Fundamental Study on IoT Monitoring System of Steel Damper with Thermoelectric Conversion Technology

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Abstract

Recently, the number of vibration control building has increased since recent severe earthquakes. These damping frames can absorb the seismic input energy, and the seismic response is mitigated. Therefore, the damper is sometimes damaged during seismic response behavior. So, it needs to estimate the damage status whether the frame has enough seismic resistant performance against aftershocks. Herein, the damper is often covered with interior wall or ceilings, so the visual diagnosis is not easy. Furthermore, many investigators check the damage status of damper, however, it spends a lot of time.

This study suggests the damage detection method which is based on Internet of Things (IoT). In other words, this system aims to detect the damage under the unmanned by detecting the fracture of damper itself, and the results and information are communicated to building owners with no power supply.

Here, it is widely recognized that the heat is generated on metal materials during ultimate state. So, the electricity is obtained by a thermoelectric conversion technology, and it applies as a power supply of this monitoring system. From the electrical signal, it reads the change in the amount of voltage before and after damage and performs the detection of damage states of damper.

To investigate the effectivity of proposed monitoring system, this study conducts an experimental study. To study the heat generation characteristics of steel damper, the tensile loading test is performed. During loading test, the thermoelectric element is attached. From the test results, it can be said that the steel damper generates the heat with high temperature, and the thermoelectric can convert the voltage.

Keywords: Internet of Things, Damage detecting, Thermoelectric, Power generation, Steel structures

1. Introduction

Japan is one of the countries that earthquake occurs frequently in the world. So, the technology for protecting buildings and cities from natural disaster has been developed, and it makes possible to continuous using building after the earthquake occurred. For that reason, it is important to not only mitigate the damage by the earthquake, but also pay attention to restoration of building.

The structural types are roughly categorized into three as follows, earthquake resistant construction, base isolation structure, and vibration control structure. The earthquake resistant structure has enough seismic resistant performance of strengthening walls, columns, or installation the reinforcing materials. The base isolation structure is separated the building and ground, and the input motion is reduced. Also, the vibration control structure has the various types of specific device to mitigate the vibration response which can absorb the vibration energy. There is some disadvantage as follows; in case of earthquake resistant structures, it is not easy to repair the damaged frame after severe seismic motions, because any damage of frame is allowed for elastic energy absorption. And in case of base isolation structures, the system needs special materials, and the cost becomes high. On the other hand, the vibration control structure can solve the above problem, because the damaged building is repaired to the original state by replacing the damaged damper after severe earthquake. Also, due to its low cost and installation of damper is comparatively easy, vibration control structure has become very popular in recent years (see Fig.1).

However, there are some difficulties and problems as follows. The damper is covered with interior walls or ceilings, it makes difficult to investigate the state of damage (see Fig.2). Also, the investigators are sometimes shortage and there is the risk that investigator enter the building after the disaster in the aftershock.

Herein, the system that can diagnose the state of building under the unmanned and use with no power supply in the blackout after the disaster is proposed.

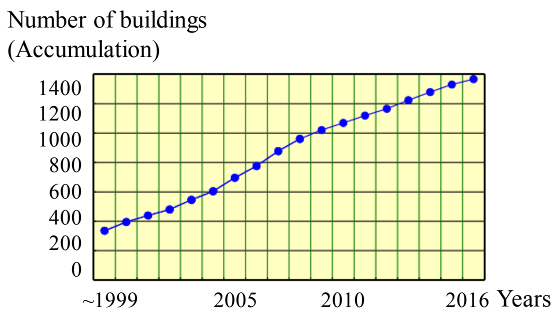


Figure1: Number of Cumulative Planning Building for Damping Structure

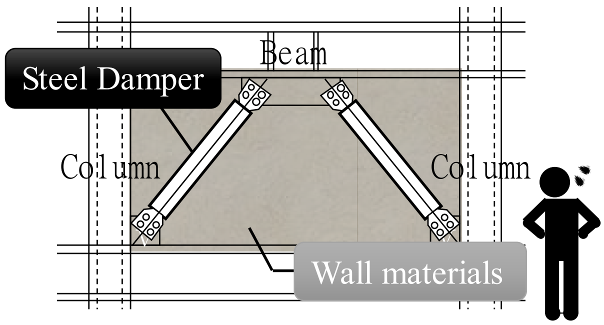


Figure 2: Image of Installation of the Damper

2. Outline of Monitoring System

2.1 Conceptual image of proposed system

Fig.3 shows the conceptual image of our proposed system. This system focuses on the heat generation of metal damper during ultimate state. And the heat is converted to the electricity by using the thermoelectric conversion technology. Herein, the system can detect the damage to pay an attention to changes in voltage before and after damage by reading the voltage value of thermo electric conversion element as electric signal. In other hand, the shortage of power supply is predicted due to blackout, so this system can start and operate with no power supply by using the electricity generated from thermoelectric conversion element as the power source of the system. The electric signal is communicated to the place away from the afflicted area by the system for analysis. And it is determined whether the damper has been broken or how much residual performance it has, after that the result is conveyed to the building owner.

Previously, it takes a lot of time and people to do judgement on disaster. But it is possible to do judgement of damage degree under the unmanned and in a short time by establishing this system.

As a result, it is possible not only to reduce damage due to aftershock, but also to reduce time to start restoring work.

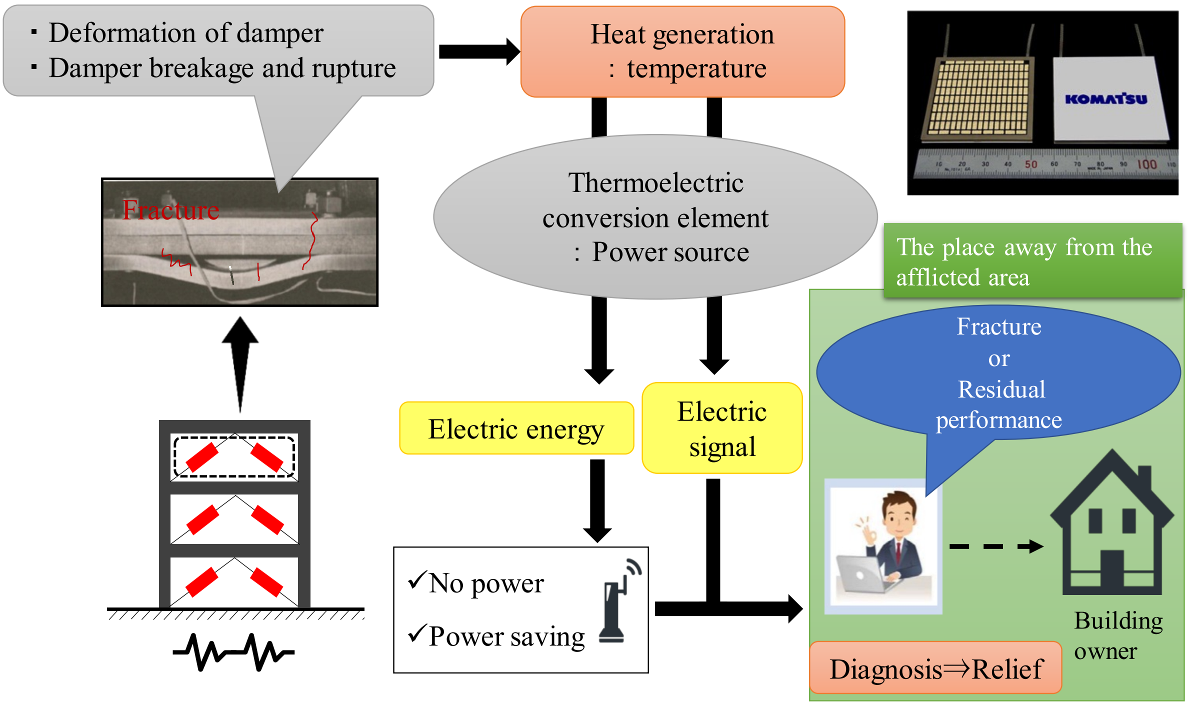


Figure 3: Conceptual Image of Proposed System Operation

2.2 In developing the system

As shown in Fig.4, this research is an interdisciplinary research crossing through three specialized fields of building structure, thermodynamics, and thermoelectricity. And a fundamental research in each field has already been conducted. In the field of building structure, the relationship between the deformation of the building and the damage degree has been clarified experimentally and analytically. Also, in the field of thermodynamics, the relationship between deformation and calorific value is clarified theoretically. Furthermore, in the field of thermoelectricity, thermoelectric conversion technology has been developed, and the relationship between heat and voltage is clearly stated.

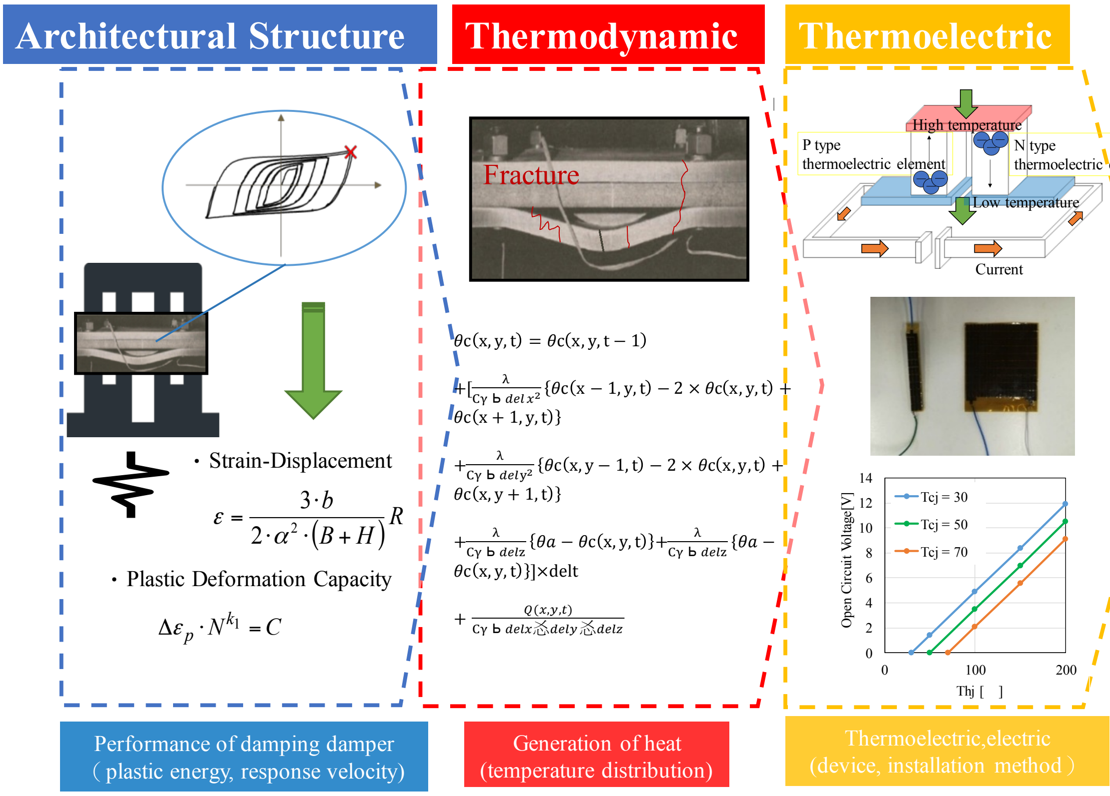


Figure4: Specialized Fields Regarding to System

2.3 Technology of thermoelectric conversion

In our proposed system, the thermoelectric conversion element (see Fig.5) contributes two roles as follows; the first is power source of the system, and the other is monitoring by the measurement of electric signal. Here, the principle of the thermoelectric conversion element is described.

It is widely recognized that the See-beck effect under an electromotive force is generated by giving a temperature gradient to a material. The See-beck effect is applied to the thermoelectric conversion element. Thermoelectric conversion element can pass current by connecting a n-type thermoelectric element in which electrons flow and a p-type thermoelectric element in which holes flow along the temperature gradient in series (see Fig.6). Because the power generation is so small in case of connecting one by one, thermoelectric conversion element is constituted of some pairs of a n-type and a p-type thermoelectric element in series to increase the voltage.

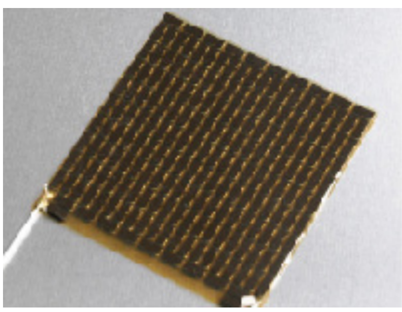


Figure5: Thermoelectric Conversion

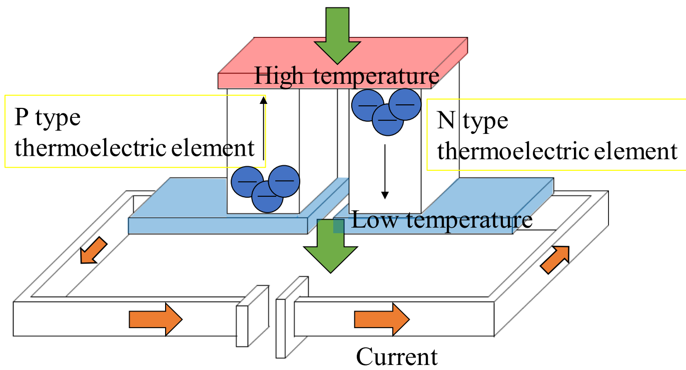


Figure6: Principle of Thermoelectric Conversion Element

Element(200elements))

3. Outline of Experiment Study

3.1 Verification experiment of heat generation

3.1.1 Purpose

To confirm the heat generation during the ultimate response behavior of metal materials, the loading test study is conducted.

3.1.2 Loading and measurement plan

First, the building model on which damping members is placed for reducing the drift angle within 1/50 rad when JMA Kobe NS wave standardized to 50m/sec is applied to fourth story building model shown in Fig.8. And this test with a rod specimen (see Fig.9) is conducted.
A monotonic tensile test is performed with a speed as a parameter, and a loading is done until the specimen fractures. Regarding the parameters, a time history response analysis is performed on the above-mentioned building model, and the strain rate is calculated by using the response speed of the damping member calculated.

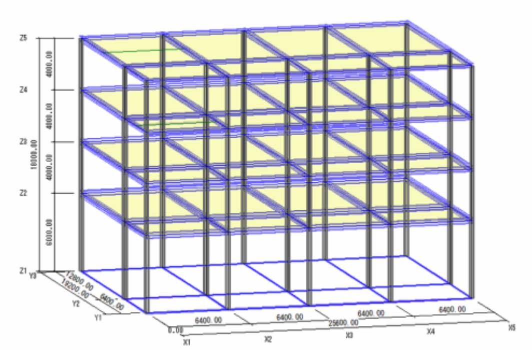


Figure 8: Building Model

Table 1:Loading Plan

Specimen name	Steel type	Loading method	Speed [m/sec]
M-0	SNR 400	Monotonic	—
M-0.03			0.03
M-0.23			0.23
M-0.93			0.93

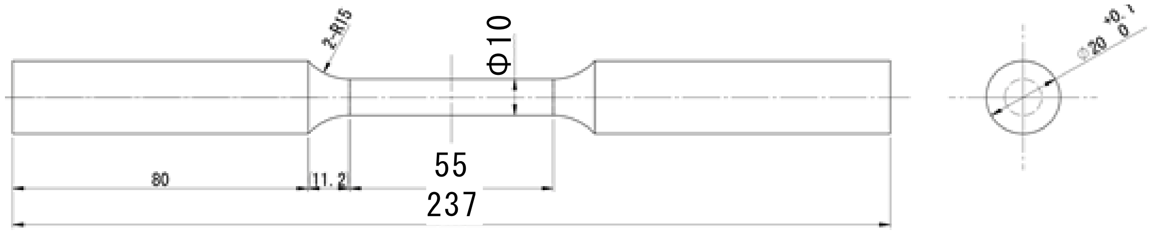


Figure 9: Outline of Rod Specimen (unit: mm)

3-2. Verification experiment on fracture detection

3.2.1 Purpose

To investigate the verification of fracture of metal materials, the detection of change of electric signal is studied. And the difference of the electric signal by the installation method of the thermoelectric conversion element is verified.

3.2.2 Outline of test study

The monotonic tensile loading test of a JIS-1A specimen is performed, and the electric signal is monitored when the test specimen is broken. In case of specimen A, a thermoelectric conversion element of 30 elements is attached with an adhesive. And the thermoelectric conversion elements consist of 200 elements is sandwiched by clamp in the grip part. In case of specimen B, it is attached in the same way in the parallel part, and it is installed with or without grease in the grip part. The outline of the specimen and setup diagram are shown as below (see Figs. 10, 11).

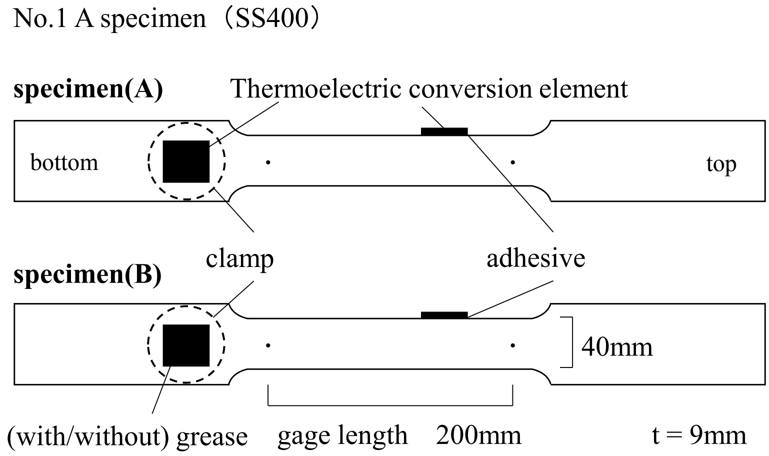


Figure 10: Outline of the Specimen

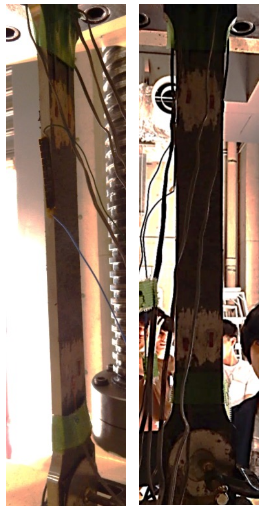
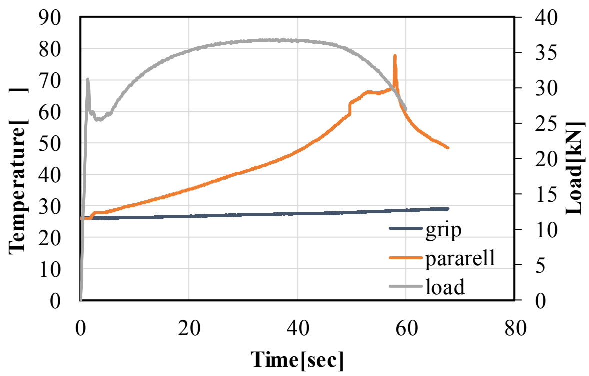


Figure 11: Setup Diagram

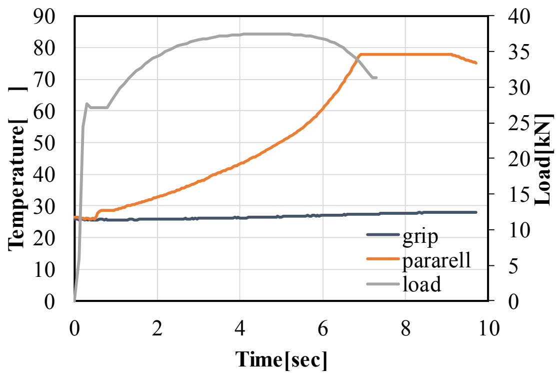
4. Test Result and Observations

4.1 Result of verifying test of heat generation

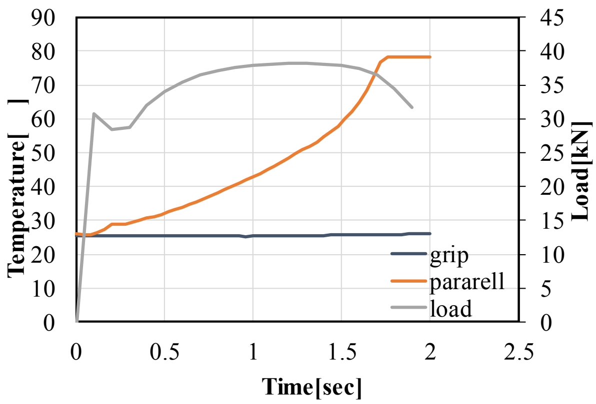
As shown in Fig. 12 (a), in case of specimen (M-0.03) under slow speed loading, the maximum temperature is 78.2℃ at the parallel part (near the fracture point). Also, the great change of the temperature when the specimen is broken. On the other hand, at the grip part, a slight change of temperature is observed. It is guessed that a heat conduction is not so much. In case of specimen (M-023,M-0.93) under fast speed loading, although it is impossible to obtain a data of the temperature above 80℃ with a thermo camera, it is considered that it reaches 90℃ or more when the specimen is broken (see Figs. 12(b)(c)). From the previous study, it is known that 90% of the plastic absorbed energy is converted into thermal energy (Masahiro TOYOSADA, 1991, p.651). So, the plastic absorption energy is calculated from the load-deformation relationship, and the temperature is calculated from the thermal energy formula by using 90% of that as thermal energy, it becomes as shown in Fig.13. From the above, in case of fast speed loading, it is found that the low effect of heat conduction is appeared. And the higher temperature is appeared when the same energy is given.



(a)M-0.03



(b)M-0.23



(c)M-0.93

Figure 12: Test Result of Load-Temperature Diagram

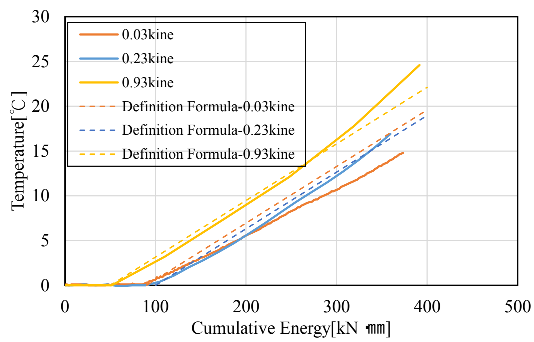
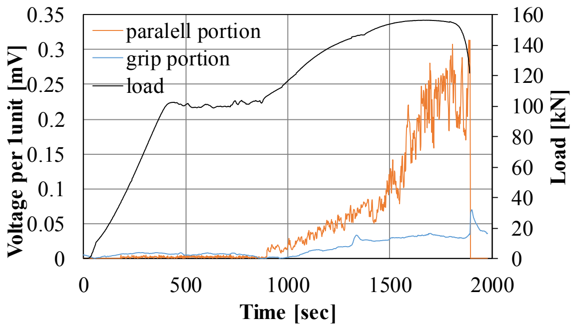


Figure 13: Test Result of Plastic Absorption Energy-Temperature Diagram

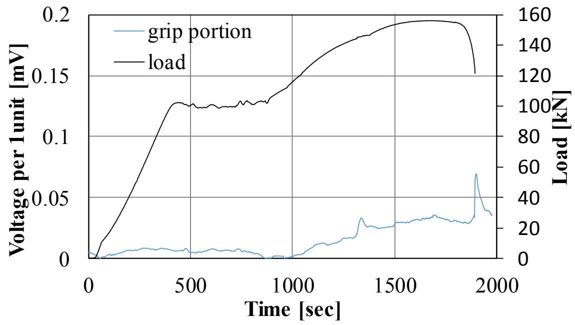
4-2. Verification experiment on fracture detection

Fig.14 shows the test result of load-deformation diagram and the electric-generating capacity per one element of the thermoelectric conversion element. In case of specimen A, the deformation becomes large on the parallel part and the maximum voltage is 0.35mV per element since the temperature is increased (Fig.14). Furthermore, at the parallel part, as the heat is saturated in the thermoelectric conversion element, the voltage is equilibrium state at a large range of electric-generating capacity.

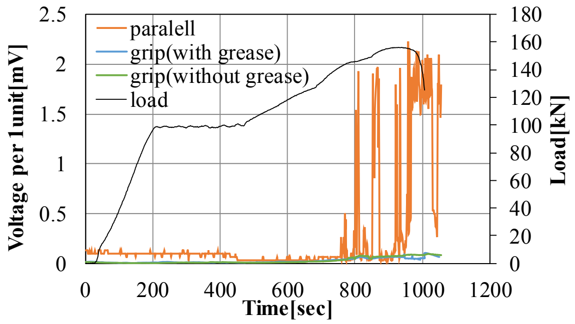
On one hand, the small deformation is presented at the grip part. Although the small voltage is occurred since only heat transferred by heat conduction is converted into voltage, the large voltage is observed at the fracture because the heat is not saturated. So, it is possible to detect the fracture. In case of specimen B, although the same consideration can be made, the maximum electric-generating capacity is 2 mV, which is about six times larger than that of the specimen A. At the parallel part, the installation method is adhesive. In case of specimen A, it is considered as the reason for above that it was not possible to follow the deformation and conversion from heat to voltage was not sufficient for some elements.



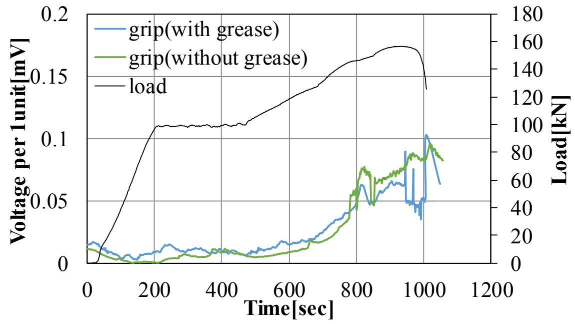
(a)Specimen A



(b)Specimen A-grip Part



(c)Specimen B

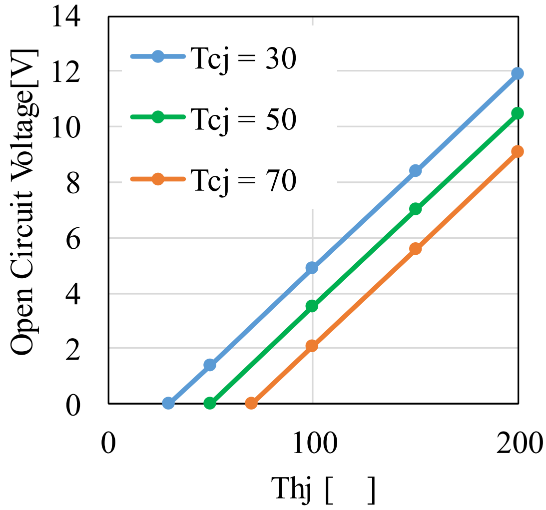


(d)Specimen B-grip Part

Figure14: Test Result of Load-Voltage Diagram

5． Considerations

From the experimental results, the possibility of detection of fracture is found. However, in order to detect the fracture using the thermoelectric conversion element accurately, it is necessary to establish a designing method of installation position and method of the thermoelectric conversion element and to maintain the temperature difference of the surface. And then, the elements are attached to two points of a parallel part (large part of deformation) and a grip part (small part of deformation), however, it is important that the location is selected where it is possible to read electric signal for detect and the elements can chase under earthquake motion.
Also, regarding to the installation method, it is necessary to further examine the thermal efficiency, deformation followability, workability at the time of installation, durability. Regarding the securing of the temperature difference on material surface, at the present stage, a heat sink is used. However, there are some difficulties because it cannot be used for small elements, and such as the necessity of some space with limitation of the size.
Furthermore, when the residual seismic performance is evaluated with following method; the relation of the plastic energy absorption and temperature of material is clarified as parameter with strain speed, and these relations are stored into database, and the installation method is considered.
Next, regarding a communication method, it is said that 3V voltage is required to send the data. However, from the test results, the maximum voltage is shortage on parallel part. In order to make the communication method, the area of the thermoelectric conversion element becomes considerably large, however, which is not easy condition. It can be seen from the performance curve of the thermoelectric conversion element (see fig.20) that 4V power generation with a heat generation of about 80℃. Thus, to solve the above-mentioned problems makes communication possible from the result of verification Experiment of heat generation.
From the above, it is considered that it is possible to detect damage in the vibration damping building after the earthquake under unmanned and no power supply.



※ Thj: Temperature of High Temperature Side Tcj: Temperature of Cool Temperature Side

Figure 15: Performance Curve of Thermoelectric Conversion Element

6. Conclusion

This study suggests the IoT monitoring system of steel vibration control building with thermoelectric conversion technology. It means that it is possible to detect the damage under the unmanned and with no power supply. Herein, the conceptual image of proposed system is mentioned, and the fundamental experiment studies for practical use are performed. The main conclusions are as follows;

1) The tensile loading tests are performed as parameter with loading speed, installation method of thermoelectric device.

2) From the test results, the heat generation is observed, also the power generation is clarified. However, the electric signal is small, so it needs to enhance more power generation.

3) From the consideration of test results, it is possible to detect the damage of steel materials using the thermoelectric conversion technology during inelastic process.

4) By establishing the proposed system, some problems can be solved as follows; the shortage of investigator for damage status, the risk mitigation of investigation works under the damaged building when the aftershock, and self-power supply by thermoelectric devices.

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Appendix

Installation method of the element

It is found that the electric-generating capacity changes greatly depending on the adhesion state of the element from the result of the verification experiment of fracture detection.
In this issue, what materials are suitable for converting the heat of steel material into electricity is examined with respect to heat conductive adhesive, heat conductive grease and heat conductive sheet. As a method, the air layer between the thermoelectric conversion element and the heat sink was filled with each material, and the temperature difference on the surface of the thermoelectric conversion element and the voltage amount were measured while gradually warming the steel material (see fig.16).
As shown in fig. 21, it was found that the voltage amount was the largest when the sheet was used. The reason for this may be that the air layer was sufficiently filled because the sheet was sticky.
In addition, when a thermoelectric conversion element is installed as a system, it is necessary to select an optimum one by examining the thermal efficiency, the deformation followability, the workability at the time of installation, and the durability.

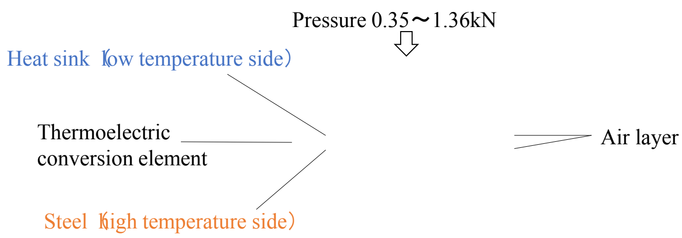

Figure 16: Outline of Experiment

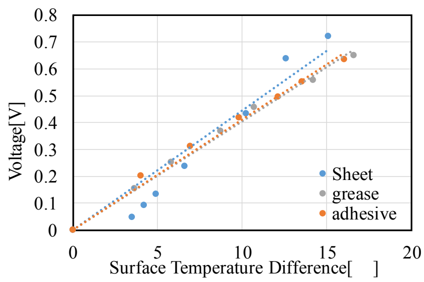

Figure 17: Comparison of Power Generation by Bonding Method