- Technical Paper -

VISUAL RATING METHOD FOR SEISMIC EVALUATION OF EXISTING RC BUILDINGS WITH MASONRY INFILL: A CASE STUDY OF BANGLADESH

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ABSTRACT

In Bangladesh, seismic evaluation of an enormous stock of vulnerable masonry infilled RC buildings is necessary. Identifying most vulnerable buildings by visual inspection would reduce time and cost of detailed evaluation. However, existing visual screening methods have limitations to provide seismic capacity of building as shown in this study. Therefore, a Visual Rating method is proposed and applied to several existing RC buildings at Dhaka city in Bangladesh. The Visual Rating Index has been then compared with detailed seismic evaluation results, which shows good correlation.

Keywords: Seismic capacity, Visual Rating method, Existing RC building, Masonry infill.

1. INTRODUCTION

Past earthquake damage in developing countries have been exhibiting the necessity of seismic evaluation and strengthening of existing buildings. In addition, enormous stocks of vulnerable buildings exist in those countries. Identifying vulnerable buildings using a quick and reliable evaluation procedure, and prioritizing for retrofitting and/or strengthening would be of a great interest in terms of time and costs.

Existing visual screening methods have limitation to provide seismic capacity because those methods do not consider the variation of cross-sectional area of structural elements (i.e. column, masonry infill and RC wall area etc.).

This study aims to develop a Visual Rating (VR) method which provides an approximate estimation of seismic capacity. The proposed method is based on the cross-sectional area of columns and cross-sectional area masonry infills in existing infilled masonry-RC buildings. The method has been investigated by applying on existing RC buildings in Dhaka city, Bangladesh as a case study. The effectiveness of the proposed method has been verified by comparing with detail seismic evaluation of investigated buildings.

2. STUDY ON SEISMIC CAPACITY OF EXISTING BUILDINGS BASED ON PAST EQ DATABASE

This section provides the correlation between seismic capacity and damage state of buildings experienced past earthquake using simplified procedure.

2.1 Overview of Past EQ Damage Database

53 buildings for the Taiwan earthquake, 2016 has been investigated, which are provided by post-earthquake damage survey database [1]. Fig.1 shows distribution of RC buildings according to number of story. Most of the buildings are two to four storied. A typical survey datasheet was used to record information as shown in Fig. 2. Buildings have been categorized into three damage classes based on visual inspection [1]. Definitions of each damage states are shown in Table 1.

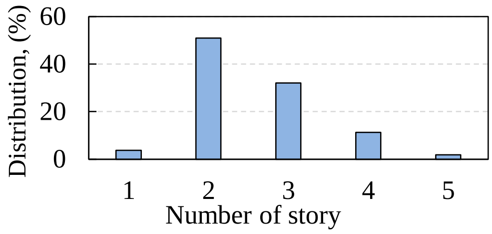

Fig.1 Distribution (%) with number of story

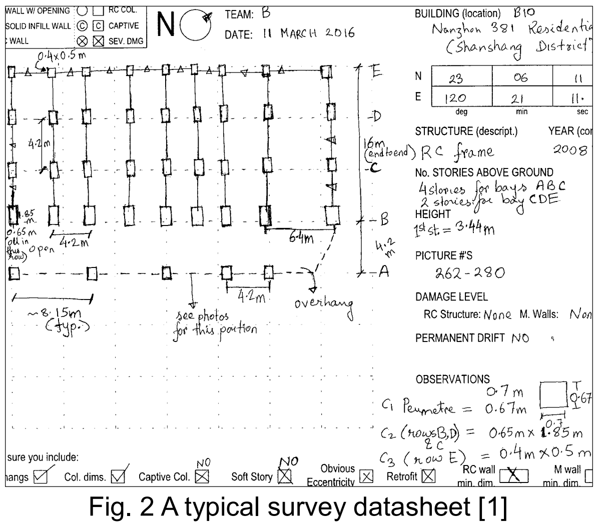

Fig. 2 A typical survey datasheet [1]

Table 1 Damage definition [1]

Damage state	Selection criteria
Light	Hairline flexural cracks.
Moderate	Wider cracks, concrete spalling.
Severe	At least one element has failed.

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2.2 Calculation of Seismic Capacity Index

The basic concept of seismic capacity is based on the Shiga Map [2]. However, the Shiga map does not consider the effects of masonry infill. In this study, the seismic capacity index has been considered as the summation of lateral strength of RC column, masonry infill and concrete wall normalized with total building weight [3] as expressed by Eq. 1.

$$\text{Seismic capacity index}=\left[\frac{\tau_c.A_c}{n.A_f.w}+\frac{\tau_{inf}.A_{inf}}{n.A_f.w}+\frac{\tau_{cw}.A_{cw}}{n.A_f.w}\right] \quad (1)$$

where A_c/A_f, A_{inf}/A_f, and A_{cw}/A_f refer to column area ratio, masonry infill area ratio, and concrete wall area ratio, respectively. n is the number of story. In the Eq. 1, τ_c, τ_{inf}, and τ_{cw} are average shear strength of column, masonry infill, and concrete wall.

The following assumptions have been made for the seismic capacity computation in Eq.1:

(a) Average shear strength of RC column (τ_c)

The Japan Building Disaster Prevention Association (JBDPA) [4] 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 depth of column). However, Tsai et al. [5] summarized the detailed assessment results of school buildings in Taiwan and proposed the average ultimate shear strength of RC column as 15 kgf/cm^2 (1.47 MPa) for preliminary evaluation. In this study, therefore, τ_c is assumed 1.0 Mpa as conservative value.

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

ASCE seismic guideline [6] prescribes shear strength as 34 psi (0.24 MPa) for masonry infill wall. However, Chiou et al. [7] 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 0.2 MPa has been adopted as lower boundary of the lateral shear strength.

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

JBDPA standard [4] considers τ_{cw} as 1.0 MPa considering without boundary column. Therefore, τ_{cw} has been assumed 1.0 MPa as lower boundary.

(d) Average unit weight per floor area (w)

The unit floor weight of existing buildings has been found from 10 to 12 kN/m^2 based on study of existing RC buildings [8]. In this study, the average unit weight per floor area, w, is set as 11kN/m^2.

2.3 Results and Discussion on Seismic Capacity with Damage state

Fig. 3 shows seismic capacity index of surveyed buildings in two orthogonal (NS and EW) directions with actual damage state in the Taiwan earthquake, 2016. From Fig.3, it is obvious that the buildings having low seismic capacity index, i.e. low column and masonry area, experienced severe damage. The good agreement of the seismic capacity index with damage states implies that column area and masonry infill area ratio are very effective parameters for identifying the seismically vulnerable buildings.

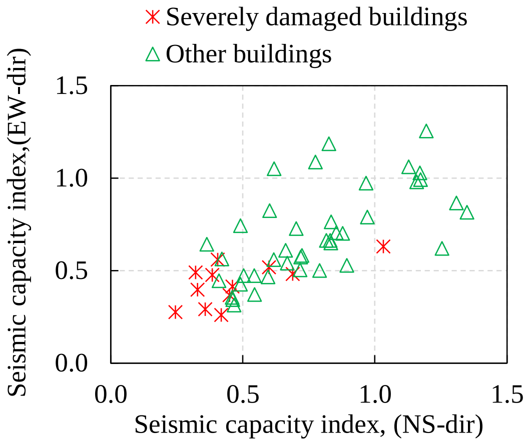

Fig.3 Seismic capacity index with damage state

Though, cross-sectional area of vertical elements (e.g. column, RC wall and masonry infill) and corresponding strength have profound influences on seismic capacity. However, screening of large numbers of existing buildings, using aforementioned method is quite challenging because it requires detail architectural drawings. If architectural drawings are not available, then as-built drawing preparation are necessary, which takes much time for seismic evaluation procedure. Hence, there is need for developing very simple method based on visual inspection which takes less time and cost. In this aspect, existing rapid visual screening (RVS) methods in different countries are described in subsequent section.

3. STUDY ON EXISTING RAPID VISUAL SCREEING (RVS) METHOD

3.1 Discussion on Existing RVS Method

A number of guidelines/procedures are available from different countries for rapid screening out the vulnerable buildings. The following sub-sections describe three existing RVS methods briefly:

3.1.1 FEMA P 154

The FEMA P 154 [9] has been proposed by the U.S. Federal Emergency Management Agency (FEMA) for seismic risk assessment and rehabilitation of existing buildings. This method provides score which predicts the probability of collapse. However, the FEMA final score is the summation of basic score and score modifiers due to other vulnerability parameters. FEMA considers a basic score for masonry infilled RC structure based on lateral force resisting system as shown in the manual [9].

3.1.2 Turkish RVS Method

Middle East Technical University (METU) [10] proposed RVS method based on past EQ damages in Turkey. This method determines seismic performance score which is a combination of initial score, vulnerability score and score modifiers. The initial score is given with respect to the number of stories and the seismic intensity as well as study on past earthquake.

3.1.3 Indian RVS method

Jain et al. [11] proposed RVS method for India based on damage database of past earthquake. This method predicts expected performance score which is summation of basic score, vulnerability score, and vulnerability modifiers. Basic score also considers local soil type and seismic zone.

3.2 Comparison between Existing RVS Method and Seismic Capacity Index

The existing RVS methods described in the earlier section have been applied on the 2016 Taiwan EQ damage database [1]. Performance scores for each method are calculated based on survey information in the database. Afterward the performance scores of each method have been compared with previously calculated the seismic capacity index (minimum of two orthogonal directions) as shown in Fig. 4. There is no clear correlation of seismic capacity and the performance scores for each method as shown in Fig. 4.

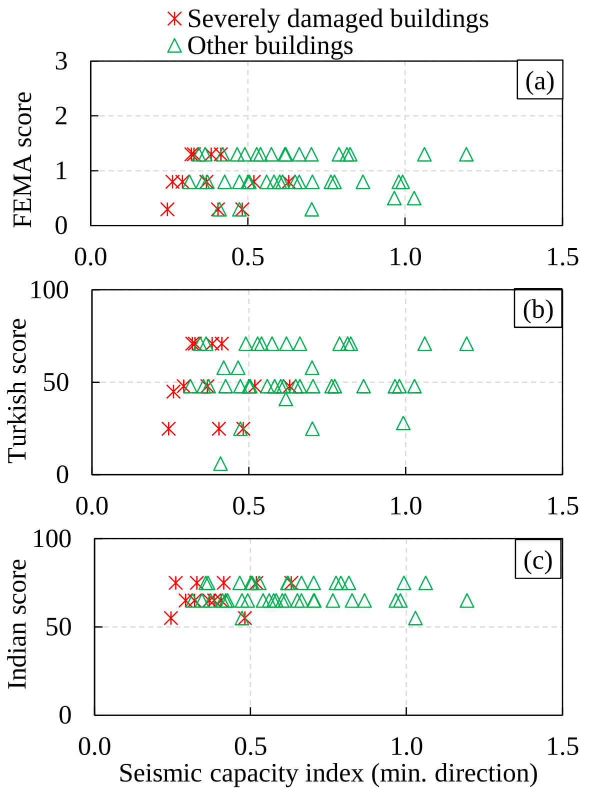

Fig. 4 Seismic capacity index vs. the results of existing RVS method: (a) FEMA P 154, (b) Turkish RVS method, (c) Indian RVS method.

Existing RVS methods do not consider the variation of cross-sectional areas of vertical structural elements (such as column area, masonry wall area and span length) which are very important factors influencing the seismic capacity. Therefore, this study presents a simplified way for estimation of column area ratio, masonry infill wall area ratio, and concrete wall area ratio thorough visual inspection. This method considers a score, 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.

4. PROCEDURE OF VISUAL RATING METHOD

Visual Rating Index (I_{VR}) indicates the seismic capacity of existing buildings which is expressed by Eq. 2.

$$I_{VR} = \frac{1}{n.w}\left[\tau_c.I_c + \tau_{\inf}.I_{\inf} + \tau_{cw}.I_{cw}\right] \quad (2)$$

where, I_c, I_{inf}, and I_{cw} are defined as column area ratio (A_c/A_f), masonry infill area ratio (A_{inf}/A_f), and concrete wall area ratio (A_{cw}/A_f) respectively.

The proposed method is based on visual inspection within a short duration, as it is not easy to measure all dimensions of all columns, masonry infill walls, and concrete walls, as well as total floor area. Therefore, a simplified way has been proposed for estimating the column, masonry infill and concrete wall area ratio using visual inspection.

4.1 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 of all column size of a building and average span length (l_s) represents the floor area of a surveyed building as shown in Fig. 5 as a typical floor plan. Hence column area ratio is simplified as follows in Eq. 3:

$$I_c = \frac{A_c}{A_f} \approx \frac{b_c^2}{l_s^2} \quad (3)$$

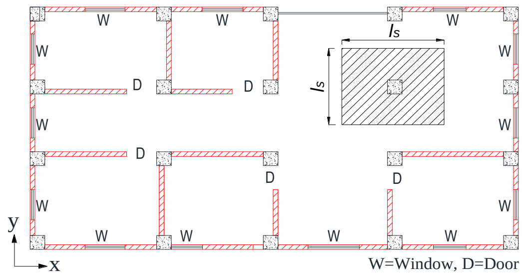

Fig. 5 Typical floor plan showing location of infill

4.2 Simplified Masonry Infill Area Ratio

The masonry infill area ratio has been simplified by using masonry infill ratio (R_{inf}), thickness of masonry infill (t_{inf}) and average span length (l_s) as shown in Eq. 4.

$$I_{\inf} = \frac{A_{\inf}}{A_f} \approx \frac{t_{\inf}}{l_s}.R_{\inf} \quad (4)$$

where, masonry infill ratio (R_{inf}) indicates the quantity of masonry infill as expressed by Eq. 5. Masonry infill 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.

$$R_{inf} = \frac{\text{Number of masonry panel in a direction}}{\text{Total no of span in a direction}} \quad (5)$$

For clarification of the way, an example is shown in Fig. 6. 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 [8]. However, this study assumes the masonry infill thickness (t_{inf}) as 125 mm for single layer of infill panel.

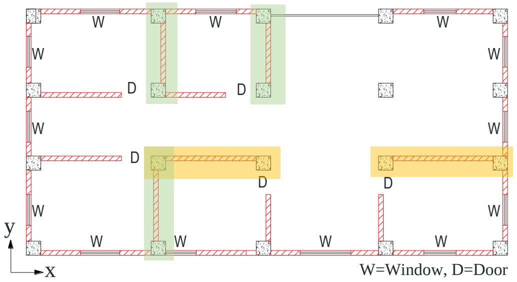

Fig. 6 Typical floor plan showing location of infill

4.3 Simplified RC Wall Area Ratio

The concrete wall area (I_{cw}) ratio has been simplified by using similar way of masonry infill area ratio (I_{inf}) 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. 6.

$$I_{cw} = \frac{A_{cw}}{A_f} \approx \frac{t_{cw}}{l_s}.R_{cw} \quad (6)$$

where, concrete wall ratio (R_{cw}) indicates the quantity of concrete wall expressed as the ratio of the total number of solid concrete wall panel in a direction to the total number of spans for that direction as shown in Eq. 7.

$$R_{cw} = \frac{Number\ of\ \text{concrete wall}\ in\ a\ direction}{Total\ no\ of\ span\ in\ a\ direction} \quad (7)$$

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 from the survey.

Considering simplified form of column area ratio (I_c), masonry infill area ratio (I_{inf}), and concrete wall area ratio (I_{cw}), the Visual Rating Index (I_{VR}), the Eq. 2 can be re-written as Eq. 8.

$$I_{VR} = \frac{1}{n.w}\left[\tau_c\left(\frac{b_c^2}{l_s^2}\right) + \tau_{\text{inf}}\left(\frac{t_{\text{inf}}}{l_s}.R_{\text{inf}}\right) + \tau_{cw}\left(\frac{t_{cw}}{l_s}.R_{cw}\right)\right] \quad (8)$$

In addition, other parameters such as building irregularity, deterioration and year of construction have large influence on seismic capacity of buildings. Fig. 7 shows some photographs of severely damaged building due to irregularity of buildings. Several studies [10, 11] also focused on the importance of such parameters. After considering the influence of aforementioned parameters, the VR index in the Eq. 8 can be expressed as:

$$I_{VR} = \frac{1}{n.w}\left[\tau_c\left(\frac{b_c^2}{l_s^2}\right) + \tau_{\text{inf}}\left(\frac{t_{\text{inf}}}{l_s}.R_{\text{inf}}\right) + \tau_{cw}\left(\frac{t_{cw}}{l_s}.R_{cw}\right)\right] F_{IV}.F_{IH}.F_D.F_Y \quad (9)$$

where, F_{IV}, F_{IH}, F_D and F_Y are the modification factors for existence of vertical irregularity, horizontal irregularity, deterioration of concrete and year of construction respectively.

The basic assumptions about material properties are already described in earlier section. The basic assumptions for modification factors are described in the subsequent section.

(a) Damage due to torsional effect (b) Collapse due to soft story effect

Fig. 7 Damage due to irregularity in 2015 Nepal Earthquake (www.datacenterhub.org)

4.4 Basic Assumption for Modification Factors

The following assumptions have been considered for seismic capacity modification factors based on concepts and values used in the JBDPA standard [4]:

(i) 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. The reduction factors for different vertical irregularity criteria are shown in Table 2 [4].

Table 2 Factor for vertical irregularity (F_{IV})

Items	Regular	Nearly Regular	Irregular
Criteria	Regular	Small opening at ground floor	Soft story floor
F_{IV}	1	0.8	0.6

(ii) *Horizontal irregularity factor (F_{IH})*

Horizontal irregularity factor (F_{IH}) also affects the seismic capacity of existing buildings. The JBDPA [4] proposes guidelines for different criteria of plan irregularity and reduction factor for modifying the seismic capacity. Criteria for plan irregularity are described in JBDPA seismic evaluation manual [4] and the reduction factors are shown in Table 3.

Table 3 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
Projecti-on area	≤ 10 % of floor area	≤30% of floor area	>30% of floor area
F_{IH}	1	0.8	0.6

(iii) 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 [4] as shown in Table 4.

Table 4 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

(iv) Building year of construction factor (F_Y)

Generally, old building 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 [12]. The JBDPA standard [4] proposed a reduction factor for F_Y as shown in Table 5.

Table 5 Year of construction factor (F_Y)

Item	New	Middle	Old
Criteria	<15 years	15-30 years	> 30 years
F_Y	1	0.95	0.9

The aforementioned assumed values for each parameter in Eq. 9 could be adjusted later for each country based on suitable characteristics of buildings and materials strength properties in that region.

5. APPLICATION IN BANGLADESH AS A CASE STUDY FOR DEVELOPING COUNTRIES

In order to investigate the applicability of the Visual Rating (VR) method, 14 (Fourteen) existing buildings located in Bangladesh have been inspected under a technical research project SATREPS [8]. After analysis, it has been observed that the VR method provides conservative values for both simplified column area ratio and simplified masonry infill area ratio as shown in Fig. 8. Actual column area ratio normalized with simplified column area ratio, the average value 1.40 and coefficients of variation 19 % also shows good estimation of actual column area ratio.

The Visual Rating Index (I_{VR}) has been calculated based on information found from building survey in Bangladesh. The calculated I_{VR} scores are shown in Table 6. 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 [13] and JBDPA standard [4]. The values of seismic index for first level and second level evaluation in minimum directions are shown in in Table 6. It has been seen 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 details reinforcement details and material strength in second level evaluation procedure.

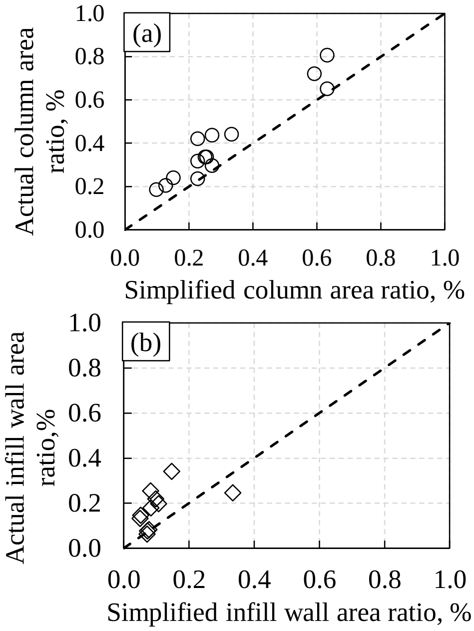

Fig. 8 Comparison: (a) actual column area ratio vs. simplified column area ratio (b) actual masonry infill area ratio vs. simplified masonry infill area ratio

Table 6 VR Index with minimum I_s in first and second level evaluation

Building ID	VR Index	Seismic Index, I_s	
		1st level	2nd level
Bldg # 1	0.51	0.47	0.64
Bldg # 2	0.08	0.09	0.17
Bldg # 3	0.20	0.21	0.29
Bldg # 4	0.20	0.23	0.45
Bldg # 5	0.18	0.31	0.35
Bldg # 6	0.24	0.35	0.51
Bldg # 7	0.20	0.25	0.44
Bldg # 8	0.23	0.32	0.53
Bldg # 9	0.13	0.27	0.42
Bldg #10	0.06	0.16	0.17
Bldg #11	0.26	0.49	0.40
Bldg #12	0.21	0.27	0.36
Bldg #13	0.11	0.31	0.35
Bldg #14	0.17	0.18	0.23

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. It has been observed that the I_{VR} scores show conservative values for both evaluation procedures. 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 can provide lower boundary of seismic capacity.

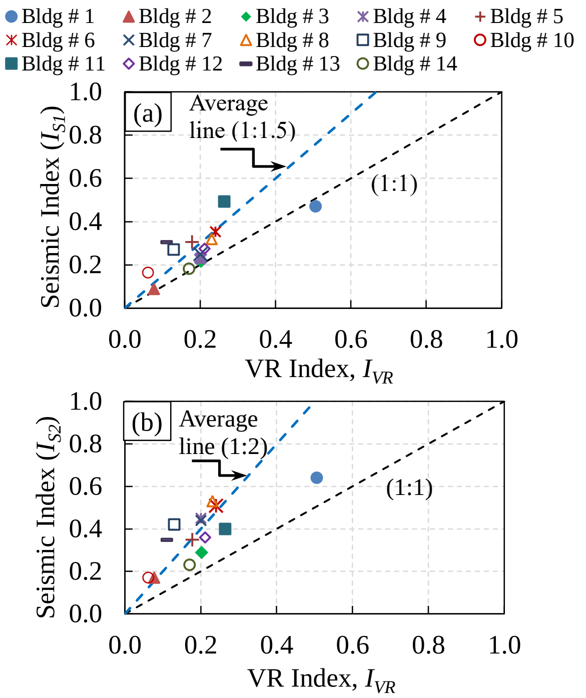

Fig. 9 Comparison of VR Index (I_{VR}) with (a) First level evaluation, I_{S1} ;(b) Second level evaluation, I_{S2}

6. CONCLUSIONS

This study describes a simple screening method for masonry infilled RC building 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 RC 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 seismic capacity of buildings. 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 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.

However, the assumptions considered for column, masonry infill and concrete wall need further investigation for each countries according to local materials. Even though, this method is intended to 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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