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Detection of loosened bolt- joint in braced steel frame structure based on impact hammer test

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Abstract. This work performed an impact hammer test to track the loosened bolt joints in a braced steel frame structure. The measured frequency response functions (FRFs) data in the neighborhood of the first resonance frequency are extracted to estimate the proper orthogonal decomposition (POD) and proper orthogonal mode (POM). Two damage cases are handled in evaluating the performance of bolted joint in the braced steel frame structure.

Keywords: bolted joint, damage detection, frequency response function, proper orthogonal decomposition, resonance frequency

1 Introduction

A steel structure is a metal structure fabricated with steel. Steel members are joined by connections like bolts such that they function together as one unit. Bolted joints are susceptible to bolt load loss due to viscoelastic creep and/or environmental effects. The repair and maintenance of bolted joints to improve the deteriorated load-carrying capacity are required for enhancing the structural durability. There have been many attempts to detect damage of bolted connection in steel frame [1]-[5].

This study performed the impact hammer test to find the loosened bolt joints in a braced steel frame structure. The experiment was carried out by two accelerometers at each joint and impact hammer at a fixed point, and the FRF data were collected. The collected FRF data were transformed to the POD and POM, and the bolted looseness was evaluated by the POM curve corresponding to the first POV. Two damage cases were performed in this experimental work and its validity was investigated.

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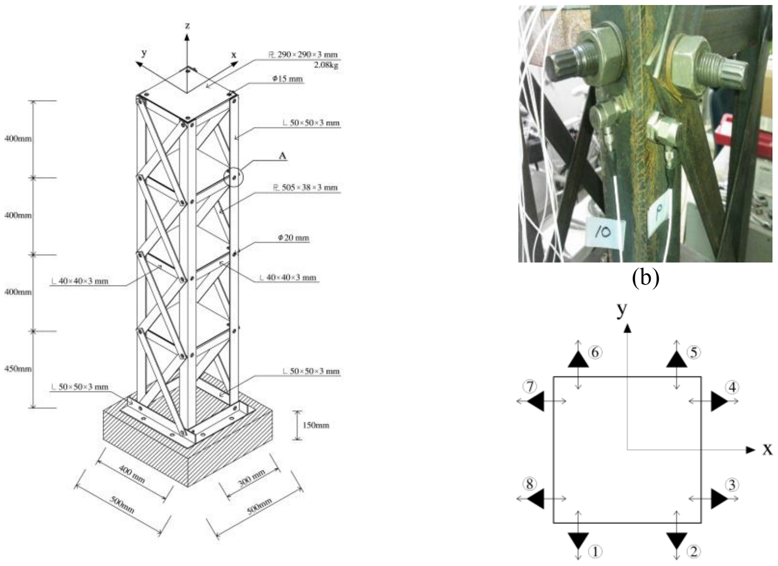
2 Experiment

An experiment to evaluate the joint tightness related with the lateral strength was performed in a four-story, one-bay by one-bay steel frame scale-model structure, shown in Fig. 1(a). A photograph shows the bolting joint of braced frame structure in Fig. 1(b) and the accelerometers as measurement sensors are installed as shown. The four vertical columns were comprised of continuous steel angles $L50 \times 50 \times 3$ in height and were bolted to a concrete foundation with dimensions of $b \times w \times t = 500 \times 500 \times 150\text{mm}$. The concrete foundation consists of four steel flanges bolted to each column, and the column was fastened to a massive concrete foundation. Four steel shim sheet squares represented the slab and measured approximately $290 \times 290 \times 3\text{mm}$ and 2.08kg, and were placed on the flanges of the steel beams. Cross bracing was externally added within each story along two faces. All cross bracing members were made using $38 \times 3\text{mm}$ wide steel strips, each measuring approximately 505mm in length. The bolts were tightened by torque wrench. The torque is a measure of how much a force acting on an object causes that object to rotate and is measured in Newton-meter $(\text{N} \cdot \text{m})$. All bolting joints at the initial state were tightened in the torque of $60\text{N} \cdot \text{m}$. If the torque is less than $60\text{N} \cdot \text{m}$, the bolting joint should be loosened and the lateral strength should be deteriorated.



(a) (c)

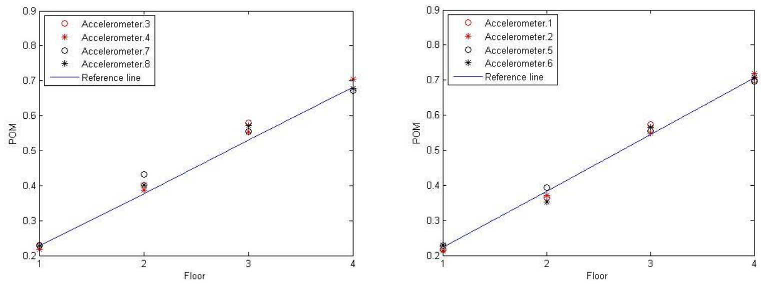
Fig. 1. A steel frame scale-model structure and installed accelerometers: (a) a steel frame structure model, (b) bolt joint and installed accelerometers to amplify the region A in Fig. 1(a), (c) x and y measurement directions by installed accelerometers.

Two accelerometers in the perpendicular directions at each corner column were installed as shown in Fig. 1(c) and measured the FRF in the indicated directions. The accelerometer set is composed of eight accelerometers at each floor. An impact hammer was used to excite the frame and hit the midspan point of the beam at the fourth floor in the bracing direction. The impact was taken in the positive y-direction on the x-y plane as shown in Fig. 1(c). The response measurement was carried out using an accelerometer set. Ten measurement channels were utilized for data acquisition, including a channel for the impact hammer and a reference channel. Four different experiments were repeated in changes of the accelerometer set on each floor. The experiment was conducted using DYTRAN model 3055B1 uniaxial accelerometers along with a miniature transducer hammer Brüel & Kjaer model 8204 to excite the system. The data acquisition system was a DEWETRON model DEWE-43.

We considered two different cases depending on the location ③ of the bolting looseness of the second and third floor. The torque at the bolted joint to be described as the damage was established as $20\text{N} \cdot \text{m}$. The difference in the receptance magnitude comes from the impact effect depending on the measurement and impact directions.

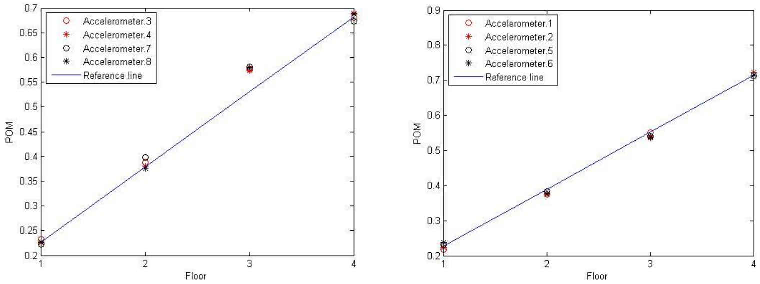
This work considers the only FRF data in the first resonance frequency. The first resonance frequencies regardless of bolting looseness and measurement locations locate in the range of 16.5-16.9Hz and the 46 FRF data sets in the range of 13.123-19.989Hz to extract the POM were collected. The FRF data were transformed to the POD and POM.

The POMs corresponding to the first POV extracted from the FRF data are shown in Figs. 2 and 3. They represent the plots in the impact direction (y-direction) and its perpendicular direction (x-direction). It is shown that the POM variation in the x-direction from the reference line is larger than in the y-direction due to the bolt loosening at bracing joint end. The plots in Figs. 2 and 3 exhibit that the damage exists at the location of bolting looseness to represent the large POM variation, respectively.



(a) (b)

Fig. 2. Damaged steel frame with the bolting looseness at the bracing joint of the second floor: (a) x-direction, (b) y-direction



(a) (b)

Fig. 3. Damaged steel frame with the bolting looseness at the bracing joint of the third floor: (a) x-direction, (b) y-direction

3 Conclusions

This study carried out the impact hammer test to find bolting looseness at bolted joint to connect the frame and bracing system. Extracting the POD and POM from the FRF data in the neighborhood of the first resonance frequency, the POM curve corresponding to the first POV was utilized in detecting the bolt loosening. It was observed that the damage exists at the position to represent large variation in the POM of the bracing direction to be related with the lateral strength. Based on the proposed experiment, it was illustrated in this experimental work that the damage due to the bolt loosening can be detected.

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