Engineering Structures 94 (2015) 113–121

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Evaluation of effective lateral stiffness of a Korean-traditional wooden house with new joint types

Yeong-Min Kim [a], Seul-Gi Lee [a], Sang-Hyun Lee [b,*]

[a] College of Architecture, Myongji University, Yongin, Republic of Korea
[b] Department of Architectural Engineering, Dankook University, Yongin, Republic of Korea

ARTICLE INFO

Article history:
Received 19 June 2014
Revised 2 March 2015
Accepted 2 March 2015
Available online 2 April 2015

Keywords:
Korean traditional wooden house
Hanok
Joint with steel plate
1/4 scale test specimen
Static loading test
Effective lateral stiffness
Joint rotational stiffness

ABSTRACT

Recently in Korea, extensive research on developing a new style of Korean traditional wooden house, Hanok, has been conducted for duplicating architectural plan composition and appearance of the Hanok and for improving construction and economic efficiencies. The beam–column joint of the new Hanok is composed of general timber and steel plates for ensuring workability on site and enhancing the structural performance while a traditional Hanok simply adopts general mortise and tenon joints. In this study, the lateral stiffness of a 2-story new Hanok was evaluated by conducting the static lateral loading tests using a 1/4 scale specimen. The 'I' shaped plan part of the specimen was first tested and the effective rotational stiffness of the joints with steel plates was estimated by comparing roof displacements of the test specimen and a numerical model. The effective stiffness of the specimen increased with increasing vertical loads and decreased with increasing roof displacements. An equation for estimating the joint rotational stiffness was proposed with regard to the steel plate type based on the test result from the 'I' shaped plan specimen. The effectiveness of the equation was verified by showing that roof displacement of the test specimen with 'L' shaped plan could be approximately estimated by using an analytical model having joint rotational stiffness determined by using the proposed equation.

1. Introduction

Hanok is a term for a Korean traditional wooden house. Hanok is made of raw materials such as timber, stone, and soil which are available almost everywhere in Korea, and are all recyclable. The architectural type of Hanok represents some features which most Korean favor. For example, its materials are eco-friendly and its plan composition differs according to the surrounding environment. In a cold region, the plan takes a closed form like a square with a patio in the center because this closed square is proper to maintain the heat of the house. The plan takes an open 'I' shape in a warm region, and 'L' shape in a region between the warm and cold regions.

Fig. 1 shows the major structural elements of the Hanok such as beams, columns, joints, rafters for supporting the roof, and foundation stones. The structure of the Hanok is a typical frame system composed of beams and columns which are connected by general mortise and tenon joints. However, this type of traditional Hanok connection requires highly skilled labor, which reduces construction efficacy and requires a longer construction period. The strength and stiffness of the joints are some of the most critical design factors for accurately evaluating the structural performance of a wooden structure.

Recently, interest in the traditional Hanok has increased so that the Korean government has been encouraging many researches on the development of a new style of Hanok which can inherit the merits of the traditional Hanok and have improved economic and construction efficacy. Fig. 2(a) and (b), respectively, show a 1-story traditional Hanok and a 2-story new Hanok, which were constructed for full scale test and located at Myongji University, Yongin, Korea. Table 1 shows the structural materials, roof load and joint construction method used for the traditional and new Hanok. The new Hanok has a much smaller roof load than the traditional Hanok, and steel plates are used for the joints of the new Hanok. The joint detail of the new Hanok was developed to make its site construction easier and minimize dependence of the construction quality on labor proficiency.

In terms of a conservative design concept, general hinge boundary condition can be applied to joint modeling even though the joint with steel plates has, in some degree, rotational stiffness. Additionally, the Hanok with all hinged joints may become unstable under a slight amount of lateral force or eccentric load because the Hanok generally does not have any brace or wall as a lateral

* Corresponding author.
E-mail address: lshyun00@dankook.ac.kr (S.-H. Lee).

http://dx.doi.org/10.1016/j.engstruct.2015.03.008
0141-0296/

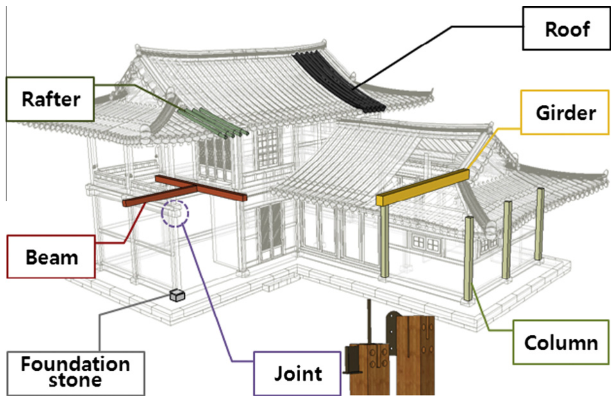

Fig. 1. Main structural components in Hanok.

force resisting system. Although the nonstructural elements such as the infill wall slightly add lateral resistance, the structure should be stable by itself and the exact estimation of the rotational stiffness of the joints is required for the effective or economical design of the new Hanok against wind or earthquake load.

Actually, the large roof load of the traditional Hanok is expected to play a role of increasing rigidity of the beam–column or column–column connection. This can be inferred from the fact that a wooden structure transfers force in some degree through friction mechanism that has resisting capacity depending on the load normal to the surface. Accordingly, the decreased roof load for improving construction efficacy of the new Hanok can cause negative effects in terms of rigidity or redundancy, and in some occasions the roof uplift can occur under strong wind load.

In many countries including Korea, extensive research has been conducted for investigating the structural characteristics of the traditional wooden structures such as temples or royal palaces or the Hanok. The static and cycle behaviors of a traditional Korean wooden frame with tenon joints under lateral load were investigated [1]. Kim et al. analytically obtained the capacity spectrum of a Korean wooden structure for the seismic performance evaluation [2]. Shaking table test results showed that the natural frequency of a Korean traditional wooden structure has its amplitude dependence [3]. Lee et al. proposed an analysis method for estimating behavior of a single wooden frame by modeling its joint shear and rotational stiffness and compared it to the response measured by a 1/2 scale specimen static loading test on a Korean traditional temple [4]. Kang et al. studied the static performance of mortise and tenon joint of a Chinese traditional timber structure [5]. Artificially degraded joint characteristics of traditional Chinese wooden frames were experimentally investigated and numerical method was proposed for predicting the static response of a wooden frame response with the joint [6]. Calderoni et al. evaluated the flexural and shear resistance of ancient wooden beams [7]. The dynamic behavior and the modal characteristics of an ancient Chinese timber architecture were studied through a full scale seismic loading test [8–9]. Parisi et al. analyzed the mechanics of the existing and retrofitted connections of traditional timber structures of the Mediterranean area [10]. Finite element modeling of Japanese "Nuki" joint was proposed by considering the initial stress and racking resistance [11]. There has been research for investigating the global or joint characteristics of a modern style wood structure. Lindt et al. experimentally obtained the seismic response of a 6-story light-frame wood structure [12]. Guan and Rodd proposed a hollow steel dowel for enhancing the ductility of a semi-rigid timber joint [13].

In this study, the lateral stiffness of a new Hanok is evaluated by conducting static lateral loading tests using a 1/4 scale specimen with the identical joint configuration to that of a full scale building

Table 1
Comparison between traditional and new Hanok.

Items	Traditional-Hanok	New-Hanok
Material	Raw wood	Raw wood, glued laminated wood
Roof load (kN/m^2)	4–10	2–4
Connection	Mortise and tenon joint	Joints with steel plates

(a) Traditional Korean wooden house

(b) New Korean wooden house with 'L'shaped plan

(c) A two storied specimen with 'I' shaped plan

Fig. 2. Hanok Speicmens.