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Kim, Gwang-Chul
Department of Housing environmental design, College of Human Ecology, Chonbuk National University

Matsumura, Junji
Laboratory of Wood Science, Division of Sustainable Bioresources Sciences, Department of Agro-environmental Science, Faculty of Agriculture, Kyushu University

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# Numerical Analysis of Compressive Performance for the Korean Traditional Joints

**Gwang–Chul KIM[1] and Junji MATSUMURA[2]**

Laboratory of Wood Science, Division of Sustainable Bioresources Science, Department of Agro–environmental Sciences, Faculty of Agriculture, Kyushu University, Fukuoka 812–8581, Japan
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A full three–dimensional finite element model was created using continuum solid elements in ANSYS to gain more insight into the mechanical behavior of the Korean traditional joints. Orthotropic properties were characterized and non–linear analysis was also conducted for the reflection of wood property. For the joint character, not simple joint analysis but specially contact–target analysis was considered to reflect the situation between mortise and tenon. The numerical value is similar to the average value of actual compressive strength tests. Also, the types of stress concentration on the joint were similar to actual failure types. Therefore, we could verify the validity of finite element model that we have developed on the traditional joints. So, the numerical analysis model developed from this study may be utilized for the analysis and design of the various traditional joints.

**Key words**: finite element model, Korean traditional joint, orthotropic properties, non–linear analysis, contact–target analysis

## INTRODUCTION

Each country has its own traditional construction methods. Korea's traditional building construction method is called *Hanok*, which is a wooden framed house with a cultural heritage and an old history. Demand and supply on the traditional *Hanok* and new–style *Hanok* is rapidly increasing through an active support of government, compatibility with Korean sentiment and healthy emotion for the wooden building construction.

However, existing engineers have not inculcated the skills to the younger– generations during apprenticeship, so scientific and systematic skills have not been passed down through the generations, therefore we don't have enough construction engineers in the construction of *Hanok*. Particularly, to overcome the difficulty of the traditional *Hanok* construction, it should be scientifically designed and analyzed on the mechanical capacity of its joints which are the most difficult part in the *Hanok* construction, so economically the new–style *Hanok* will be able to be produced.

The *Joomeokjang* joint (*J*–joint) and *Nabijang* joint (*N*–joint) are most widely used in traditional Korean wooden frame constructions. Detailed theoretical research for joint patterns, which have fully engineered characteristics, may be essential because *J*–joint and *N*–joint are the most fundamental joint methods in Korea. Of course, the specific shapes and sizes of each joint can affect the mechanical properties of the traditional joints in a complicated fashion. Therefore, finite element model on the traditional joints should be developed to utilize as basic data for the traditional joints.

A full three–dimensional finite element model was created using continuum solid elements in ANSYS to gain more insight into the mechanical behavior of the Korean traditional joint and to determine the feasibility of predicting its behavior through numerical models alone. Once the finite element model was validated by the experimental tests, it could be modified to explore the effect on joint behavior of changes made to geometry and wood species etc.

## MATERIALS AND METHODS

Our previous study results (Kim *et al.*, 2010) were compared to verify the numerical analysis results. Japanese Larch, which has been widely used in Korean construction, was chosen for this study. The number of traditional joints and control specimens (non–joint) were

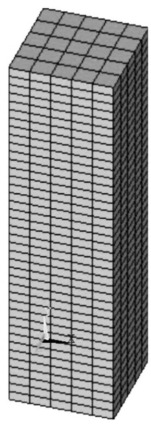


**Fig. 1.** Finite element model of the control specimen.

[1] Department of Housing environmental design, College of Human Ecology, Chonbuk National University, Jeonju 561–756, Korea

[2] Laboratory of Wood Science, Division of Sustainable Biorecoureces Science, Department of Agro–environmental Sciences, Faculty of Agriculture, Kyushu University, Fukuoka 812–8581, Japan

* Corresponding author (E–mail: gckim@jbnu.ac.kr)

five each. The compressive strength of the control specimen and traditional joint specimen were tested as in KSF 2206–2004–06. The loading speed was 10 mm/min. The dimensions of the traditional joint and control specimen were both 60×60 mm per section and 200 mm in length. Finite element model of the control specimen is shown in Fig. 1

*J*–joint and *N*–joint were selected as the traditional joints, and the non–jointed control specimen was also assumed. A schematic diagram and finite element models of the traditional joint specimen were shown in Fig. 2 and Fig. 3. Numerical analysis was conducted using ANSYS V. 10 with 3–Dimensional structural analysis. Orthotropic properties were characterized and non–linear analysis was also conducted for the reflection of wood property. Solid 64 element (unique element in ANSYS) was used to reflect the anisotropic material property.

For the joint character, not simple joint analysis but specially contact–target analysis was considered to reflect the situation between mortise and tenon. Coefficient of friction between members was fixed as 0.5.

Both target element and contact element were assumed flexible. Initial penetration was considered in analysis to prevent abruptly breakaway between members. Also, unsymmetrical stiffness matrix was used. In the case of *J*–joint, the bottom block is the target element and the top block is the contact element (Fig. 3). As in *N*–joints, however, the lowest block is the target element, the top and middle blocks are the contact elements (Fig. 3). Normal penalty stiffness was 0.1 for both traditional joints.

For the nonlinear analysis, large–displacement–static option was used. Further selected options were: time at the end of loadstep=100, automatic time stepping=off, number of substeps=1.

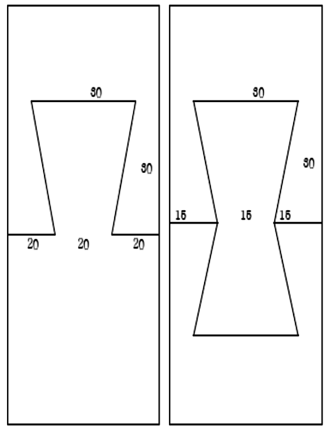



**Fig. 2.** The features of the traditional joint specimens (*Joomeokjang* joint and *Nabijang* joint)

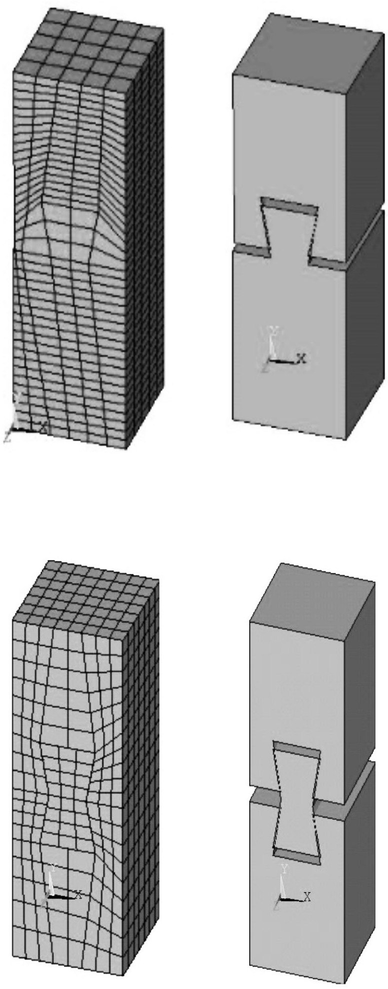


**Fig. 3.** Numerical model and solid model for *Joomeokjang* joint and *Nabijang* joint.

## RESULTS AND DISCUSSION

### Evaluating the feasibility of the numerical analysis method

*For the ultimate load capacity of the control specimen*

Table 2 shows the experimental results and numerical results of the control specimen. The experimental value (Kim *et al.*, 2010) is the average of five actual compressive strength tests for the control specimen. The numerical result is the eigenvalue of the control specimen by finite element analysis. The numerical value, 215890N, is similar to the average value, 209643N, of actual compressive strength tests. Therefore, we could

**Table 1.** ANSYS modeling spec

| EX(MPa) | EY(MPa) | EZ(MPa) | PRXY | PRYZ | PRXZ | GXY(MPa) | GYZ(MPa) | GXZ(MPa) |
|---|---|---|---|---|---|---|---|---|
| 12900*0.079 | 12900 | 12900*0.065 | 0.03 | 0.276 | 0.389 | 12900*0.063 | 12900*0.069 | 12900*0.007 |

**Table 2.** The experimental value and numerical value for the control specimen

| Experimental value | Numerical value |
|---|---|
| 209643 N | 215890 N |

verify the validity of finite element model that we have developed.

*For the load–deformation relationship of the control specimen*

The Fig. 4 shows the load–deformation curves between experimental values and numerical values of the control specimen. To compare the actual compressive strength test curves, we got the numerical results by step–by–step in 60000N, 90000N, 120000N, 170000N, 210000N. The two results don't completely coincide, but the numerical results show quite similar results with the actual load–deformation curve. So, we have confidence of the validity of our finite element model. With certainty

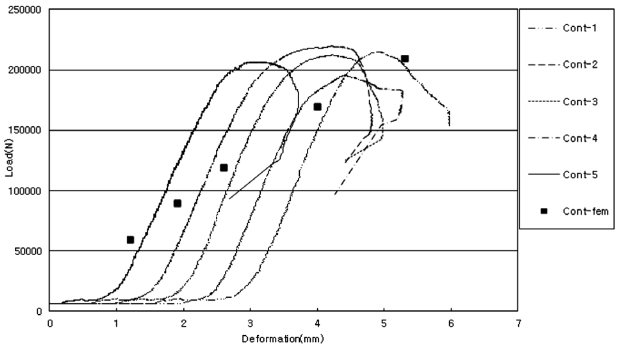



**Fig. 4.** Load-deformation curves for the control specimen between experimental results and FEM results.

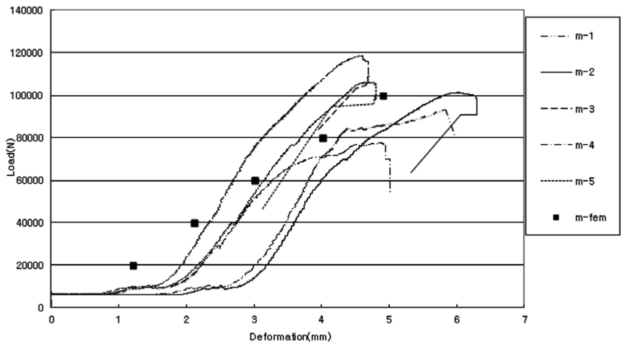



**Fig. 5.** Load-deformation curves for the *Joomeokjang* joint between experimental results and FEM results.

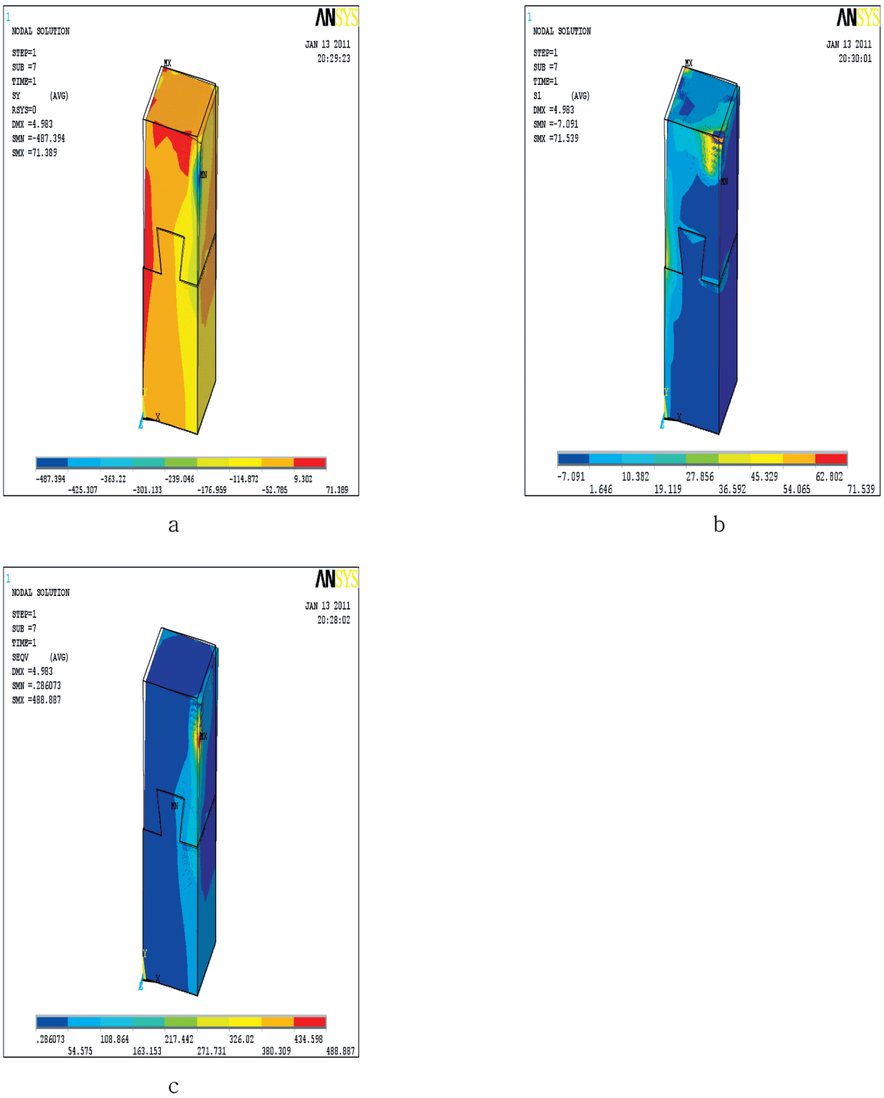
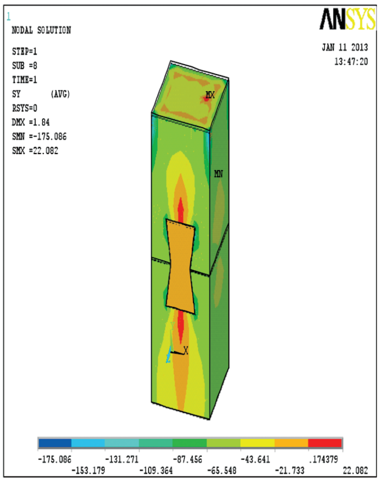


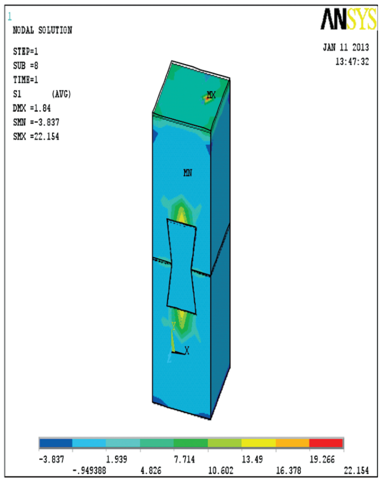

**Fig. 6.** Numerical results for the *Joomeokjang* joint.(a: y-axis stress, b: 1st stress, c: Von-mises stress)

**Fig. 7.** The actual fracture mode of *Joomeokjang* joint specimen.

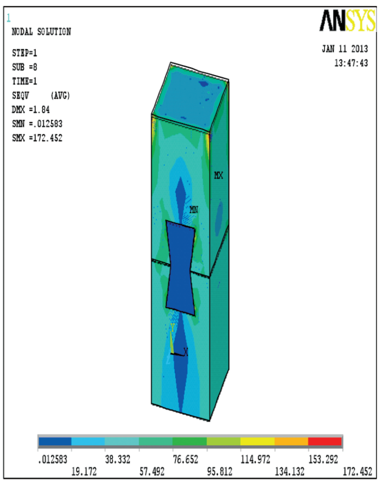
**Fig. 8.** The actual fracture mode of *Nabijang* joint specimen.




a




b




c

**Fig. 9.** Numerical results for the *Nabijang* joint.(a: y-axis stress, b: 1st stress, c: Von-mises stress)

we developed a new finite element model for the Korean traditional joints by applying the finite element model of the control specimen.

**Comparison between experimental value and numerical value of the traditional joints**

The compressive strengths of the *N*–joints and *J*–joints were 55% and 47%, respectively, compared to the non–jointed control group (Kim *et al*., 2010). As both the *J*–joints and *N*–joints had nearly half the compressive strength of the control group, both joints might be expected to show a considerable compressive performance if additional adhesive were applied (Kim *et al*., 2010). Korean traditional joints are mostly manually built and therefore the organization between the members of framework is poor, also the contraction and swelling of the gap between them results in low performance. Because of this reason, the numerical analysis result for the traditional joint was forced to low accuracy. It is therefore needed to select an optimum joint type through comparison between numerical analysis and the actual experimental results, and is also required to readjust basic coefficients which are necessary for numerical analysis.

*Applicability of the J –joint group*

When actual compressive strength test and numerical analysis results of traditional joints are compared, there is a slight difference as depicted in Fig. 5 but considering the fact that it is a manually made joint, it can be possible to analyze the traditional joint using the numerical analysis results with significant accuracy. The average of ultimate compressive loads was 99545N and the average of maximum deformations was 5.2 mm by actual compressive strength test on the five *J*–joints (Kim *et al*., 2010). In the case of numerical analysis, the maximum deformation, 4.9 mm was obtained when compressive load 100000N was applied. Like the control specimen, the numerical value is similar to the average value of actual compressive strength test. Therefore, we could verify the validity of finite element model that we have developed on the traditional joint. Also, as like control specimen, we got the numerical results by step–by–step in 20000N, 40000N, 60000N, 80000N, 100000N to compare the actual compressive strength test curves. The two results don't completely coincide like the control specimen, but the numerical results show quite similar results with the actual load–deformation curve. So, we have confidence in the validity of our finite element model on the traditional joint. Fig. 6 shows the various numerical analysis results using a maximum loading of 100000N on the *J*–joints. The results of the numerical analysis showed excessive deformation and principal stress in the bottom of the joint, which are similarly seen in the fracture mode of the actual *J*–joints specimen as in Fig. 7.

Difference between two is minimal and, considering the fact that the traditional joint was manually made without using pre–cut machine, the numerical analysis model developed from this study may be utilized for analysis and design of the various traditional joints.

*Applicability of the N–joint group*

Fig. 8 shows the actual fracture mode of the *N*–joint. Fig. 9 shows various graphical presentations of numerical results. Like *J*–joints the types of stress concentration on the joint were similar to actual failure type in Fig. 8. Therefore, we have also confidence that the validity of finite element model on the *N*–joint. The applicability of numerical modeling on the Korean traditional joints was proven, so we will use this on the performance analysis and structural design of the traditional joints with the developed finite element model.

## CONCLUSION

Korea's traditional building construction method is called *Hanok*, which is a wooden framed house with a cultural heritage and an old history. Detailed theoretical research for joint patterns may be essential because *J*–joint and *N*–joint are the most fundamental joint methods in Korea. Therefore, finite element model on the traditional joints was developed to utilize as basic data for the traditional joints.

A full three–dimensional finite element model was created using continuum solid elements in ANSYS to gain more insight into the mechanical behavior of the Korean traditional joint and to determine the feasibility of predicting its behavior through numerical models alone. Korean traditional joints are mostly manually built and therefore the organization between the members of framework is poor, also the contraction and swelling of the gap between them results in low performance. Because of this reason, the numerical analysis result for the traditional joint was forced to low accuracy. It is therefore needed to select an optimum joint type through comparison between numerical analysis and the actual experimental results, and is also required to readjust basic coefficients which are necessary for numerical analysis. When actual compressive strength test and numerical analysis results of traditional joints are compared, there is a slight difference but considering the fact that it is a manually made joint, it can be possible to analyze the traditional joint using the numerical analysis results with significant accuracy. The results of the numerical analysis showed excessive deformation and principal stress in the bottom of the joint, which are similarly seen in the fracture modes of the actual joints specimens. Difference between two is minimal and, considering the fact that the traditional joint was manually made without using pre–cut machine, the numerical analysis model developed from this study may be utilized for analysis and design of the various traditional joints.

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