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Key Technology of Overall Structure Monitoring of Super-Huge and Profiled Steel Structure Based on FEA Simulation and LIDAR

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Abstract: In traditional construction process of huge steel structure, plane and altitude cannot be monitored at the same time, so they fail to reflect the three dimensional information of steel structures and the features of overall deformation. In order to solve this problem, we employ the three-dimensional laser scanning technology to collect three dimensional spatial data of this super-huge and profiled steel structure. On basis of these data, we reconstruct the three dimensional feature data of the structure elements from point?cylindrical?spherical and so on ,and then we can analysis the structure deformation by statistical charts. Firstly, this study put forward the remote sensing technology on overall structure of the construction process of super-huge profiled steel structure. Secondly, the stress situation, strain situation and overall deformation characteristics were also be studied with FEA simulation and LIDAR. Consequently, technical support for the process of installation, construction and the quality testing are proposed. Several typical cases of super-huge and profiled steel structure are listed to verify this method is efficient and feasible.

Key words: Steel structure, structure monitoring, FEA simulation, LIDAR, point cloud

INTRODUCTION

In 1851, London built the Crystal Palace in Hyde park. Since then, steel structure, a new building mode, has been more and more widely used, especially in China which is rapidly developing, various super-huge and profiled steel structures appear. From the competition venues of the 2008 Olympic Games to all kinds of modern railway station and airport, all these show the strong vitality of this special structure. The deformation monitoring has been an essential part of a project cycle, whose exactness and effectiveness affect the security of the construction and after-run. Despite some traditional methods, such as Total Station, close range photogrammetry and Global Positioning System (GPS), other high-tech measurements such as measurement robots, 3D laser scanners and hydrostatic water level are also being applied. (Chen *et al*., 2012; Cui *et al*., 2007; Guo, 2011).

On the base of summarizing various successful experience of deformation monitoring on super-huge and profiled steel structure, this report put forward general implementation on overall structure monitoring-using three dimensional laser scanning technology to exact the geometric characteristics of super-huge and profiled steel structure manually and automatically; using stress and strain analysis and structural deformation analysis to calculate and discuss structural monitoring variables; putting forward the method of overall deformation analysis on steel structure creatively which could improve work efficiency and monitoring accuracy of super-huge and profiled steel structure fundamentally.

An IMPLEMENTATION PLAN ON OVERALL STRUCTURE REMOTE SENSING

The design for overall deformation remote sensing network: The deformation remote sensing includes measurement for some elements such as horizontal displacement, vertical displacement, offset, deflection, cracking and so on which mainly focus on remote sensing of deformation of deformable body itself and geometrical rigid displacement.

The arrangement of remote sensing points of displacement should depend on the results of simulation analysis of construction process. Remote sensing points of displacement mainly includes (the arranging map is showed in Fig. 1).

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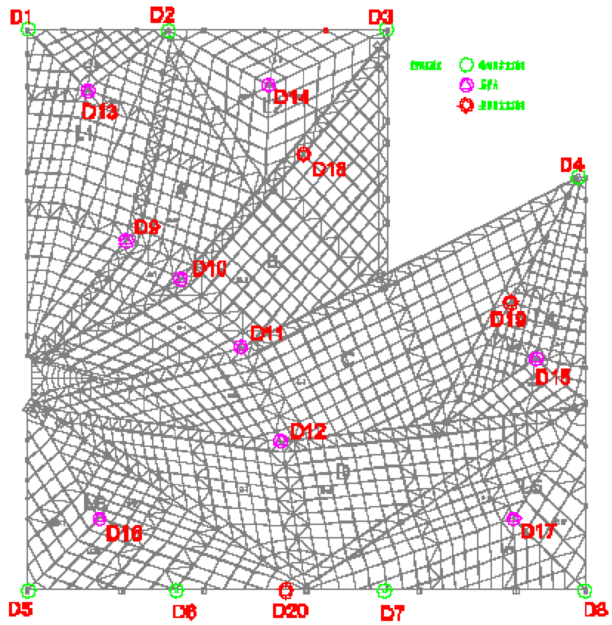

Fig. 1: The schematic of structural displacement deformation monitoring network

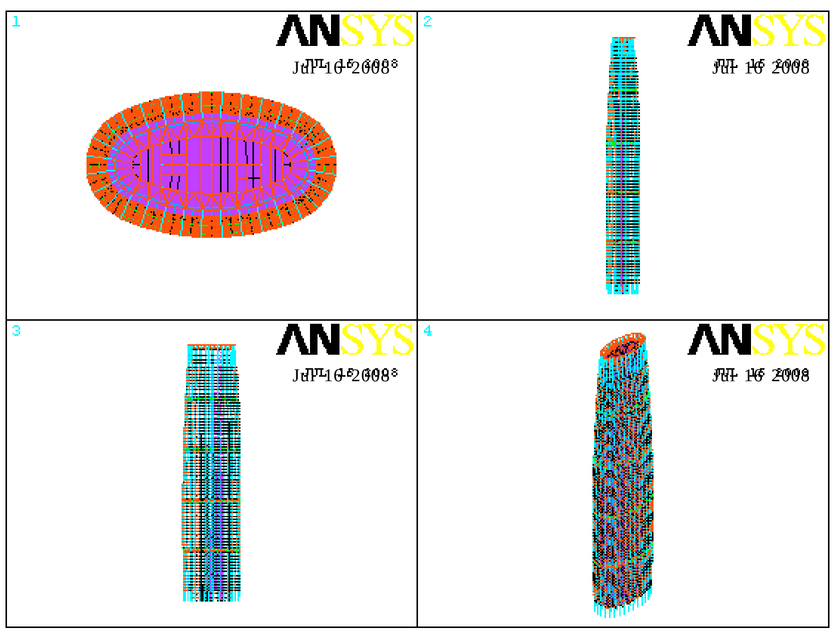

Fig. 2: Finite element simulation model of super-huge and profiled steel construction

Simulation analysis of structure construction process: According to the structural characteristics of large profiled steel and construction methods, based on preliminary data to establish steel finite element simulation models (Lanata and Del Grosso, 2010) (Fig. 2) and both the construction plan combined with construction loads condition and the observed results of constructional part, we analysis and calculate the finite element model, at the same time simulate deformation and internal force condition at different stages of construction. We consider it as an ideal state during early period. Then we confirm the vertical and horizontal initial value of each control point and predicate the deformation and internal force of key parts and key components in construction process through further analysis of being installed and flip analysis t in construction process. Additionally, on-site monitoring results can be used as the actual value of structural analysis model supporting valid data for the health monitoring of the whole structure for life-long term.

FEATURE EXTRACTION TECHNIQUES FROM POINT CLOUD

Generally, steel deformation monitoring mainly set monitoring points and contrasting them point by point which is a hard and may miss the large deformation place. For large shaped steel structure, deformation of installation and uninstall is unpredictable. But three-dimensional laser scanning technology can achieve a three-dimensional displacement analysis of monitoring points on deformation; on the other hand we can achieve overall deformation analysis for more points. It is a key technique to extract feature for deformation monitoring from the point cloud data obtained by three-dimensional laser scanning technology (Bolles and Fischler, 1981; Guo and Wang, 2012; Rabbani and Van Den Heuvel, 2005; Schnabel *et al.*, 2007).

Exacting features of steel structure from laser point cloud data manually: We use pitch method to judge the accuracy of plane fitting, that is to say we calculate the distance d between each laser point and fitting plane firstly and we set d as the composite error influenced by various factors and then calculate the mid-error. After calculating d, we could get the accuracy of plane fitting according to Eq. 1.

$$\delta = \sqrt{\frac{\sum_{i=1}^{n} d_i^2}{n}} \tag{1}$$

For feature point, we use three-dimensional space positioning to position and use plane fitting method to exact the coordinate of corner point through the intersection of three planes. We adopt these methods to deal with data: First, we sort out all the point cloud of all the steel ports and then plane fitting every point cloud by the scanned point cloud separately, trying to plane fitting the outer-port with point cloud. The error of plane fitting should be controlled within 2 mm; then to intersect the 5 port planes and choose the 4 intersection points namely the outer corner point of the port; finally, compare all the outer-corner points with point cloud data, checking the accuracy of the position of outer-corner point. The progress is showed in Fig. 3 below.

After exacting the point cloud corner point of the port of steel structure, we should exact the coordinates we get, so that people could adjust the position of port. As the steel rigid components of the whole structure, if a port has a problem, it will cause the failing of entire lifting, so positioning accuracy requirements limit within millimeter. Additionally, other method s also can obtain the feature points of steel structure despite of plane fitting, such as fitting the cylindrical and spherical features, as Fig. 4, an example of point cloud through laser scanning fitting cylindrical and spherical features to monitor deformation.

A technique used for exacting features automatically based on updated RANSAC algorithm: RANSAC algorithm has a great advantage over segment and extract scattered point cloud in three-dimensional space, the method of updated RANSAC algorithm in this report can achieve both speed and accuracy of algorithm (Shanmugam *et al.*, 2010; Wang and Guo, 2012; Wang and Wang, 2009). In this study, we put forward an updated algorithm based on RANSAC algorithm aiming at exacting

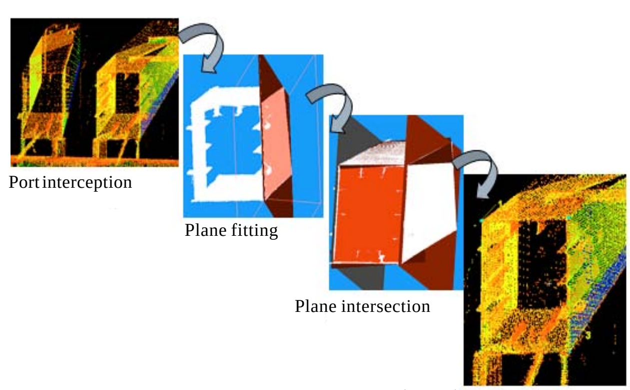

Fig. 3: The process of exacting the coordinates of outer-corner points

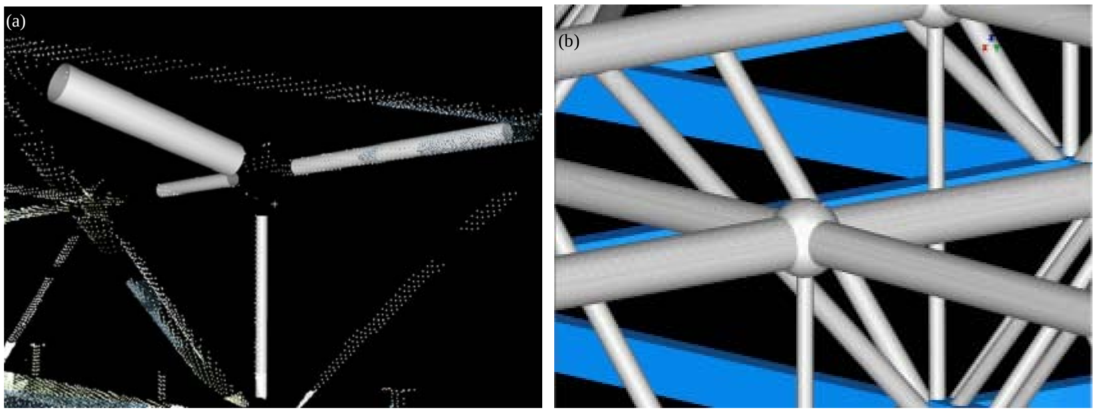

Fig. 4: Deformation monitoring through point cloud to fit cylindrical and spherical features

the feature points of the point cloud data of super-huge and profiled steel structure,which can quickly extract the spherical cylindrical and planar feature point cloud of laser point cloud and get the parameters of these features exactly.

CALCULATION AND ANALYSIS OF STRUCTURAL MONITORING VARIABLES

Simulation analysis on stress-strain: In monitoring process of large profiled steel construction, the component of key parts are influenced by various factors such as component size, material properties, misalignment, component connections, welding residual stresses, temperature changes, loads and construction quality, so in the key parts of the critical floors, there may be stress concentration phenomenon for part of the components. So in order to ensure that the effect of construction reflects the design intent, to realize safety of construction and to make dynamic adjustment, of design plan, we should focus on stress and strain.

Strain monitoring is important parameters to reflect the mechanical characteristics of structures, rods. The premise condition of structure monitoring is to extract parameters that reflect the structure's feature from the structure itself which can show the characteristics of some part exactly. Strain signal is convenient to structural safety evaluation and damage localization. From the data of strain monitoring strength reserve component information can be analyzed which can determine actual load conditions and local stress concentration of components and suffered structures under different conditions. In order to verify the correctness of the construction simulation models ANSYS and ETABS two software are used to establish models of construction simulation, choosing some of the key components of steel structure, using chart analysis to analyze its deformation and stress.

Structural deformation analysis: In order to check the analytical accuracy of the calculation model, we usually analyze and compare the vibration characteristics of steel structures and structural weight and also compare ETABS results providing by Design Company with that of ANSYS software. If the two calculation models are in good agreement in structural weight and vibration characteristics, it indicates that model reasonable; To ensure comparability with ETABS model, models based on ANSYS simulation calculation does not consider construction steel building layers total vertical reaction force and part of the column axial force, the weight and the additional dead load .

Deformation analysis of the whole steel structure: After splicing and coordinate transformation of the laser point clouds of steel structure, the scanning data has been completely converted to the design coordinate system. Because the scanning data is scatter data, we always use the point set with point set, point set with the triangular surface to carry out comparative analysis. The specific progress is:

- **Step 1:** To separate the point cloud data from the two split correspondingly
- **Step 2:** To form Triangular Irregular Network (TIN) from point cloud data, usually according to scanning step length
- **Step 3:** To project point cloud onto the nearest triangular facets and calculate the projection distance that is the actual deformation

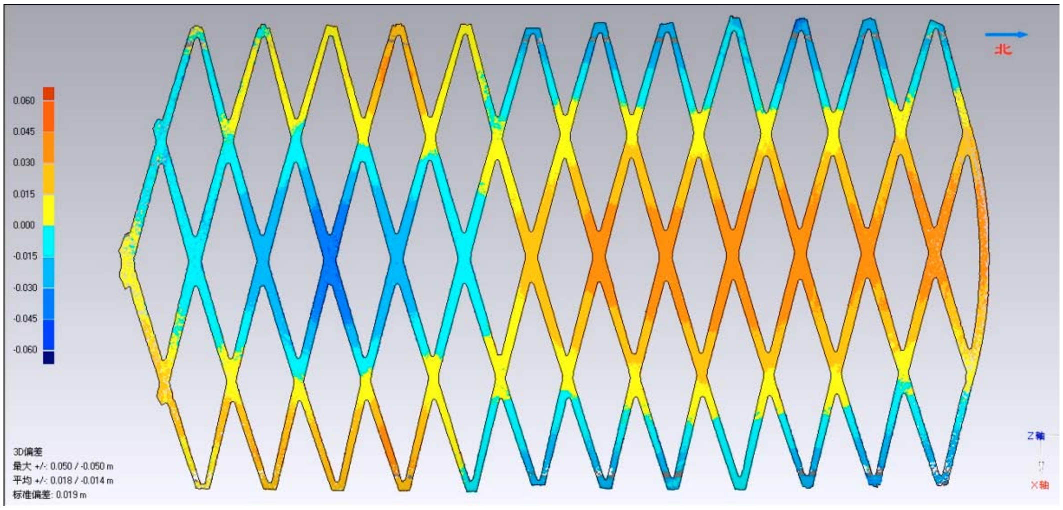

Fig. 5: Analysis of the whole deformation of super-huge and profiled steel structure

- **Step 4:** To compare vertical distance projection analysis between the whole point cloud and the corresponding triangulation constructed marking with different colors to indicate the specific deformation, Fig. 5 shows the deformation of the whole structure of a railway station in China, obviously the left blue dome region has a sinking trend apparently in the vertical

CONCLUSIONS

Based on the specific features of super-huge profiled steel structure and the requirements in structural monitoring, a basic research on three-dimensional laser scanning technology is applied in the field of monitoring on steel structure after summarizing different construction plans on deformation monitoring of whole structure. Through a deep research on three-dimensional laser point cloud' manual and automatic extracting technology on features, this study discussed the method of calculate and analysis for various monitoring variables of steel structure and siding. At the same time, these studies have its feasibility and accuracy. By comparing several deformation monitoring technologies for some typical super-huge and profiled steel structure in China, it shows that the new monitoring technology, represent by LIDAR scanning technology on steel structure, has great advantages such as high speed, high accuracy and full access to data, processing and analysis data and it can fully be applied to the monitoring of super-huge and profiled steel structure and testing of construction quality.

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