Research on Reinforcement Technology of Grid Bars with Oversized Slenderness Ratio

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Abstract. The stiffness of axially loaded members is usually measured by slenderness ratio, which is the ratio of the calculated length of the member to the minimum turning radius of the member section. If the slenderness ratio is too large, the component is easy to produce bending deformation in the process of use. Under the action of dynamic load, it will produce large amplitude vibration, and it is easy to produce bending deformation in the process of transportation and installation. Therefore, the slenderness ratio of the component should be controlled in the design to make it not exceed the allowable slenderness ratio specified in the specification. Aiming at the problem that the slenderness ratio of space truss exceeds the limit, this paper puts forward the method of reducing the calculated length of members by adding supporting members or auxiliary members, so as to reduce the slenderness ratio of members, and studies the influence of increasing supporting members on the bearing capacity, deformation and seismic performance of space truss, so as to provide theoretical basis and guidance for the implementation of the reinforcement method.

Keywords. Circumambient supporting; dead weight calculation; correction factor.

1. Introduction
Stiffness of axially loaded members is usually measured by the slenderness ratio. Slenderness ratio refers to the ratio between the calculated length and the least radius of gyration of the section of a member. The smaller the slenderness ratio is, the greater the stiffness of the member is; the greater the slenderness ratio is, the smaller the stiffness of the member is. Members with oversized slenderness ratio are prone to be bent out of shape during use, and produce vibration with a large amplitude under dynamic load and are defected during transportation and installation [1]. Therefore, the slenderness ratio of the members should be controlled in the design to ensure that it does not exceed the allowable slenderness ratio specified in the specification.

Cases that the slenderness ratio of the grid members does not meet the design requirements often occur in engineering detection and identification, and the main reasons are [2-6]: 1) the original design is not well considered, and the load or working condition combination is not properly considered in the design; 2) the minus deviation of bar materials is larger during construction, and the slenderness ratio is over the limit when checked according to the actual wall thickness; 3) the bar specifications are confused or wrong during the installation of the grid, causing the misuse of small bars in a place where big bars are required.

At present, there is not much research on the reinforcement method of the members whose slenderness ratio exceeds the limit in the grid structure. So, aiming at the problem of oversized slenderness ratio of the grid, this paper proposes a method of reducing the calculated length of the bar by adding a supporting bar or auxiliary bar to reduce the slenderness ratio of the member, using the
method of finite element analysis to study the influence of adding the supporting bar on the bearing capacity, deformation and seismic performance of the grid, which provides a theoretical basis and guidance for the implementation of the reinforcement method.

2. Reinforcement Method for the Bar with Oversized Slenderness Ratio
When supporting bars are made to reinforce the bars with oversized slenderness ratio (figure 1-figure 3), the supporting bars and grid bars are binged. At the supporting point, the supporting bar is hooped on the bar to be reinforced. Three supporting bars must be added to each bar to be reinforced, and the three supporting bars must be closed to form a stable triangular stress system, with the bar to be reinforced and the three supporting bars not be in the same plane to ensure the stability of the reinforced bar [7-10]. Purpose of the method is to reduce the calculated length of the grid bars by adding supporting bars, so as to reduce the slenderness ratio of grid bars.

Figure 1. Diagram after adding supporting bars.

Figure 2. Diagram of supporting bar.

Figure 3. Diagram of supporting points.
Note: 1. Hoop; 2. Supporting bar; 3. Bar with oversized slenderness ratio.
Compared with existing reinforcement methods, this method has the following advantages: 1) the bars are assembled and connected on site without welding, which avoids the adverse effect of welding on the bearing capacity of the reinforced bars; 2) the method is simple to operate (the bars are assembled and connected on site) and applicable in a wide range, which can effectively improve the reinforcement efficiency; 3) the method does not change the stress system of the original structure, can check the design, and increases relatively little dead weight.

3. Checking of Reinforcement Design of Bars with Oversized Slenderness Ratio

A grid is selected and the structure is checked according to the current specifications, and the reinforcement design is carried out for the bars with oversized slenderness ratio. Data such as the bearing capacity, structure deformation and seismic performance of the grid before and after reinforcement are compared, and the feasibility of the reinforcement method of adding supporting bars and the influence of reinforcement on the checking results of grid structure.

3.1. Structural Arrangement

Grid structural arrangement is shown in figure 4. The elevation difference of ball centers on the upper and bottom chords of the grid is 1800 mm, and the elevation of ball center on the support is 10000 mm.

![Figure 4. Structure plan (Unit: mm).](image)

3.2. Member Specification

There are six specifications for the grid bar, i.e. 1#(Φ48×3.5), 2#(Φ60×3.5), 3#(Φ75.5×3.75), 4#(Φ88.5×4), 5#(Φ114×4) and 6#(Φ140×4), and the design value of the material strength is 215 MPa.

3.3. Load Value

(1) Dead load of upper chord 0.3 KN/m²; (2) Roof live load 0.5 KN/m²; (3) Basic wind pressure 0.35 KN/m²; (4) 8 degrees (0.20 g), the first group; (5) Temperature difference ±20; (6) The dead weight of the grid is automatically generated by computer program.

3.4. Working Condition Combination

(1) 1.35 dead load + 1.40 x 0.70 live load; (2) 1.20 dead load+ 1.40 live load; (3) 1.00 dead load+ 1.40 wind load; (4) 1.20 dead load+ 1.40 live load+ 1.40 x 0.60 wind load; (5) 1.20 dead load+ 1.40 x 0.70 live load+ 1.40 wind load; (6) 1.00 dead load+1.00x0.50 live load+1.30 earthquake; (7) 1.20 dead load+1.00x0.50 live load+1.40x0.20 wind load+1.30 earthquake; (8) 1.00 dead load+1.00x0.50 live load+1.40x0.20 wind load+1.30 earthquake; (9) 1.00 dead load+ 1.00 live load
3.5. Checking Results
It has been checked that there are 14 bars with oversized slenderness ratio on the bottom chord of the grid structure, with the maximum slenderness ratio of 228, as shown in the red bar in figure 5.

![Figure 5. Distribution of bars with oversized slenderness ratio (red bars).](image)

3.6. Calculation Model after Reinforcement
In this grid calculation model, supporting bars are added at the bars with oversized slenderness ratio. Three supporting bars are added at each bar with oversized slenderness ratio to form a stable triangular stress system, and the distance between the supporting points of the three supporting bars and the ball nodes is 1000mm. The Unit No. of the reinforced bars is shown in figure 6-figure 7.

The reinforced calculation model is based on the following assumptions:
1. The connection node between the grid bar and the bolt-sphere joint is hinged;
2. The connection node between the supporting bar and the original grid bar is hinged;

![Figure 6. Plan after reinforcement (inside the dotted line is the reinforced area).](image)

![Figure 7. Elevation after reinforcement (inside the dotted line is the reinforced area).](image)

3.7. Comparison between Calculation Results before and after Reinforcement
(1) Changes in distribution of grid structural internal force
Table 1 shows the comparison data of stress ratio of 10 bars with the maximum stress before and after reinforcement. The distribution of stress of the bars is basically the same before and after reinforcement, and the strength and overall stability-stress around axis 2 are slightly increased after
reinforcement, which suggests that the added supporting bar has little impact (which can be basically ignored) on the stress of grid bars.

Table 1. Checking results of the first 10 units with the maximum “strength-stress ratio” before and after reinforcement.

| No. | Unit No. | Strength-stress ratio before reinforcement | Strength-stress ratio after reinforcement | Results | Overall stability-stress ratio around axis 2 |
|-----|----------|-------------------------------------------|------------------------------------------|---------|----------------------------------------------|
| 1   | 289      | 0.92                                      | 0.93                                     | Consistent | 289 0.92 0.93 Consistent |
| 2   | 291      | 0.92                                      | 0.92                                     | Consistent | 291 0.92 0.92 Consistent |
| 3   | 344      | 0.91                                      | 0.92                                     | Consistent | 344 0.91 0.92 Consistent |
| 4   | 346      | 0.91                                      | 0.92                                     | Consistent | 346 0.91 0.92 Consistent |
| 5   | 155      | 0.88                                      | 0.88                                     | Consistent | 155 0.88 0.88 Consistent |
| 6   | 240      | 0.88                                      | 0.88                                     | Consistent | 240 0.88 0.88 Consistent |
| 7   | 160      | 0.87                                      | 0.88                                     | Consistent | 160 0.87 0.88 Consistent |
| 8   | 235      | 0.87                                      | 0.87                                     | Consistent | 235 0.87 0.88 Consistent |
| 9   | 280      | 0.86                                      | 0.86                                     | Consistent | 280 0.86 0.86 Consistent |
| 10  | 355      | 0.86                                      | 0.86                                     | Consistent | 355 0.86 0.86 Consistent |

Table 2 shows the comparison of stress ratio of the reinforced bar before and after adding the supporting bars. The strength-stress and stability-stress of the reinforced bars are significantly reduced after adding the supporting bars. This suggests that adding the supporting bars can significantly reduce the strength-stress and stability-stress of the bars, which also provides an idea for the reinforcement of the overstress bars.

The strength-stress and stability-stress of the supporting bar are relatively small, which can even be ignored, and the slenderness ratio of the supporting bar also meets the design requirements. This suggests that the added supporting bar can be considered as a zero bar that only plays a supporting role, which is consistent with the expectation and basically realizes the design intention of reinforcement.

Table 2. Changes in internal force of reinforced bars.

| Bar No. | Before reinforcement | After reinforcement |
|---------|----------------------|---------------------|
|         | Strength (MPa)       | Stability-stress (MPa) | Strength (MPa) | Stability-stress (MPa) |
| 124(124)| 0.041                | 0.260               | 0.085         | 0.197               |
| 112(112)| 0.053                | 0.337               | 0.091         | 0.240               |
| 76(76)  | 0.062                | 0.392               | 0.100         | 0.270               |
| 64(64)  | 0.067                | 0.424               | 0.109         | 0.291               |
| 52(52)  | 0.064                | 0.404               | 0.102         | 0.278               |
| 16(16)  | 0.055                | 0.349               | 0.093         | 0.247               |
| 4(4)    | 0.044                | 0.280               | 0.088         | 0.209               |
| 1004(129)| 0.042               | 0.264               | 0.084         | 0.200               |
| 1008(117)| 0.054               | 0.338               | 0.091         | 0.241               |
| 1017(81)| 0.062                | 0.388               | 0.099         | 0.269               |
| 1011(69)| 0.066                | 0.414               | 0.107         | 0.285               |
| 1014(57)| 0.060                | 0.381               | 0.098         | 0.264               |
| 1020(21)| 0.056                | 0.355               | 0.094         | 0.251               |
| 1022(9) | 0.041                | 0.259               | 0.086         | 0.197               |

Note: The Bar No. outside the brackets is the Bar No. in the model after reinforcement, and the Bar No. inside the brackets is the Bar No. in the model before reinforcement.
(2) Changes in slenderness ratio of reinforced bar
There are 14 bars with a slenderness ratio of 228 in the original grid structure, which exceeds the design requirements; after reinforced by adding the supporting bars, the slenderness ratio of the 14 bars is 165, which meets the design requirements. The reason is that this reinforcement method can effectively reduce the calculated length of the bar.

(3) Changes in vertical deflection of grid structure
The vertical deformation of nodes of grid before and after reinforcement has some changes, though not much. This shows that the overall stiffness and stiffness distribution of the grid before and after reinforcement have not been significantly changed, which is mainly because the number of reinforced bars is relatively small and is not enough to have an essential impact on the grid. When a large number of bars are reinforced, the changes in the stiffness of the grid after reinforcement should be considered.

(4) Earthquake period and frequency
When the structure is vibrating, the basic frequency is the smallest one of the natural vibration frequency of the structure (corresponding to the longest basic period), but actually, under the action of earthquake, the first few vibration modes play a controlling role (the frequency is relatively small and is close to the earthquake frequency). Table 3 shows the comparison between the earthquake period and frequency before and after grid reinforcement. The period of the 9 vibration modes is slightly reduced and the frequency is slightly increased after grid reinforcement, which suggests that adding the supporting bars has a certain adverse effect on the seismic performance of the grid. Therefore, the seismic checking must be considered when supporting bars are added to reinforce the grid in areas with earthquake fortification requirements.

Table 3. Earthquake period and frequency before and after reinforcement.

| Vibration mode | Before reinforcement | After reinforcement |
|----------------|----------------------|---------------------|
|                | Period (s)           | Frequency (Hz)      | Period (s) | Frequency (Hz) |
| 1              | 1.49665              | 0.66816             | 1.50060    | 0.66640       |
| 2              | 1.46032              | 0.68478             | 1.46461    | 0.68278       |
| 3              | 1.44866              | 0.69029             | 1.45608    | 0.68678       |
| 4              | 0.32257              | 3.10006             | 0.32410    | 3.08542       |
| 5              | 0.31370              | 3.18781             | 0.31475    | 3.17712       |
| 6              | 0.23634              | 4.23128             | 0.23859    | 4.19122       |
| 7              | 0.23027              | 4.34280             | 0.23112    | 4.32671       |
| 8              | 0.20225              | 4.94446             | 0.20238    | 4.94113       |
| 9              | 0.18914              | 5.28714             | 0.18951    | 5.27685       |

4. Conclusions
According to the results, the conclusions are as follows:
(1) It is feasible to reinforce the bars with oversized slenderness ratio by adding a supporting bar, which can effectively reduce the stress and slenderness ratio of the bar to be reinforced;
(2) To ensure the reinforcement effect, the supporting bar should form a stable geometric system to ensure that the supporting points can effectively restrain the bar;
(3) The influence of the supporting bar on the stress of the grid members must be considered when the supporting bar is added; after reinforcement design, the bearing capacity and seismic performance of the reinforced grid members are checked.

Reference
[1] Zhang L, Li Y R and Guo Q 2019 Case study on influencing factors of steel consumption for structural components Building Structure 1 535-540.
[2] Shen J X 2015 Steel structure design and rationality analysis with limited amount of steel of the first international a tower in xuchang new airport Town Building Science 10 143-147.
[3] Tan X C 2018 Discussion on saving of steel in architectural design Building Technology
Development 8 152-153.

[4] Hao M and Wang W G 2019 Analysis of Steel Weight for Offshore Platform Based on Multi-element Linear Regression China Offshore Platform 8 53-58.

[5] Huang J F 2019 Seismic performance analysis of main gymnasium reconstruction of a large gymnasium Construction Technology 15 12-14.

[6] Lou X and Wang F P 2020 Cause analysis of roof grid collapse in a school Construction Quality 10 103-107.

[7] Wang Y and Feng Z P 2017 Analysis of common faults in operation and maintenance of steel structure canopy in gas station Oil Depot and Gas Station 26 1-5.

[8] Ding B D and Xiao N Q 2017 Research on NDT technology in inference of steel member strength based on macro/micro model Mathematical Problems in Engineering 1-8.

[9] Wang Y and Chen J 2017 Study on the relationship between the fastening degree of high strength bolts and the bearing capacity of steel grid Steel Structure 32 29-34.

[10] Jiang L P and Lou X 2018 Experimental study on reinforcement of truss rod with clamp casing Earthquake Resistant Engineering and Retrofitting 5 124-130.