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Integral lifting simulation of long-span spatial steel structures during construction

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ABSTRACT

This paper presents an analysis of the synchronous and asynchronous integral lifting of a China Eastern Airline hanger's steel roof. A novel asynchronous analysis method known as single and interlaced points is proposed. The results showed that setting up the lifting points according to Scheme 1 and multiplying the design strength by the reduction factor of 0.95 is a reasonable solution. Including the horizontal elastic stiffness in the multi-particle model was confirmed to improve the computational accuracy. The structural safety was ensured for synchronous lifting. The displacement difference of the lifting points was less than 15 mm. Thus, the method of single and interlaced points is appropriate for analyzing the asynchronous lifting of long-span steel roof structures. Replacing out-of-code members is feasible and has little effect on the overall structure under the design conditions, and the lifting trestles, lifting points, and concrete columns are reliable.

1. Introduction

With the emergence of long-span steel structures, several unique mechanical problems to their construction process have gained importance. For example, Li et al. [1] discussed the construction sequence of a practical suspend-dome for the Jinan Olympic Center and provided meaningful conclusions. Liu and Chan [2] proposed an advanced simulation-based design using improved second-order analysis of the structure to account for local and global imperfections, sequential loads, and the construction process. The steel roof of a China Eastern Airline hanger has an orthogonal diagonally welded spherical grid structure system and is composed of a triple-layer grid structure and cantilever truss, as shown in Fig. 1. The dimensions of the architectural plane are 85 × 155 m. The roof of the structure is characterized by a long cantilever and multiple layers. Hydraulic integral lifting technology is often adopted to construct this type of structure [3–7]. There is a significant difference between the mechanical behaviors under the design conditions and during the lifting process [8]. In order to meet the design requirements and ensure safety, the structure needs to be analyzed during the lifting process with the construction mechanics method [9–12].

The synchronous integral lifting method is based on the finite element theory and is a commonly used lifting analysis algorithm for long-span steel roof structures. For example, Guo et al. [13] analyzed the synchronous integral lifting of the main trusses of the Macao Gymnasium to determine the lifting scheme feasibility. Zhao et al. [14] studied the integral lifting of a lattice shell lighting roof based on a genetic algorithm. Guo et al. [15] presented the integral lifting and seismic isolation retrofit of the great hall of Nanjing Museum. Zheng et al. [16] rebuilt the finite element model of a structure while being lifted to judge whether the lifting status is safe. Lou et al. [17] proposed a deployable integral lifting construction technology for cylindrical latticed shells. The basic principle is that the whole structure is completely horizontal. Thus, all of the lifting points are synchronously fully lifted according to the computer. In fact, differences in the hydraulic jacks and measurement errors make it almost impossible to achieve complete synchronization, and there is an inevitable displacement difference between lifting points. However, at present, the displacement difference of lifting points for complex long-span steel roof structures is often only determined through experience. This paper presents an analysis of the synchronous and asynchronous integral lifting of the China Eastern Airline hanger's steel roof and compares the results with those of an experiment. A novel asynchronous analysis method known as single and interlaced points was developed that is especially suitable for long-span grid structures and was demonstrated to be accurate and reliable by accounting for all unfavorable situations during the asynchronous lifting process.

2. Hydraulic integral lifting technology

The hydraulic integral lifting system consists of a lift cylinder cluster, steel strands, a hydraulic pump station, a laser range finder, and a

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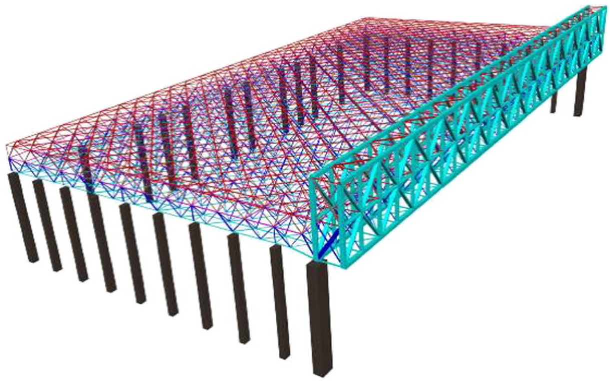

Fig. 1. Rendering of the overall structure.

Fig. 3. Control computer.

control computer, as shown in Figs. 2 and 3 [18,19]. The lift cylinder cluster and steel strand are supporting components that bear the structure. The hydraulic pump station, which is important to the stability of the lifting system, is the engine drive component. The laser range finder obtains the positional information of the lift cylinder cluster and structure, which is transmitted to the control computer through the network. The control computer then judges the synchronous adjustment amount of system and determines the next step of the lift cylinder cluster. In this project, three specifications were adopted for the lift cylinder (350, 200, and 100 t), and the steel strands were pre-stressed.

Position sensors are installed on every lift cylinder during the integral lifting process. The sensor can reflect the position of the lift cylinder and tightness of the anchorage device. By using the real-time network, the control computer decides the next step according to the current state of the lift cylinder and required user control (i.e., manual, sequential, or automatic). In order to guarantee the safety of the structure during the lifting process, oil pressure sensors are set up on every lifting point, as shown in Fig. 4. Therefore, the control computer can monitor the load changes of the lifting point through data transformation in the data acquisition network. Once the stress or added lifting force exceeds the preset alarm value (e.g., 10%), the monitoring system sends out an alarm signal to inform technicians to suspend the lifting process immediately and check for any problems that may have occurred.

In addition, a standard lifting point is set up in the lifting system for comparison with the displacements of the other lifting points during the process. The displacement difference between the other lifting points and the standard lifting point should be controlled within an allowable range (e.g., 15 mm). If the displacement difference exceeds this range, the system ceases to lift and automatically adjusts the difference to the allowable range before starting again.

3. Synchronous lifting analysis

3.1. Lifting scheme

Based on the structural characteristics of the China Eastern Airline hanger's steel roof, auxiliary lifting points and some temporary lifting members were added to the grid structure to form a stable system, as shown in Fig. 5. Temporary reinforced members were added to the cantilever truss, as shown in Fig. 6. By lifting the auxiliary lifting points and endpoints of the reinforced members at the same time, the structure was lifted simultaneously. After the reinforced members were added, the maximum stress of the members around the lifting points of the truss was reduced by 30% from 372.5 to 260.6 MPa. Moreover, the strength of the lifting points was enhanced, and safety was guaranteed.

3.2. Setting of the lifting points

The lifting points setting should be associated with the stiffness of the structure [20]. Therefore, the supporting points of the original structure should be chosen as lifting points as much as possible, and the number of lifting points should be equal to half the number of supporting points. Two schemes were analyzed before construction according to the calculated end reaction of the columns, column section, roof form, and site conditions. In Scheme 1, the lifting points were set at columns Z1, Z3, Z5, Z7, Z11, Z12, Z14, and Z15. In Scheme 2, the lifting points were set at columns Z1, Z2, Z4, Z6, Z11, Z12, Z14, and Z15. Because the structure was almost symmetrical, the lifting point setting on the other side can be mirrored). Table 1 compares the analysis results for the two schemes, and Fig. 7 shows the concrete column positions.

Table 1 indicates that the maximum vertical deformation and stress of Scheme 1 were less than those of Scheme 2, and the stresses of several members in Scheme 2 were greater than the design strength. Therefore, the lifting points were set up according to Scheme 1, as shown in Fig. 8.

Fig. 2. Lift cylinder cluster.

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