VISUAL RATING METHOD AND PRIORITY SETTING OF DETAILED EVALUATION OF EXISTING RC BUILDINGS WITH MASONRY INFILL

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Abstract

Past earthquakes, in developing countries, caused major destruction in masonry infilled RC buildings indicates the existence of a huge stock of seismically vulnerable RC buildings. There is an urgent need to conduct seismic capacity evaluation of these existing RC buildings stock to avoid future catastrophic damages. There are several existing methods and/or procedures available for the detailed seismic evaluation of existing RC buildings. However, detailed seismic evaluations are very challenging for a large stock of existing RC buildings due to several reasons, including requirements for detailed architectural and structural drawings along with other necessary information that are not available in most of the existing RC buildings in developing countries. In this regard, identification of the most vulnerable buildings through rapid visual screening, and prioritization of those buildings to conduct detailed evaluation are the effective ways to reduce the aforementioned limitations. There are several rapid visual screening (RVS) methods available to conduct preliminary evaluation before undertaking detailed evaluation. However, those methods provide score which does not reflect the seismic capacity of buildings due to ignoring the basic parameters of RC buildings, such as column area, masonry infill area, and building weight in the evaluation procedures. Therefore, it is very essential to develop a rapid seismic evaluation method considering the aforementioned parameters influencing the seismic capacity of an existing RC buildings.

This research work focuses on development of a rapid visual screening method, herein mentioned as Visual Rating (VR) method, for identifying the most vulnerable RC buildings and proposes judgment criteria for prioritization of existing RC buildings for detailed evaluation. The proposed VR method considers cross-sectional area and shear strength of vertical elements such as RC column, masonry infill wall, and RC wall as well as other building attributes such as structural configuration, deterioration and age of building. The presented method estimates the seismic capacity of existing RC buildings in terms of Visual Rating index (I_{VR}) and lower value of I_{VR} corresponds to the most vulnerable building. The proposed method is applied on post-earthquake surveyed buildings database after the 2016 Taiwan Earthquake (M_w:6.4) to understand the effectiveness of identifying the most vulnerable buildings. It has been observed that VR method can identify most of severely damaged buildings. Afterward, the applicability and effectiveness of the proposed method have been verified by investigating several existing RC buildings, located in Bangladesh, as a case study. It has been observed that, I_{VR} provides a lower boundary of seismic capacity of an existing RC buildings comparing with the results of detailed evaluation.

Since the main intention of the VR method is to set priority for detailed seismic evaluation, judgment criteria have been proposed for I_{VR} using the obtained correlation between I_{VR} and detailed seismic evaluation results of investigated buildings. Based on the proposed judgement criteria, the buildings with I_{VR} score less than 0.10 are considered as the most vulnerable buildings and detailed seismic evaluation is highly recommended. Furthermore, the proposed method can be used in other developing country by reconsidering material strength properties and local seismicity in intended region.

Keywords: Existing RC buildings; Visual Rating index; Masonry infill; Priority setting; Large buildings stock

1. Introduction

Past earthquake damage in developing countries have been exhibiting the necessity of seismic evaluation and strengthening of existing RC buildings for reducing potential seismic risk. However, there are existence of enormous stock of vulnerable masonry infilled-RC buildings in these developing countries. It is challenging to conduct detailed seismic evaluation wtih limited resources and time for those developing countries. Prioritization for detailed seismic evaluation is an effective way to overcome the issue. Identification of the most vulnerable buildings using rapid visual screening method beforehand would be helpful in prioritizing the detailed seismic evaluation of existing RC buildings. Therfore, developement of practical rapid visual screening method and prioritization of existing buildings for detailed seismic evaluation is the key issues in terms of time and costs.

A number of guidelines and methods, such as FEMA rapid visual screeing (RVS) method [1], Turkish rapid RVS method [2,3], Indian RVS method [4], are available for quick identification of vulnerable buildings based on visual inspection. However, these existing RVS methods provide a score which do not have good relationship with the actual seismic capacity of an existing RC building as shown in a previous study [5]. The main reason is that these RVS methods do not consider the variation of cross-sectional area and shear strength of structural elements (i.e. column, masonry infill and RC wall area) in order to calculate the performance score. In other words, these methods do not consider based shear and a common score is considered for a common type of structural system.

Besides, study on past earthquake damage databases [6-12] reveals that cross-sectional area of structural elements and their shear strength have a great influence of seismic capacity of existing RC buildings. These studies proposed several methods for estimation of seismic capacity using dimensions of the vertical members and floor area (such as column area ratio and infill wall area ratio, which are defined as ratio of cross-sectional area of RC column to total floor area and cross-secional area of masonry infill panels to total floor area, respectively). These methods require architectural drawing and structural drawings for calcualtion of column area, wall area and floor area. In the case of absence of drawings, preparation of as-built detailed drawing is necessary to apply these methods which takes much time and efforts. Therefore, it is of a great interest to develop a rapid evaluation method for estimating seismic capacity thorough visual inspection.

This study presents a rapid evaluation method referred as Visual Rating (VR) method, to estimate the seismic capacity of existing RC buildings taking into account the column area ratio and the infill wall area ratio in a simplified way thorough visual investigation. First of all, the proposed method is applied on post-earthquake surveyed building database for understanding the applicability and effectiveness. Afterward, the method has been investigated by applying on several existing RC buildings located in Dhaka city, Bangladesh as a case study. The effectiveness of the proposed method has been verified by comparing with detailed seismic evaluation of investigated buildings in Bangladesh. Furthermore, judgement criteria have been proposed for prioritization of existing RC building based on results of VR method and detailed seismic evaluation.

2. The development of Visual Rating (VR) method

2.1 Theoretical background of Visual Rating (VR) method

The Japanese seismic evaluation method (JBDPA) [13] proposes a practical way for estimating the seismic capacity of existing RC buildings. The JBDPA standard [13] considers three levels of seismic evaluation procedures to estimate seismic capacity in terms of seismic index (I_S). According to JBDPA standard, seismic index (I_S) is estimated by following Eq. (1).

$$\text{Seismic index } (I_S) = C \times F \times S_d \times T \tag{1}$$

where, C is the strength index which is expressed as base shear coefficient of a RC buildings. F is the ductility index based on deformation of existing RC building. S_d is the irregularity index considering both horizontal and vertical irregularity. T is the time index considering deterioration of concrete, corrosion of reinforcing steel and buildings year of construction.

In the first level evaluation, strength index (C) can be estimated by lateral strength (V) normalizing with total building's weight (W) as shown in Eq. (2). Here, lateral strength (V) is simply calculated by cross-sectional area of vertical elements and their average shear strength. However, ductility index (F) is considered as 1.0 assuming the building is brittle.

$$\text{Strength index, } C = \frac{V}{W} \tag{2}$$

Second level evaluation procedure considers detailed calculation for estimation of strength index (C) and ductility index (F) based on lateral force-deformation capacity and failure mechanism of each vertical member [13]. However, detailed architectural and structural drawing along with reinforcement detailed is required for both evaluation procedures.

Based on first level evaluation procedure of JBDPA standard [13], strength index (C) of masonry infilled RC building is calculated by Eq. (3) proposed in the previous study [12].

$$C = \frac{1}{w}\left[\tau_c.\frac{A_c}{n.A_f} + \tau_{\inf}.\frac{A_{\inf}}{n.A_f} + \tau_{cw}.\frac{A_{cw}}{n.A_f}\right] \tag{3}$$

where, τ_c, τ_{inf}, and τ_{cw} are average shear strength of RC column, masonry infill, and reinforce concrete wall; A_c, A_{inf}, and A_{cw} are the cross-sectional areas of RC column, masonry infill and reinforced concrete wall. n is the number of story, A_f is the floor area, and w is the unit weight per floor area of a RC building. In the Eq. (3), $A_c/n.A_f$, $A_{inf}/n.A_f$, and $A_{cw}/n.A_f$ are expressed as column area ratio, masonry infill area ratio, and concrete wall area ratio, respectively.

Hence, the seismic index (I_s) of first level evaluation as shown in Eq. (1), considering masonry infilled RC buildings, can be estimated by following Eq. (4).

$$I_S = \frac{1}{w}\left[\tau_c.\frac{A_c}{n.A_f} + \tau_{\inf}.\frac{A_{\inf}}{n.A_f} + \tau_{cw}.\frac{A_{cw}}{n.A_f}\right].S_D.T \tag{4}$$

Although the first level evaluation method is very simple and easy to applicable, it is quite challenging to apply on large numbers of existing buildings because it requires architectural drawings. If architectural drawings are not available, as-built drawing preparation are necessary, which takes much time and efforts for seismic evaluation procedure. For this instance, the VR method proposes a simplified way for estimation of column area ratio ($A_c/n.A_f$) masonry wall area ratio ($A_{inf}/n.A_f$) and concrete wall area ratio ($A_{cw}/n.A_f$) by visual inspection instead of measuring of cross-sectional area of all RC column, infill wall, concrete wall, and total floor area. Simplified way considers visual inspection, collection of several parameters which provide approximate estimation of column area ratio, masonry infill area ratio and concrete wall area ratio. This method proposes a score, hereafter reported as Visual Rating index (I_{VR}), which is approximated seismic capacity of existing buildings. The calculation procedure of Visual Rating index (I_{VR}) is described in the following section.

2.2 Calculation procedure of Visual Rating method

Visual Rating index (I_{VR}) indicates the seismic capacity of existing buildings which is expressed by Eq. (5).

$$I_{VR} = \frac{1}{n.w}\left[\tau_c.\frac{A_c}{A_f} + \tau_{\inf}.\frac{A_{\inf}}{A_f} + \tau_{cw}.\frac{A_{cw}}{A_f}\right].S_D.T \tag{5}$$

where, A_c/A_f, A_{inf}/A_f, A_{cw}/A_f can be expressed as simplified column area ratio, simplified masonry infill area ratio, and simplified concrete wall area ratio, respectively. It should be noted that these simplified column area ratio, masonry infill area ratio and concrete wall area ratio are calculated for a single floor of a buildings. The following sections describe about the simplification procedure in details.

2.2.1 Simplified column area ratio

The cross-sectional area of column and floor area has been simplified using representative column size (b_c) and average span length (l_s), respectively. By visual inspection, the representative column size (b_c) has been chosen which represents the average value of all column size of a surveyed building and average span length (l_s) represents the floor area of a surveyed building as shown in Fig. 1 as a typical floor plan. Therefore, simplified column area ratio of a single floor can be estimated by Eq. (6).

$$\frac{A_c}{A_f} \approx \frac{b_c^2}{l_s^2} \tag{6}$$

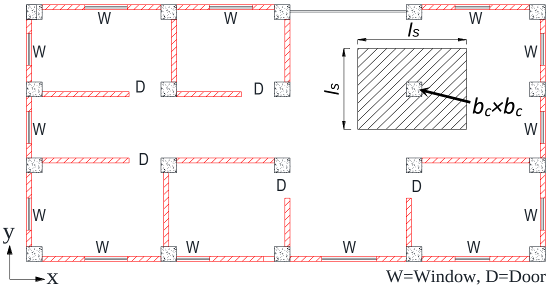


Fig. 1 – Typical floor plan showing location of infill

2.2.2 Simplified masonry infill area ratio

The simplified masonry infill area ratio of a single floor has been estimated by using masonry infill ratio (R_{inf}), thickness of masonry infill (t_{inf}) and average span length (l_s) as shown in Eq. (7).

$$\frac{A_{\text{inf}}}{A_f} \approx \frac{t_{\text{inf}}}{l_s} . R_{\text{inf}} \tag{7}$$

where, masonry infill ratio (R_{inf}) indicates the quantity of masonry infill as expressed by Eq. (8). Masonry infill panels with opening due to door and window have not been considered in this method. R_{inf} shall be calculated for both orthogonal directions and the minimum value is considered.

$$R_{inf} = \frac{\textit{Number of masonry panels in a direction}}{\textit{Total number of spans in a direction}} \tag{8}$$

For clarification of the way, an example is shown in Fig. 2. The total number of masonry infill panels are 2 and 3 in X and Y direction, respectively. On the other hand, the total number of spans are obtained as 16 and 15 in X and Y direction, respectively. Therefore, R_{inf} are to be found 2/16 and 3/15 for X- direction and Y-direction, respectively. Here, minimum R_{inf} value 2/16 has been considered for capacity prediction. In general, the thickness of masonry infill is within a range of 125 mm to 250 mm as found in the field survey in Bangladesh [14]. The masonry infill thickness (t_{inf}) is assumed as 125 mm for single layer of infill panel for conservative estimation.

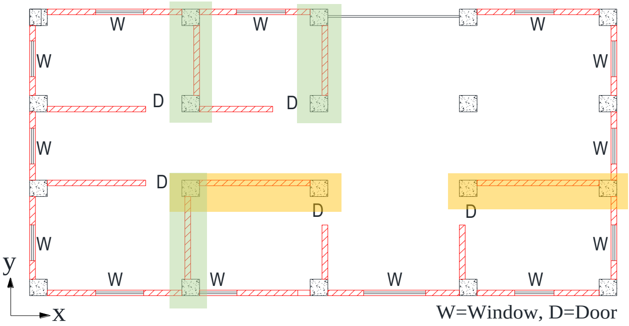


Fig. 2 – Typical floor plan showing location of masonry infill

2.2.3 Simplified RC wall area ratio

The simplified RC wall area ratio has been estimated by using similar way of simplified masonry infill area ratio as mentioned in the previous sub-section. Therefore, it is simplified by concrete wall ratio (R_{cw}), thickness of concrete wall (t_{cw}) and average span length (l_s) as shown in Eq. (9).

$$\frac{A_{cw}}{A_f} \approx \frac{t_{cw}}{l_s}.R_{cw} \tag{9}$$

where, concrete wall ratio (R_{cw}) indicates the quantity of concrete walls expressed as the ratio of the total number of solid concrete wall panels in a direction to the total number of spans for that direction as shown in Eq. (10).

$$R_{cw} = \frac{Number\ of\ \text{concrete walls}\ in\ a\ direction}{Total\ no\ of\ spans\ in\ a\ direction} \tag{10}$$

Only solid RC wall have been considered in this method. R_{cw} shall be calculated for both orthogonal directions and the minimum value is considered. In this study, the minimum thickness (t_{cw}) has been assumed as 200 mm as found as common in construction practices in RC buildings. However, it should be noted that this parameter could be changed based on each countries construction practices.

Considering simplified form of column area ratio, masonry infill area ratio, and concrete wall area ratio, the Visual Rating index (I_{VR}) in the Eq. (5) can be re-written as Eq. (11).

$$I_{VR} = \frac{1}{n.w}\left[\tau_c\left(\frac{b_c^2}{l_s^2}\right) + \tau_{\inf}\left(\frac{t_{\inf}}{l_s}.R_{\inf}\right) + \tau_{cw}\left(\frac{t_{cw}}{l_s}.R_{cw}\right)\right].S_D.T \tag{11}$$

In addition, other parameters such as building irregularity, deterioration and year of construction have large influence on seismic capacity of buildings. After considering the influence of these parameters, the Visual Rating index (I_{VR}) in the Eq. (11) can be expressed as:

$$I_{VR} = \frac{1}{n.w}\left[\tau_c\left(\frac{b_c^2}{l_s^2}\right) + \tau_{\inf}\left(\frac{t_{\inf}}{l_s}.R_{\inf}\right) + \tau_{cw}\left(\frac{t_{cw}}{l_s}.R_{cw}\right)\right]F_{IV}.F_{IH}.F_D.F_Y \tag{12}$$

where, F_{IV} and F_{IH} are the reduction factors for existence of vertical irregularity, horizontal irregularity for S_D index used in the Japanese standard. F_D and F_Y are the reduction factors for deterioration of concrete and buildings' year of construction for T index also used in the Japanese standard.

The basic assumptions for reduction factors and material properties for concrete strength, masonry infilled strength are described in the following sections.

2.3 Basic assumption for reduction factors

The following assumptions have been considered for seismic capacity reduction factors based on concepts and values used in the JBDPA standard [13]:

2.3.1 Vertical irregularity factor (F_{IV})

Vertical irregularity factor (F_{IV}) has been imposed to check balance of story stiffness distribution along the height, the inconsistency between adjacent floor and soft story etc. Therefore, vertical irregularity which includes setbacks in building, heavy overhanging portion and soft stories are considered, as shown in Fig. 3. The reduction factors for different vertical irregularity criteria are shown in Table 1 [13].

2.3.2 Horizontal irregularity factor (F_{IH})

Horizontal irregularity factor (F_{IH}) also affects the seismic capacity of existing buildings. The JBDPA [13] proposes guidelines for different criteria of plan irregularity and reduction factor for modifying the seismic capacity. Criteria for plan irregularity are shown in Fig. 4 as described in JBDPA manual [13] and the reduction factors are shown in Table 2.

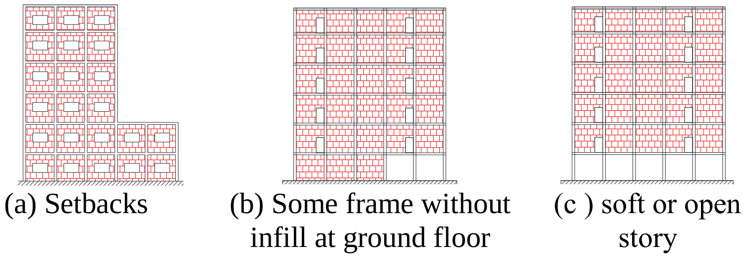


Fig:3 –Some typical RC frame having vertical irregularities

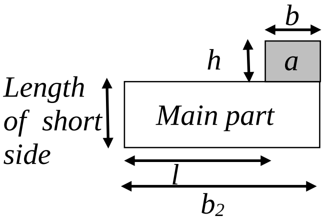


Fig: 4 –Criteria for plan irregularity

Table 1 – Factor for vertical irregularity (F_{IV})

Items	Regular	Nearly regular	Irregular
Criteria	Regular	Small opening at ground floor and setback	Soft story or opening at ground floor
F_{IV}	1.0	0.8	0.6

Table 2 – Factor for horizontal irregularity (F_{IH})

Items	Regular	Nearly Regular	Irregular
Shape	Regular	L, T or U shaped plan	L, T or U shaped plan
Projection area “a” (shaded part^a)	≤ 10 % of floor area	≤30% of floor area	>30% of floor area
F_{IH}	1.0	0.9	0.8

^{a}Projection area indicates shaded part in the Fig. 4

2.3.3 Deterioration factor (F_D)

Deterioration of concrete such as presence of cracks as well as spalling in structural elements indicates the degradation of seismic capacity of building. In this study, a reduction factor has been proposed based on JBDPA standard [13] as shown in Table 3.

2.3.4 Building’s year of construction factor (F_Y)

Generally, old buildings cannot be expected to have a good performance during earthquake due to old construction practices and building codes. For example, in Japan, poor seismic performance has been observed in old building, specially to those constructed before adopting new seismic design code 1981, in the 1995 Kobe earthquake [14]. The JBDPA standard [13] proposed a reduction factor for F_Y as shown in Table 4. It should be noted that the ranges mentioned in Table 4 can be changed based on year of publication and enforcement of local seismic design code in respected countries.

Table 3 – Deterioration factor (F_D)

Item	None	Minor	Severe
Criteria	No deterioration	Some cracks in structural element	Spalling in concrete
F_D	1	0.9	0.8

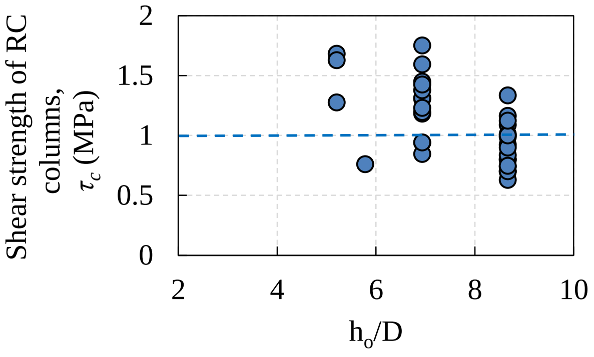
Table 4 – Year of construction factor (F_Y)

Item	New	Middle	Old
Criteria	Less than 15 years	15- 30 years	More than 30years
F_Y	1	0.95	0.9

2.4 Material properties

2.4.1 Average shear strength of RC column (τ_c)

The JBDPA standard [13] considers the average shear stress for column is 1.0 MPa for first level screening procedure based on shear span ratio, where h_o/D ranged between 2 to 6 (h_o is the clear height of column, D is the column width). Other study such as in Taiwan, Tsai et al. [15] summarized the detailed assessment results of school buildings and proposed the average ultimate shear strength of RC column as 15 kgf/cm^2 (1.47 MPa) for preliminary evaluation in Taiwan’s RC buildings. Fig. 5 shows a relationship between shear strength of column and h_o/D ratio based on analysis of existing RC buildings located at Dhaka, Bangladesh [5] as a case study of developing countries. In this study, therefore, τ_c is assumed 1.0 MPa as average value.



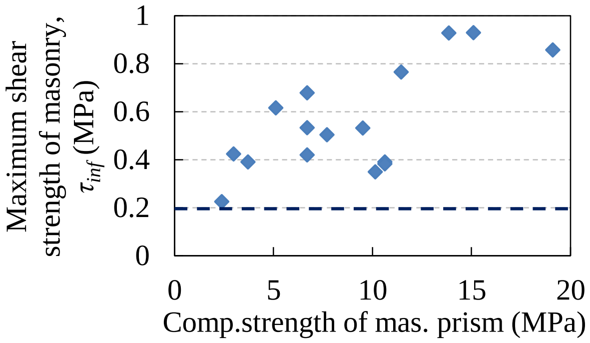


Fig. 5 – Average shear strength for column vs. h_o/D ratio for investigated RC buildings in Bangladesh [5]

Fig. 6 – Average shear strength for masonry infill with compressive strength of masonry prism [16]

2.4.2 Average shear strength of masonry infill (τ_{inf})

The masonry infill average shear strength, τ_{inf}, commonly ranges between 0.2MPa~1.0 MPa as shown by Fig. 6 in previous study [16] which shows a correlation between maximum shear strength of masonry infill corresponding to compressive strength of masonry prism. Other codes such, ASCE seismic guideline [17] prescribes shear strength as 34 psi (0.24 MPa) for masonry infill wall. A study by Chiou et al. [18] proposed lateral shear strength for masonry infill as 4.0 kgf/cm^2 (0.39 MPa) for preliminary assessment of RC Buildings in Taiwan. In this study, average shear strength of masonry infill, τ_{inf}, as 0.20 MPa has been adopted of the lateral shear strength for buildings in Bangladesh since the prism compressive strength is expected to be as low as 5 MPa.

2.4.3 Average shear strength of concrete wall (τ_{cw})

JBDPA standard [13] considers average shear strength of concrete wall (τ_{cw}) as 1.0 MPa considering without boundary column which is also adopted in this study.

2.4.4 Average unit weight per floor area (w)

The unit floor weight of existing buildings is found ranges from 10 to 12 kN/m^2 based on study of existing buildings in Bangladesh [5]. In this study, the average unit weight per floor area, w, is set as 11kN/m^2.

The aforementioned assumed values for each parameter in Eq. (12) could be adjusted later for each country based on suitable characteristics of buildings and materials strength properties in that region.

3. Validation of Visual Rating method based on past earthquake damage database

The proposed Visual Rating method has been intended to be applied on existing buildings in Dhaka city, Bangladesh under a Japanese project [19] to understand the seismic capacity of existing buildings in Bangladesh. However, there are no existence of past earthquake damage database in Bangladesh. In order to understand the effectiveness of the proposed method, the VR method applied on post-earthquake surveyed buildings database in Taiwan after the 2016 Taiwan earthquake (M_w: 6.4) and data have open access in the website of www.datacenterhub.org [20].

3.1 Overview of Taiwan EQ damage buildings' database

A number of 53 RC buildings from the Taiwan earthquake, 2016 has been investigated, which are obtained from the post-earthquake surveyed buildings' database [20]. A typical datasheet, used to record information in the survey, can be found from the database [20]. However, surveyed RC buildings were categorized into three damage classes, such as severe, moderate and light damage. Most of the RC buildings are school building with 2 to 5 storied, located at Tainan city, Taiwan [20].

3.2 Application of VR method and results

The Visual Rating method, developed herein, has been implemented based on information found from the post-earthquake buildings' database as mentioned in earlier section. Each survey datasheet consists of buildings' information related to size and thickness of RC column and masonry infills, floor plan and damage states. The average column size and average span length have been determined from the sketch of building's floor plan as found from the surveyed datasheet. The simplified column area ratio has been calculated using average column size and average span length for all surveyed buildings. It should be noted that the deterioration of the surveyed buildings could not be investigated after the earthquake, therefore, deterioration factors has been considered as one (1.0) for all investigated buildings. Visual Rating index is calculated for these buildings and seismic index (I_{S1}) is obtained by Eq. (4) as shown in previous section. The estimated Visual Rating index (I_{VR}) is compared with seismic index (I_{S1}) and damage ratio, as shown in Fig. 7(a) and 7(b), respectively. It has been observed that 70% of buildings with Visual Rating index (I_{VR}) < 0.3 are identified as severely damaged, and buildings with $I_{VR} > 0.60$ escaped from severely damaged. Such correlations show that the proposed Visual Rating method can screen the most vulnerable buildings.

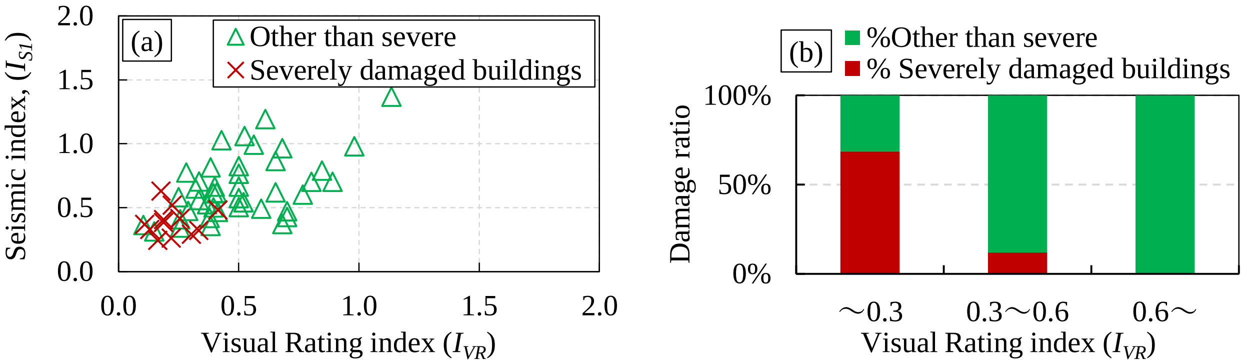


Fig. 7 – (a) Seismic index vs Visual Rating index (I_{VR}); (b) Damage ratio vs. Visual Rating index (I_{VR})

4. Application in existing RC building of Bangladesh: a case study in developing countries

4.1 Building survey in Bangladesh

In order to investigate the applicability of the proposed VR method, twenty-three existing RC buildings located at Dhaka in Bangladesh, have been surveyed under a technical research project SATREPS [19]. The following sections describe about the survey results.

4.2 Column area ratio of VR method

Fig. 8(a) shows a correlation between actual column area ratio and column area ratio of VR method estimated by dividing simplified column area ratio with number of story (n). It has been observed that VR method provides conservative values for column area ratio. The value of R^2 is of 0.89 indicates the effectiveness of the proposed method as shown in Fig. 8(a). It has been observed that actual column area ratio normalized with column area ratio of VR method, the average value 1.40 and coefficients of variation 19 % also shows good estimation of actual column area ratio.

4.3 Infill wall area ratio of VR method

The correlation between actual masonry infill area ratio and masonry infill area ratio of VR method estimated by dividing simplified masonry infill area ratio with number of story (n) is shown in Fig. 8(b). The masonry infill area ratio of VR method shows conservative results compared with actual masonry infill area ratio. Only solid masonry infill is counted during visual inspection for VR method, whereas actual wall area ratio is estimated considering both solid infill and also partial infill with less than 40% opening area.

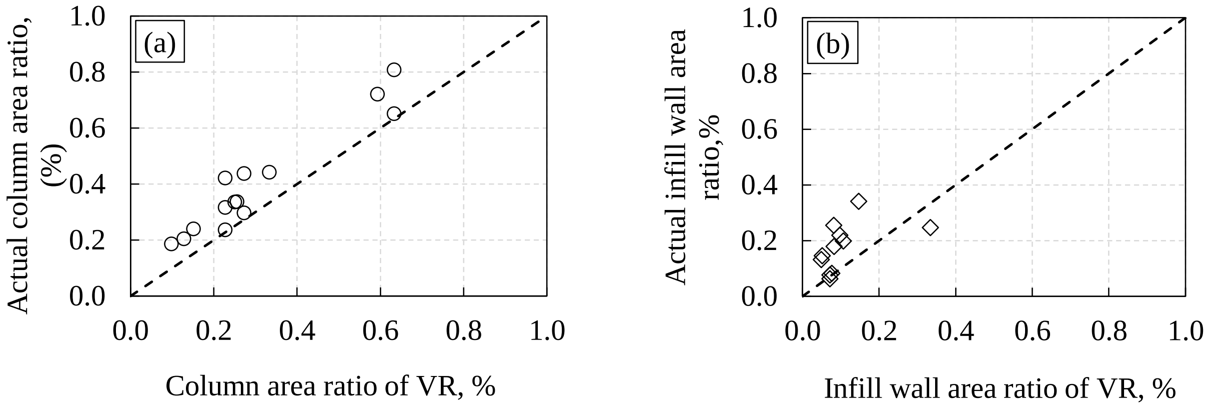


Fig. 8 – Comparison: (a) actual column area ratio vs. column area ratio of VR method (b) actual masonry infill area ratio vs. masonry infill area ratio of VR method

4.4 Comparison between detailed seismic evaluation and Visual Rating index (I_{VR})

The Visual Rating Index (I_{VR}) has been calculated based on information found from building survey at Dhaka in Bangladesh. Furthermore, seismic capacity (first and second level evaluation for both direction) has been investigated for these buildings using the proposed seismic evaluation procedure for RC building with masonry infill [16] and JBDPA standard [13]. Fig. 9(a) and 9(b) show the comparison of Visual Rating Index (I_{VR}) score with the minimum value of seismic index for both first level (I_{S1}) and second level (I_{S2}) evaluation procedure. It has been observed that the I_{VR} scores show conservative values for both evaluation procedures. It has been observed that first level evaluation provides conservative results compared to second level evaluation. The main difference is due to consideration of ductility of structural members based on reinforcement details and material strength in second level evaluation procedure which is ignored in the first level evaluation procedure. The average value of normalized seismic indices by VR index (e. g. I_{S1}/I_{VR}, I_{S2}/I_{VR}) are 1.5 and 2.0 with coefficient of variation 36% and 30%, respectively as shown in Fig. 9. Therefore, it indicates that I_{VR} score has good tendency with the values of the seismic capacity investigated by detailed evaluation method.

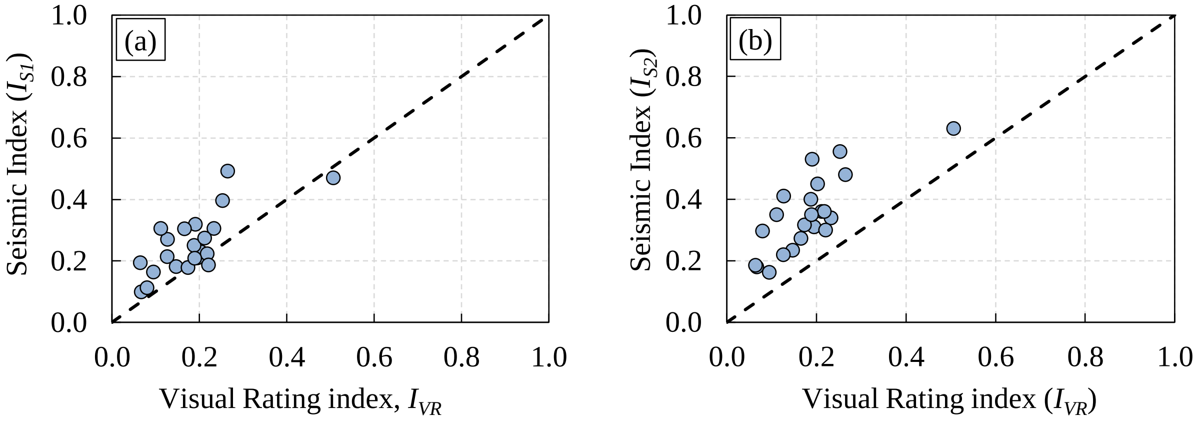


Fig. 9 – Comparison of VR Index (I_{VR}) with (a) First level evaluation, I_{S1}; (b) Second level evaluation, I_{S2}

5. Judgement criteria of VR method for priority settings of detailed evaluation

As previously mentioned, the main intention of the proposed VR method is to prioritize the existing RC buildings for detailed seismic evaluation. This section discusses about a proposal of judgement criteria of VR method for prioritization of existing building. In this study, judgment criteria for VR method is proposed based on judgement criteria (referred as seismic demand index, I_{SO}) of detailed seismic evaluation and a correlation between seismic index (I_{S2}) and VR index (I_{VR}).

Bangladesh now has adopted JBDPA standard [13] in CNCRP seismic evaluation manual [21] for seismic evaluation of existing RC buildings. In the CNCRP manual [21] judgement criteria of seismic demand index (I_{SO}) is proposed ranging from 0.28 to 0.36 according to seismic demand in Bangladesh National Building Code (BNBC), 2015 [22]. However, due to lack of past earthquake database in Bangladesh, the seismic demand index (I_{SO}), proposed by CNCRP manual [21], needs further verification before applying in the proposed VR method. Therefore, seismic demand index (I_{SO}) for detailed seismic evaluation is verified and proposed based on investigation of several model buildings which represents the existing RC building in Bangladesh. Detailed procedure is discussed in previous study by the author [5]. In that previous study [5], buildings are classified into 5 groups namely A, B, C, D and E according to proposed the judgement criteria as shown in Table 5. In the criteria, the buildings have lower seismic capacity (i.e. I_{S2} less than 0.40) are considered as vulnerable buildings and E are the most vulnerable buildings. In this study, judgment criteria of VR method are proposed using the categorization according to seismic index (I_{S2}), and correlation between seismic index (I_{S2}) and Visual Rating index (I_{VR}).

Table 5 – Judgement criteria according to seismic index (I_{S2}) [5]

Seismic index (I_{S2})	Categories	Description
0.50~	A	No damage
0.40~0.50	B	Light damage
0.30~0.40	C	Less possibility of collapse
0.20~0.30	D	Moderate possibility of collapse
<0.20	E	High possibility of collapse

A correlation between seismic index (I_{S2}) and Visual Rating index (I_{VR}), is already obtained as shown in Fig. 9(b), is considered to propose judgement criteria of the VR method. Based on the judgement criteria of seismic index (I_{S2}), as shown in Table 5, the surveyed buildings are categorized into 5 (five) classes according to Visual Rating index (I_{VR}). The upper and lower limit of VR index (I_{VR}) score of each category of seismic index (I_{S2}) is shown in Fig. 10. It has been observed that there is large variation of Visual Rating index (I_{VR}) score in between higher range of seismic index (I_{S2}). Due to these variations, it is not easy to set boundaries for Visual Rating index (I_{VR}) according to seismic index (I_{S2}).

Since the proposed VR method is a preliminary evaluation by visual inspection and the main target is to screen all of vulnerable buildings, it is acceptable if not vulnerable buildings are being identified as the vulnerable buildings (such as in categories C to E). However, the number of not vulnerable buildings within these categories (such as in categories C to E) should be as few as possible. A correlation between cumulative distribution of buildings (in percentage) for each range of seismic index (I_{S2}) and Visual Rating index (I_{VR}) is developed in the previous study [5] as shown in Fig. 11. According to the Fig. 11, this study proposes the boundaries of judgement criteria of VR method considering the target number of buildings (in percentages) in

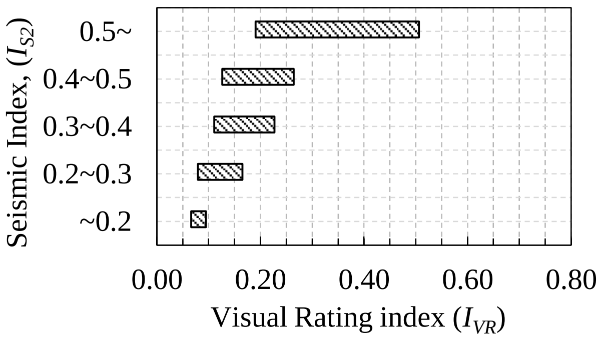


Fig. 10 – Variation of Visual Rating index (I_{VR}) score in each range of seismic index (I_{S2})

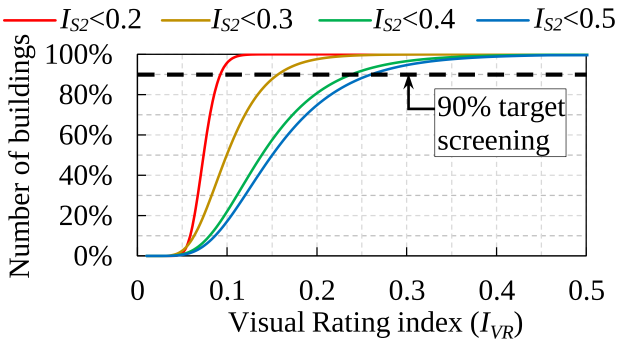


Fig. 11 – Cumulative percentage of buildings according to Visual Rating index (I_{VR})

each category are to be screened. Considering the target screening 90% in each category as shown in Fig. 11, boundaries of I_{VR} are set as mentioned in Table 6. It has been observed that there are still some variations in each range ranges of I_{VR} and the difference of range $0.24 \leq I_{VR} < 0.26$ is 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 building might change the range of these boundaries.

Table 6 –Boundaries according to different target number of buildings

Number of buildings (percentages) identified in each categories	90%
Visual Rating Index (I_{VR}) ranges	$0.26 \leq I_{VR}$
	$0.24 \leq I_{VR} < 0.26$
	$0.16 \leq I_{VR} < 0.24$
	$0.09 \leq I_{VR} < 0.16$
	$I_{VR} < 0.09$

Based on above discussion and considering simplification of each range, boundaries of judgement criteria of VR method is proposed as shown in Table 7. From the criteria, the buildings with I_{VR} is less than 0.10, located at E category, are the most vulnerable buildings and detailed evaluation is highly recommended.

Table 7 – Proposed boundaries for Visual Rating method

Range	Categories	Description
$0.25 \leq I_{VR}$	A	No damage
$0.20 \leq I_{VR} < 0.25$	B	Light damage
$0.15 \leq I_{VR} < 0.20$	C	Less Possibility of collapse
$0.10 \leq I_{VR} < 0.15$	D	Moderate possibility of collapse
$I_{VR} < 0.10$	E	High possibility of collapse

6. Conclusions

This study describes a simple screening method for RC building with masonry infill based on visual inspection. The method calculates the Visual Rating Index (I_{VR}) which is an approximate estimation of seismic capacity of existing building. The Visual Rating Index (I_{VR}) has been calibrated with first level and second level evaluation by investigating of existing buildings located in Bangladesh as a case study in developing country.

The following conclusions can be stated as follows:

1. The Visual Rating method considers the simplified column area ratio and the simplified wall area ratio, which approximately estimates the base shear of a building. The inclusion of those ratio in Visual Rating method is the new concept that have not been considered in the existing visual screening methods.

2. The effectiveness of the Visual Rating index (I_{VR}) has been found by obtaining good agreement with the damage distribution of existing buildings based on the 2016 Taiwan post-earthquake buildings' database.

3. The Visual Rating index (I_{VR}) score shows good correlation with seismic index (I_{S1}) in first level evaluation. However, I_{VR} score shows more conservative with second level evaluation (I_{S2}). The reason is that I_{VR} assumes structural members as non-ductile members since ductility of column is difficult to be judged based only on visual inspection. Detailed information such as reinforcement details and actual material strength is needed to judge ductility which is considered in second level evaluation.

4. The judgement criteria for I_{VR} are set into five classes such as A, B, C, D and E from less to most vulnerable buildings. Where, I_{VR} lower than 0.20 are regarded as vulnerable buildings, and the buildings with $I_{VR}<0.10$ are the most vulnerable and high priority for detailed seismic evaluation.

Even though, this method is intended to RC buildings in Bangladesh, but could be easily adjusted to other countries by modifications for suitable characteristics of buildings and materials strength properties in the intended region.

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