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Experimental study on the seismic performance of a double-span traditional timber frame

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ABSTRACT

Based on the prototype of a timber palace built during the Chinese Song Dynasty with inverted-trapezoid sectioned dovetail (ITSD) mortise–tenon joints, three 1:4 scaled specimens were fabricated and tested subjected to cyclic lateral loadings. Efforts have been made to study the characteristics of the timber frame, such as the failure mode, the hysteretic and envelope curves, the strength and the stiffness degradation, and the energy dissipation. Besides, the influence of P–Δ effect on the analytical results of timber frames was discussed in detail. Furthermore, the moment–rotation relationship for the ITSD mortise–tenon joints was presented and validated.

1. Introduction

Timber structures have been used widely around the world in history, notably in China, Japan, Korea, Canadian, USA and northern Europe [1,2]. The architectural style of traditional timber structures varies from region to region. In China, timber structures have been developed through long-term historic practices. The main architectural characteristics for royal style timber palaces in ancient China are both the hip roof and the raised platform (Fig. 1). The Chinese traditional timber structures have special features and their structural performances are largely influenced by some special details. For example, columns are directly erected on cornerstones as shown in Fig. 2, beams are connected to columns using the mortise–tenon joint as seen in Fig. 3, the peripheral columns lean inwardly by a tangent angle of 1/100, columns are lengthened from the center of a building to both sides in longitudinal direction, the wooden peripheral beams locate upon the top end of columns, and the corbel brackets which are a system of brackets inserts between the column tops and the crossbeams (Fig. 4).

Recently, researchers had renewed interests in ancient timber structures. And some achievements about traditional single-span timber frames and mortise–tenon joints have been attained. Researchers have carried out a few studies on ancient timber frames and pointed out that the connections of timber frames are semi-rigid joints [3–8], which overwhelm the behaviors of timber frames, and that the P–Δ effect should be taken into consideration as analyzing timber frames with semi-rigid joints. In the past decades, scholars have studied kinds of timber joints and presented varieties of connectional properties [9–15].

Previous researches mainly focused on the mechanical mechanisms about the single-span frame, the dovetail tenon joint and the plug–slot joint with a rectangular section. In fact, the Chinese ancient palaces with important heritage value are typically multi-span timber structures and its beam–column connections are always ITSD mortise–tenon joints (Fig. 3). This sort of joint is composed of a pair of dovetail tenon and mortise with the inverted trapezoid cross-section. The top side of the trapezoid cross section is wider than its bottom side [16].

The mortise–tenon connection is a weak link of traditional timber structures. It is not only a kind of susceptible joint, but also has a nonlinear semi-rigid (NSR) property (Fig. 5). As analyzing timber frames with the NSR joints, there are two important factors that should be taken into consideration, i.e., the P–Δ effect (second-order effect) of the integral frame, and the instant stiffness of the joints. This study aimed to give the failure mode, the hysteretic and envelope curves, the strength and the stiffness degradation, and the energy dissipation for timber structures, to discuss the

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Fig. 1. Taihe Palace.

Fig. 2. Cornerstone.

Fig. 4. Corbel bracket set.

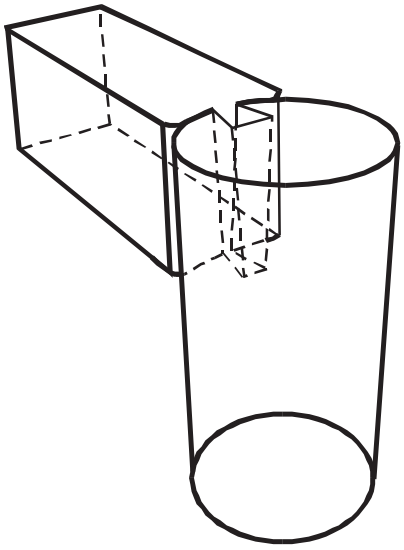

Fig. 3. Mortise–tenon joint between the beam and the column.

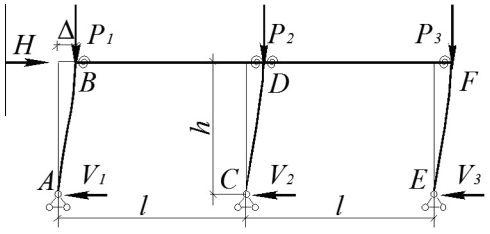

Fig. 5. Frame with NSR joints.

influence of P–Δ effect on the analytical results of the timber frame, and to present the moment–rotation relationship for the ITSD mortise–tenon joint. Based on the prototype of the three-columns-frame (TCF) structure constructed during the Chinese Song Dynasty with ITSD mortise–tenons, three scaled specimens have been experimentally and numerically studied. Based on that, the seismic performance of the double-span traditional timber structure was examined.

2. Experimental program

2.1. Fabrication of specimens

The ancient TCF palace (Fig. 6), built during the Chinese Song Dynasty, is one of the most popular types of Chinese traditional timber structures. The TCF palace used to serve as the main entrance of ancient architectural complex. According to the schematic elevations of *Explanation of building standard* [16], the