Structural Planning of Long-span Hanok Considering Lateral Loads

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***Abstract*— In this research, structural planning of long-span Hanok considering lateral loads has been studied. Hanok is a Korean traditional timber house, the structural members of which are mainly comprised of timber. The long-spanning of Hanok can be considered by two types, that is, beam direction and dori direction. Beam direction is related to depth, and dori direction is related to width of Hanok. In general, beam is subjected to concentrated load, on the other hand, dori is subjected to distributed load. Therefore, beam direction is more sensitive to long-spanning than dori direction. Hanok has various appearance types in elevation, that is, single storied, two-storied, partly two-storied, double storied, two-storied castle gate, two-storied palace gate, multi-storied pagoda, and so on. And Hanok has various appearance types in plan, that is, linear type, L type, C type, closed type, and so on. If Hanok is subjected to lateral loads, such as wind load or seismic load, both the elevation and plan irregularities can cause irregular lateral movement, that is, torsional movement. To prevent torsional movement and secure the safety of Hanok, three design methods can be applied, that is, seismic resistant design, vibration control design and seismic isolation design. In this research, the schematic structural planning approaches for long-span Hanok against lateral loads have been studied and presented.**

***Index Terms*—Hanok, lateral loads, structural planning, long-span**

I. Introduction

HANON is a Korean traditional timber house, the structural members of which are mainly of timber. The traditional Hanok, which is shown in Fig. 1(a) has histories of more than 2,000 years, and the structure type of Hanok can be classified as post and beam structure as shown in Fig. 1(b). Nowadays, the new-styled Hanok, which is shown in Fig. 1(c) has been developed and get people's attention. The new-styled Hanok has modernized bathroom, kitchen, insulation system, heating and air-conditioning system, and so on, to accommodate the contemporary life style of people. The joints of main structural members of traditional Hanok are mostly mortise and tenon joints, whereas, those of the new-styled Hanok are steel joints. The wood which is used in the traditional Hanok is mainly raw wood, that is, lumber, whereas, that of the new-styled Hanok is engineered wood, that is, glue-laminated wood.

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The main structural characteristics of Hanok can be summarized as lumber and mortise and tenon joints in traditional Hanok and engineered wood and steel joints in new-styled Hanok.

(a) Traditional Hanok

(b) Post and beam structure of traditional Hanok

(c) New-styled Hanok

Fig. 1. Traditional Hanok and new-styled Hanok

Various researches on the timber structure and Hanok have been carried out around the world. Seo et al. [1] studied the static and cyclic characteristics of wooden frames with traditional mortise and tenon joints under lateral load, Han et al. [2] evaluated the mechanical performance of tenon joints to modernize the traditional Hanok, Kang et al. [3] studied the static performance of mortise and tenon joint, Lee et al. [4], [5] performed analytical modeling and evaluated lateral capacity of dori-direction Hanok frame with mortise and tenon joint, and Kim et al. [6] evaluated effective lateral stiffness of steel joints used in new-styled Hanok.

As for the dynamic analysis of timber structure or Hanok, Fang et al. [7], [8] studied static and dynamic characteristics of ancient Chinese timber structure, Hwang et al. [9] analyzed the natural frequency of Hanok according to vibration amplitude, and Kim [10] and Lee et al. [11] performed dynamic experiments on a new-styled Hanok and extracted its dynamic characteristics according to excitation amplitude.

For the longevity of Hanok, researches on the maintenance and management are now on the rise. Park et al. [12] studied on the distribution of moisture contents on traditional Hanok, and Kim [13] evaluated moisture contents of column members of traditional Hanok more than three years and extracted patterns of moisture contents according to orientation to the sun and wood type.

To help the structural design of Hanok in early design stage, Kim et al. [14] and Kim [15] developed section list tables for both lateral and vertical members, respectively. And Kim [16], [17] developed automated structural design software for both horizontal and vertical members of Hanok.

In this study, the schematic structural planning of long-span Hanok considering lateral loads has been studied. The concept of long-spanning of Hanok, the appearance types both in elevation and in plan, and the conceptual seismic design method peculiar to Hanok has been presented.

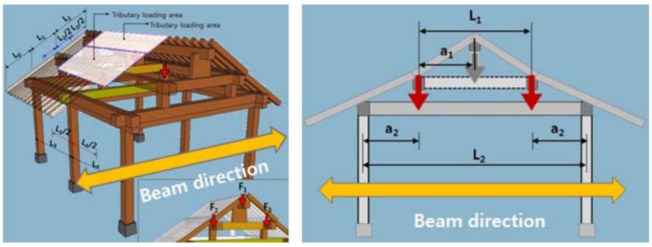
II. The Long-Spanning of Hanok

The long-spanning of Hanok can be considered by two types, that is, beam direction and dori direction. Beam direction which is shown in Fig. 2(a) is related to depth, and dori direction shown in Fig. 2(b) is related to width of Hanok.

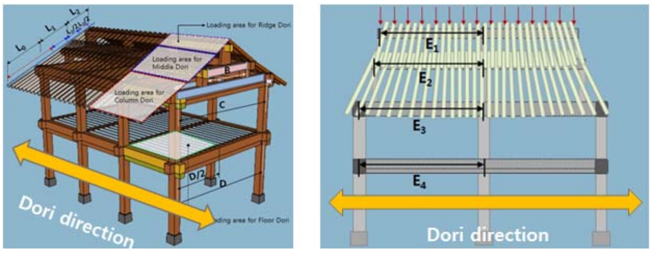
In Hanok, beam is subjected to concentrated load and the deflection is proportional to the third times of its length and flexural stress is proportional to just its length. On the other hand, dori is subjected to distributed load and the deflection is proportional to the fourth times of its length and flexural stress is proportional to the second times of its length. Due to the structural characteristics of Hanok the actual deflection and flexural stress is more in beam direction than dori direction, so that, beam direction is more sensitive to long-spanning than dori direction. If the span of beam or dori is more than about 10m, the section size needed becomes so large that lumber is no longer feasible to be used but glue-laminated wood is more feasible and the use of hybrid system must be considered to accommodate the long span.

III. Types of Hanok in Structural Viewpoint

Hanok has various appearance types, and these types can be analyzed both in elevation and in plan.



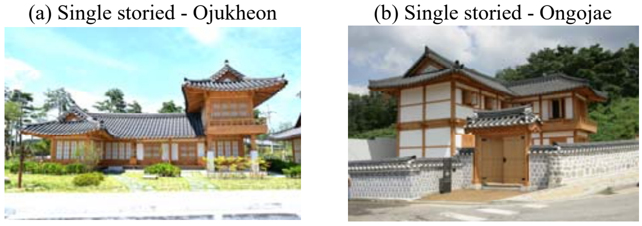
(a) Long spanning of Hanok in beam direction



(b) Long spanning of Hanok in dori direction

Fig. 2. Two-types of long-spanning of Hanok

(a) Single storied - Ojukheon (b) Single storied - Ongojae



(c) Partly two storied - Jeeshingwan (d) Two storied - Hwakyeongdang

(e) Double storied Buddhist sanctuary–Magoksa Daeungbojeon (f) Double storied Buddhist sanctuary - Beopjusa Daeungbojeon

(g) Two storied castle gate - Sungnyemun (h) Two storied castle gate - Paldalmun

(i) Two storied palace gate - Manghaeroo (j) Five storied pagoda - Beopjusa Palsangjeon

Fig. 3. Various appearance types of Hanok in elevation

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In elevation, Hanok has appearances of single storied, two-storied, partly two-storied, double storied, two-storied castle gate, two-storied palace gate, multi-storied pagoda, and so on, as shown in Fig. 3. And in plan, Hanok has appearances of linear type, L type, C type, closed type, and so on, as shown in Fig. 4. The irregular appearances of Hanok both in elevation and in plan can cause vertical irregularities and plan irregularities, respectively. These irregularities can make the movement of Hanok under later loads so complex that Hanok may undergo severe damage during earthquakes.


(a) Linear type – isometric view


(b) Linear type – top view


(c) L type – isometric view


(d) L type – top view


(e) C type – isometric view


(f) C type – top view


(g) Closed type – isometric view


(h) Closed type – top view

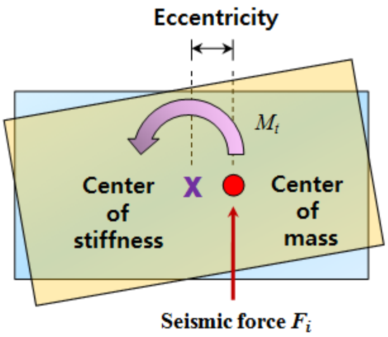

(i) Closed type – isometric view


(j) Closed type – top view

Fig. 4. Various appearance types of Hanok in plan

IV. STRUCTURAL CHARACTERISTICS OF HANOK UNDER LATERAL LOADS

If Hanok is subjected to lateral loads, such as wind load or seismic load, both the elevation and plan irregularities can cause irregular lateral movement, that is, torsional movement. The torsional movement is mainly caused by the difference between the center of mass and the center of stiffness as shown in Fig. 5. The center of mass is where the seismic force is applied and the center of stiffness is where the structure resists the applied force. To prevent torsional movement it is necessary to make the center of mass and the center of stiffness as close as possible. Various structural techniques can be applied to these processes, that is, structural separation both in plan and elevation, installing braces or walls and installing seismic resistant devices.



(a) Concept of torsional movement

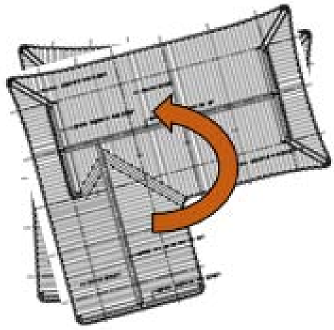

(b) Torsional movement induced in Hanok

Fig. 5. Torsional movement due to difference between center of mass and center of stiffness

V. STRUCTURAL PLANNING OF HANOK CONSIDERING LATERAL LOADS

As the span of Hanok becomes more long it becomes more difficult to control torsional movement. To prevent torsional movement and secure safety of long-span Hanok, it is necessary to take more active methods. In this research, the schematic structural planning methods for long-span Hanok against lateral loads have been studied thoroughly and three schematic design methods have been presented. The presented design methods are seismic resistant design, vibration control design and seismic isolation design. The concept of these three design methods are discussed briefly as follows.

A. Seismic Resistant Design

Seismic resistant design is to make the structure of Hanok strong enough to resist the seismic load, and this design method includes to make the member size big enough or to make joint have enough stiffness. Installing seismic resistant device, which can be said seismic bracket as shown in Fig. 6(a) is one of the seismic resistant design method.

B. Vibration Control Design

The main characteristic of Hanok is that it has heavy roof weight compared to its under-roof structure. The heavy roof weight can make Hanok overturn when it undergoes earthquake and can cause severe damage. This phenomenon

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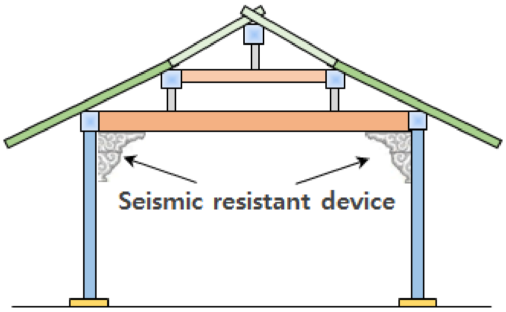
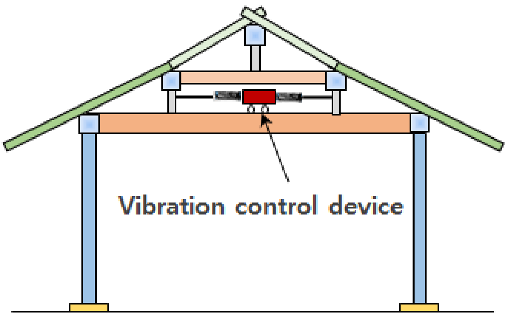
can be mitigated by installing vibration control device, such as, tuned mass damper (TMD) or tuned liquid damper (TLD) on the upper part of the Hanok as shown in Fig. 6(b). It is estimated that, a small mass, approximately 1/100 of roof weight will be sufficient to control the vibration induced by earthquake.

C. Seismic Isolation Design

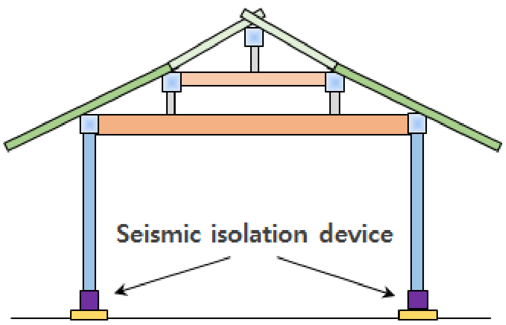
Seismic isolation design is realized by installing seismic isolation device between superstructure of Hanok and its foundation as shown in Fig. 6(c), so that the vibration period of Hanok becomes large enough to avoid the resonance caused by earth movement of relatively short vibration period.



(a) Seismic resistant design



(b) Vibration control design



(c) Seismic isolation design

Fig. 6. Three methods of the structural planning of Hanok for seismic loads

VI. Conclusion

In this research, structural planning of long-span Hanok considering lateral loads has been studied. The long-spanning of Hanok can be considered by two types, that is, beam direction and dori direction. The structural characteristics of Hanok make beam direction more sensitive to long-spanning than dori direction.

The shapes of Hanok can be analyzed both in elevation and in plan. In elevation, Hanok has appearances of single storied, two-storied, partly two-storied, double storied, two-storied castle gate, two-storied palace gate and multi-storied pagoda. And in plan, Hanok has appearances of linear type, L type, C type and closed type.

Under lateral loads, both the elevation and plan irregularities of Hanok can cause irregular lateral movement, that is, torsional movement. To prevent torsional movement and secure safety of Hanok, three design methods, such as, seismic resistant design, vibration control design and seismic isolation design can be applied.

Seismic resistant design is to make the structure of Hanok strong enough to resist the seismic load, and this includes to make the member size big enough or to make joint have enough stiffness. As for the vibration control design, tuned mass damper (TMD) or tuned liquid damper (TLD) can be installed on the upper part of the Hanok. As for the seismic isolation design, seismic isolation device can be installed between superstructure of Hanok and its foundation.

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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. S. Han, C. J. Kim, “An Experimental Study on mechanical performance of tenon for analysis of structural system and Modernization of Traditional Wooden Architecture”, *Journal of the Architectural Institute of Korea: Planning & Design*, vol. 21, no. 4, pp. 121-128, 2005.
[3] 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.
[4] 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.
[5] 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.
[6] Y. M. Kim, S. G. Lee, S. H. Lee. “Evaluation of effective lateral stiffness of a Korean-traditional wooden house with new joint types”, *Engineering Structures*, vol. 94, no. 1, pp. 113-121, 2015.
[7] 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.
[8] 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.
[9] 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.
[10] Y.M. Kim: Dynamic Experiments on a 1-4 Scale New-styled Korean Traditional Wooden House. Applied Mechanics and Materials, 2014, Vol 598: 743-746.
[11] 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, 2013.

[12] 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.

[13] Y.M. Kim: Monitoring of Moisture Contents in Korean Traditional Wooden Houses. In Proceedings of the World Congress on Engineering 2014, London, England, June 2-4, 2014, pp.1298-1303.

[14] Y. M. Kim, J. H. Kim. "A Study on the Development of Section Tables for Lateral Members of Hanok". *Journal of the Architectural Institute of Korea: Structure & Construction*, vol. 30, no. 2, pp. 37-44, 2014.

[15] Y. M. Kim. "Structural Check Schemes for the Initial Design of Columns of Hanok for Vertical Loads". *Journal of the Architectural Institute of Korea: Structure & Construction*, vol. 31, no. 11, pp. 21-28, 2015.

[16] Y. M. Kim. "Development of Automated Structural Design Tool for Horizontal Members of Hanok". *Journal of the Architectural Institute of Korea: Structure & Construction*, vol. 33, no. 4, pp. 21-28, 2017.

[17] Y. M. Kim. "Development of Structural Design Tool of Hanok Columns Considering Rotational Stiffness". *Journal of the Architectural Institute of Korea: Structure & Construction*, vol. 33, no. 8, pp. 29-36, 2017.