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Evaluation of Specific Gravity in Post Member by Drilling Resistance Test*1

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ABSTRACT

The structural wooden members of the ancient building are deteriorated by fungi and termite over time. The deteriorate of the members causes the decrease of the specific gravity and the strength of it, so the stability of the building is threatened. Therefore, in this study, the evaluation of the specific gravity, which is correlated with the strength of the wood, was conducted in the post member using Nondestructive Evaluation (NDE) - Drilling Resistance Test (DRT). For the purpose of it, the specific gravity and drilling resistance of small specimens was measured to obtain the correlation between the specific gravity and the drilling resistance. And then, the drilling resistance test of the post members, which were expected to have the deteriorated parts, was performed. Consequently, the correlation between the specific gravity and the drilling resistance was very high (R^2=0.89) and the distributions of the specific gravity were evaluated for the each member. Also, the results were verified by the visual inspection of the cross section of it. Especially, the various variations of the wood member such as the deteriorated parts with termite or fungi and the crack could be detected exactly but the knot couldn't because the drill could pass by or could not penetrate the knot.

Keywords : NDE, DRT, drilling resistance, specific gravity, deterioration

1. INTRODUCTION

Korea has a glorious history of 5000 years. A lot of cultural properties have succeeded in forms of tangible and intangible cultural treasures and we preserve these important treasures by appointing those national treasure and cultural asset etc. Especially, raw materials like wood has been utilized in buildings since human had settled in shelter, and the form of them has been progressed in various type such as palace, temple and house. Building being presently is existed through well planting, trimming and constructing with wood. Therefore, the members such as rafters, posts, beams etc. are very important and must be preserved very well, too.

However, a lot of wooden buildings have been destroyed by a national crisis like the war and deteriorated by various fungi for a long time. Consequently, these problems threat the structural

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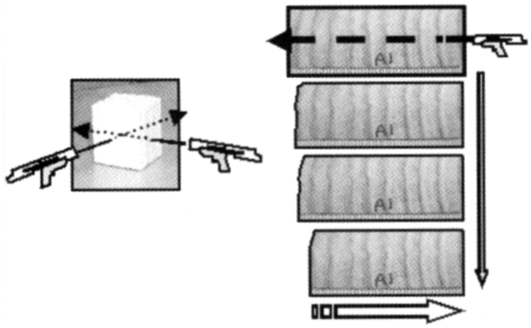


Fig. 1. The small specimens of DRT.

stability and induce the difficulty on preservation of cultural treasures. But, most of deterioration could not be identified by the visual inspection and the scientific method to detect the deterioration has not been applied yet. Recently, the study about NDE, which was used in steel-concrete building to detect the fracture, has been progressed actively in various aspects to inspect the decay in wood member (Fuller *et al.*, 1994; Wilcox 1988; Lee and Bae 2004). If NDE for wood is developed more effectively, it will be possible to evaluate the decrease of strength more scientifically, objectively, efficiently and accurately and cultural treasures can be preserved more effectively.

Rinn (1994) presented the results of drilling resistance test for wood, telegraph poles and lumber. And Helms and Niemz (1994) reported the density profile for grading lumber through a verification of the internal state of wood and wood based composite. Bethe and Mattheck (1998) evaluated the internal deterioration of tree in situ. But the previous researches could not evaluate the specific gravity of the structural member with the deterioration. So in this study, the quantitative evaluation of the deterioration was performed by DRT in wood member of ancient building.

In Korea, wood structure has been built generally in post-beam types. The load applied to this structure is transmitted to the foundation through post members and the post is under the effect of the compressive load (Shinozuka, 1983). The post member is decayed by termites and fungi. This deterioration decreases the specific gravity of the post member, and it causes the decrease of the strength. In order to detect exactly the deterioration and evaluate the distribution of the specific gravity of the wood, DRT was performed to the post wooden member of ancient buildings in this study.

2. MATERIALS and METHODS

2.1. Materials

The small specimens were manufactured from the deteriorated wooden members of ancient building to obtain the correlation between the specific gravity and drilling resistance. Two or three specimens were obtained from one member. Dimensions of each specimen were $2 \times 2 \times 2$ (cm) and $2 \times 2 \times 6$ (cm) and numbers were 84 and 10. The moisture content was 17～24% and the species are larch and Korean red pine (*Pinus densiflora*).

And 6 deteriorated post members were selected from the same building to evaluate the distribution of the specific gravity with DRT. Diameters of the members were 15～25 cm and the species were Korean red pine.

2.2. Methods

Firstly, in order to obtain the correlation between the specific gravity and drilling resistance, drilling resistances of the small specimens were measured by two methods. One was performed in $2 \times 2 \times 2$ (cm) specimens and the other in $2 \times 2 \times 6$ (cm) specimens. In the former, the test was performed in two directions which were perpendicular to the grain (Fig. 1).

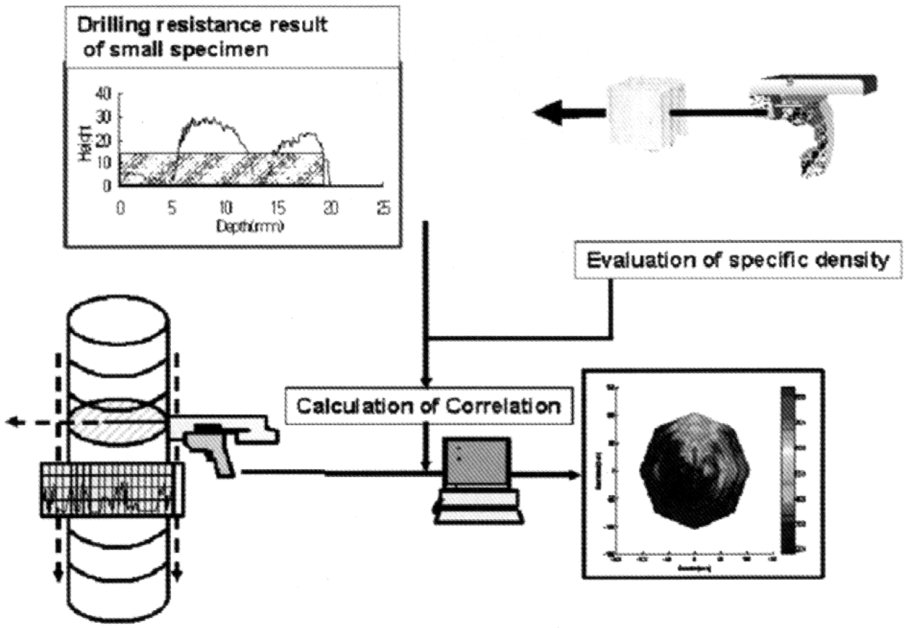


Fig. 2. Flow chart of DRT.

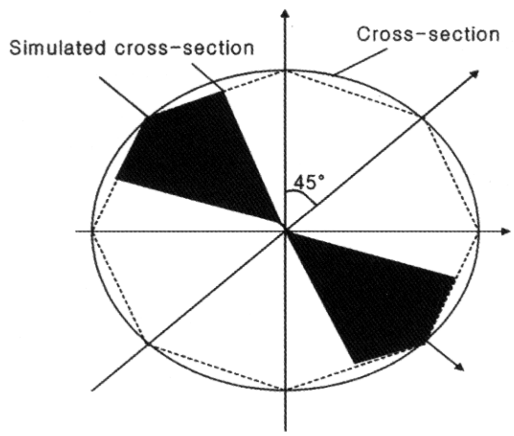


Fig. 3. Recomposed cross-section by DRT with program.

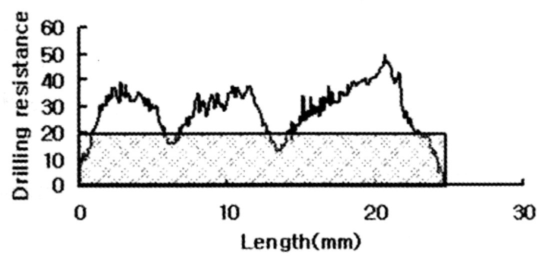
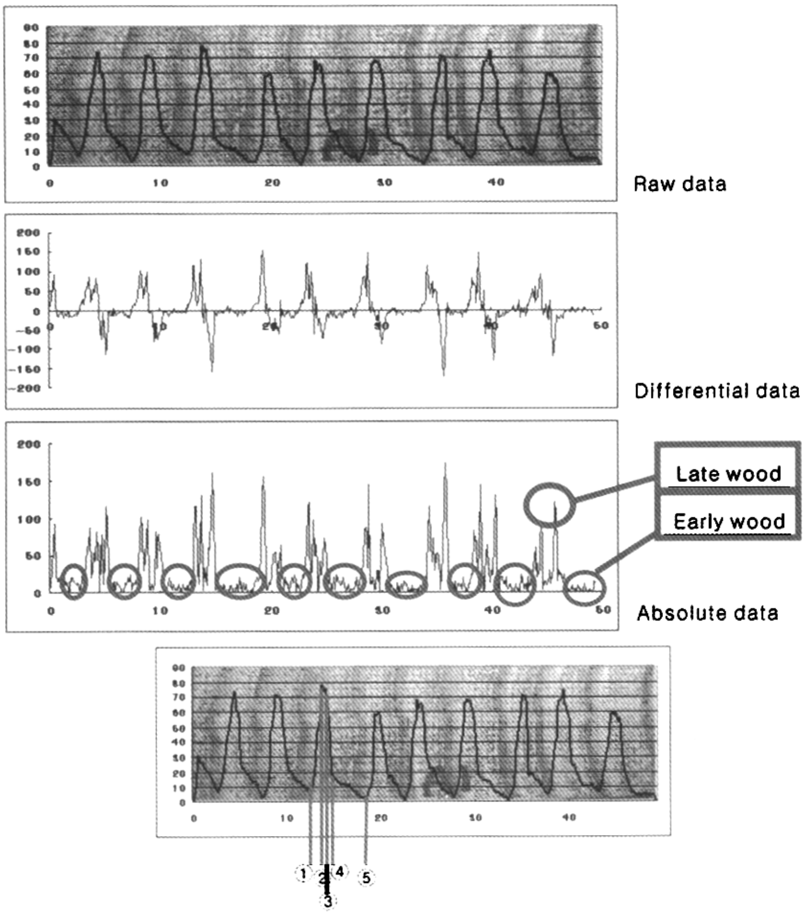


Fig. 4. Result of DRT and evaluation of average resistance.

The direction of drilling was perpendicular to the grain and other directions were excepted in results. For one specimen, two drilling resistances were obtained and the average of them was calculated. And then the specific gravity was measured in oven-dry condition. The specific gravity of the each specimen was compared with the average of drilling resistances respectively. In the other, drilling resistance test was performed perpendicular to grain and the specific gravity was measured in oven-dry condition as early and late wood were removed. The specific gravity of early and late wood was calculated respectively and compared with drill resistances. Finally, two data were collected in one graph and the correlation was obtained between the specific gravity and drilling resistance. Drilling resistance devices (L-RESI F 400) was operated



1. The start point of the late wood
1-2. The block between the early and the late wood
3. The end point of the late wood
3-4. The block between the late and the early wood
5. The end point of the early wood

Fig. 5. Pattern analysis of drilling resistance.

under the premise that the resistance against penetration was correlated with the material density. To obtain the distribution of the specific gravity for the member, the drilling resistance results were converted to the specific gravity by the correlation with the specific gravity.

The whole flow chart is shown in Fig. 2.

Also, the programming, which recomposed the DRT results to the distribution of specific gravity, was conducted by means of Matlab (version 5.5). DRT of the post member was performed 4 times at 45 degrees interval for one cross section (Fig. 3) and each result was converted to the specific gravity by the regression equation between the specific gravity and the drilling resistance. And then the distribution of specific gravity was recomposed by the program. In Fig. 3, the dark region

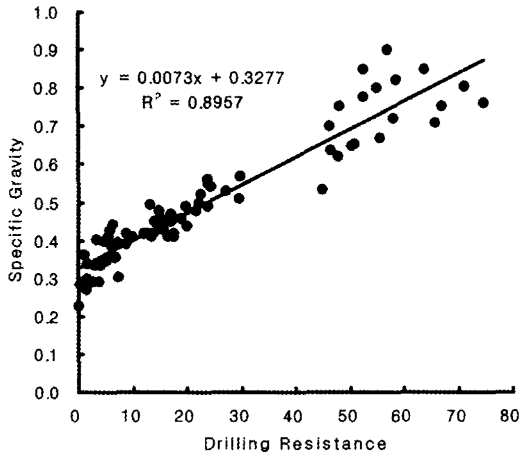


Fig. 6. Correlation of specific gravity and average resistance.

indicates the part which is recomposed by one drilling resistance.

3. RESULTS and DISCUSSION

3.1. Analysis of Drilling Resistance

Results of DRT were analyzed in two methods. In case of one method, the average of drilling resistance was used as the representative value and in the other, drilling resistance of late and early wood was used respectively by the pattern analysis of the drilling resistance. Firstly, average resistance of 2×2×2 (cm) specimen was calculated and compared with the specific gravity to obtain the correlation.

Fig. 4 presents the result of DRT and the average resistance for one specimen. High resistance was indicated in late wood and low in early wood. The representative value of each specimen was defined as the average of drilling resistance as shown in Fig. 4. But the drilling resistance, which did not penetrate the annual ring, was excluded.

Secondly, the result of 2×2×6 specimen was shown in Fig. 5. In order to find the representative value of the specimen, pattern analysis of the drilling resistance was performed. As shown in Fig. 5, the gradient of drilling resistance was changed rapidly and linearly in the interval from the early wood to the late wood or from the late wood to early wood. This interval was excepted from the representative results because it is only the changing interval and not meaning. Therefore the average of drilling resistance was calculated from the only part of the early and late wood as the representative value. Consequently, both first and second results were collected and analyzed to obtain the correlation between the

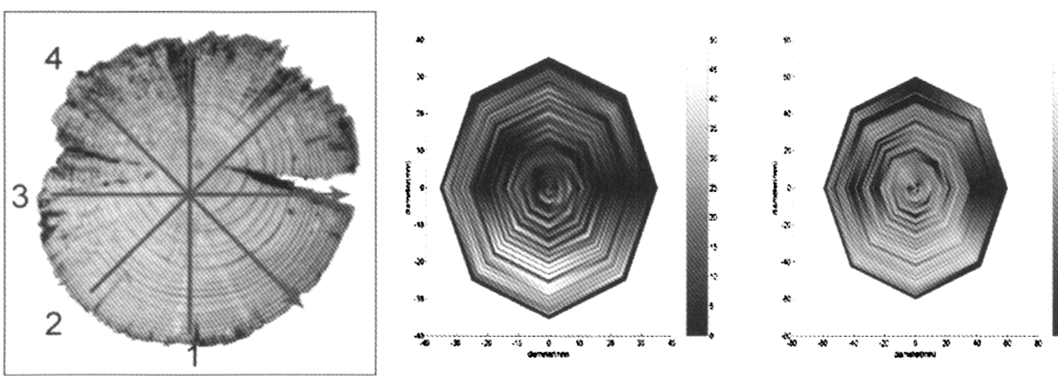


Fig. 7. Section analysis by specific gravity distribution for the crack. (Light) actual section (Middle) section recomposed by drilling test (Right) distribution of specific gravity.

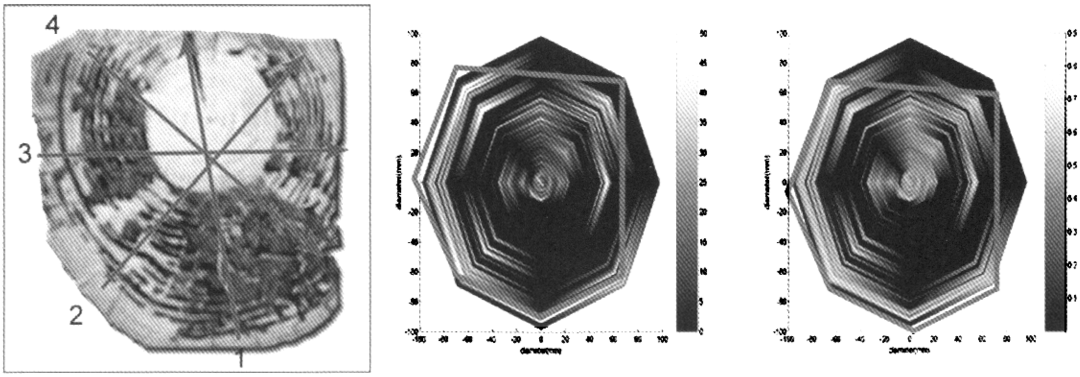


Fig. 8. Section analysis by specific gravity distribution for the severe termite. (Light) actual section (Middle) section recomposed by drilling test (Right) distribution of specific gravity.

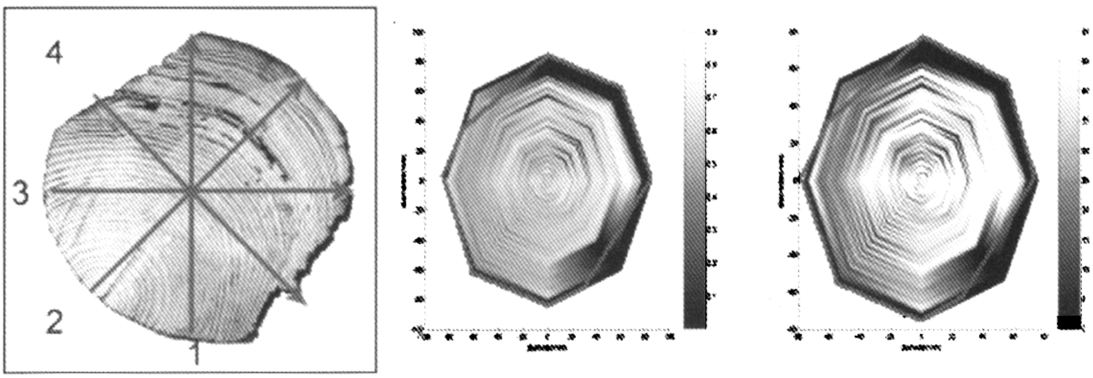


Fig. 9. Section analysis by specific gravity distribution for the incipient termite. (Light) actual section (Middle) section recomposed by drilling test (Right) distribution of specific gravity.

specific gravity and the drilling resistance.

3.2. Correlation between Specific Gravity and Drilling Resistance

The relationship between the specific gravity and the drilling resistance was shown and the correlation was obtained in Fig. 6.

The coefficient of determination was very high (R^2=0.8957), and the regression was induced in equation (1). But, the drilling resistance approaches nearly 0 below the specific gravity of 0.3.

$$S.G. = 0.0079D + 0.3277 \quad (1)$$

Where, SG is the specific gravity and D is the average of drilling resistance.

3.3. Evaluation of Specific Gravity

To evaluate the structural stability, the deteriorated part of post members were recomposed by the distribution of specific gravity and analyzed according to each pattern. First, when the crack was in the cross section of the post member, the drilling resistance and the specific gravity indicated zero to the pith continuously (Fig. 7).

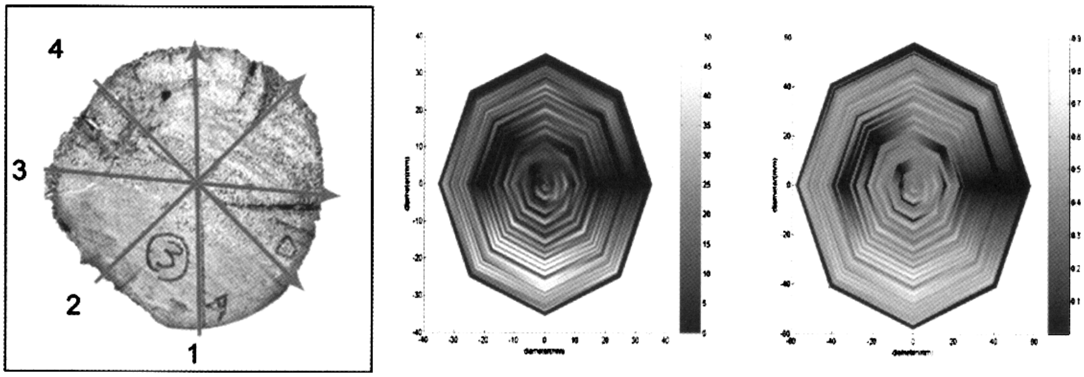


Fig. 10. Section analysis by specific gravity distribution for the decay. (Light) actual section (Middle) section recomposed by drilling test (Right) distribution of specific gravity.

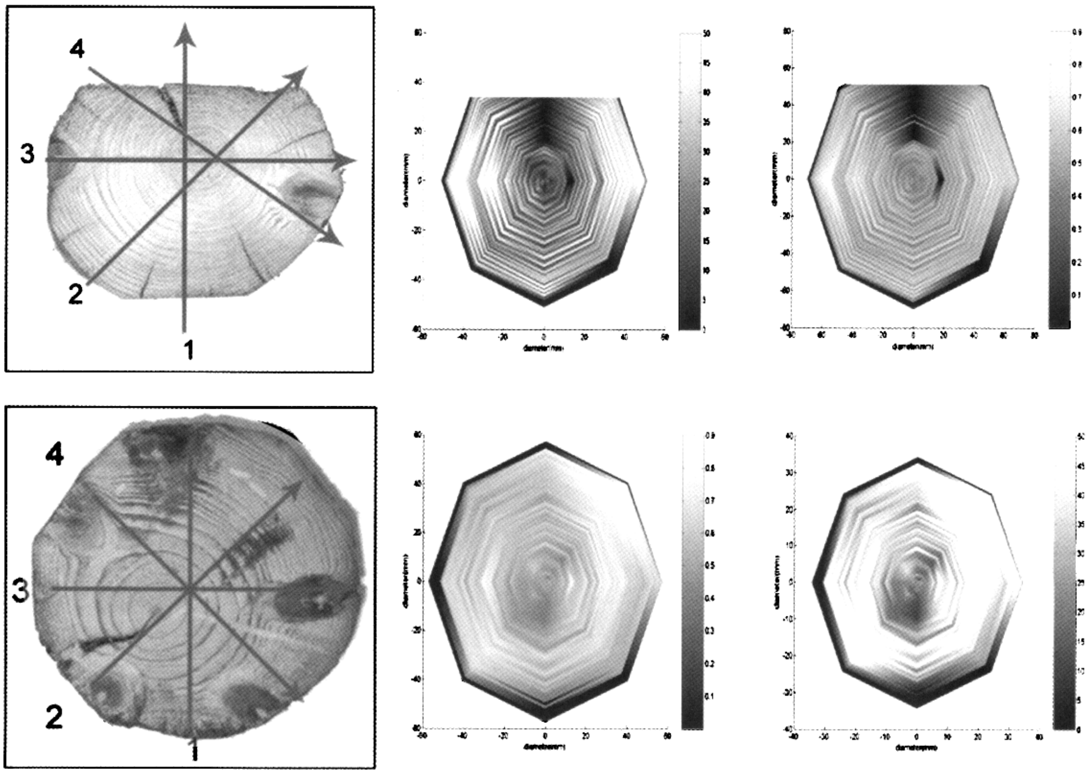


Fig. 11. Section analysis by specific gravity distribution for the knot (Light) actual section (Middle) section recomposed by drilling test (Right) distribution of specific gravity.

The brightness indicates the drilling resistance and the specific gravity in Fig. 7. In other words, as the brightness is white, the values are higher and as black, lower.

In case of the termite, specific gravity was discontinuously 0 or below 0.2 in the shape of a concentric circle. But the parts near the termite region might have high specific gravity (Fig. 8). Especially, in the incipient termite, it was shown as the thin band of the high specific gravity region (Fig. 9). It is due to the fact that termite attacks mainly the early wood.

In the deteriorated part by fungi, the specific gravity was low in the whole decayed region, because wood was decayed by fungi over all not partially. This result was confirmed as shown Fig. 10. The region, which was expressed in black, was the internal cavity in Fig. 10.

In the last, the needle of drill could be inserted away from the knot and could not penetrate the knot. Therefore, it was hard to distinguish the knot as shown in Fig. 11. But if the needle penetrate the knot, the location and the size of the knot could be detected because of higher specific gravity of knot.

Through the above results, the various patterns, which could be observed in the wood member, were evaluated. Consequently, The distribution of the specific gravity, which were recomposed by DRT, was obtained successfully in each member and the various deteriorations (termite, decay, crack etc.) were detected well.

4. CONCLUSION

Previous research of NDE has been focused on studying the material except wood or detecting the decay in wood. In this study, the structural member of the cultural building was analyzed based on NDE and the distribution of specific gravity, which have high correlation with the strength, was evaluated. And various deteriorations to effect on the member strength was detected such as termite, decay, crack, knot etc. These were important factors to decrease the structural stability and could be evaluated exactly by DRT except the knot. Consequently, In this study, several results are obtained as follows

1) Deteriorations of post members such as fungi, decay and crack could be detected exactly using DRT. But, knot might not be detected, if the drill was not passed through the knot.

2) The distribution of specific gravity is related closely with the strength of the member. In this study, the distribution of specific gravity was evaluated very well by DRT.

3) The structural stability of wooden cultural property could be evaluated by analyzing the structural member. The specific gravity distribution of the post member with the various deteriorations could be evaluated exactly in this study, so DRT will be utilized effectively to evaluate the safety of the structural member.

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