Structural Analysis of Steel Pipe Scaffolding Based on the Tightening Strength of Clamps

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Abstract
In this study, the authors' plan to investigate the status of steel pipe scaffolding assembled on domestic construction sites, to use specific tests to determine whether the torque of the clamps surveyed satisfies the test criteria specified in the functional examination standard of the provisional facility, to compare and analyze the marginal load of buckling using main variables (by size, construction work type) by applying the spring coefficient of the clamps as calculated using the MIDAS structural analysis program and, with all these results, to propose improvements and direction for the future. Ultimately, the goal is to establish measures to prevent accidental falls due to the collapse of improperly assembled scaffolding.

The result of functional certification standard tests for clamps showed that the fastening strength of clamps on the main members (poles, wales, and joists) reached only 63.3% (13.03 average maximum load/35Nm Standard fastening strength × 100) of the standard fastening strength (35Nm), indicating that certified clamps were not used. Accordingly, there is a necessity for thorough public relations, education, guidance, and examination to allow workers to engage in safety management and understand the importance of clamp fastening strengths on outdoor steel pipe scaffolding.

Keywords: scaffolding; clamp test; fastening strength; spring coefficient

1. Introduction
The strength of joints is very important for any structure and, thus, is thoroughly managed and supervised during building construction. Improperly designed joints will cause very serious problems with regard to structural integrity and/or strength. However, up to this point, there have been no regulations outlining how strongly to fasten clamps when building steel pipe scaffolding on a construction site, except for one provision which states that clamps should be fastened with the force of 35 Nm when performing an official approval test for a provisional facility. On most construction sites, typically only certain parts of the scaffolding, such as the poles, etc. and the structure at the base of the scaffolding (i.e., those which are included in the safety provisions), are carefully managed to be free of problems; however, the fastening strength of the clamps are not managed at all. Therefore, there always is a potential risk in any scaffolding structure as site workers fasten clamps to varying degrees using adjustable wrenches with no provision for exact fastening strength.

In this study, the authors' plan to investigate the status of steel pipe scaffolding assembled on domestic construction sites, to use specific tests to determine, whether the torque of the clamps surveyed satisfies the test criteria specified in the functional examination standard of the provisional facility, to compare and analyze the marginal load of buckling using main variables (by size, construction work type) by applying the spring coefficient of the clamps as calculated using the MIDAS structural analysis program and, with all these results, to propose improvements and direction for the future. Ultimately, the goal is to establish measures to prevent accidental falls due to the collapse of improperly assembled scaffolding.

2. Survey of Actual Situation of Using Steel Pipe Scaffolding
2.1 Plan and method of survey
In this study, a conversational survey was conducted in order to investigate problems related to the use of steel pipe scaffolding on construction sites. Twenty subjects were surveyed, including four safety managers, three site managers, four supervisors of scaffolding work, three site workers who perform scaffolding work and seven site workers who use external scaffolding.
Also, in order to measure the fastening strength of clamps, the torque of 2,701 clamps in scaffolding poles, wales, joists, braces, struts, and safety railings were measured. This was accomplished by directly fastening the clamps in the fastening direction using a torque wrench on 23 construction sites including 2 large sites, 5 medium-sized sites, and 16 small sites, all of which were located in Seoul and within Gyeonggi province.

2.2 Result of the survey of an actual situation

The authors found that the average interval between steel pipe scaffolding poles, 1.704 mm, was within the specified value of 1,500~1,800 mm, indicating that, in most of the cases, the standard was observed, as shown in Fig.1. This also may indicate that the poles may be deformed because of the wide allowable interval, especially in cases where high scaffolding is used. An investigation of the actual intervals between wales on construction sites revealed an average height of 1,718 mm even though the standard specifies that the height of the first platform must be 2,000 mm or lower and subsequent platforms should use a measurement of 1,500 mm or less. When the authors inquired to site supervisors and site managers as to why the height of the first and second platforms were similar despite the safety standard specifying otherwise, they replied that even though they knew the regulation, they could not help violating it when building scaffolding because workers demand such a height and the working foothold needs to be convenient while working.

Wales were installed with an average interval of 650 mm in the direction of the joist, connecting footholds in a series at widths of 400-500 mm. It was thought that there would be no problem in doing steelwork or moving on these footholds; however, at this narrow width, there is a high risk of falling, particularly for plaster or brick workers who require material to be piled on the foothold.

Joists with no footholds were installed at average intervals of 2,717 mm in the direction of the wales for every 2 to 3 poles. Even where footholds were present, they were installed using rectangular lumbers laid across or only one scaffolding pipe fixed by a clamp, disregarding the provision which specifies that a joist should be installed every 1,500 mm.

Given that the fastening strength of poles, wales, and joists ranged from 10 to 20 Nm while braces and struts revealed relatively higher values, it was determined that site scaffolding workers fastened clamps for braces and struts more strongly by about 17.27% when assembling a scaffolding in order to prevent the collapse of braces and struts, which are fewer than the poles, wales and joists.

An analysis of the average torque in 548 cases among large sites indicated that 180 clamps (33%) were found to be unfastened and, among the remaining 368 fastened clamps (67%), the average torque of braces, poles, wales, and railings finishing work were much higher than in structure work. When the clamp fastening safety value (35 Nm) specified by law was taken as 100%, the clamp fastening force at the large sites revealed a value of 38.11%, far below the fastening value indicated by the safety standard.

Among 894 cases from medium-sized sites, 119 clamps (13%) were found to be unfastened and the order of fastening torque was wales, followed by joists and finally, poles.

At small sites where the fastening torque order was found to be pole, wale and joist, 217 clamps (17%) out of a total of 1,259 clamps were found to be unfastened, as shown in Table 1.

| Table 1. Average Torque of Clamp by Site size (N · m) |
|-----------------------------------------------------|
| **Large size** | **Medium size** | **Small size** |
| Pole | 14.90 | 16.33 | 18.06 |
| Wale | 13.41 | 19.91 | 13.35 |
| Joist | 11.18 | 16.42 | 14.92 |
| Brace | 15.90 | 21.85 | 17.30 |
| Strut | - | 27.21 | 18.28 |
| Railings | 11.31 | - | - |

The fact that 410 clamps (21%) were found to be used in steelwork without being fastened means that 1 out of 5 clamps is being used without being fastened. This is linked to collapsing accidents involving scaffolding used in the construction of high structures.

Also, with steelworks, the average torque of poles was 16.22 Nm and that of wales was 15.76 Nm, which were similar to the total average. With moulding or steel reinforcement work, the average joist torque was 13.64 Nm, indicating that there were a lot more poorly fastened clamps, likely because there are many cases where workers perform their duties without having footholds.

The average torques of braces and scaffolding pole struts, which are linked to the collapse of scaffolding, showed values of 23.84 Nm and 24.73 Nm, both of which are approximately 5.26Nm higher than the total...
average of steel work, 18.26Nm, as shown in Table 2.

In cases of finishing works (plastering, bricklaying, dryvit, and stone works), the number of unfastened clamps found was 106 (14%), which was lower than that of steelworks by 7%. This increased fastening of the clamps on joists etc. for finishing work was likely due to the fact that there were more footholds installed for finishing work.

The fastening torque of clamps on scaffolding poles (19.07 Nm), and that on wales (17.01 Nm) was slightly higher than those in steelwork. The fastening of clamps on joists (16.96 Nm) was done more in order to install work footholds.

3. Clamp Material Test

Pipes and clamps which have been tested were not used again in order to secure the accuracy of the test. For the test, UTM (Manufacturer Daeha Technology Co., Ltd., Korea) of 98 kN was used and a displacement measurement was performed using the displacement measurement instrument of the tester itself.

3.1 Test plan and method

For this test, a roller jig was constructed, as shown in Fig.2., in order to mount the UUT (Unit Under Test). Steel pipes and clamps were not used again in order to secure the accuracy of the test. For the test, UTM (Manufacturer Daeha Technology Co., Ltd., Korea) of 98 kN was used and a displacement measurement was performed using the displacement measurement instrument of the tester itself.

In order to perform the clamp material test, two clamps were mounted on the tester using steel pipes and roller jigs as shown in Fig.3. The tensile strength test was performed as specified below.

1. With respect to the right angle cross-type clamps on which a tensile load is applied, check the change in the distance between the centers of rollers while the load is changed from 0 N to 9.8 kN. Be sure to check the fastening torque of the clamps (35 Nm).

2. The load must be 9.8 kN or more when the displacement measurement is 10 mm.

Table 2. Average Torque (N·m) of Clamps of Small Sites by Construction Types

|                | Steelwork | Finishing |
|----------------|-----------|-----------|
| Pole           | 18.26     | 19.07     |
| Wale           | 17.01     | 16.97     |
| Joist          | 17.30     | 16.97     |
| Brace          | 17.30     | 17.30     |
| Strut          | 20.98     | 20.98     |
| Railings       | 18.26     | 18.26     |
| Total average  | 17.58     | 18.26     |

Table 3. Maximum Load and Displacement of the UUT by Measurement Criteria

| By Site          | Measurement criteria (Fastening strength) | 1     | 2     | 3     | Average |
|------------------|------------------------------------------|-------|-------|-------|---------|
|                  | Max load (kN) | Max displacement (mm) | Max load (kN) | Max displacement (mm) | Max load (kN) | Max displacement (mm) | Max load (kN) | Max displacement (mm) |
| Norm (35N.m)     | 18.42        | 41.45        | 18.62        | 41.68        | 18.72        | 42.11        | 18.62        | 41.75        |
| Large Scale      | Pole (14.9N.m) | 11.96        | 25.60        | 10.78        | 11.39        | 13.03        | 28.67        | 11.96        | 21.89        |
|                  | Wale (13.4N.m) | 17.54        | 38.26        | 13.82        | 30.29        | 9.80         | 22.04        | 13.72        | 30.20        |
|                  | Joist (11.8N.m) | 15.53        | 37.03        | 14.60        | 31.82        | 14.31        | 40.93        | 14.21        | 36.59        |
| Middle Scale     | Pole (16.3N.m) | 13.23        | 23.34        | 13.13        | 18.46        | 15.29        | 31.21        | 13.92        | 24.34        |
|                  | Wale (19.9N.m) | 13.52        | 8.36         | 12.15        | 34.77        | 13.52        | 33.48        | 13.03        | 25.54        |
|                  | Joist (16.4N.m) | 12.45        | 40.54        | 13.92        | 34.58        | 10.49        | 30.73        | 12.25        | 35.29        |
| Small Scale      | Pole (18.0N.m) | 13.81        | 19.51        | 13.92        | 20.61        | 13.92        | 23.40        | 13.52        | 21.17        |
|                  | Wale (13.3N.m) | 18.62        | 30.91        | 12.45        | 31.25        | 13.03        | 37.37        | 14.79        | 33.18        |
|                  | Joist (14.9N.m) | 17.74        | 41.34        | 11.37        | 19.64        | 11.86        | 15.99        | 13.62        | 25.66        |
| Small Scale      | Pole (16.2N.m) | 11.86        | 35.35        | 14.90        | 38.69        | 15.68        | 40.15        | 14.11        | 38.06        |
| Steelwork        | Wale (15.7N.m) | 10.09        | 17.56        | 15.78        | 38.21        | 10.49        | 41.49        | 12.15        | 32.42        |
|                  | Joist (13.6N.m) | 12.05        | 41.09        | 11.76        | 39.98        | 12.54        | 31.83        | 12.15        | 37.63        |
| Small Scale      | Pole (19.0N.m) | 13.33        | 40.94        | 16.27        | 37.52        | 11.37        | 28.71        | 13.62        | 35.72        |
| Finishing work   | Wale (17.1N.m) | 9.41         | 23.09        | 15.39        | 40.96        | 15.39        | 41.27        | 13.43        | 35.11        |
|                  | Joist (16.9N.m) | 9.80         | 16.50        | 12.45        | 18.18        | 15.39        | 29.74        | 12.54        | 21.47        |
Table 4. Test Result of Suitability of Clamps for Functional Certification Standard by Measurement Criteria

| By Site          | Measurement criteria (Fastening strength) | 1          | 2          | 3          | Average          |
|------------------|------------------------------------------|------------|------------|------------|------------------|
|                  |                                          | Max load   | Max load   | Max load   | Max load         |
|                  |                                          | (kN)       | displacement | (kN)       | displacement     | (kN)    |
|                  |                                          | (mm)       | (mm)       | (mm)       | (mm)             | (mm)    |
| Norm (35N.m)     | Pole (14.9N.m)                           | 12.54      | 10.01      | 13.23      | 10.00            | 13.33   | 10.00            |
|                  | Wale (13.4N.m)                           | 4.12       | 10.03      | 9.90       | 10.00            | 7.15    | 10.01            |
|                  | Joist (11.8N.m)                          | 8.13       | 10.00      | 7.64       | 10.01            | 6.66    | 10.00            |
|                  | Pole (16.3N.m)                           | 9.51       | 10.01      | 10.38      | 10.00            | 9.11    | 10.01            |
| Middle Scale     | Wale (19.9N.m)                           | 13.33      | 8.90       | 6.66       | 10.01            | 7.84    | 10.00            |
|                  | Joist (16.4N.m)                          | 6.86       | 10.01      | 8.13       | 10.00            | 5.49    | 10.00            |
| Small Scale      | Pole (18.0N.m)                           | 8.82       | 10.00      | 10.39      | 10.00            | 9.13    | 10.00            |
|                  | Wale (13.3N.m)                           | 12.25      | 10.01      | 9.31       | 10.00            | 6.96    | 10.00            |
|                  | Joist (14.9N.m)                          | 10.09      | 10.00      | 7.15       | 10.00            | 9.70    | 10.00            |
| Small Scale      | Pole (16.2N.m)                           | 5.98       | 10.00      | 9.31       | 10.00            | 9.60    | 9.99             |
| Steelwork        | Wale (15.7N.m)                           | 7.74       | 10.00      | 9.02       | 10.00            | 5.78    | 10.00            |
|                  | Joist (13.6N.m)                          | 7.64       | 10.01      | 5.68       | 10.00            | 7.15    | 10.01            |
| Small Scale      | Pole (19.0N.m)                           | 8.82       | 10.01      | 10.00      | 10.00            | 6.47    | 10.00            |
| Finishing work   | Wale (17.1N.m)                           | 6.27       | 10.00      | 8.72       | 10.00            | 8.23    | 10.00            |
|                  | Joist (16.9N.m)                          | 6.27       | 10.00      | 9.80       | 10.01            | 8.62    | 10.00            |

3.2 Test result

The test result of clamps using these measurement criteria is shown in Table 3.

According to the functional certification clamp standard, if the load is below 9.8 kN when the measurement after fastening the clamp at 35 Nm (which is the test standard) is 10 mm, the function of the UUT is considered imperfect. Accordingly, tests were performed with different fastening strengths for each measurement standard. The result showed that, with standard installation, the load value measured was 13.03 kN when the displacement was 10 mm, meaning that the UUT was functioning perfectly; however, for all other variables, it showed that clamps did not satisfy the functional certification standard, as the loads measured were all below 9.8 kN when the displacement was 10 mm, as shown in Table 4.

Table 5. Test Result Concerning Suitability of Clamps for Functional Certification Standard by Measurement Criteria

| By site   | Measurement criteria | Spring coefficient (kN/m) |
|-----------|----------------------|--------------------------|
| Standard  |                      | 2489.27                  |
| Large     | Pole (14.9N.m)       | 2103.79                  |
|           | Wale (13.4N.m)       | 1916.45                  |
|           | Joist (11.8N.m)      | 1525.60                  |
| Medium    | Pole (16.3N.m)       | 1965.66                  |
|           | Wale (19.9N.m)       | 1956.51                  |
|           | Joist (16.4N.m)      | 1332.10                  |
| Small     | Pole (18.0N.m)       | 2314.70                  |
|           | Wale (13.3N.m)       | 1771.04                  |
|           | Joist (14.9N.m)      | 1185.72                  |
| Steelwork | Pole (16.2N.m)       | 2008.70                  |
|           | Wale (15.7N.m)       | 1282.21                  |
|           | Joist (13.6N.m)      | 945.57                   |
| Finishing | Pole (19.0N.m)       | 2150.59                  |
|           | Wale (17.1N.m)       | 1601.80                  |
|           | Joist (16.9N.m)      | 1865.21                  |

The spring coefficient was calculated using the following equation after finding the elastic limit points referring to the load-displacement curve in Fig.4., as measured by each variable.

Spring coefficient (kN/m) = Load(P) / Displacement(Δ)

4. Structural Analysis of Steel Pipe Scaffolding

4.1 Test plan and method

It is assumed that steel pipe of Φ 48 x 2.3 mm, which is included in Korean Standard (KS) and is the most widely used on construction sites, is used to build steel pipe scaffolding. Additionally, although only the scaffolding which satisfies the related standard shall be considered, braces have been disregarded as it was found that in reality, braces tended not to be used, as shown in Fig.5., Fig.6., and Fig.7.

Also, given that the survey revealed, that at small sites, scaffolding was built without joists in the middle part, the authors applied the same field conditions to this structural analysis.

The UUT was designed so that both-end hinge and an axis of ordinates (Z axis) of the upper part were free to move up and down. It was designed considering each displacement of steel supports which fix the end of steel pipe scaffolding, as shown in Table 6.

Table 6. Axis and Boundary Conditions

| Node and axis | Boundary condition | Axis condition at boundary |
|---------------|--------------------|---------------------------|
| Upper part    | Hinge              | Restraint                 |
|               |                    | Free                      |
|               |                    | Free                      |
|               |                    | Restraint                 |
| Bottom part   | Hinge              | Restraint                 |
|               |                    | Free                      |
|               |                    | Free                      |
|               |                    | Restraint                 |
Also, as the spring coefficient measured in the material test described in Table 5. was applied to the clamp connections with scaffolding poles, wales, and joists, it was not considered a single body structure and was structurally analyzed.

Boundary conditions by axis are shown in Fig.8.
4.2 Result of structural analysis

When performing buckling analysis, first, only factor division, factor/material characteristic, binding conditions, and load condition were set up, as in stress analysis. However, the field condition was set up as the basic load for buckling. Accordingly, if the unit load is established in load setup, the buckling limit load can be easily calculated using the buckling eigen value which is the result of output.

The buckling limit load of steel pipe scaffolding is as follows:
- Standard installation (1.5 m) 38.34 kN/pole × 6 pole (2 bays) = 230.01 kN
- Proposed standard installation (1.8 m) 27.36 kN/pole × 6 pole (2 bays) = 164.15 kN

and the other cases are derived from the above method, as shown in Table 7.

Table 7. Buckling Limit Load of Steel Pipe Scaffolding

| Test variables                  | Buckling Limit Load (kN) | Buckling limit load per pole (kN) |
|---------------------------------|--------------------------|----------------------------------|
| Standard Installation (Interval between wales: 1.5 m) | 230.01                   | 38.34                            |
| Standard Installation (Interval between wales: 1.8 m) | 164.15                   | 27.36                            |
| Large size                      | 108.58                   | 18.10                            |
| Medium size                     | 24.30                    | 4.05                             |
| Small size                      | 70.36                    | 11.73                            |
| Small size steelwork            | 48.80                    | 8.13                             |
| Small size finishing            | 76.34                    | 12.72                            |

5. Analysis

1) 20/23 (87%) of sites were found to neglect the safety provision by building steel pipe scaffolding using an interval of upper and lower wales of 1,700 mm or higher.

2) The investigation regarding the use of steel pipe scaffolding at small sized construction sites revealed that the fastening values of pole, wale, and joist clamps when performing finishing work were higher than those used in steelworks by 2.43 Nm (13.97%).

3) The analysis of the installation interval of steel pipe scaffolding revealed that joists were installed every 3 meters in medium-sized and small sites only.

4) The result of structural analysis revealed that the buckling limit load was 230.01 kN in the case of existing standard installation (interval between wales: 1.5 meters). On the other hand, in the case of proposed standard installation using 1.8 meter intervals between wales, the buckling limit load was 164.15 kN, a 28.64% decrease from that of the standard installation using 1.8 meter intervals between wales.

5) When performing a structural analysis of steel pipe scaffolding, the buckling form of the framework was measured at the halfway point and, when
connected to a wall of the structure, showed a partial buckling 2/3 from the bottom.

6. Conclusion
The following conclusions were made based on the analysis:

1) It was found that workers are fastening clamps randomly and thus, many clamps are being used for steel pipe scaffolding at construction sites without being fastened. The result of functional certification standard tests for clamps showed that the fastening strength of clamps on the main members (poles, wales, and joists) reached only 63.3% (13.03 average maximum load/35Nm Standard fastening strength × 100) of the standard fastening strength (35 Nm), indicating that certified clamps were not used. Accordingly, there is a necessity for thorough PR, education, guidance, and examination to allow workers to engage in safety management and understand the importance of clamp fastening strengths on outdoor steel pipe scaffolding.

2) The reason why wales are installed using 1.7 meter intervals or better between the lower and upper wales in most construction sites is because workers can not move around and perform their duties while standing on the 1.5 meter interval as specified in "Safety Rules, Industrial Safety Act." When structural analysis was performed on a wale interval of 1.8 meters, the breakdown strength of a pole was found to be 27.34 kN, which is about four times the maximum breakdown strength of a scaffolding pole as specified in "Installation of Steel Pipe Scaffolding and Use Safety Guide" (6.86 kN). As there is enough room to secure safety and even economic efficiency of construction, the authors believe it is necessary to modify the related law to allow the installation of wales with intervals of 1.8 meters or less.

3) Though strut, brace, and joint are important in order to prevent the buckling of scaffolding, site examination of the actual status indicated that in many cases, installation was done improperly. The result of the structural analysis test revealed that the breakdown strength of scaffolding in medium-sized and small sites, where joists were installed at intervals larger than 3 meters, was 3.1 times lower than that of large sites, as well as that of the standard installation (interval between wales: 1.5 and 1.8 meters) where joists were found to be installed between every pole. This result suggests that the provisions for installation of scaffolding in "Safety Rules, Industrial Safety Act" should be adhered to in order to secure scaffolding safety.

References
1) Han, S. W. (2008) Seismic hazard analysis in low and moderate seismic region-Korean peninsula. Structural Safety, 30 (6), pp.543-558.
2) Ministry of Labor, Korea government. (2003) Standard for Function measurement of temporary material & machinery. 18th ed. Korea: Ministry of Labor, Korea government.
3) Ministry of Labor, Korea government (2008) Rules for industrial safety and health standard. Ministry of Labor. 308th ed. Korea: Korea government.
4) Song, I. Y. and Back S. W. (2008) Investigation for current status of tightening clamp and using steel pipe scaffolding. Korea: KISS.
5) Choi, S. J. and Song, I. Y. (2008) Investigation of accident in steel pipe scaffolding. Korea: KISS.
6) Na, Y. C. (2006) Test for resist incapacity of steel pipe scaffolding. Korea: Seoul National University of Technology.
7) MIDAS IT. (2002) Structural dynamic learning form MIDAS. Korea: Kimoon dang Publication.
8) Song, I. Y. (2008) Development for fabricated horizontal connections of pipe support. Korea: Health and Safety research institute of KOSHA.