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A Case Study of the Korean Traditional Wood House-Mindori

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Abstract. The purpose of this study is to show logical member models considering the Korean traditional construction method and present a simple but rational modeling method of the whole structure to evaluate the structural stability of the *KTWS*. For this purpose, one of the *KTWS*, *the Mindori House* is selected and a structure analysis is performed considering its construction stage and load transfer mechanism. The variation of the behaviors according to joint modeling methods is studied using SAP2000 program and its results are compared with those of manual calculation.

Keywords: Korean traditional wood structure, layer-built construction, multiplicity of joining method, modeling method, delivery system of vertical load

Introduction

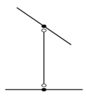
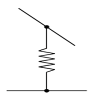
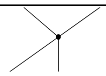
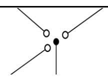
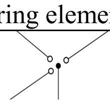
In the field of the *Korean Traditional Wood Structure(KTWS)*, theoretical modelling method that can rationally describe multiplicity of joint method is not set up and the research on interaction of individual members is insufficient for field engineers to apply it to the actual *KTWS* .

In this study, rational modelling method of individual members for solving problems experienced in analysis of the *KTWS* will be investigated by interpretation of unique construction method of the *KTWS* and basic data for credibility of the result will be given by the analysis on the delivery system of vertical load in the *KTWS.*

Problems of Existing Analysis Method

For the investigation of problems met in structural analysis of the *KTWS*, representative modelling methods used in field engineering for analysing the *KTWS* are selected. Table 1 shows the three cases in this study.

Table 1: Representative modeling methods used in field engineering

CASE No.	*CASE1*	*CASE2*	*CASE3*
Beam-Rafter (Dori-Seoggarae)	 Rigid joint	 End-moment release	 Spring element
Beam-Column (Dori-Column)	 Rigid joint	 End-moment release	 End-moment release

Rigid joints are used in CASE1. In intuition, we know that this case can't show the real behaviour of the *KTWS* because the joints of the *KTWS* are not rigid in general. But for the our study on vertical load transfer in *KTWS*, this case is selected and compared with the other cases.

In CASE2 and CASE3, end-moment release is used to reflect the joint characteristics of the *KWTS.* Elastic spring is used for support system in CASE3. One of the structural characteristics of the *KTWS* is a rectangle, consisting of short column(the Dongjaju) and short beam(the Jongbo), which exists in the triangle, consisting of rafter(the Seoggarae) and main beam(the Daedlbo). The rectangles existing in a truss make a structure more unstable. Consequently, it makes the results of the structural analysis using moment release suspicious.

Fig. 1 shows an analytical model for the Mindori-House and Table2 shows the axial force variation of columns according to modelling methods.

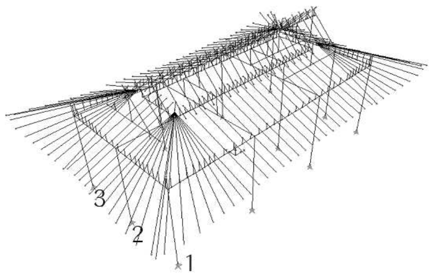


Figure 1: Analysis model of the Mindori-House

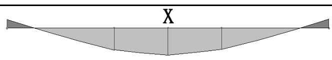
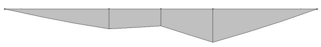
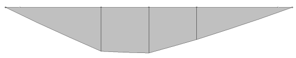
Table 2: Axial forces of column at 1,2,3

	CASE1	*CASE2*	*CASE3*
1	-4613.84 N	-6470.72 N	-3914.99 N
2	-5687.75 N	-1814.91 N	-6406.13 N
3	-4608.06 N	-7524.20 N	-4393.37 N

Case 1 shows the symmetrical axial forces and this result is considered reasonable because designed structure of Mindor-House has symmetrical shape. But, axial forces of CASE2 and CASE3 are not symmetrical because of stability problems. So, these cases can not show right deformed shape.

Table3 shows the moment variation of the main beam (the Daeryang) according to modelling methods.

Table 3: Moment distribution of each case in Daeryang

CASE1	*CASE2*	*CASE3*
		

CASE1 shows the moment distribution like a fixed end but this case is not real. In CASE2, the analysis cannot be performed reasonably and moment distribution is also irrational. CASE3 shows the moment distribution like a simple beam but this case has a tendency to overestimate the moment.

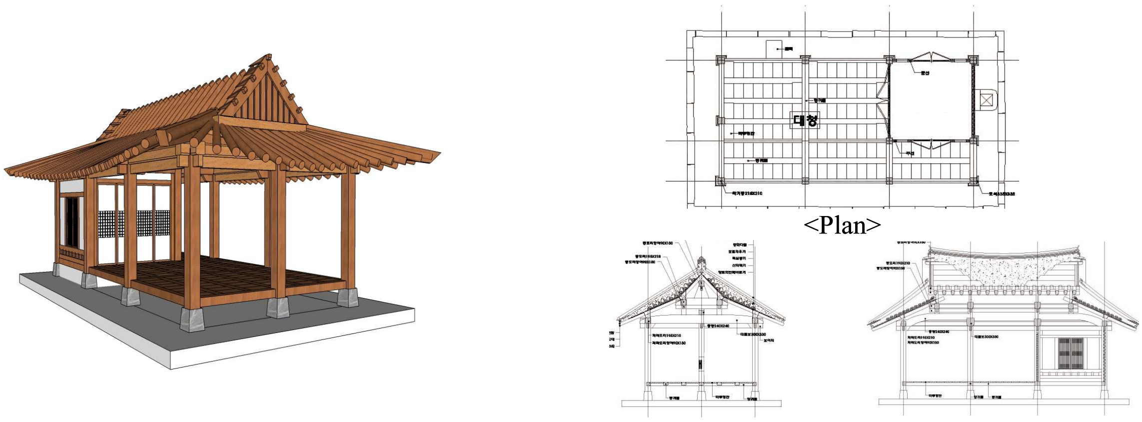
Consequently, existing modelling method about individual members can not show the correct structural behaviours. So, it is necessary to develop a new reasonable modelling method considering the joint conditions of the *KTWS*.

Delivery System of Vertical Load

The Mindori-House with one Goju and five Daeryang Fig.2 shows the Mindori-House with one Goju and five Daeryang. The front of this building has three bays and the side has two bays. Roof is the Pal-zak style.

Delivery System of vertical loads in the Mindori-House Fig. 3 shows the vertical load transfer system of the Mindori-House .

Vertical loads of the Mindori-House are delivered from member to member as shown in the Fig. 4. Rafters like the Jangyeon and the Danyeon carry loads of the Boto and the Kiwa - material of roof - to the Dori. Top member like the Jongdori delivers loads of the Danyeon and the Yongmaru to middle members like the Jongbo and Joongdori, through short prop like the Hwaban. One side of the Sunjayeon is connected with the Choonyeo by the Sanji or nail. Therefore, upper part of loads of the Sunjayeon is delivered to the Choonyeo. On the other hand, lower part of loads of the Joongdori and the Jongbo to beam elements like the Daeryang, the Toeiryang and the Choongryang. Lastly, the Jusimdori delivers vertical loads carried from upper part of structure to columns.



<3D Model> <Longitudinal-Section> <Cross-Section>

Figure 2: the Mindori-House

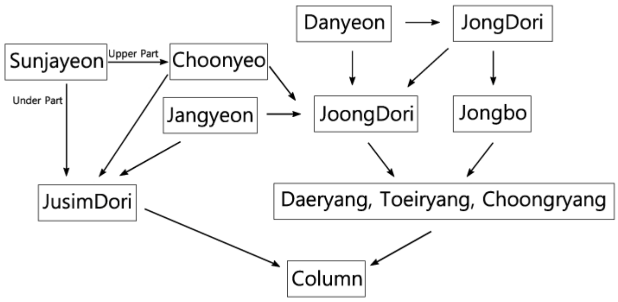
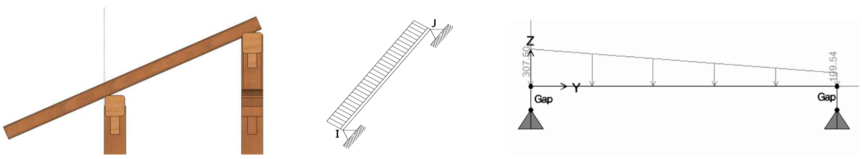


Figure 3: Delivery system of vertical load in the Mindori-House

Suggestion of Modeling Method

Considerations of the aforementioned situations say that it is reasonable to analyse the *KTWS* on the basis of individual member. So, we calculate the reactions of each member which are caused by load distribution. The reactions are calculated by manual and a computer program SAP2000. Reactions are applied as loads at the next step. For the simplification of calculation, simple beams are used for manual calculation and gap elements are used in the analysis using a computer program.

The Danyeon and the Jangyeon – top rafters Connection between rafter and the Dori – roof beam - must be modelled using a compression only spring like gap element because rafter simply rests on the roof-beam. This element makes it possible to describe the raise of rafter. It is not desirable to use hinge and roller for the modelling of this part. Fig. 4 shows the connection of a rafter and analytical models.



(a) connection *(b) model 1* *(c) model 2*

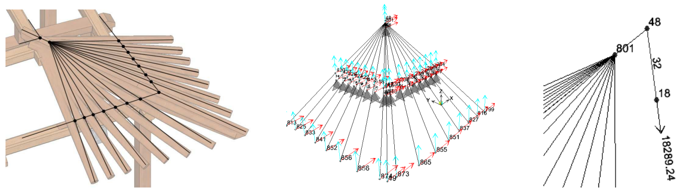
Figure 4: Analytical model of the Danyeon

Fig. 5(b) is an analytical model for manual calculation and Fig. 5(c) is that for a computer program SAP2000. In the structural analysis by a computer program, gap elements are used for modelling supports. Also, for the simplicity in manual calculation, it is assumed that uniformly distributed load acts on a beam. But the variation of load by the thickness of Boto (filled soil) is considered in the structural analysis by a computer program. Table 4 shows the results of calculation.

Table 4: Support reaction of the Danyeon *(kgf)*

	I node	*J node*	*Total*	*A/B*
SAP2000(A)	163.25	120.03	283.28	1.00
Manual calculation(B)	142.12	142.12	284.25	

The Choonyeo (corners of eaves) and the Sunjayeon (rafter connected with the Choonyeo) Fig. 5 shows the connection in neighbourhood of the Sunjayeon and analytical models.



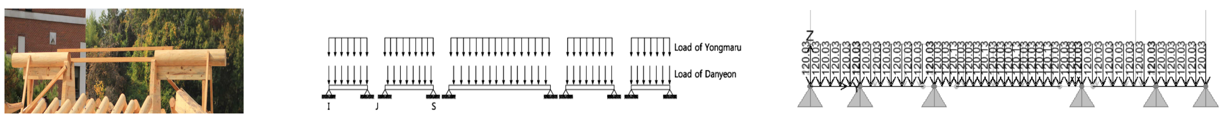
(a) connection *(b) model 1* *(c) model 2*

Figure 5: Analytical model of the Sunjayeon

The Choonyeo supports the loads transferred from roof and the Sunjayeon because the Sunjayeon is connected to the Choonyeo by the Sanji (wood peg) or nail. But this connection cannot transfer the moment from the Sunjayeon to the Choonyeo. So, end-moment release condition is used in the connection between the Choonyeo and the Sunjayeon. The supports of the Choonyeo and the Sunjayeon are modelled with compression only springs like the Danyeon.

The analysis result by SAP2000 shows that tensile reaction occurs at upper support of the Choonyeo. This phenomenon explains that upper part of Choonyeo is disconnected and lifted from support, the Joongdori.

The Jongdori – beam for supporting rafters Fig. 6 shows the connection of the Jongdori and analytical models.



(a) connection *(b) model 1* *(c) model 2*

Figure 6: Analytical model of the Jongdori

The Dori consists of some beams and each beam is supported by the Hwaban or the Dongjaju. So, the structural analysis for the Dori must be performed with considering such discontinuity. According to these features, each member of the Dori must be modelled as simply supported beam.

Fig. 6(b) shows simply supported beam for manual calculation. Each member is disconnected on the support. Fig. 6(c) shows an analytical model for a computer program in which end-moment release method is used.

Table 5: Support reactions of left side of the Jongdori *(kgf)*

	I node	*J node*	*S node*	*Total*	*A/B*
SAP2000(A)	309.07	1390.32	527.24	2226.63	0.89
Manual calculation(B)	528.45	1249.40	732.04	2509.89	

The difference of result comes from the difference of applied loads. Uniformly distributed load is assumed in manual calculation but the variation of load by the thickness of Boto(filled soil) is considered in the analysis using a computer program.

In the case of manual calculation, members are disconnected at all supports. But the real joint conditions are considered in the analysis using a computer program. Fig. 7 shows the moment distribution of the Jongdori by SAP2000.

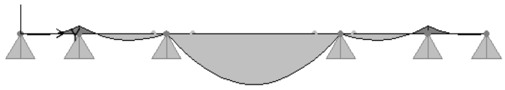
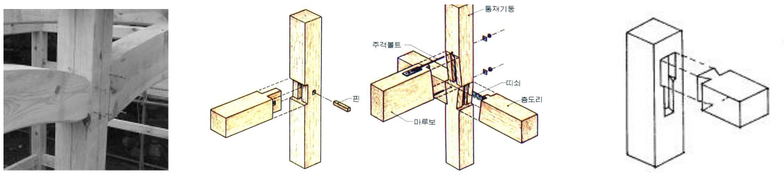


Figure 7: Moment distribution of the Jongdori

The Daeryang, the Toeiryang, the Choongryang Fig. 8 shows the various connecting methods used in the connections of the Daeryang, the Toeiryang, and the Choongryang.



(a) connection *(b) the Sanj* *(c) the Jumukjang*

Figure 8: Connecting methods used in the Goju

Beams like the Daeryang, the Toeiryang or the Choongryang are connected with the Goju by the Sanji or the Jumukjang. So, these members must be modelled as simply supported beam. The analysis condition of the Choongryang is same in the case of manual calculation and an analysis using a computer program. Only one concentrated load acts on the Choongryang at midpoint. This load is transferred from the Dongjaju. Table 6 shows the support reactions of the Choongryang.

Table 6: Support reactions of the Choongryang (kgf)

	I node	*J node*	*Total*	*A/B*
SAP2000(A)	1001.46	1001.46	2002.92	0.95
Manual calculation(B)	1055.20	1055.20	2110.40	

Fig. 9 shows an analytical model for the Goju.

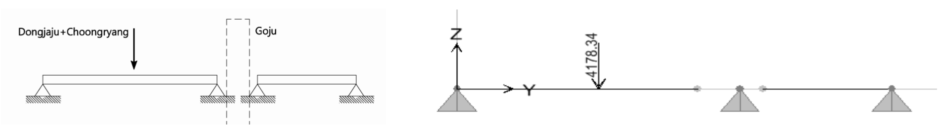


Figure 9: Analytical model for the Goju

In the case of manual calculation, the Daeryang and the Toeiryang connected with the Goju are disconnected at all supports. End-moment release is used at the joint of the Goju in the analysis using a computer program.. Loads transferred from the Dongjaju and the Choongryang act on the Daeryang. But, the Toeiryang is not connected with any above members. Therefore, this member is influenced by only lateral loads.

Conclusion

This study has proposed an analytical approach for the rational modelling of the *KTWS*. To do this, delivery system of vertical loads acting on the *KTWS* was analysed by manual calculation and a computer program. The following conclusions can be drawn from this study.

(1) Delivery system of vertical loads in the *KTWS* : Distributed load of roof disperse through middle structure like the Dori or beam. After that, the loads congregate in the substructure and columns.
(2) The results of manual calculation and an analysis using a computer program shows the suggested modeling method for the analysis of the *KTWS* is rational for field engineers to use it.
(3) As a result of performing the analysis for the *KTWS*, existing analysis methods are difficult to find stable values. So, sequential analysis method on the basis of individual member is more reasonable.

Table 7: Support reactions of the Daeryang (kgf)

	I node	*J node*	*Total*	*A/B*
SAP2000(A)	2153.47	2153.47	4306.94	0.88
Manual calculation(B)	2439.46	2439.46	4878.92	

Table 8: Support reactions of the Toeiryang (kgf)

	I node	*J node*	*Total*	*A/B*
SAP2000(A)	28.6	28.6	57.2	1.00
Manual calculation(B)	28.60	28.60	57.2	

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