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- Technical Paper -

PROPOSAL OF JUDGEMENT CRITERIA FOR PRIORITY SETTING OF DETAILED SEISMIC EVALUATION OF EXISTING RC BUILDING IN BANGLADESH

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ABSTRACT

Visual Rating method is a simple way to identify the most vulnerable buildings and prioritize them for detailed seismic evaluation. This study presents a proposal of judgement criteria for prioritization of existing RC buildings. A response spectrum method is applied on several model buildings representing existing RC buildings in Bangladesh. Judgement criteria have been set for detailed evaluation using a correlation between capacity-demand ratio and seismic index. Finally, judgment criteria of Visual Rating method are proposed based on the correlation between Visual Rating method and seismic index.

Keywords: Visual Rating method, Priority setting, Existing RC building, Judgement criteria.

1. INTRODUCTION

In developing countries such as Bangladesh, an enormous stock of vulnerable RC buildings is to be considered for seismic evaluation and strengthening. Identification of the most vulnerable buildings using rapid screening method beforehand would be helpful in prioritizing the detailed seismic evaluation of existing RC buildings.

A rapid seismic evaluation method defined as Visual Rating (VR) method has been developed for identifying the most vulnerable buildings [1]. The Visual Rating (VR) method estimates the seismic capacity of existing buildings which is useful for prioritization of existing RC buildings for detailed seismic evaluation. However, judgement criteria for VR method is not yet decided for prioritization of existing buildings which is an important point for seismic evaluation procedure.

In high seismic region such as Japan, the Japanese Seismic Evaluation Standard (JBDPA) [2] sets the seismic demand index (i.e. I_{SO} =0.6) as judgment criteria for seismic safety evaluation based on performance of existing RC buildings experienced past earthquakes. On the other hand, Bangladesh now has been adopted JBDPA standard [2] in CNCRP seismic evaluation manual [3] for seismic evaluation of existing RC buildings. In the CNCRP evaluation manual [3], the judgment criteria are proposed for seismic demand index ranging from 0.28 to 0.36 based on seismic demand in Bangladesh National Building Code, 2015 [4]. However, due to lack of past earthquake database in Bangladesh, the proposed judgement criteria by CNCRP evaluation standard [3] needs further verification. Therefore, judgment criteria setting for identification of vulnerable building is a key issue regarding seismic evaluation and/or strengthening of existing RC buildings in Bangladesh.

This study aims to propose judgement criteria for categorization of existing RC buildings to be gone thorough detailed seismic evaluation. First of all, several model RC buildings, representing the existing RC buildings in Bangladesh, have been chosen. A simplified response spectrum method is applied on these model buildings to estimate the capacity-demand ratio based on local seismicity. Then, a correlation has been developed between the obtained capacity-demand ratio with the seismic index of detailed evaluation. Using the correlation, judgement criteria for detailed evaluation have been proposed. Finally, judgement criteria for VR method has been proposed using the results of VR method and detailed seismic evaluation results.

2.INTRODUCTION OF VISUAL RATING METHOD

The Visual Rating (VR) method [1] is a simplified way for screening of existing RC buildings based on visual inspection within a short duration. The main intention of the VR method is to screen large numbers of buildings stock and categorize the buildings into less vulnerable to high possibilities of vulnerable buildings. Fig. 1 shows an overview of categorization of existing RC buildings based on VR method.

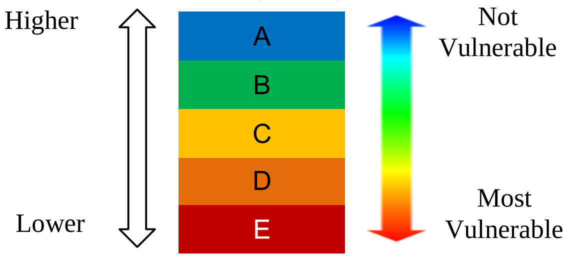

Fig. 1 The conceptual priority setting by the Visual Rating method

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The VR method estimates seismic capacity of an existing RC building in terms of Visual Rating index (I_{VR}) based on a simplified way to calculate the lateral strength of RC column and infill wall of a RC building. The detail calculation procedure of Visual Rating index (I_{VR}) has been discussed by the Authors [1]. The Visual Rating method has been applied on several existing RC buildings located at Dhaka, Bangladesh, under an ongoing Japanese project called SATREPS-TSUIB [5] project. The Visual Rating index has been compared with the detailed seismic evaluation results of those investigated RC buildings in order to understand the effectiveness of the Visual Rating method [6]. The main objective of Visual Rating method is to screen the most vulnerable buildings and make a categorization of these buildings for further detailed seismic evaluation. Hence, it is required to propose judgement criteria for classification of existing RC buildings from higher to lower priority for detailed seismic evaluation according to Visual Rating index (I_{VR}).

As previously mentioned, CNCRP evaluation manual [3] assumes judgement criteria for detailed seismic evaluation in Bangladesh. However, due to lack of past earthquake damage database in Bangladesh, the judgement criteria has been further investigated and verified by this study. This study considers several model RC buildings representing existing RC buildings in Bangladesh. The selection criteria of those model buildings are considered based on another study [7]. A judgment criteria have been set based on a correlation between capacity demand ratio and seismic capacity using simple capacity spectrum method. The following sections discuss about the proposal of capacity demand ratio and judgement criteria in details.

3. CAPACITY-DEMAND RATIO CALCULATION PROCEDURE

A capacity spectrum method has been applied on several model RC buildings for calculation of capacity-demand ratio. The following sections has been described in details.

3.1 Outline of Model RC Buildings

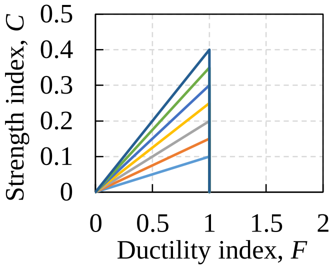
A total of 105 model RC buildings, representing the existing RC buildings in Bangladesh, have been considered in this study. The selection criteria of those model buildings are based on several basic parameters: number of stories (n), strength index (C) and ductility index (F). The number of stories have been considered ranging from two to six storied because most of the buildings in Bangladesh are within this range [7]. The strength index (C) of RC model buildings is ranging from 0.10 to 0.40 which is similar as found in detailed seismic evaluation of existing RC buildings in Bangladesh [7]. In addition, the model buildings are divided into 3 (three) categories according to ductility index ranging from 1.0 to 1.75 as also obtained from detailed evaluation of investigated buildings [7]. Fig. 2 shows the model buildings into varying with number of stories, strength index (C) and ductility index (F). The floor height of the model buildings is considered as 3000mm which is also common practice in Bangladesh [7]. The force deformation relationship along with other information are also shown in Fig. 2.

Case 1:

Numbers of buildings:35

Number of stories ranges:2 to 6

Strength index (C)	Ductility index (F)
0.10	1.00
0.15	1.00
0.20	1.00
0.25	1.00
0.30	1.00
0.35	1.00
0.40	1.00



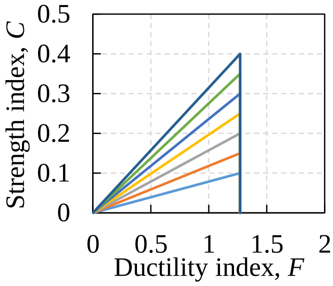
Force-deformation relationship for Case 1

Case 2:

Numbers of buildings:35

Number of stories ranges:2 to 6

Strength index (C)	Ductility index (F)
0.10	1.27
0.15	1.27
0.20	1.27
0.25	1.27
0.30	1.27
0.35	1.27
0.40	1.27



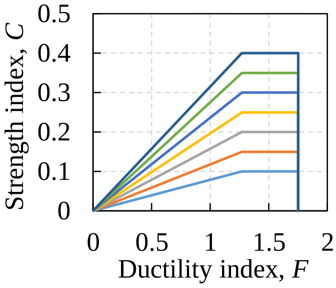
Force-deformation relationship for Case 2

Case 3:

Numbers of buildings:35

Number of stories ranges:2 to 6

Strength index (C)	Ductility index (F)
0.10	1.75
0.15	1.75
0.20	1.75
0.25	1.75
0.30	1.75
0.35	1.75
0.40	1.75



Force-deformation relationship for Case 3

Fig. 2 Force Deformation Relationship of Model Buildings along with other information

3.2 Conversion of Equivalent Single Degree of Freedom (ESDOF) System

All model buildings are converted into equivalent single degrees of freedom system (ESDOF) from multiple degree of freedom (MDOF) system. The properties such as equivalent mass and equivalent height of ESDOF system are determined based on a force-deformation relationship (i.e. C-F relationship) of MDOF system. In general, a plot of base shear versus roof displacement is used as the basis for establishing the properties of the ESDOF system. In this study, force deformation relationship of model buildings is used for calculating the properties of the ESDOF system. For ESDOF system, the equivalent mass (w) has been calculated by multiplying 0.8 with total mass (W) of the model buildings. On the other hand, the equivalent height (h) has been calculated by multiplying 0.7 with total height (H) of the investigated buildings.

3.3 Seismic Demand of Bangladesh

Bangladesh National Building Code (BNBC) [4] proposes response acceleration spectra based on earthquake ground motion for different soil condition ranging from hard to soft soil as shown in Fig. 3. In this study, seismic demand has been estimated according to response acceleration from BNBC [4].

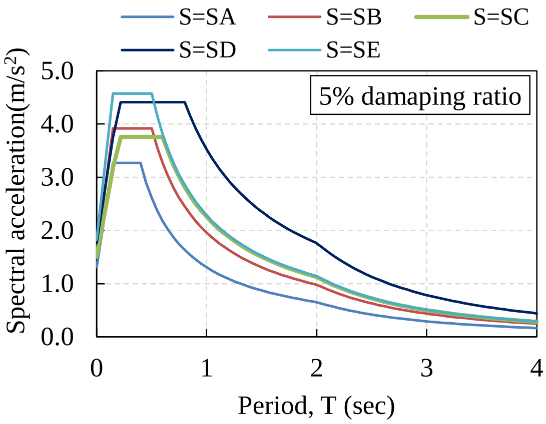


Fig. 3 Design Response Spectrum of BNBC [4]

This study considers response acceleration corresponding to soil type SD for setting the judgement criteria. The main reason is that most of soil type in Dhaka city is considered as SD type of soil (very soft clay) [4]. Elastic response acceleration has been converted into acceleration displacement response spectrum (ADRS) for Single Degree of Freedom (SDOF) system using Eq. 1. Acceleration-Displacement Response Spectrum (ADRS) has been shown in Fig. 4.

$$S_d = \frac{T^2}{4.\pi^2} S_a \qquad (1)$$

where, S_d = Spectral displacement, S_a = Spectral acceleration, T= Period (sec)

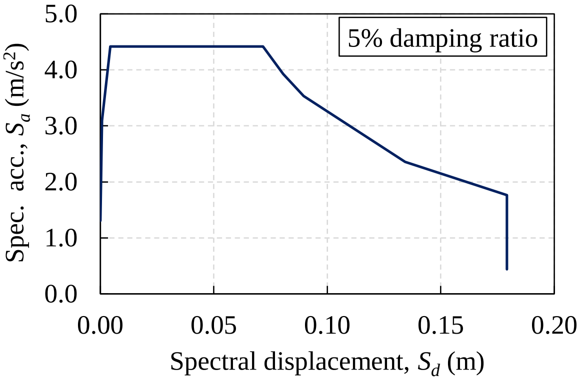


Fig. 4 Acceleration-displacement response spectrum for SD type soil

3.4 Calculation of Capacity Demand Ratio

Fig. 5 shows a typical calculation procedure of capacity-demand ratio of a model building. The demand curve is obtained by damped response spectrum corresponding to equivalent damping ratio at ultimate deformation of each model building as shown in Fig.5. The demand curve is plotted with the capacity curve of equivalent single degree of freedom (ESDOF) system of model building as shown in Fig 5. From the Fig. 5, it has been seen that capacity (S_a) indicates the ultimate lateral strength of building at demand spectrum line which represents safety limit of the building. On the other hand, seismic demand ($S_{ae}.F_h$) is obtained by reducing the elastic response spectrum by response reduction factor. Capacity demand ratio can be calculated by using Eq. 2 as follows:

$$Capacity - demand\ ratio\ (CDR) = \frac{S_a}{S_{ae}.F_h} \qquad (2)$$

where, S_{ae}=Spectral acceleration at elastic response acceleration, S_a= Capacity in terms of spectral acceleration at safety limit, F_h= Response reduction factor can be calculated by Eq. 3 [8].

$$F_h = \frac{1.5}{(1+10*h_{eq})} \qquad (3)$$

where, h_{eq}= equivalent damping ratio

The equivalent damping ratio (h_{eq}) of equivalent single degree of freedom system is used to correlate the maximum response of an equivalent linear system and a nonlinear system under a random earthquake ground motion. Here, h_{eq} is calculated using following Eq. 4[8].

$$h_{eq} = 0.05 + 0.25(1 - \frac{1}{\sqrt{\mu}}) \qquad (4)$$

where, μ is the ductility factor which is defined as the ratio of ultimate deformation (Δ_u) at ultimate drift (R_u) and yield deformation (Δ_y) calculated at yield drift (R_y) of equivalent single degree of freedom (ESDOF). It should be noted that yield drift is considered as 1/150 deformation angle. Therefore, the ductility factor can be calculated using Eq. 5 as follows:

$$\mu = \frac{\Delta_u}{\Delta_y} \qquad (5)$$

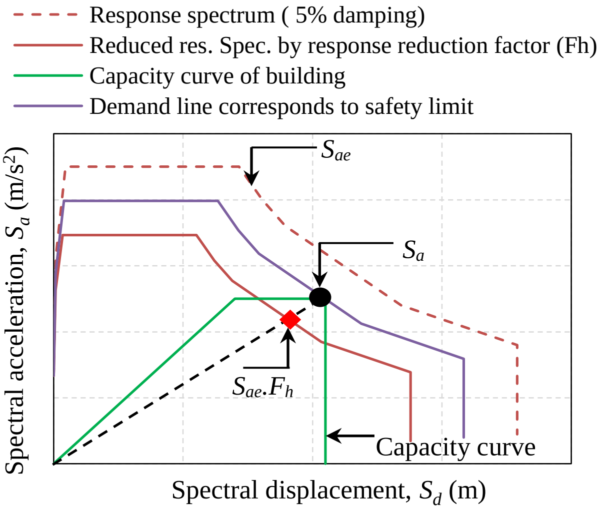


Fig. 5 A typical diagram showing calculation of capacity demand ratio of model buildings

3.5 Correlation Between Capacity-Demand Ratio (CDR) and Seismic Index (I_{S2})

The capacity demand ratio is calculated for all model buildings. The obtained capacity-demand ratio is plotted with the seismic index (I_{S2}) of model buildings as shown in Fig. 6. The capacity- demand ratio (CDR) greater than 1.0 indicates that the seismic capacity of an existing building is larger than the seismic demand. In this case, the building is considered as light damage or no damage during earthquake. However, the capacity-demand ratio lower than 1.0 indicates that the seismic capacity of an existing building is lower than the seismic demand and the building is possible to be collapsed during earthquake. In addition, the capacity-demand ratio lower than 0.50 indicates that the seismic capacity of a building is 50% lower than the seismic demand and the building is assumed to be high possibility of collapse.

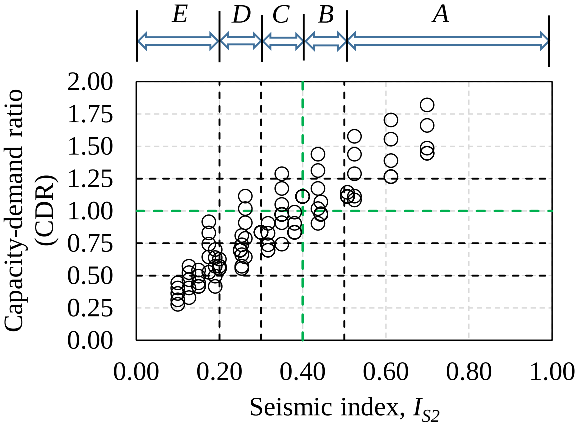


Fig. 6 Proposal of boundary for Seismic Index according to capacity - demand ratio

Since, the seismic index (I_{S2}) is calculated to understand the seismic performance of an existing RC building, the judgment criteria of seismic index (I_{S2}) is required. In this study, the judgement criteria of seismic index (I_{S2}) is considered based on the obtained correlation between capacity-demand ratio and seismic index (I_{S2}). Based on the aforementioned assumptions, the judgment criteria for seismic index (I_{S2}) is considered as 0.40 as the capacity-demand ratio larger than 1.0 as shown in Fig. 6. It is assumed that seismic index (I_{S2}) larger than 0.40 indicates that the building is to be considered as no damage during earthquake. The seismic index (I_{S2}) lower than 0.40 indicates that the building is assumed to be collapsed during earthquake.

In this study, buildings are categorized into 5 groups namely A, B, C, D and E depending on seismic index (I_{S2}) and capacity-demand ratio as shown in Table 1. A and B categories are described as no damage and light damage since the seismic index (I_{S2}) value of these building are larger than 0.40. E category is described as high possibility of collapse since the seismic capacity less than 50% of seismic demand (i.e. I_{S2} less than 0.20 and CDR value less than 0.50). In addition, C and D categories are described as less and moderate possibility of collapse since the seismic capacity of these buildings are in between 50% ~100 % of seismic demand.

Table 1 Proposal of categories of building according to capacity-demand ratio and seismic index (I_{S2})

Capacity-demand ratio	Seismic index (I_{S2})	Cate-gories	Description
1.25~	0.50~	A	No damage
1.00~1.25	0.40~0.50	B	Light damage
0.75~1.00	0.30~0.40	C	Less Possibility of collapse
0.50~0.75	0.20~0.30	D	Moderate possibility of collapse
~0.50	<0.20	E	High possibility of collapse

In case of screening of large building stock, judgement criteria for Visual Rating method is required. Therefore, judgement criteria according to Visual Rating index has been proposed and discussed in the following section. In this regard, seismic capacity of model buildings is compared with investigated existing RC building in Bangladesh.

4. SEISMIC INDEX OF MODEL BUILDINGS AND SURVEYED EXISTING RC BUILDINGS

4.1 Building survey in Bangladesh

A total 23 existing RC buildings located at Dhaka, Bangladesh are surveyed in Bangladesh under SATREPS-TSUIB [5] project. Detailed seismic evaluation has been done for these investigated buildings [6, 7]. The seismic capacity of model buildings has been compared with the seismic evaluation result of the surveyed existing RC buildings in Bangladesh. Table 2 shows the mean and standard deviation of seismic capacity of both model RC building and surveyed buildings in Bangladesh. Fig. 7 shows the distribution of seismic index of both model buildings and surveyed existing RC buildings. It has been observed that the average value of model building is 0.33 which is closer to existing investigated RC buildings.

Table 2 Comparison of seismic index (I_{S2}) between model buildings and investigated RC buildings

Buildings type	Mean	Standard deviation
Model buildings	0.33	0.16
Surveyed buildings in Bangladesh	0.31	0.12

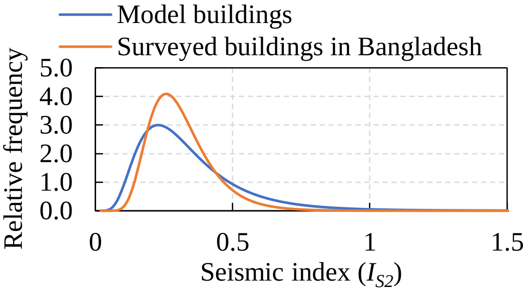


Fig. 7 Distribution of seismic index (I_{S2}) of model buildings and surveyed buildings

4.2 Correlation Between Seismic Index and Visual Rating Index of Surveyed Buildings

Visual Rating method has been applied on those existing RC buildings in Bangladesh. A correlation between seismic index (I_{S2}) and Visual Rating index (I_{VR}) is obtained in another study [6] as shown in Fig. 8. Judgment criteria with respect to seismic index (I_{S2}) already developed in previous section has been applied on surveyed RC building in Bangladesh in the Fig.8. In the plot, these investigated buildings are categorized into 5 (five) categories according to judgement criteria and boundary proposed for seismic index (I_{S2}) as mentioned in previous section.

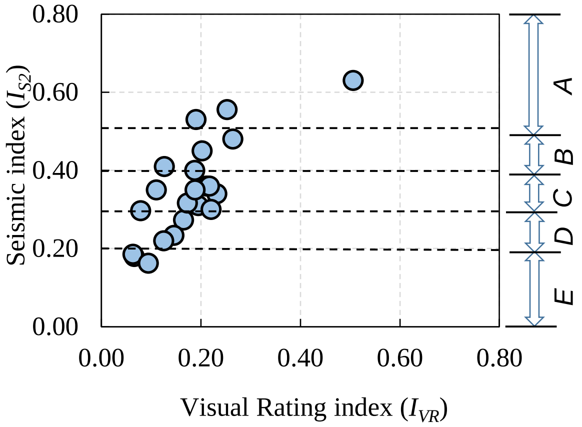


Fig. 8 Correlation between seismic index (I_{S2}) and Visual Rating index (I_{VR})

From above Fig. 8, it has been observed that there is large variation of Visual Rating index (I_{VR}) of each range of seismic index (I_{S2}). Therefore, it is not easy to set boundaries for Visual Rating index (I_{VR}). The variation of Visual Rating index (I_{VR}) of each range of seismic index is shown in Fig. 9. It has been observed that the variations are increasing while increasing the range of seismic index (I_{S2}).

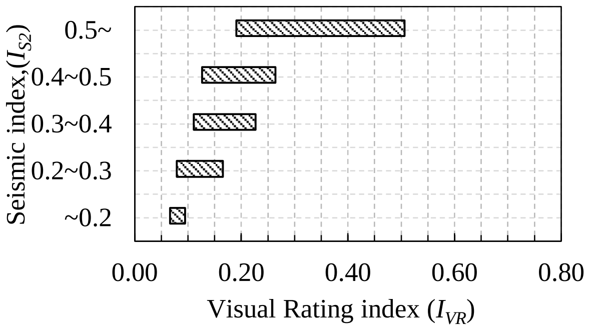


Fig. 9 Variation of Visual Rating index (I_{VR}) in each range of seismic index (I_{S2})

Table 3 shows the mean and standard deviation of cumulative summation of Visual Rating index (I_{VR}) of each range of seismic index (I_{S2}). However, the judgement criteria of VR method are set based on cumulative distribution of Visual Rating index (I_{VR}) and seismic index (I_{S2}). The following sections discuss in details.

Table 3 Variation between Visual Rating Index (I_{VR}) corresponding to Seismic Index (I_{S2})

Seismic index, I_{S2}	Visual Rating index, (I_{VR})		
	Average	Standard Deviation (*SD*)	Average +1*SD*
I_{S2}<0.50	0.16	0.06	0.22
I_{S2}<0.40	0.15	0.06	0.21
I_{S2}<0.30	0.11	0.04	0.15
I_{S2}<0.20	0.08	0.01	0.09

4.3 Cumulative Distribution between Seismic Index (I_{S2}) and Visual Rating Index (I_{VR})

Cumulative distribution function has been calculated for each range of seismic indices using mean and standard deviation from Table 3 of Visual Rating index which are log-normally distributed. Fig. 10 showing distribution of buildings in percentage for each range of seismic index (I_{S2}) has been plotted according to Visual Rating index (I_{VR}). From the Fig. 10, it has been observed that there is small variation in cumulative distribution function in between seismic index (I_{S2}) is of 0.40 and 0.50. The reason is that the average of I_{VR} values in these two ranges are almost similar due to few numbers of investigated buildings within these ranges.

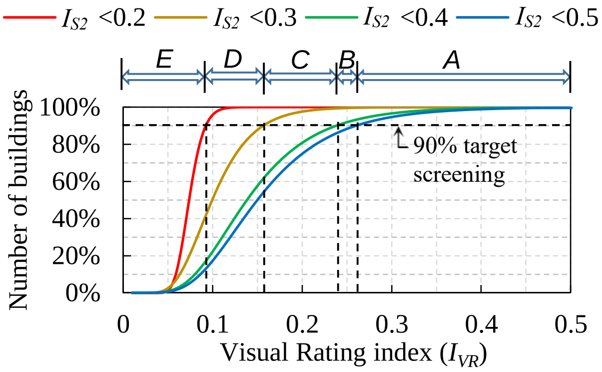


Fig.10 Cumulative percentage of buildings according to Visual Rating index

5. JUDGEMENT CRITERIA CORRESPONDING TO VISUAL RATING INDEX

The main target of setting the judgement criteria is all of vulnerable buildings should be identified or screened out based on Visual Rating method. As this method is based on visual investigation within very short time by using limited parameters, it is acceptable if not vulnerable buildings are included in the most vulnerable buildings list. It should be noted that the numbers of not vulnerable buildings should be as low as possible.

Based on above discussion, boundaries for each range is set according to target number of buildings (in percentage) to be screened out for each range of Visual Rating index (I_{VR}). Based on Fig. 10, two categories of boundaries according to Visual Rating index (I_{VR}) are shown in Table 4, based on number of buildings (in percentage).

Table 4 Number of building screened for two cases boundaries

Number of buildings (percentages) identified in each categories	90%	95%
Visual Rating Index (I_{VR}) range	I_{VR} <0.26	I_{VR} <0.31
	I_{VR} <0.24	I_{VR} <0.27
	I_{VR} <0.16	I_{VR} <0.18
	I_{VR} <0.095	I_{VR} <0.10

Based on above discussion, judgement criteria according to Visual Rating index has been proposed assuming the target screening 90% of each category of Visual Rating index (I_{VR}). Table 5 shows proposal of boundaries of judgement criteria corresponding to description of each category. The buildings are to be classified into 5 categories for A to E depending on Visual Rating index (I_{VR}). According to Table 5, the buildings categorized as E are considered as the most vulnerable buildings and detailed evaluation is highly required. It has been observed that the range of I_{VR} (i.e. $0.24 \leq I_{VR} < 0.26$) of B category is very narrow comparing with other ranges. The reason behind is that the number of buildings investigated within these range are few. It is noted that increasing the number of buildings might change the range of these boundaries.

Table 5 Proposed boundaries for VR method

Range of each Categories	Categories	Description
$0.26 \leq I_{VR}$	A	No damage
$0.24 \leq I_{VR} < 0.26$	B	Light damage
$0.16 \leq I_{VR} < 0.24$	C	Less Possibility of collapse
$0.10 \leq I_{VR} < 0.16$	D	Moderate possibility of collapse
$I_{VR} < 0.10$	E	High possibility of collapse

6. CONCLUSIONS

This study proposes judgement criteria for categorization of existing RC buildings for detailed seismic evaluation in Bangladesh using the Visual Rating (VR) method which is a rapid screening method based on visual inspection of large building's stock. Firstly, judgement criteria according to seismic index (I_{S2}) is set based on capacity-demand ratio of several model buildings. Finally, judgement criteria according to Visual Rating index (I_{VR}) is proposed considering the obtained relationship between seismic index (I_{S2}) and Visual Rating index (I_{VR}).

The main conclusions are stated as follows:

1. The judgement criteria have been proposed according to the Visual Rating index (I_{VR}) and the buildings are divided into 5 (five) categorizes such as A, B, C, D and E describing from less vulnerable to most vulnerable buildings.
2. From the above criteria, the existing RC buildings with Visual Rating Index (I_{VR}) lower than 0.24 are regarded as vulnerable buildings, and the buildings with I_{VR}<0.10 are categorized as the most vulnerable buildings and high priority for detailed seismic evaluation.

The proposed judgement criteria are based on seismic evaluation of 23 existing RC buildings in Bangladesh. In order to increase the accuracy and effectiveness of the proposed judgement criteria, additional RC buildings survey and investigation are recommended.

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