RESEARCH ON DEFORMATION MEASUREMENT APPROACHES TO BODHISATTAVA PAVILION IN DULE TEMPLE

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ABSTRACT:

The ancient Chinese architecture is the quintessence of ancient Chinese people and is also a medium of the ancient Chinese culture. To preserve the ancient architecture and the remains of those buildings in existence is an important event to the present and future generations. With the passage of time, due to the impact of wind, rains, thunder and lightning, earthquakes, and other natural forces and human activities concerned, especially the overdue exploration of underground water, the ancient Chinese buildings tend to change to a larger and larger extent in deformation. Accurate and detailed knowledge of the situations and development and changes in major points in ancient buildings is a direct and effective protection of ancient architecture in China.

The deformation monitoring and measuring of ancient buildings is done to offer technical supports for the next protective measures to take, by periodic measuring of ancient buildings and comparing, contrasting, and analyzing the measured results to obtain information about the extent and law of deformation. In terms of modern buildings, ancient architecture has more than hundreds of years of history, the rate of deformation is minor and more accuracy is required for it. Meanwhile, in the process of deformation measuring, more consideration should be taken into the least interference of the buildings to be measured.

Taking the deformation measures of the Bodhisattava Pavilion of Dule Temple built in the Liao Dynasty of ancient China, and based on the features of ancient Chinese wooden buildings and the requirements for deformation monitoring and measuring, the paper makes analyses of advantages and disadvantages of the approaches ranging from traditional frontal cross to the most advanced 3D laser scanning technology, explores the accuracy and enforcement scheme of deformation measuring of ancient buildings and points out the shortage of knowledge and misuse of 3D laser scanning technology in the monitoring and measuring of deformed ancient buildings.

'Deformation' refers to the alteration of dimensional state of the object in investigation, which contains the two following aspects: alterations with respects to its initial or previous state. In the field of ancient buildings' metric surveys and archaeological studies, scholars tend to regard the former instance as cases of deformation while ignore the later circumstance and 'initial state' is often replaced by 'ideal state', which in fact rarely exist. 'Architecture deformation' should be defined as 'the alterations between the current state and its former state'; deformation monitoring hereby refers to the dimensional alterations detected by repeating observations within a certain period.

1. CHARACTERISTICS OF WOODEN ARCHITECTURE' DEFORMATION AND ITS REQUIREMENTS OF MONITORING

1.1. Characteristics of Timber Architecture

The unique beam-column structure system of Chinese buildings defers from the western arch structure system. Beams and columns are used as the main bearing components, with ties and bracket sets forming the particular frame. The odds of displacements caused by roof loads to endanger vertical pressure are considerably small. However, the main destructive factor is the lateral pressure, in which case the frame would suffer tenon disjoints and column inclinations, or even end up with its total collapse. In the meantime, hip rafters, which served as a cantilever structure inevitably, reach the maximum length and bear the maximum amount of load, which prone to result in bending, sinking and even collapsing. The existing ancient architecture has often undergone hundreds and even thousands of years to reach a stabilized period in sedimentation, which cannot help but be disturbed by over exploitation in the surrounding area. Unbalanced earth and hydraulic pressure will further result in total collapsing of the entire structure.

1.2. Content Requirements

Based on the deformation character of timber architecture, the deformation monitoring should include the following aspects:

(1) Deformation monitoring aimed at foundation. Tabia is commonly used in foundations in ancient Chinese architecture. Being the bearing stratum, tabia foundation receives the load passed through columns and column bases. Its uneven settlement of the base will directly lead to the deformation of the whole structure. To measure the deformation of the base, the measure of the settlement and deformation of column bases should be put under regular metric surveys.

(2) Deformation monitoring aimed at inclinations of columns. Inclinations of columns are fatal among architectural deformations. For single-eave roof buildings, azimuths and angles of column inclination are documented periodically,

which are later converted into capital inclination components (or capital horizontal displacement). For multi-eave roof buildings, column inclinations are measured by floors, and then inclination components at different heights are accumulated. Full-height columns could be measured by subsections regarding to its constraining forces.

(3) Deformation monitoring aimed at hip rafter capitals' sinkage. The sinkage is caused by deflection change of hip rafters, which can be monitored by measuring the inclinations of corner columns and deflection of hip rafters.

(4) Deformation monitoring aimed at beams' bending. A bending beam reflects the deformation of roof, which directly causes the entire settlement of roof and the upper bearing beam structure.

1.3. Accuracy Requirements

Accuracy requirements of deformation monitoring vary according to estimated quantum of deformation and the purpose of monitoring.

During the 13th Conference of the International Federation of Surveyors (1971), Engineering Survey Team brought forward the following proposal for discussion: In protection oriented surveys that in order to insure the stabilization of the building, errors should be controlled under 1/10~1/20 of the tolerable quantum of deformation. In research oriented surveys aimed at studying the deformation progress, the errors should be much smaller. (Li, 1982)

Industry Standard of the P. R. China, *Specifications for Building Deformation Measurements (JGJ/T8-97)* standardized the errors to under 1/10 of the tolerable quantum in metric surveys for the deformation of the entire architecture (capital horizontal displacement, full-height verticality deformation, horizontal axis deviation of engineering facilities, etc.). It's also noted that, metric surveys for scientific research projects could modify the errors by adding a coefficient of 1/5~1/2 to refine the survey's accuracy. (China Institute of Geographical Investigation and Surveying, 1998)

Concerning the tolerable deformation of ancient buildings, Prof. LI Shiwen from Taiyuan University of Technology pointed out in *A Preliminary Study on Seismic Evaluation of Ancient Trimble Single or Even Roof Buildings* that, the tolerable relative displacement between the top and base of a column should meet the requirements that the tolerable value is smaller than 1/80 of the column height. Moreover, regulations in *Standard of Dangerous Buildings Appraisal (JGJ 125-99)* involving the stability of timber architecture regard an inclination of 1/120 frame-height as a dangerous point. (Housing and Land Administration of Chong Qing, 2000)

Given the regulations mentioned above, errors could be controlled according to the scale of the building and the purpose of measurement. Scheme and procedure of control survey could then be proposed in further accordance with peripheral conditions.

1.4. Other Requirements

In order to detect the deformation of observed objects through repeated surveys, proper accuracy should be met by setting up observation points in different places, where identity, pointing accuracy and permanence can be ensured.

2. METHODS

2.1. Forward Intersection

Forward intersection, which includes horizontal and space intersections, measures 2D and 3D coordinates of observed points through angular intersections from ground control points for deformation of buildings. It is a conventional means of measuring, and guarantees millimeter accuracy upon proper pointing accuracy. And it demands permanent targets on each observed point and good visibility and is labour consuming.

2.2. Close Range Photogrammetry

Photogrammetry orientation has evolved from single baseline and single pair to multi baseline and multi pairs, which fulfils the needs of deformation monitoring to ancient Chinese buildings in its sub-millimeter level. But the consistency of observed points is difficult to guarantee.

2.3. Total Station Coordination

Total station coordination monitors deformation of buildings through the variation of coordinates of observed points. Those coordinates are defined by a ground geographic coordinate system and re-measured by a total station device. This method offers acceptable accuracy without demanding high visibility or heavy workload. But it requires prism on each observed point, thus, appearance interference even damage to buildings are inevitable. Non-prism technique is not capable of measuring key features of buildings such as edges and corners which are curves. This fact leads to unreliable consistency of pointing targets in re-measurement and an interrupted measuring process due to mass signal loss.

2.4. 3D Laser Scanning

3D laser scanning, as a measuring technology, has become more and more prevalent in recent ten years. The approach works like a total station spinning at high speed, with lens driven by motors, scanning points at vertical and horizontal step intervals set in advance. 3D coordinates of every scanned points are obtained, which are processed to generate points set called 'clouds' for scanned targets. The position coordinates are determined by the instant horizontal and vertical angles of the laser beam and distance between targets and instruments. Thus the accuracy lies on the accuracy of angle and distance measurements. Besides, the ambient temperature, humidity and the target's material, levels of surface irregularity should also be taken consideration. Judged by the nominal accuracy and quality of the obtained data, the widely used instruments all failed to meet the requirements.

2.5. Inclination Sensor

It is stated above that columns being the vital parts of the beam-column system, its common form of deformation is inclination. Inclination sensors are set up according to the subsections of the column to collect the inclination values respectively, which gained together to calculate the displacement between top and bottom. It can be set up at covert capital places and achieve a desirable accuracy, also with little workload. For storied buildings or towers which are relatively high, it can be placed inside to avoid being an eye sore while it is easy to observe.

3. THE IMPLEMENTATION OF DEFORMATION MONITORING TO BODHISATTAVA PAVILION IN DULE TEMPLE

The initial building of Dule Temple dated back from Tang Dynasty (618~907). Bodhisattava Pavilion (984), which accommodates a giant statue to Bodhisattava, is the main survival building. It is the oldest storied timber buildings in existence in China. During the reconstruction in 1753, eight columns were added to support the eight hip rafters on both floors and the statue of Bodhisattava inside the pavilion was strengthened.

Tianjin University, in 1993, conducted a deformation measurement to Bodhisattava Pavilion and the statue. The data suggested a southeast inclination of both. In 1999, a second deformation measurement was done of the building and further inclination to the southeast was proven. In April, 2009, a third measurement was conducted of the building.

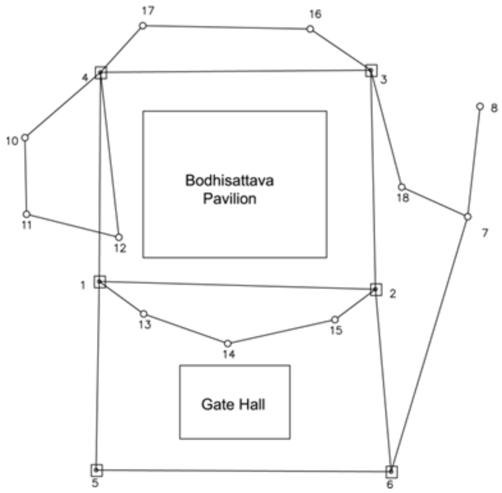
3.1. Scheme Selection and Implementation in Deformation Monitoring

Considering the general deformation peculiarities of Chinese timber buildings and Bodhisattava Pavilion, and features of different measurement proposals, a detailed plan was determined of deformation monitoring.

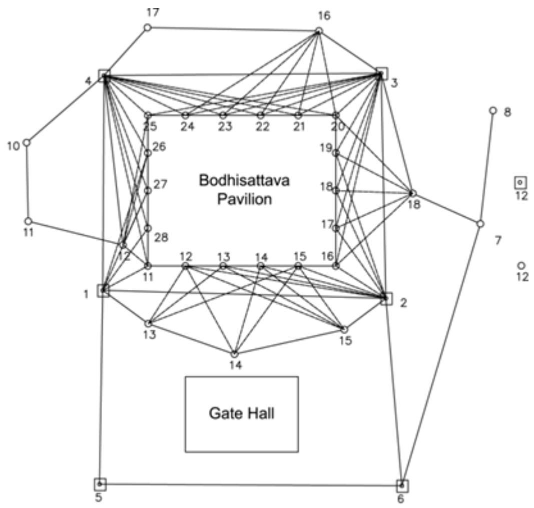
The following measurements were included: the horizontal displacement measuring to column capitals of the outer-ring on both floors, the subsidence of cornices near the hip rafters on both floors, the oblique measurement of the statue.

Existing deformation monitoring blocks around the pavilion with forced centering apparatus were utilized to form a primary traverse control network (Illus. 1). On the basis of the primary net, densified traverse net was set up around the pavilion as a secondary network (Illus. 2). Vertical and horizontal control surveys were conducted according to the national standards: Specifications for the third order traverse network and Specifications for the second order levelling.

Supported by the control survey, measurements of horizontal displacement of the outer-ring column capitals were done using forward intersection method. The subsidence measurements of cornices near hip rafters on both floors used both spatial forward intersection method and relative triangular height measurement method. The oblique measurement utilized forward intersection method and non-prism total station coordination method.



Illu.1. Sketch of densified control network



Illu.2. Intersection of columns on the first floor

3.2. Result and Analysis

Horizontal control survey used condition adjustment method of the whole net; the results are shown in Table 1 and Table 2.

Traverses	Second Closing Error (s)	X Closing Error (mm)	Y Closing Error (mm)	Full Length Closing Error (mm)	Relative Closing Error (mm)
Main Traverse 1	-2.1	1.6	0.7	1.8	**67764**
Main Traverse 2	0.4	1.2	0.4	1.2	**135254**
Densified South	5.3	7.5	1.5	7.6	**10180**
Densified North	-4.3	3.1	0.4	3.1	**22751**
Densified West	-1.7	1.0	1.6	2	**25687**
Densified East	-3.7	1.8	1.9	2.7	**32710**

Table1.Surveying accuracy of the horizontal control network

Every intersection angle was measured using whole circle intersection method at each control point. Every single intersection point, which was measured from more than three control points, in group formed multiple intersection triangles.

Hip rafters' sinkage on both floors was measured using spatial intersection and relative triangular height measurement. The benefits are obvious. First, errors caused by instrument height are avoided. Second, measurement can be conducted from different directions and calculation process can starts from different control points. Third, the accuracy is improved in hip rafter measurements.

Position	Northwest	Northeast	Southeast	Southwest
First Floor	30.0404	29.8116	29.7552	Object Missing
Second Floor	38.4345	38.4757	38.4243	38.4394

Table 2.Measurements of hip rafters' height

Horizontal coordinates and heights of both top and bottom of the Bodhisattava statue were measured, which were then used to calculate the status, especially the inclination of the statue.

Top-bottom	1999	2009	Difference
ΔH (m)	13.2813	13.2818	-0.0005
Distance (m)	0.4433	0.4832	+0.0401
Inclination (° ' ″)	1 54 42.1	02 05 01	+00 10 16.9
Azimuth (° ' ″)	221 31 30.5	223 08 05.4	+01 36 35

Table 3.Inclination of the Bodhisattava statue

Results show that columns had southeast inclinations with an average horizontal displacement of 10mm, which indicates an inclination of the entire pavilion towards the same direction. The statue had a southeast inclination with a top-bottom-relative displacement of 40mm. Hip rafters' displacements were considerably small.

4. CONCLUSION

(1) Deformation monitoring of Chinese timber buildings requires high accuracy due to buildings' longevity and its low deformation velocity. The scheme of measurement needs a combination of different techniques, in response to some limitations and requirements, such as narrow site, difficulties of setting up long term fixed observation points on buildings and meeting with the low interference principle.

(2) Deformation monitoring observes unfixed points through static points, which can be measured in high accuracy via forced centering apparatus. But it is still a problem to guarantee the consistency of observed points in different measurement process.

(3) Current 3D laser scanning technique doesn't offer a satisfactory accuracy in deformation monitoring of Chinese timber buildings.

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