Monitoring of Moisture Contents in Korean Traditional Wooden Houses

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Abstract—**This research monitored surface moisture contents of wooden columns of Korean traditional wooden houses called Hanok and analyzed the monitored data. The monitored buildings are comprised of three different types of Hanok, that is, (1) one-story traditional Hanok built by traditional construction method, (2) two story new-styled Hanok built by modernized construction method and (3) traditional pavilion Hanok built by traditional construction method. The monitoring of moisture contents had been carried out during one and a half years. The monitored data was analyzed based on three criteria; column location to the sun, wood types and relative humidity. The moisture contents of the columns at north side were 0.57% higher than ones at south side, and moisture contents of raw wood was 1.21% higher than that of the glued laminated wood. Also, regardless of wood types, variation patterns of the moisture contents showed similar to that of the relative humidity.**

Index Terms—**Korean-traditional wooden house, monitoring, moisture contents, relative humidity**

I. Introduction

THE Korean traditional wooden house is called Hanok. The word Hanok is composed of two syllables, that is, “Han” and “Ok”. Here “Han” means Korea and “Ok” which is pronounced as “[ɔːk]” means house. So Hanok simply means Korean house, but the term “Hanok” only refers to a traditional wooden house, not a contemporary house.

Hanok has the history of almost 2,000 years or more. The building material of Hanok is mainly wood, stone and soil, and the main structural members are made of wood. The general structure of Hanok is a framed structure connected by mortise and tenon joints only by wood. We say that Hanok is the reflection of the Korean sentiment and life styles, but the traditional Hanok has some inconvenient factors for the contemporary people to live in. Nowadays, researches are making steady progress to enhance traditional Hanok to fit for the contemporary life style and as a result, the new-styled Hanok recently appeared.

The traditional Hanok and the new-styled Hanok are similar in appearance and frame structure, but much different in interior space, connection type of members and construction method. Especially, in terms of frame material, the traditional Hanok used raw wood, but the new-styled Hanok generally uses glued laminated wood to help steel plate and bolt connections.

Researches on the wooden buildings have been consistently carried out domestically and internationally. In Korea, researches were carried out mainly on the Buddhist temple building, traditional Hanok, and wooden buildings of palace. Seo et al.[1] analyzed static and cyclic behavior of wooden frames of ancient Korean commoner’s house with tenon joints under lateral load, and investigated lateral loading capacity and failure modes. They show that ancient Korean wooden house has a significant nonlinearity and inelasticity. Hwang et al.[2] performed shaking table test on the Korean traditional wooden house and extracted natural frequency and damping ratio according to vibration amplitude. Lee et al.[3], [4] evaluated lateral load resistance capacity of Korean traditional wooden structures of various connection types by analytical method and experiments.

Researches on the new-styled Hanok which is constructed by the modernized construction method have been just started. Lee et al.[5] performed shaking table tests both on the traditional Hanok and new-styled Hanok and compared dynamic characteristics between them according to excitation amplitude. Kim et al.[6] evaluated rotational stiffness of new connection types which are used in the new-styled Hanok by static loading test on a 1/4 scale model.

In abroad, Kang et al.[7] evaluated static performance of mortise and tenon joint in Chinese traditional column and tie timber structure. Lindt et al.[8] performed shaking table experiment on a full-scale six story light frame wooden building and evaluated its seismic response. Fang et al.[9], [10] analyzed load-displacement relationship on a ancient Chinese timber architecture by full-scale shaking table test. Parisi et al.[11] evaluated behavior characteristics of retrofitted Mediterranean traditional timber connections.

The most distinct feature of wood as a building material is cracking and splitting as it dries. Especially, large sectional wood used as structural members of Hanok is generally thicker than 200mm, and cracking and splitting occurs severely and inescapably as it dries. In traditional Hanok, the section sizes of structural members are generally much larger than stress requirement, and connections between members are generally made of mortise and tension joints without using nails or bolts. So, even though crack may occur, it does not have a significant effect on the structural stability. But, in a new-styled Hanok, as section sizes of structural members are optimized to the stress requirement so as to minimize material cost, and steel plate and bolt connections are used for the construction efficiency, the cracking and splitting of wood may affect structural safety severely. Therefore, in a new-styled Hanok, glued laminated woods which sufficiently

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dried and rarely crack are generally used as structural members.

The most influential factor to the cracking of wood is moisture contents. As of the researches to the effects of moisture contents to the wood, Hwang[12] investigated relationship between moisture contents and mechanical properties of wood, and Park et al.[13] studied distribution of moisture contents in wooden post member of Korean traditional wooden building. In material point of view, moisture contents of wood are closely related to the maintenance and management of wooden structure and eventually its long life.

In this study to establish the basic data for the maintenance and management of Hanok, I monitored the surface moisture contents of column members of both traditional and new-styled Hanok for a certain period of time, and analyzed the patterns of moisture contents based on three criteria, that is, column location to the sun, wood types and relative humidity.

II. Introduction to The Monitored Building

The monitored buildings, called test-bed Hanok, were built in Myongji university in city Yongin, which is located about 40km south of Seoul, capital of Korea, as shown in Fig. 1. Geometric position of test-bed Hanok is 127.2 degrees east longitude and 37.2 degrees north latitude. Yongin has a moderate climate with four distinct seasons, and its annual average temperature is 12°C and annual average precipitation is 1,300mm.

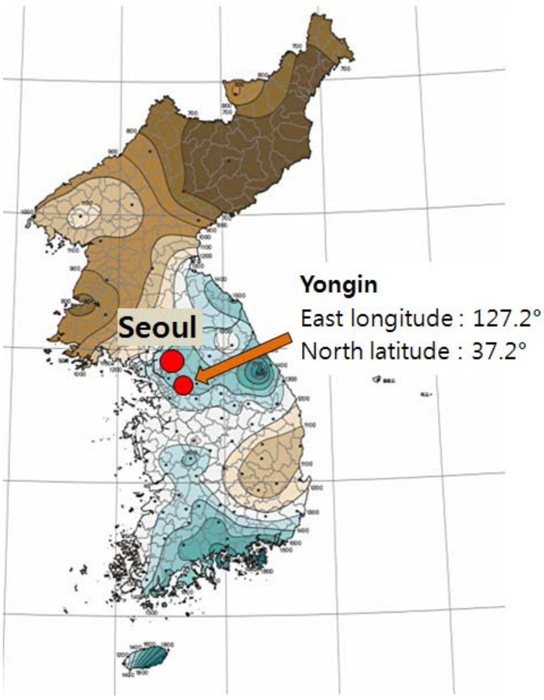

Fig. 1. Location of test-bed Hanok in Korea –its latitude and longitude.

The monitored buildings are composed of three different types of Hanok, that is, (1) one-story traditional Hanok built by traditional construction method shown in Fig. 2(a), (2) two-story new-styled Hanok built by modernized construction method shown in Fig. 2(b), and (3) traditional pavilion Hanok built by traditional construction method shown in Fig. 2(c). The basic information on each of the Hanok is summarized in Table I. raw wood are used for the traditional Hanok and traditional pavilion Hanok as the structural members, as shown in Fig. 3(a), and their connection types are mostly mortise and tenon joints of only wood as shown in Fig. 4(a). Whereas, Fig. 3(b) shows that the glued laminated wood used for the new-styled Hanok as their structural members, and their connection types are mostly steel plate and bolt joints as shown in Fig. 4(c). Fig. 4(b) and Fig. 4(d) show construction process of traditional Hanok and new-styled Hanok respectively. Traditional pavilion Hanok was completed in December 2007, whereas traditional Hanok and new-styled Hanok were completed in May 2012. So there is about four and half year gap between the completion date of two traditional Hanoks and the new-styled Hanok.

TABLE I
Basic Information for Three Types of Hanok

Type of Hanok	Wood type	Connection type	Year of completion
Traditional-Hanok	raw wood	mortise and tenon joint	2012.05
New-styled Hanok	glued laminated wood	steel plate and bolt joint	2012.05
Traditional Pavilion Hanok	raw wood	mortise and tenon joint	2007.12

Fig. 2. Three types of Hanok for monitoring of moisture contents.

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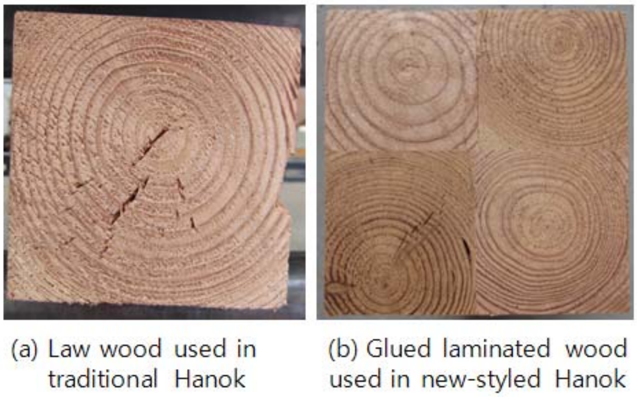


Fig. 3. Comparison of wood type between traditional Hanok and new-styled Hanok.

Fig. 4. Comparison of joint types and construction methods between traditional Hanok and new-styled Hanok.

III. Monitoring Plan

Monitoring of moisture contents of columns for the three types of Hanok had been carried out from August 2012 to January 2014, which means total period of monitoring is one and a half years. Moisture contents were measured two or three times a month and they were averaged and the averaged value was used as each month's representative value.

Fig. 5 shows position of monitoring columns for each three types of Hanok. Moisture contents were measured at half height of column which is about 120cm above the bottom of column as shown in Fig. 6(a). The measuring equipment shown in Fig. 6(b) is an electric-resistant device from TESTO Inc., of which model number is 606-2 with measurement error ±1%.

The number of monitoring columns and their section sizes are summarized in Table □. Five columns were monitored for both the traditional Hanok and new-styled Hanok, respectively, where southern columns are three and northern columns are two. Eight columns were monitored for the traditional pavilion Hanok, where southern and northern columns are four, respectively. Section size of monitored columns of traditional Hanok and traditional pavilion Hanok is 210mm x 210mm, and that of new-styled Hanok is 180mm x 180mm.

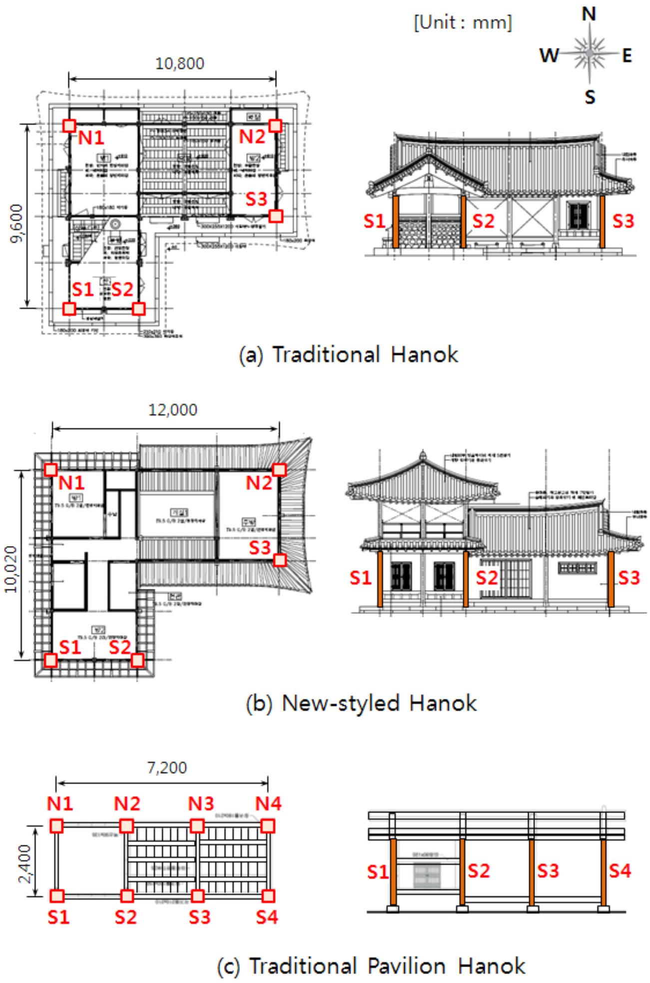
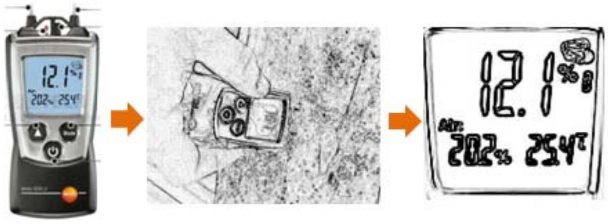


Fig. 5. Position of monitored columns for three types of Hanok.

TABLE II
NUMBER OF MONITORED COLUMNS AND COLUMN SIZE

Type of Hanok	Number of monitored columns		Column size (mm)
	Southern	Northern	
Traditional-Hanok	3	2	210 x 210
New-styled Hanok	3	2	180 x 180
Traditional Pavilion Hanok	4	4	210 x 210

(a) Measuring of moisture contents



(b) Equipment for moisture contents measuring

Fig. 6. Measuring of moisture contents and measuring equipment

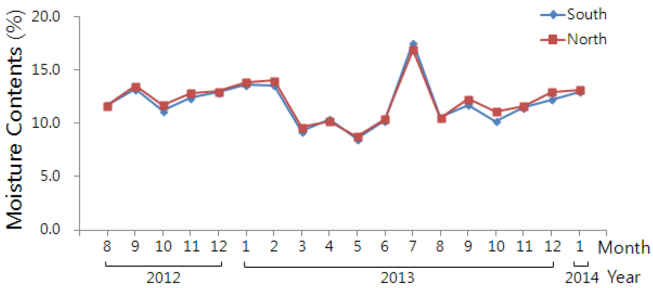
IV. Analysis of Monitoring Results

A. Analysis Criteria

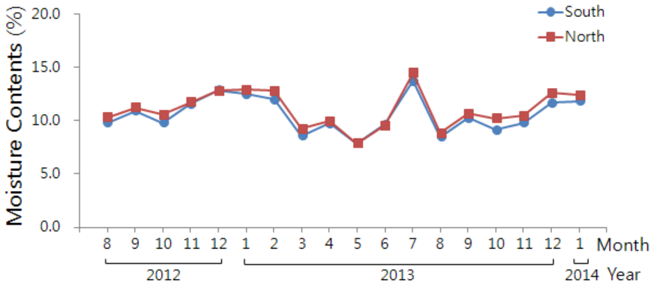
The measured moisture contents were analyzed based on three criteria. First criterion is difference of moisture contents according to column location to the sun, that is, southern columns which have much sunshine and northern columns with little sunshine. Second criterion is difference of moisture contents according to wood types, that is, traditional Hanok and traditional pavilion Hanok are made of big sized raw wood which is hard to be dried sufficiently, whereas new-styled Hanok is made of glued laminated wood which can be dried sufficiently. Third criterion is relationship between moisture contents and relative humidity, as the monitored region has four distinct seasons, and regular patterns of temperature and relative humidity according to four seasons. The wood material of all three monitored Hanok is domestic larch wood, so they have the same material properties.

B. Moisture Contents and Column Orientation

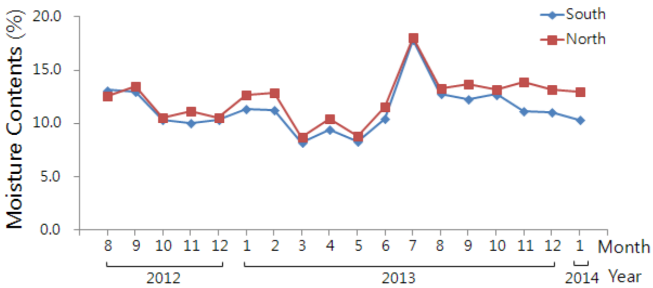
Fig. 7 shows the comparison of moisture contents graphically according to column location to the sun for three types of Hanok. Although the difference is small, northern columns show more moisture contents than that of southern columns. Table Ⅲ shows the difference of moisture contents according to column locations to the sun. It reveals the highest value of 0.99% in the traditional pavilion Hanok, and 0.47% in the new-styled Hanok and 0.25% in the traditional Hanok. The average value of these differences is 0.57%, and this value is less than measurement error ±1% of measuring equipment. But, as can be seen in Fig. 7(a), Fig. 7(b), and Fig. 7(c), the moisture contents of the northern columns of all the three types of Hanok are thoroughly higher than those of the southern columns throughout the entire monitoring period. And from this fact we can conclude that the difference is meaningful. It can be deduced that the southern columns with much sunlight dry faster than the northern columns with less sunlight, and it leads to the fact that the southern columns have less moisture contents.



(a) Traditional Hanok



(b) New-styled Hanok



(c) Traditional Pavilion Hanok

Fig. 7. Comparison of moisture contents according to column location to the sun for three types of Hanok

TABLE Ⅲ
Comparison of Moisture Contents for Three Types of Hanok

Type of Hanok	Average moisture content (%)		
	South (A)	North (B)	Difference (B - A)
Traditional-Hanok	11.87	12.12	0.25
New-styled Hanok	10.56	11.03	0.47
Traditional Pavilion Hanok	11.31	12.30	0.99

C. Moisture Contents and Wood Type

Fig. 8 shows the comparison of moisture contents graphically between traditional Hanok and new-styled Hanok. The key difference between these two Hanok is that the structural members of the traditional Hanok are made of raw wood and those of the new-styled Hanok are made of glued laminated wood.

Both southern and northern columns of the traditional Hanok show more moisture contents than those of the

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new-styled Hanok throughout the entire monitoring period.

In Table IV, the moisture contents were compared numerically. The average moisture contents of southern columns of the traditional Hanok turned up 1.32% higher than that of the new-styled Hanok, and 1.10% higher in northern columns. From this fact it can be deduced that as the glued laminated wood is made of thinner wood with sufficient drying and glued together, it contains less moisture than big sized raw wood from manufacturing, and this initial gap continues after completion.

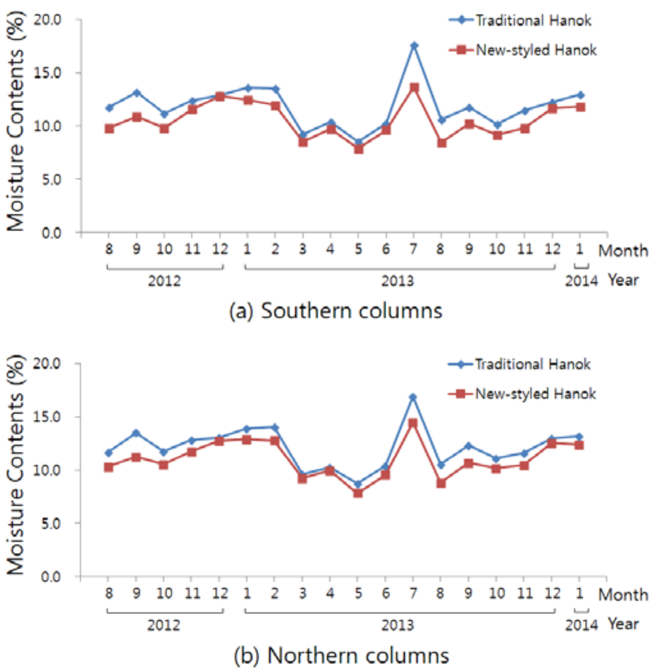

Fig. 8. Comparison of mean moisture contents between traditional Hanok and new-styled Hanok for each column location to the sun

TABLE IV
COMPARISON OF MOISTURE CONTENTS ACCORDING TO WOOD TYPE

Type of Hanok	Average moisture contents (%)	
	Southern	Northern
Traditional-Hanok (A)	11.87	12.12
New-styled Hanok (B)	10.56	11.03
difference (A - B)	1.32	1.10

D. Moisture Contents and Relative Humidity

It is known that there is a proportional relationship between surface moisture contents of wood and relative humidity of atmosphere. The region where the monitored buildings are located, Yongin, has a climate of high temperature and humidity in summer season with mean maximum temperature of 30.3°C and much precipitation. Whereas, Yongin has cold temperature and less humidity in winter season with mean minimum temperature of -6.3°C and less precipitation. But, in winter the relative humidity does not fall much, as the snow lay thick without melting during the most of the winter season. In spring and fall seasons, it is warm and dry so the relative humidity is somewhat low. The seasonal difference of relative humidity between summer (highest) and spring (lowest) is about 11%, and with the monthly difference between the highest and lowest humidity is about 23%.

Fig. 9(a) shows graphically the relationship between mean temperature and mean relative humidity. In a rough way, mean temperature and mean relative humidity show similar variation pattern. Fig. 9(b) compares graphically the mean relative humidity and the mean moisture contents of both the traditional Hanok and the new-styled Hanok, and they also show similar variation pattern. The relationship between seasonal mean temperature and their mean relative humidity can be checked numerically in Table V.

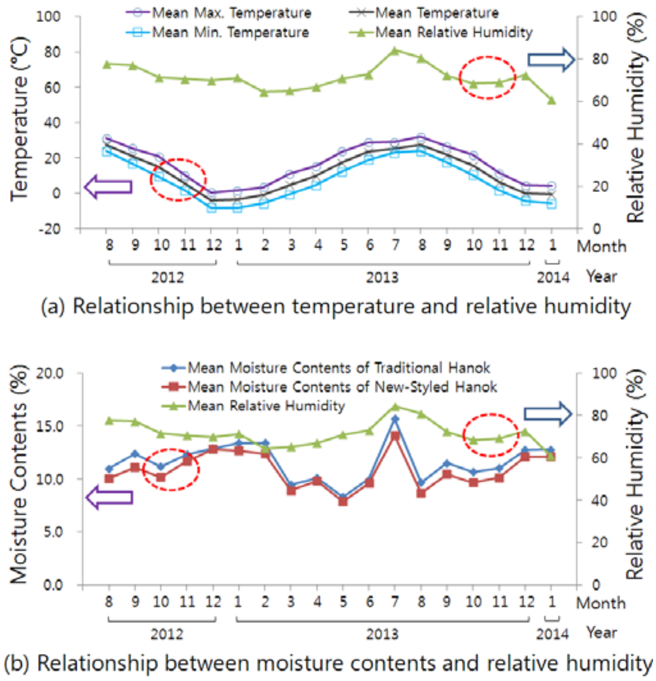

Fig. 9. Relationship between temperature and relative humidity and between moisture contents and relative humidity

TABLE □
RELATIONSHIP BETWEEN MEAN TEMPERATURE AND MEAN RELATIVE HUMIDITY ACCORDING TO SEASONS

Item	Spring	Summer	Fall	Winter
mean temperature (°C)	10.7	25.9	14.2	-3.7
mean relative humidity (%)	67.5	78.9	71.5	69.5

V. CONCLUSION

This study aimed to establish the basic data for the maintenance and management of the Korean traditional house - Hanok through the monitoring of the surface moisture contents of wooden columns of Hanok. The moisture contents were measured and analyzed during one and a half years period, focusing on their relationship to the column location to the sun, wood types and relative humidity were analyzed.

The northern columns with less sunlight showed more moisture contents than the southern columns with much sunlight, and raw wood showed more moisture contents than the glued laminated wood. And moisture contents showed similar variation pattern to that of the relative humidity.

During the monitoring period, roof deformation was also monitored with moisture contents, and total monitoring schedule is planned to extend another three years as a continuation of this research. If moisture contents and roof deformation are analyzed together, it can be expected that the relationship between moisture contents and wood deformation would be revealed.

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REFERENCES

[1] J. M. Seo, I. K. Choi, J. R. Lee, "Static and cyclic behavior of wooden frames with tenon joints under lateral load", *Journal of Structural Engineering*, vol. 125, no. 3, pp. 344-349, Mar. 1999.

[2] J. G. Hwang, S. G. Hong, Y. W. Lee, S. J. Jung, "Natural Frequency Characteristics of Traditional Wooden Structure for Vibration Amplitude", *Journal of the Architectural Institute of Korea : Structure & Construction*, vol. 25, no. 5, pp. 3-10, May. 2009.

[3] Y. W. Lee, B. S. Bae, S. G. Hong, J. G. Hwang, N. H. Kim, S. J. Jung, "An Analytical Modelling of the Beam-Direction Frame of Traditional Wood Structure System", *Journal of the Architectural Institute of Korea : Structure & Construction*, vol. 22, no. 3, pp. 29-36, Mar. 2006.

[4] Y. W. Lee, S. G. Hong, J. G. Hwang, B. S. Bae, "Capacity of Lateral Load Resistance of Dori-Directional Frame with Jangbu-connection in Traditional Wood Structure System", *Journal of the Architectural Institute of Korea : Structure & Construction*, vol. 23, no. 2, pp. 35-42, Feb. 2007.

[5] S. G. Lee, Y. M. Kim, J. E. Roh, S. H. Lee, S. S. Woo, "Dynamic Characteristics of traditional and New Korean-style Houses According to Excitation Amplitude", *Journal of the Architectural Institute of Korea : Structure & Construction*, vol. 29, no. 1, pp. 49-58, Jan. 2013.

[6] Y. M. Kim, S. G. Lee, "Evaluation of Connection Stiffness of Test-bed Hanok Using a 1/4 Scale Two-Storied Model", *Journal of the Architectural Institute of Korea : Structure & Construction*, vol. 29, no. 12, pp. 73-80, Dec. 2013.

[7] M. Kang, N. Yang, Q. Cha, "Studies on Static Performance of Mortise and Tenon Joint in Traditional Column and Tie Construction Timber Structure", *Electric Technology and Civil Engineering (ICETCE), 2011 International Conference*, pp. 6197-6200, 2001.

[8] J. W. Lindt, S. Pei, S. E. Pryor, H. Shimizu, H. Isoda, "Experimental Seismic Response of a Full-scale Six-Story Light-Frame Wood Building", *Journal of Structural Engineering*, vol. 136, no. 10, pp. 1262-1272, Oct. 2010.

[9] D. P. Fang, S. Iwasaki, M. H. Yu, Q. P. Shen, Y. Miyamoto, H. Hikosaka, "Ancient Chinese Timber Architecture I: Experimental Study", *Journal of Structural Engineering*, vol. 127, no. 11, pp. 1348-1357, Nov. 2001.

[10] D. P. Fang, S. Iwasaki, M. H. Yu, Q. P. Shen, Y. Miyamoto, H. Hikosaka, "Ancient Chinese Timber Architecture Ⅱ: Dynamic Characteristics", *Journal of Structural Engineering*, vol. 127, no. 11, pp. 1358-1364, Nov. 2001.

[11] M. A. Parisi, M. Piazza, "Mechanics of Plain and Retrofitted Traditional Timber Connections", *Journal of Structural Engineering*, vol. 126, no. 12, pp. 1395-1403, Dec. 2000.

[12] J. G. Hwang, "The Moisture Content and Mechanical Characteristics of Wood", Journal of the Structure Diagnosis, vol. 15, no. 4, pp. 3-6, Apr. 2011.

[13] C. H. Park, G. C. Kim, "Study on Moisture Contents Distribution of Wooden Post Member by Precise Monitoring in Un-Bong Confusion School", Journal of the Korea Furniture Society, vol. 21, no. 1, pp. 104-112, Jan. 2013.

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