PROPOSAL OF A NEW DETAIL SEISMIC EVALUATION METHOD BASED ON JAPANESE AND AMERICAN EAVALUATION STANDARDS FOR THE EXISTING RC BUILDINGS

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Abstract

In most of the developing countries in the world, there are large number of existing reinforced concrete (RC) buildings which are very vulnerable to earthquake due to a lack of widespread availability of seismic evaluation standards and low construction quality. Those countries need urgently to conduct the seismic evaluation of existing buildings to judge whether the seismic retrofit is necessary or not, but they do not have enough knowledge and technology for doing. In case of international activity on seismic evaluation, the Japanese technical engineers with much experience and technology can be providing support for them to establish their own seismic evaluation methods based on the structural characteristics of their buildings, referring to the existing Japanese and the American standards. But it is regrettable to say that those methods have not yet been widely applied. The primary reason is that it takes much time to be familiar with the Japanese seismic evaluation method. Most of those countries use the American standards such as ASCE41-13, etc., but they were not also commonly used, because of lack of awareness and of difficulty for conducting. The Japanese seismic evaluation method targets mainly the weak-column buildings designed by the old Japanese building code so that it is insufficient to accurately estimate the weak-beam buildings which are designed by the American standard, but it has an advantage of being able to indicate the seismic capacity of a building as a simple seismic index. The American seismic evaluation method can evaluate the actual behaviors of weak-beam buildings during the earthquake, but it requires a large amount of knowledge and experience of structural design to estimate seismic capacity.

Considering the above situation, we proposed a new detail seismic evaluation method which based both on the Japanese and the American methods but more rational and practical one. With this new method, it is easier to evaluate the accurate seismic capacity of RC existing buildings, easier to rank the seismic capacity of larger number of buildings by using the seismic capacity index and be able to calculate easily how much retrofit quantity are needed.

This paper discusses this new detail seismic evaluation method and shows an example of evaluation and a retrofit plan applied to an actual building.

Keywords: Seismic Evaluation; Seismic Retrofit; Developing Countries; Japanese Standard; American Standard

1. Introduction

The buildings of the earthquake prone developing countries are vulnerable in general. For these countries, as they don't have own standards on seismic evaluation and retrofit, the development of the seismic evaluation and seismic retrofit are urgent. In case they need these standards in practical applications, they are trying to use the American seismic evaluation standards for the existing buildings, such as ASCE/SEI41-13 (hereafter we call ASCE41) [1], because they are familiar with the American seismic code for structural design of the new buildings. But unfortunately, these American evaluation standards are very complicated and hard for calculation and it is very rare to use, because of lack of knowledge and experience of structural engineers.

Base on the above situation, we are proposing a new detail seismic evaluation harmonizing the Japanese seismic evaluation standard; JBDPA (Japan Building Disaster Prevention Association) [2] and American seismic evaluation standards; ASCE41and ATC40 [3]. The benefit of Japanese standard is that the seismic capacity can be expressed as one simple seismic index and the quantality of retrofit can be calculated easily. On the other hand, American standards consist of the combination of the response spectrum and the capacity curve and the acceptance criteria for each structural member. From both the Japanese and the American standards procedures, the target capacity and the performance level for each member in the nonlinear stage can be obtained clearly.

In this paper, the content of the proposed detail seismic evaluation method and one example building applied by the proposed method are discussed.

2. Seismic evaluation standards of Japan and America

2.1 The Japanese seismic evaluation method

The concept of the Japanese seismic evaluation standard [JBDPA] is introduced here. The seismic index of structure I_S is calculated by Equation (1). The calculation is done at each story and in each principal horizontal direction of a structure.

$$I_S = E_0 \times S_D \times T \qquad (1)$$

Where:

E_0 : Basic seismic index of structure

S_D : Irregularity index

T : Time index

$$E_0 = C \times F \qquad (2)$$

C : Strength index

F : Ductility index

The most important index Eo is calculated by Equation (2). In this equation, F index is the ductility index and means the maximum response ductility to the target seismic ground motion level. F index of Japanese method is based on Fig. 1 (a). This is based on the constant energy principle by J.A. Blume, N.M. Newmark et al. [4]. It is said that this principle can be applied to the building which has a short fundermental period. On the other hand, the American seismic design code adopts the Fig. 1(b), based on the constant displacemment principle, and used for the buildings which has a long fundermental peiod. In this paper, adopts the latter as F index.

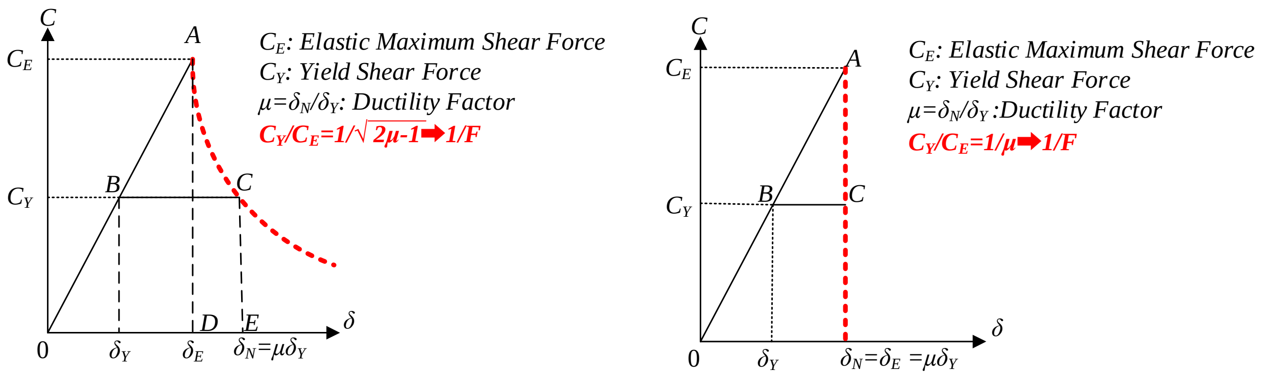
The seismic demand index Iso is calculated by Equation (3)

$$I_{S0} = E_S \times Z \times G \times U \qquad (3)$$

Where, Es: Basic seismic demand index, Z: Zone index, G: Ground index and U: Usage index

Seismic safety of building shall be judged by Equation (4)

$$I_S \geq I_{S0} \qquad (4)$$



(a)Constant Energy Principle (b)Constant Displacement Principle

Fig. 1 – Constant Energy Principle and Constant Displacement Principle

2.2 The American seismic evaluation method

The American seismic evaluation method employed here is composed of the following two items:

a) In order to determine the seismic demand index; Iso, the initial elastic demand spectrum (Damping =5%) and the capacity curve are used. The procedur will be described in detail in the following section 3.

b) The performance level of each structural member on the process of pushover analysis is decided based on ATC40. The example of hinge mechanism and acceptance criteria is shown in Fig.2 and Fig.3, respectively. Three acceptance criteria [ATC40, ASCE41]: Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP) are shown in Fig.3. For the proposed evaluation method, CP point is adopted as the performance limit displacement for the capacity of the structure.

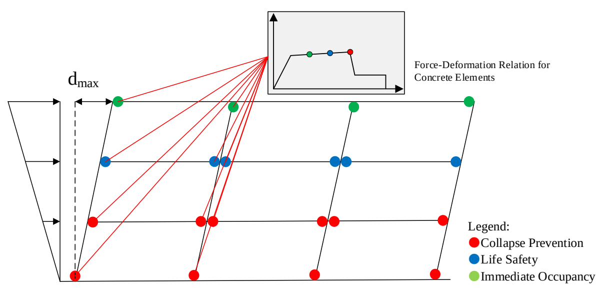


Fig. 2 –Example of hinge mechanism by pushover analysis

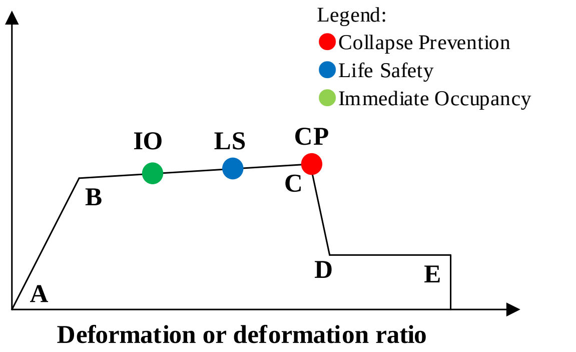


Fig. 3 –Acceptance Criteria for Nonlinear Procedures-Structural members (ATC40, ASCE41)

3. The proposed detail seismic evaluation method

The proposed detail seismic evaluation method consists of the following four steps:

(1) Calculate the seismic demand index: Iso
(2) Calculate the seismic index: Is
(3) Judge the seismic safety of building
(4) If the seismic capacity is insufficient, calculate the required strength

3.1 The seismic demand index: Iso

Spectral acceleration vs. Spectral displacement curve is shown in Fig. 4. This figure shows the initial elastic demand spectrum (Damping =5%) and the capacity curve obtained by pushover analysis. According to the capacity spectrum method [ATC 40], the intersection of elastic stiffness of capacity curve and response spectrum (Point A in the figure) is defined as the demand seismic acceleration: a, and also is defined as the seismic demand index: Iso.

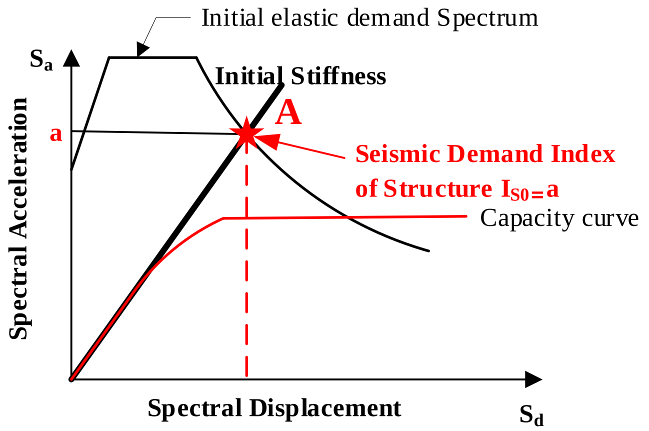


Fig. 4- Seismic Demand Index of Structure: I_{S0}

3.2 The seismic index: Is

The seismic index Is is calculated by Equation (1) and (2). The spectral acceleration vs. spectral displacement curve is shown in Fig. 5.

The seismic index $_{CP}I_S$ at CP point and $_{LP}I_S$ at LP point shall be calculated as following Equations (5) and (6), respectively.

$$_{CP}I_S = {}_{CP}C \times {}_{CP}F = {}_{CP}C \times {}_{CP}\mu \quad (5)$$

$$_{LP}I_S = {}_{LP}C \times {}_{LP}F = {}_{LP}C \times {}_{LP}\mu \quad (6)$$

Where,

CP point: A point where the collapse prevention at some members in the structure occurred.

$_{CP}C$: Strength index at CP point

$_{CP}F$: Ductility index at CP point

LP point: A point where the limited displacement defined in the seismic code occurred. Generally, 0.02 story drift ratio is defined as criteria.

$_{LP}C$: Strength index at LP point

$_{LP}F$: Ductility index at LP point

$$I_S = \mathrm{Min}\left({}_{CP}I_S, {}_{LP}I_S\right) \quad (7)$$

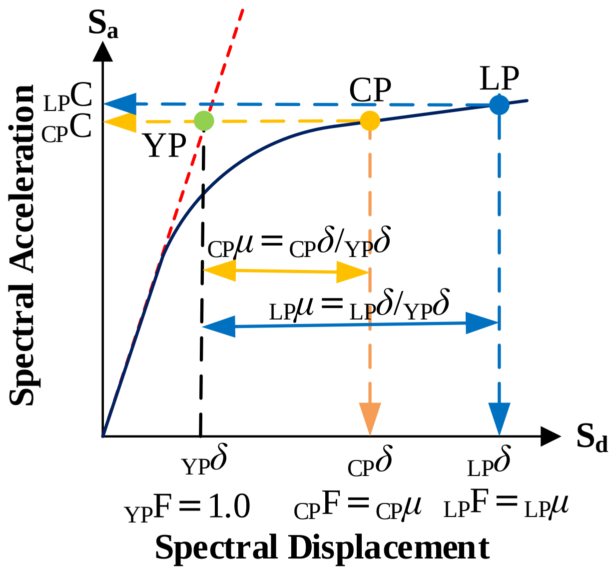


Fig. 5 – Evaluation of C index and F index by CP point and LP point

Table 1-Legend of each point in Fig. 5

Point	Yeild ●	Collapse Prevention of member●	Limited Displacement of building ●
Notaion	YP	CP	LP
Strength	$_{YP}C$	$_{CP}C$	$_{LP}C$
Deformation	$_{YP}\delta$	$_{CP}\delta$	$_{LP}\delta$

3.3 Judgment of seismic safety

Seismic safety of structure shall be judged by Equation (8).

$$I_S = \mathrm{Min}\left({}_{CP}I_{S}, {}_{LP}I_S\right) \geq I_{S0} \quad (8)$$

Table 2 shows the potential case of judgment. The final Is becomes different according to the displacement magnitudes between at CP point and at LP point. The judgment cases corresponding to Table 2 are illustrated in Fig. 6.

Table 2- Potential case of judgment

Comparison between I_S and I_{S0}	Case	Judgment
$I_{S0} \leq I_S = \mathrm{Min}({}_{CP}I_S, {}_{LP}I_S)$	Case I, II	Safe
$I_{S0} > I_S = \mathrm{Min}({}_{CP}I_S, {}_{LP}I_S)$	Case III	Unsafe

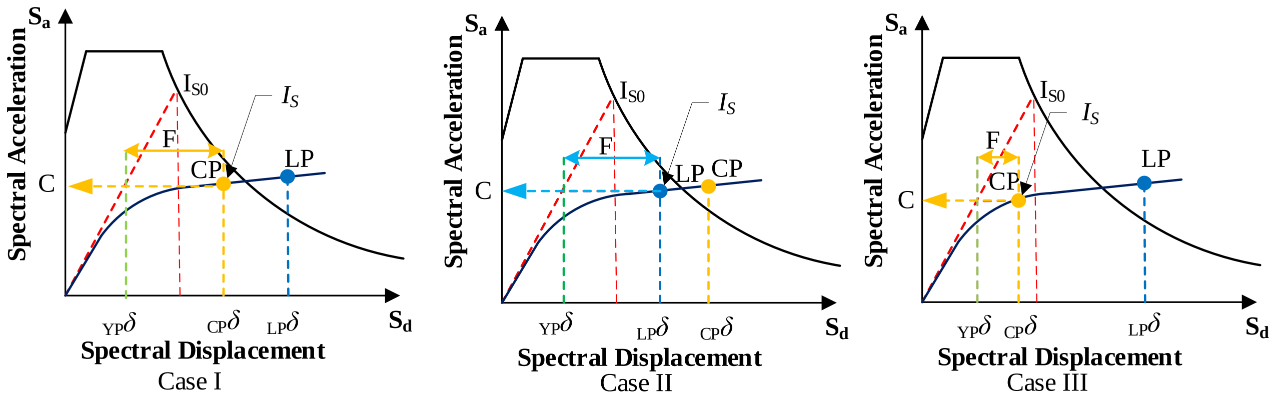


Fig. 6 – Potential case of judgment

3.4 Required shear strength for retrofit

After judgment by Equation (8), if the seismic capacity is insufficient, the retrofit plan shall be implemented. The procedure of calculation of the required strength is described below. The outline of the procedure is shown in Fig. 7. This is a case that CP point is less than LP point.

The following shows the calculation step according to Fig. 7.

Step 1: Draw the vertical line from CP point to the elastic demand spectrum. The intersection point is defined as retrofitted Iso ($_{AR}I_{SO}$) at A point.

Step 2: Assume the $_{AR}F$ index after retrofit is same as before retrofit at CP point. The F index at CP point is defined as the ratio of $_{CP}\delta$ at CP point to $_{YP}\delta$ at YP point. YP point is an intersection of the horizontal line from CP point and the initial stiffness line.

Step 3: Look for the AR point satisfying the $_{AR}F$ index on the straight line: OA. The strength index at AR point is defined as $_{AR}C$.

Step 4: Calculate the required strength index $_{AR}\Delta C$ is calculated as $_{AR}\Delta C = {}_{AR}C - {}_{CP}C$.

Step 5: Calculate the required strength at ground floor is calculated as $Q = {}_{AR}\Delta C \times W$. Where, W is effective seismic weight of building.

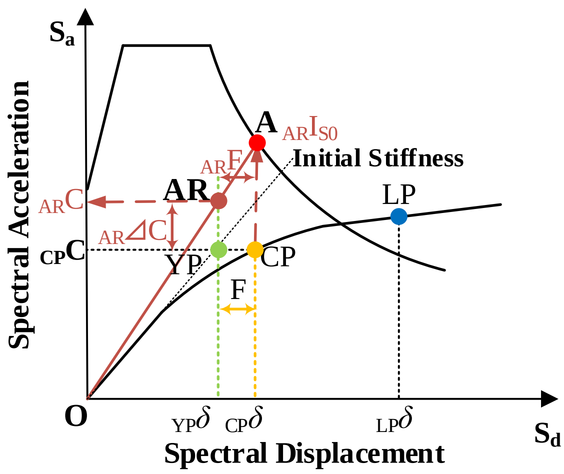


Fig. 7- Calculation procedure of the required strength at ground floor

4. An example building applied by the proposed method

4.1 Outline of building

We evaluated a six-story office building in Dhaka, Bangladesh using our proposed seismic evaluation method. The building information is outlined below.

Table 3 –Building Information

Name of building	Office A		
Location	Dhaka	Building height	19.81m
Occupancy	Office	Total of the effective seismic weight	13308kN
Year Built	1980	Concrete (f'_c)	11.2N/mm^2
Number of stories	6 stories	Reinforcing bar (f_y)	420N/mm^2
Building area	262.2m^2	Soil type	SD
Total floor area	1,573.2m^2	Seismic zone	2

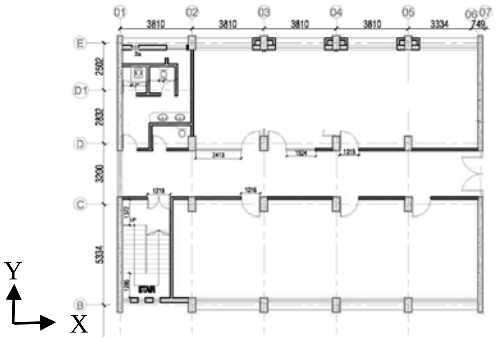


Fig. 8 – Typical Floor

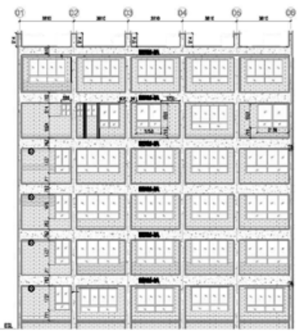


Fig.9 – Elevation

4.2 Seismic evaluation

The design spectrum of BNBC2015 Draft [5] was used as the demand spectrum. For analysis, we used the commercial software ETABS (Computers and Structures, Inc.), which is widely used for designing new buildings in South and Southeast Asian countries. In this paper, we show the analysis for the X direction.

Fig. 10 and Fig. 11 show the result of the pushover on plastic hinge occurrence at the first CP and at the final step respectively. CP occurred at the end of a grade beam of the grid C in Step4. Grade beams are generally very vulnerable in the country due to insufficient depth. After the first CP, many of hinges occurred to surrounding grade beams, which finally led to the story collapse of the ground floor.

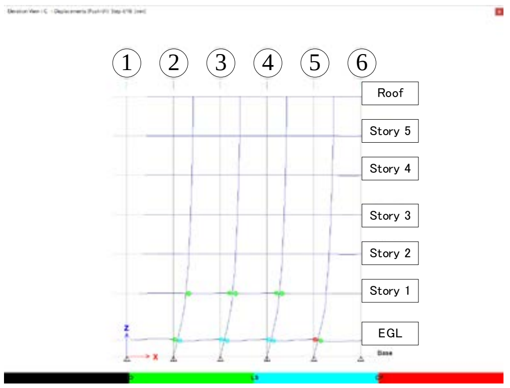


Fig. 10 – Plastic hinges at the first CP (Grid C)

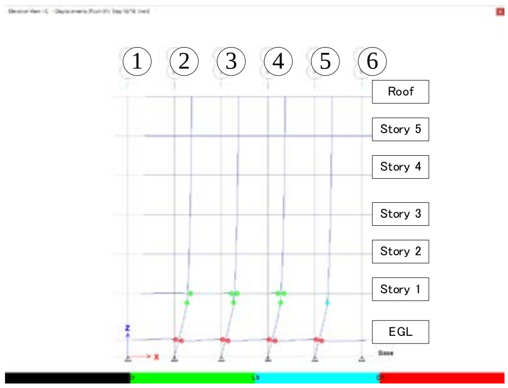


Fig. 11 – Plastic hinges at the final step (Grid C)

Fig. 12 shows the result of the seismic evaluation and I_S. As the building collapses before it reaches LP, evaluation is not performed on LP. As a result, I_{S0} becomes greater than I_S (I_{S0} = 0.42 > I_S = 0.36) and it is judged that this building may not have adequate seismic capacity.

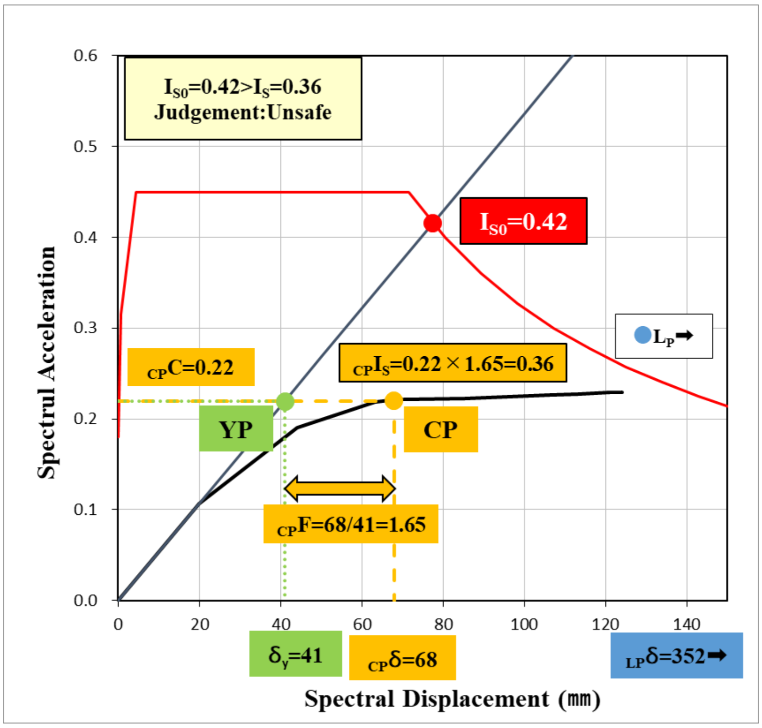


Fig. 12 – I_{S0} index and I_S index before retrofit

4.3 Seismic retrofit

One of the reasons why Japan's assessment method is adopted is that required shear strength for retrofit is estimated by section 3.4, in other words, that the seismic capacity can be judged by comparing the target capacity with the index obtained by multiplying strength and ductility. Shear walls are usually used to suppress deformation only. Shear walls are hardly used for retrofit, but columns and beams are usually used as improving in the deformation or the strength capacity. It is expected that estimating the required strength using the proposed method will facilitate the strength reinforcement type retrofit using shear walls, etc. Fig. 13 shows how the required strength for retrofit is obtained.

a) The target seismic capacity after retrofit ${}_{AR}I_S$, as it is the deformation of Min(${}_{CP}\delta$,${}_{LP}\delta$) or below, is to be the intersection point of a vertical line from ${}_{CP}\delta$ with the demand spectrum. Therefore ${}_{AR}I_S$ = 0.45.

b) As the ductility capacity after retrofit is assumed to be equal to or below the ductility index F at the time of the evaluation, which is Min(${}_{CP}F$, ${}_{LP}F$) during the evaluation, it is the same as ${}_{CP}F$ and therefore ${}_{AR}F$ =1.65.

c) The required strength ${}_{AR}\Delta C$ is shown below.

$${}_{AR}\Delta C = {}_{AR}I_{S0} / {}_{AR}F - \mathrm{Min}({}_{CP}C, {}_{LP}C) = 0.45/1.65 - 0.22 ≒ 0.06$$

The required strength for the ground floor is calculated as: 0.06×13,130 ≒ 790 kN

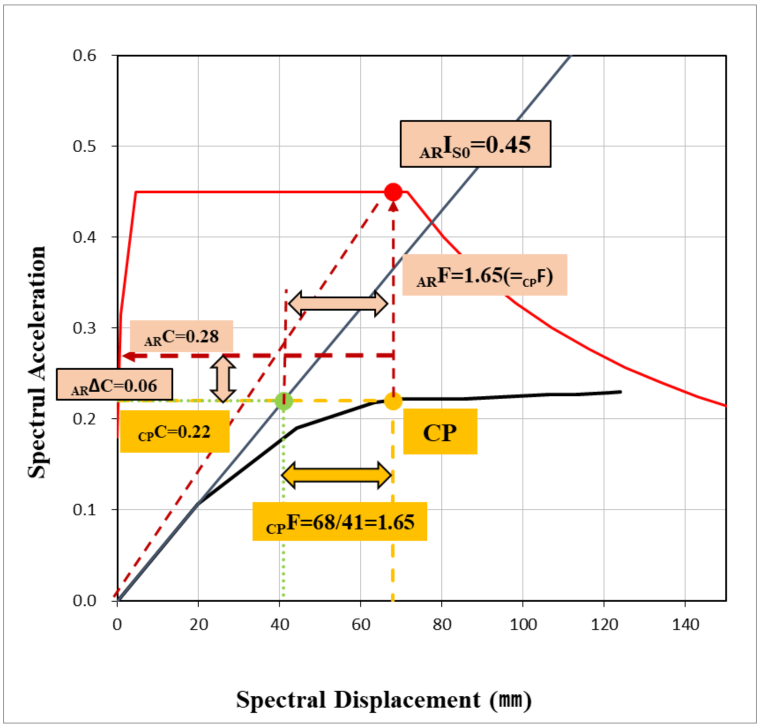
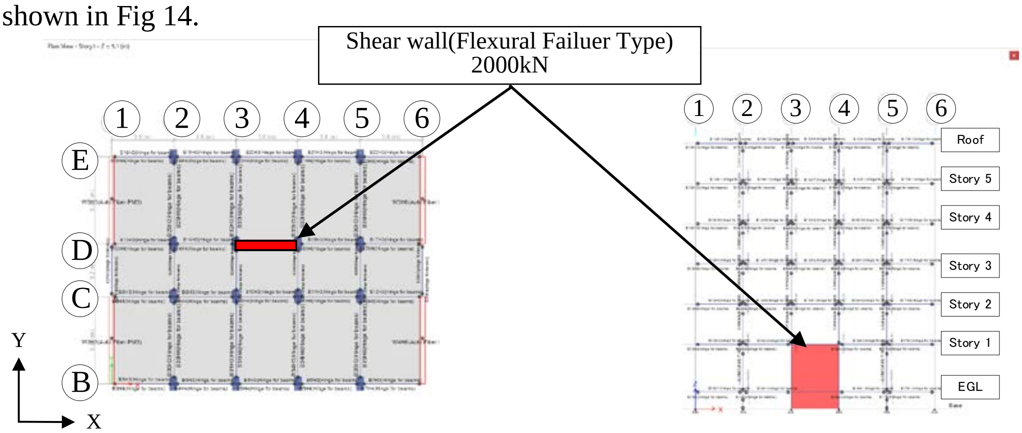


Fig. 13 – Example for estimation of required strength

The collapse mode of the target building is the story collapse of the ground floor. No plastic hinges occur on the upper floors. CP occurs at the end of the grade beam in many places. However, it is not practical in terms of workability and cost to provide flexural reinforcement to all the beams where CP occurs. Our retrofit plan is to install an RC shear wall for ductility (flexural failure type) of 2000 kN or more on the ground floor. We aim to concentrate stress on the shear wall and to suppress deformation so as to prevent CP on the grade beams as shown in Fig 14.



(a) Plan after retroffit (Grand floor) (b)Eelevation after retroffit (Grid D)

Fig. 14 – Retrofit plan

<Calculation After Retrofit>

The analysis is performed for the X direction in this paper. Fig. 15 shows the result of the pushover on hinge occurrence at first CP after retrofit at Grid C.

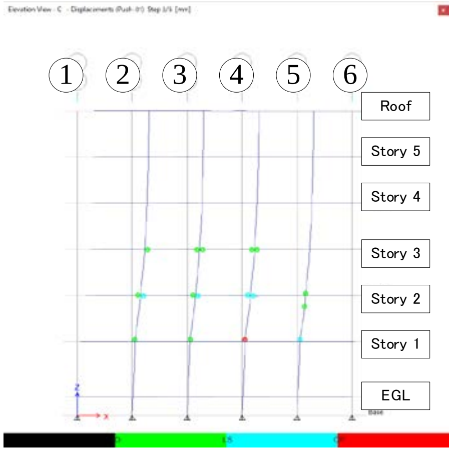


Fig. 15 – Plastic hinges at just first CP after retrofit (Grid C)

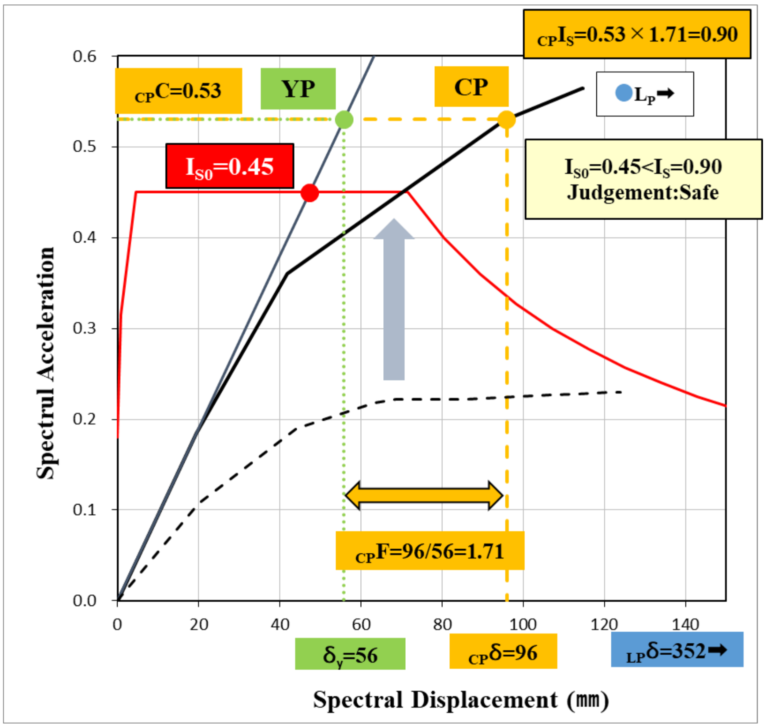


Fig. 16 – I_{S0} index and I_S index after retrofit

The collapse mode is story collapse of the first floor. As we have planned, no hinges occur on the ground floor, due to the suppression of deformation because of the shear walls. Fig. 16 shows the capacity curve result and I_S. As the building collapses before it reaches LP, evaluation is not performed on LP. As a result, I_{S0} becomes smaller than I_S (I_{S0} = 0.45 < I_S = 0.90) and this building is evaluated safe as shown in Table 4.

Table 4 –Comparison of Is index before after retrofit

	δ(mm)	F	C	Is	Iso	Judgment
Before Retrofit	68	1.65	0.22	0.36	0.42	Unsafe
After Retrofit	96	1,71	0.53	0.90	0.45	Safe

We have compared the indexes before and after retrofit in Table 4. The resulting I_S index before retrofit is less than I_{SO}. The Is after retrofit is larger than the prediction, because the shear wall strength with 2,000kN is installed against the required strength 790kN in this trial retrofit planning.

5. Conclusion

We have proposed adopting the basic concept of Is index based on the Japanese seismic evaluation standard to the constant displacement principle used as the basic design concept in the USA and some other countries. The characteristics of the seismic capacity proposed in this paper can be evaluated by the important parameters such as seismic index I_S, strength index C, ductility index F, LP point and CP point on the capacity curve, etc. This method makes it easier to compare the seismic capacity of a building with that of another building. Furthermore, the required strength for sufficient capacity has been easily estimated using the proposed estimation method. In other words, it is a very effective and rational approach for retrofit planning.

6. Acknowledgements

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