16th World Conference on Earthquake, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 551

Registration Code: S-E1459395248

SUGGESTED MODIFICATION OF JAPANESE SEISMIC EVALUATION AND RETROFIT FOR RC BUILDINGS FOR ITS APPLICATION IN BANGLADESH

A. Inoue [1], M. R. Islam [2], Y. Nakajima [3]

[1] *Senior Structural Engineer, OYO International Corporation (OIC), Tokyo Japan, inoue@oyointer.com*
[2] *Executive Engineer, Public Works Department (PWD), Government of the People's Republic of Bangladesh, rafiq89bd@gmail.com*
[3] *Senior Structural Engineer, Engineering and Risk Services (ERS), Tokyo Japan, nakajima@ers-co.jp*

Abstract

Present Bangladesh National Building Code (BNBC) 1993 became mandatory in 2006. Most of the buildings constructed before 2006 were designed without the consideration of seismic loads. Since there are no clear regulations both in BNBC1993 and recent BNBC 2015 final draft, the practice of the Japanese Standard of Seismic Evaluation and Guidelines of Retrofit Design for existing RC buildings 2001 by JBDPA has been studied. The basic idea of the Japanese method is that, the seismic index of structure *Is* is calculated for each story and each principal direction, and compared with the seismic demand index *Iso.* This seismic index of structure *Is* is composed of strength index *C,* ductility index *F,* irregularity index S_D and others. As an actual result, more than 50,000 public school buildings in Japan have been retrofitted up to the present based on the Standard and the Guidelines.

Suggested modification in Bangladesh is, i) Seismic demand index *Iso* based on a time-history response analysis incorporating the design seismic load of BNBC 2015 final draft. ii) Ductility index *F* and strength index *C* incorporating the local design and construction practices. iii) Scope of application and others. As a result, 80% of the elastic response shear force coefficient of BNBC 2015 final draft is proposed as the *Iso*. For example, mid to low-rise buildings with the value of usage index 1.0 in Dhaka, *Iso* = 0.30 for soil type *SC* (hard soil) and 0.36 for soil type *SD* (soft soil) respectively. In Sylhet, *Iso* = 0.55 and 0.65 respectively. Suggested modification has been developed as the application manuals. It is expected that these application manuals are utilized and disseminated for the seismic assessment and retrofit design, which will enhance the seismic performance of existing RC buildings in Bangladesh. This study has been done as a part of the technical cooperation project (CNCRP) between PWD (Bangladesh) and JICA.

Keywords: Bangladesh, Seismic Evaluation, Retrofit Design, Seismic Demand Index, Seismic Index of Structure

1. Introduction

Present Bangladesh National Building Code (BNBC) 1993 became mandatory in 2006. Most of the buildings constructed before 2006 are either non-engineered or designed without considering seismic loads. The present construction scenario is not very encouraging either. Under these circumstances large number of buildings both public and private, in the urban areas needs a structural assessment and retrofit if found vulnerable.

However BNBC 1993 and recent BNBC 2015 final draft also don't cover clearly the regulations of seismic assessment and retrofit design of existing RC buildings. In this circumstance, the concept and practice of the Japanese Standard of Seismic Evaluation and Guidelines of Retrofit Design for existing RC buildings by The Japan Building Disaster Prevention Association [1] has been studied to apply existing RC buildings in Bangladesh. Its basic idea of the Japanese seismic evaluation method is that, the seismic index of structure *Is* is calculated for each story and each principal direction, and compared with the seismic demand index *Iso*. *Is* is composed of strength index *C*, ductility index *F*, irregularity index S_D, time index *T* and others.

In this paper, the proposed *Iso* is introduced. A simulation by a time-history response analysis based on supposed restoring force characteristics (degrading tri-linear models for a RC frame), and artificial earthquake waves corresponding to the seismic zoning and the design response spectrum (Fig. 1) of BNBC 2015 final draft is done. It is noted that the load factor for a earthquake load is 1.0 (1.0*E*) by the strength design method for information.

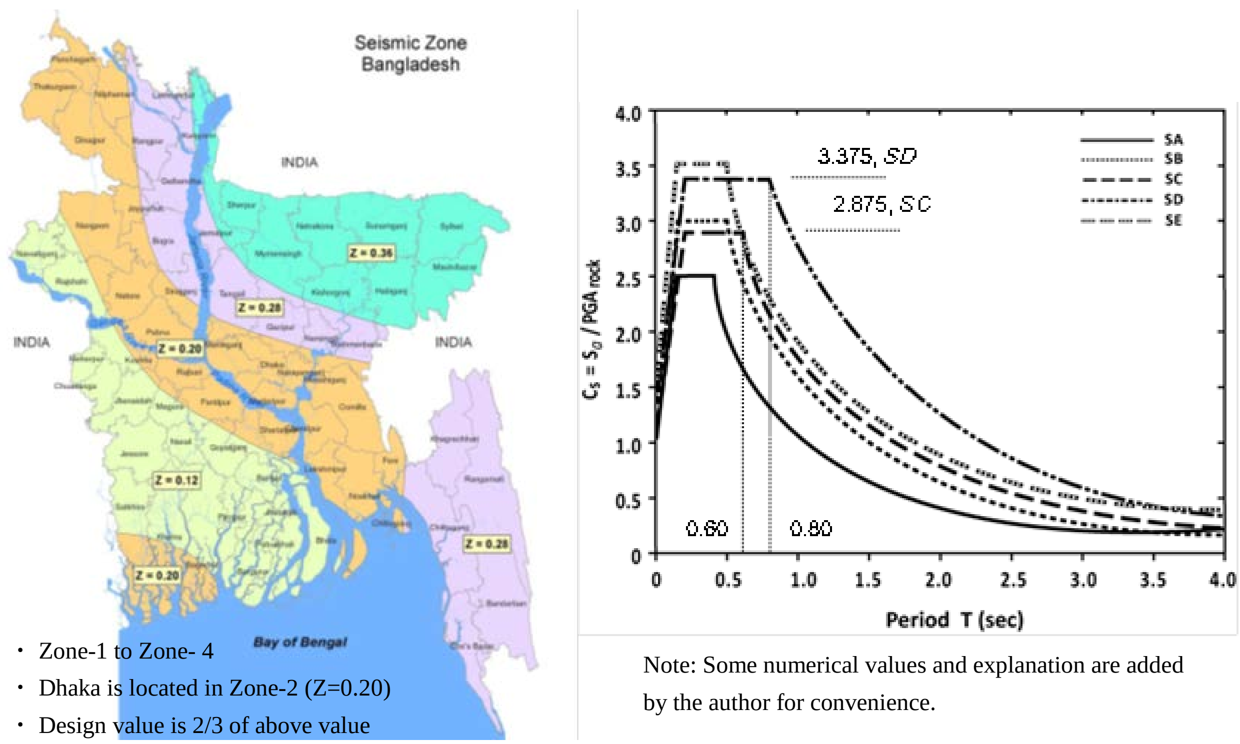


Fig. 1- Seismic zoning map and Design acceleration response spectrum of BNBC 2015 final draft [2]

An option selecting the other codes, such as ASCE 31-03 ("Seismic evaluation of existing buildings", and this code is intended to replace FEMA 310, "Handbook for sesimic evaluation of buildings") might be considered. The use of check list and an analytical approach are introduced in the code. Following investigation and modification will be required in order to meet local conditions, i) Change of the default value of materials, ii) Selection of the seismic intensity level, and iii) Selection of a building type. ASCE 41-06 (Seismic rehabilitation of existing buildings) introduces performance-based design approach. Since there are many non-engineered RC buildings with low strength concrete in Bangladesh, establishing the evaluation method of seismic performance will be the key. This is for reference only.

2. Proposed Seismic Demand Index of Structure I_{SO}

2.1 Methodology

The seismic index of structure *Is* is expressed as, $Is \propto C \cdot F$ in a simple form. Where *C* is strength index (yield shear force coefficient, *Cy*) and *F* is ductility index as defined in Section 2.2. This curved line $C \cdot F$ = constant, is a hyperbolic curve. Several combinations of the *C* and the response ductility ratio (μ) are calculated through a time-history response analysis. The ductility index *F* is calculated from this μ. The combination of *C* and *F* by the responses is studied, and then proposed *Iso* is introduced.

A time-history response analysis is applied based on the supposed restoring force characteristic and the artificial earthquake waves. Degrading tri-linear models as restoring force characteristics of RC frames are applied. The response of the shear force coefficient and the story deflection angle (a story deflection divided by the story height) is studied. Proposed *Iso* is investigated using the ductile 1 story frame through case 1 to case 6. A brittle 1 story frame is studied by case 7 and case 8 for comparison purpose.

Structure Vibration Model: An RC frame with a 1 lumped mass shear type model is used. A response at the peak area of design response spectrum is assumed.

Restoring Force Characteristic: A degrading tri-linear type model, $Q_c = 0.4\ Q_y$ is supposed. Where $Q_{y=}$ Shear force at the yield, Q_c= Shear force when cracks occurs. The initial stiffness is supposed as two times of the yield stiffness.

Case 1 to Case 6: A story deflection angle (story drift ratio) at the yield is supposed as 1/150, and with 3 cases of different yield strength for soil type *SC* (hard soil) and *SD* (soft soil) respectively, which are the typical soil types in Dhaka. Refer to Fig. 2 a.

Case 7 to Case 8: A story deflection angle at the yield is supposed as 1/250, and the yield strength is changed for soil type *SC* and *SD* respectively. Refer to Fig. 2 b.

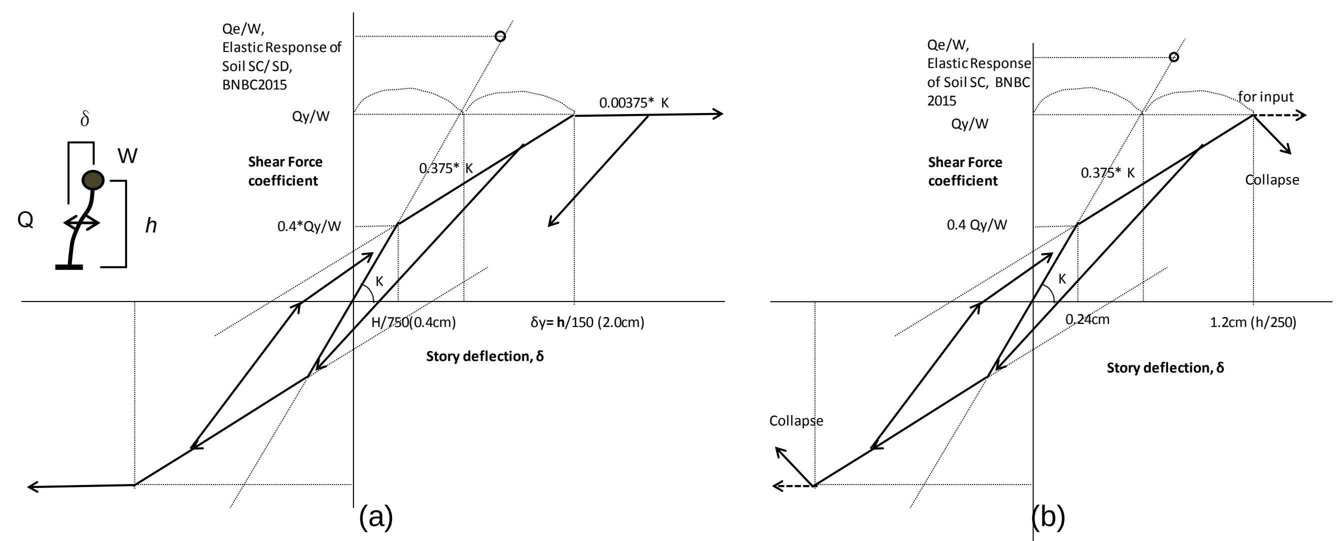


Fig. 2- Supposed restoring force characteristics
A model supposing the story deflection angle 1/150 for (a) and 1/250 for (b) at the yield of a frame

Input earthquake waves: Artificial waves corresponding to the response spectrum of soil type *SC* (hard soil) and *SD* (soft soil) in Dhaka (zone 2) are produced and 3 waves are applied for each type. The maximum ground acceleration is not 0.133g of the Code. The response maximum elastic acceleration is controlled to meet the requirement of the Code. It is noted 0.133g is for the design use and is the 2/3 of 0.2g at zone 2. Refer to Table 1 and Fig. 3.

Damping constant: A damping constant of stiffness proportional type 5% is supposed based on the study of elastic response. A tangential stiffness type is also assumed but for reference only.

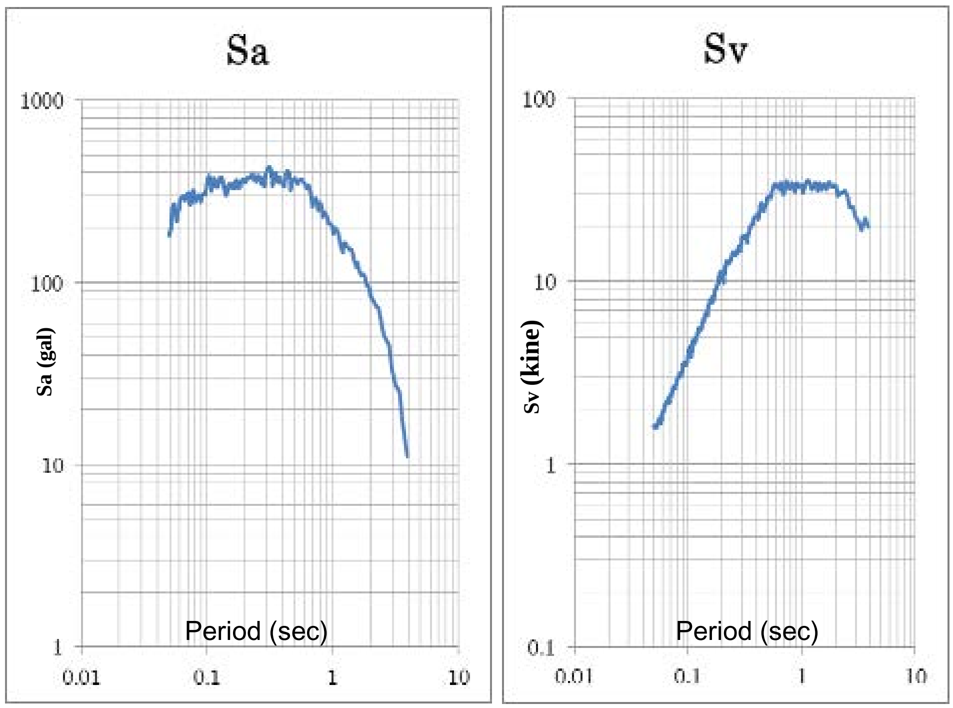
Building data: The building weight W= 5,040kN, the story height h = 3,000mm.

Case 1 to case 3 for soil type *SC* and are supposing a ductile RC frame. The yield shear force coefficient is supposed as 0.236 (=Is/F= 0.30/1.27), 0.20 (= 0.30/1.5), and 0.171 (= 0.30/1.75) by changing the ductility index. The natural period is 0.410 sec, 0.448 sec and 0.485sec respectively. Case 4 to case 6 for soil type *SD* are also supposing a ductile RC frame. The yield shear force coefficient is supposed as 0.283 (=Is/F= 0.36/1.27), 0.240 (= 0.36/1.5), and 0.206 (= 0.36/1.75). The natural period is 0.377 sec, 0.409 sec and 0.442 sec respectively. Case 7 and case 8 are supposing a brittle frame. The restoring force characteristic is a degrading tri-linear type and the bi-linear portion is evaluated. The yield shear force coefficient is 0.30 for soil type *SC*, and 0. 36 for soil type *SD*. The story deflection angle at the yield (story drift ratio) is supposed as 1/250. The natural period is 0.283 sec and 0.259 sec respectively.

Table 1- Peak ground acceleration and velocity of each wave

Name	gal	kine
SC_1	179.7	16.50
SC_2	215.4	14.14
SC_3	187.5	14.85
SD_1	218.6	23.01
SD_2	256.1	21.46
SD_3	210.0	21.53

Note: The response of the acceleration is controlled, but the acceleration amplification factor is not controlled.



Response Acceleration Spectrum

Response Velocity Spectrum

Fig. 3- Response spectrum of applied wave (SC 1) for soil type *SC* in Zone 2 by BNBC 2015 final draft

2.2 Results

2.2.1 Elastic response

A damping constant 5% of stiffness proportional type is supposed based on the case study. In case of waves of soil type *SC* in Zone 2, the values of shear force coefficient distribute in the range of plus minus 10% from the peak design value 0.38. In case of waves of soil type *SD* in Zone 2, the values of shear force coefficient also distribute in the range of plus minus 10% from the peak design value 0.45. It is reasonable to use the damping constant 5%.

2.2.2 Response of a degrading-trilinear model

Case 1 to case 6: All results through case 1 to case 6 excluding case 3 (the response is not the peak of elastic response spectrum and is reference only) were evaluated as the response within the peak range of the response spectrum.

Case 7 & case 8: A restoring force characteristic is a degrading tri-linear type, and bi-linear portion is evaluated.

The yield shear force coefficient is 0.30 for soil type *SC*, and 0. 36 for soil type *SD*. A story deflection angle (story drift ratio) at the yield is supposed as 1/250. The ductility index *F* is supposed as 1.0. The target response ductility ratio is less than 1.0.

2.2.3 Strength index and ductility index (*C*–*F*) relation for soil type *SC* (hard soil)

The result of the time-history response analysis, total 12 cases (3 waves x 4 models for case 1 to case 3 and case 7), are shown in Fig. 4. At here, similar idea of the J. Standard [1], relationship between the maximum response ductility ratio (= maximum displacement/ yield displacement) and the ductility index *F* is studied. The ratio of the yield shear force coefficient (C_y) against the maximum elastic response shear force coefficient (C_e) is indicated in the vertical axis, and the maximum response ductility ratio (μ) is indicated in the horizontal axis. Eq.(1) (Commentary Eq. 3.2.3-2 of the J. Standard [1]) is an envelope curve of these points and is the modification of so-called Newmark's equation.

$$C_y / C_e = \frac{0.75(1+0.05\cdot\mu)}{\sqrt{(2\mu-1)}} \tag{1}$$

(Commentary eq. 3.2.3-2 of the J. Standard [1])

The value of ductility index *F* of a flexural column is defined as follows [1];
When the size of ground motion at the ultimate limit response for "a system of restoring force characteristic with a flexural yield type (yield shear force coefficient C_y)" is expressed by the response shear force coefficient C_e of "Shear failure type (*F*= 1.0) vibration model of which an elastic natural period is same to this elastic plastic system", then *F* is defined as F=C_e /C_y (Commentary Eq. 3.2.3-1). Eq. (1) (Commentary Eq. 3.2.3-2) is corresponding to this Commentary Eq. 3.2.3-1. In Eq. (16) of the main portion of J. Standard (refer to Sec. 3), an yield story deflection angle R_y instead of a ductility ratio μ and an ultimate flexural story deflection angle R_{mu} are used. In this case, R_{mu}=1/150 is corresponding to μ=1.0 and *F* = 1.27. Unlike a shear wall which is *F*= 1.0, this value *F*= 1.27 is evaluated as reasonable for a flexural column in the J. Standard.

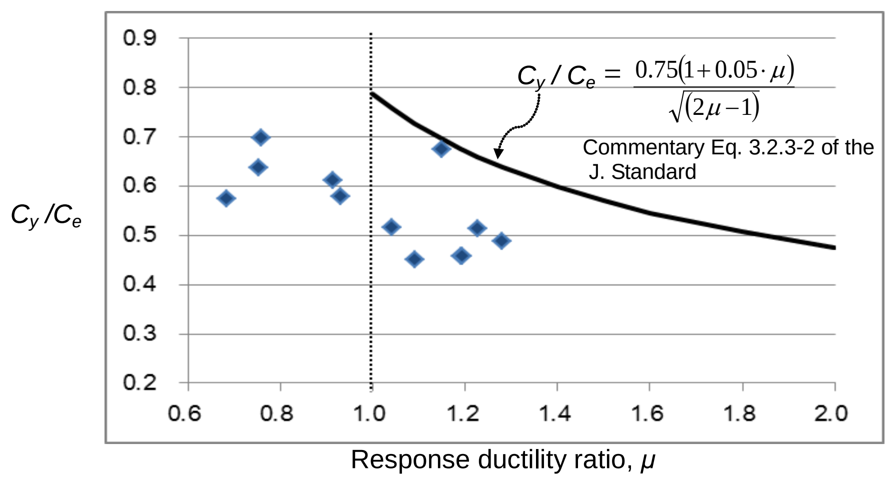


Fig. 4- Yield shear force coefficient/ response elastic shear force coefficient and response ductility ratio, soil type *SC*

The strength index and ductility Index (*C* – *F*) relation is considered. The conversion from a response ductility ratio μ to a ductility index *F* is expressed by Eq. (2) as follows, and is the reverse of Eq. (1) (Commentary Eq. 3.2.3-2).

$$F = \frac{\sqrt{(2\mu-1)}}{0.75(1+0.05\mu)} \tag{2}$$

(Commentary Eq. 3.2.3-3 of the J. Standard [1])

Following is Eq. (15) of *F* of the J. Standard [1], and is applied in case that μ is less than 1.0.

Case 7, μ =1 and *R*=1/250 is taken in principle, and in case μ is less than 1.0, $F = 0.8 + \frac{0.2(0.004\mu - 0.002)}{0.002}$ is used.

The response expressed by *C-F* relation is shown in Fig. 5. Most of cases are below the proposed curved line of *C* ・*F* = 0.30 as shown. It will be reasonable under the condition that the elastic response shear force coefficient is in the range of 0.38 (the design elastic response of BNBC 2015 Final Draft) plus minus 10%.

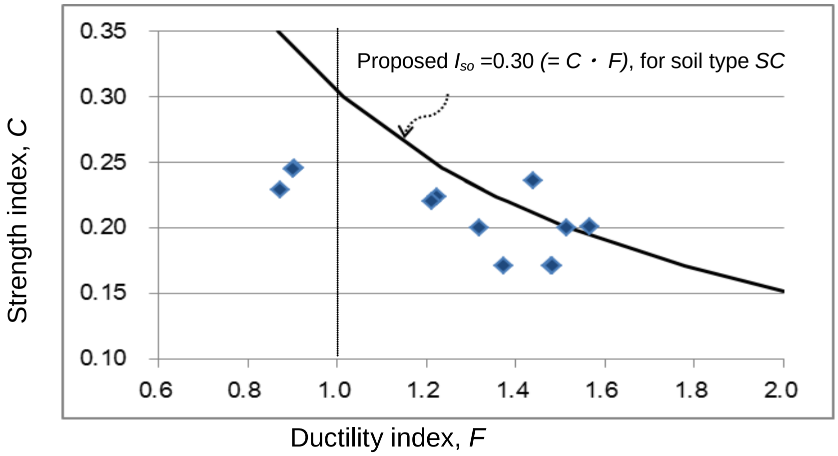


Fig. 5- Strength index and ductility index *(C–F)* relation, soil type *SC*

2.2.4 Strength index and ductility index (*C–F*) relation for soil type *SD* (soft soil)

The result of the time-history response analysis, total 12 cases (3 waves x 4 models for case 4 to case 6 and case 8), are shown in Fig. 6. The curve of Eq. (1) (Commentary Eq. 3.2.3-2) is also shown, which is almost an envelope curve against the response for soil type *SD*.

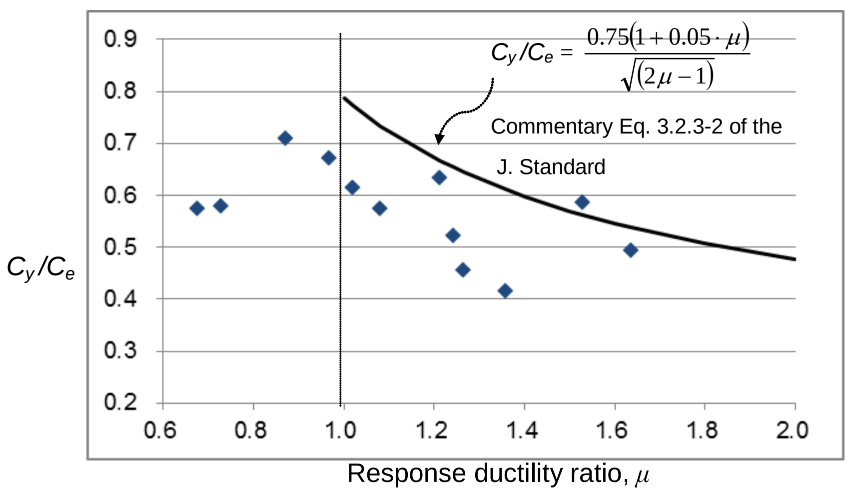


Fig. 6- Yield shear force coefficient/ response elastic shear force coefficient and response ductility ratio, soil type *SD*

The strength index and ductility index (*C–F*) relation for soil type *SD* is considered. The conversion from a response ductility ratio μ to a ductility index *F* is same to that of soil type *SC*. 5 cases out of 12 cases exceed the curve of I_{so}= 0.36 as shown in Fig. 7, and proposed I_{so}= 0.36 will be the average of responses in case of soil type *SD*. This will be acceptable under the condition that the elastic response shear force coefficient is in the range of 0.45 (the design elastic response of BNBC 2015 final draft) plus minus 10%.

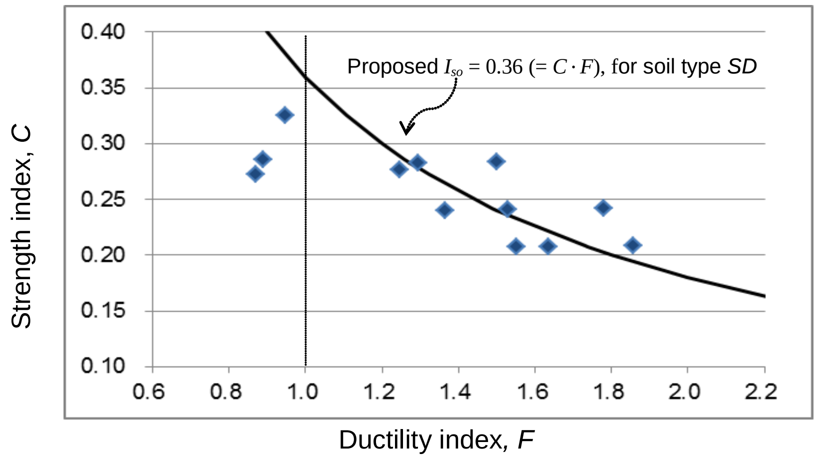


Fig. 7- Strength index and ductility index *(C–F)*, soil type *SD*

2.2.5 Response shear force coefficient and story deflection angle relation

The relation of shear force coefficient *C* (=Q/W, Q= shear force, W= building weight) and story deflection angle (*R*= δ / h, story drift ratio) by an elastic and a degrading tri-linear restoring force characteristic are provided for comparison purpose. The initial stiffness is same for each case. The damping constant of stiffness proportional type 5% is supposed. Case 1e, case 2e, case 3e and case 7e are elastic responses for soil type *SC* (hard soil) as shown in Fig. 8. Red color circle (○) at a tri-linear model shows the target allowable response, such as *R*=1/150 (*F*=1.27) for case 1, *R*=1/124 (*F*=1.50) for case 2 and *R*=1/250 (*F*=1.0) for case 7 respectively. The response of case 3 seems not the response of the peak of response spectrum and is reference only. The average value of responses will be acceptable.

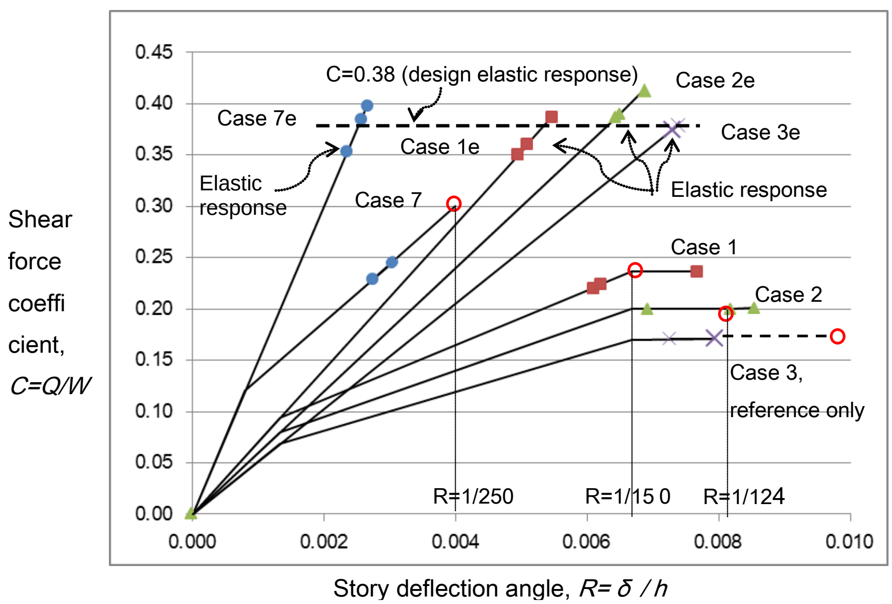


Fig. 8- Response shear force coefficient and story deflection angle, soil type *SC*

Case 4e, case 5e, case 6e and case 8e are an elastic response for soil type *SD* (soft soil) as shown in Fig. 9. The red color circle (○) at a tri-linear model shows the target allowable response, such as *R*=1/150 (*F*=1.27) for case 4, *R*=1/124 (*F*=1.50) for case 5, *R*=1/100 (*F*=1.75) for case 6 and *R*=1/250 (*F*=1.0) for case 8 respectively. The average value of responses will be acceptable.

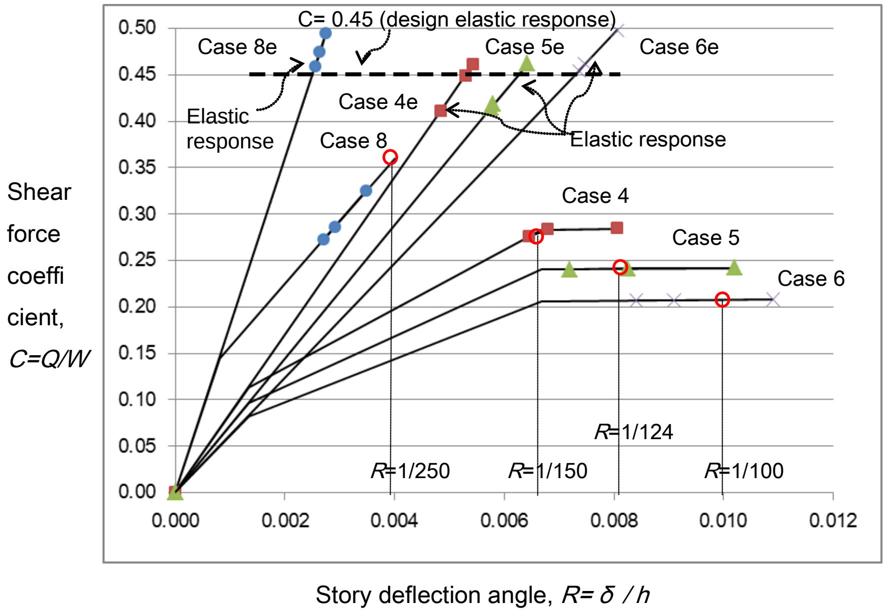


Fig. 9- Response shear force coefficient and story deflection angle, soil type *SD*

2.3 Summary

(1) A time-history response analysis is applied using artificial waves, to evaluate the required strength index (the response shear force coefficient) and the story deflection angle.

(2) Proposed seismic demand index *Iso* is 80% of the elastic response shear force coefficient. This value is proposed incorporating the effect of energy absorption (hysteresis) by the crack occurrence for case 1, 4, 7, and 8.

(3) A damping constant of stiffness proportional type 5% is supposed. If a tangential stiffness proportional type 5% is assumed, the response is increased by 20% for soil type *SC* and 26% for soil type *SD* respectively. It is noted that the results depend on the analytical condition for information only.

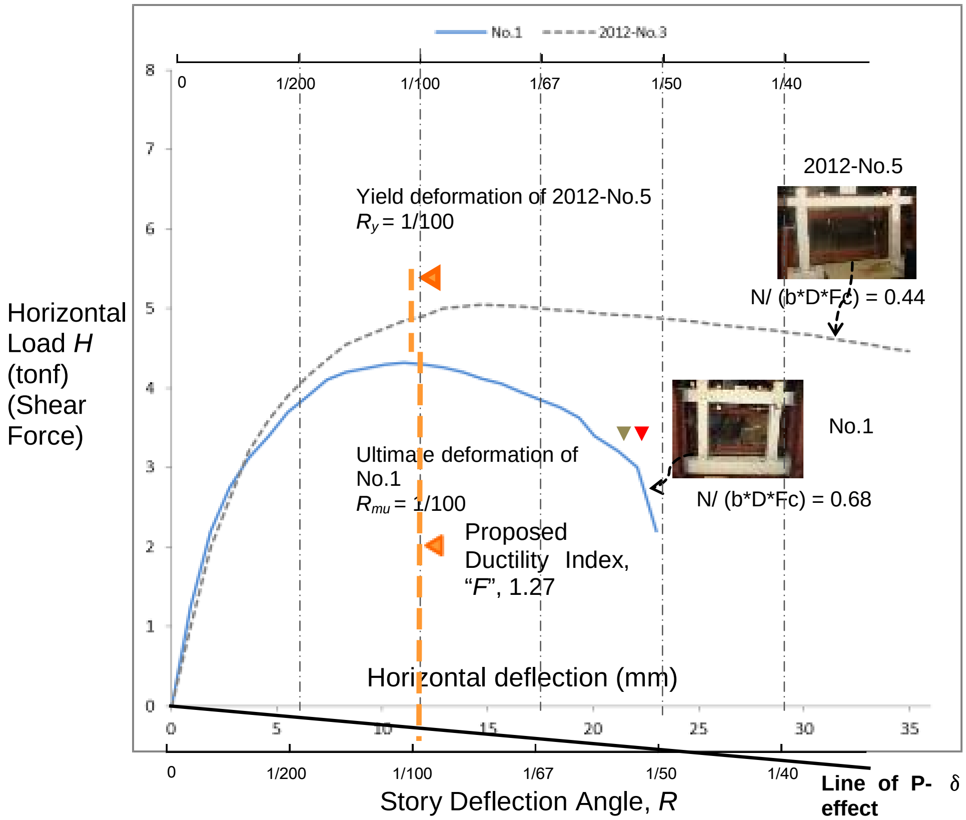
(4) As a result, mid to low-rise buildings with the usage index 1.0, *Iso* = 0.30 for soil type *SC* (hard soil) and 0.36 for soil type *SD* (soft soil) are proposed in Dhaka (zone 2) respectively. *Iso* = 0.55 for soil type *SC* (hard soil) and 0.65 for soil type *SD* (soft soil) are proposed in Sylhet (zone 4) respectively.

3. Proposed Ductility Index *F* related to axial force ratio

Another important issue is the ductility of a column related to the axial force ratio. Generally the expected ductility of a column is evaluated based on the size of the allowance against the shear failure of a column. This is following the requirement of Japanese code [1]. In addition to that, the axial force ratio $N/b{\cdot}D{\cdot}F_c$ (*N*= axial force, $b{\cdot}D$ = width and depth of a column, and Fc= concrete strength) is an important factor to evaluate the ductility of a column. The Japanese standard states that the ductility index *F* is 1.0, when the value of axial force ratio exceeds 0.4 and the column tie interval is more than 100mm. On the other hand, typical working axial force of a column following BNBC 93 is approximately 60% of the combined strength of the concrete and main re-bars. It has been coordinated and is proposed incorporating the requirement of BNBC. In case of the value of the axial force ratio $N/b{\cdot}D{\cdot}F_c$ exceeds 0.40 and up to 0.60, the ductility index *F* will allow 1.27 for the low strength concrete, from a structural experiment by JICA CNCRP Project [3]. The ductility index of a column will be 1.0 in case axial force ratio exceeds 0.6.

Simplified monotonic load-deflection curves of two frame specimens are shown in Fig. 10. The low strength concrete is used for specimen No. 1 and the axial force ratio is 0.68. The storey deflection angle (story drift ratio) of this specimen at the ultimate capacity R_{mu} is estimated as approximately 1/100. The ordinaly strength concrete is used for specimen 2012-No.5 and the axial force ratio is 0.44. The storey deflection angle at the yield

R_y is estimated as approximately 1/100. On the other hand in case that the typical deflection angle of the Japanese Standard is applied, R_y =1/150 is taken in principle.



R: Story deflection angle (story drift ratio) = Horizontal deflection (δ, mm)/ Story height (h=1,175mm)

Fig. 10- Simplified monotonic load-deflection curves of frame specimens

The ductility index of specimen No.1 (the axial force ratio, $N/b{\cdot}D{\cdot}F_c$= 0.68) as a flexural failure column, is evaluated. In case $R_{mu} \geq R_y$, following Eq. (3) is applied.

$$F = \frac{\sqrt{2R_{mu}/R_y - 1}}{0.75\cdot(1+0.05R_{mu}/R_y)} \qquad F \leq 3.2 \tag{3}$$

(Eq. of (16) The Japanese Standard [1])

As a result, F = 1.27 is obtained (R_{mu}/R_y= 1).

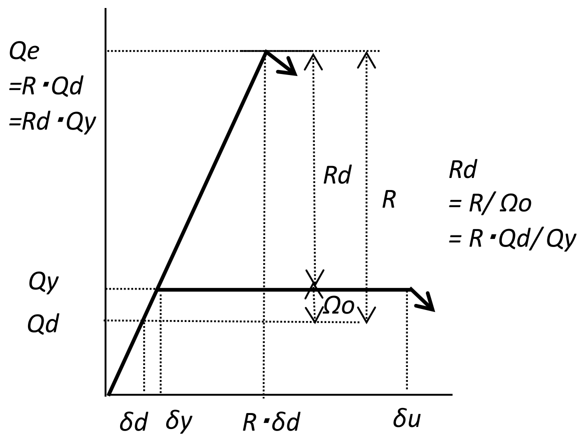
4. Ductility Index *F* and Response modification factor

Factors of other codes related to the ductility index *F* are considered. The response modification (reduction) factor *R* (note: this symbol is also used as a story deflection angle in this paper) and the over-strength factor Ωo are used for the calculation of design seismic loads of new buildings in ASCE 7-10 (Minimum design loads for buildings and other structures) and in UBC 97 as shown in Table 2 and in Fig. 11. Fig. 11 is an explanatory figure based on a bi-linear (elastoplastic) model. The value of the over-strength factor 3.0 in ASCE 7-10 and 2.8 in UBC 97 are indicated respectively. The value *R* of ASCE 7-10 has been incorporated in BNBC 2015 final draft, but there is no description on the over-strength factor in BNBC. The investigation of this over-strength factor will be required for buildings in Bangladesh. It is noted that the value *Rd* (=$R/\Omega o$) will be a similar concept and can be compared with the ductility index *F* of the Japanese code ($0.8 \leq F \leq 3.2$) for information.

Table 2- Response modification factor *R* and over-strength factor *Ωo*

Basic structural system	UBC 94	UBC 97			ASCE 7-10		
	R	*R*	*Ωo*	*Rd= R/ Ωo*	*R*	*Ωo*	*Rd= R/ Ωo*
Special moment resisting frames	12	8.5	2.8	3.06	8	3	2.67
Intermediate moment resisting frame	8	5.5	2.8	1.96	5	3	1.67
Ordinary moment resisting frame	5	3.5	2.8	1.25	3	3	1.0

Note: The symbol *R* is also used as a story deflection angle in this paper.



Where;
Qd = Design base shear force
Qe = *R* ・*Qd* = Elastic design response base shear force
Qy = Yield strength or horizontal load carrying capacity
R = Response modification factor
Ωo= Qy/Qd = Over-strength factor
Rd = Revised response modification factor, and is expressed by *R* divided by over-strength factor *Ωo*.
δu = Horizontal deflection at the ultimate stage

Fig. 11- Response modification factor and over-strength factor based on a bi-linear (elastoplastic) model

5. Summary of suggested modification

The modification of the method of Japanese Standard and Guidelines for its application in Bangladesh is summarized with respect to A: General, B: Ductility index, C: Strength index, D: Irregularity index, E: Quality management of retrofit work and F: Others. Item A only is shown in Table 3 for information. As far as the ductility index, the upper limit is proposed in case that the shear failure is not studied for a short column caused by brick standing walls and/or the structural capacity is not studied for beam-column joints.

Table 3- A part of suggested modification of Japanese Standard for its application in Bangladesh

Item	Japan	Bangladesh
Title	The Standard for Seismic Evaluation of Existing RC Buildings, Guidelines for Seismic Retrofit Design of Existing RC Buildings 2001 (JBDPA)	Seismic Evaluation Manual and Seismic Retrofit Design Manual of Existing RC Buildings (CNCRP project)
A: General		
1. Status	"The Standard" and "Guidelines"	Technical **"Recommendations"**
2. Level of screening	1st, 2nd and 3rd level screening method. 2nd level is mainly used.	1st, 2nd and 3rd level screening method. 2nd level screening method is applied, which is suitable and practical for buildings. 1st level screening method is not used for the judgment. (Retrofit, Chap.1.1)
3. Existing buildings	Min. strength is secured by the building law at construction.	Many buildings are not following BNBC93, which became mandatory in 2006. Detail building survey is required. (Retrofit, Chap.1.9)

	Strength of concrete core = Average – standard deviation/ 2, 100mm diameter in general.	(*)Strength of concrete core: (No change) Core strength is generally lower than that of cylinder, and strength of tested value divided by 0.85 may be used, minimum 50 mm diameter in general for columns. Ref. ACI 437 and 214 [4]
4. Application: Concrete strength	Concrete strength F_c, not less than 13.5N/mm^2 (Not low strength concrete)	Concrete strength F_c, not less than 9.0N/mm^2. Reduction factor K_r is used for column shear strength in case of concrete strength lower than 13.5 N/mm^2. (Chap.1.2)
5. Seismic index of structure, I_s	$I_S = E_o \times S_D \times T$ $E_O \propto \frac{n+1}{n+i} \times C \times F$ E_o= Basic seismic index of structure S_D= Irregularity index T= Time index	$I_S = E_o \times S_D \times T$ $E_O \propto \frac{n+1}{n+i} \times C \times F$ (No change)
6.Seismic demand index of structure, I_{so}	Seismic demand index of structure I_{SO}, (1) I_{SO} $I_{SO} = E_S Z \cdot G \cdot U$ E_S = Basic seismic demand index of structure E_S = 0.8, for 1st level screening E_S= 0.6, for 2nd level screening E_S= 0.6, for 3rd level screening Z = Seismic zone index G = Ground index U= Usage index (2) $C_{TU} \cdot S_D \geq 0.3 Z \cdot G \cdot U$ C_{TU} = Cumulative strength index at the ultimate deformation of structure. S_D = Irregularity index. (Example) Midrise RC in Tokyo, $I_{SO} = 0.6 \times 1.0 \times 1.0 \times 1.0 = 0.6$ ($Z = G = U = 1.0$)	(*) Proposed I_{SO} for 2nd and 3rd level screening, $I_{SO} = 0.8 \times \frac{2}{3} Z \cdot I \cdot C_s$ (80% of elastic response shear force coefficient) Z : Seismic zone coefficient, as defined in Section 2.5.4.2 of BNBC2015 I : Structure importance factor C_s :Normalized acceleration response spectrum, which is a function of structure (building) period and soil type (site class) (Example) Zone 2 (Dhaka), medium height RC buildings soil *SC*, I_{so} = 0.8× 0.38= 0.30 (Z=0.2, I=1.0, C_s=2.875) soil *SD*, I_{so} = 0.8× 0.45= 0.36 (Z=0.2, I=1.0, C_s=3.375) Zone 4 (Sylhet), medium height RC buildings soil *SC*, I_{so} = 0.8×0.69=0.55 (Z=0.36, I=1.0, C_s=2.875) soil *SD*, I_{so} = 0.8×0.81=0.65 (Z= 0.36, I=1.0, C_s=3.375) $C_{TU} \cdot S_D \geq 0.4 \times \frac{2}{3} \times Z \cdot I \cdot C_s$ C_{TU} = Cumulative strength index at the ultimate deformation of structure. S_D = Irregularity index.

6. An example building of seismic retrofit

An example building of the seismic retrofit applying the suggested modification of the Japanese method is shown in Fig.12. This is a 4 storied RC building and is a garments factory located in Dhaka. The seismic index of structure *Is* before the retrofit is 0.12 for both directions at the ground floor. The irregularity index S_D is lower than 1.0 because of the low horizontal stiffness caused by the high story height of the ground floor and the eccentricity caused by the double height area at one side of the building. The seismic index of structure *Is* has been improved to more than 0.3 (*Iso* = 0.3 for soil type *SC*) by providing steel braced frames properly at the inside and the perimeter of the building [5]. The retrofit design and the construction work were done so as not to affect the function and the operation of the factory.

a) A steel braced frame at inside (a storage area) c) Steel braced frames at perimeter
b) An underground RC wall provided beneath a steel braced frame

Fig. 12- An example building of seismic retrofit in Dhaka

7. Conclusion

The main concept of the Japanese seismic evaluation for existing RC buildings will be evaluating how a building collapse related to the strength, the ductility and the irregularity, and the seismic index of structure can be provided by a manual calculation. Maitaining this characteristics, suggested modification for its application in Bangladesh, which has different sesimic loads and construction practices, including the proposed seismic demand index *Iso* and others are intorduced. Suggested modification has been developed as application manuals [6]. It is expected that these manuals are utilized for the seismic evaluation and retrofit design of exisiting RC buildings in Bangladesh. It is also expected to improve the contents further through the comprehensive experimental and analytical studies.

8. Acknowledgements

The authors express appreciation for advices provided by Professor Emeritus S. Otani and Professor Y. Kabeyasawa of the University of Tokyo, and Prof. J. R. Choudhury, Vice Chancellor of University of Asia Pacific, A.H.Md. M. Rahman of PWD, Professor (Retd.) M. S. Z. Bosunia of BUET, Professor I. Anam of UAP, and Professor A.F.M S. Amin of BUET. The Authors also express appreciation to Mr. S. Segawa of OIC for the production of artificial waves, and Md. A. Malek Sikder, Md. Ahsan Habib and Md. Mafizur Rahman of PWD, and Dr. M. Seki of BRI Japan for their suggestion. Financial support by JICA is also appreciated.

9. References

[1] The Japan Building Disaster Prevention Association: *Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings 2001, and Guidelines for Seismic Retrofit of Existing Reinforced Concrete Buildings 2001, English version, 1st*, Japan.

[2] Housing and Building Research Institute (HBRI): *Chapter 6 Structural Design, Bangladesh National Building Code 2015 Final Draft*, Bangladesh.

[3] Akira Inoue et al. 16WCEE: *Seismic Deformability of Existing RC Buildings in Dhaka Bangladesh, through the Basic Experiment*, JICA CNCRP Project (2011~2015), Bangladesh.

[4] American Concrete Institute Committee: *ACI 437R-03, Strength Evaluation of Existing Concrete Buildings, the Sec 5.1.1, ACI 318R-14, Commentary on Building Code Requirements for Structural Concrete,* and *ACI 214.4R-03, Guide for Obtaining Cores and Interpreting Compression Strength Result, Sec 6.2.*

[5] Anup K. Halder et al. New Technology for Urban Safety of Mega Cities in Asia, Nepal Kathmandu 2016: *Seismic retrofitting of a garments factory building in Bangladesh*, JICA CNCRP project, Bangladesh.

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