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A PROPOSAL FOR SEISMIC VULNERABILITY ASSESSMENT OF PRE-ENGINEERED STEEL BUILDINGS IN BANGLADESH USING SIMPLIFIED JAPANESE INDEX METHOD

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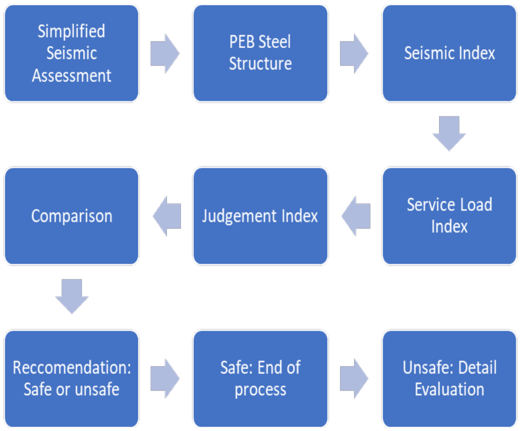
Graphical abstract



Abstract

At present seismic evaluation of structures has become very crucial in Bangladesh as the country is in earthquake prone region. Lots of studies have been performed and many methods have been proposed for the rapid seismic evaluation of reinforced concrete (RC) buildings. Over the past two decades the country has been going through an important evolution which is rapid construction of pre-engineered steel buildings (PEB). Unfortunately, there has not been a single research work done or any method proposed for the seismic evaluation of these type of structures. In this work, simplified structural evaluation which is based on Japanese Index Method has been used for the seismic evaluation of 05 existing PEB steel structure. The structural seismic index of the building, I_{BS} has been compared with the seismic judgement index I_{BSO} which is a function of seismic zone co-efficient, structural importance coefficient and normalized acceleration response spectrum. The service load index I_{BD} has also been compared with service load judgement indices, I_{BD01} and I_{BD02} which has been calculated from the material strength. For example, from the judgement of one building at ground floor, $0.5I_{BSO} \leqq I_{BS} < I_{BSO}$ and $I_{BD02} < I_{BD}$ have been observed hence immediate detail evaluation recommended.

Keywords: Pre-engineered building, steel structure, seismic vulnerability assessment, simplified seismic evaluation, Japanese Index Method.

1.0 INTRODUCTION

Disaster due to a seismic event happens when it strikes populated area, specially densely populated. Life and property loss is the result of damage or complete collapse of weak structures, specially building structures due to seismic ground motion. The past seismic records of Bangladesh are rich with many moderate and few strong events, hence making her one of the moderate earthquake prone countries in the world [1, 2].
The location of Bangladesh is near the junction of the two tectonic plates, north moving Indo-Australian plate and the Eurasian plate [3]. According to a study by Comprehensive Disaster Management Program (CDMP) in 2009 Dhaka, Chattogram and Sylhet metropolitan the major three cities of Bangladesh will be highly affected against moderate to strong earthquake because of unplanned and congested structural construction [4].
Though in Bangladesh majority of the existing building structural system is reinforced concrete (RC) frame structure but construction of ordinary steel moment resisting frame structure which is known as pre-engineered steel building (PEB) has become very popular over the past two decades. In the last 2-3 years the construction of steel PEB system has grown by around 45% because of some mega projects initiated by the Bangladesh Government where 30% of the total cost are due to

steel structures [5]. Steel requires smaller foundation as it has high strength to weight ratio. And because of its long spanning capability and better flexibility steel structure has become very popular over the past two decades in Bangladesh [6].

The seismic vulnerability of a structure is the structure's sensitivity to damage occurred by seismic shaking of a given intensity. Vulnerability assessment of building structure is performed to obtain the response of a structure due to a scenario seismic activity [7]. Structural seismic vulnerability assessment method is important to examine the ability of structures to withstand against moderate to strong ground motion [8]. Over the years seismic vulnerability assessments were performed for building stocks of urban areas. For example, CDMP 2009 performed vulnerability assessment of the major three urban cities of Bangladesh: Dhaka, Chattogram and Sylhet using rapid visual screening (RVS) method [4]. If building stock is to be evaluated rapidly for a city than Modified Turkish Method is suitable which offers easy walk down evaluation technique in the first level [9]. Japanese Index Method was successfully used for easy seismic evaluation of individual building [10, 11]. All in all, these past studies of seismic vulnerability assessment were done for RC building structures only. Considering these facts and the rapid construction of steel pre-engineered building (PEB) system in Bangladesh, this research work is performed. Here it is proposed to use the simplified version of Japanese Index Method for the seismic vulnerability assessment of PEB steel structure. This simplified structural evaluation method is a version of Japanese Index Method especially proposed for the seismic vulnerability assessment of existing medium rise buildings in Bangladesh. Seismic damage indices are frequently used to forecast potential harm. These damage indices were developed utilizing structure response parameters obtained from analytical structural response evaluation.

2.0 METHODOLOGY

In this study seismic vulnerability assessment is performed on five existing medium-rise pre-engineered steel building with ordinary moment resisting steel frame system. All the buildings are located in the Sylhet metropolitan city.

By the Japanese Index Method, seismic assessment of medium rise (up to 08 floors) reinforced concrete existing building can be performed [12, 13]. The method has three levels (simple to sophisticated level) and the 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. The comparison between structure's seismic index with seismic demand index is the basic theme of the vulnerability assessment [12, 13, 14].

$$I_s = E_o * S_d * T \tag{1}$$
$$I_{so} = E_s * Z * G * U \tag{2}$$

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.

From 2015 to 2017 Seki at el. proposed simplified structural evaluation method for existing buildings specially for Bangladesh based on the Japanese Index Method [15, 16, 17, 18]. The newly proposed basic equation for seismic index is as follows,

$$I_{BS} = E_{BS} * S_D * T \tag{3}$$

where, E_{BS} = basic structural index, which is to be calculated by,

$$E_{BS} = C_{BS} * F_B \tag{4}$$

were, C_{BS} = strength capacity of building and F_B = ductility index. The value of S_D of depends on the shape of the building and T depends on the time deterioration of building. These two values can be approximated to 0.9 or 1 based on the condition mentioned in the Table 1. A new equation is proposed which is for the calculation of service load index,

$$I_{BD} = W/\sum A_c \tag{5}$$

where, W = total load of building and $\sum A_c$= total cross-sectional area of columns. According to the new proposal, the seismic demand index or seismic judgement index is to be calculated by,

$$I_{BSO} = V = 2/3 * Z * I * C_s \tag{6}$$

where, V = design base shear coefficient as per Bangladesh National Building Code (BNBC) 2020 [19], Z = zone coefficient, I = structural importance coefficient and C_s = normalized acceleration response spectrum, which is a function of structure (building) period, T and site soil type, S (site soil classification) [19]. C_S is calculated by,

$$C_S = (1.25 * S)/T^{(2/3)} \tag{7}$$

Now the service load index (Equation 5) is judged by the following two equations,

$$I_{BD01} = 0.4\ F \tag{8}$$
$$I_{BD02} = 0.7\ F \tag{9}$$

where, F = design strength of material.

Using the values of I_{BS}, I_{BD}, I_{BSO}, I_{BD01} and I_{BD02} the seismic judgement ranking is done following Table 2.

Table 1 Value of Irregularity Index, S_D and Time Index T [16, 17]

Irregularity Index, S_D		Time Index, T	
Value	**Condition**	**Value**	**Condition**
0.9	If the building has the following shapes: wellhole style, different floor level, setback, piloti, irregular shape etc.	0.9	If the building has the following time deteriorations: cracking, uneven settlement, spalling off of plaster, deflection in slab and beam etc.
1	If none of the above are present.	1	If none of the above are present.

Using Table 3, from combined result of seismic capacity index and service load capacity index the rank is decided and recommendation is given regarding seismic vulnerability.

All the seismic vulnerability assessment done so far using the above equations are on RC moment resisting frame structure. In this study for the first time the method and equations are used to assess PEB steel structures having ordinary moment resisting frames.

Table 2 Index comparison and ranking [16]

Comparison	Indication	Rank
$I_{BS} \geqq I_{BSO}$	Higher than seismic demand	SA
$0.5I_{BSO} \leqq I_{BS} < I_{BSO}$	Lower than seismic demand	SB
$I_{BS} < 0.5I_{BSO}$	Remarkably lower than seismic demand	SC
$I_{BD} < I_{BD01}$	Higher than service load demand	DA
$I_{BD01} \leqq I_{BD} \leqq I_{BD0}$	Lower than service load demand	DB
$I_{BD02} < I_{BD}$	Remarkably lower than service load demand	DC

Table 3 Index Combination and Final Recommendation [16]

Final Capacity Ranking	Combination		Recommendation
	Seismic Capacity	Service Load Capacity	
A	SA	DA	Safe
B	SB	DA, DB	Detail evaluation recommended
C	SC	DA, DB, DC	Immediately detail evaluation recommended

2.1 Study Area

To perform the seismic vulnerability assessment on pre-engineered steel structure, the case study buildings were selected from the north eastern metropolitan city Sylhet in Bangladesh. The city is under Sylhet division and at 24.8917°N and 91.8833°E on the banks of the Surma River. The population density of the city is very high with nearly 500,000 people living in 26.5 square kilometer area. Sylhet consists of 27 wards [20]. According to the seismic zoning map of Bangladesh, Sylhet is in zone 04 which has the highest seismic zone coefficient (Figure 1, Table 4) [19]. The buildings are located in ward-17 of Sylhet city corporation as shown in Figure 2.

2.2 Outline Of The Case Study Buildings:

Selected all the 05 case study buildings for structural seismic evaluation are pre-engineered commercial medium rise steel buildings. The locations of the buildings are shown in the goggle map (Figure 3). The buildings are numbered as #1, #2, #3, #4 and #5 and some basic information regarding the buildings are given in Table 5. All the buildings have wide flange steel columns which are popularly known as I section and according to American Institution of Steel Construction (AISC) these are termed as W section. The steel materials are A36 with yielding stress 36000 psi [21, 22].

Figure 1 Seismic zoning map of Bangladesh [19]

Table 4 Seismic zone coefficient [19]

Zone	Zone Coefficient
1	0.12
2	0.20
3	0.28
4	0.36

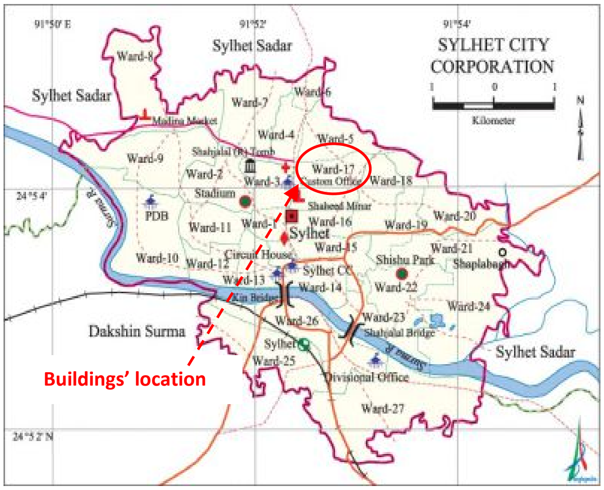


Figure 2 Sylhet City Corporation and Study Area – Ward 17

Figure 3 Location of target buildings in goggle map

Table 5 Basic information of the five case study buildings

Id	Floors	Floor Area (ft^2)	Total Number of Col.	Total Cross-sectional Area of Col. (in^2)	Floor height (ft.)
#1	06	3245	21	191.74	10
#2	06	1683	09	68.14	10
#3	04	3390	21	142.62	10
#4	04	3050	15	129.94	10
#5	05	3400	12	99.04	10

3.0 RESULTS AND DISCUSSION

3.1 Calculation Result Of Seismic Index I_{BS}

The seismic index I_{BS} was calculated for each floor of each building. Result of which is listed in the Tables 6, 7, 8, 9 and 10. To calculate strength capacity of building C_{BS}, average shear strength (τ) of columns was required to calculate. In index method the value for τ for RC column is fixed, which is 100 psi when $h_o/D > 6$ and 145 psi when $h_o/D \leq 6$ (where, h_o = clear height of column and D = depth of column cross section) [13]. As all the columns were wide flange (W shape) steel columns, the τ value for all the columns were calculated separately. To calculate the ductility index F_B, response modification factor, R was taken as 3.5 and over strength factor Ω_o was taken as 3 based on BNBC 2020 as all the buildings are ordinary steel moment frame structure [19]. The time deterioration index, T was taken as 1 for all the buildings apart from #5, as from visual observation no cracking, uneven settlement or deflection in slab and beam was found. Building #1, #3 and #4 were regular in shape, so the irregularity index, S_D was taken as 1 for these buildings but building #2 and #5 had setback in shape so the S_D value for these two was taken as 0.9.

Table 6 Seismic index result for building #01

Floors	I_{BS}	E_{BS}	S_D	T
GF	0.410	0.410	1	1
1st	0.492	0.492	1	1
2nd	0.614	0.614	1	1
3rd	0.819	0.819	1	1
4th	1.229	1.229	1	1
5th	2.458	2.458	1	1

Table 0 Seismic index result for building #02

Floors	I_{BS}	E_{BS}	S_D	T
GF	0.155	0.172	0.9	1
1st	0.186	0.207	0.9	1
2nd	0.233	0.259	0.9	1
3rd	0.310	0.345	0.9	1
4th	0.465	0.517	0.9	1
5th	0.931	1.034	0.9	1

Table 8 Seismic index result for building #03

Floors	I_{BS}	E_{BS}	S_D	T
GF	0.369	0.369	1	1
1st	0.492	0.492	1	1
2nd	0.738	0.738	1	1
3rd	1.477	1.477	1	1

Table 9 Seismic index result for building #04

Floors	I_{BS}	E_{BS}	S_D	T
GF	0.366	0.366	1	1
1st	0.488	0.488	1	1
2nd	0.732	0.732	1	1
3rd	1.464	1.464	1	1

Table 10 Seismic index result for building #05

Floors	I_{BS}	E_{BS}	S_D	T
GF	0.216	0.267	0.9	0.9
1st	0.271	0.334	0.9	0.9
2nd	0.361	0.445	0.9	0.9
3rd	0.541	0.668	0.9	0.9
4th	1.082	1.336	0.9	0.9

3.2 Calculation Result Of Service Load Index I_{BD}

The calculated result for service load index I_{BD} for all the buildings are listed here in Table 11. The service load index I_{BD01} and I_{BD02} is calculated for the final judgement using Equation 8 and 9 as 8800 psi and 15400 psi respectively.

Table 11 Service load index results for all 5 buildings

Floors	Building #01	Building #02	Building #03	Building #04	Building #05
GF	2538	37048	23769	23472	42911
1st	21154	30873	17827	17604	3432
2nd	16923	24699	11884	11736	25747
3rd	12692	18524	5942	5868	17164
4th	8461	12349			8582
5th	4230	6174			

3.3 Calculation Result Of Judgement Index, I_{BSO}

To calculate judgement index I_{BSO} = V (design base shear), seismic zone coefficient for Sylhet was required which is 0.36 (Figure 1) [19]. The structural importance coefficient is 1 as defined by BNBC 2020 [19]. These two values are same for all the five buildings. To calculate the normalized acceleration response spectrum C_s was calculated using Equation 7. The value of S was 1.4 (for SE type soil) for the building #01, #03 and #04 and the value was 1.35 (for SD type soil) for the building #02 and #05. The calculated values for judgment index I_{BSO} for all the five buildings are listed in the Table 12.

Table 12 Judgement index results for all 5 buildings

	I_{BSO}	Z	I	C_s
Building 01	0.52	0.36	1	2.14
Building 02	0.5	0.36	1	2.08
Building 03	0.63	0.36	1	2.63
Building 04	0.63	0.36	1	2.63
Building 05	0.55	0.36	1	2.29
Average	0.57	-	-	-

3.4 Result Comparison

Comparison of I_{BS} and I_{BSO} along with the I_{BD} and I_{BD01} and I_{BD02} is listed in Tables 13, 14, 15, 16 and 17. The floor wise judgment, capacity ranking and recommendations are mentioned in these tables for all the buildings following the process mentioned in Table 2 and Table 3. A comparison is also shown through Figure 4 where I_{BS} of all the buildings is compared with an average value of I_{BSO} = 0.57 (Table 12).

Table 13 Judgement, ranking and recommendations for building #1

Fl.	Judgement	Capacity Combo	Capacity ranking	Recommendation
GF	$0.5I_{BSO} \leqq I_{BS} < I_{BSO}$ $I_{BD02} < I_{BD}$	SB + DC	B + C	Immediately detail evaluation recommended
1st	$0.5I_{BSO} \leqq I_{BS} < I_{BSO}$ $I_{BD02} < I_{BD}$	SB + DC	B + C	Immediately detail evaluation recommended
2nd	$I_{BS} \geqq I_{BSO}$ $I_{BD02} < I_{BD}$	SA + DC	A + C	Detail Evaluation Recommended
3rd	$I_{BS} \geqq I_{BSO}$ $I_{BD01} \leqq I_{BD} \leqq I_{BD02}$	SA + DB	A + B	Detail Evaluation Recommended
4th	$I_{BS} \geqq I_{BSO}$ $I_{BD} < I_{BD01}$	SA + DA	A + A	Safe
5th	$I_{BS} \geqq I_{BSO}$ $I_{BD} < I_{BD01}$	SA + DA	A + A	Safe

Table 14 Judgement, ranking and recommendations for building #2

Fl.	Judgement	Capacity Combo	Capacity ranking	Recommendation
GF	$I_{BS} < 0.5I_{BSO}$ $I_{BD02} < I_{BD}$	SC + DC	C + C	Immediately detail evaluation recommended
1st	$I_{BS} < 0.5I_{BSO}$ $I_{BD02} < I_{BD}$	SC + DC	C + C	Immediately detail evaluation recommended
2nd	$I_{BS} < 0.5I_{BSO}$ $I_{BD02} < I_{BD}$	SC + DC	C + C	Immediately detail evaluation recommended
3rd	$0.5I_{BSO} \leqq I_{BS} < I_{BSO}$ $I_{BD02} < I_{BD}$	SB + DC	B + C	Immediately detail evaluation recommended
4th	$0.5I_{BSO} \leqq I_{BS} < I_{BSO}$ $I_{BD01} \leqq I_{BD} \leqq I_{BD02}$	SB + DB	B + B	Detail Evaluation Recommended
5th	$I_{BS} \geqq I_{BSO}$ $I_{BD} < I_{BD01}$	SA + DA	A + A	Safe

Table 15 Judgement, ranking and recommendations for building #3

Fl.	Judgement	Capacity Combination	Capacity ranking	Recommendation
GF	$0.5I_{BSO} \leqq I_{BS} < I_{BSO}$ $I_{BD02} < I_{BD}$	SB + DC	B + C	Immediately detail evaluation recommended
1st	$0.5I_{BSO} \leqq I_{BS} < I_{BSO}$ $I_{BD02} < I_{BD}$	SB + DC	B + C	Immediately detail evaluation recommended
2nd	$I_{BS} \geqq I_{BSO}$ $I_{BD01} \leqq I_{BD} \leqq I_{BD02}$	SA + DB	A + B	Detail Evaluation Recommended
3rd	$I_{BS} \geqq I_{BSO}$ $I_{BD} < I_{BD01}$	SA + DA	A + A	Safe

Table 16 Judgement, ranking and recommendations for building #4

Fl.	Judgement	Capacity Combination	Capacity ranking	Recommendation
GF	$0.5I_{BSO} \leqq I_{BS} < I_{BSO}$ $I_{BD02} < I_{BD}$	SB + DC	B + C	Immediately detail evaluation recommended
1st	$0.5I_{BSO} \leqq I_{BS} < I_{BSO}$ $I_{BD02} < I_{BD}$	SB + DC	B + C	Immediately detail evaluation recommended
2nd	$I_{BS} \geqq I_{BSO}$ $I_{BD01} \leqq I_{BD} \leqq I_{BD02}$	SA + DB	A + B	Detail Evaluation Recommended
3rd	$I_{BS} \geqq I_{BSO}$ $I_{BD} < I_{BD01}$	SA + DA	A + A	Safe

Table 17 Judgement, ranking and recommendations for building #5

Fl.	Judgement	Capacity Combination	Capacity ranking	Recommendation
GF	$I_{BS} < 0.5I_{BSO}$ $I_{BD02} < I_{BD}$	SC + DC	C + C	Immediately detail evaluation recommended
1st	$I_{BS} < 0.5I_{BSO}$ $I_{BD02} < I_{BD}$	SC + DC	C + C	Immediately detail evaluation recommended
2nd	$0.5I_{BSO} \leqq I_{BS} < I_{BSO}$ $I_{BD02} < I_{BD}$	SB + DC	B + C	Immediately detail evaluation recommended
3rd	$0.5I_{BSO} \leqq I_{BS} < I_{BSO}$ $I_{BD02} < I_{BD}$	SB + DC	B + C	Immediately detail evaluation recommended
4th	$I_{BS} \geqq I_{BSO}$ $I_{BD} < I_{BD01}$	SA + DA	A + A	Safe

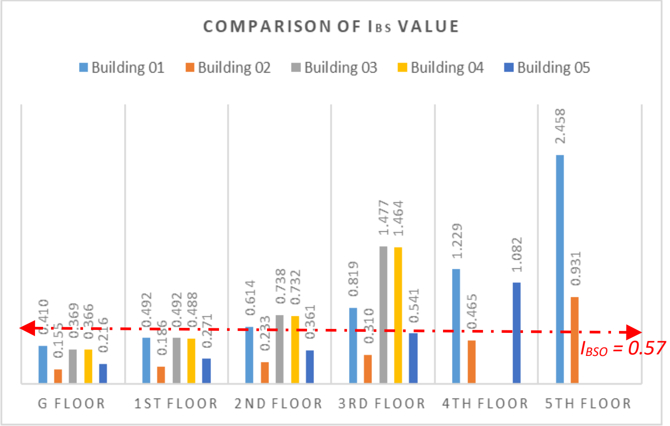


Figure 4 Comparison of seismic index value

3.5 Discussion

If we go through Tables 13, 14, 15, 16 and 17, from the judgement columns it can be observed that, all the five buildings have the seismic index I_{BS} value less than the demand index value I_{BSO} at ground floor. Also, at ground floor the service load index I_{BD} is less than the $I_{BD02} = 0.7 F$. From the combination of capacity, ranking for each floor is given in the ranking column. With the help of Table 3 all the floors of a building are given double rank (seismic index + service load index). And the recommendation is given following the lower value of the two ranks.

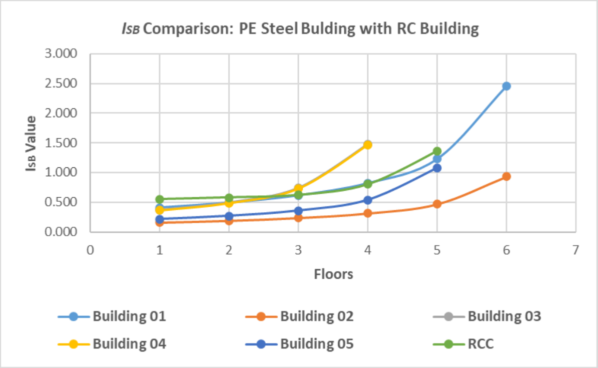


Figure 5 Index value comparison between PEB steel and RC frame structure

For example, the GF of building #1 gives us rank B + C (seismic index + service load index, respectively). Though rank B suggests that, *"detail evaluation recommended"* but the suggestion of comparatively lower rank C which is, *"immediately detail evaluation recommended"* is given in the recommendation column for the GF of building #01. Thus, all the floors of the 05 buildings are categorized for the seismic vulnerability. The rank B or C suggests that the particular floor is not safe and it requires a detail frame evaluation which can also be done using Japanese Index Method level 03 [10, 13]. If the rank is A, only than a particular floor of a building can be termed as safe against seismic occasion. It is to be noted that, though in this study all the buildings are analyzed for all floors individually, based on the result of GF only the whole building can be categorized as safe or unsafe. It can be seen that the top floor of all the buildings show strong index value because of the loading condition. If the judgment average index (0.57) is compared as shown in the Figure 04, it can be observed that, all the buildings are below the judgement index up to 1st floor.

In the Figure 5, a comparison between the seismic index results of the selected 05 PEB steel structure is shown and these results are compared with an existing 5 storey RC building. The RC building is a commercial building as well and selected from Sylhet metropolitan city. The results are compared to check the pattern of the curve formulated by the index values from PEB steel buildings of different floors. Because of the cumulative loading condition from top floor to the bottom, all the buildings both PEB steel and RC has showed up warding curves of similar pattern from left to right.

4.0 CONCLUSION

In this study updated Japanese Index Method, which is a simplified structural evaluation process is proposed for the seismic evaluation of pre-engineered steel buildings. From the assessment all the 05 case study buildings were found unsafe at ground floor hence, immediately detail evaluation was recommended. Previously, lots of seismic vulnerability assessment were performed and proposed for urban building stocks in different earthquake prone cities around the world using walk down evaluation or rapid visual screening method. Also, time to time studies were performed and many methods were proposed for the seismic vulnerability assessment of reinforced concrete building individually. As over the past two decades, lots of pre-engineered steel buildings were constructed in Bangladesh and the rate of construction is rapidly increasing, it is high time to propose a suitable seismic vulnerability assessment method for the pre-engineered steel buildings. A suitable seismic assessment method will not only detect the unsafe buildings but also from detail structural evaluation suggestion can be given for the future construction of seismically safe pre-engineered building.

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