S225-2

Seismic repair cost of R/C structures using a geometrical damage estimation model

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ABSTRACT: To evaluate visible damage of reinforced concrete (R/C) members such as crack width and length, cyclic load tests of one third scaled R/C members were carried out. Based on the tests, a geometrical damage estimation model is proposed to quantify each crack width and corresponding length. The model consists primarily of a geometrical condition for the relationship between the sum of crack widths and drift ratio and a probabilistic model between crack widths and lengths. Applying the proposed model to seismic response analyses of R/C building structures modeled as fish-bone shaped frames, the damage and repairing process, as well as life cycle economic loss were simulated. Life cycle economic loss was defined here as the repairing cost for maintenance of the functionality of a building through its life length. As a result, it is implied that the case of main damages on beams will suffer more life cycle economic losses than the case of main damages on columns because of the extent of damaged area and the construction cost of falsework.

Keywords*: Reinforced Concrete, Crack Widths, Crack Length, Damage Quantification*
Geometrical Damage Estimation Model, Life Cycle Economic loss

1. INTORODUCTION

Loss estimation of a building due to earthquake events in its life length is important to facilitate the decision making of the building owner to choose the reasonable seismic performance. In this paper, life cycle economic loss defined as the repairing cost of a building structure through its life length was simulated using a new damage estimation model which is partially based on cyclic load tests of one third scaled R/C members.

2. EXPERIMENTAL PROGRAM

2.1 Test specimens, setup and instrumentation

Two R/C beam specimens proportioned to approximately 1/3 of full scale were tested under cyclic loading. The design parameters and corresponding values are given in Table 1. The dimension for the test specimens and test setup are shown in Fig. 1. To obtain the propagation of crack width and length corresponding to attained and present drift ratio, the cyclic displacement pattern shown in Fig. 2 was operated. Crack widths were measured by crack gauges. Crack lengths were measured by image processing of sketched cracking pattern.

Table 1: Description of Test Specimens

Specimen	Concrete Strength (N/mm^2)	Rebar - Tensile reinforcement ratio to the section	Yield strength of rebar (N/mm^2)	Lateral reinforcement - Lateral reinforcement ratio to the section	Yield strength of lateral reinforcement (N/mm^2)	Failure mode
F-1	30	8-D13 - 0.0121	295	D4@60 - 0.0022	295	Flexure
S-1	18		785		295	Shear

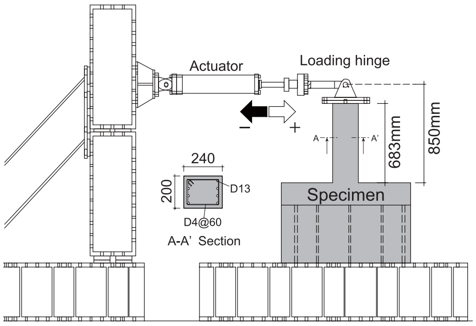


Fig. 1: Dimensions of Beam Specimen and Test Setup

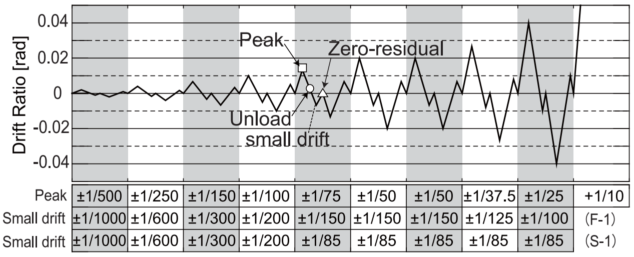
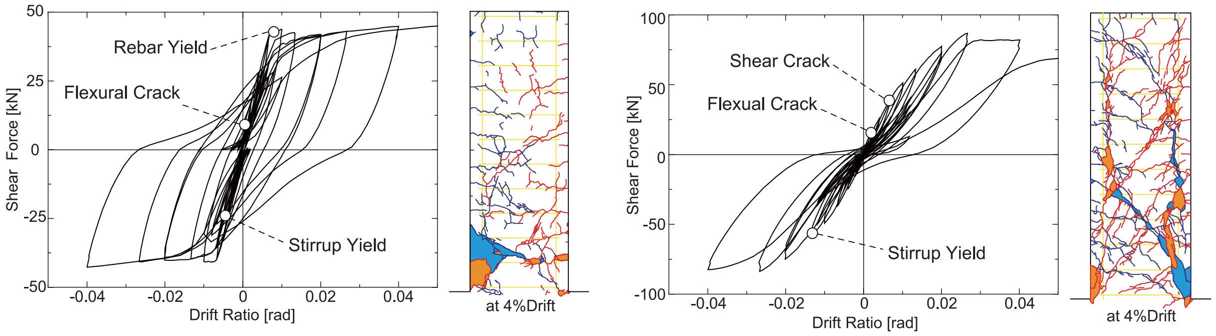


Fig. 2: Cyclic Displacement Pattern

2.2 Test results

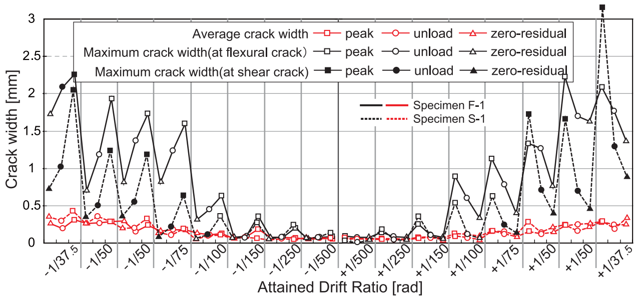
Fig. 3 shows the shear force versus drift response for each specimen and the cracking pattern at 4.0% drift. Measured maximum and average crack widths are shown in Fig. 4. Measured crack lengths are shown in Fig. 5. Crack width and length of Specimen S-1 increased rather than Specimen F-1 in large drift.



(a) Specimen F-1

(b) Specimen S-1

Fig. 3: Shear Force versus Drift Ratio Response, and Cracking Pattern



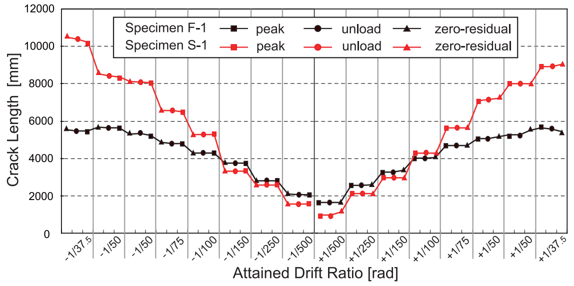
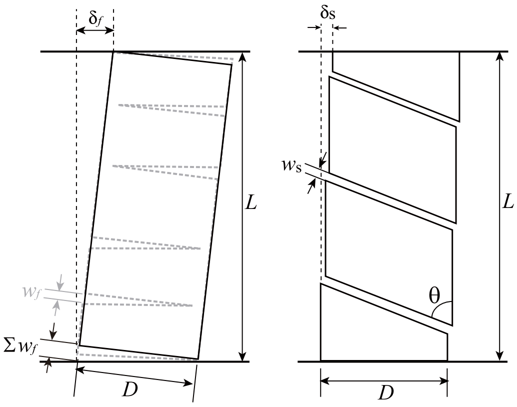


Fig. 4: Crack Width for Attained Drift Ratio

Fig. 5: Crack length for Attained Drift Ratio

3. GEOMETRICAL DAMAGE ESTIMATION

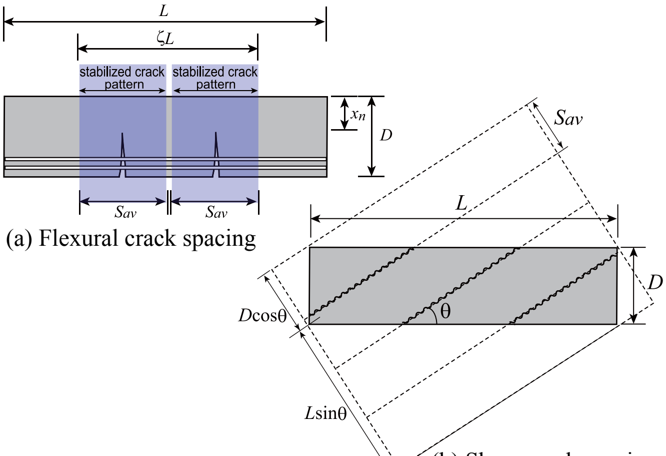
Architectural Institute of Japan (AIJ, 2004) proposed geometrical macro model of relation between crack width and drift ratio shown in Fig. 6. CEB-FIP (1978) proposed crack spacing shown in Fig. 7. Using these geometrical models, crack width and length of Specimen F-1 and S-1 were estimated in Fig. 8, 9 and 10. Based on Fig. 10, crack length propagation model is proposed in Fig. 11. Additionally, spalling propagation model is expressed as spalling ratio $[m^2/m^2] = 3.67 \times (\text{drift ratio} - 0.01)$ based on previous research (Takahashi et al. 2005). And a new probabilistic model between crack widths and lengths is introduced. In this model, crack length distribution to crack width is represented as log-normal distribution.



(a) Geometrical model of relation between Flexual crack width - Drift

(b) Geometrical model of relation between Shear crack width - Drift

Fig. 6: Geometrical Model between Crack width and Drift



(a) Flexural crack spacing

(b) Shear crack spacing

Fig. 7: Crack spacing

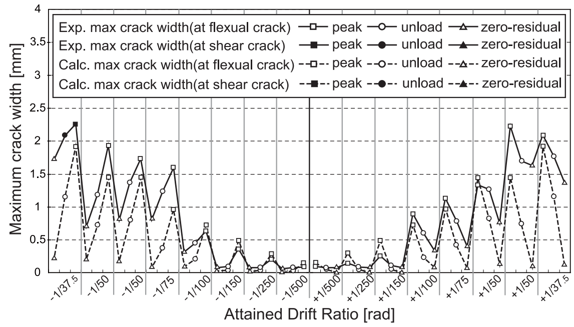


Fig. 8: Crack Width Estimation of Specimen F-1

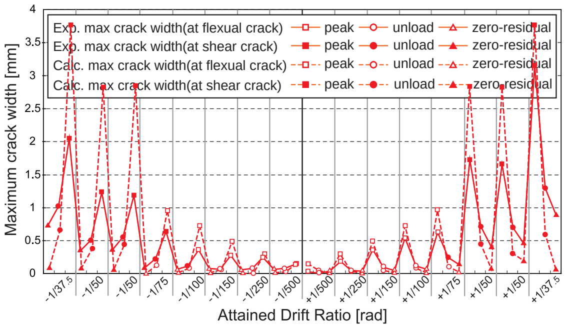


Fig. 9: Crack Width Estimation of Specimen S-1

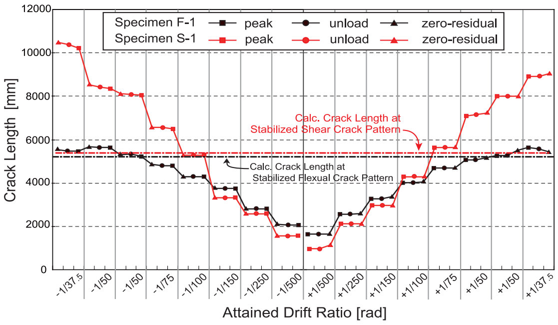
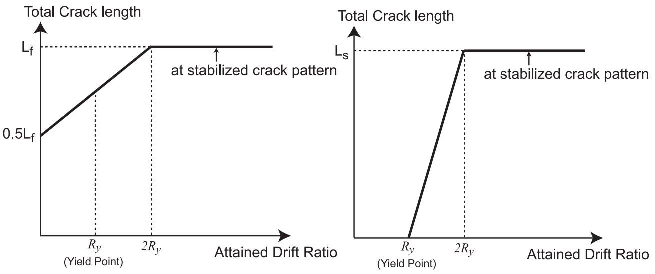


Fig. 10: Crack Length Estimation



(a) Flexural crack length

(b) Shear crack length

Fig. 11: Crack Length Propagation Model

4. LIFE CYCLE COST ESTIMATION

4.1 Input ground motion

Based on the seismic hazard curve proposed by National research Institute for Earth science and Disaster prevention (NIED, 2005), Fig. 12 is obtaind as peak velocities of ground motion on engineering bedrock in Tokyo. Applying the enhanced plotting position equation (Takahashi et al. 2006) to Fig. 12, a series of peak velocities through lifecycle is created as Fig. 13. And four artificial earthquake motions are generated such that they should fit the design spectra defined by Government of Japan, while the phase characteristic of Kobe 1995 (NS), El Centro 1940 (NS), Hachinohe 1968 (EW), and Tohoku Univ. 1978 (NS) are used. They are factored such that their peak velocities should match to the target peak ground velocities in Fig. 13.

4.2 Structural model

Two fishbone-shaped frames shown in Fig. 14 are used for estimating the life cycle repair cost. One is strong-column and weak-beam frame with beam rebar strength σ_s=390kN. Another is weak-column and strong-beam frame with beam rebar strength σ_s=490kN. Takeda hysteresis model (Takeda et al. 1970) is used for each member modeled as one-component model. Viscous damping factors proportional to instantaneous stiffness are assumed to be 3%. The cracking strength is assumed to be one third of yielding strength, the secant stiffness at yielding point is assumed to be 30% of the linearly elastic stiffness, and the third stiffness after yielding is assumed to be 1% of the linearly elastic stiffness for each member.

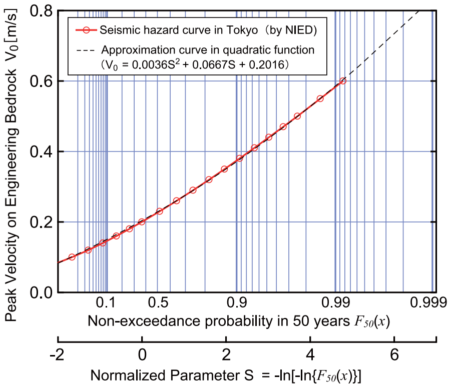


Fig. 12: Hazard Curve in Tokyo

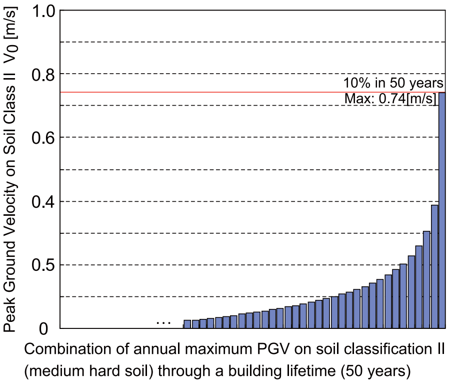
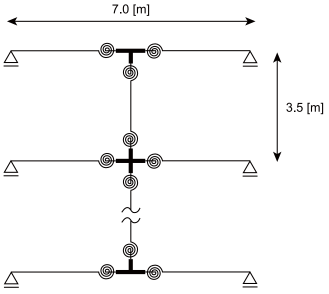


Fig. 13: Example of Life Cycle PGV



Mass: 1.2 t/m^2
Column: 700×700 (Fc32, 8-D32)
Beam: 400×800 (Fc24, 8-D25)
Footing: 600×1800 (Fc32, 12-D32)

Fig. 14: Structural Model

4.3 Calculation results of life cycle economic loss

When the maximum drift ratio is larger than yielding drift (1/120rad), structures are repaired based on Table 2. Life cycle economic losses of two strucutres described in Chapter 4.2 are shown in Fig. 15.

Table 2: Repairing Scenario

Condition	Repair method		Unit price
Crack width < 0.2mm	Sealing		$\$9.1/\mathrm{m}$
Crack width < 1.0mm	Epoxy injection		$\$66.0/\mathrm{m}$
Crack width ≥ 1.0mm	U-cut sealing / Cement grout		$\$125.4/\mathrm{m}$
Spalling ratio < 0.05	Patching resin mortar		$\$270.0/\mathrm{m}^2$
Spalling ratio ≥ 0.05	Jacketing / Replacement		$\$542.3/\mathrm{m}^2$
at Interior Column	No falsework		$\$20.0/\mathrm{m}^2$
at Interior Beam	False-work hight	Half floor hight	
at Exterior Column		Damaged floor level	
at Exterior Beam		Damaged floor level + half floor hight	

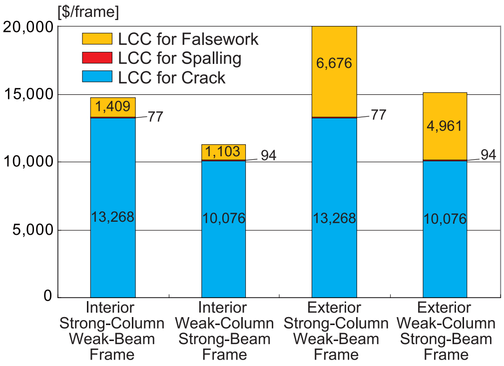


Fig. 15: Life Cycle Economic Loss

5. CONCLUDING REMARKS

Strong-column and weak-beam system will suffer more life cycle economic loss than weak-column and strong-beam system because of the extent of cracking area and the construction cost of falsework.

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