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硕 士 学 位 论 文

应县木塔结构仿真分析及倒塌危险工况推
测

Structural Simulation and Collapse Analysis on Yingxian
Wooden Tower

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摘要

应县木塔是我国古代土木工程集大成的杰作，结构十分复杂，研究木塔结构对现代工程结构科学技术的发展以及文物建筑保护都有重要意义。

木塔结构为中国古代特有的干架木结构。其搭建的技术要领是使各个构件的支座部位为偏方形状，构件水平放置，垂直磊叠，摆积木式搭建，构件之间并非连续，而是平面接触、摩擦关系，在接触点不滑移时，整体结构可以看作一个连续杆系的框架结构。

本文根据《营造法式》及相关测绘、文献研究，建立了应县木塔理想复原模型；在田野调查基础上，根据包含有历代修改、加固、损毁的现状，建立木塔的增修残损仿真模型。采用三维工程有限元软件进行两个模型在重力工况、风载工况、地震工况下的结构反应仿真模拟，可以得出每一个构件的受力及变形。根据模拟结果，进行倒塌可能性推测。其中，根据干架结构中的柱与阑额的榫卯连接，柱脚及栌斗底的接触滑移，本文提出“拟刚接模型”用于柱额节点，和“摩擦滑移-拟弹塑性剪切模型”用于柱脚及栌斗底节点，使得这种离散接触的节点可以在有限元软件中实现仿真计算。木塔结构的倒塌可能方式，本文定义为“柱侧移”，“斗滑落”，“梁落架”之任一种。

采用YJK工程软件建模、仿真计算得出：

(1) 构件完好、结构完整的理想复原木塔结构，在地震、风等极端自然灾害工况下，不会发生倒塌。

(2) 现状残损的木塔的二层明层外槽西面偏南角柱，在自重长期作用下会倾斜失效，导致结构倒塌，需要进行相应的维修加固。

关键词：应县木塔；仿真分析；倒塌可能性预测

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ABSTRACT

Yingxian Wooden Tower is a masterpiece of ancient civil engineering in China. The structure is very complicated. The research of the tower structure is of great significance to promote modern civil engineering and protect cultural relics.

The structure of the tower is a unique dry joint timber frame structure in ancient China. In this structure, the support parts of each component are made to be flat and square, and the components are placed horizontally, stacked in vertical direction one by one, just like putting building blocks. The components are discontinuous, and only compressive and frictional interactions are considered. While the components are not sliding, the overall structure can be seen as a continuous frame structure.

According to YING ZAO FA SHI and the related research, an idealized restored model of Yingxian Wooden Tower was established. Based on the field investigation, including the modification, reinforcement, damage in the history, the existing damaged model of the tower is established. The three-dimensional engineering finite element software is used to simulate the structural response of two models under gravity load, wind load and earthquake actions. And the force and deformation of each component can be obtained. According to the simulation results, the possibility of collapse is speculated. In this paper, considering the sliding contact in the column base and the bottom of the Lu-tou, the "friction sliding quasi-elastic-plastic model" is used for the column-base node and the bottom of the Lu-tou, and considering the tenon connections between the column and the architrave, the "quasi-rigid model" is used for the beam-column node. So that the discrete nodes can be simulated in the finite element software. The collapse of the tower structure may be the way defined as "column lateral shift", "bucket lateral shift", "beam falling from frame" any one in this article.

By using YJK engineering software to simulate, this paper can get:

(1) The idealized restored model of the tower is intact and does not collapse under gravity load, wind load (basic wind pressure 0.55 kN/m^2), earthquake

actions(design base seismic acceleration value 0.40 g).

(2) The existing damaged model will collapse under gravity load, because of the corner column on the south side in the west of the outside drum in the second floor of shaft lateral shift.

Key Words: Yingxian Wooden Tower; Structural Simulation; Collapse Analysis

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