APPLICATION OF VISUAL RATING METHOD AND PRIORITY SETTING FOR DETAILED EVALUATION OF EXISTING RC BUILDING IN BANGLADESH

Md S Islam*1, AKM S Rahman2, Masaki Maeda3 and Md A Alam4

[1] *Senior Research Engineer, Housing and Building Research Institute, Bangladesh,e-mail:shafiulce@gmail.com*
[2] *Graduate Student, Tohoku University, Japan, e-mail: sajedur143@gmail.com*
[3] *Professor, Tohoku University, Japan, e-mail: maeda@rcl.archi.tohoku.ac.jp*
[4] *Director General, Housing and Building Research Institute, Bangladesh, e-mail: hbribd@gmail.com*

***Corresponding Author**

ABSTRACT

Past earthquakes, in developing countries, caused major destruction in masonry infilled RC buildings highlights the existence of a large stock of seismically vulnerable buildings. It is necessary to conduct seismic evaluation of these existing RC buildings to avoid future earthquake damages. However, it is a challenge to conduct detailed seismic evaluation for a large stock of existing RC buildings due to several reasons, including the limitations of availability of detailed architectural and structural drawings along with other necessary information for most of the buildings. To reduce the limitations above, a rapid visual screening method, namely Visual Rating (VR) method, has been developed for screening and prioritization of the most vulnerable buildings for detailed seismic evaluation. The VR method estimates seismic capacity of existing RC buildings in terms of Visual Rating index (I_{VR}) which 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 building's age. This paper presents an application of the VR method on existing RC buildings located in Dhaka, Bangladesh. A total number of 1020 masonry infilled RC buildings are investigated and I_{VR} score has been calculated for all surveyed buildings. Buildings are categorized and prioritized for detailed evaluation according to I_{VR} score. It has been observed that about 35% of the surveyed buildings are categorized into least to highest priority of detailed seismic evaluation for retrofitting. Based on detailed evaluation of 20 (twenty) existing RC buildings among the all-surveyed buildings, it has been observed that, I_{VR} provides a lower boundary of seismic capacity of an existing RC building comparing with the results of detailed evaluation, which shows a good correlation.

Keywords: *Seismic capacity, Visual Rating method, Existing RC buildings, Masonry infill, Prioritization*

1. INTRODUCTION

Past devastating earthquakes in developing countries (such as Nepal, Turkey, and Ecuador) have been highlighted the existence of a large stock of vulnerable rein-forced concrete buildings, and exhibits the necessity of seismic evaluation and retrofitting of existing RC buildings. However, there are an existence of large stock of seismically vulnerable masonry infilled-RC buildings. It is urgent to conduct detailed seismic evaluation of all these existing buildings but with the limited resources and time, which is a challenge for those developing countries. To overcome the issues, prioritization thorough identification of the most vulnerable buildings using rapid visual screening method is an effective way for de-tailed seismic evaluation of existing RC buildings.

Several onsite visual inspection methods and guidelines, such as FEMA rapid visual screening (RVS) method (FEMA P 154 2015), Turkish RVS method (Sucuoglu et at. 2007 and BU-ITU-METU-YTU 2003) and Indian RVS method (Jain et al. 2010), are available for quick identification of seismically vulnerable buildings. However, recent study (Islam M.S. 2019) shows that these existing RVS methods provide a score which does not have good relationship with the seismic capacity of an existing RC building. Other several methods (Shiga et al. 1968, Hassan and Sozen 1997, Bonmez and Pujol 2005, O'brien et al. 2005, Chou et at. 2017, Maeda et al. 2018, Islam M.S. 2018 and AlWashali et al. 2020) developed based on study on past earthquake damage databases, states that cross-sectional area of structural elements and their shear strength have a great influence on seismic capacity of existing RC buildings. However, these methods require detailed architectural and structural drawings for calculation of the cross-sectional area of RC column, RC wall, masonry infilled wall, and floor area. In case of absence of drawings, as-built detailed drawing is prepared to apply these methods which requires much efforts and time.

To overcome the limitations above, a rapid evaluation method referred as Visual Rating (VR) method (Islam et al. 2019, Islam M.S. 2019, Islam et al. 2020, HBRI 2022) has been developed under a research project namely SATREPS-TSUIB (2015), which is a technical cooperation project between Government of Bangladesh and Japan International Cooperation Agency (JICA), and Japan Science and Technology Agency (JST), Japan. The VR method estimates the seismic capacity of existing RC buildings considering the lateral strength of RC column, masonry infilled wall and RC wall in a simplified way thorough visual investigation. The purpose of VR method is to set the priority for detailed evaluation based on the proposed judgement criteria (Islam M.S. 2019, HBRI 2022, Islam et al. 2020). However, it is necessary to apply the VR method on large number of existing RC buildings to understand its applicability and effectiveness. This paper presents an application of the VR method on existing RC buildings located in Dhaka city, Bangladesh. A common survey datasheet is used to conduct the field survey. The Visual Rating index (I_{VR}) score has been calculated. Furthermore, buildings are categorized for prioritization as per judgement criteria based on I_{VR} score. Afterward several existing masonry infilled RC buildings have been investigated in detailed during the building survey. The detailed seismic evaluation has been carried out and the results has been compared the output of the Visual Rating index of those investigated buildings. This research outcomes will be helpful to prepare a seismic prioritization map toward screening large number of buildings stock in future.

2. VISUAL RATING METHOD

The Visual Rating (VR) method 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 vulnerability. The main concept of the VR method comes from the Japanese seismic evaluation standard (JBDPA) (2001), which proposes a practical way for calculating the seismic capacity of existing RC buildings. There are three levels of evaluation procedure in the JBDPA standard (2001). However, the VR method is developed based on the simplified seismic evaluation procedure (Maeda et al. 2018, Islam et al. 2018, AlWashali et al. 2020, Islam et al. 2020) of the first level evaluation procedure of JBDPA standard (2001), considers the summation of lateral strength of RC column, masonry infill and concrete wall normalized with total building weight. The VR method provides a score, reported as Visual Rating index (I_{VR}), which approximates seismic capacity of existing RC buildings. The Visual Rating index (I_{VR}) is calculated by following Equation (1).

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

where, τ_c, τ_{inf}, and τ_{cw} are average shear strength of RC column, masonry in-fill, and reinforce concrete wall; b_c, l_s and t_{inf} are the average span length, average column size and masonry infill thickness; R_{inf} and R_{cw} are the masonry infill ratio and RC wall ratio. n is the number of stories, A_f is the floor area, and w is the unit weight per floor area of a RC building. F_{IV}, F_{IH}, F_D and F_Y are the reduction factors for existence of vertical irregularity, horizontal irregularity, deterioration of concrete and year of construction respectively. The detailed calculation procedure, and basic assumptions of material properties and reduction factors are dis-cussed in another study (Islam M.S. 2019, Islam et al. 2019, Islam et al. 2020) and the Visual Rating (VR) manual (HBRI 2022) under the SATREPS-TSUIB project (2015).

As seismic prioritization is the main intention of the VR method, the buildings are to be categorized into different classes. Boundaries of categorization of VR method is proposed in the VR manual (HBRI 2022) proposed as shown in Table 1. From the criteria, the buildings with I_{VR} are less than 0.10, located at E category, are the most vulnerable buildings and detailed evaluation is highly recommended.

Table 1 Proposed boundaries of Visual Rating method (HBRI 2022, Islam et al. 2020)

Range	**Categories**	**Priority of detailed evaluation**
$0.25 \leq I_{VR}$	A	Least
$0.20 \leq I_{VR} < 0.25$	B	Less
$0.15 \leq I_{VR} < 0.20$	C	Moderate
$0.10 \leq I_{VR} < 0.15$	D	High
$I_{VR} < 0.10$	E	Highest

3. APPLICATION ON EXISTING RC BUILDING

3.1 Overview of investigated buildings

A total number of 1020 masonry infilled RC buildings have been considered for this building survey. The buildings survey has been conducted under the research project SATREPS-TSUIB (2015). These buildings are located at Dhaka, Bangladesh as shown in Figure 1. It is noted that the surveyed buildings are masonry infilled RC buildings which is common structural system for mid to low rise buildings in Bangladesh. Survey activities has been performed in Daniya (Ward 50, 60 & 61), Shanir Akhra (Ward 60), Muradpur (Ward 52 & 53), Shyampur (Ward 58), Jurain (Ward 53) and Shekhdi (Ward 62 & 63) in Dhaka city, Bangladesh. Several survey teams were formed for conducting building survey activities including professional engineers, diploma engineers and skilled technician. Several training programs were also done for conducting building survey effectively. Preparation of building survey includes selection of target building and number of buildings to be surveyed, negotiation with local community leaders and explanation of result to house owners. Building survey includes application of VR method to existing RC buildings.

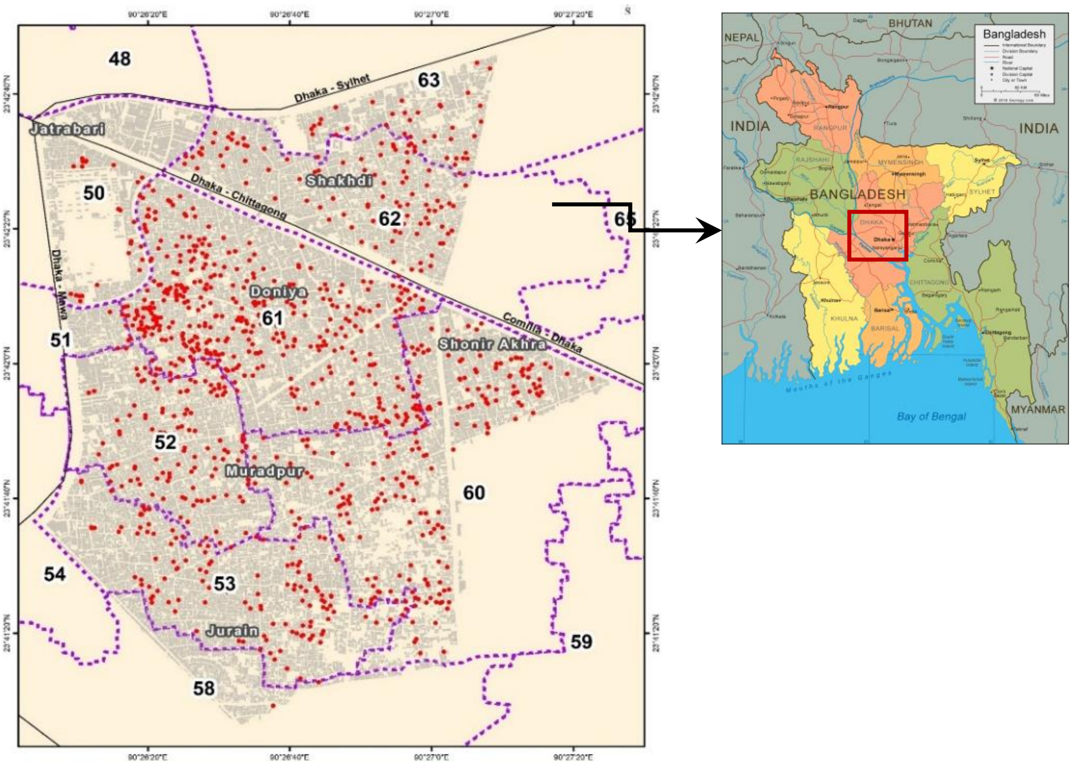

Figure 1: Location of surveyed buildings in Dhaka, Bangladesh (Source: HBRI survey report, 2022)

A common survey datasheet (HBRI 2022) was used during building inspection and necessary information were recorded according to survey specifications. Survey activities includes: entering inside the target building for physical survey, collection of building's general information (name, location, address. etc.), visual investigation of vertical members such as RC Column, RC wall and solid masonry infill, draw a rough hand sketch of ground floor plan on VR survey datasheet showing: RC column, RC wall, Solid masonry infill, dimension of building (length and width), measuring of average RC column size and average span length, measuring of the floor area (approximate), counting number of solid masonry infill, solid RC wall, and number of spans in each direction, judgment of irregularity (horizontal and vertical) by visual investigation, judgment of deterioration (cracks and concrete spoiled etc).

3.2 Number of stories

The number of stories is wide ranging in between 2 to 12 stories buildings. Figure 2 shows the number of stories distribution of surveyed buildings. Most of them are 3-4 storied buildings. Some of them are 5 to 6 storied buildings. A few of them are mid-rise buildings such as 10 to 12 storied buildings.

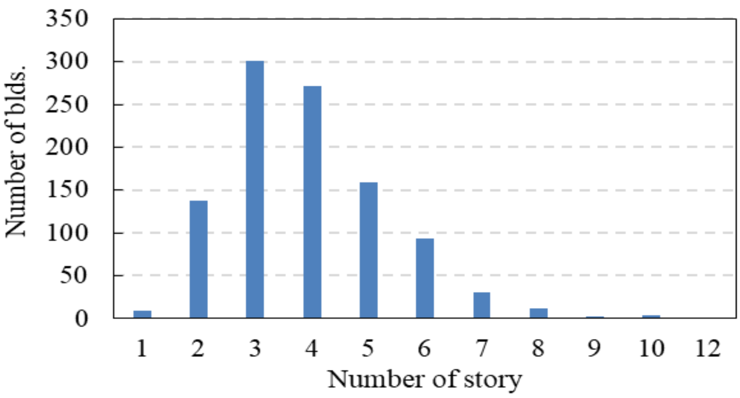

Figure 2: Number of stories distribution

3.3 Year of construction and occupancy categories

The year of construction distribution of the surveyed buildings are shown in Figure 3. The buildings are categorized into three classes: Before 1993, After 1993 and before 2006, and after 2006. Recently, the revision of BNBC 1993 has been published in 2020 (BNBC 2020). The year of construction ranging from 1985 to 2021 which covers old as well as new buildings. It has been observed that about 63% of investigated buildings are new buildings, are constructed after 2006 and 10% buildings are constructed before 1993. Occupancy categories of the surveyed buildings are shown in Figure 4. There are four different categories in the surveyed building. About 91% buildings are residential and 9% are other than residential (such as hospital, school, commercial and mixed categories).

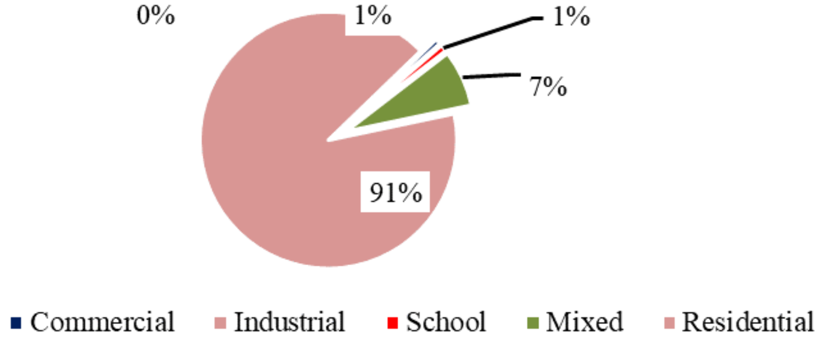

Figure 3: Percentage of buildings: occupancy categories

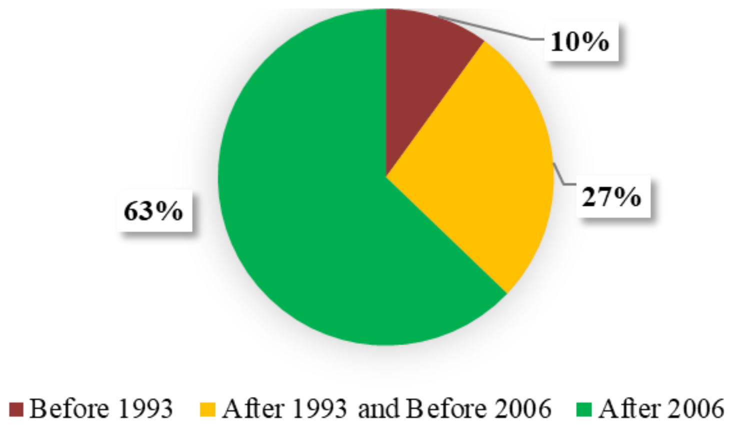

Figure 4: Percentage of buildings: year of construction

3.4 Vertical Irregularity

Buildings regularity has been conducted based on the survey data sheet and the investigation procedure discussed in the Visual Rating manual (HBRI 2022). The classification procedure is discussed in the VR manual (HBRI 2022). Figure 5 shows that most of the constructed building is vertically regular which indicates 84% and least amount of the building was found irregular constitutes 3% of the building. Building constructed with nearly vertical regular means the small opening at the ground floor is 13% only.

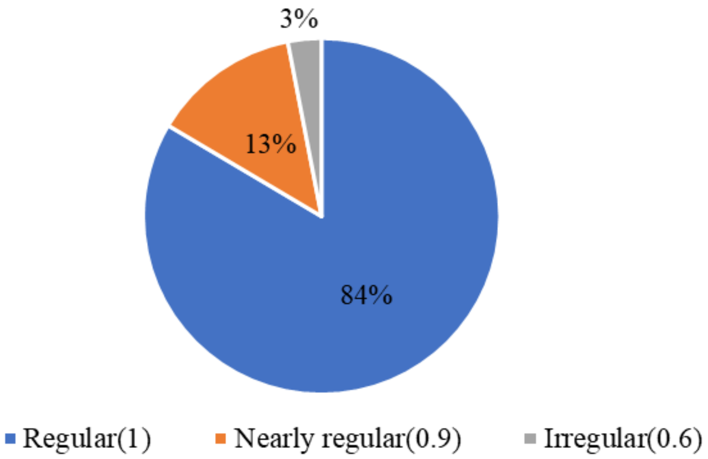

Figure 5: Vertical Irregularity in Percentage

3.5 Horizontal Irregularity

Buildings regularity has been conducted based on the survey data sheet and the investigation procedure discussed in the Visual Rating manual (HBRI 2022). The classification procedure of horizontal irregularity is described in the VR manual (HBRI 2022). The horizontal irregularity is classified as regular, nearly regular and irregular which was applied during survey activities to find out the building's horizontal irregularity. The distribution of horizontal irregularity is shown in Figure 6. From the analysis, it is found that the horizontal irregularity of the existing building, the least amount was found irregular while the horizontal regularity is the highest in surveyed building (91%). Building with nearly regular is 6%.

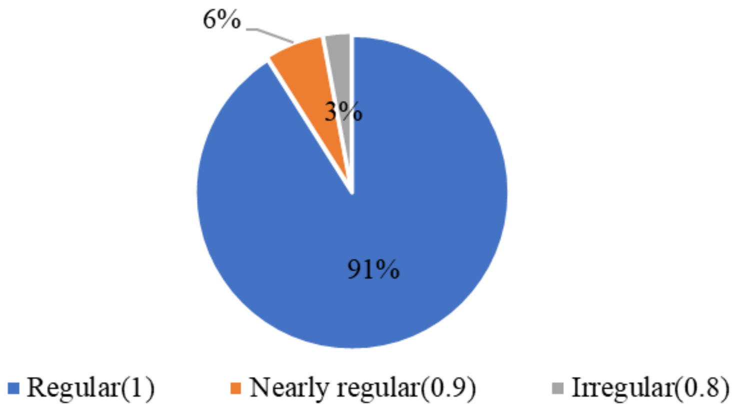

Figure 6: Horizontal Irregularity in Percentage

4. DATA ANALYSIS

4.1 Average column size and average span length

Average column size and average span length of each building have been collect-ed from the VR data sheet and a relationship is plotted in Figure 7. It has been observed that there is a large variation between average column size and average span length. It is seen that the ranges of average column size from 200 mm to 600 mm and average span length from 1500 mm to 4500 mm.

On the other hand, Figure 8 shows a relationship between average column size and number of stories. It has been observed that there is large variation in column size of building with a particular number of stories such as, average column size ranges from 250 mm to 550 mm of 5 to 7 storied buildings. In case of mid to high rise buildings with low column size are not sufficient to resist earthquake induced lateral force. These are the common characteristics in most of RC buildings in Bangladesh. It is because of many of these RC buildings are non-engineered construction without proper structural analysis and seismic design as per Bangladesh National Building code (BNBC), and poor construction supervision.

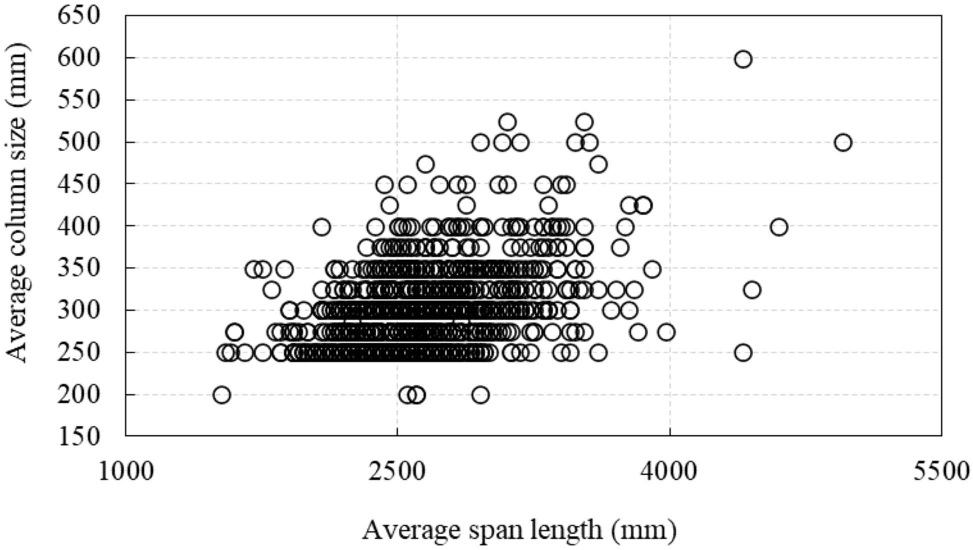

Figure 7: Average column size vs Average span length.

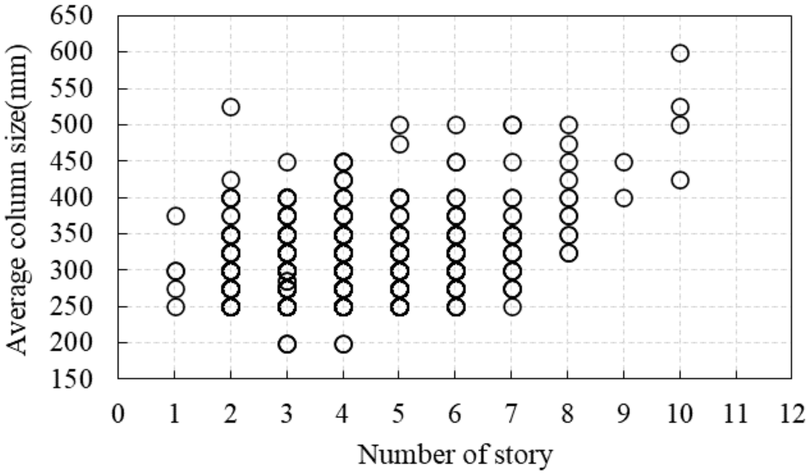

Figure 8: Average column size vs Number of stories

4.2 Visual Rating index (I_{VR})

As previously mentioned, the VR method estimates the seismic capacity in terms of Visual Rating index (I_{VR}) score. After building survey, all survey VR datasheets are collected and summarized the recorded information to calculate I_{VR} score. In this study, Visual Rating index (I_{VR}) is estimated using Equation (1) based on information found from the dataset. However, the material properties and modification factors are considered according to Visual Rating manual (HBRI 2022). Figure 9 shows a distribution of calculated I_{VR} score of the surveyed building. The average value of I_{VR} is of 0.30 indicates that the seismic capacity of these buildings is not much insufficient and hence detailed evaluation of all buildings are not required. This is the major advantage the VR method. Therefore, prioritization and categorization are required to classify the buildings that need the detailed seismic evaluation immediately.

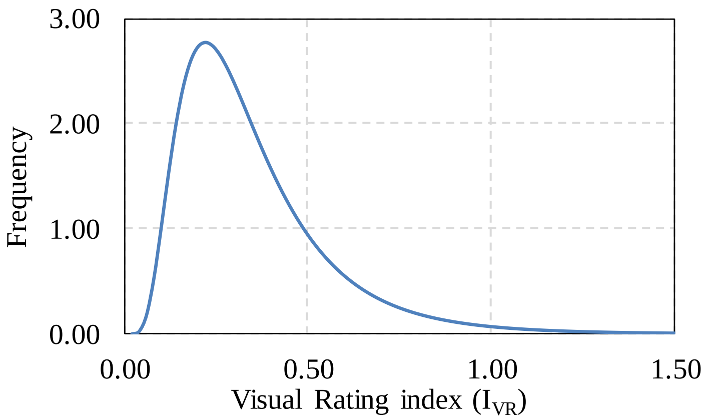

Figure 9: Visual Rating index (I_{VR}) of investigated buildings

The buildings are categorized according to Table 1 based on obtained I_{VR} scores of the investigated buildings as shown in Figure 10. It has been observed that about 645 of surveyed buildings, the I_{VR} scores are above 0.25 indicates that these buildings are at least priority for detailed evaluation and these buildings might not require detailed evaluation. On the other hand, about 375 buildings, the I_{VR} scores are below 0.25, are categorized into less to highest priority of detailed evaluation and these buildings should proceed for detailed seismic evaluation immediately.

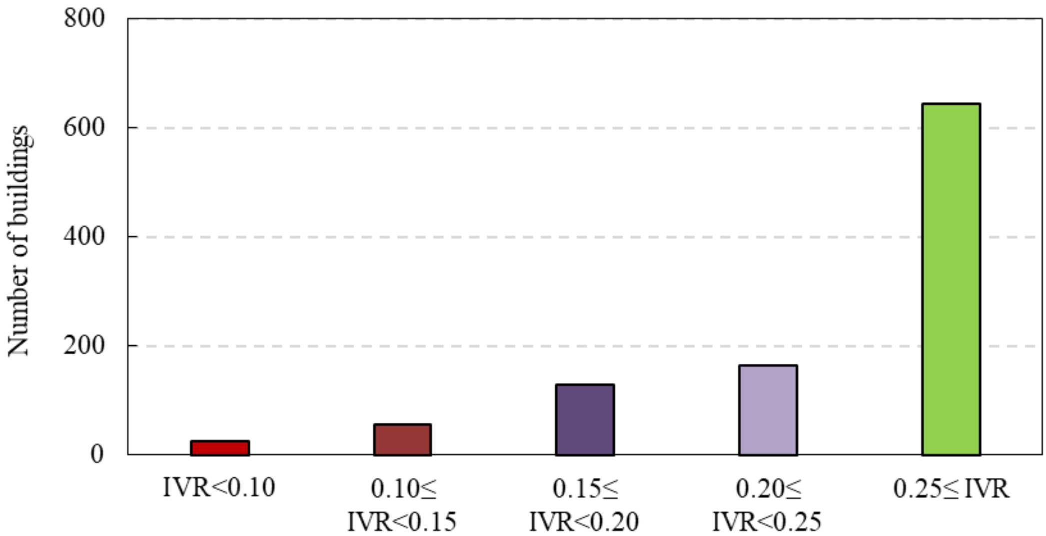

Figure 10: Distribution after categorization for detailed seismic evaluation

Based on above discussion, it has been found that about 35% of surveyed building requires detailed evaluation immediately. This prioritization helps to reduce the work volume of detailed seismic evaluation with limited budget and time.

5. DEAILED SEISMIC EVALUATION AND COMPARE WITH VR METHOD

In this study, detailed seismic evaluation has been done for several investigated buildings located at Dhaka, Bangladesh. The detailed evaluation has been conducted using the second level evaluation procedure in Japanese seismic evaluation standard (2001), BSPP seismic evaluation standard (2022) and, SATREPS-TSUIB manual (2022). It should be noted that seismic evaluation is performed at ground floor in this study which is the most critical floor during earthquake. Detailed seismic evaluation has been performed as per seismic evaluation guideline proposed by BSPP (2022), which has already adopted in Bangladesh. As previously mentioned, BSPP seismic evaluation manual is based on JBDPA standard which does not consider the effect of masonry infill. Therefore, this study follows seismic evaluation guideline proposed BSPP (2022), for bare frame and the evaluation of the effect of masonry infill proposed by SATREPS-TSUIB (2022) seismic evaluation manual. For material properties such as concrete strength, tensile strength of main and transverse reinforcement is found based on non-destructive test carried out under the SATREPS-TSUIB project (2015) and based on the existing structural design datasheet. However, reinforcement detail for main and transverse reinforcement have been found from the both field investigation by rebar scanner and the design datasheet. It should be noted that, the masonry prism strength is considered as 9 MPa in absence of field data for conservative estimation (AlWashali 2018).

Detailed seismic evaluation has been done for both longitudinal and transverse directions (X and Y directions). The Seismic Index (Is) for both directions of the investigated buildings have been shown in Figure 11. It has been observed that the seismic index is higher in Y direction compared to X direction. It means that the buildings are stronger in Y directions. Based on the local seismicity and seismic demand (BSPP 2022), it has been observed that about 45% of these investigated RC buildings require retrofitting immediately to improve the seismic capacity.

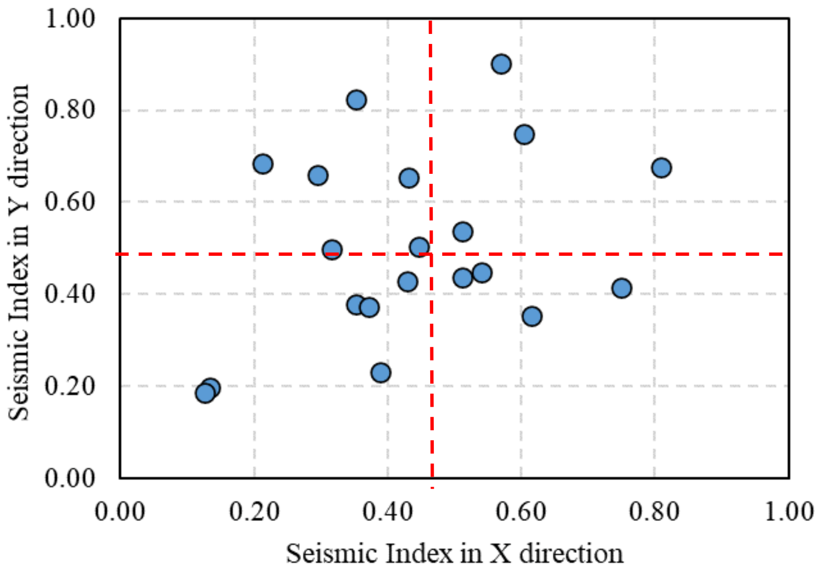

Figure 11: Seismic index of investigated buildings in both directions.

Furthermore, Visual Rating Index (I_{VR}) is compared with detailed evaluation (the second level evaluation of Japanese standard (2001)) of these investigated buildings. In this study, the comparison between Visual Rating Index (I_{VR}) and Seismic Index (I_{S2}) has been shown in Figure 12. However, the normalized seismic index of second level evaluation (I_{S2}) and Visual Rating Index (I_{VR}), the average value is of 1.35 and coefficient of variation is of 37% shows the Visual Rating Index (I_{VR}) provides much conservative results as compared with detailed seismic evaluation. The main reason is that Visual Rating Index considers ductility index is of unity whereas detail seismic evaluation considers ductility factors of structural members using reinforcement details. On the other hand, Visual Rating method estimates strength index based on only dimension of vertical members. However, detailed evaluation requires detailed material strength, reinforcement detailed, and based on detailed structural drawing. Overall, it has been observed that Visual Rating Index (I_{VR}) also provides an approximated estimation of second level evaluation and the score shows a good tendency with the values of the seismic capacity investigated by detailed evaluation method.

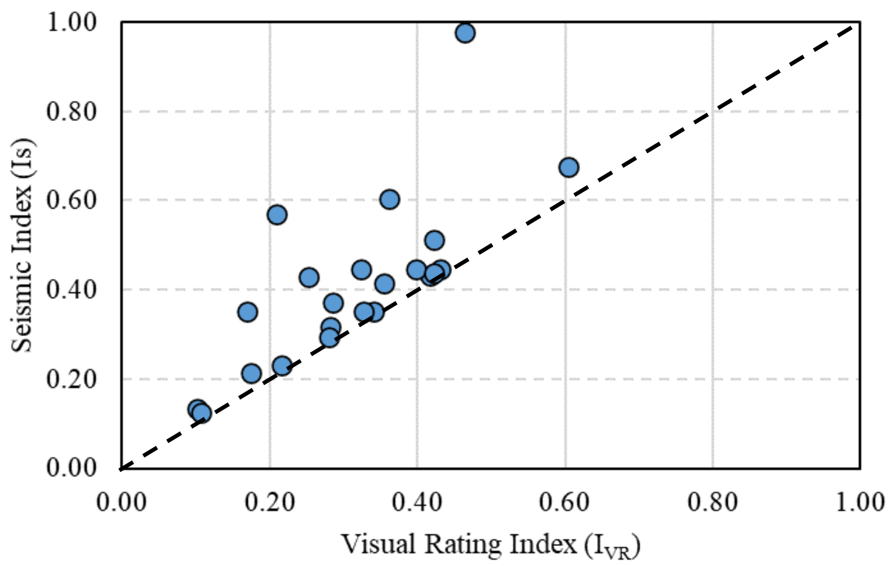

Figure 12: Seismic Index Vs Visual Rating index of investigated buildings.

6. SUMMARY

A total of 1020 masonry infilled RC buildings, located in Dhaka, Bangladesh, have been investigated by the Visual Rating method. In addition, detailed field investigation (such as as-built drawings) of 22 existing RC buildings has been done. Detailed seismic evaluation is carried out. Based on buildings investigation and data analysis, the conclusions are summarized as follows:

- 91% of the investigated buildings are residential and number of stories in between 3 to 6 storied. The mixed occupant buildings are 10-12 storied. 37% of surveyed buildings are constructed before 2006.
- There is large variation in column size of buildings in a particular number of stories such as column sizes are ranging from 250 mm to 550 mm for 5 to 7 storied buildings. Lower column size with higher number of stories results low seismic capacity index and these buildings are seismically most vulnerable.
- The average I_{VR} score is 0.30, indicates that the seismic capacity is not insufficient to required detailed evaluation of all surveyed buildings. As per judgment criteria, about 35% of surveyed buildings are categorized into less priority to highest priority for detailed seismic evaluation. It is recommended that these buildings should proceed for detailed seismic evaluation immediately.
- It has been observed that about 645 of surveyed buildings, the I_{VR} scores are above 0.25 indicates that these buildings are at least priority for detailed evaluation and these buildings might not require detailed evaluation. On the other hand, about 375 buildings, the IVR scores are below 0.25, are categorized into less to highest priority of detailed evaluation and these buildings should proceed for detailed seismic evaluation immediately.
- As for detailed evaluation, it has been observed that about 50% of detailed investigated buildings require retrofitting to improve the seismic capacity

ACKNOWLEDGEMENTS

This research is supported by SATREPS-TSUIB (TSUIB 2022) project "Technical development to Upgrade Structural Integrity of Buildings in densely populated Urban Areas in Bangladesh (TSUIB)" (https://www.jst.go.jp/global/english/kadai/h2712_bangladesh.html, https://www.satreps-tsuib.net/) jointly conducted by the University of Tokyo, Japan and Housing and Building Research Institute, Bangladesh.

REFERENCES

AlWashali H., Islam M.S., Sen D., Monical J., & Maeda M. (2020). Seismic capacity of RC frame buildings with masonry infill damaged by past earthquake, Bulletin of the New Zealand Society for EQ Engg., 53(1), 13–21, 2020, DOI: https://doi.org/10.5459/bnzsee.53.1.13-21

Bangladesh National Building Code (2020). Housing and Building research institute. Ministry of Housing and Public Works, Bangladesh.

Bogˇaziçi University, Istanbul Technical University, Middle East Technical University, and Yildiz Technical University (BU-ITU-METU-YTU) (2003). Earthquake Master Plan for Istanbul, published by the Metropolitan Municipality of Istanbul, Planning and Construction Directorate, and Geotechnical and Earthquake Investigation Department, Turkey.

BSPP (2022). Seismic evaluation manual of existing RC buildings in Bangladesh, published by Publics Works Department (PWD) under Ministry of Housing and Public Works, Bangladesh.

Chiou TC, Hwang SJ, Chung LL, Tu YS, Shen WC, Weng PW (2017). Preliminary Seismic Assessment of Low-Rise Reinforced Concrete Buildings in Taiwan. 16th WCEE, Chile.

Donmez C, Pujol S (2005). Spatial distribution of damage caused by the 1999 Earthquakes in Turkey. Earthquake Spectra, 21, 53–69. https://doi.org/10.1193/1.1850527

Federal Emergency Management Agency (FEMA P 154) (2015). Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook, 3rd edition, Washington D.C.

Gur T, Pay AC, Ramirez JA, Sozen MA, Johnson AM, Irfanoglu A, and Bobet A (2009): Performance of school buildings in Turkey during the 1999 Duzce and 2003 Bingol EQ. Earthquake Spectra, 25, 239–256.

Hassan, A. F., & Sozen, M. A. (1997). Seismic vulnerability assessment of low-rise buildings in regions with infrequent earthquakes. ACI Structural Journal, 94(1), 31-39.

Housing and Building Research Institute (HBRI), “User’s Manual on Visual Rating (VR) Method for Potential Seismic Vulnerability Assessment of Existing Reinforced Concrete Buildings in Bangladesh”, published under SATREPS-TSUIB project, June, 2022.

Housing and Building Research Institute (HBRI), “Building survey and Seismic Vulnerability Assessment of Existing Reinforced Concrete Buildings in Dhaka city, Bangladesh”, A survey report published under SATREPS-TSUIB project, June, 2022.

Islam MS (2019). Rapid seismic evaluation method and strategy for seismic improvement of existing reinforced concrete buildings in developing countries. Ph.D. dissertation, Tohoku University, September.

Islam M.S., Sen D., Alwashali H., Maeda M. (2019). Visual Rating method for seismic evaluation of existing RC buildings with masonry infill: a case study of Bangladesh. The proceedings of Japan Concrete Institute (JCI), Vol. 41(2) 1009-1014, July.

Islam M.S., Alwashali H., Sen D., Maeda M. (2020). A proposal of Visual Rating method to set the priority of detailed evaluation for masonry infilled RC building, Bulletin of Earthquake Engineering, 18(4) 1613 – 1634, March 2020, Doi: https://doi.org/10.1007/s10518-019-00763-5.

Islam M.S., Alwashali H., Torihata Y., Maeda M. (2018). Rapid seismic evaluation method of existing RC buildings with masonry infill based on earthquake damage,” The proceedings of Japan Concrete Institute (JCI), Volume-40, part-2, pp.1027-1032, July.

Islam M.S., Alwashali H., Tafheem Z., Maeda M. (2020). Proposal of judgement criteria for priority setting of detailed seismic evaluation of existing RC building in Bangladesh,” The proceedings of Japan Concrete Institute (JCI), Volume 42, Part-2, pp.889-894, July.

Jain S, Mitra K, Kumar M, Shah M (2010). A proposed rapid visual screening procedure for seismic evaluation of RC-frame buildings in India. Earthquake Spectra, 26(3). https://doi.org/10.1193/1.3456711.

Japan Building Disaster Prevention Association, JBDPA (2001). English version: Standard for seismic evaluation of existing reinforced concrete buildings, Tokyo, Japan, 2001.

Maeda M., Islam M.S., Alwashali H., Islam M.R., Seki M., Jin K. (2018): A seismic capacity evaluation and priority setting for RC building with masonry infill. 16th European Conference of Earthquake Engineering, June, Greece.

O'Brien P., Eberhard M., Haraldsson O., Irfanoglu A., Lattanzi D., Lauer S. and Pujol S. (2011). Measures of the Seismic Vulnerability of Reinforced Concrete Buildings in Haiti", Earthquake Spectra, 27:S1, S373-S386, 2011. https://doi.org/10.1193/1.3637034

Ozcebe G, Yucemen MS, and Aydogan V. (2004). Statistical seismic vulnerability assessment of existing reinforced concrete buildings in Turkey on a regional scale. Journal of Earthquake Engineering, 8, 749–773.

Science and Technology Research Partnership for Sustainable Development (SATREPS) (2015). Project of technical development to Upgrade Structural Integrity of Buildings in densely populated Urban Areas in Bangladesh. a Japan-Bangladesh research project 2015-2022. Housing and Building Research Institute, Ministry of Housing and Public Works.

Shiga T.., Shibata A, Takahashi T. (1968). Earthquake damage and wall index of reinforced concrete buildings. Architectural Institute of Japan, No.12, pp. 29-32.

Sucuoglu H, Yazgan U, Yakut A, (2007).: A screening procedure for seismic risk assessment in urban building stocks. Earthquake Spectra, 23(2). Doi: 10.1193/1.272093.