Analysis on The Collapse of The Large-span Roof Grid of A Gymnasium

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Abstract. In this paper, the method of combining on-site detection and numerical simulation analysis is used to analyze the causes of collapse accidents during the hoisting process of the grid.On-site detection found that the welding sequence of the support was unreasonable, the embedded plate and the support column, the embedded plate and the support top plate did not form an effective connection, and the embedded plate was missing. Based on the numerical simulation, the hoisting scheme and the force of the grid after the hoisting unit is in place are analyzed. The results show that, during the hoisting process and after the hoisting is completed, some of the rods in the grid system do not meet the strength and overall stability requirements.

Keywords: Large-span grid structure, Hoisting collapse, Structural inspection, Numerical Simulation.

1. Introduction

Steel structure grids are widely used in roof load-bearing structures such as gymnasiums, exhibition halls, and industrial plants due to their light weight, high stiffness, good seismic performance, convenient construction, light shape, and high utilization of building space [1].The Beijing Olympic Bird's Nest Project[2] and the Pudong International Airport Terminal Building[3] are typical representatives of large-span grid structures. In recent years, The collapse accidents of large-span grid structures are frequently reported, such as the dry coal shed of Yueyang Power Plant in Hunan, Zhengzhou International Expo Center, Xianyang Gymnasium, etc. The accidents have caused huge economic losses and casualties[4].The construction difficulty of large-span grid structure is in the hoisting stage. As the span increases, the structural form becomes more and more complex, and it is difficult to clarify the force change of the structure; at the same time, with the increase of the span, the uncertainty factors are also increasing[1]. The research on the key processes in the construction of large-span grid structures is of great significance to reducing such engineering accidents and ensuring the safety of people's lives and properties.

Based on the background of the collapse accident during the hoisting process of a large-span grid, this paper comprehensively adopts the method of combining on-site detection, laboratory test and numerical simulation to study the cause of the accident and give the treatment measures.

2. Project Introduction

The project has a construction area of 30813.63m2, a height of 27.5m, 1 storey. The structural form is reinforced concrete bearing, steel structure grid roof, the seismic fortification intensity is 6 degrees, the design service life is 50 years, and the foundation adopts mechanically drilled rock-socketed cast-in-place piles.

The grid is constructed by the overall hoisting method. The grid is assembled on the ground by span, and then hoisted to the design elevation by a crane to be fixed.The left supports of the first span grid frame are four rubber supports, and the right supports are two finished supports (Figure 3). The grid is 74m long, 55m wide and has a total weight of about 150t. It is a large-span grid. After the first span grid frame is assembled, it collapses during the hoisting operation(Figure 1).

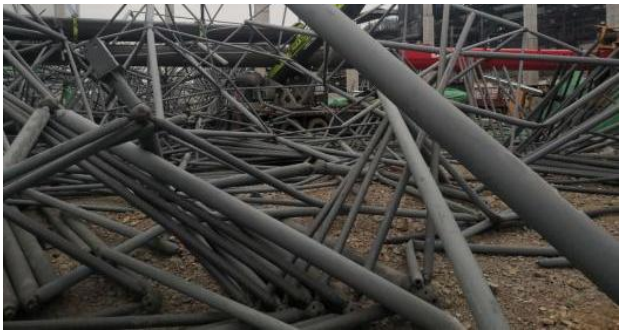


Figure 1. After the collapse.

3. The Hoisting Scheme and Accident Process

This hoisting operation uses 6 cranes for hoisting operation. The hoisting point layout is shown in Figure 2. One crane is placed at each corner, and one crane is placed on each side of the mid-span. During the hoisting process, when the overall hoisting of the grid is close to the design elevation, individual rods within the range of ②-② axes begin to fall, and then the 1, 2, and 3 sides of the hoisting points begin to collapse, eventually leading to the collapse of the entire grid.

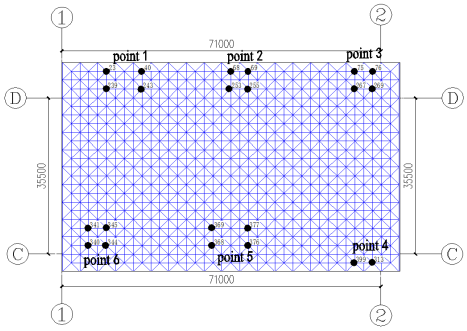


Figure 2. Hoisting point diagram.

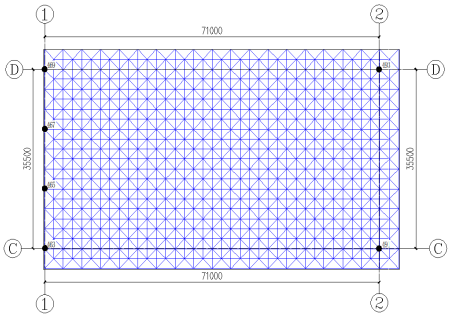


Figure 3. the support of hoisting unit.

4. Accident Cause Analysis

2.1. On-site Detection Results

The on-site detection results show that the support concrete column integrity, strength, section size, reinforcement ratio and the appearance quality and welding reliability of the grid members meet the design and specification requirements. Laboratory test results show that the mechanical properties of grid members, bolt balls, and high-strength bolts all meet the design and specification requirements.

The on-site detection found the following problems:

(1) The ball joint of the support and the cross plate of the support are not pre-welded according to the design requirements, but the grid support and the finished support are welded together.

(2) The pre-embedded plate is not welded with the pre-embedded steel reinforcement on the top of the support column according to the design requirements.

(3) There is no embedded board in some supports.

(4) The size of the embedded plate is smaller than the size of the top plate of the finished support.

2.2. Simulation Analysis of On-site Hoisting Construction of Grid

In this paper, numerical simulation is used to calculate and analyze the on-site hoisting scheme of the grid frame and the overall force of the grid frame after the hoisting and forming. Only the self-weight of the material is considered in the calculation (the self-weight of the bolt ball and the welding

ball is considered as 30% of the self-weight of the member), and only the vertical restraint is considered for the support. The material parameters are shown in Table 1.

Table 1. Material parameters.

Material	Elastic modulus（N/mm^2）	Poissons ratio	Linear expansion coefficient	Mass density（kg/m^3）
Q235B	$2.06*10^5$	0.30	$1.20*10^{-5}$	7850
Q355B	$2.06*10^5$	0.30	$1.20*10^{-5}$	7850
C30 Concrete	$0.30*10^5$	0.20	$1.00*10^{-5}$	2500

4.2.1. The simulation analysis of On-site hoisting scheme.

This model simulates and analyzes the hoisting scheme used on site, assuming that each hoisting point is uniformly stressed, and the schematic diagram of the calculation model is shown in Figure2. This model involves two kinds of materials, Q235B and Q355B. The material parameters are shown in Table 1, and the calculation results are shown in Figure 4 and Tables 2~3.

Table 2. Statistical table of calculation results of strength-stress ratio of members.

Value	>1.00	1.00~0.90	0.90~0.70	0.70~0.50	0.50~0.00
Number of units	0	0	0	4	1889
Percentage	0.0%	0.0%	0.0%	0.2%	99.8%

Table 3. Statistical table of calculation results of overall stable stress ratio around 3 axes.

Value	1.34~1.00	1.00~0.90	0.90~0.70	0.70~0.50	0.50~0.00
Number of units	20	10	38	45	1780
Percentage	1.1%	0.5%	2.0%	2.4%	94.0%

The calculation results show that the maximum stress ratio of the member is about 1.34, which exceeds the allowable value of the relevant specifications (Figure 4). As shown in table 2, the number of rods whose strength-stress ratio is between 0.5 and 0.7 is 4, accounting for 0.2% of the total. As shown in table 3, the calculation results of the overall stable stress ratio around the 3 axes show that the overall stable stress ratio of 20 rods is between 1.00 and 1.34, accounting for 1.1% of the total, which exceeds the allowable value of the relevant specifications. The overall stable stress ratio of 10 rods is located in Between 0.90 and 1.00, accounting for 0.5% of the total, the overall stable stress ratio of most members is not greater than 0.5.

On the whole, the overall stress of the grid is poor, and the stress ratio and the overall stable stress ratio around the 3 axes of the grid exceeds the limit, which cannot meet the requirements of strength and overall stability.

4.2.2. Simulation analysis after hoisting and forming.

This model analyzes the stress after the grid frame is hoisted and formed in place. The model involves three kinds of materials: Q235B, Q355B and C30 concrete. The material parameters are shown in Table 1. The schematic diagram of the calculation model is shown in Figure3. The calculation results are shown in Figure5 and Tables 4~5.

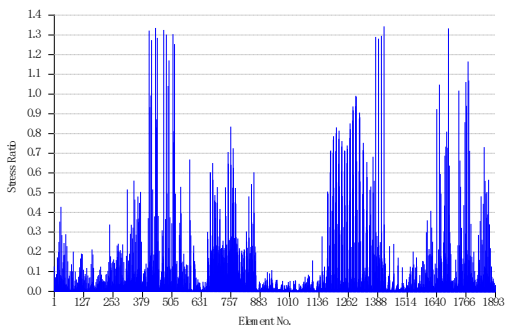


Figure 4. Stress ratio distribution of member

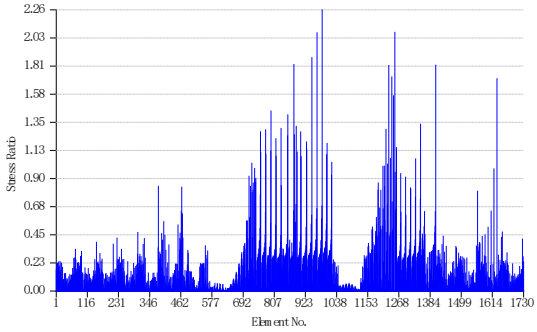


Figure 5. Stress ratio distribution of member

Table 4. Statistical table of calculation results of strength-stress ratio of members.

Value	1.81~1.00	1.00~0.90	0.90~0.70	0.70~0.50	0.50~0.00
Number of units	12	8	26	30	1654
Percentage	0.7%	0.5%	1.5%	1.7%	95.6%

Table 5. Statistical table of calculation results of overall stable stress ratio around 3 axes.

Value	2.26~1.00	1.00~0.90	0.90~0.70	0.70~0.50	0.50~0.00
Number of units	30	2	7	30	1661
Percentage	1.7%	0.1%	0.4%	1.7%	96.0%

The calculation results show that after the hoisting and forming are in place, the maximum stress ratio of the rods in the grid system is about 2.26 (Figure.5), which seriously exceeds the allowable value of the relevant specifications. As shown in table 4, there are 12 rods with the ratio of strength to stress between 1.00 and 1.81, accounting for 0.7% of the total, and the ratio of strength to stress is between 0.90 and 1.00. The number of rods is 8, accounting for 0.5% of the total, and the strength-stress ratio of most rods is not greater than 0.5. The calculation results of the overall stable stress ratio around the 3 axes show that after the hoisting and forming are in place, there are 30 rods whose overall stable stress ratio is between 1.00 and 2.26. root, accounting for 1.7% of the total, which exceeds the allowable value of the relevant specifications. There are 2 members with the overall stable stress ratio between 0.90 and 1.00, accounting for 0.1% of the total. The overall stable stress value of most elements is not greater than 0.5, As shown in table 5.

In general, the overall stress condition of the grid is poor, and there are rods in the grid with the stress ratio and the overall stable stress ratio around the 3 axes exceeding the limit, which cannot meet the requirements of strength and overall stability.

5. Analysis on The Reasons of Grid Collapse

Combined with the on-site detection results and simulation results, the reasons for the collapse of the grid frame during the hoisting process are analyzed as follows:

(1) The welding sequence of the support is unreasonable. The design requires that the ball joint of the support be welded to the double-sided groove of the cross stiff plate of the support in advance. After the hoisting and forming, the bottom plate of the support and the top plate of the finished support are welded and connected. On-site inspection found that the ball joint of the support and the cross stiffening plate of the support were not pre-welded according to the design requirements, but the grid support and the top plate of the finished support were welded together. This construction causes the support to have no reliable restraint on the grid. When the grid is greatly deformed or displaced, the

grid support ball at the support will be separated from the support due to no effective restraint, further increasing the deformation of the grid, resulting in the grid as a whole was unstable and collapsed.[5]。

(2) The grid frame does not meet the overall stability requirements. According to the simulation results of the hoisting scheme, there are 20 rods in the grid frame that do not meet the overall stability requirements. According to the calculation results after the grid frame is hoisted and formed in place, it can be seen that there are rods with the overall stable stress ratio and the strength-to-stress ratio exceeding the limit. The maximum strength-stress ratio is 1.814. There are 42 rods do not meet the requirements for strength and overall stability.

(3) In the original design drawing, the embedded plate of the anti-seismic spherical support should be perforated and welded with the longitudinal stress steel bar. The on-site inspection found that there were no steel bars at the bottom of the embedded board, the embedded board could not provide effective restraint for the grid support, and the embedded board at this position had been pulled off.

(4) On-site inspection found that the size of the embedded plate of the finished support was smaller than the size of the top plate of the finished support. After the grid is hoisted and formed in place, because the bottom plate of the finished support is slightly larger than the size of the embedded plate, it cannot meet the requirements of peripheral welding between the top plate of the finished support and the embedded plate, which makes the connection reliability of the two poor.

(5) The on-site inspection found that there were no embedded boards in some supports, which failed to provide effective support restraint for the grid.

(6) Six cranes are used for overall hoisting on site. This method can well ensure the accuracy of welding quality and geometric dimensions, but requires higher capacity of hoisting equipment. During the hoisting process, if all cranes cannot be lifted or unloaded synchronously, it will cause stress concentration of the hoisting unit in a certain area, resulting in the destruction of individual rods.

To sum up, the reason for the collapse of the grid is: hoisting process and after the forming in place, there are rods with the stable stress ratio and the strength-to-stress ratio exceeding the limit in the grid system. During the hoisting process, the rods whose strength stress ratio and stable stress ratio exceed the limit are first destroyed, and the deformation or displacement of the grid frame is further increased. Because the support fails to provide effective restraint, the bearing ball of the grid frame is separated from the support plate of the grid frame, resulting in overall collapse [6-7].

Acknowledgments

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