RESPONSE OF A PIEZOELECTRIC SENSOR DESIGNED FOR HEALTH MONITORING OF A WELDED STEEL JOINT

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Abstract

Piezoelectric film is used to build sensors that can detect failures or specific levels of loads that occur in welded steel beam-column joints. The proposed sensor consists of a steel plate that is setup at the corner of the beam-column connection. On this steel plate, a piezoelectric film is fixed using a silicon bond and a glass plate. The purpose of this system is that when a steel plate is deformed, the resulting stress causes a crack in the glass plate, and a sudden change in this stress condition causes a reaction in the piezoelectric material that releases an electrical current. Test specimen was subjected to lateral load that was applied by a hydraulic jack. Lateral deformation is measured with a displacement transducer and piezoelectric sensing system was setup at both sides of the column. Displacement control is used for the cyclic loading test. Peaks of the test were setup at 5 mm (1/100 of drift) and 10 mm (1/50 of drift). As expected, first crack of glass plate was observed near 1/100 of drift angle and other cracks were observed near 1/50 of drift angle. Cracks of glass plate do not occur at the middle of the plate. These cracks occur near the upper part of the plate. Then, an analysis of stress distribution in the steel when the test specimen is subjected to lateral load was performed using a finite element model. From stress analysis results it can be observed that larger stress occurs near the upper part of the steel plate and this fact confirms the occurrence of glass cracking near this zone of maximum stress. The proposed piezoelectric sensor system can detect lateral drift angle levels on the order of 1/100, but by improving its sensitivity, it could detect deformation at an early stage of lateral load.

Keywords: piezoelectric sensor; static loading test; stress analysis; damage detection

1. Introduction

In steel frame buildings, in general the connections are bolted or welded joints. In the case of bolt fastening, when a dynamic external force such as impact, vibration, or thermal load (expansion) acts on the bolted joint, the bolt often loses its fastening force due to loosening of the nut and loses its fastening function. In the case of welded joints, there are few accidents due to vibrations and loosening of nuts, but on the other hand, due to the thermal effects during welding, brittleness occurs simultaneously around the joints. In other words, the relationship between heat treatment of tempering and annealing of the steel material is produced, and it can be very difficult to manage the strength of structural joint. In order to solve this problem at the construction site, it is necessary to quantitatively judge the relationship between the ductility and toughness of the weld, and even the relationship between the residual stress. In addition, the ductility and toughness decrease, and the problem of lowering the fatigue strength must be overcome.

Inspection methods for welded joints include nondestructive inspection techniques and visual inspection, which include X-ray analysis techniques, image analysis techniques using ultrasonic waves and magnetism, and hammering. Judgment and visual inspection techniques are also effective tools.

It is difficult to realistically express crack propagation and fracture analysis even if analysis is based on results measured in the initial welding state and the results of aging over many years after aging using the finite element method. In Japan, which has experienced the Great East Japan Earthquake, when a huge earthquake with a seismic intensity of 6 or more occurs according to the architectural design standards, the entire building is plasticized without collapsing the building, absorbing the seismic energy and saving human life. In other developed countries that have experienced also great earthquakes, there is no report of monitoring the long-term soundness by precise measurement by focusing only on the joints.

In the 1995 Kobe earthquake, many steel structures were damaged, causing large lateral displacements. Assessing the level of damage is an important task for estimating the security and safety of a building after an earthquake. If the number of buildings to be evaluated is very large, it is desirable to have an indication of the level of stress or displacement experienced. This indicator can be obtained if the appropriate sensors are installed in the building.

In this study, a piezoelectric sensor for damage detection was developed. The sensor consists of a piezoelectric film mounted on a thin steel plate and covered with a thin small glass plate. The idea is that when a large deformation occurs, the glass plate breaks, at which point the piezoelectric material emits a voltage signal that is indicative of a certain level of damage.

2. Test specimen and cyclic test

Fig. 1 shows the general layout of the test specimen and loading test setup. It can be considered as a column-beam connection of a low-rise steel structure. However, it is a reduced scale specimen which elements has a box section of 100 mm X 100mm with a thin of 6 mm. This steel section is specified by the Japanese Industrial Standards as a carbon steel square tube (STKR400) for general structures. Column and beam elements are joined vertically using fillet welds. The obtained test specimen is an inverted T-shaped structure.

The horizontal element is welded to steel plates of 9 mm of thickness. These steel plates are located at both ends and at the middle of the horizontal element. Then, these plates are fixed to the reaction test system by means of 12 anchorage bolts (M27).

Piezoelectric sensors connecting the beam and the column were installed at both corners of the test piece using small diagonal steel plates containing the piezoelectric sensors. Later, when a lateral force is applied to the specimen, the plate becomes in tension or compression, depending on its position.

Test specimen was subjected to lateral load as is shown is Fig. 1 (b), where load is applied by a hydraulic jack (a), lateral deformation is measured with a displacement transducer (b) and piezoelectric sensing system (c) is setup at both sides of the column. The lateral load is applied at the free end at top of the vertical element. To applied lateral load, a hydraulic jack of 500 kN of capacity was used (Rikken 500).

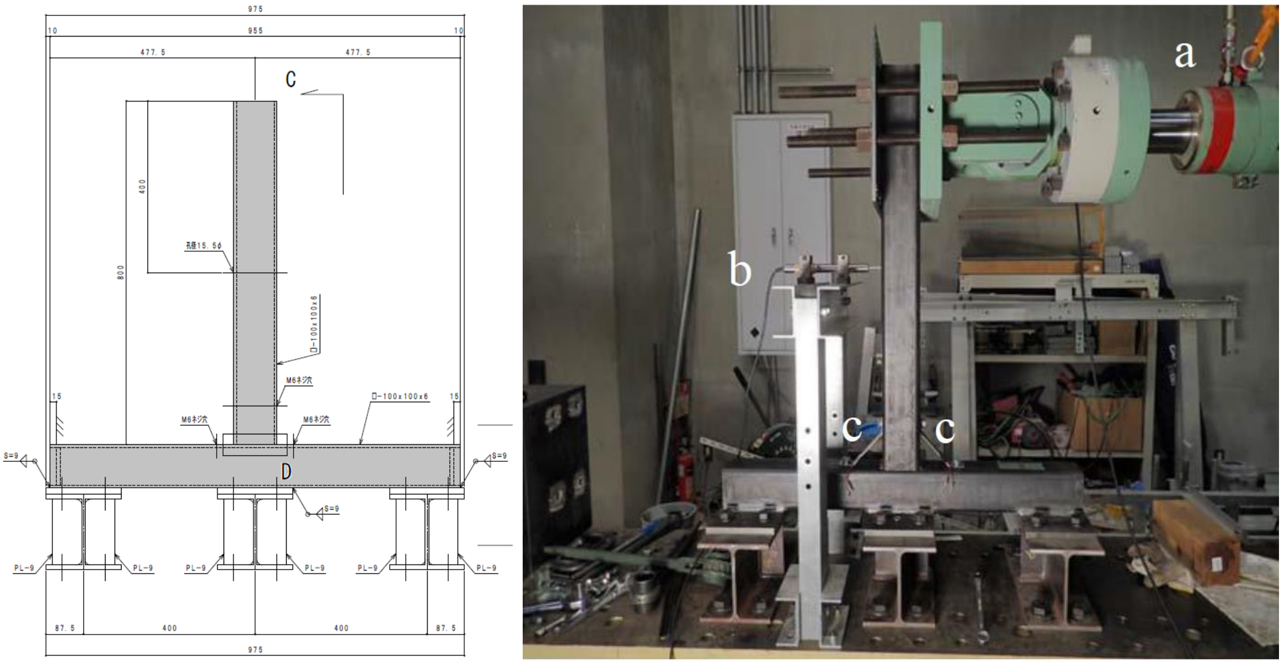


Fig. 1 – Test specimen and loading test setup

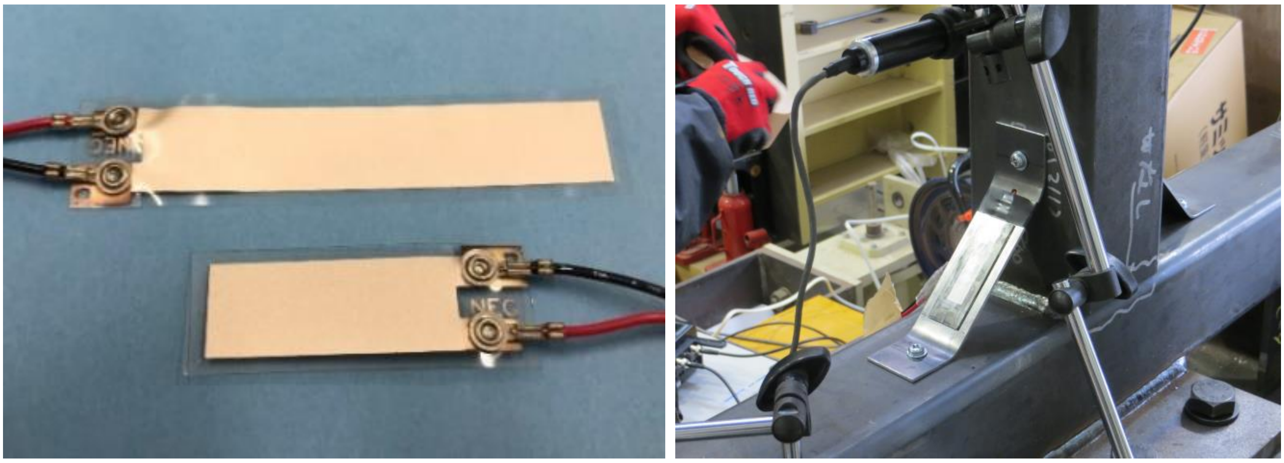
Static cyclic loading test was performed considering maximum displacements of 5 mm, 10 mm and 15 mm for each cycle. These load patterns are shown in Table 1.

Table 1 – Cyclic load pattern

Load Pattern	**Max. Disp (mm)**	**Drift angle (rad)**	**Load direction**
Load 1	5	1/100	±
Load 2	10	1/50	±
Load 3	15	1/25	±

3. Piezo electric sensor

Film type piezoelectric sensors is the most common use of piezoelectric sheet film. For example, sensor DT2-028K (16mm×73mm) and sensor LDT1-028K (16mm×73mm) are shown in Fig. 2(a). These are commercial multi-purpose, piezoelectric sensors for detecting physical phenomena such as vibration or impact. The piezo film element is laminate to a sheet of polyester and produces a useable electrical signal output when forces are applied to the sensing area. The dual wire lead attached to the sensor allows easy connection to a circuit or monitoring device to process the signal. In this research the piezoelectric film is setup on a steel plate and covered by a layer of glass, as is observed in Fig. 2(b). A special glue is used to fix the glass. This glue is a silicone that requires the application of ultraviolet rays for its hardening.



(a) Piezoelectric film (b) Sensing system

Fig. 2 Piezoelectric sensor

4. FEM analysis

Cyclic loading was simulated using the commercial software SAP 2000. In this analysis the welded joint is simulated using a link element to simulate the its inelastic response. The hysteresis rule that fit the test results is the Takeda model that was modified to fit the steel specimen response. Comparison of analysis and experiment can be observed in Fig. 3 where results for two loading cycles are shown.

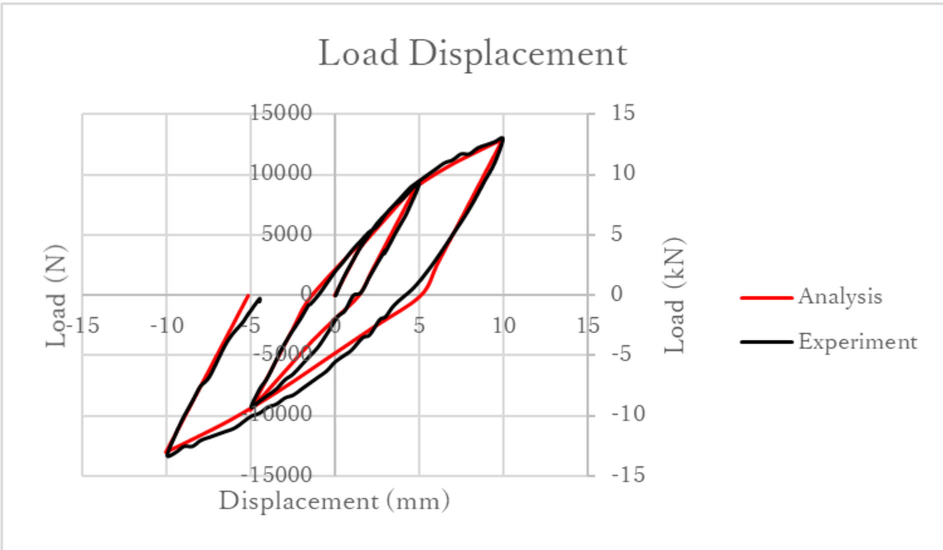
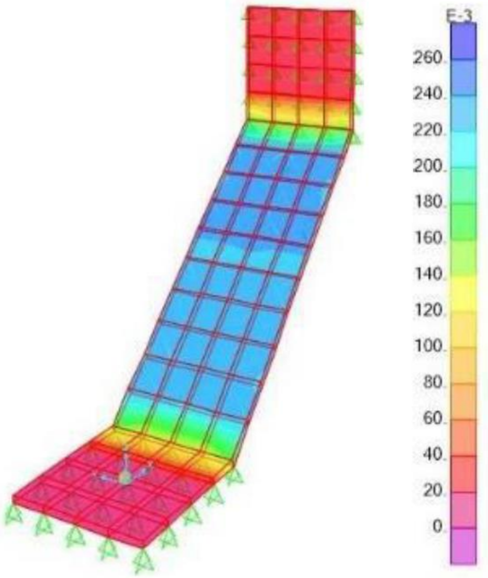


Fig. 3 Comparison of analysis and cyclic loading test results

As it is observed in Fig. 4(a), cracks of glass plate do not occur at the middle of the plate. These cracks occur near the upper bolt. Then, an analysis of stress distribution in the steel when the test specimen is subjected to lateral load was performed using a finite element model. Stress analysis results are shown in Fig. 3(b) and it can be observed that larger stress occurs near the upper bolt and this fact confirms the occurrence of cracking near this zone of maximum stress.

(a) Glass cracking



(b) Stress distribution in steel plate

Fig. 4 Detail of glass cracking and stress distribution in sensor system

5. Sensor system response

Cyclic lateral load was applied reaching a maximum load of the order of 13 kN aproxximately. Results for load history and sensor response are show in Fig. 5. Piezoelectric sensors show a first response at a drift angle of the order of 1/100, and also this response is observed at a drift angle of 1/50. The drift angles at which piezoelectric sensors respond are relatively large. Therefore, it is necessary to improve the setup of sensors to obtain responses at early steps of loading. Although these preliminary results permit to verify the response of sensors for large deformation it can be concluded that it is possible to estimate the level of deformations using these simple piezoelectric sensors.

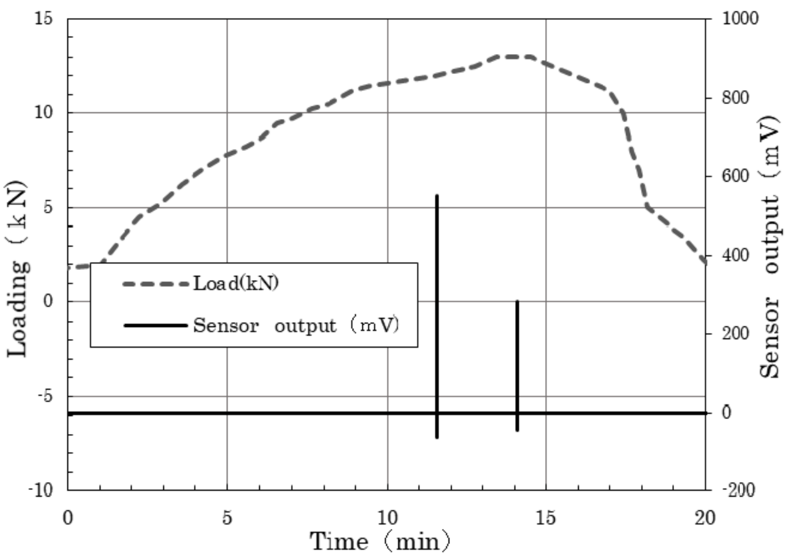


Fig. 5 Load history and sensor system response

6. Conclusions

In this research, thin rectangular set up of a piezoelectric film layered with a glass plate is proposed. Applicability of this piezoelectric sensor system to detect the failure occurrence was verified experimentally using a steel specimen subjected to lateral cyclic load. Although preliminary results permit to verify the response of sensors for large deformation it can be concluded that it is possible to estimate the level of deformations using these simple piezoelectric sensors.

7. References

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