PERFORMANCE EVALUATION OF REINFORCED CONCRETE GARMENTS BUILDINGS LOCATED IN MODERATE SEISMIC ZONE OF BANGLADESH

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ABSTRACT

In this study, the seismic performance of three existing reinforced concrete garment buildings located in moderate seismic zone (0.20g) of Bangladesh has been investigated according to proposed Bangladesh National Building Code (BNBC-2014). Three dimensional analytical models of these buildings have been developed to assess different performance indices. Performance parameters such as average column compressive stress, realization rate of longitudinal reinforcement for columns, shear force capacity ratio and the moment capacity ratio were computed using the analytical model developed in finite element platform. The performance of these structural properties are evaluated in two step process - in the first step considering only the effect of gravity loads and later considering the seismic loading as per Bangladesh National Building Code along with the contribution of the vertical loads. Result shows that, columns in the ground floor level are highly susceptible to collapse due to inadequate longitudinal reinforcement and lack of shear reinforcement to provide adequate lateral confinement. Most of these columns also possess a threat of premature failure due to inadequate shear capacity under earthquake hazard.

Keywords: Garment buildings; seismic performance; capacity ratio; finite element analysis

INTRODUCTION

Bangladesh garment industry has went through a rapid expansion to approximately 5600 garments factory with approximately 4 million workers working under this sector (BGMEA website). In financial year 2015, Ready Made Garments (RMG) industry exported garment products of 24.49 billion USD that accounts for about 80% of the country's foreign earnings (Wadud & Huda, 2016). Despite the huge contribution of garment industry in country's economic development, the infrastructure system of this sector is now being castigated due to the recent incident of 'Rana Plaza' collapse which caused a total death of over 1138 workers. Furthermore few past earthquakes in nearby region of Bangladesh such as 2011 Sikkim earthquake (M=6.9) and the devastating 2015 Nepal earthquake (M=7.8) that jolted Bangladesh with long duration shaking have garnered attention among the stakeholder and researchers to evaluate the performance of structural properties of these garment buildings (Al-Hussaini et. al., 2015). Moreover, the recent Myanmar earthquake (2016) revealed the inadequacies of current reinforced concrete building stocks in Bangladesh which resulted in 11 tilted buildings sustaining different damage level in Chittagong city. One of these buildings has been assessed and suggested for demolition due to the sustained damage posed by the earthquake ground motion.

The damages in RC structures due to past earthquakes around the world are of similar nature and are attributed to virtually very few parameters like inadequate design and detailing, inferior material quality, construction malpractices, change in occupancy category over time, presence of different distress due to environmental conditions etc. (Ergun et. al., 2015; Sezen et. al., 2003; Kaplan et. al., 2004; Dogangun, 2004). The existing garment building stock comprises most of these inadequacies in advance with accommodating a large number of garment workers. Hence, they possess a great risk of causalities as well as monitory losses due to infrastructural damage and a passive impact due to hindrance in manufacturing garment products. The performance of structural properties of these buildings under earthquake hazard is thus a primary measures for their seismic vulnerability assessment and hence to ensure the margin against collapse.

The seismic performance evaluation of large number of reinforced concrete garment buildings in Bangladesh necessitates a simplified method over the detailed structural evaluation. The detailed assessment seems practically impossible and rather extravagant for structures with minimum level of vulnerabilities. Hence, the parameters and structural variables affecting the performance of the garment buildings should be determined through a preliminary assessment. At the same time the preliminary assessment procedure needs to represent the true behavior of the buildings under earthquake loading. Previous researches have been conducted to investigate the contribution of different structural performance indices such as concrete quality, number of floors, lateral confinement in the seismic performance of reinforced concrete buildings (Ergun et. al., 2015; Inel et. al., 2010). The current study aims at to investigate the effect of abovementioned parameters on seismic performance of the garment buildings. For this purpose, three reinforced concrete garment buildings in moderate seismic zone with different floor height is considered to represent the current garment building stock in Bangladesh.

DESCRIPTION OF SELECTED GARMENT BUILDINGS

In order to attain the aforementioned objectives that is effect of structural properties on seismic performance of reinforced concrete garment buildings, a total of three RCC garment buildings from moderate seismic zone (0.20g) of Bangladesh have been selected for the current study. The three buildings have further been classified into three specific categories namely well designed, moderately designed and poorly designed depending on the design consideration while constructing the building. Well-designed building represent the current design code and considers the seismic design provision mentioned as per the Bangladesh National Building Code (BNBC), whereas the poorly designed building lacks proper design guideline and has been constructed based on local practices without following any particular design specification. In contrary, the moderately designed garment building follows basic design guideline but doesn’t consider any specific seismic design code for construction. They are classified and named as Well designed low-rise building; moderately designed mid-rise building and poorly designed mid-rise building. All the three buildings are selected in a way so that they represent the low to mid-rise building stocks of current reinforced concrete garment buildings in the moderate seismic zone of Bangladesh. The floor system of all the buildings comprises of solid slabs of 125mm for poorly designed building and 200mm for both moderately designed and well-designed buildings. Properties of the selected buildings are presented in Table 1.

Table 1: Selected garment factory building parameters

Building Parameters	Well Designed	Moderately Designed	Poorly Designed
Number of storey	3	7	5
Bottom storey height (m)	6.75	4.7	5
Typical storey height (m)	5.75	3.5	4
Plan area (m^2)	1180	3147	336
Plan irregularities	Regular	Irregular	Regular
Vertical irregularities	Regular	Irregular	Irregular
Bays in X-Z plane	8	6	6
Bays in Y-Z plane	2	9	2
Infill wall (Peripheral)	Brick Masonry Wall	No Infill Wall	Brick masonry Wall
Structural System	Beam-Column Moment Resisting Frame	Beam-Column Moment Resisting Frame	Beam-Column Moment Resisting Frame
Concrete strength (MPa)	28	21	21
Rebar yield strength (MPa)	413	413	413

The loading conditions considered for the analysis are divided into two steps. In the first step of analysis only the dead loads (buildings self-weight, partition wall load and floor finishes) and live loads for special occupancy structures are considered as per Bangladesh National Building Code (BNBC'14). Both the live loads and floor finish loads are applied as uniformly distributed shell loads and the partition wall loads are applied as both shell loads and uniformly distributed on peripheral beams of the buildings. The magnitude of live loads considered are of 3.8 kN/m^2 for well-designed and poorly designed buildings and 4.8 kN/m^2 for moderately designed building. A uniformly distributed load of 1.2 kN/m^2 has been applied for floor finish loadings. Furthermore the second stage of loading consists of earthquake and wind loads in addition to the basic gravity loadings. The seismic design category "C" has been considered for all the three buildings. Cross sectional properties and reinforcement detailing of the structural concrete columns considered for the analysis are represented in the study of Murtuz et. al., 2015.

METHODOLOGY

Three different reinforced concrete garment buildings of varying height have been considered to represent the low and midrise building stock of Bangladesh. All the necessary design data regarding structural properties of the buildings are obtained from the as build drawing provided by the designer of these buildings. In this study, the performance of the buildings are assessed in two loading steps i.e. considering only the gravity loadings and later considering the earthquake loading as per proposed Bangladesh National Building Code (BNBC'2014) along with the gravity loads applied in step 1.

The average column compressive stresses (σ_{ca}) were computed as the ratio of the total weight of the building and total column cross sectional area in the ground floor level and the average stresses at ground floor base (σ_{ga}) were calculated by dividing the sum of gravity loads by the total floor area in the ground level.

$$\sigma_{ca} = (\sum DL + \sum LL)/A_{g,\,col} \qquad (1)$$

$$\sigma_{ga} = (\sum DL + \sum LL)/A_{g,\,gf} \qquad (2)$$

Here, DL = dead load considered in the building, LL = Total live load considered, $A_{g,\,col}$ = Column x-sectional area in ground floor level and $A_{g,\,gf}$ = Total floor area in the ground level.

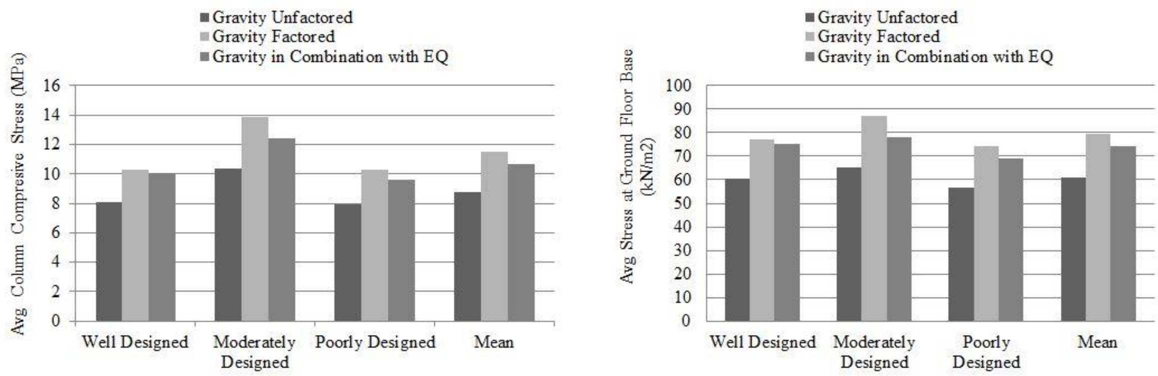

Fig. 1: Variation of (a) Average Column Compressive Stress (σ_{ca}) and (b) Average Stress at Ground Floor Base (σ_{ga})

The realization rates of longitudinal reinforcement have been obtained from the analysis result of the buildings. Two sets of realization rate and reinforcement optimization factor for all the columns in the ground floor levels are obtained in the two steps of analysis and their variation due to the employment of earthquake load is compared for each column in the ground floor level. The realization rate and optimization factor of longitudinal reinforcement is calculated following the stated Eq. (3) and Eq. (4).

$$\text{Reinforcement Realization Rate (RRR)} = (\sum A_{s,\,req} / \sum A_{s,\,pr}) / n \qquad (3)$$

$$\text{Reinforcement Optimization Factor (ROF)} = (\sum A_{s,\,pr} - \sum A_{s,\,req}) / \sum A_{s,\,pr} \qquad (4)$$

Here, $A_{s,\,req}$ = Total reinforcement area required, $A_{s,\,pr}$ = Total reinforcement area provided and n = Total number of columns/beams considered.

Finally, the shear force capacity ratio (V_{cr}), normalized shear capacity ratio (V_{ncr}) and the moment capacity ratio (M_{cr}) in the two orthogonal directions of the buildings are calculated following Eq. (5), (6) and (7) bellow –

$$V_{cr} = (\sum V_{cap} / V)_{X \text{ and } Y} \qquad (5)$$

$$V_{ncr} = (\sum V_{cap} / \sum W)_{X \text{ and } Y} \qquad (6)$$
$$M_{cr} = (\sum M_{cap} / M_o)_{X \text{ and } Y} \qquad (7)$$

Here, V_{cap} and V represent the shear capacity of individual column in the ground floor level and the base shear demand considering the seismic loading in two orthogonal directions. The moment capacity ratio is determined in the similar fashion as the ratio of moment capacity of the columns (M_{cap}) with the overturning moment (M_o) at the base of the building. Details description of the above parameters can be found in Ergun et. al., (2015).

RESULTS AND DISCUSSIONS

The result obtained from the study is used to evaluate the properties of structural components in the ground floor level to check their performance under existing loading condition and expected behaviour under earthquake loading. The Mean of average column compressive stress as shown in Fig. 1(a) is found to be 11.48 N/mm^2 under factored gravity loads which is well below the specified concrete column compressive strength of 21 N/mm^2. Hence, it can be concluded that the column cross sectional area are adequate against the existing gravity loading condition and thus justifies the fact that they are still functioning under service loading without undergoing any major damage. The variation of average ground floor stress level is represented in Fig. 1(b). The maximum average stress at ground floor base is observed for moderately designed building and the other two buildings follows similar average stress rate at the ground floor base level.

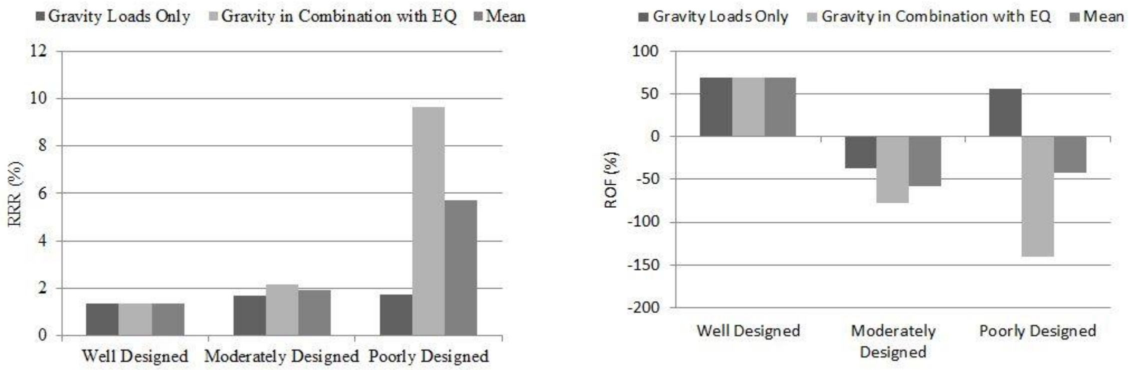

Fig. 2: Variation of (a) Reinforcement Realization Rate (RRR) and (b) Reinforcement Optimization Factor (ROF) for the three garment factory buildings

However, the average reinforcement realization rate as shown in Fig. 2(a) under gravity loads in combination with earthquake loading is found to be 9.62 for poorly designed building whereas the value is only 1.34 for well-designed building. Result clearly depicts that the column in the ground floor level of poorly designed building are extremely under-reinforced and thus expected to undergo severe damage due to design level earthquake. The more deliberate view of the reinforcement deficiency or surplus is presented in Fig. 2(b) as the Reinforcement Optimization Factor (ROF) for all the three buildings. Result shows that the design reinforcement requirement for well-designed building is far less than the provided reinforcement area and hence they are represented in the positive side of the bar charts. In contrary, moderately designed and poorly designed buildings follows a negative trend that shows the deficiency in total reinforcement area provided for these buildings.

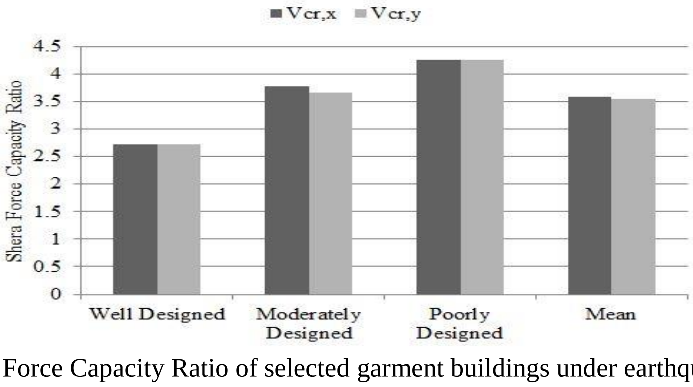

Fig. 3: Shear Force Capacity Ratio of selected garment buildings under earthquake loading

The maximum normalized shear force capacity ratio (the ratio of total shear force capacity of the ground floor columns to that of the total building weight) for the ground floor column as presented in Fig. 4 is computed as 0.26 for poorly designed building which exceeds the limiting value of 0.25 and thus showing inadequate shear capacity of reinforced concrete columns under lateral loading posed by earthquake excitation. All other buildings have lower normalized shear capacity ratio than the poorly designed building and hence predicting safe against shear failure. Variation in Shear Force Capacity Ratio for all the three buildings are illustrated in Fig. 3, where the base shear is calculated according to the Bangladesh National Building Code (BNBC) and the shear capacity of the column sections are computed considering the effect of concrete and transverse reinforcement as specified by the design data of the examined buildings. Result shows a linear increase from well-designed building towards poorly designed buildings having the maximum shear force capacity ratio for the poorly designed building.

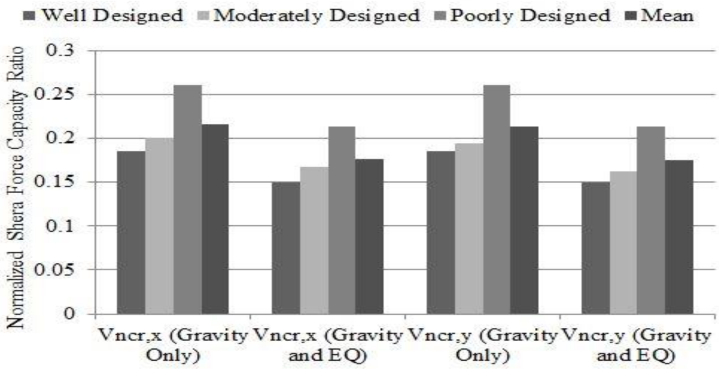

Fig. 4: Normalized Shear Capacity Ratio of examined garment buildings

The Moment Capacity Ratio and the Normalized Moment Capacity Ratio are illustrated in Fig. 5 and Fig. 6 respectively. The ratio of moment capacity as computed by dividing the ultimate moment capacity of the ground floor columns to that of the overturning moment at the base of each building considered. The normalized moment capacity in both the orthogonal direction (global X and Y axes) has further been computed with respect to the total building weights. Maximum moment capacity is obtained with the well-designed building whereas the minimum capacity is observed for the poorly designed garment building.

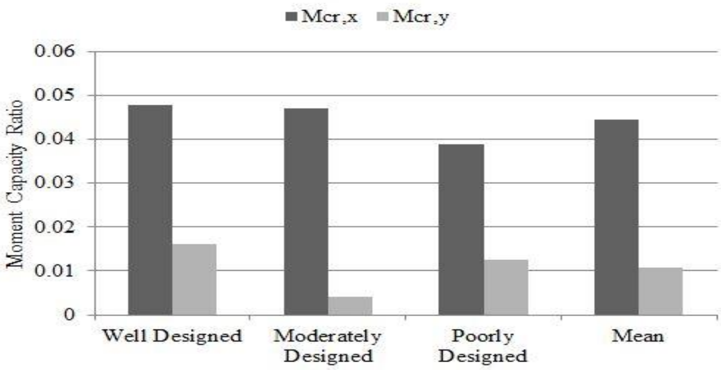

Fig. 5: Moment Capacity Ratio of the selected buildings in two orthogonal direction

CONCLUSION

The study conducted investigates different performance parameters for three different buildings classified as well-designed, moderately designed and poorly designed according to their design philosophy and consideration of loadings from earthquake excitation. Comparing the results obtained from the investigation, the following conclusion can be drawn –

- Average column compressive stress for all the three designed buildings were far below the specified concrete compressive strength and hence prove that the design of these buildings inevitably considers the effect of gravity loads. It can also be inferred that the buildings under investigation are still functioning without any damage is due to their capacity to sustain the gravity loads but their performance under earthquake events are questionable resulting from the increased shear and moment demand posed by the seismic excitation.

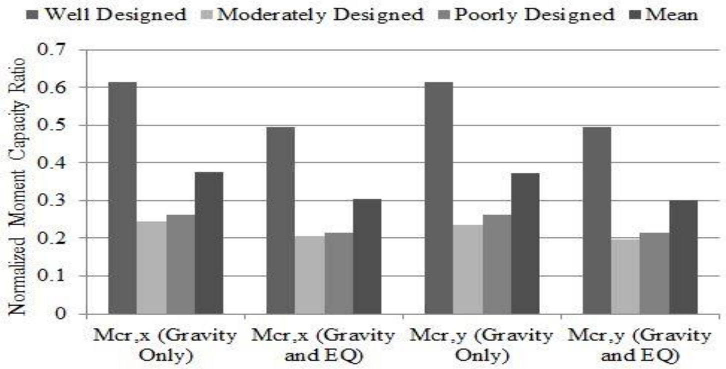

Fig. 6: Normalized Moment Capacity Ratio for the examined buildings under different loading conditions

- Result shows that two of the buildings (presented as moderately designed and poorly designed) lacks the required longitudinal reinforcement area required to sustain the designed level earthquake and hence making them under-reinforced building during any earthquake events. So it can be concluded that catastrophic damage due to brittle structural failure could takes place during any moderate level earthquake event.
- From the result of shear force capacity ratio and normalized shear force capacity ratio it can be concluded that the columns in the ground floor level satisfy the requirements to sustain against shear failure except the poorly designed building where the ratio exceeds slightly beyond the critical value.
- Overturning moments generated due to the seismic action shows insufficiency of the buildings capacity to resist demand and hence making them vulnerable against earthquake loadings.

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