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Effectiveness of Repair Action in Recovering Steel Frames with Earthquake-induced Irregularity

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1. Introduction

Structural irregularity, such as irregular structural arrangement, mass, and stiffness, increase vulnerability in buildings, and modern seismic codes impose penalties for them. Structural irregularity induced by seismic damage results in severe damage under aftershocks or future events. Therefore, identifying structural irregularity immediately after earthquakes and recovering regularity by rapid repair methods are increasingly important.

This study first presents an overview of a full-scale shaking table test for a four-story steel frame. The structural response identification, which determines the changes in natural frequencies, modal shape, and story stiffness of the 4-story building, was performed according to the test results. The applicability and effectiveness of a simple repair method of retightening anchor rods for exposed column bases were investigated through tests and simulations.

2. E-defense shaking table testing of a steel frame

A full-scale shaking table test of a hospital facility specimen was conducted.. The specimen comprises a four-story steel moment-resisting frame (SMRF) and a three-story base-isolated steel frame. This study examines the behavior and the damage of the 4-story SMRF only. Fig. 1. shows the general floor plans and elevations of the 4-story SMRF. The structural design followed the building law of Japan with reserved strength of 1.5 times the code minimum and adopted the weak-base/strong-column design.

Two ground motions were scaled to six scales, including elastic level, life safety level, and 1.5 times design level and input to the shaking table sequentially, as shown in Table 1.

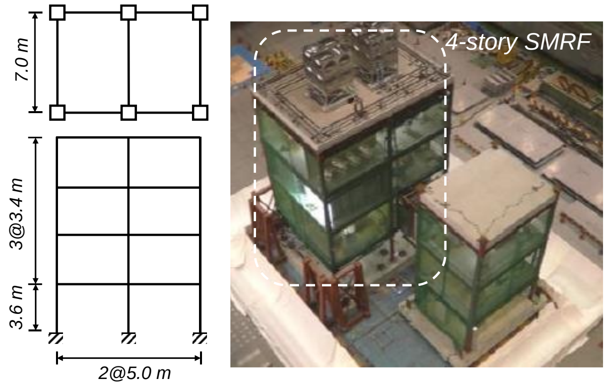

Fig. 1 Floor plans and elevations, and photo of the adopted 4-story SMRF

Table 1. A list of the loading cases

ID	Ground motion
1	JMA Kobe NS X dir. 16%
2	JMA Kobe NS Y dir. 16%
3	OS-2 Y dir. 20%
4	JMA Kobe NS X dir. 50%
5	OS-2 XY dir. 50%
6	JMA Kobe NS XY dirs. 50% UD Z dir. 100%

3. System identification results

The natural frequencies, modal shape, and story stiffness of the 4-story SMRF were identified from the test results, as shown in Fig. 2. The story stiffness was identified directly with a method proposed for damage evaluation of a steel structure based on ambient vibration measurements.

For story stiffness, the results become relatively stable after 10 seconds. In ID1, the story stiffness remained unchanged, implying the structure is in the elastic range. In ID6, the story stiffness decreased significantly at the first floor. The reduction in stiffness at around 13 seconds corresponded to the visual observation of column base fracture.

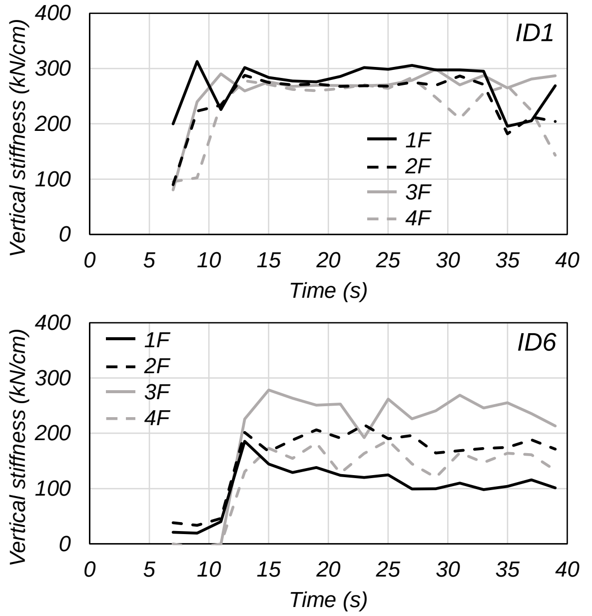

Fig. 2 Identification results of the mode shape and story stiffness in ID1 and ID6

4. Numerical simulation on repair

A unique feature of the exposed-type column base is a simple repair option, where constructors retighten elongated anchor rods with ensured ductility by specifications, as shown in Fig. 3.

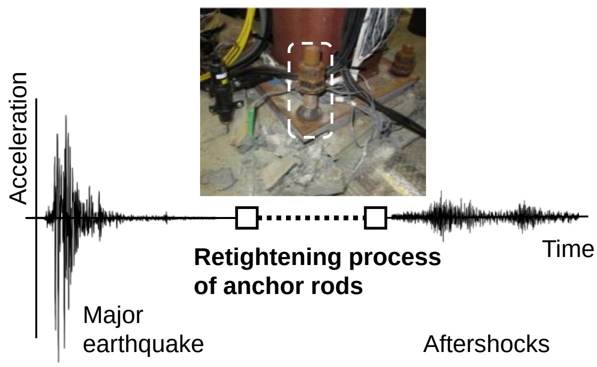

Fig. 3 Column base repair methodology

The numerical model of the four-story building was developed using OpenSees framework to investigate the effectiveness of the repair method. Dynamic analysis with and without the repair between each inputted ground motion was performed. Fig. 4 showed that the repair reduced the maximum story drifts under the ground motions of ID5 and ID6 by 23% and 4%, respectively. It indicated that the simple repair method could rapidly revert the overall stiffness of the column base and reduce the story drift after a strong earthquake such as ID4.

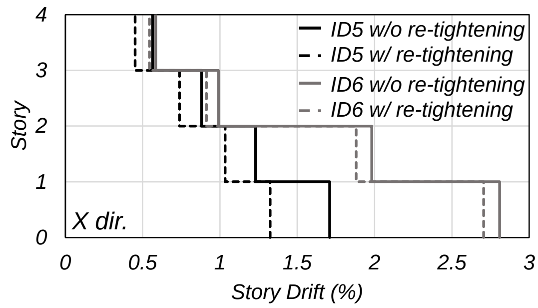

Fig. 4 Comparison of dynamic responses with and without retightening process

5. Conclusions

The study concluded several remarks as listed follows:

(1) System identification results indicated that the structural irregularity caused by damage enables to be identified from the changes in structural characteristics.

(2) The irregularity of changes in mode shapes corresponds to concentrated deformation at the lower floor resulting in severe damage in subsequent ground motions as a failure of column bases.

(3) The simple repair method of the retightening process of anchor rods was proven to be effective through the test program and subsequent analyses for low-rise buildings.

Reference

1) Lin KS., Kurata M., Pettinga D., Suzuki Y., Matsuo M., Perea T. (2023). Effectiveness of repairing yielding anchor rods in exposed column bases in steel structures. Earthquake Engineering & Structural Dynamics.
2) Lin KS., Kurata M., Kawamoto T., Matsuo S., Pettinga D. Identification and reparation of earthquake-induced irregularity of steel frames with weak-base/strong-column design. 10th European Workshop on the Seismic Behaviour of Irregular and Complex Structures, Catania, 2023.10