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A Proposal on the Simplified Structural Evaluation Method for Existing Reinforced Concrete Buildings Based on the Japanese Seismic Evaluation Standard vis-a-vis the International Seismic Code

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ABSTRACT

In 1995 HyogokenNanbu (Kobe) Earthquake in Japan a large number of buildings which were designed by the old Japanese seismic code suffered severe damage. Based on this lesson, the Japanese government has encouraged promoting of the seismic evaluation and retrofitting work for existing buildings, especially constructed before 1980. After 1995, several big earthquakes occurred but these retrofitted buildings survived safely. Now buildings all over Japan are becoming better seismic resistant even to higher level hazard and damage by earthquakes is remarkably decreasing.

On the other hand, 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 the inadequate structural design by engineers and/or poor quality control of construction works.

In this paper, in order to contribute to the disaster mitigation for the developing countries, the simplified structural evaluation method based on the philosophy of Japanese evaluation standard aiming to apply it for the buildings which were designed by international seismic code is presented

1. Introduction

The seismic evaluations for existing building are generally categorized into two methods; (1) seismic evaluation and retrofitting before earthquake, (2) seismic evaluation and retrofitting just after earthquake such as quick inspection. Japan has already issued many standards and these are used for the practical field of evaluation and retrofitting for both categories.On the other hand, many of countries in the world, especially the developing countries which usually suffer severe damage by reason of poor quality buildings, are yet on the way to the goal of achievement for disaster mitigation.

In this paper, in order to investigate the seismic capacity before earthquake for developing country's buildings the simplified structural evaluation method is discussed.

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Basic Principle for Evaluation

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

(i) Seismic evaluation is basically based on the philosophy of the Japanese Seismic Evaluation Standard for existing reinforced concrete buildings issued by The Japan Building Disaster Prevention Association (hereafter called as JBDPA Standard) and International Building Code, 2000 (hereafter called as IBC, 2000).

(ii) The target building is the reinforced concrete moment resisting frame building.

(iii) Evaluation is done by only original structural drawings and architectural drawing. This evaluation is performed on the condition that the building was constructed faithfully due to the approved original drawings.

(iv) Evaluation is basically performed at the first (ground) floor which may be usually the weakest floor of the whole building floors.

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

(vi) As for the final judgment after simplified structural evaluation, the vulnerability evaluation on two items; (1) Seismic capacity by horizontal seismic load, (2) Gravity load capacity by dead load is carried out. If the evaluation result doesn't satisfy the target capacity values, the higher detail evaluation method will be recommended.

The flow diagram of a proposed simplified structural evaluation is shown Fig. 1.

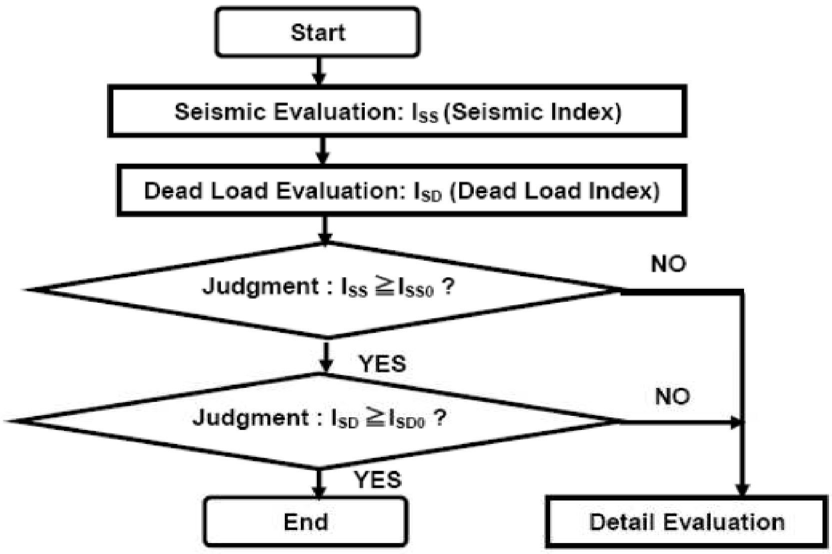


Figure 1.Flow Diagram of Simplified Structural Evaluation for Existing Reinforced Concrete Buildings

3. Evaluation Method

***Simplified Seismic Index*:I_{SS}**

$I_{SS} = E_{SS} * S_{SD} * T_S$(1)   (Commentary A)

Where,

E_{SS}: Simplified Structural Index

$E_{SS} = C_{SS} * F_S$(2)
C_{SS}: Simplified Strength Capacity of Building
$C_{SS} = \tau * \Sigma A_C / W$ (3) (Commentary B)

τ: Average Shear Strength of Column (N/mm^2)

$h_0/D>6$: τ=0.7 N/mm^2

$h_0/D \leqq 6$: τ=1.0 N/mm^2

h_0: Clear height of column (mm)
D: Depth of column section (mm)
ΣAc : Total area of columns (mm^2)
W: Total weight of building (N)
F_S : Simplified Ductility Index

$F_S = R/\Omega_0$ (4) (Commentary C)

R : Response modification factor based on structure type in IBC200
Ω_0 : Over strength factor
S_{SD} : Simplified Irregularity Index (here assumed to be S_{SD}=1.0)
T_S : Simplified Time Index (here assumed to be T_S=1.0)

***Simplified Dead Load Index*:I_{SD} (N/mm^2)**

$I_{SD} = W / \Sigma Ac$(5)

Where,
W : Total weight of building (N)
ΣA_C : Total sectional area of columns (mm^2)

4. Judgment Index

***Simplified Seismic Judgment Index*:I_{SS0}**

$I_{SS0} = S_D * I_S$(6) (Commentary D)

Where,

I_{SS0} : Design base shear coefficient of a building
S_D : The design spectral response acceleration
I_S : The occupancy importance factor

***Simplified Dead Load Judgment Index*:I_{SD0} (N/mm²)**

$I_{SD01} = 0.4 * Fc$ (7) Commentary E)
$I_{SD02} = 0.7 * Fc$

Where, Fc : Designed concrete strength (N/mm²)

5. Judgment Method

Simplified Seismic Capacity

$I_{SS} \geqq I_{SS0}$: Higher than seismic capacity demand(SA)(8)
$0.5I_{SS0} \leqq I_{SS} < I_{SS0}$: Lower than seismic capacity demand(SB)
$I_{SS} < 0.5I_{SS0}$: Remarkably lower than seismic capacity demand(SC)

Simplified Dead Load Capacity

$I_{SD} < I_{SD01}$: Higher than dead load capacity demand(DA)(9)
$I_{SD01} \leqq I_{SD} \leqq I_{SD02}$: Lower than dead load capacity demand(DB)
$I_{SD02} < I_{SD}$: Remarkably lower than dead load capacity demand(DC)

Final Rank based on Combination of Seismic Capacity and Dead Load Capacity

Final structural rank based on combination of seismic capacity and dead load capacity can be obtained as following Table 1.

Table 1.Final Capacity Rank of Simplified Structural Evaluation

Final Capacity Rank	Combination		Recommendation
	Seismic capacity	Dead Load capacity	
A	SA	DA	Safe
B	SB	DA, DB	Detail Evaluation Recommended
C	SC	DA, DB, DC	Immediately Detail Evaluation Recommended

COMMENTARY

Commentary A:

The seismic index of structure Is shall be calculated by Eq. (C1) and Structural Index E_0 shall be calculated by Eq. (C2) at each story and in each horizontal direction of a building after the Japan Building Disaster Prevention Association (JBDPA Standard, 2001)

$Is = E_0 * S_D * T$ (C1)

Where:

E_0 : Basic seismic index of structure
S_D : Irregularity index
T : Time index
$E_0 = C * F$ (C2)

Where:

C : Strength index

F : Ductility index

Commentary B

C-F relation in JBDPA Standard is shown in Fig. C1. In this proposed simplified seismic evaluation, first level inspection method is employed. Column strength and ductility in the first level inspection in JBDPA Standard is shown in Table C1.

As for the appropriateness for use of average shear stress τin Table C1, an example of calculation of ultimate strength of columns is shown in Fig. C2. This data is from Bangladesh which is chosen as one of developing countries. Calculated ultimate shear stress τvary from 0.5 N/mm^2 to 1.8 N/mm^2 and the assumed shear stress is 0.7 N/mm^2 for $h_o/D \geq 6$ and 1.0 N/mm^2 for $h_o/D \leq 6$. This assumption is more conservative than the calculated strength but might be suitable for evaluation.

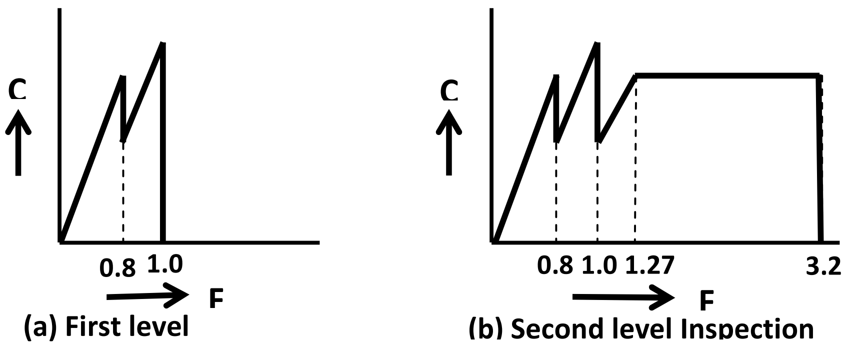
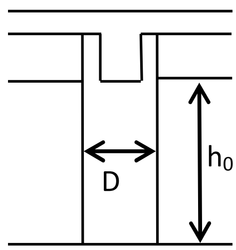


Figure C1. **C-F Relations in JBDPA Standard for Existing Buildings (JBDPA, 2001)**

Table C1.Column Strength and Ductility in First Level Inspection (JBDPA Standard, 2001)

Kind of Column	Clear Height /Column Depth : h0/D	Average Shear Stress: τ(N/mm²)	Ductility Index :F	Definition of h_0/D
Column	6≦h0/D	0.7	1.0	
	2＜h0/D＜6	1.0		
Short Column	h0/D≦2	1.5	0.8	

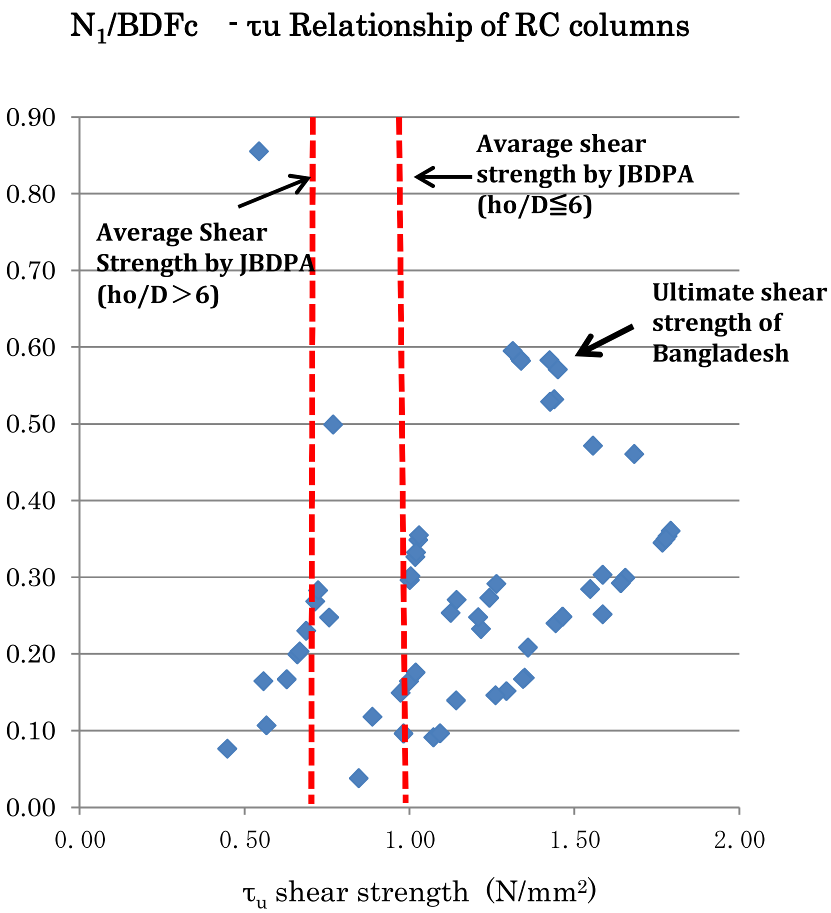


Figure C2.Ultimate Shear Strength of RC Columns of Bangladesh Buildings

Commentary C

The relation of Lateral Seismic Force V and Lateral Deformation (Drift) D is shown in Fig. C3. Also response modification coefficient R, system over strength factor Ω_0 and deflection amplification factor Cd are shown. These values for the reinforced concrete moment frame defined in IBC2000 are shown Table C2.

For the seismic evaluation, as Japanese standard is based on the inelastic behavior, ultimate inelastic lateral deformation should be defined. In Fig. C4 the relationships between R factor and Fs factor based on IBC2000 is shown. R is reduction factor which is the same as ductility factor for elastic design and Fs is the ductility factor for inelastic design. In this proposed simplified seismic evaluation Fs should be used. The relationship between R and Fs can be performed as formula C3.

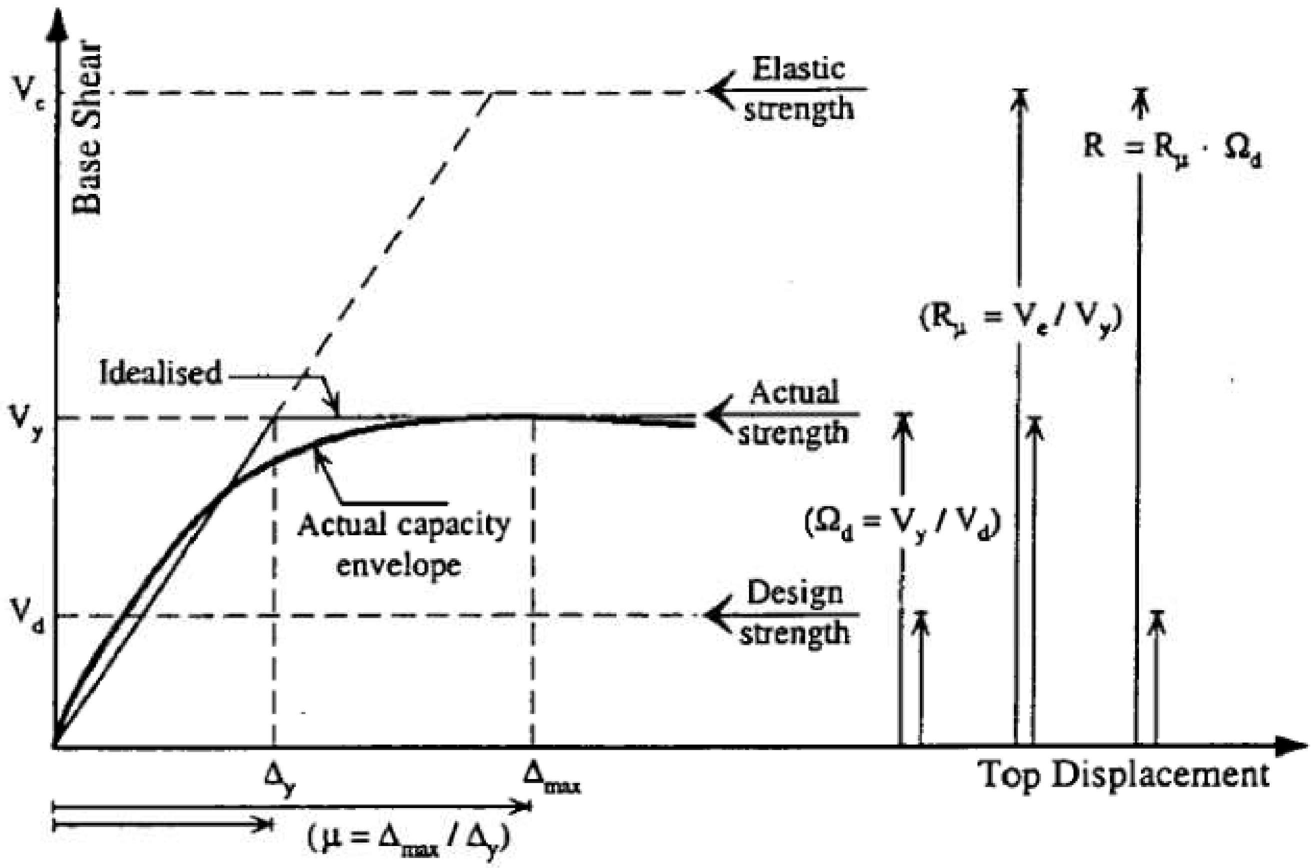


Figure C3.Relationships between the Force Reduction Factor R and Structural over Strength Factor Ωd and the Ductility Reduction Factor R_μ(modified after Mwafy and Elnashai, 2002)

Table C2.Design Coefficients and Factors for Basic Seismic-Force-Resisting System for Reinforced Concrete Moment Frames (IBC2000)

Basic Seismic - Force – Resisting System	Response Modification Coefficient, R	System Over strength Factor, Ω_0	Deflection Amplification Factor, Cd
Special reinforced concrete moment frames	8	3	5 *1/2*
Intermediate reinforced concrete moment frames	5	3	4 *1/2*
Ordinary reinforced concrete moment frames	3	3	2 *1/2*

From Fig. C4, ductility index F_S can be obtained by the following relationships;

$\therefore V_Y/V_E = 1/\mu$

∴VŶ=VS∗ΩÔ=ΩÔ∗VÊ/R∴VŶ/VÊ=1/μ= ΩÔ/R∴μ= rR/ΩÔ (C3)

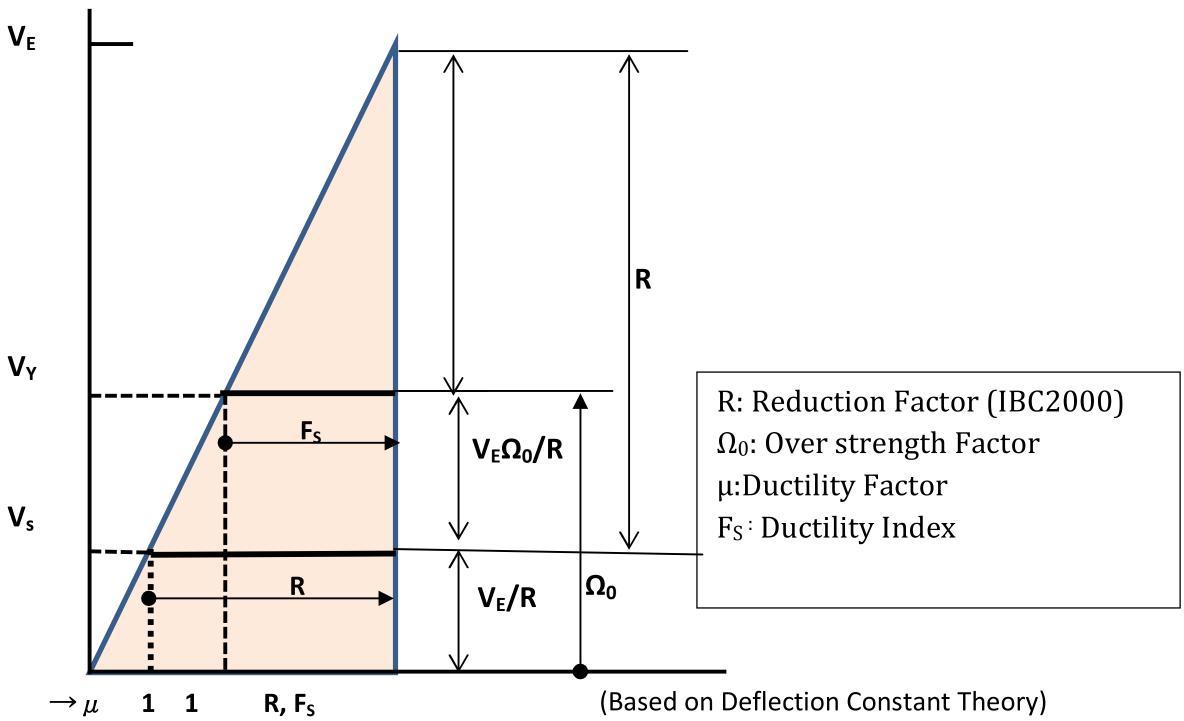


Figure C4.Response Acceleration (V) – Ductility Index (F_S) Relations (IBC2000)

Commentary D

The design base shear coefficient is usually calculated by the design spectral response acceleration based on the characteristic of building, site soil condition, seismic intensity corresponding to the seismic zone and the occupancy importance factor, etc.Table C3.Shows the seismic response coefficient Cs (the design base shear coefficient) defined in IBC, 2000. Table C4 shows the occupancy importance factor defined in IBC, 2000.These values will be decided considering the situation of the corresponding country.

Table C3.The Seismic Response Coefficient C_S (IBC, 2000)

$C_S=S_{DS}*I_E/R$ (Equation16-35)
$C_S=S_{DL}*I_E/R$ (Equation 16-36)
Minimum conditions;
$C_S \geqq 0.044S_{DS}*I_E$ (Equation 16-37)
$C_S \geqq 0.5S_I*I_E/R$ (Equation 16-38)
Where,
I_E : The occupancy importance factor
R : The response modification factor
S_{DS} : The design spectral response acceleration at short period
S_{DL} : The design spectral response acceleration at 1-second period
S_I : The mapped maximum considered earthquake spectral response acceleration at 1-second period
T : The fundamental period of the buildings (seconds)

Table C4.Occupancy Importance Factors (IBC, 2000)

Category	Nature of Occupancy	Seismic Factor I_E
I	Buildings and structures except categories II, III and IV	1.0
II	Public utility facilities and buildings with big human capacity	1.25
III	Designated as essential facilities such as hospital, fire station, rescue station, police station, etc.	1.5
IV	Structures of low hazard to human life such as agriculture, certain temporary, etc.	1.0

Commentary E

Simplified dead load judgment index I_{SD0} is defined as $I_{SD01}$is 0.4 * Fc (N/mm^2) based on the JBDPA Standard, 2001.

Fig. C5 shows relations of Dead Load Capacity and Ultimate Horizontal Deflection Angle relations after JBDPA Standard, 2001. From this Figure, in the region above $0.4N_S/(bDF_C)$, the ultimate horizontal deflection angle is defined as 0.005 of quite small value. Furthermore, performed testing data are given between only $0.4N_S/(bDF_C)$ and $0.7N_S/(bDF_C)$. In this evaluation method as for critical limited value I_{SD01} for the dead load judgment of column is assumed as $0.4N_S/(bDF_C)$ and as for the most critical value I_{SD02} is assumed as $0.7N_S/(bDF_C)$, respectively.

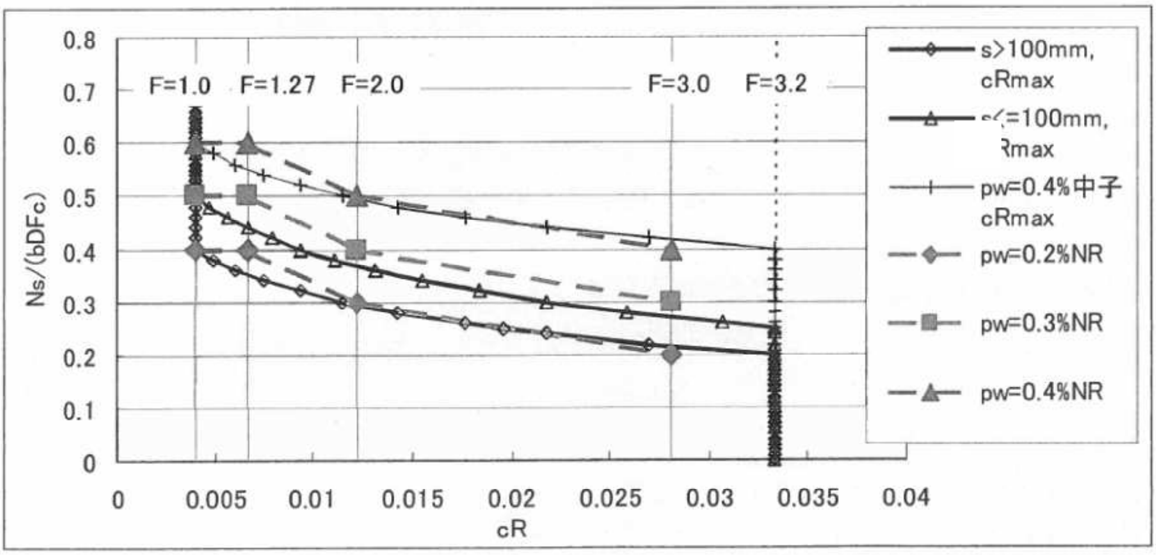


Figure C5. **Dead Load Capacity - Ultimate Horizontal Deflection Angle Relations (JBDPA, 2001)**

7. Conclusion

In this paper,a simplified seismic evaluation method was discussed and proposed for utilizing to the preliminary screening stage for the developing countries.

The target building is the reinforced concrete moment resisting frame building. Seismic evaluation is basically based on the philosophy of the Japanese Seismic Evaluation Standard for existing reinforced concrete buildings issued by The Japan Building Disaster Prevention Association (JBDPA Standard, 2001) and International Building Code, 2000 (IBC, 2000).

As for the final judgment by the simplified structural evaluation, the vulnerability evaluation on two items, such as (i) Seismic capacity by horizontal seismic load and (ii) Gravity load capacity by dead load were proposed.

8. Acknowledgement

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