A Study on the Behavioral Characteristics of Traditional Timber House under Lateral Loads

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Abstract— **There are differences in structural style and connection method between the traditional timber frame structure, that is, Hanok and the modern wooden structure, and these differences make it difficult to predict structural capacity of Hanok. The purpose of this study is to examine the structural meaning of the construction method and show idealization of each joint type for the Korean traditional timber frame structure. This study consists of several steps. The overall flow of research analyzes the Hanok from a micro perspective to a macro perspective. Specifically, each joint is analyzed through the idealization in the first step, and joint is analyzed in the overall structure of the second step. Through this study, we suggested the method to assure lateral stiffness of Hanok.**

Index Terms—**Hanok, connection, lateral loads, lateral stiffness**

I. Introduction

HANOK, a traditional building in Korea, is being promoted for its beauty and eco-friendly performance. The Hanok is being introduced to not only traditional living facilities but also various public facilities for citizens.

As this change in the Hanok, the new-styled Hanok requires various sized structures rather than a single storied structure. In order to develop structure, it is necessary to investigate the structural capacity of the Hanok and consider ways to improve the disadvantages of its structure. The problem caused by the development is that because of Hanok is based on the wooden connection, it is vulnerable to lateral loads such as seismic or wind loads compared steel connection. That is, connections of wooden frame based on hinge and roller are weaker than the steel connection even though various forces such as vertical compression and friction are applied on connection.

In order to improve these disadvantages, this study aims to analyze the Hanok from a micro perspective to a macro perspective. In the first step, each connection is analyzed, and in the second step, connections are analyzed in the entire structure. Through this study, we consider the method of lateral stiffness.

To solve noted problems, various researches have been conducted. Researches can be divided into two categories. One category is the study on the overall behavior characteristics of wooden frame structure. And the other is the study on stiffness connection and horizontal members related to the lateral loads.

First of all, it is important for the Hanok to understand the capacity based on the overall behavioral characteristics rather than the behavior of some members. Kim [9], [10] studied characteristics of structural analysis of Hanok. Hong et al.[2] studied the behavior characteristics of various wooden frame structures, Hong et al.[3] studied the behavior characteristics of lateral load in frame type structure, In Choi et al. [1], three wooden frames were tested to show the ability to behavior under lateral loads. Jung et al. [6], [7] also studied the idealization and modeling of the connection in order to analyze behavior characteristics of the Hanok.

In the second category, the study on stiffness connection and horizontal members related to the lateral loads, Han et al. [4] showed the bending strength and displacement through the tension test. Kim et al. [11] analyzed the relationship between the connection and load by making 1/4 size of the building to evaluate the stiffness due to the self-weight of roof.

As a result of the two studies, to understand the behavior of Hanok and prepare the stiffness under lateral loads, it is necessary to perceive the overall understanding of the frame structure and the characteristics of the behavior of members due to load transfer. That is, it is difficult to predict the capacity of only a unit of member without frame structure. Because the Hanok is a main laminating type structure, the stepwise load transfer from the upper member to the lower member is performed, rather than securing the lateral rigidity through binding.

As showed in the preceded part, the connections are idealized by hinge joint. But, it is more reasonable to idealize the joints with semi-rigid due to the friction stiffness by self-weight. Therefore, the stiffness of the joint has to be considered in the overall behavior of the frame structure.

II. The Idealization of Wooden Frame Structure

The structural characteristics of the wooden buildings can be classified according to the construction method of the plan. Two of the most representative forms are the outer column type and the two-column type. The outer column type building is supported only by the outer column. On the other hand, the two-column type is using more than two columns supported by the inner column with outer column.

In order to investigate the overall behavior of the lateral load on the frame structure, rather than the two-column type, the characteristics of the outer type building were

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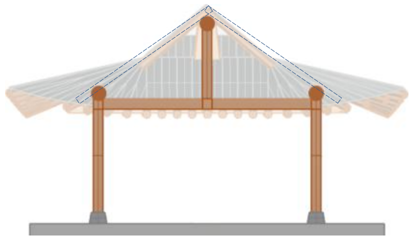
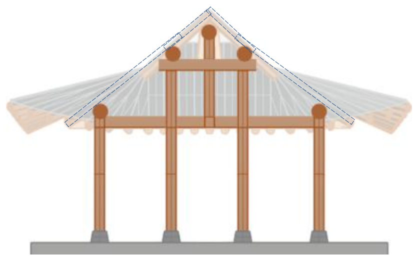


(a) The outer column type of the Hanok



(b) The two column type of the Hanok

Fig. 1. The typical wooden frame structure of the Hanok

The connection of the wooden frame structure can be classified into three parts: a connection between a column and a foundation stone, the bracket member, and the column and beam. In order to perform the structural analysis for the Hanok, likewise the modern structure, the idealization of the joint between the members should be preceded like hinge, rigid, roller. The most important feature of construction is that the wooden frame has constructed by using the method of wood-to-wood joints.

The main connection is made only by joint and splice, which is a way to fit the wood exactly together. The joint means that the member is connected in the longitudinal direction and the splice means connecting members in a vertical direction to each other. The structural effect of this method can distribute its own weight evenly and resist the lateral stiffness by frictional force. Therefore, it can help preventing a formal collapse due to lateral loads such as overturning or base shear.

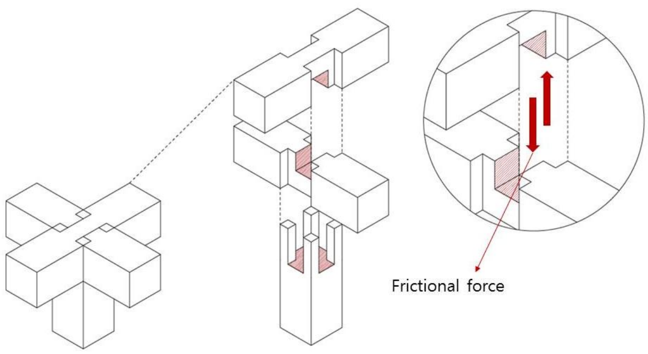


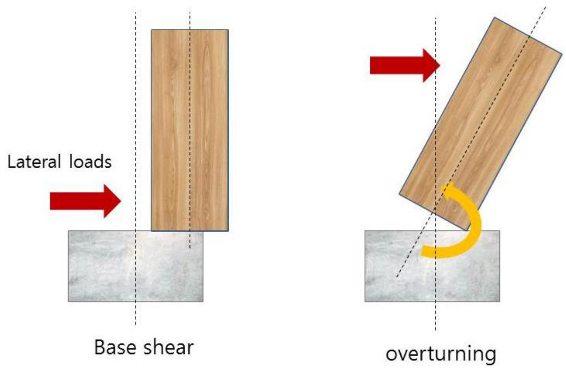
Fig. 2. The construction method of the connection member

A. *The Column and Foundation stone*

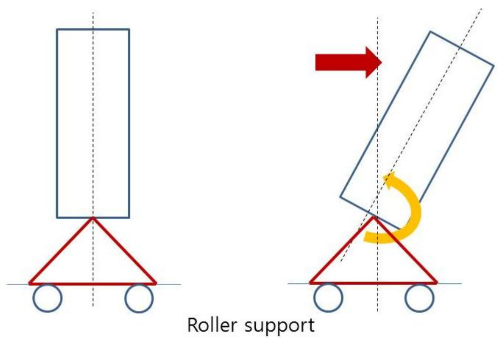
The support means how the structure is standing from the ground. In the case of the Hanok, the connection between the column and foundation stone can be defined as some of the support. But, the disadvantage of this connection is that when the bottom of the column is exposed to the ground, it will be weathered and destroyed over time. Eventually, it can cause severe damage to the structural members. Therefore, in the Hanok to prevent these problems, the column is built on the foundation stone. In this process, if the connection is idealized in units of member, the column is placed on the foundation stone without any special equipment. And as a result, it is classified as a roller support that can be easily moved. The roller supports at both ends of the frame are regarded as unstable structures that slip easily into lateral forces such as wind and earthquake.

However, judging from the overall behavior characteristics, the roller support of the Hanok can be regarded as the roller support having a spring coefficient due to the frictional force and compression force obtained by the self-weight of the roof. Therefore, it is reasonable to assume that these connections idealize the hinge support.

(a) The column and foundation stone



(b) The behavior of the connection under the lateral loads



(c) The idealization of the connection

Fig. 3. The connection: the column and foundation stone

B. *The Column and Beam*

In the same way columns and beams are constructed by

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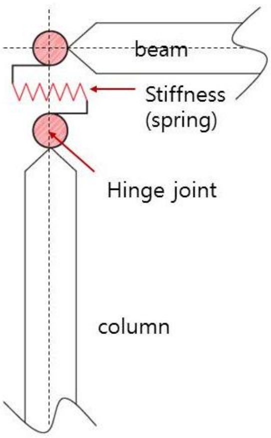
using the method the wood-to-wood joint. When the connection of column with beam is structurally idealized in a member unit, it is classified as a hinge joint because it can`t move bilaterally. If the four corners of both ends are idealized by hinge joints, the Hanok should be defined as an unstable structure that can`t resist lateral loads. But, in reality, Hanok has survived several earthquakes even though it hasn`t the equipment such as seismic isolation, vibration control. The wood-to-wood joint method used to connect the members unifies the behavior of the frame movement by the compression and friction force. Therefore, it is considered to be a structure having stiffness higher than the hinge joint in correspondence to the lateral loads, as noted the overall behavior characteristics.

(a) The column and beam

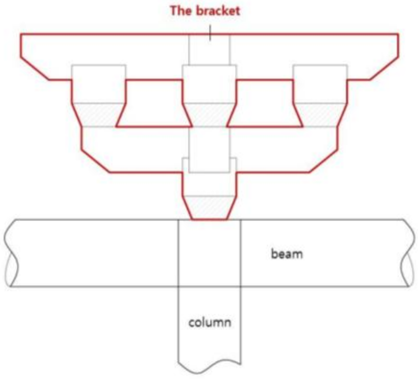


(b) The idealization of the column and beam

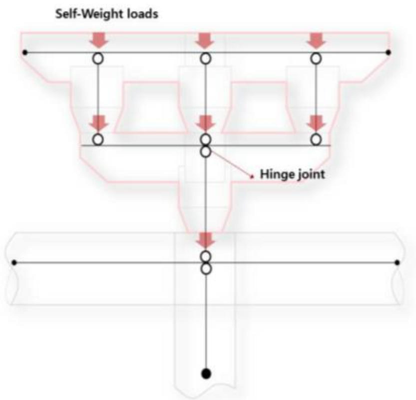
Fig. 4. The connection: the column and beam

C. The Bracket Connection

The bracket is used as a member connecting the roof structure to the column-beam frame placed under the roof. It is depicted as a stack of multiple members. Various members belonging to the bracket are tied together by joint and splice, which has stronger strength than modern connection. Likewise, since the compression force does not push it sideways easily, the idealization of the bracket member is more reasonable to assume that it can be classified as the hinge joint or semi-rigid joint.



(a) The bracket Connection



(b) The idealization of the bracket member

Fig. 5. The connection: the bracket

As discussed, the classification of connections belonging to the Hanok is composed of its behavior with two joints and one support such as the column and foundation stone followed by column, beam, and bracket connection. Also each of the joint and support is idealized as the hinge joint and the roller support. However, it can be assumed that each of the parts have stiffness above the hinge joint. It is presumed that the frictional force is increased by the compressive force obtained by the self-weight and the members can`t move easily due to the jointing and splicing technique. In order to check the structural capacity of the Hanok, it is important to check the function of the member solely, but as noted, the results are different according to the whole system of the wood structure.

III. The Structural Behavior of the Hanok under Lateral Loads

The collapse due to the lateral loads applied to the structure is the overturning, the base shear, the racking and the same result as conduction occurs. The Hanok belonging to weight deflection type out of vertical irregularities list can be tilted by the wind direction or roof structure shanked easily.

In the case of wind loads, the roof of the Hanok can be separated by static pressure. Similarly, in the case of an earthquake, considering that the magnitude of the seismic loads is the "mass (x) acceleration" of the building, the

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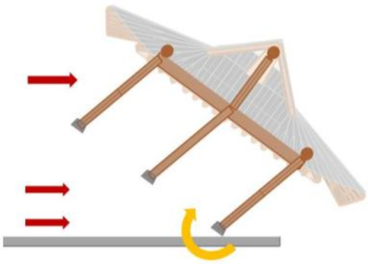
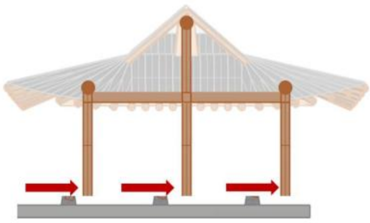
Hanok may be more vulnerable to seismic loads than the general building because the weight of the roof is higher than the weight of the concrete building. Also, modern buildings use the rigid joint through the steel connection, while the Hanok uses hinge joint made of wooden joint and joint. Modern buildings use rigid joints through steel connections, while the Hanok uses hinge that use wood and wooden joints. Even though the Hanok has a lot of frictional force and compressive force due to its own weight, it is fundamentally unstable structure, it can be more vulnerable than modern buildings if the lateral load is strong.



(a) Overturning



(b) Base shear

Fig. 6. The lateral loads collapse

IV. The Lateral Stiffness Assurance Method

In order to secure lateral stiffness in the Hanok, using a bearing wall is effective for lateral resistance. Generally, the bearing walls should be more arranged than average in the direction of the lateral force. As shown in Fig. 7, it is common to install the bearing wall in two directions of X axis and Y axis. If one direction is insufficient, eccentricity may be occurred. The bearing wall has different strength depending on the material. The stronger the bearing wall has strength, the shorter the wall is in length. Thus, the wall magnification is related to the strength of the material and the amount of wall. For example, there are two types of bearing structures with a width of 1m. If the "A" wall is able to resist lateral forces of 2KN with a width of 1m and the "B" wall can resist lateral forces of 4KN with a width of 1m, the wall magnification of "B" is about twice as strong as "A". In this case, it is judged that the bearing wall has sufficient lateral stiffness even if only 0.5 m of the "B" wall is installed even though the 1m of the "A" wall is installed for the same lateral force.

As noted in Fig. 7, the amount of the bearing wall can be adjusted according to the strength of the material, but the arrangement is not free. The walls should be balanced throughout the shape of plan.

If earthquake is occurred as shown in Fig. 8, lateral forces are generated at the center of mass in the plan. If the bearing wall is not balanced, the center of mass and stiffness will have different nodes and eventually the building will be twisted or rotated. Therefore, the difference of two nodes must be matched as closely as possible to minimize the damage caused by installing the bearing wall or the others.

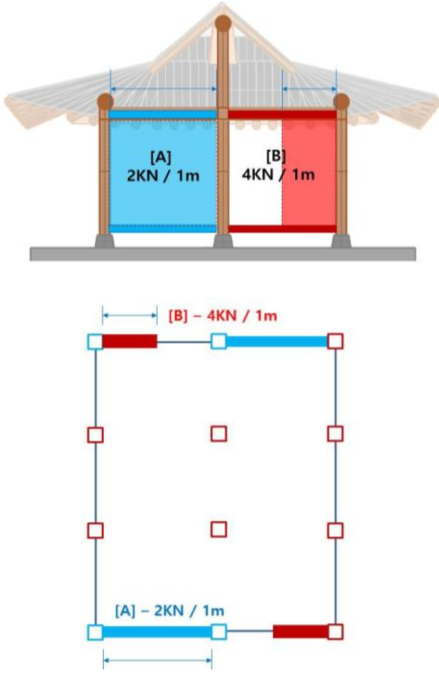


Fig. 7. The strength of the bearing wall

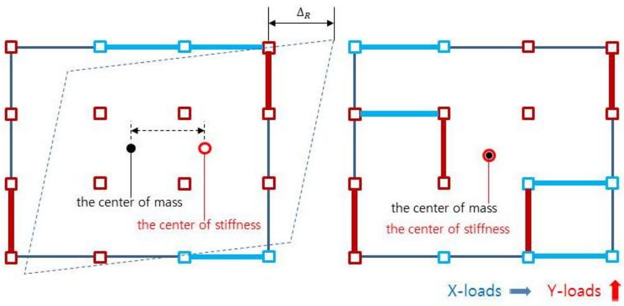


Fig. 8. The difference of the center of mass and stiffness

In the Hanok, 'Inbang' has got lateral stiffness by having a horizontal member between columns. The Inbang is a member connected between columns. It is used as a member to hold columns in the position of upper, middle, and lower, providing lateral stiffness by unifying the behavior of the wooden frame structure.

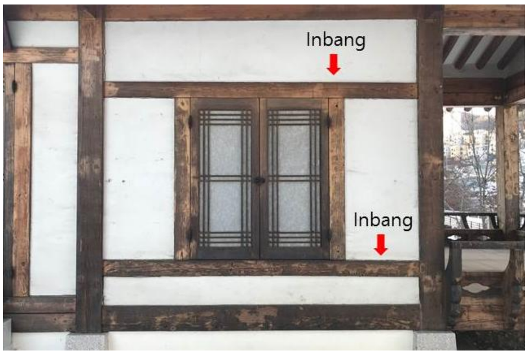


Fig. 9. The Inbang member of traditional Hanok

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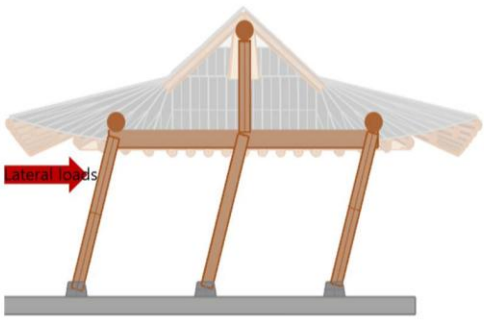
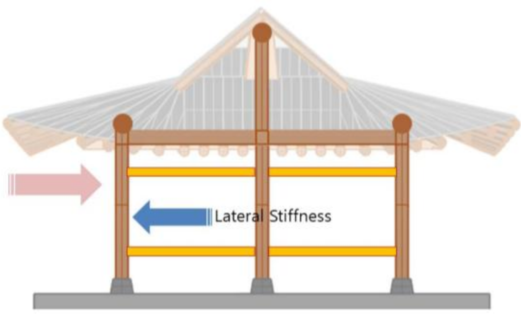
The performance of the Inbang is similar to installing the bearing wall. After installing Inbang, the inside of it can be filled with materials such as soil and concrete or bricks. Also it can be controlled by calculating the stiffness through the characteristic of material, and then the wall magnification standard can be equally applied. In addition, it can be arranged in a balanced way in the X to Y direction, so that the damage caused by the earthquake can be minimized.



(a) Racking due to lateral loads



(b) The lateral stiffness through the Inbang

Fig. 10. The capacity of the Inbang under the lateral loads

V. Conclusion

Unlike rigid joints, which are commonly used in modern buildings, hinge joints are used, so in the future, improvement in the wooden frame structure is ensuring the stiffness by the lateral loads. If lateral loads are generated, the wooden frame structure is structurally unstable, which can be caused by collapse damage such as overturning, base shear, racking.

In order to prevent these damages, we have to install a bearing wall, in the case of the Hanok, the performance of the bearing wall can be replaced by the Inbang member, which can be regarded as a kind of horizontal frame and brace structure for lateral stiffness. Furthermore, if it is used with some materials that have the certain strength such as soil or concrete and wood board to be filled with the inside of these, it can be evaluated that the strength and capacity of bearing wall is suitable for the Hanok.

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