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IMPLEMENTING AN EFFECTIVE SEISMIC RISK MITIGATION STRATEGY FOR EXISTING READY MADE GARMENT FACTORIES IN BANGLADESH

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ABSTRACT

Following the collapse of the Rana Plaza Factory in Dhaka in 2013, which caused the death of 1,134 people, extensive programmes of factory assessment and strengthening have been established to improve the safety of the Ready Made Garment (RMG) factories in Bangladesh. Improvement programmes have been driven by international consortia of RMG companies, the Bangladesh government, global workers' unions and the International Labour Organisation. Work has mainly focused on gravity load risks which are associated with overloading, uncontrolled extensions, inadequate design and poor construction control, as these were key factors in the Rana Plaza collapse. However, recent research studies show that earthquake risk in Bangladesh is also very real and very high, due to a highly vulnerable building stock and moderate to high level of seismic hazard and a very high exposure level. The earthquake scenarios created for Dhaka and Chittagong predict that approximately 50% of the buildings might collapse and there would be high numbers of deaths. Implications for the economy and business continuity would also be very significant. Given the contribution of the RMG sector to Bangladesh's overall GDP, the resilience of these factories will play a very important role during and after an earthquake. Whilst the existing assessment programmes and methodologies make reference to seismic actions in load combinations, they do not define a comprehensive method for seismic assessment nor propose seismic retrofit solutions to be designed and implemented for existing buildings. This paper discusses why a seismic risk reduction strategy is essential for RMG factories, the proposed methodology for seismic assessment and retrofit design of RMG factories and the challenges in implementing such methodology.

Keywords: Seismic assessment methodology; Risk mitigation; ASCE41-13; RMG Factories; Bangladesh

1. INTRODUCTION

Bangladesh is located in an area where the seismic hazard level ranges from moderate to high. (GSHAP,2003) Considering the high vulnerability of the building stock and dense population, seismic risk can be rated as high. This results in a need for special attention and care for the building stock, especially for RMG factory buildings mainly due to the high development rate of the sector and the high contribution of the sector to the overall GDP of the country.
Following the collapse of the Rana Plaza Factory in Dhaka in 2013, which caused the death of 1,134 people (RPCC,2013), extensive programmes of factory assessment and strengthening were established to improve the life safety of the Ready Made Garment (RMG) factories in Bangladesh. The Rana Plaza collapse has been attributed primarily to excessive gravity loading (dead and live), poor workmanship and poor material quality. Thus most of these programmes either ignore the seismic

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effects and focus purely on gravity loading effects or use improper or incomplete methods for seismic evaluation which are mostly methods for designing new buildings rather than evaluating existing ones. Therefore, a comprehensive method which includes seismic evaluation of the existing buildings would increase the value of the ongoing assessment studies.

As an initial effort, a preliminary seismic evaluation methodology was developed by the authors by modifying an internationally known and accepted method, ASCE41-13 Tier 1 evaluation method (ASCE,2014), to take account of the local conditions and construction capabilities.

This paper gives a brief description on the seismicity of Bangladesh and discusses the seismic risk of the RMG factories, which includes a discussion on the main characteristics and deficiencies of such buildings. It summarizes several risk assessment studies for buildings located in Dhaka and Chittagong cities. With the consideration of international practices and local capabilities and/or familiarities, a recommended seismic evaluation and strengthening approach is described. Several case studies for seismic evaluation and strengthening with the proposed approach were conducted. Results and comparison between gravity and seismic strengthening schemes are discussed.

2. SEISMIC RISK FOR RMG FACTORIES IN BANGLADESH

2.1 Seismic Hazard

Bangladesh is located in the active seismic zone at the foot of the Himalayas and the Arakan Yoma. Earthquakes with magnitudes greater than 7.0 on the Richter scale occurred in areas close to or within Bangladesh in the last 150 years are listed in Table 1 below. The Great 1897 Indian earthquake with a Richter magnitude of 8.7Ms is occurred in 1897 and caused the deaths of 1542 people (MoDMR,2013). In the recent past, a number of moderate to severe seismic activity is observed in and around Bangladesh. The Sylhet Earthquake (Mb = 5.6) of May 8, 1997, the Bandarban Earthquake (Mb = 6.0) of November 21, 1997, the Moheshkhali Earthquake (Mb = 5.1) of July 22, 1999, and the Barkal (Rangamati) Earthquake (Mb=5.5) of July 27, 2003 may be cited as examples of these events. (Persio,2014). During Bandarban Earthquake in 1997 a five storey building was collapsed in Chittagong and 23 people were killed. (USGS,1997).

Table 1. List of Major Earthquakes affecting Bangladesh in last 150 years (MoDmr,2014).

Date	Earthquake Name	Magnitude (Richter)	Epicentral Distance from Dhaka (km)	Epicentral Distance from Chittagong (km)
14 July 1885	Bengal	7.0	170	350
12 June 1897	Great Indian	8.7	230	340
8 July 1918	Srimongal	7.6	150	200
21 November 1997	Bandarban	6.1	375	125

The Global Seismic Hazard Assessment Programme (GSHAP, 2003) have published a seismic hazard map for Bangladesh (Figure 2. Seismic Hazard Map of Bangladesh for 475-year return period event (BNBC 2015).

The map gives Peak Ground Acceleration (PGA) values for an earthquake that has a 10% probability of exceedance in 50 years (475-year return period event).

The draft Bangladesh National Building Code (BNBC), dated 2015, has an updated seismic zonation map for Bangladesh (Figure 2) which follows a similar trace as the map of GSHAP.

Most of the RMG factories are located in Dhaka and Chittagong. As can be seen from the seismic zonation map given in BNBC 2015 (Figure 1) Dhaka has two different seismic zones. The south part of the city where Narayanganj, one of the areas with many RMG factories, is in moderate seismic zone. Whereas the north part of the city, again where many other RMG factories are located at regions like

Gazipur, is in high seismic zone. Chittagong is also in high seismic zone. This shows that most of the RMG factories are located either in moderate or high seismic zones.

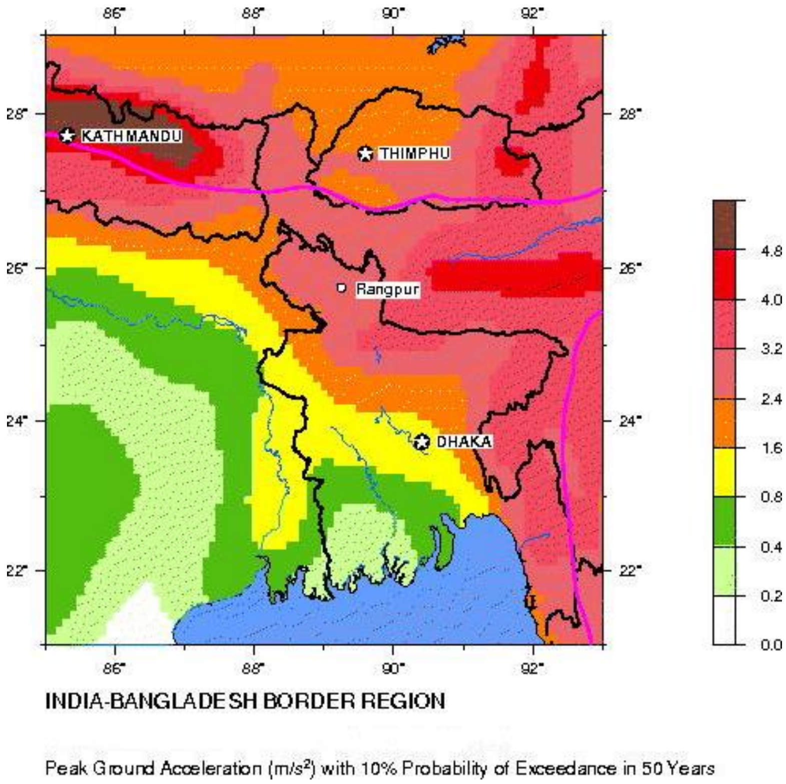

Figure 1. Seismic hazard map of Bangladesh for 475-year return period event (GSHAP, 2003).

Figure 2. Seismic Hazard Map of Bangladesh for 475-year return period event (BNBC 2015).

2.2 Seismic Vulnerability of Ready-Made-Garment (RMG) Industry Buildings

More than 90% of the RMG factory buildings are multi-storey reinforced concrete moment-resisting frame buildings with unreinforced masonry infill panels. A minority of them are reinforced concrete flat slabs, steel frame, unreinforced masonry, etc.

The building material properties vary depending on the year they were built but the majority of the buildings have poor quality of materials and poor workmanship.

Additionally, most of them are not designed and built as code compliant which creates a potential lack in their seismic performance.

It is known that local authorities, with the exception of the Public Works Department (PWD), are checking only the layout plans of buildings as part of the permitting process. As a consequence, almost no structural design and construction reviews are done for many buildings. The only certification is that if the building is being designed by the enlisted engineers, they issue a certificate with their names.

The PWD does carry out detailed reviews for both the design and construction of government buildings and for buildings lying outside the responsibility boundary of other local authorities. The PWD carries out reviews to ensure that the design is done as per the local code (BNBC) and that the construction is done as per the design. However, RMG factories are private buildings and the percentage of those located outside the local authorities' responsibility is estimated to be very low (maybe less than 5%).

Even where the original building was constructed in line with a structural design, there may have been later additions, extensions and modifications without a revision to the structural design.

As a result, it can be concluded that most of the buildings may not have proper structural design and even if they do, they may not have been constructed as designed.

From our experience during inspections, which were done in the context of the evaluation studies for Inditex S.A. and ACCORD, it was seen that many buildings had serious issues even only under gravity loads. When available design drawings were reviewed, the following major deficiencies on seismic performance of the buildings were commonly found. It should be noted that the information on soil and foundations were very limited and the deficiencies listed below excludes the issues related to the soil and foundations.

- High level of axial, shear and flexural stress on columns. This is mainly due to slender members.
- Lack of ductile detailing for frame members. Beams which are flexurally stronger than columns and elements inadequately designed such that shear is often first predicted failure mode rather than flexure.
- Poor detailing. Inadequate laps and anchorages and shear links generally bent 90^0.
- Little or no consideration of interaction between RC frame and masonry infill.
- Masonry infill not properly tied back to frame.
- Poor material quality. Mostly hand-mix concrete with weak brick aggregates and little control of water.
- Soft storey irregularity due to higher storey heights at ground levels which are being used as loading areas.

As a conclusion it can be said that the vulnerability of the building stock to seismic events is very high.

2.3 Seismic Risk

Considering moderate to high seismicity and the high level of vulnerability of the building stock, seismic risk should be rated as high.

The high level of exposure is also increasing the risk significantly. The density of population is very high in Bangladesh. The number of RMG factories has been rapidly increasing for several decades and most of the factories are multi-storey buildings with densely placed sewing or knitting machines, manually operated by employees.

The literature review of publications related to seismic risk assessment of Bangladesh, indicate a high seismic risk for Dhaka and Chittagong, where most of the RMG factories are located. Key points and outcomes of the studies are summarized below:

- Several potential earthquakes have been taken into account for Dhaka. The highest magnitude has been estimated as 7.5 Mw which would be generated along Madhupur fault line, the closest fault to Dhaka (BURP, 2014)
- 50% of the buildings in Dhaka City are estimated to be collapse in the worst case scenario (Md. Shafiqul Alam, et.al, 2011).
- Losses related to the buildings and their contents during potential earthquakes could be between 4 to 7 billion USD (BURP, 2014).
- 10 to 30% of the population may be killed during the potential event (M.R. Sadat, et.al, 2010).

3. RECOMMENDED APPROACH FOR SEISMIC EVALUATION OF THE BUILDINGS

3.1 Current approach for structural remediation

After the Rana Plaza event several actions have been taken to assess the factory buildings under “everyday” loads. For this purpose, the National Tripartite Plan of Action on Fire Safety and Structural Integrity guidance document was developed and published by the Government of Bangladesh and representatives of Bangladesh employer’ and workers’ organisations. This document is seen as a source for all parties dealing with the factories. Although from a structural perspective, the primary aim was to quickly assess capacity of the structural members under gravity loads, the guidance also contains seismic load combinations in order to help develop a basic understanding of the seismic performance of the building. The main stakeholders of the RMG export sector in Bangladesh are both following NTPA guidance during preliminary inspections and detailed engineering assessment (DEA) studies. In most cases seismic load combinations are not taken into account in a DEA study. If the building is found not to have sufficient capacity to resist gravity and wind loads, then an additional DEA is carried out as per BNBC 2006 which does include seismic loads. From this study the retrofit needs of the building are derived and retrofit design is done again as per BNBC 2006 with consideration of seismic loads. With this approach, the buildings which have sufficient capacity under gravity and wind loads are not assessed for seismic effects.

Two other main approaches in the seismic assessment of buildings have been developed and practised by the Public Works Department (PWD) and Bangladesh University of Engineering and Technology (BUET) respectively. The PWD has created an independent methodology which is based on Japanese practice and is applying this on existing public buildings. The methodology is described in the documents called CNCRP Manuals (CNCRP,2015). This method contains only a detailed assessment procedure and do not contain any preliminary assessment procedure. It cannot be applied to flat slab structures, buildings with more than 6 stories and buildings with concrete compressive strength less than 9 MPa. Although there are limitations in the application of this method, it is consistent within itself and is supported by many investigations, including experimental studies. A serious impediment to widespread acceptance of the method is that the construction industry and engineering society of Bangladesh are not familiar with the Japanese codes and approach.

BUET has used ASCE41-13 Tier 1preliminary evaluation method on several buildings. For the detailed assessment they then followed BNBC 2006.

As a conclusion it can be said that various methods or approaches are being followed by different parties in Bangladesh and currently there is no overall consistency. The majority of RMG buildings do not pass through any kind of seismic evaluation.

3.2 Recommended approach for detailed seismic evaluation of the buildings

As noted above, there are two different approaches for detailed seismic evaluation of buildings adopted within current practice in Bangladesh. The first approach is based on using draft Bangladeshi code BNBC 2006. This is a code for designing new buildings and do not contain any chapters related to seismic evaluation and retrofit of existing buildings. The second approach involves the use of the CNCRP Manuals, which are developed by PWD. These are specifically aimed at the evaluation and retrofit of the existing buildings, however, they are primarily based on Japanese Codes which are not well known or understood within the Bangladeshi construction community.

As a general philosophy, new building design codes define specific detailing rules to be complied with and involve the use of several coefficients, such as response modification factor, safety factors, load combinations, and so on. The appropriate use of such factors are largely dependent on the proper implementation of the details defined in the code. Therefore, to be able to apply the criteria of new building design codes, all properties of the existing structure should be very well known and comply with the requirements of the code followed.

However most of the existing buildings in Bangladesh have not gone through a design check or a construction audit. This raises a serious doubt about the proper application of BNBC and thus the appropriateness of using it for seismic evaluation and retrofitting the existing buildings.

On the other hand, the codes or documents which have been prepared with a focus on evaluating and retrofitting the existing buildings follow a different approach than the new building design codes. One of those is an internationally recognised code from the USA, ASCE41-13 – Seismic Evaluation and Retrofit of Existing Buildings. The local industry and code-writers are familiar with US codes of practice such as UBC, ACI and ASCE and thus it is recommended to follow ASCE41-13 as a base document. ASCE41-13's phased approach also facilitates the inclusion of seismic evaluation to the current approach being used for RMG factories.

The preliminary evaluation phase is recommended to be carried out by modifying the ASCE41-13 Tier 1 assessment to be in line with the performance objectives and local conditions. This methodology is already being used in Bangladesh, mostly by BUET and is based on filling in checklists during a site visit and some desktop study following that.

For the seismic detailed assessment study ASCE 41-13 Tier 3 phase of the document, which is related to the detailed evaluation and retrofit of existing buildings can again be followed.

While ASCE 41-13 provides a very robust approach for the seismic assessment of existing buildings, it generally leaves the final judgment to practicing engineer's discretion. In order to provide further guidance and to clarify critical issues which are left to engineering judgment in ASCE41-13 several analytical case studies have been performed. Based on these studies several modifications are suggested for the local practitioners as a guideline.

3.3 Defining Minimum Target Performance Objective

Seismic hazard definition is generally based on the certain percentage of probability of exceedance in 50 years since the average life time of the buildings is considered to be 50 years. ASCE 41-13 considers the existing buildings have already spent some portion of their lifetime and allows the engineer to reduce the hazard level to some extent, approximately to 3/4 of the Design Basis Earthquake (10% probability of exceedance in 50 years).

Considering the high level of vulnerability of the building stock and potential resistance of the RMG factory owners to conduct seismic evaluation and retrofit due to economic considerations, to be able to facilitate a realistic strengthening scheme, a minimum objective can be recommended to be Collapse Prevention under the seismic hazard defined in BNBC 2015, which is the Design Basis Earthquake. However, the building owners will also have the choice to aim for higher performance levels which will bring life safety, business continuity and prevent economic losses due to repairing or re-building of damaged structure.

3.4 Proposed modifications to Tier-1 Procedure

ASCE 41-13 defines a "screening phase" to conduct preliminary seismic evaluation of buildings using checklists and simple calculations. This screening phase is named as Tier 1. Tier 1 checklists were originally created for two performance levels; Life Safety and Immediate Occupancy. However as explained above, the recommended minimum performance objective for existing RMG factories is Collapse Prevention. ASCE 41-13 Appendix B states that, in the case of such a decision, the Tier 1 method can be modified to suit the need.

On the other hand, ASCE 41-13 Tier 1 Method does not provide clearly identified criteria that must be met in order for compliance with the performance level to be achieved. Instead, it leaves the final decision to the engineer.

In order to achieve a widely applicable and consistent method for all RMG factories and to consider

Collapse Prevention as desired performance level, acceptance criteria which can also be used for classification of the buildings is being proposed.

The recommendations, proposed modifications and identified criteria for acceptance are not based on any published document or guidelines. These are derived from experience on the field of earthquake engineering and observations on the local construction practice and building stock.

The study is done considering reinforced concrete moment resisting frame buildings as this is the structural system for the majority of the current building stock.

One of the main items to be checked in Tier 1 method is the shear stress in columns. When calculating the demand, a modification factor, m_s, is used to reduce the elastic seismic forces. This is given as 1.5 for Immediate Occupancy and 2.0 for Life Safety performance levels. It is recommended to use this factor with a value of 2.5 for Collapse Prevention performance level.

The proposed classification criteria are summarized below, based on the existing ASCE41-13 Tier 1 checklist.

The building is classified as RED and a seismic detailed engineering assessment shall be required if any of the following criteria are valid: Column Shear Check Utilization Ratio is more than 1.5, soft storey exists or vertical irregularity check is not satisfied for more than 10% of the ground floor columns.

1- If the soft storey and vertical irregularity conditions are satisfied and the column shear check utilization ratio is between 1.0 and 1.5 any of the following critical deficiencies would also make the building classified as RED to require a detailed seismic assessment: Torsional Irregularity, Inadequate Load Path, No Shear Failure, Column Tie Spacing, Captive Columns, Flat Slab Frames.
2- If the column shear check utilization is less than 1.0 and the building is compliant for soft storey- vertical irregularity and none of the critical deficiencies listed above are non compliant the building can be classified as Green.
3- Any other Conditions which does not satisfy criteria for RED or GREEN would be classified as YELLOW.

The buildings satisfying the criteria given for Green colour code would be accepted as satisfying Collapse Prevention Performance Level.

The buildings rated as Red should proceed to Seismic DEA.

For the buildings rated as yellow, the engineer should re-evaluate the identified deficiencies and depending on the severity of the deficiencies final decision should be made.

This table only includes deficiencies described within the Tier 1 checklist of ASCE41-13, which was written primarily for the United States building stock in mind. These are generally engineered frames and so are all likely to have reasonable detailing and a reasonable capacity to begin with. The RMG factory building stock is very different, much of it being non-engineered. Therefore, it is suggested that additional checklist criteria that could be considered including further are:

1. **Global flexural capacity.** None of the other checks on the checklist provide a good indication of the overall flexural demands on the system in a seismic event, hence the building might conform to all aspects of the checklist but still fail globally in a small earthquake. Simple checks of the building stock suggested that this would often be the governing failure mode.
2. **Masonry infill stability.** Failure of infills not tied properly into the structural frame is a common occurrence in earthquakes and a significant cause of fatalities. Infills fail due to a combination of lack of lateral restraint at the edges, flexural failure out-of-plane, buckling of the panel in-plane and crushing under in-plane loads.

4. ANALYTICAL CASE STUDIES

Several analytical case studies have been performed to provide a better criteria based on the existing building stock in Bangladesh. These studies focus primarily on two categories of the buildings. The first set are the buildings which are deemed to comply with the working gravity loads. For these buildings likelihood of a seismic deficiency and possible retrofit solutions have been analyzed by the authors. The second group are the buildings that are found to be critical even under gravity loads and require retrofitting. For the latter category we have selected building schemes that are currently under ongoing a strengthening design process based only for gravity loads. A seismic assessment and retrofit design is performed to compare with the proposed gravity-only retrofit scheme. Based on these studies, a better and clear performance objective and acceptance criteria is being proposed.

4.1 Performance evaluation for Buildings that are adequate under Gravity Loading

This case study is performed based on an existing reinforced concrete 3 storey building with a considerable large factor of safety under gravity loads. Both ASCE 41-13 Tier 3 detailed evaluation method and proposed modified Tier 1 method are applied. Tier 3 is done using linear analysis methods.

The height of the ground floor is larger than the above floors which leads to a soft storey irregularity. Checks have been done on several versions of the building by varying some of the key characteristics in order to evaluate the sensitivity of our results to these characteristics. These are set out in Table 3 below. It can be concluded that the only seismic compliant building is the one with 3 stories, 24 MPa concrete compressive strength, high grade steel and without a soft storey irregularity. When the concrete failure strength is lowered to 14 MPa or when soft storey irregularity exists, although it is still rated as safe under gravity loads, the structural system does not satisfy seismic performance level and strengthening is required.

Table 2. Summary Table of Case study for "Gravity Safe" Buildings with different characteristics

Building Code	Seismic Zone Factor	No. of Stories	Concrete Compressive Strength (MPa)	Column Long. Rebar Ratio	Soft Storey Irregularity	Tier 1 Shear Check Utilization Ratio	Color Code based on proposed criteria	Required Retrofit Based on Seismic DEA
B_A1	0.28g	3	24	3,5%	Exists	1.34	RED	CJ* at GF**
B_A2	0.2g	3	24	3,5%	Exists	1.04	RED	CJ at GF
B_A3	0.2g	3	24	3,5%	Does not exists	1.12	YELLOW	None
B_A4	0.2g	6	24	3,5%	Exists	2.06	RED	CJ at first three floors
B_A5	0.2g	3	14	2,5%	Does not exists	1.32	YELLOW	CJ at first two floors

** CJ: Column Jacketing*
*** GF: Ground Floor*

4.2 Performance evaluation for buildings that require strengthening under Gravity Loads

A comparative study has been performed for two buildings that have been classified as critical after a preliminary gravity structural survey. Their columns have very high axial stress levels under gravity loads. Brief information on the study is given in Table 4.

Table 3. Summary Table of Case study for "Gravity Unsafe" Buildings

Building Code	Seismic Zone Factor	No. of Stories	Concrete Compressive Strength (MPa)	Column Long. Rebar Ratio (Avg.)	Soft Storey	Required Retrofit Based on Gravity Only DEA	Required Retrofit Based on Gravity + Seismic DEA
B_B1	0.28g	5	12	1,3%	Exists	CJ for the first three floors	CJ to all columns
B-B2	0.20g	6	14	2%	Exists	CJ for the first two floors	CJ to all columns

For the five storey building (B_B1), it is indicated that strengthening (by column jacketing) is required for the first three floors to sustain gravity loads. For the Building B_B2 it is found that column jacketing is required for the internal ground and first storey columns of the 7 storey structure under gravity loads. 10 cm thick column jacketing is found to be adequate for gravity design loading.
The buildings with applied retrofit schemes based on gravity only assessment evaluated based on ASCE 41-13 Tier 3 Linear Procedure. It is found that, for both buildings, partial retrofit and one layered column jacketing is not adequate for seismic loads and full height double layer 15 cm thick column jacketing is required.

5. CHALLENGES

Several challenges have been experienced during the discussions with the local authorities, practitioners and stakeholders who will be the primary audience of the outcome of this study.
Most of the stakeholders are not eager to include seismic loads in the structural evaluations as they fear that there will be additional costs and business interruption to the factory during the retrofit construction. Many of the buildings have already undergone corrective works following gravity-only assessments. Further retrofit works may often be considered unwelcome by building owners.
Selecting the most appropriate approach and code for the evaluation and retrofit process is also a difficult subject. Seeking full code compliance from the existing buildings in Bangladesh results in a considerably costly strengthening design solutions which may be impractical to implement or simply too expensive. Proposing overly onerous or expensive proposals are likely to be ignored or resisted. Therefore, it is very important to provide a well-balanced set of criteria of a relaxed performance objective while still improving the safety of the buildings and improving the general resilience of the built environment to seismic hazard.
Considerable engineering judgment is required to implement any seismic evaluation and retrofit solution using any seismic evaluation code. Even though ASCE 41-13 includes very detailed analysis methods it leaves the final judgment to practicing engineer. However, when a large number of buildings are needed to be evaluated, a clear and codified criterion is needed to prevent ambiguity in the evaluation process. Additional checks to the existing Tier 1 checklist should also be considered to be incorporated.

6. CONCLUSIONS

In this paper a recommended methodology is presented for the inclusion of a seismic evaluation procedure to the structural safety mitigation efforts for highly vulnerable Ready Made Garment Factories in Bangladesh. There exists a need for an established approach for an effective seismic evaluation and retrofit method for these factories. Without any law enforcement for the existing buildings to comply with the seismic code, the process would be completely voluntary. Therefore, it is very important and also difficult to provide an effective seismic risk mitigation approach that could be voluntarily adopted by stakeholders. The developed methodology is aimed to serve as a baseline for the international consortia of RMG companies, the Bangladesh government, global workers unions and the International Labour Organisation who are seeking to provide a comprehensive approach to the inclusion of a seismic evaluation methodology to the structural upgrading of the current building portfolio. As a result, a simplified ASCE 41-13 Tier 1 methodology is presented with recommended criteria. This approach is examined with several analytical studies. It is concluded that even though a building is categorized to be safe under rapid gravity and wind inspections, the possibility of failing under seismic effects is high. Therefore, it can be said that the results of the preliminary seismic evaluation studies for most of the RMG factories may pose a need for detailed seismic evaluation which will most likely conclude that seismic retrofit will be required. However regular buildings with fewer storeys, high material quality and better designs may give satisfactory results. For the buildings retrofitted for gravity loads only, there is likely to be a considerable further cost increase to achieve a reasonable seismic performance.

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8. REFERENCES

Alam S, Sakib N, Mumtaz M, (2011). Seismic Loss Assessment of Dhaka for Scenario Earthquakes Using A Displacement-Based Method, *International Journal of Civil & Environmental Engineering IJCEE-IJENS Vol: 11 No: 05*

American Society of Civil Engineers (2014). Seismic Evaluation of Existing Buildings, ASCE/SEI 41-13. Reston, Virginia: ASCE.

Bangladesh Housing and Building Research Institute, (2015). Bangladesh National Building Code 2015 (Final Draft)

CNCRP Project for Capacity Development on Natural Disaster Resistant Techniques of Construction and Retrofitting for Public Buildings – Manuals and Guidelines, Public Works Department, 2015

Dhaka HVRA Guidebook, (2014). *Bangladesh Urban Resilience Project.*

Giardini, D, Grünthal, G, Shedlock, K M and Zhang, P (2003). The GSHAP Global Seismic Hazard Map In: Lee, W., Kanamori, H., Jennings, P. and Kisslinger, C. (eds.):**.** *International Handbook of Earthquake & Engineering Seismology, International Geophysics Series 81 B, Academic Press, Amsterdam***,** 1233-1239

Ministry of Disaster Management and Relief, Department of Disaster management, www.ddm.gov.bd/earthqhake.php

Persio R, Clark M, Mason S, (2014). Seismic Risk Assessment Study for Bangladesh, Arup

RPCC Rana Plaza Coordination Committee (2013). http://ranaplaza-arrangement.org

Sadat M R, Huq M S, Ansary M A (2010). Seismic Vulnerability Assessment of Buildings of Dhaka City, *Journal of Civil Engineering (IEB),* 38 (2) 159-172

United States Geological Survey, https://earthquake.usgs.gov/earthquakes/eventpage/usp0008b2r#impact