16th World Conference on Earthquake, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 566

Registration Code: S-A1459813008

A PROPOZAL ON THE ADVANCED SIMPLIFIED STRUCTURAL EVALUATION METHOD FOR EXISTING BUILDINGS IN BANGLADESH

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Abstract

The developing countries in the earthquake prone regions in the world are still suffering a lot of casualties as well as building damage. These damages might be caused by inadequate structural design by engineers and/or poor quality control of construction works. In order to contribute to disaster mitigation for existing reinforced concrete buildings in developing countries, the simplified structural evaluation method based on the philosophy of Japanese evaluation standard [2] vis-a-vis the international seismic code[3,4] was developed by Seki (2015) [1].

JICA (Japan International Cooperation Agency) has been performing the project named "Project for Capacity Development on Natural Disaster Resistant Techniques of Construction and Retrofitting for Public buildings in Bangladesh (CNCRP)" from 2011 to 2015 and now the second phase is ongoing. In this project the seismic evaluation and retrofitting issues are involved and for the screening of the priority of reducing vulnerability against the hundreds of candidate buildings the simplified structural evaluation was developed by Seki(2015)[5] after Seki(2015)[1] for this project. Prior to the detail structural evaluation and the retrofitting work, the more precise new simplified structural evaluation in which the site investigation such as size of structural members, size and location of rebar, concrete compressive strength, etc. was required and developed in this paper and the examples of application were discussed.

Keywords: structural evaluation, reinforced concrete building, site investigation, seismic capacity, service load capacity

1. Introduction

Table 1 shows the three kinds of structural evaluation such as simplified structural evaluation, advanced simplified structural evaluation and detail structural evaluation. These three evaluation methods were developed under Japan International Cooperation Agency(JICA) project which has been performing the project named "Project for Capacity Development on Natural Disaster Resistant Techniques of Construction and Retrofitting for Public buildings in Bangladesh (CNCRP)". Furthermore, these evaluation methods were based on the Japanese evaluation method. The simplified evaluation and the advanced simplified evaluation are used for the first stage screening for lots of buildings. The former method is based on only structural and architectural drawings therefore the building lack of these drawings can't be applied. On the other hand, the latter method is more precise method because the on-site investigation has to be carried out. The detail structural evaluation is the most accurate method and it takes much times and requires the higher level analysis.
In this paper, the advanced simplified structural evaluation is discussed and applied to the practical lots of existing reinforced concrete buildings in Bangladesh.

Table 1 - Structural evaluation procedure for existing reinforced concrete buildings

Evaluation Method	Simplified structural evaluation	Advanced simplified structural evaluation	Detail structural evaluation
Objective	Average ultimate capacity for lots of buildings (Screening)	Between Simplified structural evaluation and Detail structural evaluation(Screening)	Ultimate capacity for individual building
Resource data	Structural drawing	Structural drawing & brief site investigation (Non-destructive tests)	Structural drawing & detail site investigation (destructive tests)
References	Seki(2015) [1], Seki(2015) [7]		Public Works Department (2011-2015)[3]

2. Basic principle for proposed evaluation method

The flow diagram of the proposed advanced simplified structural evaluation for reinforced concrete frame building is shown Fig.1. In this figure, various index for Bangladesh such as seismic index (I_{BS}), Judgement seismic index (I_{BS0}), service load index (I_{BD}) and judgement service load index (I_{BD0}) are used in this figure.

The proposed advanced simplified structural evaluation method is based on the following basic principles;

(1) Concept of Seismic evaluation is basically based on the philosophy of the Japanese Seismic Evaluation Standard issued by JBDPA2001[2] and USA seismic code by IBC2000[5] and FEMA450-2 [6]. Seismic intensity in Bangladesh is based on BNBC2015 Final Draft [8].

(2) Evaluation is done at the first (ground) floor which may be weakest floor of the whole building and at the lower capacity direction.

(3) Nondestructive site investigation is basically done in order to save the time and to avoid the much expense for performing and repairing and to keep the running of worker's job.

(4) If the necessary information such as material strength, profile of rebar is lack in the structural drawings, these may be assumed with construction year and/or the experience of structural engineer, etc.

(5) Column strength is calculated only for ultimate flexural strength because the long column designed in Bangladesh generally has lower flexural strength than ultimate shear strength.

(6) This method was developed for moment resisting frame with normal beam and in case of flat slab structure the horizontal structural capacity will be ignored.

(7) If the result of evaluation doesn't satisfy the target capacity, the higher detail evaluation method is recommended.

3. Japanese standard for seismic evaluation of existing reinforced concrete buildings

Basic concept of Japanese evaluation standard [2] is as follows;

(1) The seismic index of structure *Is* shall be calculated by Eq. (1) at each story and in each principal horizontal direction of a building. The irregularity index S_D in the first level screening and the time index T may be used commonly for all stories and directions.

$$I_s = E_o * S_D * T \qquad (1)$$

Where,

E_o : Basic seismic index of structure

S_D : Irregularity index

T : Time index

$$Eo = C * F \qquad (2)$$

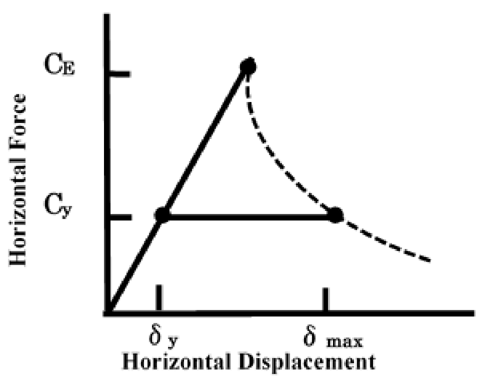
Where,

C : Strength capacity index

F : Ductility index

(2) The seismic index of structure (I_S) shall be calculated in either the first, the second, or the third level screening procedure. These procedures are categorized based on the level of calculation.

Back ground of Japanese evaluation standard is based on J.A. Blume, N.M. Newmark et al. [4] The prediction of nonlinear earthquake response is shown Fig. 1. In the figure, C_y/C_E corresponds to 1/F index in Eq.(2) and C_y corresponds to C index in Eq.(2), respectively.



C_E: Maximum elastic response force

C_y: Yielding force

$\mu=\delta_{max}/\delta_y$: Ductility factor

$C_y/C_E=1/\sqrt{2\mu-1}$

Fig.1 – Concept of prediction of nonlinear earthquake response after ref. [2]

4. Proposed evaluation method

4.1 Seismic Index (I_{BS})

$$I_{BS} = E_{BS} * S_D * T \qquad (3)$$

$$E_{BS} = C_{BS} * F_B \qquad (4)$$

$$C_{BS} = \Sigma M_u / ho / W \qquad (5)$$

The ultimate flexural strength (M_u) can be calculated alternatively by JBDPA2001 [2] or ACI318 [7].

(1) The ultimate flexural strength (M_u) after JBDPA2001 [2]

$$\text{For } N_{max} \geq N > 0.4b \cdot D \cdot F_c$$

$$M_u = \left\{0.8a_t \cdot \sigma_y \cdot D + 0.12b \cdot D^2 \cdot F_c\right\} \cdot \left(\frac{N_{max} - N}{N_{max} - 0.4b \cdot D \cdot F_c}\right)$$

$$\text{For } 0.4b \cdot D \cdot F_c \geq N > 0$$

$$M_u = 0.8a_t \cdot \sigma_y \cdot D + 0.5N \cdot D \cdot \left(1 - \frac{N}{b \cdot D \cdot F_c}\right)$$

$$\text{For } 0 > N \geq N_{min}$$

$$M_u = 0.8a_t \cdot \sigma_y \cdot D + 0.4N \cdot D \qquad \text{(A1.1-1)}$$

(2) According to BNBC2015 Final Draft[8] or ACI318[9], no specfic formula is givern to calculate flexual strength of a column. Some assumption is givern for minimum eccentricity of column, strain of extreme fiber of concrete and rebar, factor of equvalent stress block, strength reduction factor, etc. Based on the strain compatibility analysis flexual strength can be calculated for a certain column axial load.

Where,

E_{BS} : Basic structural index

C_{BS} : Strength capacity index

F_B : Ductility Index

$$F_B = R/\Omega_0 \qquad (6)$$

R: Response modification factor based on structure type in BNBC2015 Final Draft [8]

Ω_0: Over strength factor (BNBC2015 Final Draft [8])

W: Total weight of building (N)

h_o: Clear height of column (mm)

S_D : Irregularity index (Fig. A.3, Table A.2)

T : Time index (Fig. A.2, Table A.1)

4.2 Service Load Index (I_{BD})

$$I_{BD} = W/\Sigma Ac \qquad (7)$$

Where,

W: Total weight of building (N)

ΣA : Total area of columns (mm^2)

5. Judgment

5.1 Definition of Judgment Index

5.1.1 I_{BSO}: Seismic Index

$$I_{BSO} = V \qquad (8)$$

$$V = 2/3 * Z * I * C_S \qquad (9)$$

Where,

V: Total design base shear coefficient (BNBC2015 Final Draft [8])

Z: Seismic zone coefficient (Table 2, Fig. 2)

I : Structural importance coefficient (here, I=1.0)

C_S: Normalized acceleration response spectrum, which is a function of structure (building) period and soil type (site class) (Fig. 3)

Table 2 - Seismic zone coefficients, Z (BNBC2015 Final Draft [8])

Zone	Zone Coefficient (unit: g)
1	0.12
2	0.20
3	0.28
4	0.36

Fig.2 - Seismic zoning map of Bangladesh (BNBC 2015 Final Draft [8])

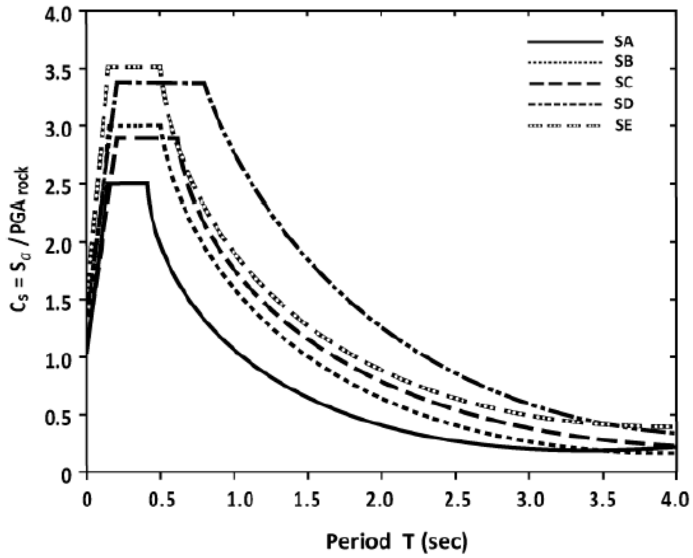


Fig. 3 - Normalized design acceleration response spectrum for different site classes (BNBC2015 Final Draft [8])

5.1.2 I_{BD0}: Service Load Index

$I_{BD01} = 0.4 * Fc$ (10)

$I_{BD02} = 0.7 * Fc$

Where,

Fc: Designed concrete strength (N/mm^2)

5.2 Judgment

5.2.1 Seismic Capacity

$I_{BS} \geqq 1.2 I_{BSO}$: Higher than seismic demand (Rank SA) (11)

$0.8 I_{BSO} \leqq I_{BS} < 1.2 I_{BSO}$: Questionable against seismic demand(Rank SB)

$0.4 I_{BSO} \leqq I_{BS} < 0.8 I_{BSO}$: Lower than seismic demand (Rank SC)

$I_{BS} < 0.4 I_{BSO}$: Remarkably lower than seismic demand (Rank SD)

5.2.2 Service Load Capacity

$I_{BD} < I_{BD01}$: Higher than service load demand (Rank DA) (12)

$I_{BD01} \leqq I_{BD} \leqq I_{BD0}$: Lower than service load demand (Rank DB)

$I_{BD02} < I_{BD}$: Remarkably lower than service load demand (Rank DC)

5.2.3 Final Rank based on Combination of Seismic Capacity and Service Load Capacity

Final structural rank based on combination of seismic capacity and service load capacity can be defined as following Table 3.

Table 3 - Final capacity rank of simplified structural evaluation

Final Capacity Rank	Combination of Seismic Capacity and Service Load Capacity	Recommendation
A	SA-DA	Safe
B	SA-DB,SB-DA, SB-DB, SC-DA	Detail Evaluation Recommended
C	SA-DC, SB-DC, SC-DB, SC-DC, SD-DA, SD-DB, SD-DC	Immediately Detail Evaluation Recommended

6. Site investigation

6.1 Investigation items and methods

In order to perform the advanced simplified structural evaluation, the following investigation should be done at the building site. Table 4 shows the items of site investigation. The supplementary photos and tables needed for each item are also shown.

Table 4- Site investigation items

Item		Investigation method	
Column	Width (B), Depth (D)	Scale measuring	Photo A.1
	Location and size of rebar	Measuring by rebar detector	Photo A.2
	Concrete compressive strength (Fc)	Schmidt hammer test	Photo A.3, Fig. A.1
Story height, Span of grid, Building size		Measuring by laser distance meter	Photo A.4
Time deterioration Index (T)		Visual inspection	Fig. A.2, Table A.1
Irregularity Index (S_D)		Visual inspection	Fig. A.3, Table A.2

[Supplementation]

Photo A.1- Measuring by scale (column)

Photo A.2- Location and size of rebar

Photo A.3- Schmidt hammer test

Photo A.4- Measuring by laser distance meter

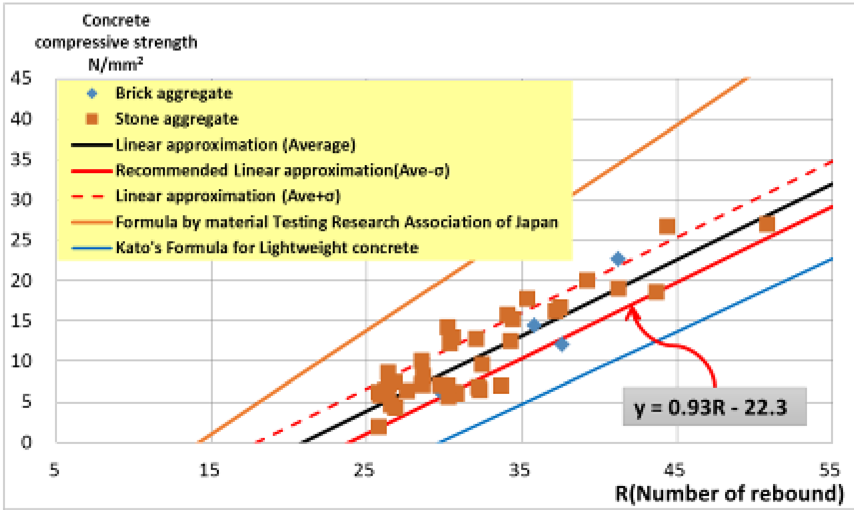


Fig. A.1- Relationship between rebound test and cylinder compressive strength

Table A.1- Time deterioration Index (T)

Degree of phenomena	None or slight in Fig. A.2	Remarkable in Fig. A.2
T index	1.0	0.9

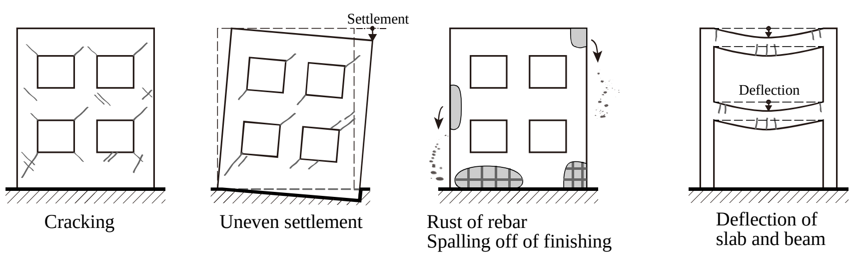


Fig. A.2- Time deterioration of existing building

Table A.2- Irregularity Index (S_D)

Degree of phenomena	None or slight in Fig. A.3	Remarkable in Fig. A.3
S_D index	1.0	0.9

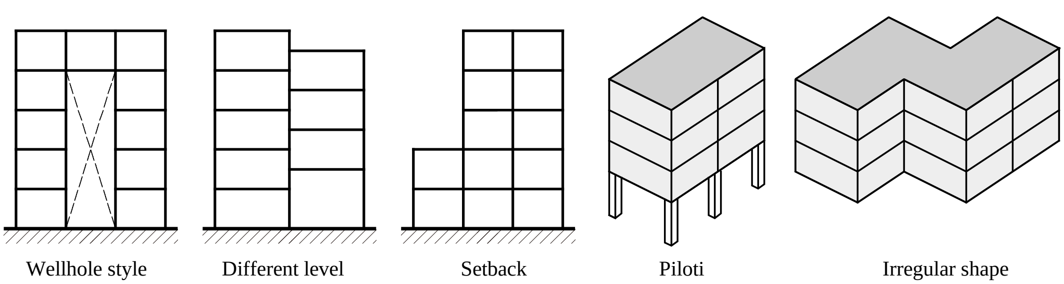


Fig. A.3- Irregularity of existing building

7. An example of Structural Evaluation

7.1 Outline of building

Photo 1- Outside view

Table- 5 outline of building

Building name	Ready-made garment building -S
Location	Dhaka city, Bangladesh
Story	3F (Approved story : 6F) As retrofitting is planned as 6 stories, evaluation is done as 6 stories.
Structural type	RC moment resisting frame
Footing	Individual footing
Approved year	2006

7.2 Evaluation

Advanced simplified structural evaluation is performed based on the following evaluation sheet.

Table 6- Evaluation sheet

Building Name	*Ready-made garment building-S*				
Location	*Dhaka city, Bangladesh*				
Story	*3F, PH 0 F, BF0 F*				
Structural type	*RC moment resisting frame*				
Basic Data	*Column*	*b (width)*	*255 mm*	*D (depth)*	*385 mm*
		ΣAc *(sec. area)*	4516×10^3 mm^2	*ho (clear ht.)*	*3151 mm*
	Beam	D_B *(depth)*	*500 mm*		
	Strength	*ho/D*		*Height:* h_n	*17.35 m*
	Material	*Fc (concrete)*	*8* N/mm^2	*(Assumed from Schmidt hammer test)*	
	Weight	*W (1st story)*	45776×10^3 *N*		
Seismic Load	I_{BS} *Index*	C_{BS}	$= \Sigma Mu/ho/W$	*0.11*	*By Japanese formula*
		F_B	$= R/\Omega o$	*2.5*	*(R=5,* Ωo *=2 , fixed)*
		E_{BS}	$=C_{BS} * F_B$	*0.275*	
		S_D		*1.0*	
		T		*1.0*	
		I_{BS}	$=E_{BS} * S_D * T$	*0.275*	
	I_{BSO} *Index*	*Z*	*Zone: 2*	*0.15*	
		I	*Important factor*	*1.0*	
		T	$=0.073 * (h_n)^{3/4}$	*0.63*	*sec*
		S	*Soil type: S3*	*1.5*	
		C	$=1.25 * S/T^{2/3}$	*2.552*	
		I_{BSO}	$=Z * I * C$	*0.383*	
Service Load	I_{BD} *Index*	I_{BD}	$=W/\Sigma Ac$	*10.13*	N/mm^2
	I_{BDO} *Index*	I_{BD01}	$0.4 * Fc$	*3.2*	N/mm^2
		I_{BD02}	$0.7 * Fc$	*5.6*	N/mm^2

Judgment	*Seismic Capacity*	$I_{BS} \geqq 1.2 I_{BSO}$	☐ *Rank* SA: *Higher than seismic demand*
		$0.8 I_{BSO} \leqq I_{BS} < 1.2 I_{BSO}$	☐ *Rank* SB: *Questionable against seismic demand*
		$0.4 I_{BSO} \leqq I_{BS} < 0.8 I_{BSO}$	■ *Rank* SC: *Lower than seismic demand*
		$I_{BS} < 0.4 I_{BSO}$	☐ *Rank* SD: *Remarkably lower than seismic demand*
	Service Load Capacity	$I_{BD} < 0.4 F_c$	☐ *Rank* DA: *Higher than service load demand*
		$0.4 F_c \leqq I_{BD} \leqq 0.7 F_c$	☐ *Rank* DB: *Lower than service load demand*
		$0.7 F_c < I_{BD}$	■ *Rank* DC: *Remarkably lower than service load demand*
	Final Capacity Rank	☐ *A : Safe* ☐ *B : Detail Evaluation Recommended* ■ *C : Immediately Detail Evaluation Recommended*	
Remarks	*This building was designed by BNBC1993 then evaluation was performed based on BNBC1993.*		

7.3 Result of evaluation

After advanced simplified structural evaluation, the final capacity rank became Rank C: Immediately Detail Evaluation Recommended. On the contrary, by the simplified structural evaluation done formerly the rank became Rank A: Safe. The main reasons that the capacity decreased are as follows;

(1) The actual size of column and actual nos. of rebar are decreased than those of structural drawing on the process of construction work or the supplied drawing is not representing actual construction.

(2) The actual compressive strength of concrete is remarkably lower than that of structural drawing, such as 8 N/mm^2 of actual value against 21 N/mm^2 of structural drawing.

8. General tendency of relationship between simplified structural evaluation and advanced simplified structural evaluation

39 ready-made garment buildings in Bangladesh were evaluated by performing the simplified structural evaluation and the advanced simplified structural evaluation. The capacity rank and the relationship of final capacity rank between two methods are shown in Fig.- 4, Fig.- 5 and Fig.- 6, respectively.

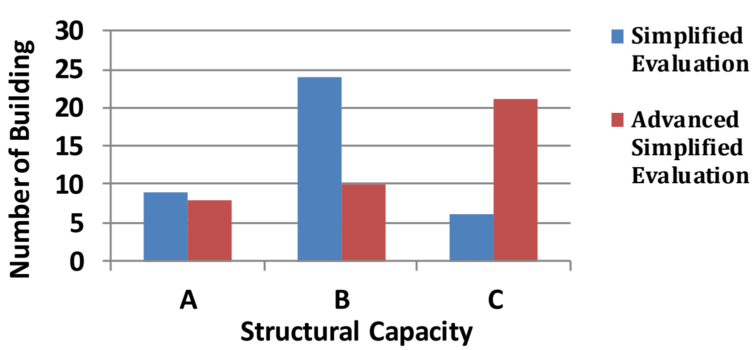


Fig. 4 - Structural capacity rank

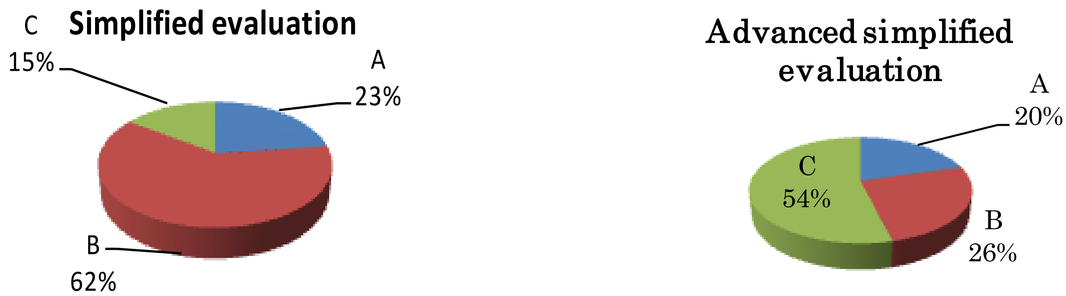


Fig.5 - Final capacity ranks between simplified evaluation and advanced simplified evaluation

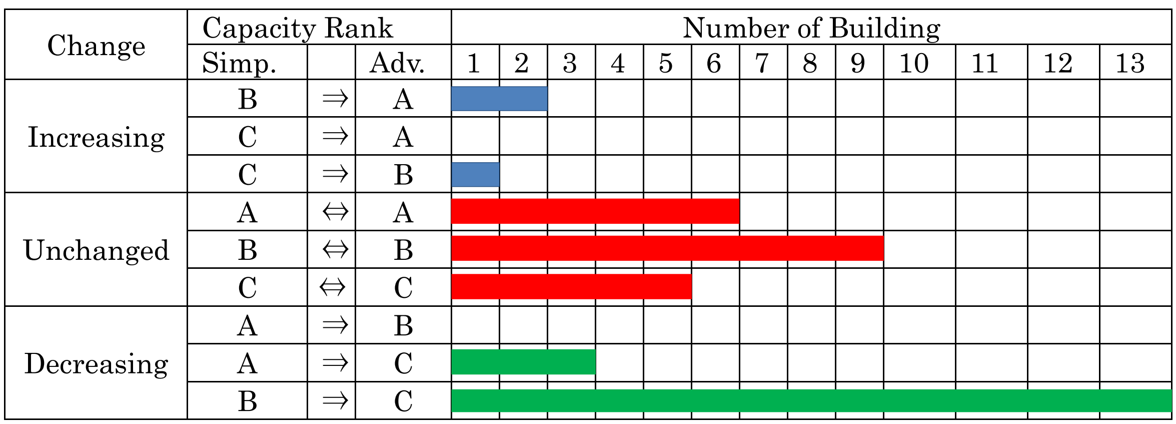


Fig.6 - Relationships of final capacity between simplified evaluation and advanced simplified evaluation

The ratio of Rank A shown in Fig.5 and Fig.6 is 23% for simplified evaluation and 20% for advanced simplified structural evaluation, respectively. These ratios are quite small values even though a large number of buildings have been designed by the latest seismic code.

Fig. 6 shows the change of final rank between simplified evaluation and advanced simplified evaluation. The buildings which increased the rank such as from B to A, from C to A and from C to B have few numbers. The buildings which didn't change the rank such as from A to A, from B to B and from C to C have a large number. This means that the simplified evaluation can simulate well the advanced simplified evaluation in which the ultimate column's strength is calculated by site investigation. On the other hand, the buildings which decreased the rank such as from A to C and from B to C have a larger number. This is the most serious problem and can be explained by the following main reasons:

a) Sectional size is smaller than the structural drawing.

b) A number of rebar and the diameter of rebar are smaller than the structural drawing.

c) The concrete compressive strength predicted by the rebound test such as Schmidt hammer test is quite smaller than the assigned value in the structural drawing. This reason is a main reason of decreasing of capacity rank in this paper's investigation.

9. Conclusions

The advanced simplified structural evaluation was proposed and discussed in this paper. This proposed procedure is basically based on the site investigation such as the size of structural members, span of grid, size of building, size and location of rebar, concrete compressive strength, time deterioration of building, irregularity of building and so on. Furthermore, this method was tried to evaluate the existing about 40 reinforced concrete buildings and was found to be quite helpful for quick capacity evaluation. It is expected that this evaluation method will be utilized as a screening method for the seismic evaluation of existing reinforced concrete buildings in Bangladesh.

10. Acknowledgements

This work was done as a part of JICA project named “Project for Capacity Development on Natural Disaster Resistant Techniques of Construction and Retrofitting for Public buildings (CNCRP)”. We would like to express our deepest appreciation for valuable advice and information by the JICA Expert members as well as for permitting and encouraging this paper presentation by the JICA Bangladesh Office. And we also appreciate the cooperation for execution of structural evaluation by the structural engineers of Public Works Department (PWD), Government of the People’s Republic of Bangladesh, Dhaka, Bangladesh.

11. References

[1] Seki M (2015): A proposal on the Simplified Structural Evaluation Method for Existing Reinforced Concrete Buildings based on the Japanese Seismic Evaluation Standard vis-à-vis the International Seismic Code, *Journal of Earthquake Science and Engineering*, Publisher ISES, http://www.joes.org.in

[2] JBDPA (2001): The Japan Building Disaster Prevention Association "Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings (Version 2001) (in Japanese)."

[3] Public Works Department (PWD), Bangladesh: Seismic Evaluation Manual and Retrofit Design Manual for Existing RC Buildings, 2015, JICA CNCRP Project (2011~2015)

[4] J.A. Blume, N.M. Newmark, and L.H. Corning: Design of Multistory Reinforced Concrete Building for Earthquake Motions, Portland Cement Association, Chicago,1961

[5] IBC2000 (2000): International Code Council, Inc., "International Building Code 2000"

[6] FEMA450-2 (2003): NEHRP Recommended Provision

[7] Seki M, Islam MR (2015): A proposal on the simplified structural evaluation method for existing reinforced concrete buildings in Bangladesh, USMCA2015, Kathmandu, Nepal

[8] BNBC 2015 Final Draft (2015): Bangladesh National Building Code 2015, Final Draft, Housing and Building Research Institute (HBRI)

[9] ACI318-08 (2008): Building Code Requirements for Structural Concrete (ACI318-08) and Commentary