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Residual capacity of a 4-storey frame-wall RC building subjected to shake-table excitation

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Abstract— **The current residual capacity index calculation method is compared to the residual capacity as calculated from the results of a shake-table test of a 4-story RC wall-frame structure. The comparison is done based on the definition of residual capacity as the ratio of the energy dissipated by the structure. It is concluded that the Japanese guideline procedures are consistent with the residual capacity ratio as calculated from the experimental results at low-moderate damage levels. At moderate-severe damage levels the Japanese guidelines are conservative by 22-27%.**

I. Introduction

Accurate and efficient reinforced concrete (RC) building post-earthquake evaluation is a critical process for the rapid recovery of communities. In Japan, RC structure post-earthquake evaluation follows the Standard of Damage Evaluation of Seismic Damaged Buildings published by the Japanese Building Disaster Prevention Association (JBDPA 2001). The basic concept of the JBDPA damage evaluation method is to quantify the residual seismic capacity index, R, as the weighted sum of the reduced strength of the individual components, as shown in **Eq. 1**. The strength reduction factor, η_i, is based on the residual internal energy dissipation capacity of the member. This factor is empirically determined and is tabulated in the JBDPA Guideline. It can be shown that **Eq. 1** is fundamentally the same as calculating the total residual internal energy dissipation capacity ratio of the entire structure under the assumption that all members have an identical ultimate deformation capacity.

$$R = \frac{\sum \eta_i M_{ui}}{\sum M_{ui}} \quad \textbf{Eq. 1}$$

Where η_i= a member strength reduction factor based on visually observed damage characteristics (this is tabulated in the JBDPA standard) and M_{ui} = is the ultimate flexural strength capacity of component i.

The assumption of equal ultimate deformation capacity has implications for structures utilizing a mixed lateral resistance system as components are very likely to have different deformation capacities. In this study, a wall-frame dual system shown in **Figure 1** is tested on a shake-table to demonstrate the failure progression of these type of structural systems, and evaluate the implications of such system performance on the JBDPA estimate of the residual energy ratio. The comparison is done by comparing **Eq. 1** with the externally dissipated energy in the structure, under the assumption that internal and external, dissipated energies are equal.

II. Design of Structure

A. Design Concept

The structure was designed such that the contribution ratios of the wall systems to the total base shear would be different in the X (55% of total base shear) and Y-directions (20% of total base shear). While not shown in **Figure 1**, the structure contained in-situ cast slabs at each floor level, which were integrated with the perimeter beams and the internal beams and wall. Table I below summarizes the basic reinforcement and dimension characteristics of each structural member.

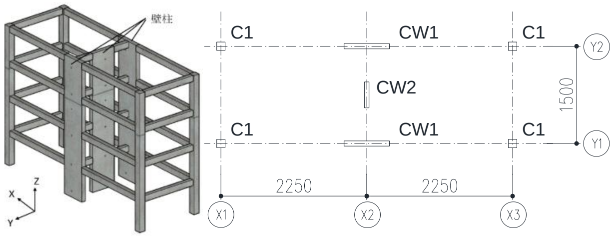


Figure 1: Isometric view of the test structure (slabs not shown) (left); plan view of the structure (right).

TABLE I
MEMBER REINFORCEMENT DETAILS

記号	種別	断面寸法 (mm)	主筋
C1	独立柱	130x130	6-D10
CW1	壁柱	80x700	24-D10
CW2	壁柱	70x400	8-D13 + 6-D6
G1	梁	100x140	上下端3-D6
G2	梁	100x150	上下端4-D6
G3	梁	120x90	上下端2-D6

B. Seismic Input

The seismic input wave, illustrated in **Figure 2**, is the 1995 JMA Kobe earthquake record modified to closely match the AIJ Standard design acceleration spectrum. The North-South component of this record was applied in the X-direction of the structure and the East-West component was applied in the Y-direction of the structure. The excitation was applied a total of nine times with amplification factors of 20%, 80%, 160%, 240%, 260%, 130%, 220%, 220%, and 260% in the Y-direction and 20%, 60%, 100%, 150%, 170%, 100%, 120%, 0% and 0% in the Y-direction. The Y-direction shaking was terminated after the seventh excitation due to unsafe residual drifts.

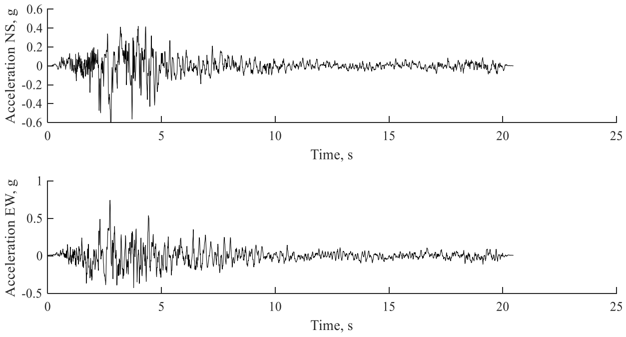


Figure 2: Modified 1995 Kobe JMA No. 1457 ground motion excitation in the NS (top) and EW (bottom) directions.

III. RESULTS

A. Force-deformation response

Figure 3 shows the locus of the maximum base shear-roof deformation points for each excitation in the X and Y-directions. The damage states in the X-direction (wall, beam and column) are shown in **Figure 4** following Run 5. It can be seen from **Figure 3** the Y-direction backbone response showed degradation (as the single Y-direction CW2 wall underwent shear failure) of approximately 17% from the peak base shear following the fifth excitation. Meanwhile, the X-direction does not indicate a strength reduction despite severe flexural damage of the CW1 walls following the final excitation.

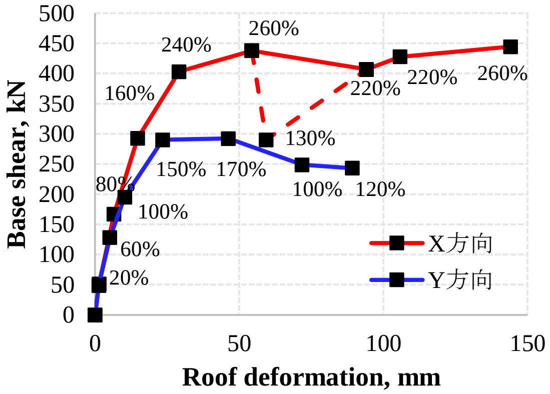


Figure 3: Maximum displacement response from dynamic analysis.

B. Residual capacity ratio

The residual external energy ratio (ratio of the remaining area under building response backbone, beyond the maximum displacement response to the total area under the response curve) was calculated following each excitation, and compared with the JBDPA approximation (**Eq. 1**) in **Figure 5**. This comparison is deemed valid given that external dissipated energy equals the internal energy. It can be seen that the JBDPA residual internal energy calculation (i.e., residual capacity ratio) results in a similar prediction to the external residual energy at low-moderate damage levels (Run 3-4). However, at moderate-severe damage level, the JBDPA Guideline results in a residual internal energy ratio that is 22% and 27% lower than external residual energy ratio in the X- and Y-directions, respectively.

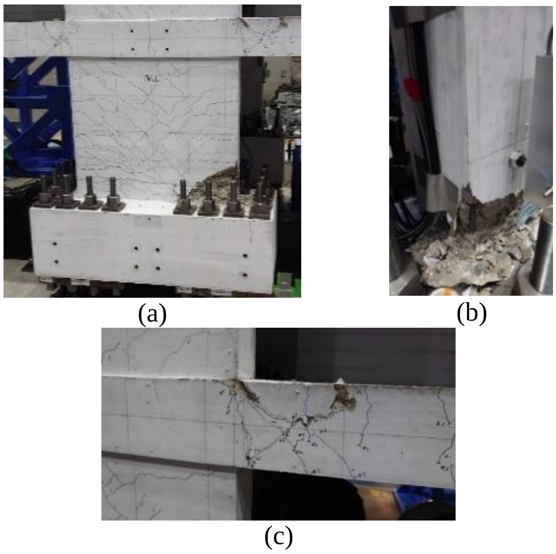
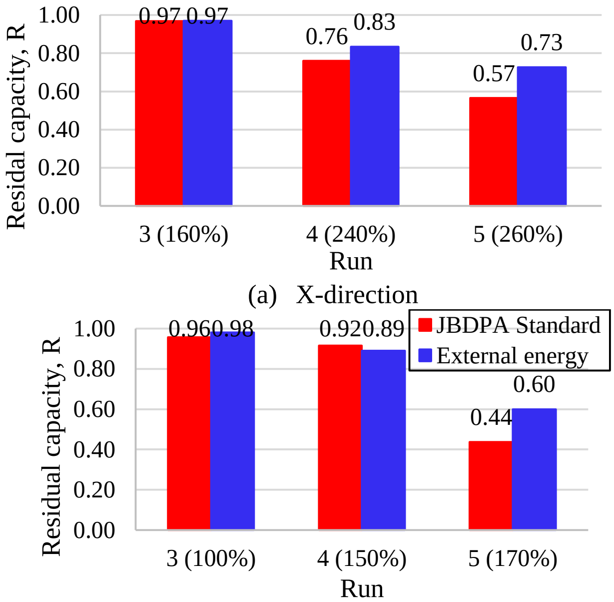


Figure 4: Damage states after Run 5 of (a) CW2 wall; (b) C1 column and (c) G2 beam.



(b) Y-direction

Figure 5: Residual capacity ratio as calculated using the (a) JBDPA method and (b) remaining external energy.

IV. CONCLUSIONS

A wall-frame RC structure was tested on a shake-table with a partial objective of evaluating the simplifying assumptions of the JBDPA standard in estimating the residual capacity ratio. The study showed that the JBDPA standard assumptions are generally consistent with residual energy calculations at low damage levels, but become conservative for moderate structural damage. The level of difference (22-27%) is similar in both X and Y-directions despite the differing response of the structure.

ACKNOWLEDGMENT

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REFERENCES

JBDPA. (2001). Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings (English).