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SEISMIC ASSESSMENT OF EXISTING BUILDING IN BANGLADESH USING JAPANESE INDEX METHOD

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Abstract

Over the years buildings are constructed in earthquake prone areas without following proper seismic design code. So the structural seismic analysis of existing buildings in the earthquake prone areas will be a prime requirement in the field of civil engineering in near future. Also the structural seismic analysis will lead to the feasibility of application of earthquake retrofitting technique in the vulnerable structures. Currently the urbanization of metropolitan cities in Bangladesh is booming rapidly leading these cities to densely populated area. In the past, there has been vulnerability assessment done for building stock on several metropolitan cities, in most cases using rapid visual screening (RVS) method. But the lacking has always been there on a detailed structural vulnerability assessment. Considering these facts a study has to be done to estimate precisely the possible damage of a building's structure. In this study an in-depth structural seismic analysis of a medium rise building has been performed using all the 3 levels of Japanese Index Method. The Seismic Index (I_s) value of the building is compared with the Seismic Demand Index (I_{so}) value which is 0.864 for the first level and 0.648 for the second and third level of the area to check vulnerability condition of the building structure. It is observed from this study that Japanese Index Method is developed in a way that it can be used for the seismic analysis of medium rise buildings in Bangladesh.

Keywords: Vulnerability assessment; seismic vulnerability; single building assessment; structural assessment; Japanese Index Method.

1.0 INTRODUCTION

The growth rate of residential structures is very high in urban cities of Bangladesh. In urban cities of developing countries very few buildings have got seismic resistivity of its own [1]. In Japan, the seismic evaluation of the existing reinforced concrete buildings has been performed since 1975 with the use of the Japanese Seismic Index Method. Standard for Seismic Evaluation of Existing RC Buildings published by the Japan Building Disaster Prevention Association (JBDPA) was based on a method developed by M. Hirosawa in 1992. The updated 2001 version of Index Method is found from "Standard for Seismic Evaluation and Guidelines for Seismic Retrofit of Existing Reinforced Concrete Buildings" published by JBDPA; which was translated in English by Building Research Institute considering the increasing acceptability of the method in many countries [2]. The English translation was published to assist other earthquake-prone countries that face problems similar to Japan in their earthquake disaster prevention efforts [2]. Currently Bangladesh experienced frequent earthquakes; a reliable structural seismic assessment and seismic resistive action is in high requirement. Before the structural retrofitting work, the structural seismic vulnerability assessment of a building should be done following a comprehensive method. Therefore a comprehensive and user friendly structural vulnerability assessment method can help in planning the earthquake disaster mitigation efforts of the existing buildings.

2.0 METHODOLOGY

In this study seismic structural vulnerability assessment of an existing medium rise building from Sylhet metropolitan city will be carried out using Japanese Index Method. The Japanese Index Method was originally proposed for vulnerability assessment of existing or damaged buildings of up to eight floors, consisting of reinforced concrete frames and/or wall structures [3]. Structural vulnerability assessment is performed through the comparison of Seismic Index of Structure I_s (Equation- 1) with the Seismic Demand Index I_{so} (Equation- 2). If $I_s > I_{so}$ than the building is termed as safe and if $I_s < I_{so}$ the building is unsafe against earthquake, this is the basic theme of the vulnerability assessment [2], [3], [4], [5].

$$I_s = E_o * S_d * T \quad (1)$$

$$I_{so} = E_s * Z * G * U \quad (2)$$

where, E_o = Basic Seismic Index, E_s = Basic Seismic Demand Index, S_d = Irregularity Index, T = Time Index, Z = Zone Index, G = Ground Index and U = Usage Index. The method includes three different levels, from simple to sophisticated analysis step. Calculation's precision depends on the level used. In the second level of assessment, strength of vertical structural elements is calculated by shear failure and flexural yielding. On the other hand, in first level global shearing strength is estimated for each floor and direction, as failure of structural elements by flexural yielding is neglected [3]. Detailed and elaborated calculation is performed in third level of assessment. Early failure mode of beams is calculated to check shear or flexural yielding. Connection of vertical elements with the horizontal element (column-beam joint) is considered. Classification of vertical members is based on Table 1 and Table 2.

2.1 Selection of the Case Study Building

To select the case study building on which seismic structural assessment is formulated using Japanese Index Method, a residential area of Sylhet metropolitan city in Bangladesh was selected. The area is under Ward# 22 and has three blocks: A, B and as C as shown in the Figure 1.

Table 1 Classification of vertical members based on failure mode [2]

Screening Level	Vertical members	Definition
2^{nd} and 3^{rd}	Shear wall	Walls whose shear failure precede flexural yielding
2^{nd} and 3^{rd}	Flexural wall	Walls whose flexural yielding precede shear failure
2^{nd} and 3^{rd}	Shear column	Columns whose shear failure precede flexural yielding, except for extremely brittle columns
2^{nd} and 3^{rd}	Flexural column	Columns whose flexural yielding precede shear failure
2^{nd} and 3^{rd}	Extremely brittle column	Columns whose h_o/D are equal to or smaller than 2 and shear failure precede flexural yielding
3^{rd}	Column governed by flexural beam	Column governed by beam whose flexural yielding precede shear failure
3^{rd}	Column governed by shear beam	Column governed by beam whose shear yielding precede flexural failure
3^{rd}	Uplift wall	Walls whose uplift failure precedes flexural yielding or shear failure

Table 2 Ductility index for the 2^{nd} & 3^{rd} level screening [5], [6]

	Screening Level	Vertical Member	Value of *"F"*
a.	2^{nd} and 3^{rd}	Extremely brittle column	0.8
b.	2^{nd} and 3^{rd}	Shear column	1.0
c.	2^{nd} and 3^{rd}	Flexural column	1.27-3.2
d.	3^{rd}	Column governed by shear beam	1.5
e.	3^{rd}	Column governed by flexural beam	3.0

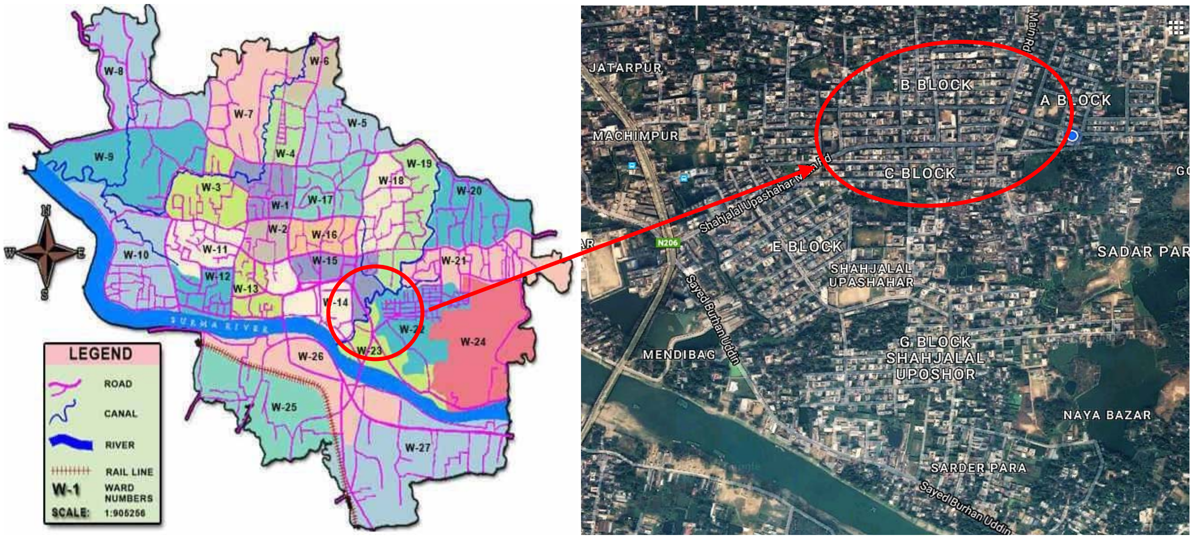

Figure 1 Case study location, Ward# 22, Uposhahar (Block A, B and C) of Sylhet City Corporation

Through the walk down evaluation proposed in Modified Turkish Method one building with lowest Performance Score (PS) was selected as the case study building [7]. It was observed that, there are total of 440 buildings available in that area most of which are one or two storied (Figure 2). Total of eight buildings have been identified as PS value less or equal to 60 (Figure 3). If PS <50, the building is a vulnerable structure [8]. It was observed that there are total of ten five-storey and eight more than five storey buildings available in the study area. Four buildings from five storey category and four buildings from >5 storey category showed PS value ≤60 of which one five-storey building has PS value 45 which is the lowest of all the 440 buildings. This building was selected as the case study building to formulate structural seismic assessment using Japanese index Method. The case study building contains both soft storey (storey of a building that is significantly more flexible or weak in lateral load resistance than the stories above it and the floors or the foundation below it) and heavy over hangings (cantilever portion of a building e.g. balconies). During walk down evaluation it was checked that the case study building has ground floor soft storey.

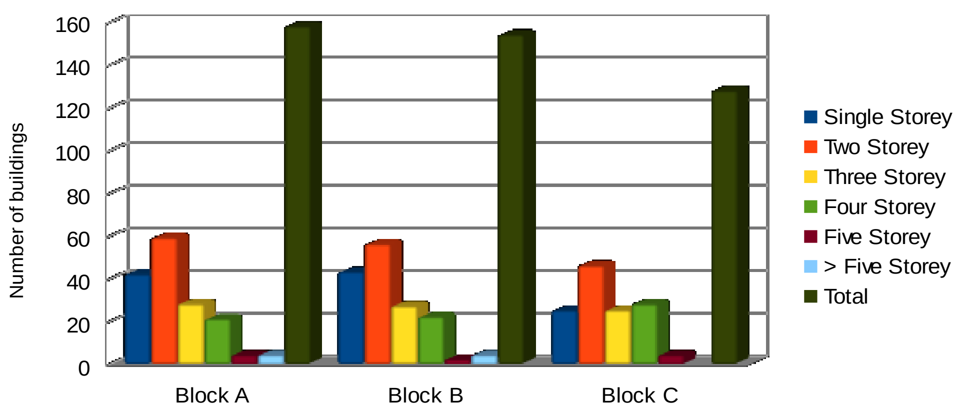

Figure 2 Walk-down evaluation status: Classification of buildings based on storey

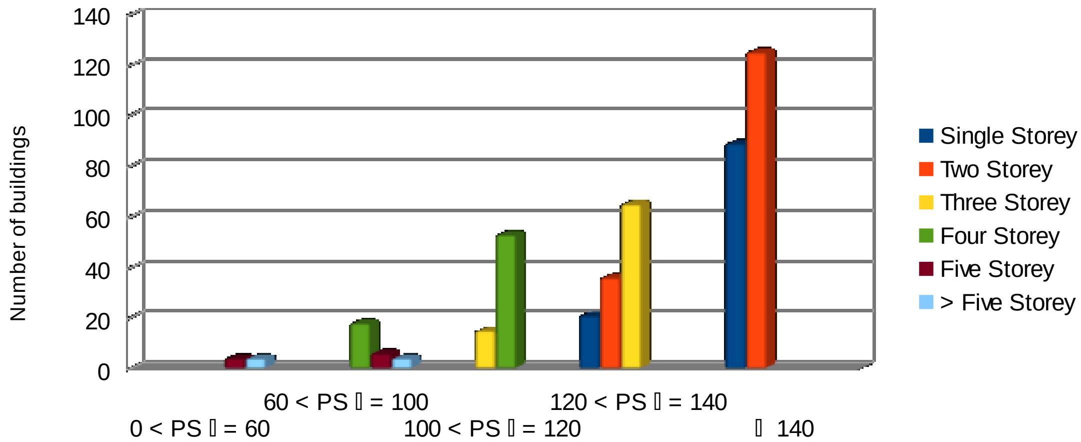

Figure 3 Walk-down Evaluation status: Classification of buildings based on PS

2.2 Outline of the Case Study Building

The building structure has five storey and three frames in longitudinal (EW) direction and six frames in transverse (NS) direction (Figure 4). Column C/C length at longitudinal direction is 21.5 m. and transverse direction is 6.4 m. The material properties of the building are it has concrete compressive strength 20 N/mm^2 and reinforcement tensile strength 413 N/mm^2. The overall wall thickness is 125 mm. and floor height is 3 m. The columns and beams are categorized into three groups and details are listed in Table 4.

Table 4 Columns and Beams details of the case study building

Frame	Cross Section	Main Reinforcement	Tie Bar
Column, C_1	305 * 305	6-16 mm. main bar	10mm. @ 150 mm. c/c
Column, C_2	305 * 305	8-16 mm. main bar	10mm. @ 150 mm. c/c
Column, C_3	381 * 381	12-16 mm. main bar	10mm. @ 150 mm. c/c
Beam, TB_1	250 * 375	3-16 mm. bottom + 4-16 mm. top	10mm. @ 150 mm. c/c
Beam, TB_2	250 * 375	5-16 mm. bottom + 4-16 mm. top	10mm. @ 150 mm. c/c
Beam, TB_3	250 * 450	5-16 mm. top + 6-16 mm. bottom	10mm. @ 150 mm. c/c

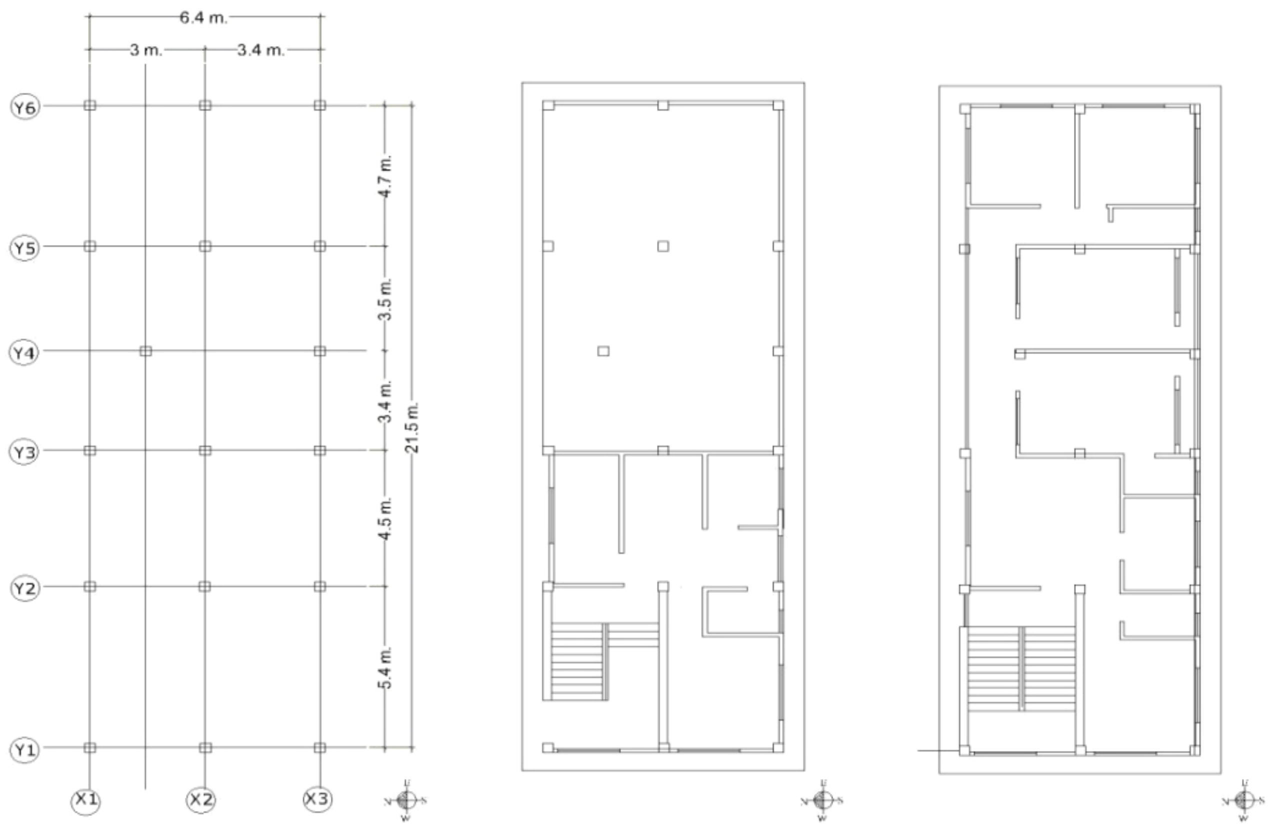

Figure 4 Column layout, GF and Typical Floor plan of the building

3.0 RESULTS AND DISCUSSION

3.1 First Level Index Result

The Basic Seismic Index E_o of structure for each storey at each direction was calculated. The value of Irregularity Index S_d was defined as 0.58. As the site was landfill, the Time Index T was taken as 0.9. Equation- 1 is used to formulate the value of Seismic Index, I_s for each storey and at both directions of the building. The result is listed in Table 5. The Basic Seismic Demand Index E_s for the 1st level screening is 0.8. The Zone Index Z for Sylhet is 0.36 as this region is in Seismic Zone 4 according to the Bangladesh National Building Code [9]. The Ground Index G for Sylhet region is 2.5 [10] and the Usage Index U was assumed as 1.2. So, Seismic Demand Index of the structure stands at I_{so} = 0.864 using Equation- 2. The comparison between I_s and I_{so} is shown in Figure 5, according to which the I_s value of the building is below the I_{so} value (green arrow line) up to 3rd floor. Consequently the building can be termed as vulnerable from 1st level analysis.

Table 5 Seismic Index Value I_s (1st level)

Storey	E_o -long	E_o -short	S_d	T	I_s -long	I_s -short
4th floor	3	1.91	0.58	0.9	1.57	1
3rd floor	1.68	1.06	0.58	0.9	0.88	0.55
2nd floor	1.24	0.79	0.58	0.9	0.65	0.41
1st floor	1.08	0.68	0.58	0.9	0.56	0.35
G. floor	0.73	0.52	0.58	0.9	0.38	0.27

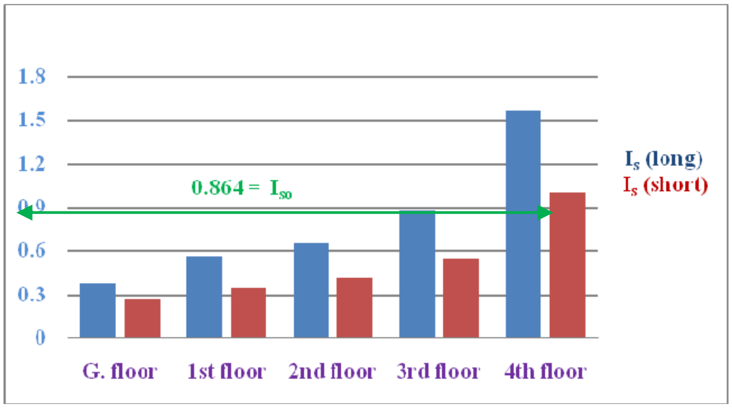

Figure 5 1st level I_s and I_{so} Index comparison

Table 6 Seismic Index Value I_s (2nd level)

Storey	E_o	S_d	T	I_s
G. floor	0.55	0.47	0.9	0.23
1st floor	0.58	0.47	0.9	0.25
2nd floor	0.62	0.47	0.9	0.26
3rd floor	0.80	0.47	0.9	0.34
4th floor	1.36	0.47	0.9	0.58

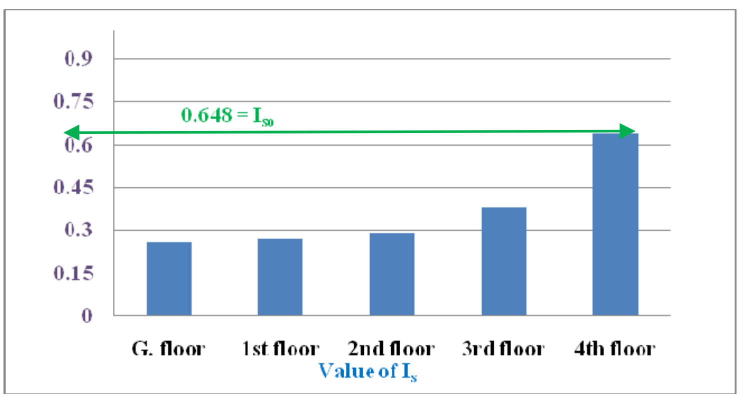

Figure 6 I_s and I_{so} Index comparison (2nd level)

3.2 Second Level Index Result

In the second level the seismic capacity of a structure was evaluated based on the performance of the vertical element on the assumption that beams are strong enough not to fail. The strength of members was calculated with the following equation:

$$C = Q_u/\Sigma W \quad (3)$$

Where, C = strength index, Q_u= ultimate lateral load carrying capacity of the vertical members of the concerned storey, ΣW = the weight of the building including live load for seismic calculation supported by the storey concerned. The value of Irregularity Index S_d was defined as 0.47 for the second level. The value for Time Index T remained same as mentioned in the first level screening. The value of Seismic Index, I_s of the building is listed in Table 6. The Basic Seismic Demand Index E_s for the second level screening is 0.6. The value of Z, G and U remained same as the first level. So, Seismic Demand Index of the structure stands at I_{so} = 0.648. The comparison between I_s and I_{so} is shown in Figure 6, according to which the I_s value of the building is below the I_{so} value (green arrow line) up to the top floor. So the building is vulnerable from second level analysis.

3.3 Third Level Index Result

In this level, seismic vulnerability was evaluated for all the frames in both longitudinal and transverse directions and for all the floors supposing the yield mechanism of the structure by considering yielding in beams. There are six frames in transverse direction and three frames in longitudinal direction. The values calculated in the second level screening were used for the strengths of columns. The failure modes of all beams were evaluated. The moment capacity at nodal point when the yield hinge is formed at the face of column was calculated here.

At each nodal point, the summation of the moment capacities of the left and right beams and that of the upper and lower columns was compared. The lower value of summation governs the failure mode at nodal point. If the failure mode at the nodal point is beam failure, the $\sum M_{beam}$ is equally divided into the upper and bottom column. If it is column failure, the $\sum M_{column}$ is equally divided into the left and right beam. But in any case the divided moment force should not exceed the moment capacity of beam and column at the nodal point.

The shear force ${}_cQ_u$ at ultimate state was calculated by dividing the sum of moment capacities estimated earlier at upper and lower nodal points of the column by its height. Once the strength index, C for the entire frame at each storey and each direction is determined, basic seismic index E_o' can be calculated for all the frames individually (Table 7). For the third level I_s calculation, the value of S_d and T remained same as mentioned in the second level screening. The result of I_s for the Frame# Y1 is listed in Table 8. The value of Seismic Demand Index I_{so} will remain same as mentioned in the second level screening.

Table 7 Basic Seismic Index, E_o'

Frame	Storey	*(n+1)/(n+i)*	E_o	*0.67(n+1)/(n+i)*	E_o'
Y1	G. floor	1	0.67	1.22	0.81
	1st floor	0.86	0.71	1.22	0.87
	2nd floor	0.75	0.82	1.22	1.01
	3rd floor	0.67	1.1	1.22	1.34
	4th floor	0.6	1.69	1.22	2.06

Table 8 Seismic Index, I_s

Frame	Storey	E_o'	S_d	T	I_s
Y1	G. floor	0.81	0.47	0.9	0.34
	1st floor	0.87	0.47	0.9	0.37
	2nd floor	1.01	0.47	0.9	0.43
	3rd floor	1.34	0.47	0.9	0.57
	4th floor	2.06	0.47	0.9	0.87

Once every required index was calculated, it was possible to compare seismic index, I_s with seismic demand index I_{so} in order to complete the seismic vulnerability assessment of structure by Index Method third level screening. In the third level screening each frame at each direction and in each floor is analyzed to get more precise seismic vulnerability assessment result. Figure 7 represents the bar chart for calculated Seismic Index of all the frames at transverse (Y) direction. It is clearly visible that, the value of seismic index, I_s for all the six frames are exceeded by the value of seismic demand index, I_{so} apart from the Y5 and Y6 frame at 4th floor. Figure 8 represents the bar chart for calculated Seismic Index of all the frames at longitudinal (X) direction. The seismic Index value for X1 and X2 frames are better than the transverse direction frames. But the X2 frame shows relatively low index value because one vertical member is designed off sat from the regular grid.

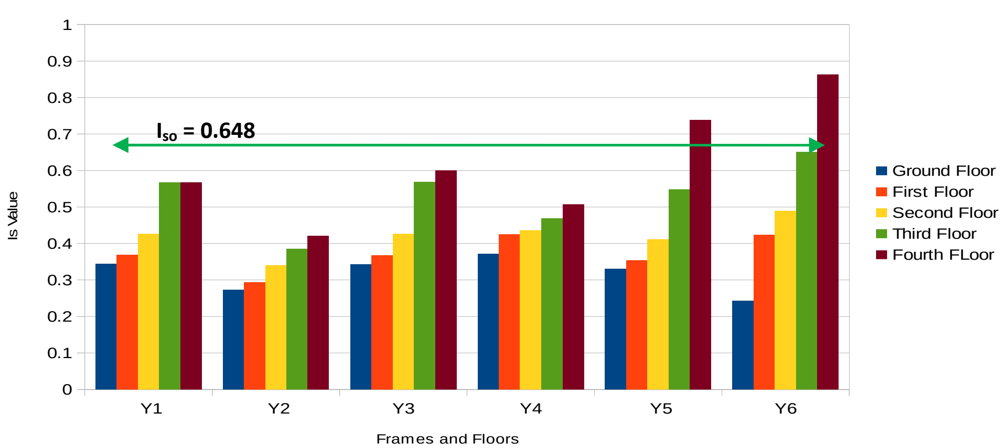

Figure- 7: I_s and I_{so} index comparison at transverse (Y) direction

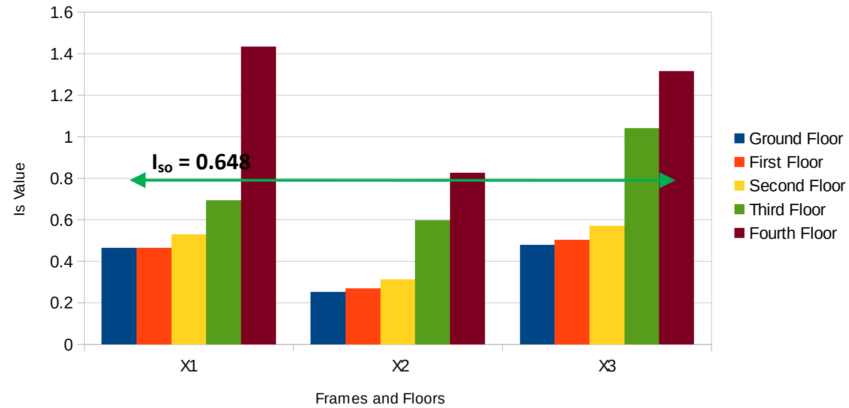

Figure- 8: I_s and I_{so} Index comparison at longitudinal (X) direction

3.4 Discussion

All the three levels of Japanese Index Method were applied on the case study building. The first level vulnerability assessment was completed based on individual storey. In the second level the vertical load bearing members were considered to formulate the vulnerability assessment and in the third level detailed structural seismic assessment was formulated.

In the first level assessment, the building was found vulnerable as up to third floor at transverse direction and up to second floor at longitudinal direction the value of seismic index, I_s remained below seismic demand index, I_{so} value. While in the second level assessment, the building was found vulnerable as up to third floor the I_s value remains below I_{so} value.

An in depth structural frame analysis was performed in the third level to check the vulnerability condition of the building. Lateral strength of beam was considered here. Through the calculation of nodal point moment, the failure member was determined at each nodal point of the structure. All the six frames at transverse direction and three frames at longitudinal direction were analyzed to evaluate the weak column and strong beam condition. Not only to calculate the Seismic Index value but to determine which members need retrofitting, the identification of weak column - strong beam or strong column - weak beam is very important which was performed in third level. Strength failure mode of beam and column actually shows the ductility performance of the member against a lateral force like earthquake. If in case the shear failure precedes the flexural failure of structural member, it extremely deteriorates seismic performance of the concerned member. On the other hand, if flexural failure precedes the shear failure it means that, shear failure does not occur under any excessive input of earthquake motion, and that full ductile performance is maintained. From Figure 7 and Figure 8 it is clearly visible that, the value of seismic index, I_s for all the six frames are exceeded by the value of seismic demand index, I_{so} apart from the Frame# Y5 and Y6 at 4th floor. On the other hand the Seismic Index value for X1 and X3 frames are better than the transverse direction frames. The X2 frame shows relatively low Index value because one vertical member is designed off sat from the regular grid. So, like the first and second level, from details structural analysis the building at third level shows vulnerability condition.

4.0 CONCLUSION

From the study it is clearly evident that Japanese Index Method is developed in a way that it can be used for the seismic analysis of a single building without much complexity. There are very few methods available to perform detail analysis that are not user friendly and require in depth data collection and analysis knowledge. Previously many studies were performed for building stock but very rarely in depth analysis of a building structure were performed and a main reason for that is the lack in availability of user friendly method for in depth structural seismic performance evaluation. In this study application of all the three levels of Japanese Index Method on a single building actually proves that this method can full fill the void regarding the details seismic structural analysis. Also by the application of level three analysis of Japanese Index Method, the seismic response of each structural frame of a building can be evaluated and decision regarding seismic mitigation can be taken.

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