SEISMIC EVALUATION AND RETROFITTING OF A WEAK 8 STORIED RC BUILDING IN BANGLADESH AND EFFECT OF MASONRY INFILL WALL

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ABSTRACT

Many of the existing buildings in Bangladesh built before publishing the first building design code in 1993. Most of the buildings found to be non-engineered and also very low seismic capacity. In addition, reinforced concrete buildings with masonry infill is very common practice in Bangladesh. However, still the masonry infill is considered as nonstructural member in seismic evaluation. The individual study aims at evaluation of RC framed building for both bare frame and considering masonry infill effect. Three methods were utilized for seismic evaluation of building namely simplified evaluation, advanced simplified evaluation and second level screening. To numerate the strength index and ductility index of masonry infill some papers were reviewed to incorporate the effect with masonry infill in seismic evaluation. It was found from the evaluation with simplified evaluation and second level screening the infill wall increased the seismic index significantly. The requirement for retrofitting was reduced when considering the masonry infill wall contribution. The three retrofitting techniques were taken into account namely RC wing wall installation, steel framed bracing and ferrocement. The unconventional retrofitting technique ferrocement was found to be the most cost effective among the three retrofitting techniques.

Keywords: Masonry infill, strength index, ductility index, seismic index, retrofit.

1. INTRODUCTION

Bangladesh is a disaster prone country. The country is under threat of moderate to strong earthquakes due to the geographical position. The risks of loss of life and damage to property due to earthquakes are almost entirely associated with manmade structure More than 70% of the buildings among the government buildings in metropolitan area were constructed before 1993 which was the 1st Bangladesh National Building Code (BNBC) publishing year. Accordingly, the buildings constructed before 1993 did not follow the seismic requirement of the building code and are found to have less capacity than the seismic demand. Considering the worse condition, CNCRP, “a technical cooperation project for Capacity development on Natural disaster Resistant techniques of Construction and Retrofitting for public buildings in the People’s Republic of Bangladesh” was commenced in 2011 to assist the technique dissemination in Bangladesh, so that the buildings should supply the sense of security. In the project of CNCRP a seismic evaluation and retrofitting guideline manual had been prepared. Masonry infills in reinforced concrete buildings cause several undesirable effects under seismic loading: short-column effect, soft-story effect, torsion, and out-of-plane collapse. Hence, seismic codes tend to discourage such constructions in high seismic regions. However, in several moderate earthquakes, such buildings have shown excellent performance even though many such buildings were not designed and detailed for earthquake forces.

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2. SEISMIC EVALUATION OF TARGET BUILDING

2.1. Target Building Details

In this study, the target building was the Purta Bhaban (PWD headquarter building) which is an 8 storied office building located in Dhaka. The parameters of the target building are shown in Table 1 and the isometric view of the building is shown in Figure 1.

Table 1. Target building parameters.

Building Type	Office
r of construction	1964
Zone	2 (Z = 0.2 BNBC 2015 final draft)
Soil Type	SC (BNBC 2015 final
Number of story	8
Concrete Strength	9 Mpa (Core test)
Steel	275 Mpa

Figure 1. Target building isometric view.

2.2. Seismic evaluation by simplified evaluation method

2.2.1. Seismic Index

The simplified evaluation is first stage evaluation method in Bangladesh. The original paper for bare frame is Seki M (2015) and this method was adopted under the project CNCRP. For the bare frame with infill frame the paper is Seki M (2017). The seismic index is given by the following equation:

$$I_{SS} = E_{SS} \cdot S_{SD} \cdot T_S \tag{1}$$

Where, E_{SS}: Simplified structural index, S_{SD} = Irregularity index, T_S=Time index. S_{SD} and T_S is taken as 1.0 here.

E_{SS} = Maximum values of following three equations:

$$E_{SS}=(C_{SSW}+0.7\cdot C_{SSB})\cdot F_W \tag{2}$$

$$E_{SS}=C_{SSB}\cdot FB \tag{3}$$

$$E_{SS}=\sqrt{(C_{SSW}\cdot F_W)^2+(C_{SSB}\cdot F_B)^2} \tag{4}$$

The strength index for the bare frame which has no infill masonry is given by the following formula:

$$C_{SSB} = \tau_c \cdot \Sigma A_C/W \tag{5}$$

Where, τ_c: Average shear strength of column (N/mm^2) (as per JBDPA standard), h_0: Clear height of column (mm), D: Depth of column section (mm), ΣAc: Total area of columns (mm^2), W: Total weight of building (N).

The strength index of infilled frame considers the strength of the adjacent columns along with the strength of the infill masonry. The strength index for frame along with infilled brick wall is given by the following expression (Seki M, 2017).

$$C_{SSW}=(2*\tau c*\Sigma A_C+\alpha*\tau w*\Sigma A_W)/ W \tag{6}$$

Where, τw: Average shear strength of infilled brick wall = 0.2 N/mm^2, ΣAw: Total area of walls (mm^2), α: Opening reduction factor of infilled brick wall, $\alpha = 1 -\sqrt{\gamma}$ here $\alpha \geq 0.6$, opening factor, $\gamma=(l' h')/lh \leq 0.4$.

The ductility index F is given by the ratio of response modification factor and the overstrength factor. According to BNBC 2015 final draft the response modification factor is 3 for ordinary moment resisting frame and for reinforced masonry shear wall is also 3 and the overstrength factor is also 3. Accordingly, for both the ductility index becomes 1.0.

Along the longitudinal direction the masonry wall does not have much density whereas along the transverse direction the masonry wall has much more density. The comparison in the 1st story along both directions are shown Table 2.

Table 2. Comparison of 'Is' for bare frame and considering masonry infill.

Direction	Seismic Index, '*Is*'	
	Bare frame	Considering masonry infill
Longitudinal	0.141	0.143
Transverse	0.10	0.17

2.2.2. Service load index (I_{SD})

As the building in Bangladesh has very high axial load on column, another index named service load index is introduced. The service load index is the average weight per unit area of column. For the target building in the 1st story the service load index becomes 7.06 Mpa which is larger than $0.7 \cdot Fc$ (6.3 Mpa).

2.3. Seismic evaluation by advanced simplified evaluation method

The advanced simplified structural evaluation method was developed by Seki et al. (2017). The simplified evaluation method is based only on structural and architectural drawings. On the other hand, the advanced simplified evaluation method is more precise because the on-site investigation has to be carried out.

2.3.1. Seismic index

The seismic index (I_{BS}) is given by same equation by Japanese formula. In this method the strength index (C_{BS}) takes into account the ultimate flexural strength of column which is given by JBDPA 2001. The strength index is calculated by the following formula:

$$C_{BS}=\Sigma Mu/h_0/W \qquad (7)$$

The ultimate flexural strength (M_U) is given by JBDPA 2001. The seismic index is compared with seismic demand index which is given by the base shear as per BNBC 2015 final draft. The seismic index is ranked from SA, SB, SC and SD. When $I_{BS} \geqq 1.2 I_{BSO}$ (Rank SA), $0.8\, I_{BSO} \leqq I_{BS} < 1.2\, I_{BSO}$ (Rank SB), $0.4\, I_{BSO} \leqq I_{BS} < 0.8\, I_{BSO}$ (Rank SC), $I_{BS} < 0.4\, I_{BSO}$ (Rank SD).

Table 3. Determination of service load index along longitudinal direction.

a_g mm^2	a_t mm^2	σy Mpa	D mm	b mm	Fc Mpa	N_{max} KN	N KN	∑Mu KNm	ho mm	W KN	Is
4909	1473	275	450	300	9	2564	1260	4243	3050	28807	0.05

2.3.2. Service load index

The service load index is the same as calculated in section 2.2.2. Therefore, the rank for service load index is DC. ($I_{BD}>0.7 \cdot Fc$). The combined capacity rank becomes for the longitudinal direction is SD-DC. Accordingly, the final capacity rank is C. In this method detailed evaluation is recommended.

2.4. Seismic Evaluation by Second Level Screening Method

2.4.1. Seismic evaluation neglecting effect of masonry infill wall

The conventional seismic evaluation does not consider the masonry infill wall as structural member. Therefore, neglecting the masonry infill stiffness and strength is considered like bare frame. The beam is considered to be rigid.

2.4.2. Seismic evaluation considering effect of masonry infill wall

The masonry infill has impact on the seismic evaluation. The effect of masonry infill is not easy as it depends on the interaction between the surrounding frame and the masonry infill effect.

From the past experimental result, the most common types of failure mechanism found were corner compression failure mode and sliding shear failure mode. Comparing the calculated shear strength with experimental strength the proposed formula by Alwashali et al (2017) is given by the following expression in Eq. 8. The Eq. 8 compared by Alwashali et al. (2017), which gives good approximation for both sliding shear and corner compression failure mode

$$V = 0.05 \cdot f_m \cdot l_{inf} \cdot t_{inf} \cdot \lambda op \tag{8}$$

Where *fm*, *tinf* and *linf* are the compressive strength, thickness and length of masonry infill respectively. λop is the reduction factor due to opening which is given by the Al-chaar formula:

$$\lambda op = 0.6\left(\frac{A_0}{Ap}\right)^2 - 1.6\left(\frac{A_0}{Ap}\right) + 1 \tag{9}$$

2.4.3. Strength and ductility index of columns surrounding the masonry infill

Solid masonry infill alters the failure mode of surrounding RC frame. There are different failure mechanisms of surrounding RC column. Plastic moment hinge at top and bottom ends of column; here the surrounding frame acts if it is a bare frame and plastic moment hinges are observed at the end of columns as shown in Figure 2. The separation of infill occurs due to lateral loading. The masonry infill acts as a compression strut.

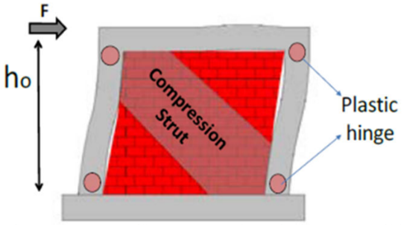

Figure 2. Failure Mechanism considered due to presence of masonry infill.

As for Drift angle (Rmax) at peak strength, based on the studied experiments, the Rmax drift has an average of 0.64% and most of values fit within the range of 0.4%~0.9% (Alwashali 2017). The F-index of masonry infill is recommended by Alwashali et al. (2017) to be taken at R-max drift angle of 0.4% (corresponding to 1/250) since the out-plane is not considered in the previous experimental data. Therefore, the ductility index was considered 1.0 for the masonry infill in this paper.

2.4.4. Comparison of bare frame and considering effect of masonry infill wall

The seismic index compared between the bare frame case and the masonry infill. Along the longitudinal direction, a very small quantity of masonry infill frame can be considered and along the transverse direction the masonry infill is larger amount. Therefore, along the longitudinal direction the 'Is' value was taken same for the bare frame case and masonry infill case. On the other hand, the different 'Is' value was taken for bare frame and masonry infill frame case (Figure 3).

The resistant method of the target building is strength resistant method. Therefore, F=1.0 was considered for retrofitting purpose. (Figure 4).

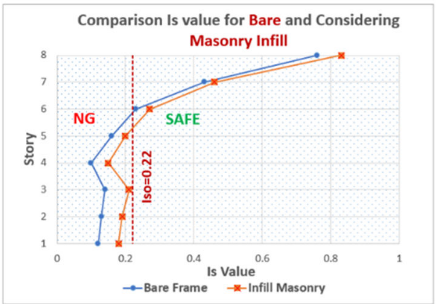

Figure 3. Comparison of behavior 'Is' with 'Iso' for bare frame and masonry infill frame.

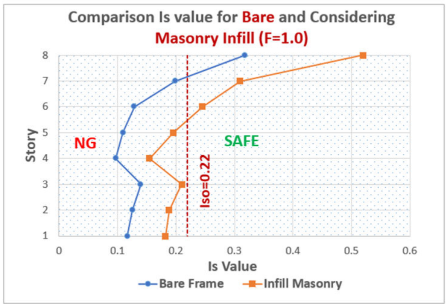

Figure 4. Comparison of behavior 'Is' with 'Iso' for bare frame and masonry infill frame(F=1.0).

The seismic demand index was taken as given by the seismic evaluation manual of Bangladesh which is given by $Iso=0.8 \cdot Z \cdot I \cdot Cs$ and was found to be 0.22 for the target building.

3. RETROFITTING OF TARGET BUILDING

For retrofitting purpose of the target building three methods were considered namely RC wing wall installation, bracing of outer frame and ferrocement.

As per the guidelines for seismic retrofit of existing reinforced concrete buildings (Japanese version) the RC wall having the horizontal vertical reinforcement of D13 @200mm c/c has the shear strength of approximately 1.5 Mpa. The wall length chosen for the longitudinal direction was 2400 mm because of keeping the opening and the thickness was chosen 150 mm. Along the transverse direction the wall length is 3500 mm.

The steel frame section taken for retrofitting the target building is H-175 X 175 X 7.5 X 11.

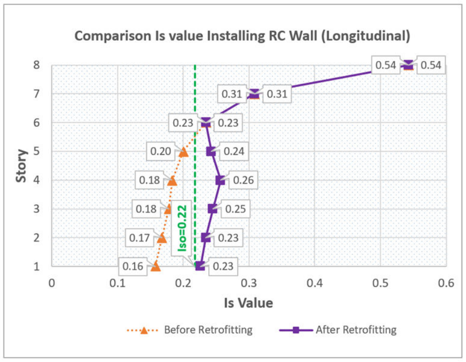

Figure 5. Comparison of Is value in longitudinal direction after retrofitting by RC wall.

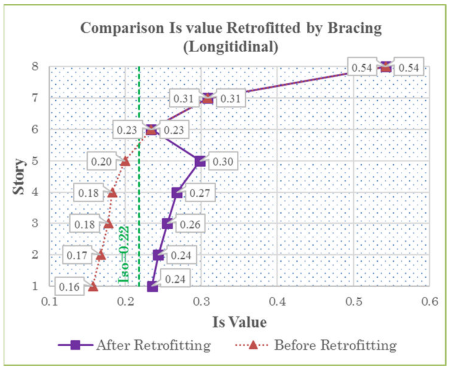

Figure 6. Comparison of Is value in longitudinal direction after retrofitting by steel framed bracing.

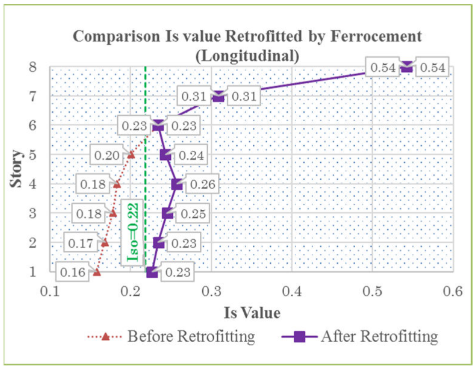

Figure 7. Comparison of Is value in longitudinal direction after retrofitting by Ferrocement.

The in-plane strength by strengthening by ferrocement still needs further study. Still from the testing of some researchers it was proven the in-plane strength increases by strengthening with ferrocement. According to Ashraf et al. the in-plane strength increases by 110%. (Silva, 2006). Accordingly, the masonry infill strength was considered as 0.2 Mpa in simplified evaluation method as mentioned in section 2.2.1, the strengthened masonry infill wall by ferrocement strength can be considered as 0.4 Mpa.

By comparing the cost among the three retrofitting techniques the retrofitting by ferrocement was found to the most cost effective technique as shown Table 4.

Table 4. Cost comparison of considered retrofitting options along longitudinal direction.

Retrofitting techniques	Total retrofitted work area (m^2)	Unit rate (USD)	Total cost (USD)
RC wing wall installation	117.12	$268.96	$31500
Steel framed bracing	106.75	$672.4	$71780
Ferrocement	307.44	$26.90	$8270

4. CONCLUSIONS

The simplified evaluation method for both bare frame and taking the strength of masonry infill showed masonry infill had very large impact in the seismic evaluation. Along the transverse direction as the opening is less compared to the longitudinal direction, the effect of masonry infill had much impact. The seismic index in case of considering the effect of masonry infill along the transverse direction was found to be 1.7 times compared to the bare frame for the first story level. From the second level screening conducted for both the bare frame and considering the masonry infill as structural member, the seismic index was found to be increased in case of taking the contribution of masonry infill. However, the effect of masonry infill along the transverse direction was also found to be larger. The effect of the masonry infill was neglected along the longitudinal direction. From the paper, the comparison of the opening reduction factor was found along with the experimental reduction factor. The Al-chaar reduction factor formula was shown to be the closest with the experimental reduction factor. Accordingly, the Al-chaar formula was used for the second level screening method when the effect of masonry infill was considered. The ductility index was used for masonry infill was 1.0 as suggested in studied paper. The maximum drift angle found was in the range of 0.4% to 0.9% by the paper. The drift angle 0.4% (corresponding to the drift angle 1/250) was suggested because the out of plain failure was not taken into account in the past experimental work. After the seismic evaluation of the target building, the building was found to be deficient in the both directions. Limited number of retrofitting techniques was studied in this paper. The two are conventional retrofitting options namely RC wing wall installation and steel framed bracing in the outer frames in the longitudinal direction. The other retrofitting option was ferrocement which is unconventional one. Retrofitting with ferrocement was found to be the most cost effective option.

5. RECOMMENDATION

The failure pattern may take some other type of failure changing of the hinge location of the frame. This type of changing of the hinge location should be studied further.

The determination of masonry infill shear strength should be determined based on the construction quality of Bangladesh. The old and new masonry infill might have different shear strength. Accordingly, the value of the shear strength should be researched.

The ductility index determination was done based on suggestion of researcher's paper. The ductility index should be taken as per some testing in which the construction quality is like Bangladesh.

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