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Evaluation of Seismic Capacity and Expected Damage of RC Buildings in Bangladesh
Part 2: Correlation between Seismic capacity and Damage level

Keywords
Seismic Capacity Damage level
RC buildings

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1. Introduction:

The study aims at determining seismic capacity using 1st and 2nd level seismic evaluation procedure and proposing a simple procedure to estimate the damage level of RC frames designed according to BNBC code. The design of the models and their characteristics are shown previously in Part 1. For determining damage index, nonlinear static pushover analysis has been performed on the studied frames using seismic demand curve from BNBC response spectrum.

2. Seismic Evaluation

1st level seismic evaluation based on JBDPA [1] and 2nd level seismic evaluation based on CNCRP [2] are conducted and results are shown in Table 1. The CNCRP manual is general the same as JBDPA except for minor modifications regarding calculation of F index. In CNCRP manual, the maximum F index is taken as 1.75. Table 1 presents seismic evaluation results of selected RC frames with medium and low strength concrete having design sections mentioned in part 1.

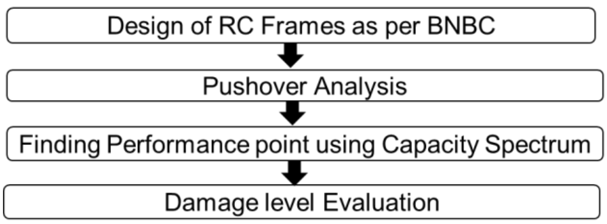
Table 1: 1st and 2nd level Seismic indices of selected RC frames

Concrete Strength	No. of Story	Span Length (X1-X2-X1)	1st level	2nd level		
			I_{s1}	I_{s2}	C-index	F-index
f_c': 25MPa (medium)	6	5m-6m-5m	0.1	0.18	0.18	1
		3m-4m-3m	0.16	0.36	0.28	1.27
		2m-3m-2m	0.23	0.47	0.37	1.27
	5	5m-6m-5m	0.12	0.29	0.23	1.27
		3m-4m-3m	0.19	0.41	0.32	1.27
		2m-3m-2m	0.27	0.54	0.42	1.27
	4	5m-6m-5m	0.15	0.35	0.27	1.27
		3m-4m-3m	0.24	0.48	0.38	1.27
		2m-3m-2m	0.34	0.64	0.5	1.27
	3	5m-6m-5m	0.2	0.42	0.33	1.27
		3m-4m-3m	0.32	0.6	0.48	1.27
		2m-3m-2m	0.45	0.8	0.63	1.27
f_c': 13.5MPa (low)	6	5m-6m-5m	0.06	0.14	0.14	1
		3m-4m-3m	0.09	0.17	0.17	1
		2m-3m-2m	0.13	0.43	0.34	1.25
	5	5m-6m-5m	0.07	0.16	0.16	1
		3m-4m-3m	0.09	0.17	0.17	1
		2m-3m-2m	0.16	0.35	0.31	1.5
	4	5m-6m-5m	0.14	0.44	0.36	1.24
	3	5m-6m-5m	0.12	0.24	0.22	1.12

From Table1, it is observed that ductility index for low strength concrete is less than those of medium strength concrete.

3.Pushover Analysis

The total procedure is shown in flow chart given below.



3.1 Structural Modeling

Lateral seismic loads are applied to the frames monotonically in step-by-step. Gravity loads are in place during lateral loading. P-Delta effects have been taken into account. Pushover analysis has been performed using software SAP 2000 V.16.

3.2 Plastic hinge assumptions

Plastic hinges are taken based on properties described in FEMA 356 [7]. Beam and column elements are modeled as nonlinear elements by defining plastic hinges at both ends of beams and columns as shown in Fig.1. In the study, plastic hinge properties for beams are assigned to moment hinges, whereas axial force-moment hinges and shear hinges are assigned in columns.

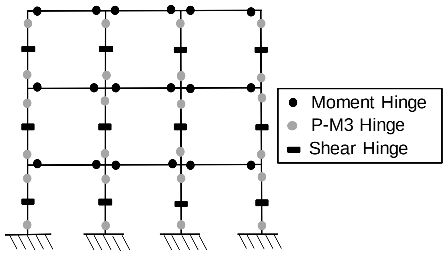


Fig. 1 Plastic hinge modeling in RC frames

3.3 Performance point Determination

Fig. 2 shows 5% damping spectral acceleration demand response spectrum for Dhaka city as per BNBC 2015 [3]. In this study, the soil type is considered as SD as most of the soil of Dhaka city is of that nature.

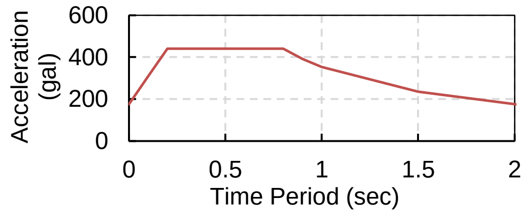


Fig. 2: Normalized acceleration response spectrum (BNBC 2015)

The performance point of each frame has been found using ATC 40 Capacity spectrum method [8]. The point of intersection of capacity curve and demand response spectrum (BNBC 2015) is taken as performance point which is shown in Fig. 3 from analysis of SAP.

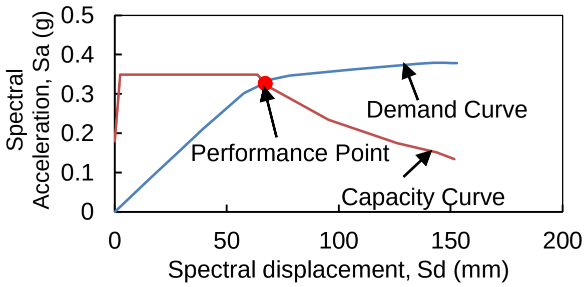


Fig. 3: Performance point from Capacity Spectrum

4. Damage level Evaluation

Damage index (DI) evaluation of a superstructure is calculated from residual seismic capacity ratio index R as shown in Eq. (1) as per

Japanese Standard [9].

Damage Index, DI=1-R (1)

R is the ratio of seismic capacity of a building after and before earthquake which is based on type of collapse of structural members after an earthquake. Table 2 shows damage classification of structural members [9].

Table 2: Damage class with Damage index (DI) and R

Damage level	Class	Damage Index	R Range
Slight	I	DI ≤ 5%	R≧95 (%)
Minor	II	5% <DI ≤ 20%	80≦R＜95 (%)
Moderate	III	20% <DI ≤ 40%	60≦R＜80 (%)
Severe	IV	40% <DI	R＜60 (%)
Collapse	V	100%	R=0

Fig. 4: (a) Story Shear (b)Total Collapse Mechanism

Residual seismic capacity index R for story shear and total collapse mechanism (Fig.4) are obtained from Eq. (2) and (3) respectively as per Japanese standard [9].

$$R = \frac{\sum \eta Q_i}{\sum Q_i} \times 100 \quad (2)$$

$$R = \frac{\sum \eta_c M_{uC} + \sum \eta_g M_{uB} + \sum \eta_{cw} M_{uCW} + \sum \eta_{cwc} M_{uCWC}}{\sum (M_{uC} + M_{uB} + M_{uCW} + M_{uCWC})} \times 100 \quad (\%) \quad (3)$$

where *η*:Seismic capacity reduction factor, *Q:* lateral strength of vertical members, M_{uc}, M_{uB}: ultimate moment capacity of columns and beams respectively. Fig.5 shows lateral force/moment–displacement/rotation behavior for plastic hinges in structural elements showing correlation between different damage class (I-V) as per Japanese standard (Fig.5a) with the performance level prescribed by FEMA 356 [7] (Fig.5b).

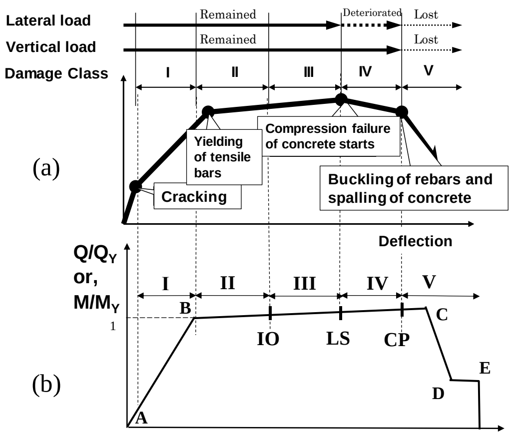


Fig. 5: Proposed damage class of structural elements based on Japanese standard [9]

These assumptions have been considered in this study. Different performance levels of plastic hinges are indicated as IO (immediate occupancy), LS (life safety), collapse prevention (CP) (Fig.5b). Relation of seismic capacity index (1st, 2nd level) with damage index of RC frames is shown in Fig.6. From Fig. 6, it is evident that damage level of frames with story shear type failure is larger than those with total collapse type failure and most importantly, story shear type collapse has been observed in low strength concrete frames.

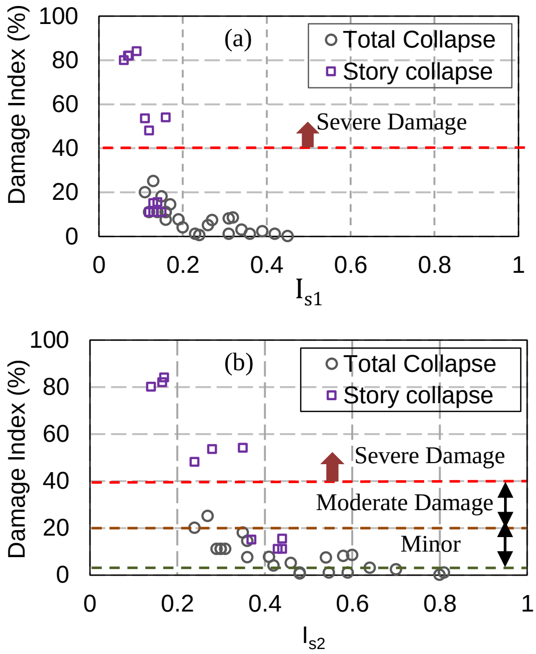


Fig. 6: Damage Index vs. Seismic Index (a) I_{s1} and (b) I_{s2} Graph

5. Conclusions

The following conclusions have been made from this study:

(1) Seismic capacity index I_{s1} greater than 0.2 shows no severe damage.

(2) I_{s2} less than 0.2 shows about more than 80% damage index which indicates severely damaged.

(3) I_{s2} between 0.2 and 0.4 shows wide ranges of damage index between 5 to 55%. It is to be noted here that most of them are minor damage.

(4) No Frames with I_{s2} index greater than 0.4 are severely damaged.

Note that, RC frames considered in this study are idealized frames not the existing structures of Bangladesh. The results of these designed frames gives the general scenario of the damage status of Bangladesh superstructures when designed according to BNBC. In addition, this study ignores the contribution of masonry infill, this point needs further future study.

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