Sustainable Solutions in Structural Engineering and Construction
Edited by Chantawarangul, K., Suanpaga, W., Yazdani, S., Vimonsatit, V., and Singh, A.

ISBN: 978-0-9960437-0-0

PRACTICAL SEISMIC STRENGTHENING OF R/C BEAM-COLUMN JOINTS WITHOUT LATERAL REINFORCEMENTS IN DEVELOPING COUNTRIES

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Several destructive earthquakes in developing countries in recent years have revealed that a large number of reinforced concrete (R/C) buildings contained no lateral reinforcements in beam-column joints. Severe damage was caused to such beam-column joints due to poor structural capacities, and resulted in complete/story collapse of buildings and loss of human lives. Considering the economic and technical conditions in developing countries, this paper proposes a practical seismic strengthening method for applying R/C wing walls to this kind of substandard beam-column joint. A feasible design concept is presented exemplifying an exterior beam-column joint, representing a typical earthquake-damaged joint by the 2009 West Sumatra, Indonesia earthquake. In this study, two 3/4-scale exterior beam-column joint specimens were constructed with the common structural details, and one of them was strengthened by R/C wing walls. Their seismic performance was evaluated through static cyclic loading tests. It was found that the strengthened specimen behaved a ductile manner with beam yielding, whereas the unstrengthened control specimen prematurely failed at the joint. The proposed strengthening method significantly increased the moment resistance of the joint. Fundamental experimental data could be successfully obtained to propose the calculation procedure for designing R/C wing walls for practical strengthening.

Keywords: Exterior beam-column joint, Laboratory test, Moment-resisting frame, Reinforced concrete, Retrofit, Wing wall.

1 INTRODUCTION

Several destructive earthquakes in developing countries in recent years have revealed that a large number of reinforced concrete (R/C) buildings contained no lateral reinforcements in beam-column joints (e.g., Sanada et al. 2011). Severe damage was caused to such beam-column joints due to poor structural capacities, and resulted in complete/story collapse of buildings and loss of human lives. Seismic strengthening of substandard R/C buildings as above contributes to reduce potential risks to prospective natural disasters.

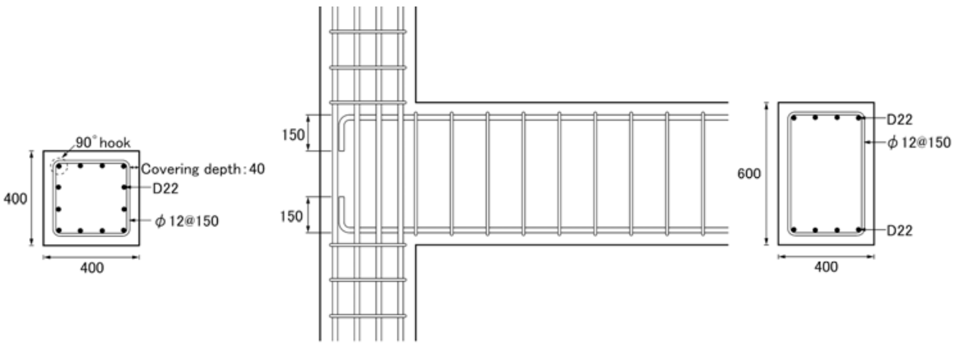
In consideration of economic and technical conditions in developing countries, this paper proposes a practical seismic strengthening method for applying R/C wing walls to this kind of substandard beam-column joint. A series of laboratory tests are presented to show the effectiveness of the proposed strengthening to upgrade the seismic performance of substandard beam-column joints.

2 OUTLINES OF INVESTIGATED BUILDING AND EXTERIOR BEAM-COLUMN JOINT

A three-story R/C building is focused upon in this study, which totally collapsed in the first story due to the 2009 West Sumatra earthquake (Sanada et al. 2011). Figure 1 shows the overall building and a damaged beam-column joint at the corner on the third floor. No lateral reinforcements and insufficient anchorage of longitudinal rebars are observed in the figure. These poor structural details caused the building to collapse. Figure 2 illustrates the structural details of the joint observed during the field investigation.

(a) Collapsed building (b) Corner beam-column joint

Figure 1. Collapsed building and one of damaged beam-column joints.



Unit: mm

Figure 2. Structural details of damaged beam-column joint.

3 CONCEPT OF SEISMIC STRENGTHENING BY WING WALLS

The authors' past study clarified that the 3/4-scale specimen, representing the beam-column joint in Figure 2, prematurely failed at the joint (Li and Sanada 2014). This result seemed to be caused by an insufficient moment capacity of the joint without lateral reinforcements (Shiohara 2012). Therefore, this study proposes a new concept to prevent such joint failure by installing wing walls beside columns, as shown in Figure 3. Wing walls can reduce bending moments applied to joints by reaction forces on boundaries between beam and wall itself, as shown in the figure.

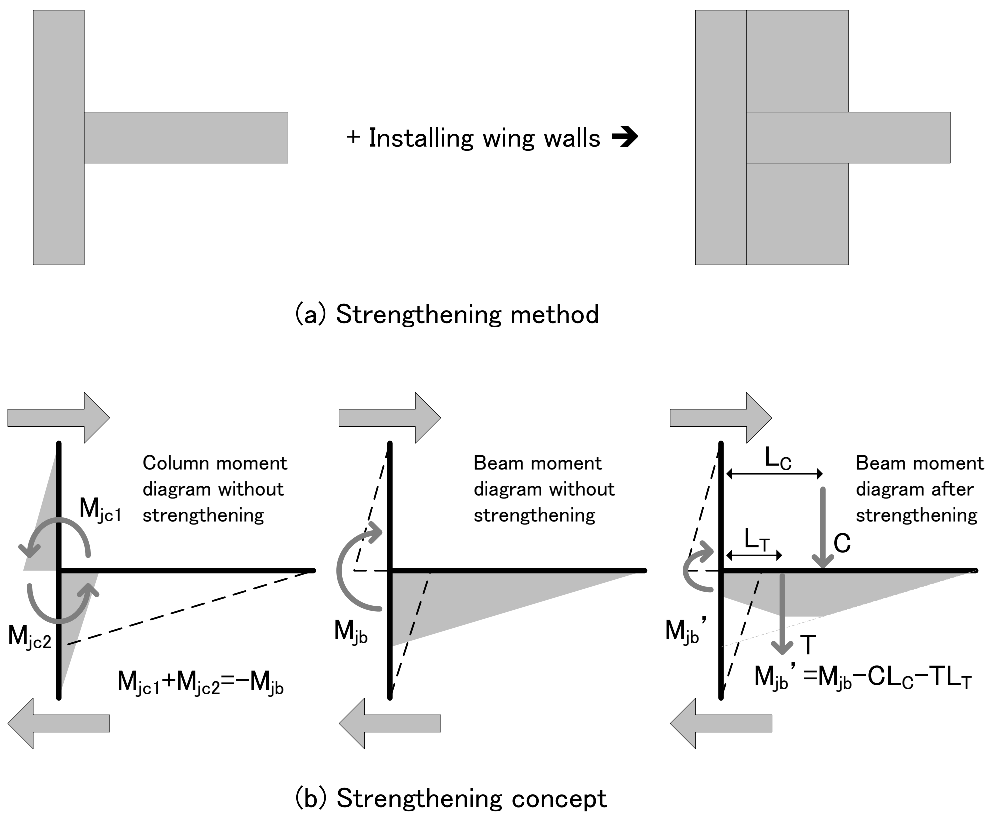


Figure 3. Concept to prevent joint failure by installing wing walls.

4 EXPERIMENTAL PROGRAM

A series of laboratory tests were conducted to verify the effectiveness of the proposed strengthening method as above. Experimental specimens and methods are described below.

4.1 Specimens

Two 3/4-scale exterior beam-column joint specimens were constructed based on the authors' preceded study (Li and Sanada 2014). They represent the earthquake-damaged exterior beam-column joint, shown in Figures 1 and 2 (however, up to the inflection points of the upper/lower column and beam). Figure 4 shows the dimensions and reinforcement details of the specimens. One of them was the control specimen, J2, whereas the other was strengthened by installing wing walls, J2-W2.

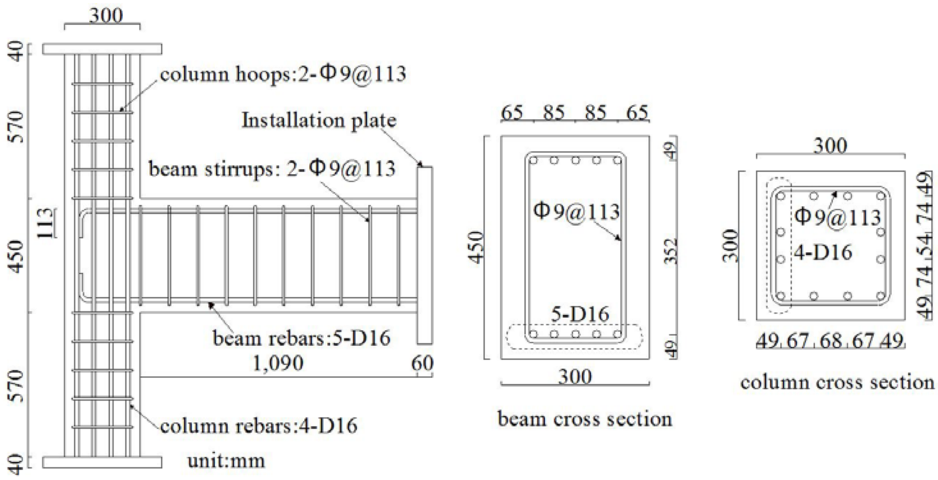


Figure 4. Dimensions and reinforcement details of the existing part of the specimens.

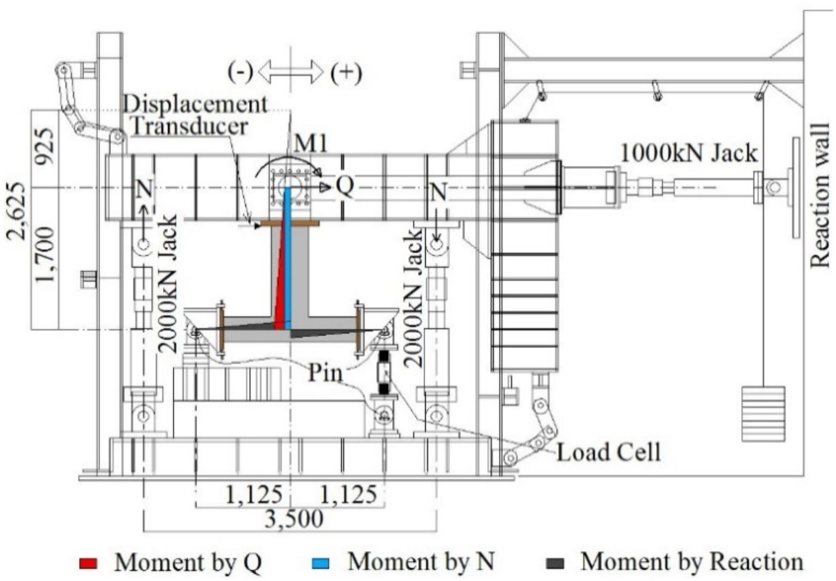


Figure 5. Schematic view of test set-up.

4.2 Loading System and Program

Figure 5 shows the loading system for the tests. The specimens were installed on the system and rotated by 90º. The left column (lower column) was supported by a pin hinge, and the right (upper column) was supported by a roller. A load cell was incorporated into the roller support to measure the column shear. Horizontal reversed cyclic loading was applied to the beam tip by a hydraulic jack controlled by the displacement of the beam tip. However, an additional moment in proportion to the horizontal load was applied by two vertical hydraulic jacks, to represent a realistic moment distribution of the full-scale beam.

5 VERIFICATION OF THE PROPOSED STRENGTHENING

Figures 6 and 7 compare the relationships between joint moment and beam drift ratio between both specimens. The joint moments are the product of the distance between pin centers and the column shear. Damage to the specimens after the tests is also given in the same figure.

Specimen J2

J2 prematurely failed at the joint, showing low strength and deformability. Its ultimate strength (+106 kN and -100 kN) was obviously below the value calculated assuming a beam yielding mechanism according to the Japanese standard (AIJ 2010) (±142).

Specimen J2-W2

The failure mode of J2-W2 successfully shifted from brittle joint failure to ductile beam yielding, showing high strength, exceeding the strength with a beam yielding mechanism (±164, assuming that a beam yields at the wall end), and good deformability.

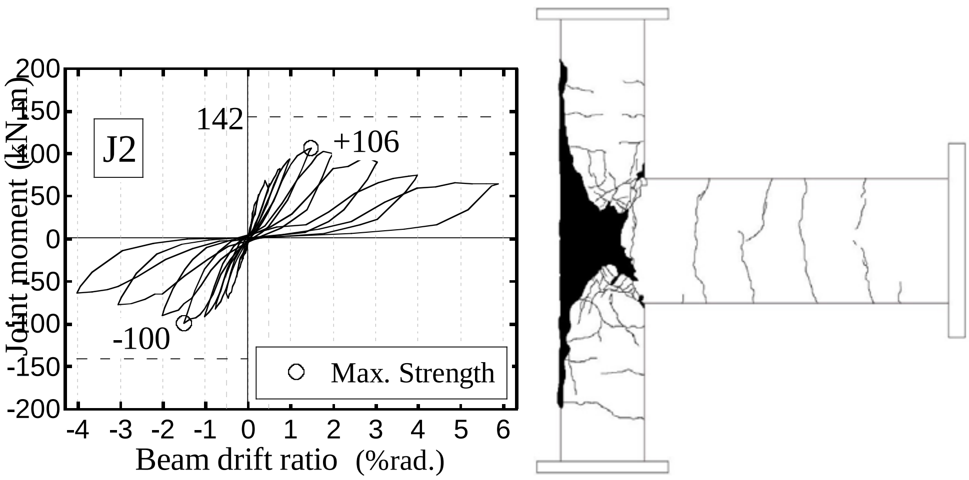


Figure 6. Joint moment–beam deflection relationships with final damage of J2.

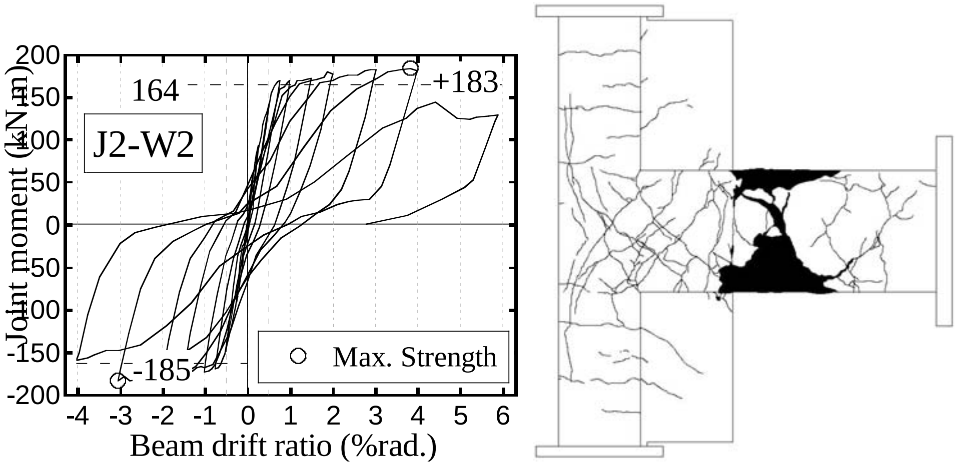


Figure 7. Joint moment–beam deflection relationships with final damage of J2-W2.

6 CONCLUDING REMARKS

This paper proposes and verifies a practical strengthening method using RC wing walls for exterior beam-column joints where no lateral reinforcement is provided. Two partial frame specimens were tested with/without the proposed strengthening. The major findings are as follows:

1. The unstrengthened specimen failed at the joint. The ultimate strength was much less than the strength based on a design calculation assuming a beam yielding mechanism.
2. On the other hand, the strengthened specimen by R/C wing walls formed a beam yielding mechanism by preventing a joint failure. Consequently, the strength of specimen exceeded a theoretical strength, and did not deteriorate up to a large beam drift ratio of 3% rad.
3. It was experimentally verified that installing of R/C wing walls is effective for rationally upgrading exterior beam-column joints without lateral reinforcements.

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