A Fundamental Study on Measurement Method of Plastic Heat Generation and Thermal Analysis of Buckling Restrained Knee Brace with The Wood

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Abstract.
It is necessary to survey the damage state of buildings after an earthquake disaster, but the current damage evaluation method takes a lot of time and efforts. Also, the experts who went to the site are suffered by aftershocks. So, in recent years, structural health monitoring using accelerometers and other devices has also been developed, however, there are also issues such as the difficulties of assessing the member-based damage. Therefore, a new damage evaluation method using plastic heat characteristics of steel under inelastic behavior is proposed.

In the previous study, the damage evaluation method by temperature measurement using the plastic heating in steel material can be used to assess the damage at the frame in global. Also, it is proposed to evaluate the damage of buildings by sacrifice components such as the knee brace to use this new damage evaluation method in actual buildings.

In this paper, for a fundamental study on the adaptability of measurement planning and analysis methods, a dynamic experiment and thermal analysis were conducted on a buckling restrained knee brace with the wood. The results show that the appropriate measurement method can be found and that the analysis results can be chased to the experimental results.

Keywords: Steel framed structure, Seismic disaster, Structural health monitoring, Internet of Things, Plastic .

1 Introduction

It is necessary to survey the damage states of buildings after an earthquake disaster, however, the current damage evaluation method takes a lot of time and effort. Also, the experts who went to the site are suffered by aftershocks. To solve these problems, structural health monitoring using accelerometers and other devices has also been developed. But there are also issues such as the difficulties of assessing the member-based damage. Therefore, a new damage evaluation method using plastic heat characteristics of steel material is proposed. Also, the goal of this study is to perform remote buildings diagnosis with the IoT technology.

In the previous study, the damage evaluation method by temperature measurement using the plastic heating in steel can be used to assess the damage at the frame in global(1). Also, it is proposed to evaluate the damage of buildings by sacrifice components such as knee brace to use this new damage evaluation method in actual buildings.(2)

This study aims to establish a damage evaluation system using the kinematic mechanism of the knee brace and the relationship between the plastic heating of the steel knee brace and the deformation of the framework. When the knee brace is subjected to cyclic loading, The buckling may affect measurement accuracy and energy absorption. Therefore, buckling restrained steel specimen with the wood is created. In this paper, a dynamic experiment and thermal analysis were conducted on this steel specimen for a fundamental study on the adaptability of measurement planning and analysis methods.

2 Methodology of Experimental Study

2.1 Composition of The Test Specimen

The test specimen consisted of a steel core plate and wood buckling restraint material. The core plate was cut from a steel plate(JIS grade, SS400) having a thickness of 3.2 mm. A rib having a thickness of 9 mm was attached near grip parts. Fig. 1 shows the geometry of the test specimen. Table 1 summarizes the material properties of steels used for the specimen.

Structural LVL(larch) having a thickness of 38 mm was used as the buckling restraint material in the weak axial direction (z-direction) of the specimens. The plywood plates having a thickness of 3 mm was used as the buckling restraint material in the strong axial direction (y-direction).The structural LVL were fixed by coarse thread, and the plywood plates were fixed by stainless steel plates.

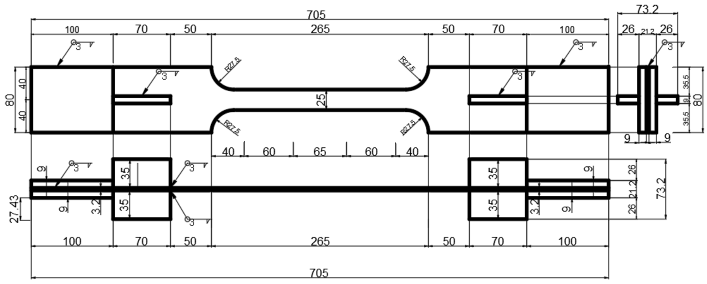

Fig. 1. Geometry of the test specimen

Table 1. Material properties of steels

Yield point (N/mm^2)	Young's modulus (kN/mm^2)	Tensile strength (N/mm^2)	Rupture elongation (%)	Yield ratio (σ_y/σ_u)
320	193	476	40	0.67

2.2 Loading Program

Fig. 2 shows the set up in the testing machine. The upper and lower parts in the specimen were gripped by the force application grips of the testing machine. Also, tensile loading was performed at a loading rate of 20 mm/min.

2.3 Measurement Methods

Load and displacement were measured from the testing machine, strain was measured by strain gauges, and steel temperature was measured by thermocouples and thermoelectric devices. As for thermoelectric devices, two types of thermoelectric devices were used: Peltier devices in the marketplace (hereinafter called "thermoelectric device A") and thermoelectric devices with a mountain shape (hereinafter called "thermoelectric device B"). Fig. 3 shows the shape of thermoelectric device B.

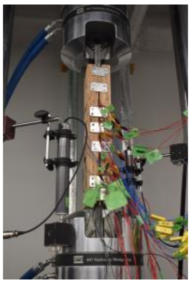

Fig. 2. Set up diagram

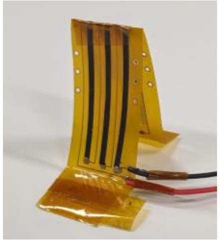

Fig. 3. thermoelectric device B

2.4 Experimental Parameters and Measurement Program

Table 2 shows experimental parameters. Structural LVLs were processed to fit the experimental parameters for the installation of thermoelectric devices. Fig. 4 shows the wood shape of each specimen.

In the specimen W-Ph, thermoelectric device A was put between heat sinks to increase measurement accuracy. On the other hand, in the specimen W-P, thermoelectric device A was put between only buckling restraint materials instead of heat sinks to reduce the wood processing.

In the specimen W-Tc, thermoelectric devices were not used, only thermocouples were used to measure the temperature of steels.

Fig. 5 shows the measurement program of each specimen.

Table 2. Experimental Variables

specimen name	thermoelectric device A	heat sink	thermoelectric device B
W-Ph	○	○	×
W-Tc	×	×	×
W-P	○	×	×
W-Y	×	×	○

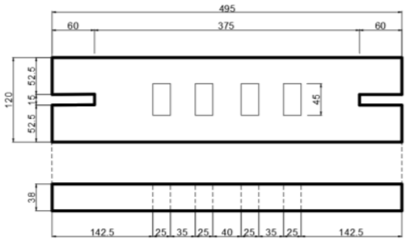

Fig. 4a. W-Ph

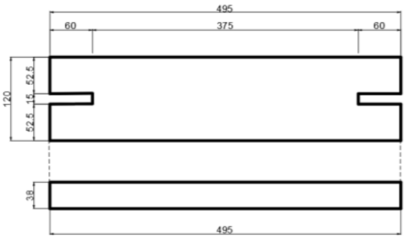

Fig. 4b. W-Tc

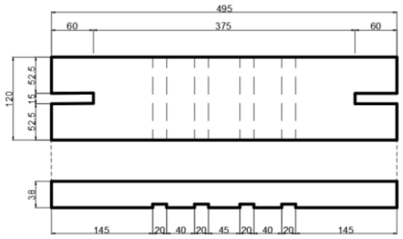

Fig. 4c. W-P

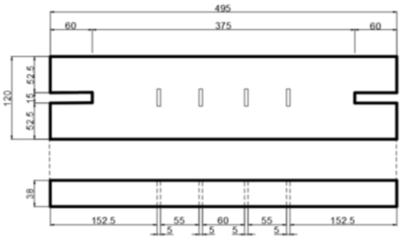

Fig 4d. W-Y

Fig. 4. The wood shape of each specimen

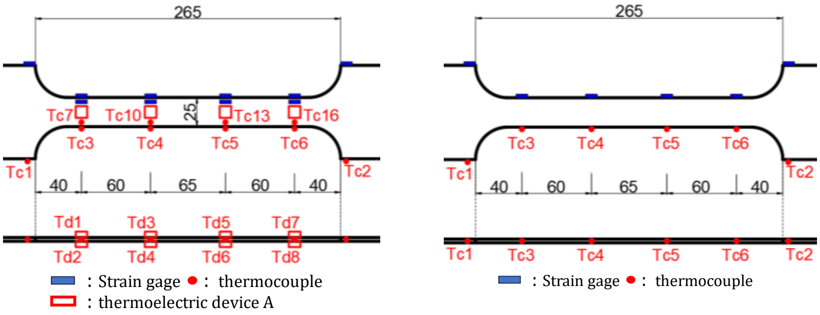

Fig. 5a. W-Ph

Fig. 5b. W-Tc

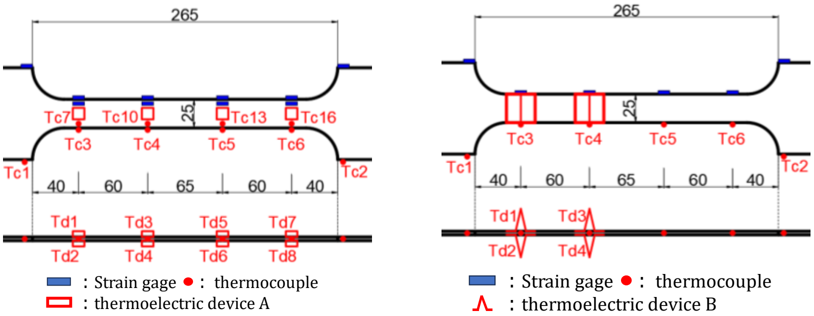

Fig. 5c. W-P

Fig. 5d. W-Y

Fig. 5. Measurement Program

2.5 Thermal Analysis Method

The thermal analysis was performed using the finite volume method. Fig. 6. shows the thermal analysis model. The heating section was divided into 42 sections with 5 mm spacing. Table 3 shows the analysis condition.

The total heat transfer coefficient *h* [W/(m^2・K)] was calculated from the experimental and analytical results by the least-squares method.

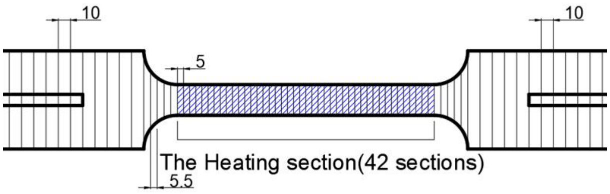

Fig. 6. The Model of The Thermal Analysis

Table 3. Experimental Variables

Specific heat	Density	Heat transfer coefficient (steel)	Heat transfer coefficient (wood)	Time difference
C [J/(K・kg)]	ρ [kg/m^3]	λ_s [W/(m・K)]	λ_w [W/(m・K)]	t [s]
473	**7860**	**51.6**	**0.087**	**0.02**

3 Results and Discussions

3.1 Loading-Deformation Relationship

Fig. 7. shows the load-deformation relationship for each specimen. Fig. 8. shows the fracture modes for each specimen. All specimens in the experiment ruptured at the bottom of the specimen.

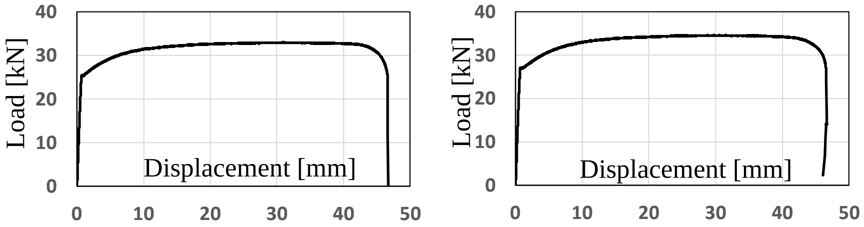

Fig. 7a. W-Ph **Fig. 7b. W-Tc**

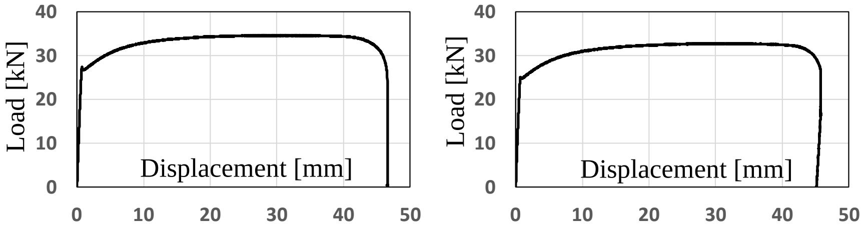

Fig. 7c. W-P **Fig. 7d. W-Y**

Fig. 7. The Load-Deformation Relationship

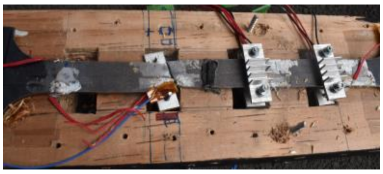

Fig. 8a. W-Ph

Fig. 8b. W-Tc

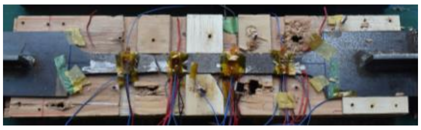

Fig. 8c. W-P

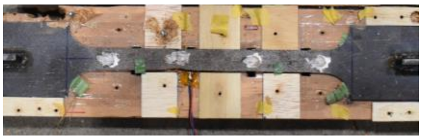

Fig. 8d. W-Y

Fig. 8. The fracture modes

3.2 Comparison of The Temperature Histories

Fig. 9. shows the temperature history of the thermocouples for each specimen. The temperature rise of the steel was observed, and the temperature rise near the fracture area was higher.

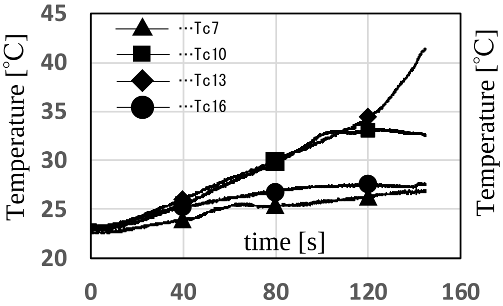

Fig. 9a. W-Ph

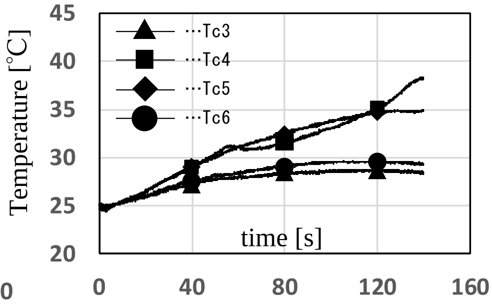

Fig. 9b. W-Tc

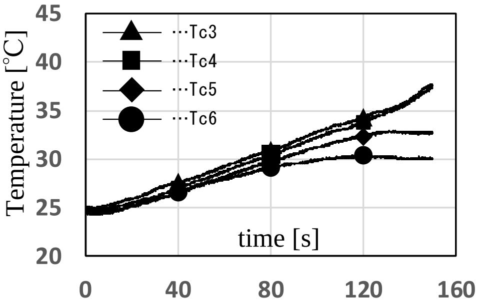

Fig. 9c. W-P

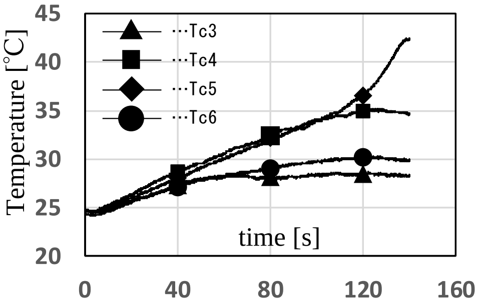

Fig. 9d. W-Y

Fig. 9. The Temperature History

3.3 Comparison of Voltage histories

Fig. 10. shows the voltage history of the thermoelectric device for each specimen. The results show that the other specimens have less increase in voltage compared to specimen W-Ph. In specimen W-P, lack of compression force on thermoelectric device A is a reason. In specimen W-Y, damage to thermoelectric device B is a reason.

Therefore, the measurement using thermoelectric device A with heat sinks was optimal as measurement method.

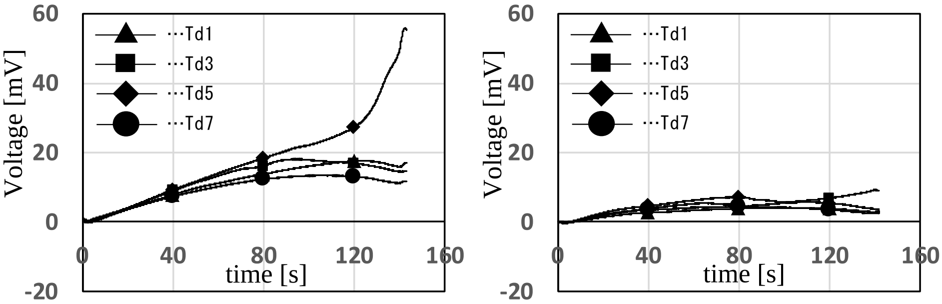

Fig. 10a, W-Ph **Fig. 10b. W-P**

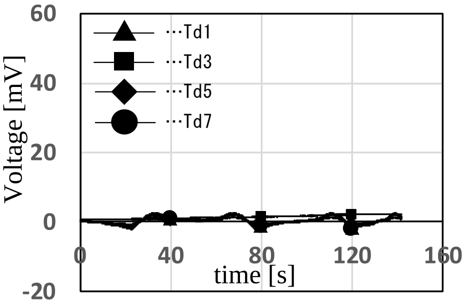

Fig. 10c. W-Y

Fig. 10. The Voltage History

3.4 Comparison of measurement and analysis results

The thermal analysis is performed on specimen W-Ph, W-Tc, and W-Y. Fig. 11. shows comparison of the measurement and analysis results for each specimen. The result of Fig. 11. shows that the analysis results can be chased to the experimental results.

Table 4. shows The total heat transfer coefficient *h* [W/(m^2・K)] for each specimen. The result shows that the figures of specimen W-Ph, and W-Y are smaller than the figure of specimen W-Tc. The possible causes of figure difference are differences in wood geometry. The total heat transfer coefficient is affected by the surrounding environment of steel specimen. The smaller the contact area of the steel plate with air

is, the smaller the total heat transfer coefficient is. Since Specimen W-Ph, and W-Y have slits, it is confirmed that the figures calculated reflect differences in wood geometry.

Therefore, the validity of the analysis method is confirmed.

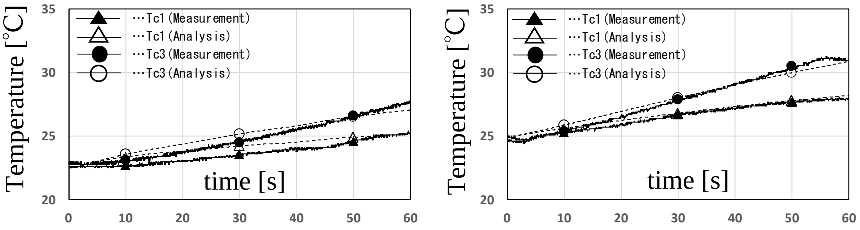

Fig. 11a. W-Ph **Fig. 11b. W-Tc**

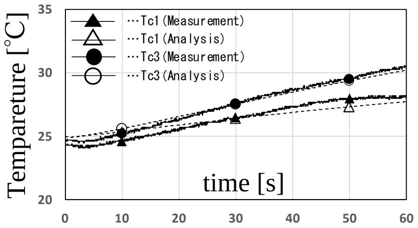

Fig. 11c. W-Y

Fig. 11. Comparison of The Measurement and Analysis Results

Table 4. The Total Heat Transfer Coefficient

specimen name	**W-Ph**	**W-Tc**	**W-Y**
the total heat transfer coefficient ***h*** [W/(m^2・K)]	**171.18**	**328.79**	**138.21**

4 Conclusion

The following conclusions were drawn from this study.

1. The proper measurement method for the buckling restrained knee brace sen sor is found.
2. The validity of the analysis method is confirmed and the total heat transfer coefficient is determined. This total heat transfer coefficient can be used in future studies.

Acknowledgements

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