixedly; The effect of the horizontal load is not taken in account; The dynamic load is not considered; The bridging is arranged to be four-step and four-span style; Beam188[3] has been used to simulate the steel pipe. The ANSYS model is built as below (Figure.1, Figure.2).

The combin14 spring unit is adopted to control the horizontal and vertical bar to rotate in the X direction, Y direction and Z direction. The torsion rigidity value K is taken to be 20kN.m/rad according to literature[4]. The superposition node coupling is used for the join points between the horizontal and vertical rods to control their horizontal movement in the X, Y, and Z directions. The scaffold node diagram is shown in Figure 3. The vertical downward force F = 4000N is applied on the node 859 of the horizontal pole for corresponding mechanical analysis. This paper focuses on the extraction of axial force on the vertical pole, which is used for the stability calculation of the scaffold.

4. Effect of the pipe-wall thickness on the stability of the semi-rigid scaffold
It can be seen from above that when the horizontal distance is 1.05m and the arrangement type of
bars is two-step three span, the axial force of the vertical pole can be obtained by ANSYS and the stability value of the scaffold can be calculated according to formula 1, formula 2 and formula 3. The data is shown in table 4.

The results of table 4 show that the stability of scaffold will be worse and worse with the decrease of the pipe-wall thickness. And, when wind load is not considered, the vertical pole meets the requirement of compression resistance.

It can be seen from above that when the horizontal distance is 1.05m and the arrangement type of connecting bars is three-step three-span, the axial force of the vertical pole can be obtained by ANSYS and the stability value of the scaffold can be calculated according to formula 1, formula 2 and formula 3, as shown in table 5.

Its results reflect the same law with that of the scaffold with two-step three-span connecting bars, that the stability of scaffold will be worse and worse with the decrease of the pipe-wall thickness.

| Table 4. Stability calculation of the scaffold with two-step three-span connecting bars. |
|----------------------------------------|--------|--------|--------|--------|--------|--------|-------|
| pipe-wall thickness (mm)  | k      | h      | l0=kµh( mm) | i      | λ = l0/i | φ     | N (N) | N/φA (MPa) |
|--------------------------|--------|--------|-------------|--------|----------|-------|-------|------------|
| 3.6                      | 1.155  | 1800   | 3118.5      | 15.9   | 196      | 0.188 | 2502  | 26.3       |
| 3.4                      | 1.155  | 1800   | 3118.5      | 15.92  | 196      | 0.188 | 2515  | 26.42      |
| 3.2                      | 1.155  | 1800   | 3118.5      | 15.98  | 195      | 0.189 | 2530  | 26.46      |

| Table 5. Stability calculation of the scaffold with three-step three-span connecting bars. |
|----------------------------------------|--------|--------|--------|--------|--------|--------|-------|
| pipe-wall thickness (mm)  | k      | h      | l0=kµh( mm) | i      | λ = l0/i | φ     | N (N) | N/φA (MPa) |
|--------------------------|--------|--------|-------------|--------|----------|-------|-------|------------|
| 3.6                      | 1.155  | 1800   | 3118.5      | 15.9   | 196      | 0.188 | 2502  | 26.3       |
| 3.4                      | 1.155  | 1800   | 3118.5      | 15.92  | 196      | 0.188 | 2515  | 26.42      |
| 3.2                      | 1.155  | 1800   | 3118.5      | 15.98  | 195      | 0.189 | 2530  | 26.46      |

It can be seen from the comparison of Table 4 and Table 5 that the arrangement of connecting bars affects the stability of the scaffold. When connecting bars are arranged to be three-step three-span style, the stability of scaffolding is obviously poorer.

5. Conclusion
This paper focuses on the effect of the pipe-wall thickness of scaffold on the stability of the scaffold, that the stability of scaffold will be worse and worse with the decrease of the pipe-wall thickness. It can be seen from the research that the stability of the vertical pole is affected by the wall thickness of the steel pipe. If there exist big deviation of actual pipe-wall thickness from required thickness during construction, the stability of scaffold will certainly be affected, which may lead to safety danger. So, steel pipes whose wall thickness does not meet requirements should not be used in construction. Besides, it is found from the calculation that the arrangement of connecting bars also has a great influence on the stability of the scaffold. Relatively, the more connecting bars arranged, the better the stability of the scaffold.

References
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