DAMAGE IDENTIFICATION OF MEMBER IN ANCIENT TIMBER STRUCTURE BASED ON MODAL STRAIN ENERGY METHOD

Xueliang Wang¹, Liang Jin², Haibo Li³

ABSTRACT: Chinese ancient timber structure has very high historical, cultural and artistic value. But long-term decay, shrinkage cracks and other natural erosion make them severely damaged. Therefore scientific conservation of such ancient timber structures has aroused an urgent concern. But when testing and maintaining in site, it’s difficult to detect the decay inside structural member as well as damage on the roof and mortise-tenon joints. A damage identification method is proposed to detect the damage location in ancient timber structure based on modal strain energy method in this paper. Firstly an undamaged finite element model and a damaged one of an ancient timber structure are built respectively and analyzed to obtain their first several natural frequencies, modes and element stiffness matrix of structural members. Secondly the mode strain energy of every element of these two models are calculated and compared to qualitatively determine possible damage elements and damage location. Finally the damage indicator MSECR of the possible damage elements is calculated to judge the damage extent of the structural members. The results show that the damage on members in the ancient timber structure can be identified effectively by the modal strain energy method, which provides a new method to maintain and preserve the ancient building.

KEYWORDS: ancient timber structure, damage identification, structural member, modal strain energy method

1 BACKGROUND

Chinese ancient timber structure is listed in the world's construction with its unique characteristics, which is a part of the cultural heritage of all human beings with high historical, cultural and artistic value. But due to the long history, the existing ancient timber structures were damaged more or less. In order to protect these valuable heritage better, it’s of great significance to identify the damage location and assess the damage extent of the ancient timber structure with scientific methods, which also can provide theoretical basis for protecting and strengthening ancient timber structure.

Ancient timber structure has been studied from several points of view including structural mechanics, seismic performance and strengthening methods. But all the works about damage detection have to be investigated by experience on site. For some special location such as roof, the mortise-tenon joint and other locations where manual access could be difficult to achieve, the conventional methods are beyond their abilities. Therefore, the need of new method is to identify such damage on ancient timber structure and consequently evaluate the structural reliability.

Since the 1970s, various technologies of damage localization were proposed. But most of these methods are for large bridge structures, their applications in the timber structure have not been reported till now. This paper proposes the method which applies the Modal Strain Energy Method to damage localization and evaluation of the ancient timber structure.

2 METHOD

Modal Strain Energy Method has high capability of positioning local damage, and it is proposed to apply to ancient timber structures. The technique is as follows:

Firstly, an ancient timber structure is taken as a project background shown as in Figure. 1, the nonlinear finite element model of mortise-tenon joint is simulated, and the finite element model of the timber structure is established shown as in Figure 2.
Secondly the dynamics characteristics of the structure before and after damage are analyzed assuming some damage locations in the structure shown as in Figure 2. the elements corresponding to the damage location is shown as in Table 1. Meanwhile the element stiffness matrix of the original structure is obtained.

**Table 1: Damage location**

<table>
<thead>
<tr>
<th>Number</th>
<th>Element No.</th>
<th>Specific location</th>
<th>Loss of stiffness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>622</td>
<td>Mortise-tenon joint</td>
<td>15%</td>
</tr>
<tr>
<td>2</td>
<td>166</td>
<td>Beam-end in side span</td>
<td>10%</td>
</tr>
<tr>
<td>3</td>
<td>163</td>
<td>Column-end in side span</td>
<td>5%</td>
</tr>
<tr>
<td>4</td>
<td>70</td>
<td>Column-end in midspan</td>
<td>5%</td>
</tr>
<tr>
<td>5</td>
<td>365</td>
<td>Column bottom in midspan</td>
<td>5%</td>
</tr>
</tbody>
</table>

Subsequently, Modal Strain Energy Change of all the elements in the structure are calculated and designated as identification index to determine the damage locations of structure according to the mutation of histogram. Finally, the damage extents of the elements are determined by comparing the value of Modal Strain Energy Change Ratio (MSECR), which is accurate to detect small damage of structure.

### 3 RESULT

The MSECR of all the elements are calculated, and shown as in Figure 3, the MSECR of the No. 70, 163, 166, 365 and 622 elements have sharp mutation which is in accordance with the assuming damage locations, and the MSECR of the adjacent elements also have some change, but not obvious. It means the MSECR is an effective damage index for damage identification. It can detect any damage location in timber structure including column ends, beam ends and centres, roof and the joint, even the damage only induces the 5% stiffness loss. Result shows that the Modal Strain Energy Change of the column bottom is more obvious than the column top with the same damage extent.

### 4 CONCLUSIONS

This paper presented the damage identification method to identify damage location and assess the damage extent in ancient timber structure based on modal strain energy method. The proposed method is numerically validated and its validity for various multiple damage cases in an ancient timber structure is investigated. An ancient timber lifted beam structure as an engineering background was simulated and analyzed to obtain the structural natural frequencies and strain modes. Modal Strain Energy Change Ratio was used to identify damage location and assess the damage extent of the structure. The results indicate that the method is capable of identifying a relatively low extent of damage such as 5% in the column ends. This is especially useful for the ancient timber structure, where some damages are difficult to detect by conventional methods.