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THE STUDY OF THE STRUCTURAL PERFORMANCE EVALUATION OF THE HUNGINJIMUN GATE (TRADITIONAL MULTI-STORIED STRUCTURE)[1]

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Abstract.

This study is to identify the structural system of the Heunginjimun gate (East gate in Seoul, a double roof wooden structure) to analyze the possible structural failures through such methodology. The Heunginjimun gate is designated as Treasure No.1 of Korea and is one of the most representative double roof storied structures in Korea. It was built during the Joseon dynasty in 1398, was newly rebuilt in 1869 and existing until nowadays.

For the structural analysis, the building has to be investigated for its construction methodology and connections to define the vertical load flow in the structure, and find the reactions in each architectural element for the purpose to identify the main cause of damage. The building is analyzed for each structural element, space and size. For the material of the structure, the type of tree and roof tiles are investigated to make a realistic and more accurate model.

[1] This study is based on the R&D organized by the National Research Institute of Cultural Heritage, 2012

Using the vertical load factors, the vertical forces and bending moments acting on the columns, bracket sets and joints are assumed and with the collected data a structural analysis is done using a structural analysis program. The load factors are basically from the roof load and the connections were defined according to its current state. The connection and joint were determined whether it is a hinge, roller or fixed support. The simulation model is compared with the real state of the building to confirm the analysis and find error ranges of the structure.

A total analysis was done analyzing the displacement, bending moment, shear force and axial force of each element. This study has the purpose of understanding the critical elements of the structure and give scientific advice for the study of traditional techniques. Through this study, a manual for the workers and designers who are working in the construction site has been made and the manual would become the basic guidelines for the restoration works of the double roof structures in Korea.

1 INTRODUCTION

There are 2 types for the definition of a multi-storied building in Korea. It could be a building with multi floors or eaves. It is mostly depending on the outlooks of the building. In China it is normally expressed as multi-eave building. From the exterior it looks as if it is a multi-storied building, but from the inside it could be a single-storied building. This is mostly seen in temple buildings to express the authority of the building also to enshrine the Buddhist statue inside. It is forbidden for a person stepping over the Buddha's head (fig 1). According to documents and historical surveys, it is known there were 73 multi-storied buildings, but most of them were burnt down during war times and now there are 16 buildings of the Joseon dynasty remaining designated as a cultural heritage. Most of the multi-storied buildings are temples, palaces and watch towers of castles. For this study the Hunginjimun Gate in Seoul (fig 2) will be analyzed.

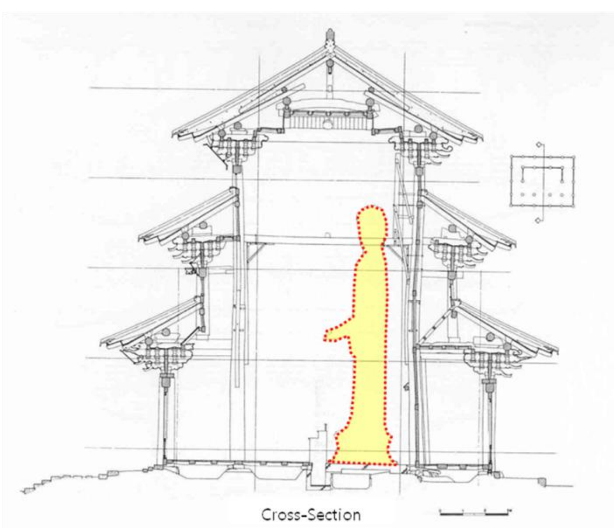


fig 1 Section drawing of the Mireukjeon Hall of Gumsansa Temple, Gimje

fig 2 Hunginjimun Gate in Seoul

The Hunginjimun Gate in Seoul was the main Eastern gate of the Joseon dynasty. It was built during the 7th reign of King Taejo (1398) with some repair works throughout the history and was rebuilt in the 6th year of King Kojong (1869) remaining the structure until now. It is a 5×2 kan[2] double storied building with a defensive stone castle/wall surrounding it. The gate was designated as Treasure No.1 in 1963 representing the Late-Joseon architectural style. The building is standing on a stone arch gate in the middle of city Seoul. It is currently being structurally monitored as there are some dangerous factors from vibration of transportation and construction but is considered to be safe.

2 STRUCTURAL SYSTEM AND LOAD TRANSFERRING MECHANISM

2.1 Load Factor

There are 3 major materials for consideration of load for traditional wooden architecture in Korea. Those are type of wood, tile size and earth mortar. For tree load it differs by type in Table 1. Mostly for building material, pine tree is the most dominant material since most of the country is covered with pine trees and it is easy to carve. Tiles are also big load factors. The Soogiwa (covering tile) and Amgiwa (laying tile) are always constructed together and there are typically 3 size types. Depending on the size and area of the roof a simple table with load information is given in Table 2. Earth mortar load varies from type of soil and mud, but generally it is ($21.4kN/m^3$)[3]

Table 1 Tree type information

Type	Dry density	Compressive strength (MPa)	Tensile strength (MPa)	Bending Moment (MPa)	Shear force (MPa)
Pine	0.53	48.0	51.9	88.0	10.1
Oak	0.89	64.1	125.0	118.0	12.3
Douglas	0.54	48.8	-	87.2	9.3
Fir	0.43	51.7	57.3	80.4	7.2

Table 2 Tile type and weight

Type		Dimensions (mm)	Weight (N)	Amount (㎡)
Amgiwa	Small	270*330*18	38.64	32.46
	Medium	300*360*21	56.28	26.88
	Large	330*390*24	70.70	22.62
Soogiwa	Small	140*270*18	26.28	13.22
	Medium	150*300*21	33.63	10.75
	Large	170*330*24	47.75	8.91

[2] Kan (칸, 干): terminology for a space in between 2 columns. The width could vary by the size or type of the building.

[3] J.KIM, Historical and Structural Survey and Comparison of the Roof Structure Typology of Buildings in Europe and Korea, 2012

2.2 Plan analysis

To analyze the Hunginjimun according to the plan, there are a total of 32 columns. The structural system is a half-kan reduced system with the angle rafters being supported directly by the corner columns. From the drawing in fig 3, it could be seen that the 2nd columns and high columns are supporting the main roof. There are mainly 2 types of columns in length, high columns (high column and corner column) which are continuous until the main roof and short columns (1st and 2nd column) supporting from each floor. The 2nd columns are reduced half-kan from the 1st column and the roof load from the corner rafters are transmitted to the ground by the corner columns.

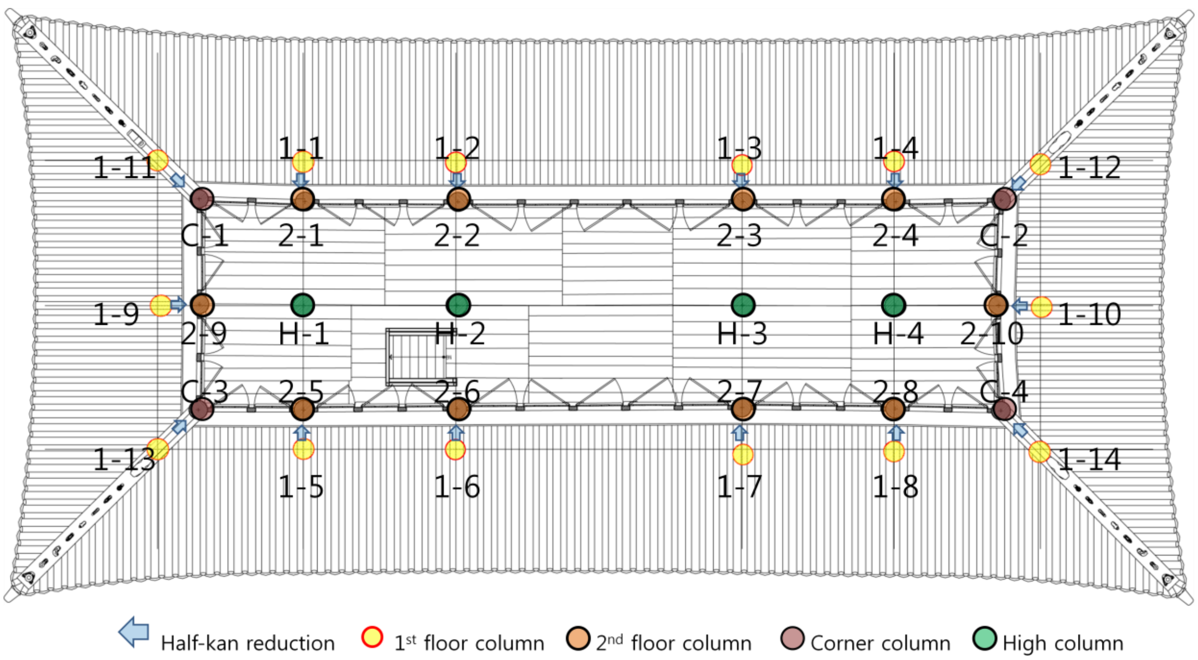


fig 3 2nd floor Plan and column arrangement of Hunginjimun Gate

2.3 Section analysis

The section analysis of the gate was performed for the verification of the load transferring system of each wooden element. According to fig 4, the load which has to be in consideration is the roof and self-weight of the building. For the main load elements from top to bottom order, the top beam is being supported by the high column and struts, and the high column is ranging from the ground to the top beam with the 1st and 2nd floor main beam connected to it. The 2nd floor column load is transferred to the 1st floor main beam.

Through the section analysis a simplified model of the section could be drawn in consideration of the load flow mechanism. It could be interpreted as a simple beam analysis with pin, roller and partially fixed supports and connections. The load flow and simplified model could be seen in fig 6.

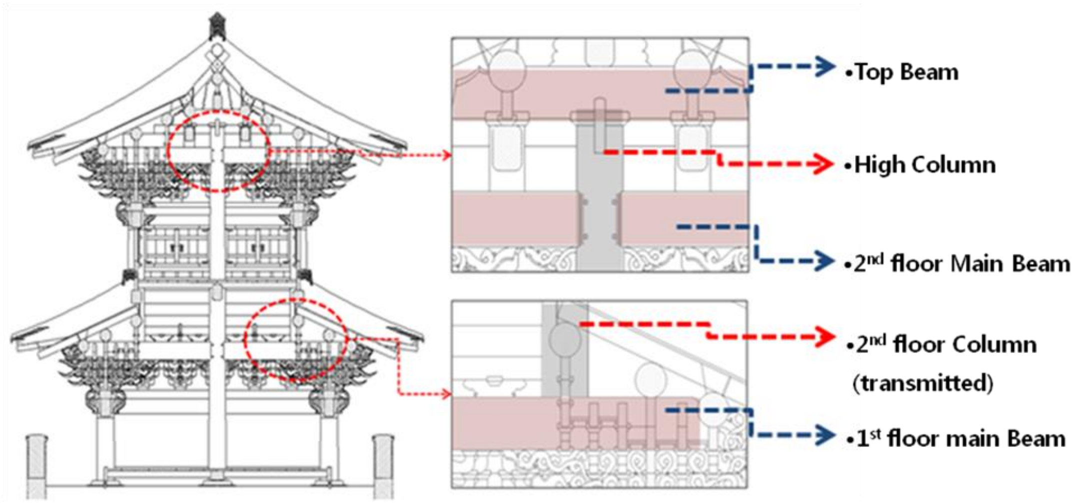


fig 4 Section of Hunginjimun Gate and structural system of main element

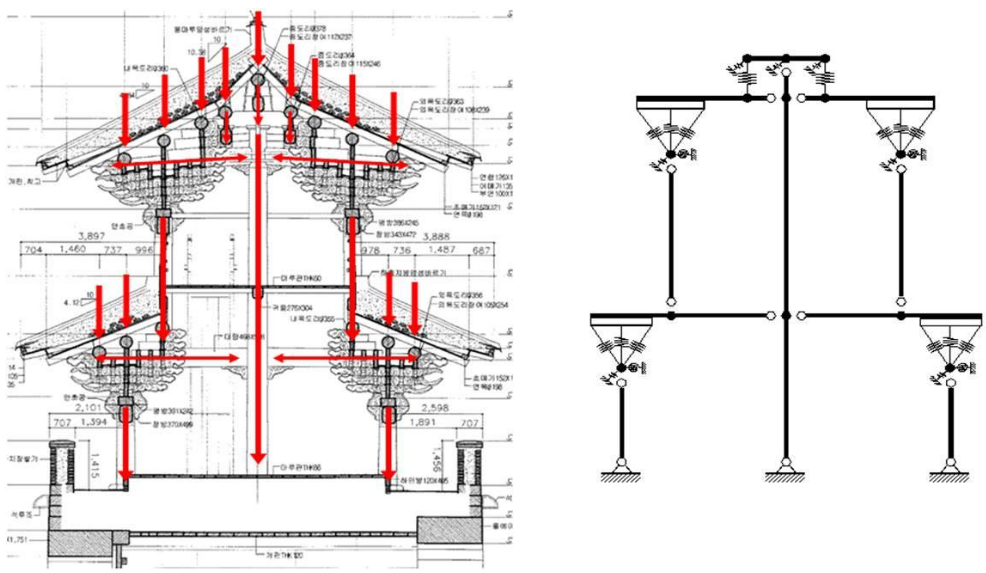


fig 5 Axial force diagram and simplified model of section

2.4 Resultant axial force on each beam element

The resultant axial load force could be calculated. The column numbering information could be seen in fig 3 and resulting force on Table 3. It should keep in mind that the load factors are taking into account the 3 major materials timber as pine tree, tile as large size and earth mortar. The raction forces are calculated in an excel spread sheet.

Table 3 Resultant axial force on each column element

Column type	1st floor		
Number	1- 1,4,5,8	1- 2,3,6,7	1- 9,10

<table>
<tr><td>Axial Force (kg)</td><td colspan="2">25,921.66</td><td colspan="2">37,310.13</td><td colspan="2">19,322.31</td></tr>
<tr><td>Column type</td><td colspan="6">2nd floor</td></tr>
<tr><td>Number</td><td colspan="2">2- 1,4,5,8</td><td colspan="2">2- 2,3,6,7</td><td colspan="2">2- 9,10</td></tr>
<tr><td>Axial Force (kg)</td><td colspan="2">39,590.07</td><td colspan="2">58,273.07</td><td colspan="2">32,691.91</td></tr>
<tr><td>Column type</td><td>2nd floor</td><td colspan="4">High column</td><td>Corner column</td></tr>
<tr><td>Number</td><td>2- 11,12,13,14</td><td colspan="2">H-1,4</td><td colspan="2">H-2,3</td><td>C-1,2,3,4</td></tr>
<tr><td>Axial Force (kg)</td><td>25,987.27</td><td colspan="2">37,809.66</td><td colspan="2">54,998.60</td><td>34,930.89</td></tr>
</table>

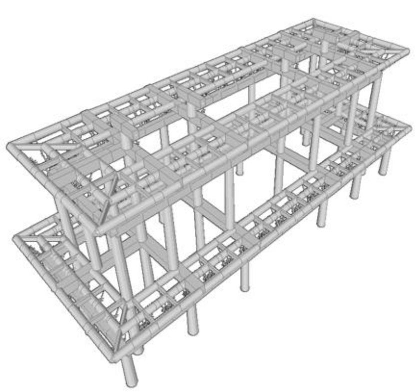
3 3D SIMULATION MODEL AND APPLCATION

3.1 Assumption for fixity and setting for each element

For an accurate interpretation for structural analysis, the fixity of the column, connection and bracket set had to be assumed. The column was assumed to be a hinge on the ground with spring element on the X and Y axis. For connections, as Korean traditional houses do not use any needles, it is considered to be a partial fixed connection releasing some parts for bending moment. Bracket sets couldn't have any tensile strength but only compression with the connection with the beam as a spring structure.

3.2 Use of SAP2000 and comparison

A with the collected information a 3D simulation model was built using the SAP2000 program. Material information and axial forces were adopted to analyze the deformation of each element. (fig 6 and fig 7). The resultant forces using the model comparing with the simple hand calculation had minor differences as an overall which gave a realistic model. Table 4 is showing the comparison of the 2 methodology. The reason for some differences could be because of the hinges of the column and the program has a flexible distribution of loads on each element while calculation by hand is basically considering it as a point load.



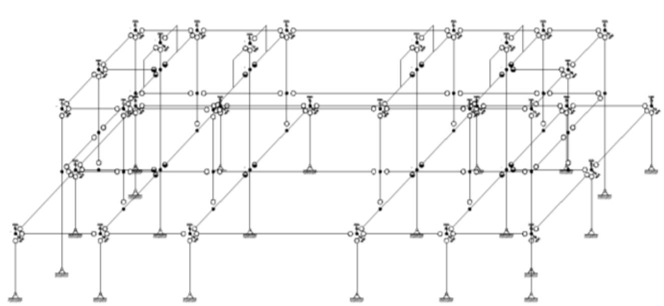


fig 6 Installation of iron straps on the column

fig 7 Column and foundation stone connection

Table 4 Comparison of 2 methodologies

floor	Position	Number	By Hand	By Program	Difference
2nd	Column	1, 4, 5, 8	25,921.66	26,037.11	0.445%
		2, 3, 6, 7	37,310.13	40,062.67	7.377%
		9, 10	19,322.31	22,929.94	18.671%
1st	Column	1, 4, 5, 8	39,590.07	39,661.37	0.18%
		2, 3, 6, 7	58,273.07	59,723.69	2.489%
		9, 10	32,691.91	36,078.76	10.360%
		11, 12, 13, 14	25,987.27	25,511.44	-1.831%
	High	1, 4	37,809.66	34,928.39	-7.620%
		2, 3	54,998.60	49,061.05	-10.796%
	Corner	1, 2, 3, 4	34,930.89	31,323.02	-10.329%
Total			366,835.57	365,317.45	-0.414%

3.3 Comparison with actual survey drawing

An actual survey of the Hunginjimun Gate was done in 2006. With the actual drawings it was possible to compare the deformation and displacement of the building with the real state and the 3D simulation model. The deformation of the 1st and 2nd main beam was compared and the deflection (creep) of the Changbang[4] was analyzed. The deformation of the main beams of each floor had a very similar deformation shape looking like a cantilever beam. The 2nd floor was showing a greater deformation (3~5times according to actual survey / 4.6 times according to 3D simulation model) than the 1st floor (fig 8). For the deflection analysis, it had also a similar result between the actual survey and 3D model. They both had bigger deflection on the middle of the Changbang. This is the result of greater span between columns. (fig 9)

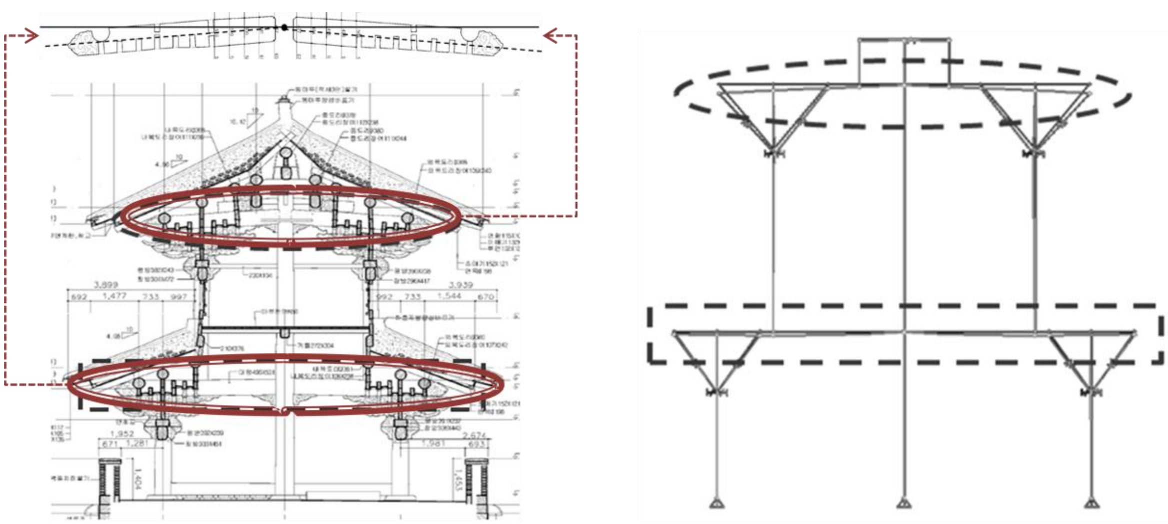


fig 8 drawings of the actual survey (left) and 3D model (right)

[4] Changbang (창방) : a beam element along the wall supporting the roof with bracket sets and rafters around the building

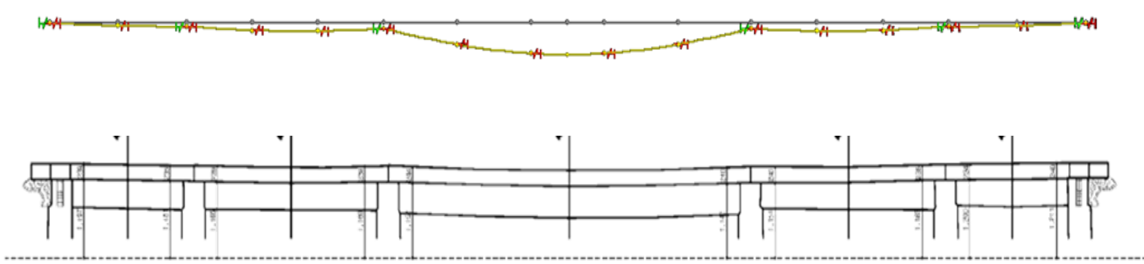


fig 9 Deflection of 3D model (top) and actual survey (bottom)

4 CONCLUSION

An analysis for the double roof system in Korea, the Hunginjimun Gate in Seoul, was done according to various methodologies. The traditional technique for construction and structure was studied and revealed for the development of academic research. Through comparison with the actual survey drawings, it was possible to reveal the structural mechanism of traditional connections and it could be widely adapted to other traditional architecture. The purpose to evaluate the structural safety resulted as a more precise evaluation.

The analysis of the double roof structure made it possible to build a realistic model with appropriate boundary conditions. The results were very similar with comparison of the axial forces, load flow, deflection and deformation etc. On the contrary, there were still some differences between the actual structure since there were some other potential load factors. For a more precise and accurate analysis it could be advisable to put in consideration other load factors like live, snow and wind load with vibration.

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