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Comparison in Displacement Measurements for Fillet Weld of Steel Column Base by Using Piezoelectric Joint Sensors

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Abstract**-**The Hyogoken Nanbu earthquake (Kobe earthquake) occurred on January 17, 1995, causing extensive and severe damage to numerous buildings throughout the Kobe city area. After the earthquake, many steel structures were constructed using frame-welded joints of fillet welded construction and a welded base. However, these weld joints have only slight capacity to absorb energy during earthquakes. Therefore, for designing steel structures that use welded joints, strong earthquake-resistance characteristics must be specially provided for those joints of steel welded bases. Moreover, structural monitoring is recommended. This paper reports the use of piezoelectric limit sensors to evaluate resistance and displacement characteristics of fillet welded construction for simple measurements.

Keywords- *Anchor Bolt, Deformed Bar, Health Monitoring, Smart Sensor, Steel Weld Joint*

I. INTRODUCTION

Many steel-framed buildings in Japan use welding or bolting as the joining method. For 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 because of loosening of the nut. By contrast, few accidents occurred with welded joints [1].However, because of heat effects during welding, brittleness arises around the joint as it hardens. In other words, a relation exists between heat treatment of quenching and annealing of the steel material [2]. Therefore, it might be difficult to achieve structural soundness. Even if one strives to analyze the results of measurements at the initial stage of joining and the results of aging over 10 years using finite element method (FEM), one cannot express the analysis of crack growth or defect location realistically. It is regarded as extremely difficult. In Japan, which has undergone a great earthquake, if a huge earthquake with a seismic intensity of six or more occurs according to architectural design standards, then the entire building must plasticize without collapse [3]. Absorbing seismic energy and preserving human life are assigned priority. The design must follow those principles.

II. TEST OF A FILLET WELD OF COLUMN BASE

A. Comparison with conventional technology

The following methods are used as measurement technologies to evaluate structural soundness quantitatively for disaster prevention and mitigation. Sensor systems used for measuring displacement and vibration caused by static loading use displacement measuring methods of laser displacement meters or a contact displacement meters. Alternatively,the natural vibration might be measured using a micro tremor vibrometer, with subsequent analysis using the finite element method to identify the state of fracture and locations such as stress concentrations [4],[5]. In addition, non-destructive and quantitative methods for evaluating the residual stress of a structure include X-ray analysis when finite element method is used. Nevertheless, performing crack propagation analysis and other analyses is difficult. A laser Doppler velocimeter (LDV) irradiates a target with laser light. Then, because of Doppler actions, it detects the velocity according to the phase difference between the irradiated light and the reflected light [6],[7],[8].

B. Overview of installation test

Figure 1 presents the shape and dimensions of the test specimen. This test piece is intended for exposed column bases of a low-rise steel frame. Plate 9 mm thick base plate is welded to a 100 × 100 × 6 mm square steel pipe. The fastening method is fixed to the pedestal using 12 of M27 anchor bolts. The joint between the base plate and the square tubular column is fixed by melting with a three-layer fillet weld.

C. Test method

Figure 2 presents the measurement apparatus of (1) the loading device, (2) the displacement meter, and (3) the piezo electric joint sensor.

Figure 3 presents details of the shape and dimensions of the piezoelectric joint sensor. The piezoelectric joint sensor base plate is a 40 × 190 mm × 2 mm general rolled steel plate, after drilling two 12.3 mm drill holes and an 8 mm hole for cable ducts, and bending of both ends of about 40 mm at 135 deg. This angle is designed so that the piezo limit sensor

(Piezoelectric Film: DT-2-028 K/L [9]) can be mounted at a 45-degree angle to the weld surface when a square steel tubular column is welded in a T-shape. The sensor output has a structure in which a maximum voltage of about 1 V is generated depending on the state of weld joint breakage [10].

Figure 4 the anchor plate portion of the test specimen was fixed to the base using high tension bolts. A 500 kN hydraulic jack was connected to the load section provided on the top of the test specimen. Then horizontal force was simulated during an earthquake. The horizontal force is based on the top displacement. The angle relation between the force and the inclination is shown in Table 1 [11]. Load 1 shown in the table is the limit of the safety standard in the Building Standards Law. Load 2 is the positive load corresponding to the deformation limit value during a strong earthquake. At the applied force 3, the deformation (displacement amount) of three times the applied force 1 is used, but the value of this displacement is equivalent to the numerical calculated value indicating complete failure of the test piece.

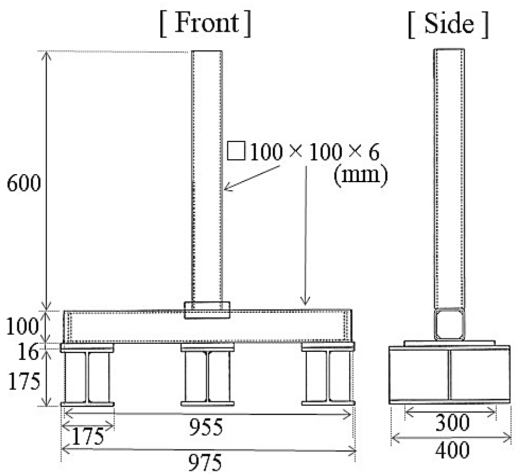


Figure 1. Test specimen layout

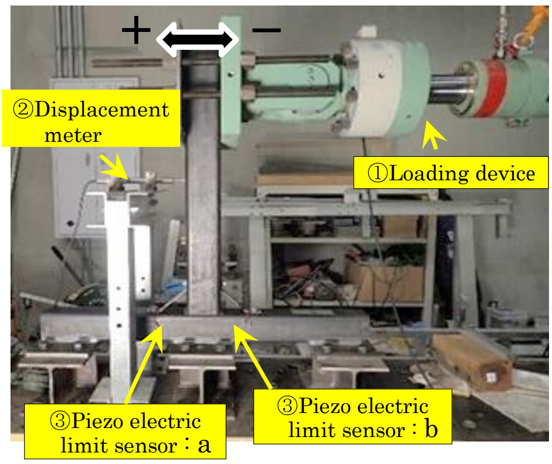


Figure 2. Load test devices

TABLE I. LOAD PATTERN CHARACTERISTICS

Load	Maximum displacement (mm)	Drift angle (rad)	Load direction
Load 1	5	1/100	+ −
Load 2	10	1/50	+ −
Load 3	15	1/25	+ −

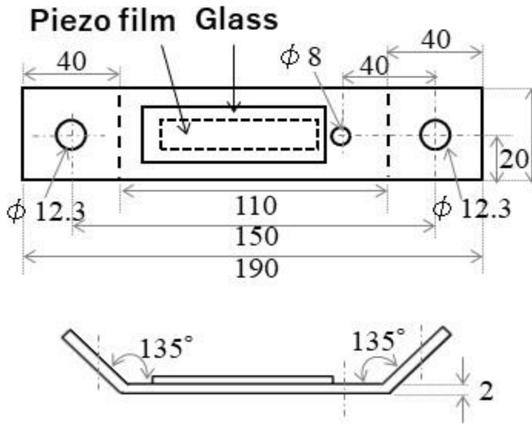


Figure 3. Characteristics of piezoelectric limit sensor

Figure 4. Setting of piezoelectric limit sensor.

III. Relation Between the Applied Force and Displacement Measurement of Welded Joints Using a New Limit Sensor

A. Relation between welding force applied to welded joint and piezo limit sensor output

Figure 5 (1) portrays the + direction force and the output results for the piezo limit sensor on the sensor installation “b “side. Measurement results show that the applied force became about 12 kN when about 11 min and 45 s passed on the time axis. The high output of about +530 mv and -70 mV was recorded from the sensor. Furthermore, it became difficult to measure after the output of about + 300 mV and -50 mV from the sensor when the applied force was about 13 kN.

Figure 5 (2) shows the positive direction force and the output results for the piezo limit sensor on the Sensor a installation side. Measurement results show that the applied force became about 12 kN when about 11 min and 45 s had passed on the time axis. Output of about +52 mV and -120 mV from the sensor were recorded. In addition, the measurement became difficult after recording + 20 mV output from the sensor when the applied force was about 13 kN. Furthermore, after recording + 20 mV output from the sensor when the applied force was about 13 kN, it became difficult to measure similarly, force was stopped to prevent danger. The sensor output on side a was confirmed immediately before the complete destruction region, but the sensor output on the side was small: the value is about one-fifth of that of that a side. In addition, the output judgment near the limit area showed that the value was small and difficult to judge.

Figure 5 (3) presents the relation between the negative force and the output of the piezo limit sensor on the Sensor a installation side. About 34 min and 20 s after the sensor, when the applied force was in the negative direction and the applied force was about 10 kN, outputs of +580 mV and -100 mV were obtained from the sensor. Furthermore, after about 38 min and 30 s, outputs of +100 mV and -150 mV were recorded at 13 kN when the applied force was 13 kN. The sensor response was lost. After 2 min had elapsed, the applied force level.

Figure 5 (4) presents the negative force and the output results for the piezo limit sensor on the Sensor b installation side. At approximately 34 min and 20 s, the output from the sensor in the negative direction was about 100 mV at about 10 kN. At about 38 min and 30 s, the output was about 80 mV at 13 kN when the force was about 13 kN. Later, the loading was stopped for safety. Compared to the positive side compression, the negative side tensile force applied was 10 kN for the first recording and 13 kN for the second, similarly to that for Sensor a, with a low level output early in the complete destruction area.

B. Relation between welding force applied to welded joint and piezo limit sensor output

A maximum force of 15 kN was applied in the + direction for about 20 min. Then force was also applied to the side under the same conditions. The relation between each displacement and the sensor output was measured. Figure 6 (1) shows the displacement by the + direction force and the output result of the b side piezo limit sensor. When the displacement became about 8 mm after about 11 min and 45 s, the sensor output showed high outputs of about +530 mV and -70 mV. Furthermore, for displacement of about 10 mm, the sensor output was about +300 mV and the output was about -50 mV. The sensor response ceased after recording. Therefore, the loading was stopped after 2 min for safety. In each case, results show that the sensor output increased immediately before the complete destruction area and near the limit area.

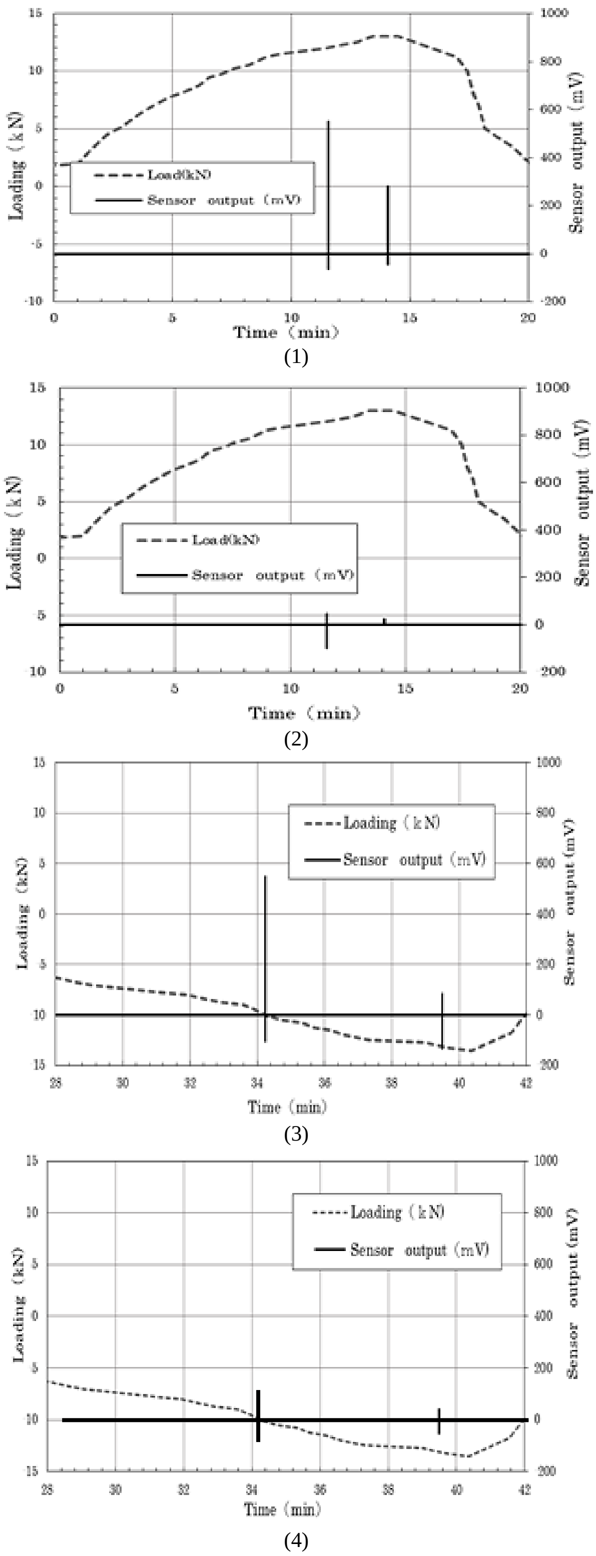
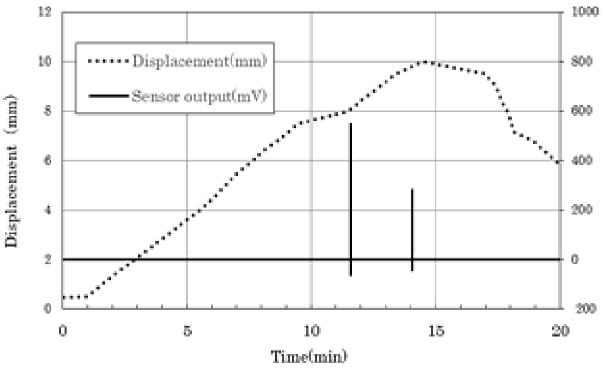
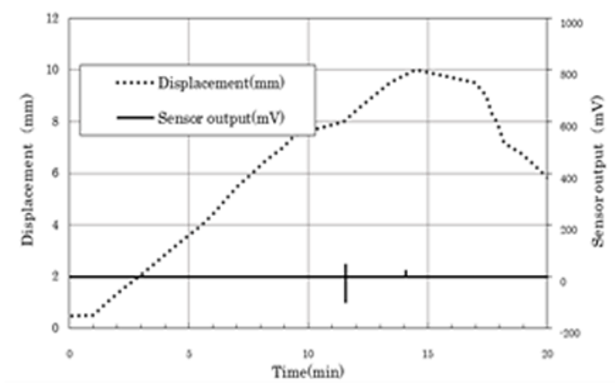


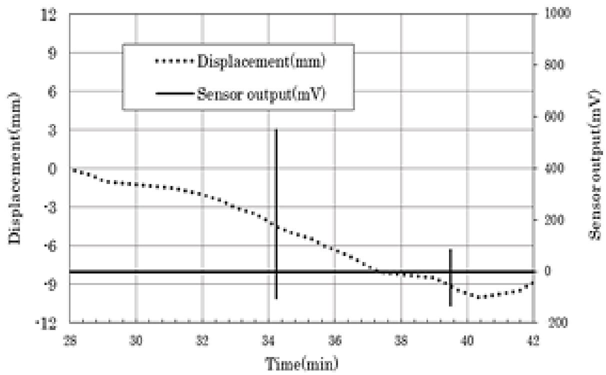
Figure 5. Relation between piezoelectric limit sensor output and loading.



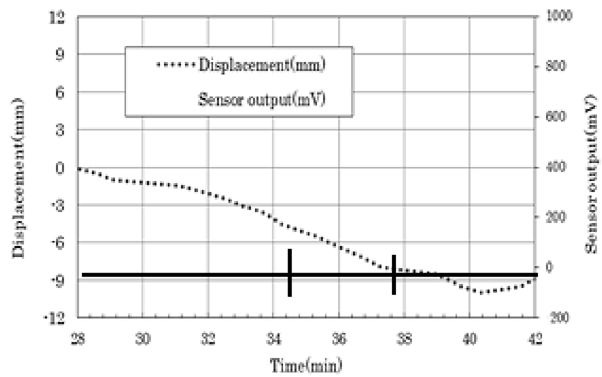
(1)



(2)



(3)



(4)

Figure 6. Relation between piezoelectric limit sensor output and displacement.

IV. CONCLUSION

Measurement using the piezo limit sensor adopted for this test has a characteristic by which, based on the output value under each condition, a dangerous value is shown immediately before the structural limit region, which maintains the welded structure integrity. Therefore, the possibility exists that risk assessment measurements might be conducted using this apparatus. Furthermore, the possibility of long-term measurement has been expanded at joints of welded structures, for which real-time soundness monitoring has been difficult in the past. Based on these results, we hope to contribute to the construction of a safe and secure society.

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