

Seismic performance evaluation of existing building using Seismic Index method

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Abstract. Indonesia has frequently suffered major damaging earthquakes over the past 50 years. There are thousands of buildings in earthquake-prone regions that require seismic evaluation and rehabilitation. This paper describes a study about the seismic evaluation of existing buildings using seismic index method based on a Japanese standard. The basic seismic index is calculated based on the criteria of strength and ductility. Two existing buildings have been evaluated in this research. The first building consists of five stories and the second one has four. The seismic index of the structure has a different value for each story. The minimum seismic index occurs on the ground floor, and the index increases as the number of stories increase. The top floor has the maximum seismic index of all stories. The structure's seismic safety shall be judged if the seismic index (I_s) is greater than the seismic demand index (I_{so}). As a result of the evaluation, buildings A, and B are in an unsatisfactory condition. Especially for the three lower floors of both of buildings. It is also confirmed by drift angle that they exceed the required limit. To sum up, evaluation by using Japanese standards can be applied to building conditions in Indonesia.

1 Introduction

Indonesia has frequently suffered major damaging earthquakes over the past 50 years. It is difficult to estimate precisely the magnitude of the earthquakes that will occur during the life of a building. Still, there are thousands of buildings in earthquake-prone regions that require seismic evaluation and rehabilitation [1]. The Japanese standard for the seismic evaluation of an existing building was introduced in this research. The Japan Building Disaster Prevention Association, JBDPA publish a standard for the seismic evaluation of an existing building and guidelines for the retrofitting of existing reinforced concrete buildings. A seismic screening procedure as a practical tool to identify vulnerable buildings was initially developed in 1977. This method became vital after new sets of rules and laws for the seismic design of buildings was issued in 1981, and severe earthquake damage was recorded for buildings constructed before 1981. The standard for the seismic evaluation of buildings has been widely used to evaluate the seismic capacity of existing buildings.

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2 Case study

There are two buildings evaluated in this study. The first is a five-story apartment building namely building A and the second is a four-story office building namely building B. Both buildings located in Indonesia and were designed by using the Indonesian code [2, 3]. Building A has an area 1360 m² per floor. The structure is a space frame which is made by reinforced concrete f_c' 25 MPa. The building has a typical floor plan and height in each floor as shown in Fig. 1.

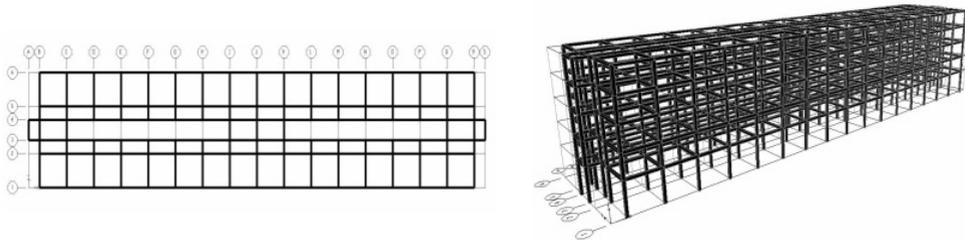


Fig. 1. Typical floor plan and perspective structure of building A.

Building B has an irregular floor plan as presented in Fig. 2. Total area per floor is 1008 m². The building has a typical area and height in each floor. The structure is a reinforced concrete space frame with f_c' 25 MPa.

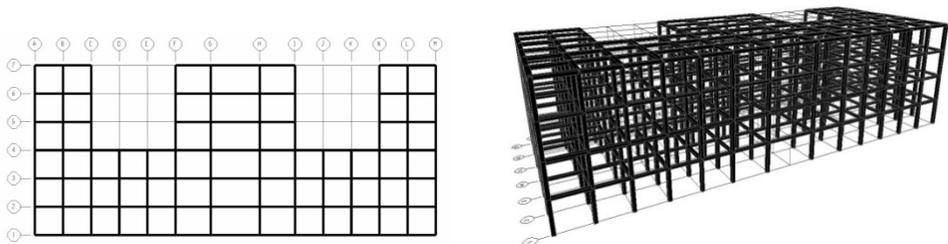


Fig. 2. Typical floor plan and perspective structure of building B.

3. Methodology

The Japanese standard for seismic evaluation [4] is introduced in this research. This standard consists of three distinct levels of procedures to determine the seismic index of an existing structure. The first level procedure is the simplest and most conservative. Only the strength of concrete and the sectional areas of columns and walls are considered to estimate the seismic capacity, and the ductility is neglected. The second level procedure evaluates the seismic building capacity based upon the strength and ductility of columns and walls assuming a strong beam concept. The third level procedure considers the strength of beams in addition to the strength of columns and walls to evaluate the seismic capacities of buildings, which are expected to be identified as beam failure types. This study adopted the second level screening procedure to calculate the seismic index.

In the end analysis, to verify this method is suitable with the condition of earthquake load in Indonesia, the capacity spectrum method is conducted. The drift angle when the performance point is reached will be analyzed to confirm the feasibility of the structure.

3.1 Seismic index of structure

Seismic Index (I_s), which is defined in the Japanese Standard is calculated by the Eq. 1 for each story and in each principal horizontal direction of the structure. Whereas (I_s) is related to the basic seismic index (E_o), time index (T), and irregularity index (S_D).

$$I_s = E_o \cdot S_D \cdot T \quad (1)$$

The primary seismic index (E_o) for each of the screening levels, calculated differently, however, is generally approximated by multiplying the shear modification factor, strength index and ductility index of each story. The irregularity index (S_D) is introduced to adjust the basic seismic index by measuring the effects of horizontal and vertical shapes, and the mass and stiffness irregular distribution of the structure following engineering judgment. The time index (T) is a modification factor of the basic seismic index which evaluates the effects of cracks, deflection, and aging of building through screening procedure defined in the Japanese standard for the seismic evaluation of an existing building.

3.1.1 Basic seismic index of structure

The primary seismic index of structure E_o , which is to evaluate the basic seismic performance of the building, shall be calculated for each story and each direction based on the ultimate strength, failure mode and ductility of the building. The primary seismic index of structure E_o of the i -th story in an n -story building is given as a product of strength index C and ductility index F , differently in the first, the second, or the third level screening procedure. The primary seismic index of structure E_o shall be taken as the larger one from Eq. 2 for ductility-dominant and Eq. 3 for strength-dominant.

$$E_o = \frac{n+1}{n+i} \sqrt{E_1^2 + E_2^2 + E_3^2} \quad (2)$$

$$E_o = \frac{n+1}{n+i} \left(C_1 + \sum_j \alpha_j \cdot C_j \right) \cdot F_1 \quad (3)$$

Where E is the multiple strength index C and ductility index of the first, second and third group. α is the effective strength factor for the j -th group.

3.1.2 Irregularity and time index

The irregularity index (S_D) is to modify the basic seismic index of structure E_o by quantifying the effects of the shape complexity, as well as the stiffness, unbalance distribution, and the like on the seismic performance of a structure with engineering judgment. Items to be considered for first level screening are related to the structural integrity of the floor plan and the sectional plan. Floor plan regularity, aspect ratio, narrow part, expansion joint, well-style hall are some aspects that should be considered. Items related to the sectional plan such as the existence of a basement, uniformity of story height and presence of pilotis. The following items are added to second level screening such as the distance between the centroids of gravity and the ratio of stiffness of the lower story to the upper story.

The time index (T) evaluates the effects of the structural defects. Item to be considered to calculate the time index consist of deflection, cracking in walls and columns, fire experience, occupation function, the age of building and finishing condition. If a defective

item is found the T value will be at range 0.7 to 0.9 but if there is no defect, the T value is 1. Building older than 30 years have a T value of 0.8, but for newer buildings less than 19 years old the T value should be equals to 1.

3.2 Seismic demand index

The seismic demand index of structure I_{so} should be calculated by Eq. 4 regardless of the number of stories in the building.

$$I_{so} = E_s \cdot Z \cdot G \cdot U \quad (4)$$

Where E_s is the basic seismic demand index of the structure, standard values of which shall be selected as 0.8 for the first level screening and 0.6 for the second and third level screenings. Z is zone index, namely the modification factor accounting for the seismic activities and intensities expected in the region of the site. G is a ground index, namely the modification factor accounting for the effects of the amplification of the surface soil, geological conditions and soil-and-structure interaction on the expected earthquake motions. U is the usage index, namely the modification factor accounting for the building.

The seismic safety of a structure shall be judged by comparing the seismic index of structure (I_s) and seismic demand index (I_{so}) as written in Eq. 5. If Eq. 5 is satisfied, the building may be assessed to be “safe”. Otherwise, the building should be assessed to be “an uncertainty” in seismic safety. In the second level screening, a structure shall also be judged by considering cumulative strength index and irregularity index by Eq. 6.

$$I_s \geq I_{so} \quad (5)$$

$$C_{TU} \cdot S_D \geq 0.3 \cdot Z \cdot G \cdot U \quad (6)$$

Where C_{TU} is the cumulative strength index at the ultimate deformation of structure. S_D is the irregularity index.

4. Seismic evaluation

Two existing buildings have been evaluated in this paper. Example calculation of the seismic index for building A on the 5th floor can be seen as follow.

Story modification factor on the 5th floor (C_5),

$$C_5 = \frac{n+1}{n+i} = \frac{5+1}{5+5} = 0.6 \quad (7)$$

The 5th floor only has one group ductility index which equals 3.11. Due to that, E_2 and E_3 value are equal to 0 in the ductility dominant basic seismic index. The total of strength factor for the other group for the strength dominant basic seismic index ($\sum_j \alpha_j \cdot C_j$) is also 0.

Ductility dominant basic seismic index,

$$E_0 = \frac{n+1}{n+i} \sqrt{E_1^2 + E_2^2 + E_3^2} = 0.6 \sqrt{(0.68 \times 3.11)^2 + 0^2 + 0^2} = 1.27 \quad (8)$$

Strength dominant basic seismic index,

$$E_o = \frac{n+1}{n+i} \cdot \left(C_1 + \sum_j \alpha_j \cdot C_j \right) \cdot F_1 = 0.6(0.68 + 0) \cdot 3.11 = 1.27 \quad (9)$$

The selected basic seismic index should be taken as the largest (8) and (9), that is 1.27. Seismic index of structure for the 5th floor, In which, the irregularity index S_D is equal to 1.0 and the time index T is also equal to 1.0 as follow,

$$I_s = E_o \cdot S_D \cdot T = 1.27 \times 1.0 \times 1.0 = 1.27 \quad (10)$$

The second parameter for evaluation is the multiplication of the cumulative strength (Ctu) and the irregularity index (S_D).

$$Ctu \cdot S_D = (0.60 \times 0.68) \times 1.0 = 0.41 \quad (11)$$

The seismic index evaluation for building A and B are presented in Table 1 and Table 2 respectively. The seismic index of building A in the longitudinal direction is higher compared to transversal. However, in the longitudinal direction, the three top floors are satisfactory, and in the transversal direction, only the fifth story is considered to be satisfactory.

Table 1. Seismic evaluation of Building A.

Direction	Story	I_s	$Ctu \cdot S_D$	I_{so}	Evaluation		
					$(I_s \geq I_{so})$	$(Ctu \cdot S_D \geq 0.3)$	Judgment
Transverse	5	1.27	0.41	0.6	Safe	Safe	Satisfactory
	4	0.61	0.28	0.6	Safe	Uncertain	Unsatisfactory
	3	0.42	0.24	0.6	Uncertain	Uncertain	Unsatisfactory
	2	0.38	0.23	0.6	Uncertain	Uncertain	Unsatisfactory
	1	0.35	0.23	0.6	Uncertain	Uncertain	Unsatisfactory
Longitudinal	5	1.65	0.53	0.6	Safe	Safe	Satisfactory
	4	1.02	0.36	0.6	Safe	Safe	Satisfactory
	3	0.81	0.32	0.6	Safe	Safe	Satisfactory
	2	0.69	0.28	0.6	Safe	Uncertain	Unsatisfactory
	1	0.64	0.29	0.6	Safe	Uncertain	Unsatisfactory

Similar to building A, the seismic index of building B in the longitudinal direction is higher compared to transversal. However, only on the fourth floor is considered to be satisfactory in both directions.

Fig. 3 shows the seismic index for each story in graph line mode. The minimum seismic index occurs on the ground floor, and the index will increase as the number of stories increase. The top floor has the maximum seismic index of all stories.

Table 2. Seismic evaluation of Building B.

Direction	Story	I_s	$Ctu.S_D$	I_{so}	Evaluation		
					$(I_s \geq I_{so})$	$(Ctu.S_D > 0.3)$	Judgment
Transverse	4	0.74	0.31	0.6	Safe	Safe	Satisfactory
	3	0.43	0.25	0.6	Unsafe	Unsafe	Unsatisfactory
	2	0.34	0.20	0.6	Unsafe	Unsafe	Unsatisfactory
	1	0.32	0.25	0.6	Unsafe	Unsafe	Unsatisfactory
Longitudinal	4	0.83	0.38	0.6	Safe	Safe	Satisfactory
	3	0.50	0.26	0.6	Unsafe	Unsafe	Unsatisfactory
	2	0.40	0.23	0.6	Unsafe	Unsafe	Unsatisfactory
	1	0.37	0.24	0.6	Unsafe	Unsafe	Unsatisfactory

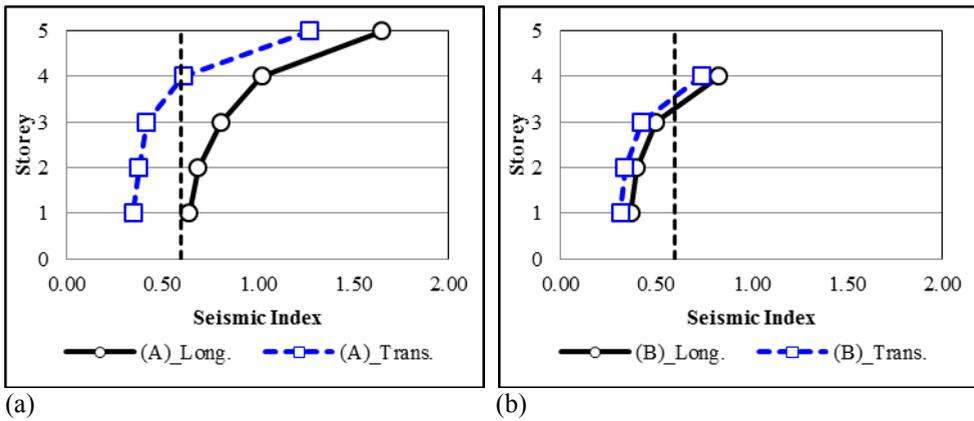


Fig. 3. (a) Building A seismic index, (b) Building B seismic index.

Building A has a seismic index greater than 0.6 for each story in the longitudinal direction. The first to third story in the transversal direction is considered to be strengthened due to being less than 0.6. Building B has on the fourth floor which considered satisfactory.

Table 3. Seismic index (I_s) and seismic demand index (I_{so}).

Building	Seismic Index (I_s)		Seismic demand Index (I_{so})	Evaluation
	Transverse	Longitudinal		
Building A	0.35	0.64	0.6	Unsatisfactory
Building B	0.32	0.37	0.6	Unsatisfactory

The other floors have a seismic index below 0.6. Although the number of floors in building B is less than in building A, the condition of building B is worse than Building A. This is because building B has an irregular floor plan so that the number of columns as vertical elements which resist lateral load is less.

To conclude the seismic index value of a building can be used the most conservative value being the seismic index on the ground floor. So the index for these two buildings can be expressed as in Table 3.

5. Capacity spectrum method

Seismic demand index in the previous section is based on hazard conditions due to earthquake loads in Japan. The Capacity Spectrum Method (CSM) [5] is carried out to investigate the performance points of building A and B based on an Indonesian seismic load. The method compares the capacity of the structure with the demands on the structure (in the form of a response spectrum). The graphical intersection of the two curves approximates the response of the structure. In order to account for the non-linear inelastic behavior of the structural system, effective viscous damping values are applied to the linear-elastic response spectrum similar to an inelastic response spectrum.

The demand response spectrum of Padang city based on the Indonesian seismic load standard is applied in this method. Where spectral acceleration at 0.2 seconds is 1.398 and at 1 second is 0.6. Site coefficient F_a and F_v are 1 and 1.5, respectively. Fig. 4 shows the graphical of capacity and performance point in building A and B. Spectral acceleration in the transversal direction is higher than in the longitudinal direction in both buildings.

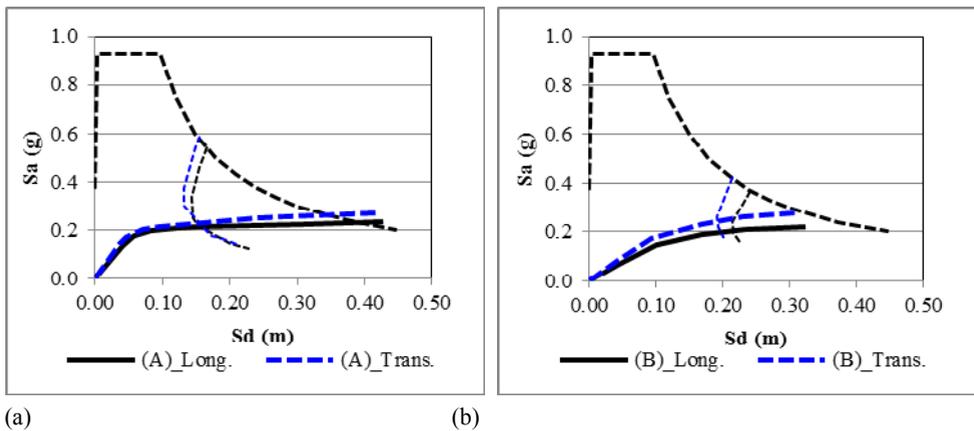


Fig. 4. Capacity curve and performance point of (a) Building A and (b) Building B.

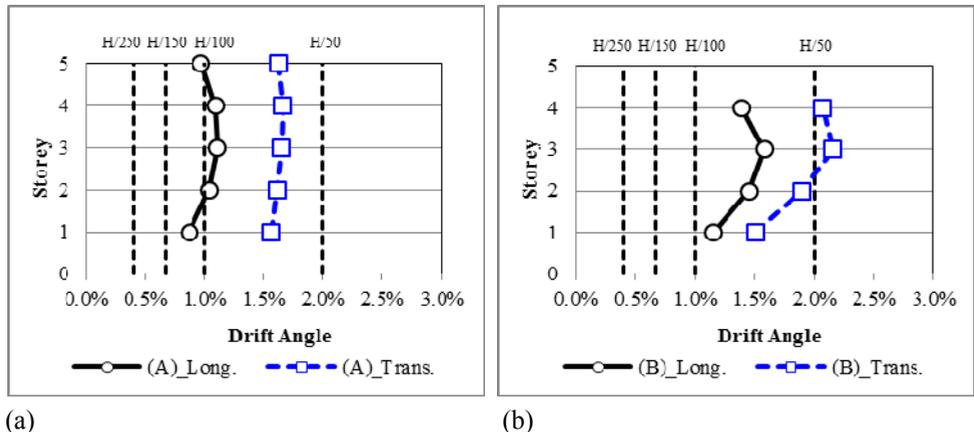


Fig. 5. Drift angle at performance point of (a) Building A and (b) Building B.

At the step in the performance point was determined inter-story drift and drift angle of the both of building. The drift angle at the performance point can be seen in Figure 5. The vertical dash line in this figure indicates the drift angle limit. The drift angle of building A and B for all direction has a value higher than 0.67% (1/150). Only on the first floor of building A has a drift angle below 1.0% (1/100) whilst the others have drift angle beyond 1.0%. Related to this, ASCE 7-10 [6] explains that the drift angle limit for a basic structure system for all risk categories is 1.0% (1/100).

As the correlation between the results of the seismic index calculation based on Japanese standard and the drift requirements as per ASCE are in accord, it can be concluded that this method can be applied to evaluate existing structures in Indonesia.

6. Conclusions

Two existing buildings have been evaluated in this paper. The first building consists of five stories and the second one has four. The seismic index of the structure has a different value for each story. The minimum seismic index occurs on the ground floor, and the index increases as the number of stories increase. The top floor has the maximum seismic index of all stories. The structure shall be judged by the seismic safety if seismic index (I_s) is higher than the seismic demand index (I_{so}). As a result of the evaluation, buildings A and B have been determined to be in an unsatisfactory condition, especially for the three lower floors. This is also confirmed by drift angle that exceeds the required limit. Consequently, evaluation by using Japanese standards can be applied to building conditions in Indonesia.

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