BANGLADESH NETWORK OFFICE FOR URBAN SAFETY

BNUS ANNUAL REPORT-2018

BANGLADESH NETWORK OFFICE FOR URBAN SAFETY

BUET, DHAKA, BANGLADESH

Edited By:

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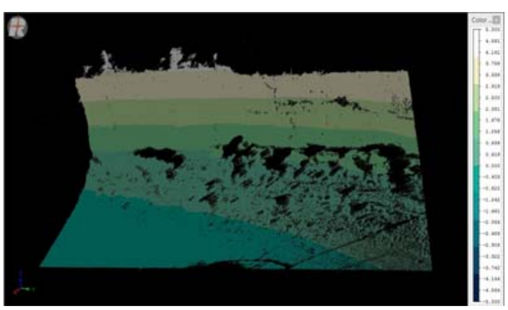

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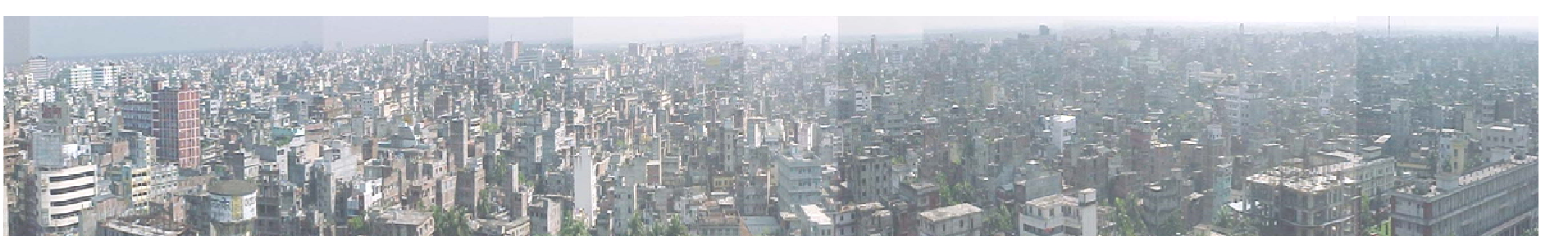

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PART-I

SAFETY IN RMG SECTOR: PERFORMANCE AND PROGRESS OF DIFE AFTER RANA PLAZA

BANGLADESH NETWORK OFFICE FOR URBAN SAFETY (BNUS), BUET, DHAKA

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1. Introduction

Safety has become an issue of major concern with the increase of population and rapid industrialization. According to ILO, every year 317 million accidents and more than 2.3 million deaths occur in workplaces worldwide as a result of occupational accidents. Substandard occupational safety practices can be attributed to an annual economic burden of 4 percent of global Gross Domestic Product (GDP) (ILO, 2017). Research works have already recognized the significance of safety interventions in order to ensure workplace safety and decrease injury rates (Ashford, 1976; Smitha *et.al.*, 2001; Locke *et.al.*, 2007; Cohen, 2013).

Most countries address occupational safety in two forms- through the establishment of safety association and formulation of safety laws and regulations. In USA, the establishment of the Occupational Health and Safety Association (OSHA) lead to the reduction of work-related deaths and injuries by more than 65 percent (OSHA, 2016). In 1919, following the end of First World War, International Labor Organization (ILO) was established as a result of growing labor and social movements. Japan adopted Industrial Safety and Health Law (ISHL) in 1972 which sharply decreased the number of work-related deaths in the country (Reich and Frumkin, 1988). China, being the fifth largest trading nation in the world, experiences industrial hazards frequently. Chinese government adopted the Work Safety Law (2002) which focuses on factory-wise safety management system, training aspects and routine inspection of production activities (Walker, 2015). European Union (EU) directives set minimum requirements to ensure safety and health at workplaces and the Member States must comply with these standards through the implementation of national legislations. ILO works in coordination with the governments, employers and representatives of 187-member states in order to ensure safe and decent work for both men and women (ILO, 2017). Bangladesh has been an active member state of the ILO since 22 June, 1972 and has ratified 35 ILO Conventions including seven fundamental conventions (ILO, 2017).

Working condition in RMG factories in Bangladesh has been low as most factories do not comply with the existing labor laws and international labor standards (Ahamed, 2012). Ready Made Garments (RMG) sector is the largest exporting industry of Bangladesh which experienced phenomenal growth during the last 25 years.

This sector contributes for 75% of foreign currency earning and 13% of GDP growth of Bangladesh (Firoz, 2011). Despite its phenomenal success in terms of remittance earning and employment generation, this sector experienced some worst industrial accidents in the history. One of the deadliest accidents include the fire incident at Tazreen Fashions of Ashulia, Dhaka in November 24, 2012, which resulted in the deaths of 111 workers and injuries of more than 300 workers (Chowdhury and Tanim, 2016). Since the Tazreen Fashions Factory fire, at least 142 RMG factory fire accidents occurred up to April, 2017 leading to the death of 1,148 workers (Solidarity Center, 2017). The collapse of Rana Plaza in 2013 is considered to be one of the deadliest accidental structural failures in history which created a worldwide concern for workplace safety in Bangladesh (ILO, 2016). The building collapsed on 24 April, 2013 due to poor structural condition, with a death toll of 1,129 lives and approximately 2,500 injured (Alam and Hossain, 2013; Butler and Hammadi, 2013). Lack of compliance to the workplaces safety issues is considered to be largely responsible for its collapse (Ansary and Barua, 2015).

Despite the tremendous growth of RMG sector in Bangladesh, the capacity of regulatory bodies, especially the labor inspectorate was not growing in the same pace. Department of Inspection for Factories and Establishments (DIFE) was established in 1972 to implement the labor laws of the country. But with its limited manpower, infrastructure and logistic support, DIFE was falling behind to meet the needs of huge number of factories and commercial establishments (GoB, 2016). Major industrial accidents like Rana Plaza collapse and Tazreen fire reflected the need for a complete renovation of the labor inspection system of Bangladesh (GoB, 2015). In this background, DIFE undergone an extensive upgrade in 2014. This paper explores the initiatives taken after Rana Plaza collapse with special focus on workplace safety. The purpose of this paper is to provide an update of the progression made by DIFE after its initiation in 2014, including the next steps for ensuring workplace safety in Bangladesh. The objectives of this article are- (1) to summarize the workplace initiatives and administrative reform that has been done so far by DIFE to determine how far the occupational safety agenda has progressed since 2014; (2) to identify the gaps in the system and outline the next steps for moving forward in order to make DIFE achieve its vision and objectives from the perspective of workplace safety in RMG sector.

2. Background of Department of Inspection for Factory and Establishments (DIFE)

2.1. Formation of DIFE: In 2010, the service sector was accounted for the largest share of employment (35.4%) within the non-agricultural sector, followed by the manufacturing industry (12.4%) (Labor Force Survey, 2010). According to Economic Census (2013), the total number of economic units was 3,708,144 in 2010 which increased to 8,075,704 in 2013

(BBS, 2013). This rapid expansion of manufacturing and service industry led to an increase in the number of factories and the number of workers engaged in the sector. Although the Chief Inspector of Factory and Establishments office was playing a vital role in ensuring legal rights, safe and hygienic work place for the huge number of working people, existing manpower, infrastructure and logistic support were poor compared to the total number of factories, and commercial establishments.

After the tragic incident of Rana Plaza collapse, the need for fundamental changes related to safety, inspection and compliance became crucial in order to safeguard the lives of four million garments workers and retain the confidence of global buyers (ILO, 2015). This resulted in several national and international commitments and initiatives directed towards reforming the RMG sector of Bangladesh and improving workplace safety in garments factories. Some of the major initiatives include National Tripartite Plan of Action on Fire Safety and Structural Integrity, European Union Sustainability Compact and United States Trade Representative (USTR) Plan of Action. Many of these initiatives had influence in shaping the roles and responsibilities of DIFE.

In this context, the government of Bangladesh took an initiative to upgrade the directorate into a "department" with greater operational and management authority. Ministry of Labor and Employment issued the government order of upgradation of Chief Inspector of Factories and Establishment office to Department of the Inspection for Factories and Establishments (DIFE) in 15 January, 2014 sanctioning 679 new staff positions and 392 new inspectors. The post of Chief Inspector (Deputy Secretary) was upgraded to Inspector General (Additional Secretary) to provide DIFE with stronger leadership. Besides, the number of district offices were increased from 7 to 23, and budget allocation for DIFE was increased more than three-fold in FY 2013-14 and 2015-16 as shown in Figure 1 (GoB, 2016).

The adopted vision of DIFE is to ensure a better working environment for workers. In the old structure, there was little inter-agency cooperation by the DIFE office (GoB, 2015). But now DIFE collaborates with various government and private agencies along with international organizations like ILO to facilitate the policy, planning, measures and directions to enhance safety in RMG sector (GoB, 2016).

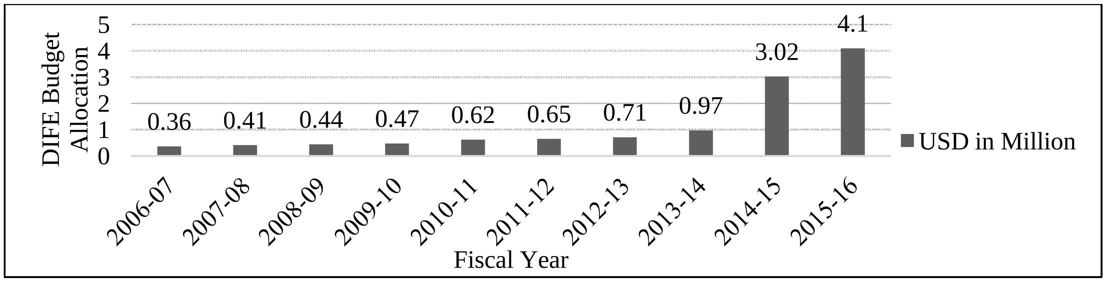

Figure 1. Budget allocation for DIFE from FY 2006-2016 (Source: GoB, 2016)

2.2. Organizational Framework of DIFE: The official headquarter of DIFE is located at Kawran Bazar, BFDC Bhaban, Dhaka which is supervised by the Inspector General (Additional Secretary). The organogram of DIFE headquarter is shown in Figure 2. Apart from the headquarter, there are 23 district offices located all over Bangladesh, each of which are chaired by one Deputy Inspector General (DIG). Government of Bangladesh has already taken an initiative to expand the existing number of district offices. A development project named as "Modernization and Strengthening of DIFE and Establishment of 5 Zonal and 4 Regional offices" has been undertaken in Gazipur, Narayanganj, Kushtia, Faridpur, Comilla, Barisal, Mymensingh, Maulvibazar and Rangpur in January, 2013.

The Safety Section of DIFE, operating under the supervision of one DIG and two Assistant Inspector Generals (AIG), coordinates the activities of Review Panel and Remediation Coordination Cell (RCC) and performs other functions such as factory assessment, approval of Corrective Action Plan (CAP), and review of factory compliance reports. Health Section of DIFE is responsible for ensuring safe workplaces, identification of work-related diseases, protection of occupational health and maternity benefits. The General Section prepares inspection plan, supervises the inspection activities and resolves labor disputes. The Law Sub-Section under Administrative and Development Section manages and takes necessary initiatives to resolve the ongoing cases related to Ministry and Department. The responsibility of Statistics and Research Sub-Section is to collect and preserve the list of factories and establishments all over the country. According to this Sub-Section, the number of registered factories and establishments is 26,953, among which 4,667 are RMG factories. The Information and Public Relation Sub-Section works on raising awareness among workers and employers through different programmes, television documentaries, social media and strives to protect information right. Lastly, the Accounts Sub-Section is responsible for budget preparation of the department including maintenance cost, procurement of equipment etc. With the assistance of ILO, the library of DIFE has been upgraded into a resource center along with infrastructural development. Apart from these four divisions, the district offices have an additional division named as Shops and Establishments Section (GoB, 2015-16).

In order to mobilize the activities of different divisions of DIFE, 18 working committees have been formed within 2016 period. The committees include Database and Website Management Committee, Social Media Admin Panel, Crisis Management Committee, Monitoring, Training, Inspection Reporting, Transparency and Accountability, LI Policy, Helpline Management Committee etc. DIFE has also formed an Occupational Safety and Health Unit consisting of 26 members which is headed by the Inspector General (CPD, 2016).

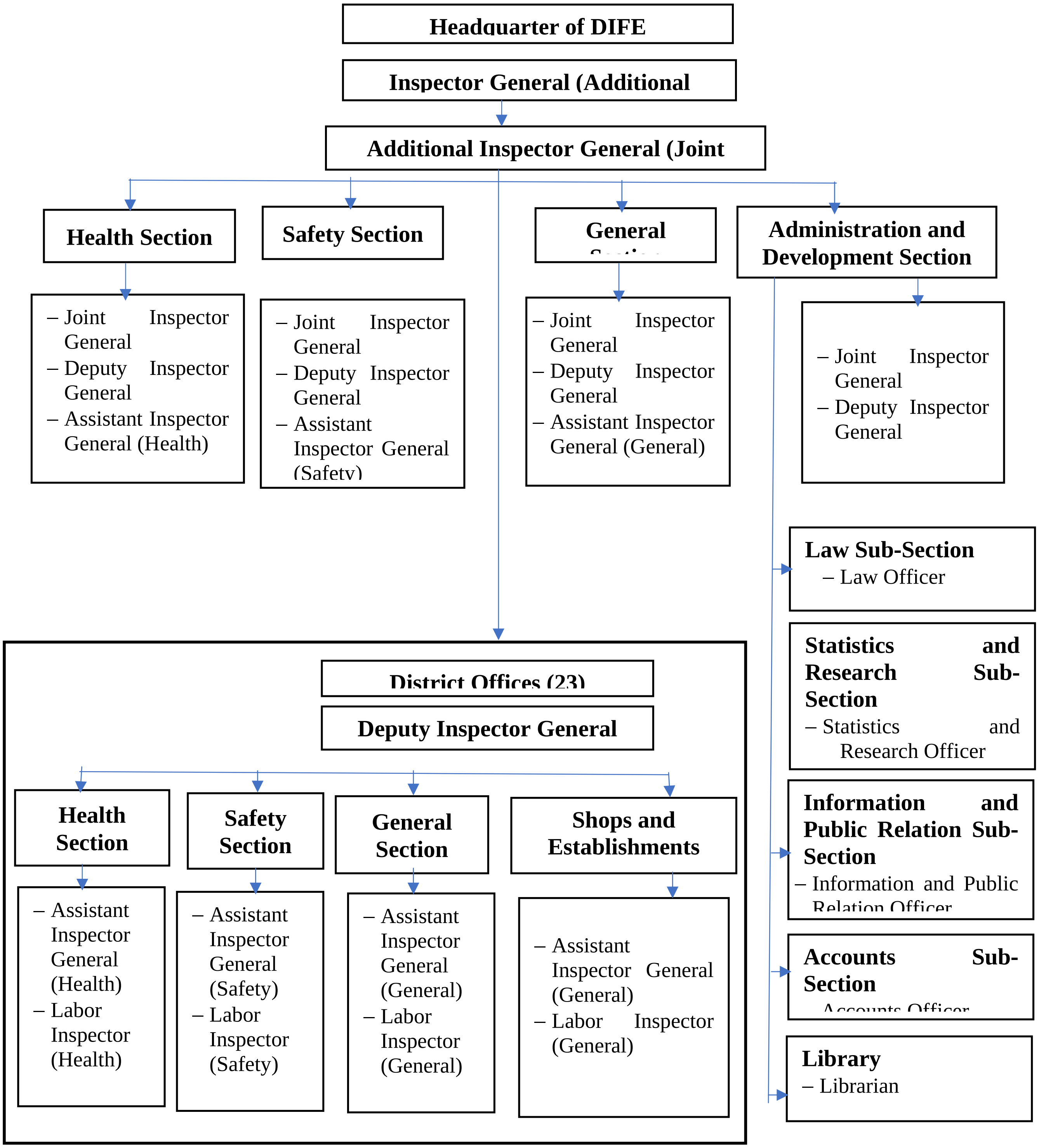

Figure 2. Organizational framework of DIFE headquarter (Source: DIFE, 2017)

3. Activities and Progress of DIFE for Improving Safety in RMG

3.1. Inspection of Factories: Factory inspection, being an essential part of labor administration system, can assist national authorities to identify the loopholes in the application of national labor laws (ILO, 2017). Regular labor inspection has been prioritized in countries like USA, Japan, and in EU, where the inspectors have formal police power and regular, programmed workplace inspections are carried out annually (OSHA, 2015). In Bangladesh, Apart from National Initiatives (NI), Accord and Alliance comprised of European and North American retailers are also conducting inspection of their enlisted factories. So far, Accord has completed 80% and the Alliance completed 90% of the inspection and remediation (The Daily Star, 2018). As seen from Figure 3, preliminary assessment of 3,780 factories has been conducted by three initiatives up to September, 2015.

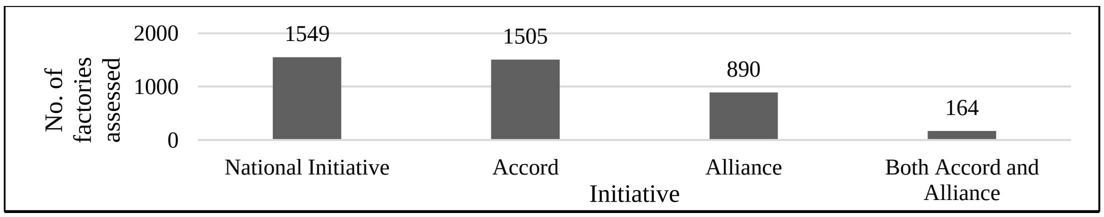

Figure 3. Preliminary assessment of factories by three initiatives up to Sept., 2015 (Source: DIFE,

Review Panel is responsible for visiting the factories in question, reviewing the evidence and making decision regarding the future operation of the factory. It is chaired by the Inspector General of DIFE and has the authority to close down factories according to labor laws. Till December, 2017, out of 145 factories that have been referred to Review Panel, 37 factories have been closed, 36 factories have been partially closed and 66 factories have been allowed to operate with some recommendations. Under NI, a total of 147 factories are asked to initiate Detailed Engineering Assessments (DEA) and primarily 13 engineering firms have been appointed to perform DEA (ILO, 2018). Table 1 shows the actions taken by Review Panel until December, 2017.

Table 1. Factories referred to Review Panel and actions taken (as of December, 2017)

Decision	**NI**		**Accord**		**Alliance**		**Total**	
	No. of factories	No. of buildings	No. of factories	No. of buildings	No. of factories	No. of buildings	No. of factories	No. of buildings
Referred to	42	18	47	23	56	27	145	68

review panel								
Partially closed	16	7	8	5	12	5	36	17
Closed	3	3	26	10	8	5	37	18
Allowed operation	23	8	12	7	31	12	66	27
Pending decision	0	0	1	1	5	5	6	6

(Source: DIFE, 2017)

3.2. Initiation of Remediation Coordination Cell (RCC): After the expiry of the tenure of Accord and Alliance in 2018, two new bodies named as "transitional Accord" and "Safety Monitoring Organization" will act as safety supervisors in RMG sector (The Daily Star, 2018). An organized national framework is needed to oversee the workplace safety issues, monitor progress in enhancing safety and manage the remediation process for garment factories. In this background, the Remediation Coordination Cell (RCC) has been launched in 15 May, 2017 with the plan of creating a long-term, coordinated approach for factory inspection and safety progress monitoring (ILO, 2017). The core body of RCC is supported by five government organizations including DIFE, Fire Service and Civil Defense (FSCD), RAJUK/ Chittagong Development Authority, Public Works Department and Chief Electrical Inspector's Department. Three officers from each organization monitor remediation activities at field level and core body meeting is held on every two months. Up to February, 2018, five core body meetings have been held and one factory has been visited on 12 February, 2018 (DIFE, 2018).

3.3. Formulation of Task Force: Three task forces have been formulated for structural, electrical and fire under RCC. Task force is comprised of IG, DIFE as Convener, and representatives from FSCD, RAJUK/CDA and BUET as members. These taskforces monitor the progress of Corrective Action Plan (CAP) and Detail Engineering Assessment (DEA) in national initiative factories. Total 28 task force meetings have been held until 13 February, 2018 with 19 meetings for structural, 8 meetings for fire and 1 meeting for electrical. Table 2 lists the decisions made on task force meeting.

Table 2. Decisions made on Task Force meeting (up to 13 February, 2018)

Task force	Total DEA required	Number of DEA/CAP submitted	Number of DEA/ CAP reviewed
Structural	147	59	40
Fire	745	15	08
Electrical	745	20	01

(Data Source: DIFE, 2018)

The manual for the preparation of CAP has already been devised and uploaded in DIFE website. A number of DIFE inspectors are also being trained on CAP development (GoB, 2016). Up to January, 2018, all NI factories have prepared their CAPs based on the findings of inspection reports (ILO, 2018). Progress of CAP up to February, 2018 has been shown in Figure 4, which denotes that progress in fire CAP is comparatively lower than that of structural and electrical CAPs. Total progress is also higher for owned buildings (33%) compared to the rented buildings (19%).

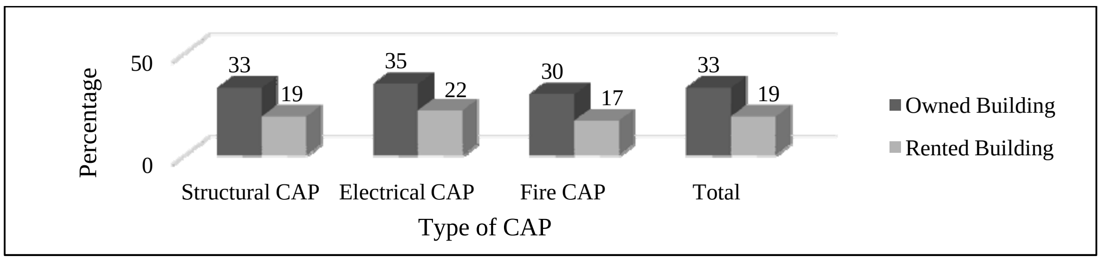

Figure 4. Progress of CAP among NI factories (Data Source: DIFE, February, 2018)

3.4. Approval of Factory Layout: The Labor Law stipulates that factory layouts shall be approved by DIFE. In order to get approval, the factory authority needs to submit necessary documents such as copies of layout, trade license, soil test report, load bearing capacity certificate, structural design prepared by any recognized engineer/engineering agency, building construction certificate and approved building design by local authority to the Deputy Inspector General (DIG). DIG will assign inspectors to submit the inspection report and may approve the design after reviewing the report. The process of registration and issuing of license of factories and establishments is quite similar to the factory layout approval process (DIFE, 2017).

3.5. Recruitment and Qualification of Labor Inspectors: Government has increased manpower from 314 to 993, out of which 575 are inspectors and 284 inspectors are working in DIFE (CPD, 2016). In 2017, the number of inspectors has been increased up to 330 (DIFE

Interview, 2017). In order to ensure the effectiveness of inspection services, the recruitment process of AIG (Assistant Inspector General) and LI (Labor Inspector) is done through Bangladesh Civil Service (BCS) examination. For the AIG (safety and general section), minimum educational requirement is B.Sc. in engineering and the AIG under health section must be a doctor. In case of the LIs, minimum graduation is required in any field of science (DIFE interview, 2017).

3.6. Training and Capacity Building of the Labor Inspectors: As part of the reform of DIFE, ILO is working closely with DIFE to improve the capacity of labor inspectors (ILO, 2016). A comprehensive series of capacity building activities, ranging from basic training of newly recruited labor inspectorates to specific training focused on labor law, fire safety assessment etc. have been taking place since January, 2014. DIFE has collaborated with a wide range of partners to provide training including ILO, GIZ, FSCD, BUET and BGMEA (GoB, 2015). The three-and-a-half-year long ILO programme on "Improving Working Conditions in the Ready-Made Garment Sector" launched in October, 2013 is working with an aim of significantly improving the capacity of inspection system in Bangladesh. Training courses under this programme covered a wide range of subjects, including accident investigation, labor inspection strategies, international labor standards, Bangladesh Labor Laws, labor-market related policies and programmes etc. to improve the professional skills of the labor inspectors.

3.7. Preparation of District Database: DIFE has taken initiatives to prepare a database containing the list of factories in different districts of the country. Already this list has been prepared for 23 among 64 districts. Figure 5 shows the type of factories in different districts according to the database. In the database, the factories have been classified into more than 100 types of sectors. These sectors have been categorized into 13 broad categories and represented in Figure 5. From the figure it can be seen that, most of the factories fall under garments and textiles category in all six districts, with the highest percentage belonging to Narsingdi (98.71%) followed by Dhaka (75.10%).

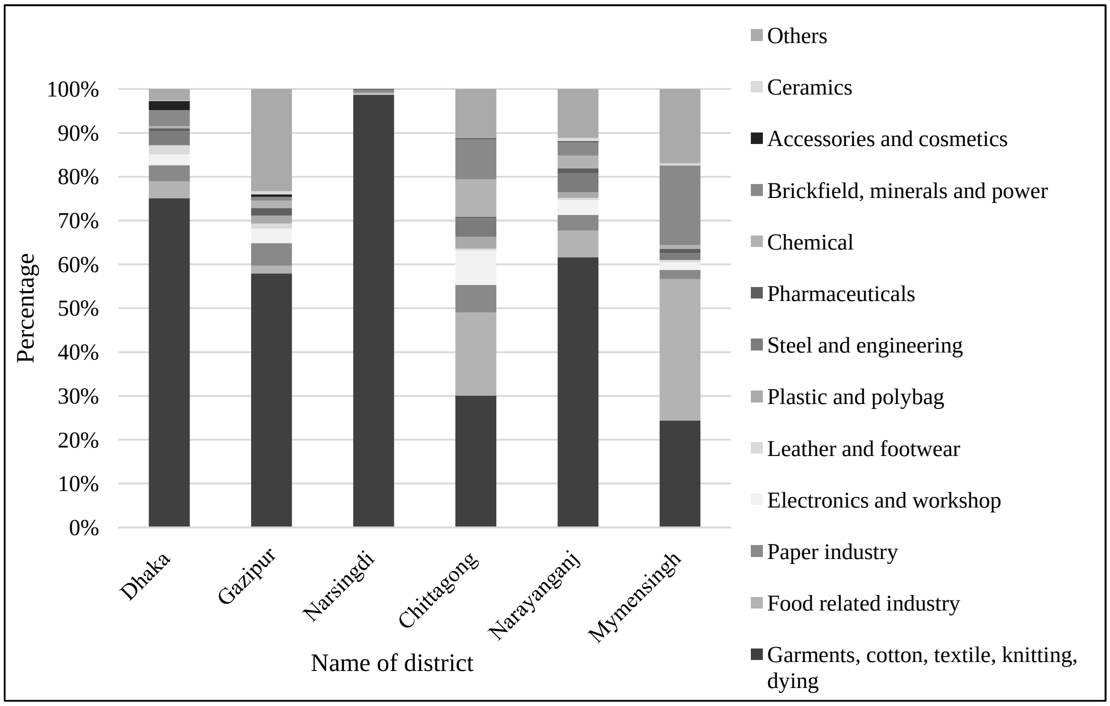

Figure 5. Distribution of factories according to type of sector in different districts (Prepared by Author, Data Source: DIFE, 2017)

3.8. Ensuring Transparency, Accountability and Workers' Participation: The launch of DIFE website and a publicly accessible data base containing the basic information of 4,808 RMG factories can be remarked as a step forwards towards ensuring transparency (ILO, 2014). According to DIFE, already 2,961 assessment summary reports have been published in the website among which 1,707 reports are prepared by NI, 712 by Accord and 542 by Alliance (DIFE, 2017). But the database is often inaccessible due to technical issues and requires necessary upgrade to be effective. The planned establishment of an accountability unit within DIFE is another major step. Any decision regarding the closing of factories are taken in the presence of stakeholders from BGMEA, BKMEA, BUET and other organizations in order to ensure impartiality. With the assistance of ILO, DIFE has launched a toll-free helpline number for the RMG workers in March, 2015. Through the number, anyone can complain to the government with a view to improving the working conditions which will be addressed by concerned authorities. DIFE has also established an email account to receive complaints or grievances of workers (GoB, 2015).

4. Factory Verification: Are Factories Closed by DIFE Really Closed?

DIFE closes down factories that fail to improve the remediation by the deadline. Then hardly any assessment is done to verify whether those factories are still operating. In order to determine the current status of the closed factories, a survey has been conducted among 37 factories covering 10 areas of Dhaka- Gulshan, Jatrabari, Malibagh, Mirpur, Motijheel, Old Dhaka, Tejgaon, Mohammadpur, Dhanmondi and Badda under the supervision of authors. Interestingly, almost 49% of the “closed” factories are still running. Among them, 83% factories are operating with a new unit name whereas the rest are working with their original names. As seen from Figure 6, the number of factories that are still operational are high in Mirpur, Jatrbabari, Tejgaon, and Mohammadpur.

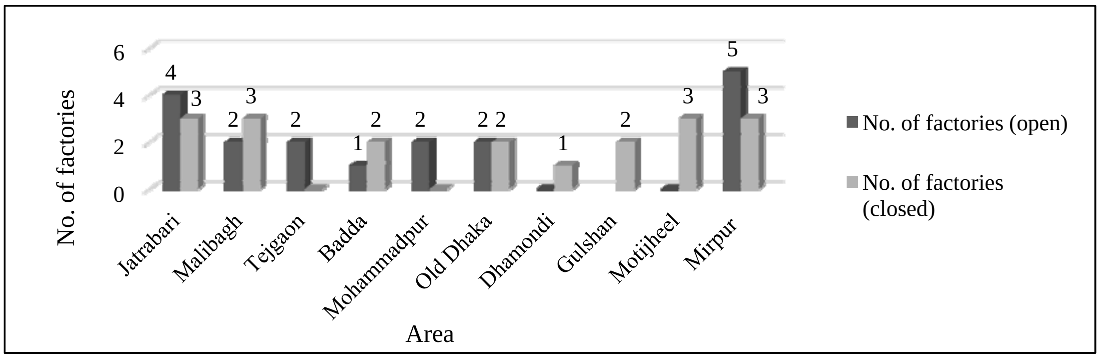

Figure 6. Area wise comparison of running and closed factories in Dhaka among factories closed by DIFE (Data Source: Field Survey, 2018)

5. Challenges and Way Forward

Despite the steady improvements being made and the number of measures taken to improve occupational safety in Bangladesh RMG sector, there is a huge workload on DIFE to deliver concrete and reportable results within a short period of time (GoB, 2015). Major challenges faced by DIFE include the lengthy recruitment process of the inspectors, lack of professional training institutes, lack of adequate labor inspectors, procurement of equipment, lack of monitoring activities and coordination among different stakeholders. Database management and regular update of database is another key challenge for DIFE. There is no dedicated member or staff at DIFE responsible for the data collection, compilation and upgradation process. Currently the data compilation and record-keeping take place based on a paper-based system which has certain limitations. Technological upgradation, procurement of new computers, and more recruitment of staff in the Statistics Cell are required for the establishment of a more modernized and efficient system of data collection and management. In order to make visible progress and facilitate inspection process, priority should be given towards increasing the number of labor inspectors. According to BBS, district offices must be established in 64 districts in order to cover 80 lakh economic units of the country. Therefore, more district offices are needed to be established to conduct inspection in a systematic manner. Overall, DIFE holds substantial potential in creating a safe workplace in RMG industries of Bangladesh. More attention is required in the field of manpower, capacity building, technical advancement and monitoring of closed factories to properly execute the national and international commitments directed towards safety compliance.

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PART-II

CAN RANA PLAZA HAPPEN AGAIN IN BANGLADESH?

BANGLADESH NETWORK OFFICE FOR URBAN SAFETY (BNUS), BUET, DHAKA

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1. Introduction

The Ready-Made Garment (RMG) industry in Bangladesh has been facing challenges to ensure workplace safety and better working conditions for the millions of garment workers. One of the deadliest fire accidents in RMG sector Bangladesh is Tazreen Fashion fire on November 24, 2012, which resulted in death of 112 workers. Since Tazreen Fashion Factory fire to 22 April 2017, about 133 fire incidents have occurred in the sector leading to at least 38 deaths and 815 injuries (Solidarity Center, 2017). In 2005, the building of Spectrum factory collapsed causing death of 64 garment workers and injury of 80. In 2006, 22 workers died due to collapse of the Phoenix Garments building. In 2012 due to partial collapse of Siams Superior Ltd. factory building in Chittagong Export Processing Zone (CEPZ), five workers received minor injuries. In February 2013, factory building of Envoy Garments Ltd. in Ashulia, Dhaka at least 100 garment workers were injured in a stampede triggered by a false fire alarm and consequent collapse of stair railing. Just months after this accident, Rana Plaza collapsed on 24 April 2013. All these accidents represent poor workplace safety condition in Bangladesh RMG factories. After Rana Plaza accident different diversified national and international initiatives have been taken to improve workplace safety condition in this sector. Five years after the accident the question is now whether these initiatives could truly succeed to ensure workplace safety or can accidents like Rana Plaza collapse happen again.

2. Ins and outs of Rana Plaza collapse

The factory building of Rana Plaza was located in Savar, Dhaka. It housed five garment factories employing around 5,000 people, more than 300 shops, and a bank. It was a 9-storied industrial building with a single basement. Local Municipality (Savar) gave permission to the owner of Rana Plaza to construct a five storey commercial building with one basement in 2005. Though the foundation of the building was for five storey, later the owner was allowed to extend the building up to nine storey without considering the structural design. Moreover, the building was converted from commercial to industrial use, and power generators were placed at the higher floors. As a result of such violations in building construction, on 23 April 2013, a day prior to the fateful day, cracks developed on some pillars and on few floors of the building following a jolt. After inspection, industrial police requested the building authorities to close the building and to suspend operations of the factories on that day. However, the building owner and top-management of the garment factories ignored the warning and forced the workers to work in the next morning on 24th April, 2013. As a consequence, the collapse resulted in the high death toll of 1,134 and more than 2500 people were badly injured at the end of the rescue operation on 14 May 2013. It was the most fatal industrial accident in RMG sector in Bangladesh, and one of the deadliest industrial disasters in the world, which was the result of the reluctant attitude of the stakeholders towards the compliance issues. This tragic accident received global attention and brought forward diverse issues concerning millions of stakeholders in the RMG sector of Bangladesh (Ansary & Barua, 2015).

3. Initiatives after Rana Plaza collapse

Considering the potential of RMG industry in Bangladesh, several and diverse national and international commitments and initiatives resulted as part of the reform and restructuring of the RMG sector after Rana

Plaza accident. The National Tripartite Plan of Action (NTPA) on Fire Safety was first outlined on March 2013 after Tazreen Fashion fire accident. Upon NTPA, tripartite partners (GoB, RMG workers, and RMG employers) signed a Joint Statement on May, 2013.Afterwards, without altering the content, the NTPA on Fire Safety was merged with the Joint Statement to form the NTPA on Fire Safety and Structural Integrity in the RMG Sector of Bangladesh in July 2013. It included 25 commitments divided into three categories: legislation and policy, administration, and practical activities. To ensure and monitor its implementation the National Tripartite Committee (NTC) was established at the same time under NTPA commitment. The committee is chaired by Labour Secretary and includes Government agencies, employers (Bangladesh Employer's Federation (BEF), Bangladesh Garment Manufactures & Exporters Association (BGMEA) and Bangladesh Knitwear Manufacturers & Exporters Association (BKMEA)), and trade unions. Based on NTPA, the EU, GoB and ILO issued an agreement of time-bound actions, "The Sustainability Compact: Compact for Continuous Improvements in Labour Rights and Factory Safety in the Ready-Made Garment and Knitwear Industry in Bangladesh" in July 2013 to promote improved labour standards and responsible business conduct in the RMG and knitwear industry in Bangladesh. A total of twenty-nine activities were listed in the EU Sustainability Compact. In addition, the United States Trade Representative (USTR) requested GoB to implement a sixteen-point action plan within one year in order to reinstate Bangladesh's GSP status in the US market. The USTR Action Plan endorsed the EU Sustainability Compact particularly for trade union related activities (Moazzem & Islam, 2015).

In addition to these initiatives, two different factory inspection programmes were established to make work place safer in Bangladesh where ILO fulfils the role of neutral chair. They are: the Bangladesh Accord on Fire and Building Safety in Bangladesh (the Accord), and the Alliance for Bangladesh (the Alliance). The Accord was initiated by over 190 apparel companies from over 20 countries in Europe, North America, Asia and Australia; two global trade unions, IndustriALL and UNI Global; and eight Bangladeshi trade unions on May 15th 2013. It is a five-year independent and legally binding agreement designed to build a safe and healthy Bangladeshi RMG Industry (Bangladesh Accord, 2015). The Alliance officially launched its local operation in Dhaka on December 9, 2013, which is also a five-year independent and legally binding agreement initiated by a group of North American apparel companies and retailers and brands (26 North American retailers and brands) to develop and launch the Bangladesh Worker Safety Initiative (Alliance for Bangladesh, 2013).

The targets and objectives of these initiatives are the same and they share some common courses of action aiming at improvement of workplace safety to safeguard the lives of over four million RMG workers and to retain the confidence of global buyers following the Rana Plaza accident (Barua & Ansary, 2017; Moazzem & Islam, 2015). Among the common actions considered in these initiatives, improving fire, electrical and structural safety of RMG factory buildings is significant to ensure a safe working environment for all in the sector preventing further accidents.

4. Actions regarding structural safety of RMG factory buildings

Considering work-place safety as one of the most important challenges to sustain RMG industry in Bangladesh, actions regarding structural, fire and electrical safety assessment of all active export-oriented RMG factories were addressed in all the action plans. The supporting actions included upgrading and strengthening of the

Chief Inspector of Factories and Establishment office to a “department”, recruitment of additional labour, fire and building inspectors, arrangement of training programs to increase capacity of the inspectors, development of plan in consultation with the ILO to conduct effective inspections, initiation of remedial actions or close or relocate factories as appropriate, and creation of a publicly accessible database of all RMG/knitwear factories as a platform for reporting labour, fire and building inspections. All of these actions are either fully or partially completed (Barua & Ansary, 2017).

Bangladesh University of Engineering and Technology (BUET) and two private engineering firms TUV SUD Bangladesh (Pvt.) Ltd and Veritas Engineering & Consultant on behalf of the NTC, the Accord, and the Alliance are responsible for conducting the assessments of the structural integrity and fire safety of RMG factory buildings. A Review Panel along with a review mechanism was established under DIFE to handle urgent safety issues in garment factories. Finally, in November 2013, assessments of the structural integrity and fire safety of RMG factory buildings officially commenced, led by engineers from BUET. The BGMEA and BKMEA agreed to share necessary documents related to factory design and layout with the Committee to facilitate a smooth assessment process.

To undertake the structural assessment of factory buildings with common approach, Guidelines for Assessment of Structural Integrity and Fire and Safety including harmonized standards were developed by the technical experts (structural engineers, fire safety experts, etc.) from the BUET on behalf of the NTC, the Accord, and the Alliance in 2013 (NTPA, 2013). In 2014, Accord and Alliance consolidated national rules and regulation related to fire and electrical, and building integrity (Bangladesh National Building Code Act, Bangladesh Labour Act 2006, and others) and prepared a comprehensive document. In case of insufficiency in local rules, the initiatives took support from international rules/guideline which further strengthened overall safety standards

A Remediation Coordination Cell (RCC)was formed in 2017 comprising of four teams to take over charge in transition phase be public agency. The teams include: the core body, field monitoring committee (to monitor remediation activities in field level), task force, and case handler and co-case handler. The activities of the cell include oversee the progress of remediation related activities (of factories initially under national initiative and later other factories under Accord and Alliance) and Detailed Engineering Assessment (DEA).

The safety assessment and remediation process for the factory buildings under national initiative is composed of six main steps.

- Firstly, preliminary assessment reports are prepared after each preliminary inspection including the findings and required recommendations for the building owner and users according to the assessment results. Whether DEA recommended or not is also included in the assessment report. Issues triggering DEA are: concerns with structural issues, i.e. extensions, lateral system, flat plate punching capacity and slender columns, and state of documentation and approvals.
- Secondly, if any factory is assessed as vulnerable, then they are referred to the review panel to order the closure and evacuation of the factories until undertaking additional strength testing or taking immediate remedial measures. Assessment alone is not enough to ensure a safe working environment for all in the sector. The weak factory buildings are required to be strengthened to ensure resilience. So, after

inspection of each factory, the inspection reports are shared with factory owners, the active brands and worker representatives. Then factory owner and the brands are tasked to develop a detail Corrective Action Plan (CAP) as per recommendation and to submit for approval with a clear timeline and a financial plan. Additionally, they propose firm for DEA (from the DEA firms short-listed by the DIFE Task Force) within a maximum of two weeks.

- Thirdly, the outline of the CAP is approved within two weeks through joint meeting between Factory Technical Team and the Initial Assessment Team.
- Fourthly, the approved firm conducts DEA and prepares report containing detail remediation scheme within six to twelve weeks and submit it for review and comments by the DIFE Task Force. DEA of the buildings involve soil investigation, other non-destructive tests and 3D building modeling. Fifthly, the DIFE Task Force review the DEA along with remediation scheme and send comments to the factory owner within two weeks after receiving the DEA report.
- Fifthly, after revision of DEA and remediation scheme by the approved firm, it is submitted to DIFE Task Force for final approval within maximum two weeks.
- Finally, after approval of CAP, remediation work is initiated under supervision of RCC. After successful completion of remediation work approved by the task force, safety clearance certificate is provided to the factory to continue business as usual. If the factory owners do not start remediation work after 3rd escalation then DIFE or BGMEA would take legal action to cancel license of the factory.

5. Progress of inspection initiative

As per DIFE website, assessment of 3582 RMG factories have been completed till March 2016, including NTC 1549, Accord 1204, Alliance 656, and common by Accord and Alliance 164 (DIFE, 2016). A total 150 factories were referred to Review Panel, out of which 39 factories were closed, 42 factories were partially closed, and 69 factories were allowed to operate, whereas decisions for five factories are pending. Among 1549 factories assessed under NTC, 24 are highly vulnerable (open 12, closed 10 and relocated 2), 219 are moderately vulnerable, 560 are low vulnerable, 449 are structurally safe, 282 are vulnerable for fire and electrical issues and owners of 15 factories did not allow to enter and assess their factories. Among these factories 745 factories are under follow-up.

Till January 2018, 83% overall remediation works have been carried out in garment factories under the Accord. Among these factories, a total of 138 factories have completed initial remediation works (Bangladesh Accord, 2018). Furthermore, till November 2017, 85% overall remediation works have been carried out in garment factories under the Alliance. Among these factories, a total of 234 factories have completed initial remediation works (Alliance for Bangladesh, 2018). The assessment reports and CAPs for the factories under Accord and Alliance have been made public through their websites. Both initiatives made timely review of remediation activities and based on the progress put necessary pressure for timely completion of remaining works. In extreme cases where the factories were unable to comply, business ties with those factories ended. On the other hand, factories which successfully completed the remediation works received “letter of recognition” from the initiatives. In contrast, 33% and 19% remediation works have been carried out in garment factories under NTC in case of owned and rented factories respectively. Factories which successfully completed the remediation works or are found to be okay after the DEA, received a “Business As Usual Certificate” from DIFE.

6. Way forward

The assessment initiative has reached its target. Yet there also are factories that have not been included in the process due to unwillingness of the factory owners, and incomplete and improper list of factories provided by BGMEA and BKMEA. Moreover, there remain a number of factories which are not member of any organizations such as BGMEA and BKMEA. So, the list of factories needs to be updated and verified including the remaining factories to ensure quick completion of the assessment. Additionally, the safety concerns of backward linkage activities of RMG enterprises (e.g. textiles, accessories, etc.) had been excluded from monitoring and inspection which also need to be taken into consideration.

Due to limited capacity in terms of human resources, technical issues and database management, the process of remediation under national initiative is getting hampered. Additionally, due to non-co-operation of rented/ shared building owners, remediation works cannot be progressed.

The assessment initiatives for workplace safety in the Bangladesh RMG sector have led to important organizational learning for Bangladesh as well as for other apparel manufacturing countries. Furthermore, both the initiatives of Accord and Alliance have entered into a transition phase after five years’ operation which are going to end in 2018. Considering the status of remediation works of the remaining factories under this initiative, both the initiatives will extend their timeline to complete the works. Accord is willing to extend their operation beyond the limited time frame but Alliance is not willing to extend their contract. So, the key issue is now to institutionalize this learning to develop and continue an effective monitoring and inspection mechanism in the future even after completion of the assessments.

Another challenge is the huge amount of money required by the factory owners, which are insolvent but willing to remedy factory safety. For that purpose, the RMG factory owners have requested for the establishment of long-term loan instruments. In response to such request, different organizations, e.g., International Finance Corporation (IFC) US, Agence Française de Dévelopment (AFD), the Accord, the Alliance, and Japan International Cooperation Agency (JICA) provided loans to the local banks. These banks will disseminate the loans to the factory owners to improve their structural, electrical and fire safety infrastructure. The GoB has vowed to set up a specialized bank for the garment industry to provide easy loans. Though it is potentially an effective initiative, but the challenge lies in the fact that these financial supports are not sufficient compared to the requirement. Although the lenders have provided Bangladesh Bank (BB) with almost zero percentage interest, BB and other private Banks while disbursing the fund (around 300 million USD) to the RMG factories are asking an interest rate of 7 to 9%. Also, Public Works Department (PWD) under Bangladesh Government is entrusted to find out the deficiency of those RMG factories, which is hindering the process of fund disbursement. So far, only two RMG factories have received fund from this source.

7. Can RANA Plaza Happen Again?

From the above discussion it can be said that even though the assessment initiative has largely reached its target of inspection and remediation of factories, there is still a long way forward to reach the goal of workplace safety in Bangladesh RMG factories. In addition to these limitations, there are many cases where factory owners are doing wrong deeds to get positive report from the assessment. We have one recent experience with a factory during training of the DIFE inspectors regarding factory assessment and follow up. This particular factory located at Dhaka has been assessed under National initiative in December 2013. Basically, there are two buildings under the factory: one is a 6-storied and the other is an 8-storied building having a basement. Two factories namely AL and PR are located there. The ground floor of the two buildings are housing several shops and go-downs, the basement of the 8-storied building has been used as the fabric store for one of the factories (factory A). This factory is occupying both buildings up to 3rd floor (connected internally) and up to 5th floor of the 6-storied building, while the other factory (factory B) is occupying 4th to 7th floor of the 8-storied building. In early 2015, factory A moved under Accord. While applying for the Accord, they have only used the 8-storied building which has larger columns and smaller spans and can be considered safe. The 6-storied building which has smaller columns and larger cantilevers is not fully safe but has not been assessed under Accord. During a recent visit to the factory, the DIFE inspectors have found several cracks in the top floor beams of the 6-storied factory, which we have had already observed during our 2013 visit and for which we required the factory to make remediation. The owner of factory A has intentionally kept the 6-storied building outside the Accord assessment. So, as a result, the safe 8-storied building has been assessed and certified by Accord, while the 6-storied building under the same factory has never been assessed by Accord. But when DIFE inspectors were checking the factories, the owners told them that the whole factory is under Accord and has been fully assessed.

This is just a case among many. If these conditions cannot be taken care of then it is sure that Rana Plaza can happen again.

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PART-III

FIRE EVACUATION SAFETY IN BANGLADESH READY MADE GARMENT (RMG) FACTORIES: A COMPARISON OF STANDARDS AND NON-COMPLIANCE ISSUES OF MEANS OF ESCAPE

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1. Introduction

Workplace safety is very important to ensure business sustainability and thus to survive in the global competitive market (Jilcha & Kitaw, 2017; Jilcha, Kitaw, & Beshah, 2016). The working efficiency of an employee dominantly relies on how they believe that safety is to be valued in the organization (Griffin & Neal, 2000). Safety performance motivates them to work harder and work with efficiency and to take ownership of responsibility for safety performance (O'Dea & Flin, 2001). Due to non-compliance with workplace safety, occupational hazards lead to permanent disabilities, death and economic loss every year in different industries all over the world (Dağdeviren & Yüksel, 2008; Jaiswal, 2012). Among different occupational hazards, fire is one of the major concerns for ready-made garments industries. There are four keys to fire safety: fire prevention, early warning of the fire, containment of the fire, and safe exits (Bangladesh Accord, 2014b). Among them, safe exits or evacuation can be ensured by providing proper means of egress, which reduces the impact of uncontrolled fire (Hall & Watts, 2008; Sekizawa, 2005). Thus, compliant means of egress is one of the most important components to ensure safe fire evacuation.

In Bangladesh, Ready Made Garment (RMG) industry is one of the most important export-oriented sectors (Ahmed, Greenleaf, & Sacks, 2014; Ahmed & Hossain, 2009; Ansary & Barua, 2015; Wadud, Huda, & Ahmed, 2014). Apart from its contribution in export earnings, it is also an important player in the economy in terms of employment generation, poverty alleviation and empowering of women (Haider, 2007; Khosla, 2009; Rahman & Hossain, 2010). Though it is one of the most important sectors of Bangladesh, the safety issues are not up to a standard yet (Ahamed, 2013; Clean Clothes Campaign, 2012; Muhammad, 2011). Such lack of workplace safety has resulted in different occupational disasters in RMG factories in Bangladesh (Ahmed & Hossain, 2009). One of the most deadly fire accidents in this sector is Tazreen Fashion fire on November 24, 2012, which resulted in the death of 112 workers. Since Tazreen Fashion Factory fire to 22 April 2017, about 133 fire incidents have occurred in the sector leading to at least 38 deaths and 815 injuries (Solidarity Center, 2017). These tragic accidents received global attention and brought forward diverse issues concerning millions of workers, employers, brands, and consumers.

To improve workplace safety and thus reduce fire accidents in Bangladesh RMG sector several initiatives have been taken since 2013 after the Tazreen Fashion fire accident. Among them, National Tripartite Plan of Action (NTPA) on Fire Safety was first outlined in March 2013. After Rana Plaza collapse, it was converted to form the NTPA on Fire Safety and Structural Integrity in the RMG Sector of Bangladesh in July 2013 (Barua & Ansary, 2017). One of the most significant activities outlined in the plan was to assess the fire safety of all active export-oriented RMG and knitwear factories and initiate remedial actions accordingly. As part of this plan, the National Tripartite Committee (NTC) agreed on an initial assessment of buildings housing RMG factories. Additionally, two different factory inspection programmes were established: the Accord on Fire and Building Safety in Bangladesh (the Accord), and the Alliance for Bangladesh Worker Safety (the Alliance), where ILO assumed the role of the neutral chair (Alliance for Bangladesh, 2013; Bangladesh Accord, 2015). Bangladesh University of Engineering and Technology (BUET) and two private engineering firms TUV SUD Bangladesh (Pvt.) Ltd. and Veritas Engineering & Consultant on behalf of NTC were responsible for conducting the assessments.

Though these three assessment initiatives/programs are all for the RMG factories, there are differences in the fire safety standards based on which compliance or non-compliance is decided under different programs. In practice, factory buildings are obliged to follow Bangladesh National Building Code (BNBC) of 1993 (BNBC, 1993) to ensure fire safety. The original 1993 BNBC is in the process to be amended in which some issues for fire safety has been upgraded (BNBC, 2018). On the other hand, to carry out the assessment with a common approach, *Guidelines for Assessment of Structural Integrity and Fire and Safety* was developed in 2013 under NTPA which is again one step ahead of both the BNBC standards (NTPA, 2013). Likewise in 2014, the Accord and the Alliance developed their assessment guide with similar issues which is again superior to previously stated standards (Alliance for Bangladesh, 2014; Bangladesh Accord, 2014a). Thus, a difference in consideration for issues can be observed. Such situations may create confusion among the factory owners regarding which standard to follow. Additionally, after assessment under three programs, comparison of assessment results of the factory buildings to understand non-compliance issues are difficult. Such comparison may also create meaningless outcomes due to the difference in standards.

Several studies were carried out on Bangladesh RMG industry. Barua and Ansary (2017); Samaddar (2016); Ansary and Barua (2015); Tania and Sultana (2014); Akhter, Salahuddin, Iqbal, Malek, and Jahan (2010); Ahmed and Hossain (2009); and Mahmud and Kabeer (2003) studied different workplace safety issues in Bangladesh garment industry. Wadud et al. (2014) developed fire risk index (FRI) for soft parameters (management practices) in Bangladesh garment industry. Ahmad and Kamruzzaman (2015) analyzed the availability of fire-fighting equipment in selected knitting garment factories in Bangladesh. Wadud and Huda (2017) developed fire risk index (FRI), considering hard (structural) and soft (management practices) parameters for the Bangladesh garment industry. None of these studies compared the standards and analyzed non-compliance issues related to fire safety in Bangladesh RMG factories.

In this background, objectives of this research are: firstly, to compare different standards of means of escape for RMG factories to ensure safe fire evacuation, and secondly, to find out the non-compliance issues of means of escape in the factories with respect to different standards. This research will enable to find out and understand the differences among the standards and the non-compliance issues related to means of escape for safe fire evacuation in Bangladesh RMG sector.

2. Methodology

2.1 Comparison of standards related to means of escape for fire safety in Bangladesh

To understand difference among the issues related to means of escape, four standards were compared: Accord and Alliance 2014 (Part 6: Means of Egress), NTPA 2013 (Section 2.9: Means of Escape), BNBC 1993 (Part 4: Chapter 3: Means of Escape), and BNBC 2018 (Draft) (Part 4: Chapter 3: Means of Egress). To maintain a systematic comparison, the arrangement of Accord and Alliance standard was followed where 115 issues were organized under twenty-one broad headings. They are: fire separation of means of egress; walking surfaces in means of egress; impediments to means of egress; reliability; occupant load; egress width; number of exits and means of egress; arrangement of exits or means of egress; doors; stairway; ramps, corridors and ramped aisle; signs; sign illumination; egress illumination; handrails and guards; travel distance; exit enclosure; smokeproof enclosure; exit passageway; exit termination; and exit discharge. After comparison, the issues were organized in a tabular format. In cases where the variation of standards could be observed, they were represented according to their superiority where a higher standard is represented by most superior and lower standard represent less superior.

2.2 Analysis of non-compliance issues related to means of escape for fire safety

Until March 2016, assessment of 3582 RMG factories have been completed (NTC 1549, Accord 1204, Alliance 656, and common by Accord and Alliance 164) (DIFE, 2016). As these assessments have been done under national and international initiatives, so for the purpose of this study these assessed reports have been considered. Again, considering detailing of assessment reports, factories assessed by Alliance have been utilized. In the website of Alliance, assessment reports are available (Alliance for Bangladesh, 2018). Among 656 assessed factories, 500 factories are active. Therefore, these active factories have been considered for this analysis. From this set 217 factories have been selected for this study. The factories have been selected through random stratified sampling method considering four quarters each from 2013 to 2017, e.g. January to March, April to June, July to September, and October to December, assuming 95 percent confidence level and 5 percent confidence interval, fire assessment reports of these selected factories have been collected from the website of Alliance.

The reports were analyzed based on the findings from the comparison of standards. The focus of the analysis was whether the factories comply with the standards or not, and if not with which standard(s) they do not comply with. Additionally, the basic information of the factories including factory name, location, number of storey, ownership status, year of construction and occupancy, were also been collected from reports. After that, the analysis findings were input in SPSS 21 and the data were analyzed through descriptive statistics.

For the convenience of discussion, all the broadheads have been divided into two groups. They are: condition of means of egress components (including fire separation of means of egress; egress width; doors; stairway; ramps, corridors, ramped aisle; handrails and guards; exit passageway; exit termination; and exit discharge), and condition of means of egress (including number of exits and means of egress; arrangement of exits or means of egress; travel distance; exit enclosure; smoke proof enclosure; walking surfaces in means of egress; impediments to means of egress; reliability; egress illumination; occupant load; signs; and sign illumination).

3. Results and discussion

3.1 Description of the dataset

Among the factories considered in this research, about 73 percent are located in Dhaka (Mirpur, Gazipur, Narayanganj, Tongi, Ashulia, Dhaka Export Processing Zone, and other areas in Dhaka), and rest are located in Chittagong (Nasirabad Industrial Area, Chittagong Export Processing Zone, Karnaphuli Export Processing Zone, different industrial areas, and other areas in Chittagong). Figure 1 shows the percentage of factory buildings considered in this research with respect to location. Among the factory buildings, about 82 percent are owned and rest are rented. Figure 2 shows the percentage of factory buildings considered in this research with respect to their year of construction. From the figure, it can be observed that most of the assessed buildings have been constructed in the period of 2001 to 2015, which are mostly new constructions.

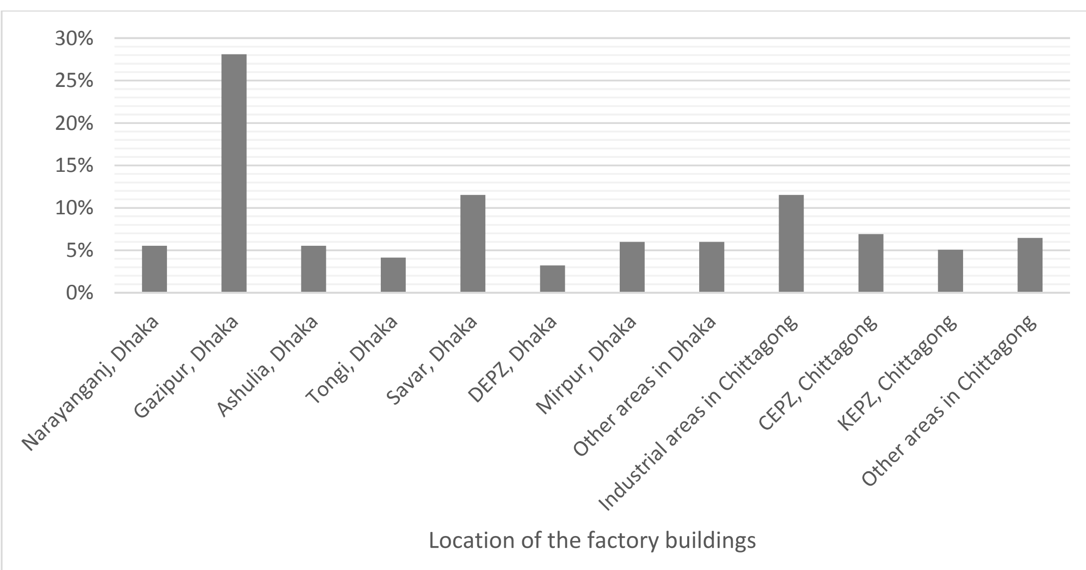

Figure 1: Percentage of factory buildings with respect to location

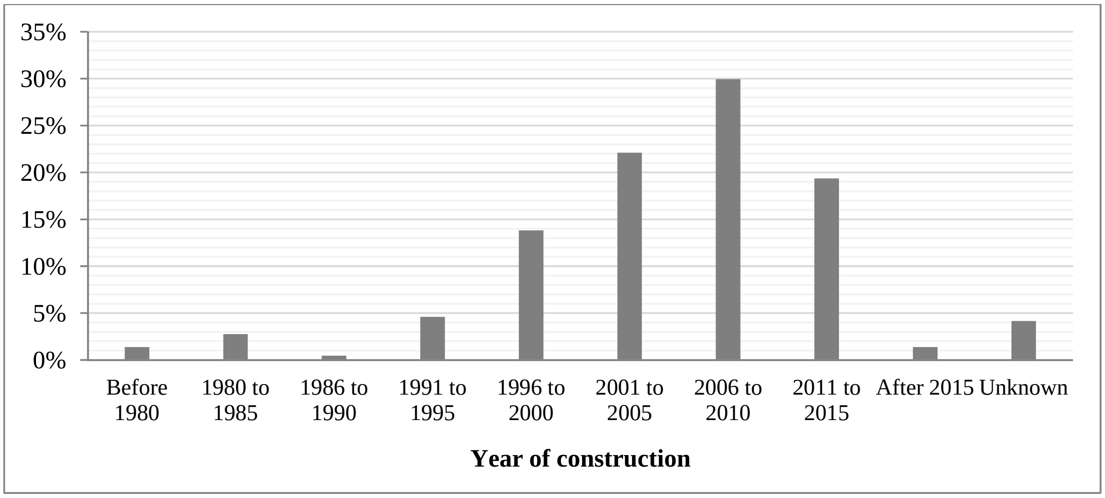

Figure 2: Percentage of factory buildings with respect to year of construction

Figure 3 shows the percentage of factory buildings considered in this research with respect to their number of storeys, which shows that most of the buildings are six storied. Figure 4 shows the percentage of factory buildings with respect to their number of occupants. Around 60 percent of the factory buildings considered in this research have number of occupants below 2000.

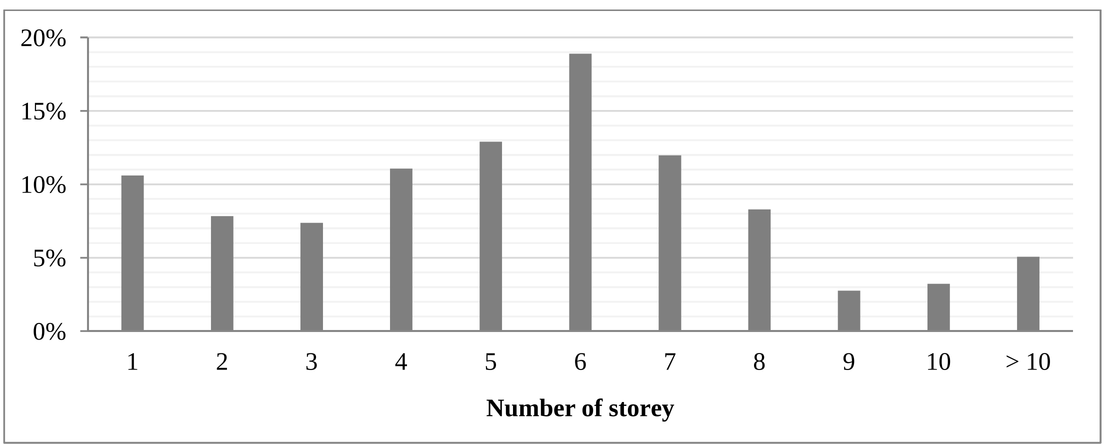

Figure 3: Percentage of factory buildings with respect to number of storey

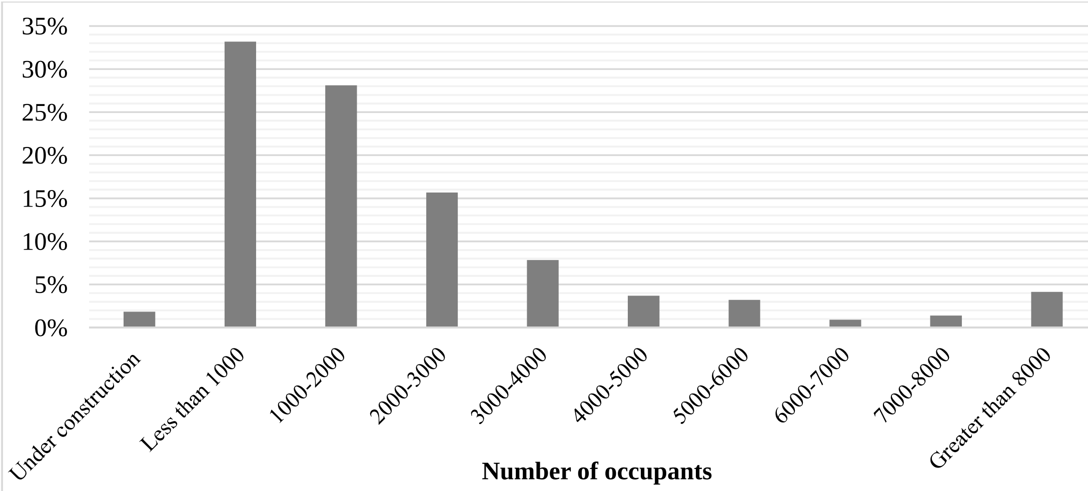

Figure 4: Percentage of factory buildings with respect to number of occupants

3.2 Means of egress for fire: Comparison of standards

In BNBC (1993), the way of means of egress is defined to consist of three parts, e.g. the exit access, the exit, and the exit discharge, which is consistent with other standards. As in BNBC (1993), the components of exit should include "…*a) A doorway, corridor or passage leading to an exterior or interior staircase, smoke proof and fireproof enclosure, ramp, balcony, fire escape or combination thereof, having direct access to the street, the roof of a building or any designated refuge area which affords safety from fire or smoke from the area of incidence; b) A horizontal exit from the affected building to an adjoining building or an area of refuge at the same level which provides safety from fire and smoke from the area of incidence and the areas communicating therewith*…". This is confirmed in Accord and Alliance (2014) as well as in NTPA (2013). In BNBC (draft 2018), the words have just been rephrased keeping the main idea same. Furthermore, in BNBC (1993), it is stated that lifts, escalators and moving walks shall not be regarded as components of means of escape (confirmed by other standards). In addition to these, in NTPA (2013) the roof of the building is prohibited to be designated as a refuge area, whereas in some contexts of fire incidents roof of a building can use as a component. Thus, from review of the definition of means of egress in different standards, it can be said that the BNBC (1993) is been considered as the basis by other standards but Accord and Alliance (2014) provide a definition in simple phases whereas, in BNBC (draft 2018), it is more elaborate and defined.

From the comparison and analysis of standards it could be observed that among 115 issues, 37 issues of BNBC (1993) are followed by other standards (about 27% of all issues). BNBC (draft 2018) provides 11 superior issues than others. NTPA (2013) specifies 11 issues higher than others which are also followed by Accord and Alliance (2014). But most significantly, Accord and Alliance (2014) provide 56 issues which are superior to others (about 48% of all issues). Thus it can be said that among four issues compared, most of the issues for means of egress for fire are superior in Accord and Alliance (2014). In the following sections, detailed findings from comparison of the standards and the non-compliance issues are discussed.

3.3 Components of means of egress for fire: Comparison of standards and non-compliance

3.3.1 Exit doors

As an exit component, doors should have minimum fire separation rating. Regarding this issue, Accord and Alliance (2014) provide higher standard (one-hour fire rating), than NTPA (2013), which specifies that rating of fire door shall not be less than that of the minimum fire resistance rating of the walls of the smoke proof enclosure. Among analyzed factory buildings, around 58 percent buildings do not have required fire rated exit doors as stated in either NTPA (2013) or Accord and Alliance (2014). Some of the inconsistencies found in these buildings regarding exit doors include: no door installed at all in the path of egress, no fire door, some fire doors, some fire doors with no credible certificate, or some fire door but not required rating.

For total capacity, minimum width and minimum width of new exit doors, BNBC (1993) specified standards are followed by other standards. But in case of the minimum width of existing exit doors, NTPA (2013) provides higher standard compared to Accord and Alliance (2014) "...*For existing RMG buildings a performance-based determination of the width of the doorway shall be adopted, but in no case, the width of the doorway shall be less than 0.9m*...". But considering limitation for reconstruction Accord and Alliance (2014) standard is more suitable. Most of the factory buildings analyzed in this research have door widths more that the requirement.

In case of door type, BNBC (1993) specified standard is followed by other standards with slight modification in Accord and Alliance (2014). About 66.5 percent buildings do not comply with either of these standards regarding door type having glass or steel sliding, roll or collapsible steel, glass or steel swing, and glass or wooden side hinged door.

In case of consistency of space outside exit doors, BNBC (1993) is followed by other standards. According to BNBC (1993), a space of width not less than the width of the doorway shall be maintained immediately outside the doorway, and shall be at the same level as that of the floor the door serves. The standard also states that, doors shall not swing out over stairs or ramps. But for allowable swing direction Accord and Alliance (2014) and BNBC (draft 2018) adds that exit doors shall swing in the direction of egress travel. Around 9 percent buildings do not comply with any of these issues.

All of the standards state that all doors should be openable in the direction of egress. Accord and Alliance (2014) prohibits any kind of hasps, locks, slide bolts, and other locking devices to be installed in exit doors, whereas BNBC (1993) prohibits use of locking devices only with detachable key. Moreover, NTPA (2013) states that locks of any of the doors should be kept unlocked during the operational hour and should be checked regularly which is also supported by Accord and Alliance (2014). About 62.7 percent buildings have locking features installed in the doors but in most of the factories they are kept open during the operation period.

Conditions for re-entry provision for stair doors have been specified only in Accord and Alliance (2014) which is very important to ensure safe fire evacuation considering from where the fire would generate or spread. About 28.6 percent buildings do not have required re-entry provisions, e.g. no re-entry provision, not enough, or re-entry provision provided but doors remain locked.

3.3.2 Stairway

Exit stairway shall be protected by a smokeproof enclosure serving occupants located more than 23 m above the ground as per BNBC (1993) which is also supported by BNBC (draft 2018). But all the stairways should have fire rated enclosure and are required to keep free from smoke for safe fire evacuation. Thus NTPA (2013) stated that "...*all exit stairways serving occupants located above the ground floor shall be smoke proof with fire-resistant walls and door*...", which is supported by Accord and Alliance (2014). For exterior stairway, BNBC (draft 2018) only stated that "...*exterior stair shall be separated from the building interior by fire resistive assemblies or walls and are constructed by noncombustible materials and free from smoke accumulation*...". Whereas, Accord and Alliance (2014) specify fire-resisting enclosure rating and its extension based on a number of the storey which the exterior stair connects. Among 217 buildings, 21.7 percent have exterior staircase which are not separated from the building with required fire rated barrier.

BNBC (draft 2018) also specifies that "...*An exit stairway shall not be built around a lift shaft unless both of them are located in a smokeproof enclosure and made of a material with fire resistance rating required for the type of construction of smokeproof enclosure*...". It also specifies that in windowless staircases mechanical ventilation shall be installed. These issues are not mentioned in any other standards.

For total capacity, BNBC (1993) specified standards are followed by other standards, which are not followed in 8.3 percent buildings. In case of the width of new stair and landing, BNBC (1993) provides a standard which is followed by others except for BNBC (draft 2018), where the former standard is superior to later. But in case of the minimum width of existing stairways, NTPA (2013) provides compatible standard considering its limitation for reconstruction specifying "...*For existing RMG buildings a performance-based determination of the width of the staircase shall be adopted,* *but in no case, the width of the staircase shall be less than 0.9m*...". This standard is also supported by Accord and Alliance (2014). Around 5.5 percent buildings do not comply with this standard. Accord and Alliance (2014) also state that, if existing landings less than the stair width, the overall available capacity of the stair shall be reduced. In around 11 percent buildings, landings were not provided with the same width as the stairs in the direction of egress travel.

Maximum riser height specified in BNBC (1993) is supported by both NTPA (2013) and BNBC (draft 2018). But considering ease of evacuation, Accord and Alliance (2014) provide lower height which is superior to the former. In case of minimum tread, BNBC (1993) standard is supported by others. In case of allowable difference of any riser height or tread depth, BNBC (draft 2018) provides superior standard than Accord and Alliance (2014) with less tolerance. Most of the factory buildings meet the terms of this standard.

A similar standard for height of new handrails for stair is provided by Accord and Alliance (2014) and BNBC (draft 2018). But for the height of existing handrails for stair, only Accord and Alliance (2014) formulated standard, which is not complied by around 11 percent buildings. BNBC (1993) specifies that handrails shall be provided on both sides of each stairway which is followed by Accord and Alliance (2014) and NTPA (2013). It is also superior to that of BNBC (draft 2018) because here requirement of the inner handrail is defined by the width of the stair whereas inner handrail is necessary in the factory buildings irrespective of the width of stair to prevent fall down of people while evacuating. About 56 percent buildings do not have consistency of handrail, e.g. handrails not provided on both sides of the stairs, handrails provided on both sides of stairways except the landings, or handrails provided on both sides of the stair in some part but not all through the stairway. Conditions for the requirement of intermediate handrails for stair is similar for BNBC (1993) and BNBC (draft 2018), which is also followed by other standards. Very few of the factory buildings do not have intermediate handrail though they require one.

To ensure proper functionality of the stairways during a fire evacuation, BNBC (1993) states that all the exit stairways should be accessible, which is supported by other standards. Additionally, Accord and Alliance (2014) state that interior exit stairways shall terminate at an exit discharge or an exit passageway, which has not been maintained in about 25.3 percent buildings. BNBC (1993) states that the exterior stairway shall not be considered as a means of exit unless they lead directly to the ground, which is supported by other standards. All the factories comply with this standard.

3.3.3 Ramps, corridor, aisles and ramped aisles

For separation of exit access corridors, though BNBC (1993) provides higher standard specifying one-hour fire rating wall for all the cases, Accord and Alliance (2014) provide more specific standard depending on occupant load and availability of automatic sprinkler system. BNBC (draft 2018) states that exit corridors shall not be designed or used as components to supply or return air. Around 15.7 percent buildings do not act in accordance with this issue.

Only Accord and Alliance (2014) provides a standard for a minimum width of aisles which has not been complied in 17.5 percent factory buildings. For the total capacity of ramps, corridor and ramped aisles, BNBC (1993) specified standards are followed by other standards. Only BNBC (draft 2018) provides a standard for the length of these components. Minimum width of ramps, corridor and ramped aisles is similar in all the standards. BNBC (1993) specifies width based on occupancy load which is more specific though it is less superior to others. Most of the buildings comply with these issues.

The allowable slope for the ramp is superior in Accord and Alliance (2014) as it allows lower slope. Only Accord and Alliance (2014) provides a standard for slope of existing ramp, which is not complied in 7.8 percent buildings. Only BNBC (draft 2018) states that "...*Landing shall be at least as wide as the ramps and shall be placed at the bottom, at intermediate levels where required, and at the top of all ramps*...". Accord and Alliance (2014) specify that handrails shall be provided on both sides of each ramp which is superior to other standards. Only Accord and Alliance (2014) states that ramps shall terminate at an exit discharge or an exit passageway. Most of the buildings meet the terms of these issues.

3.3.4 Exit passageway

Only Accord and Alliance (2014) states that exit passageways shall meet the same rating requirement as the exit that is being served, shall be considered an extension of the stairs and shall not be used for any other purpose. Rated exit passageway is not provided in around 21.2 percent factory buildings. Accord and Alliance (2014) and BNBC (draft 2018) states similar standard for exit passageway termination stating that they shall terminate at an exit discharge, which is not maintained in about 19.8 percent buildings.

3.3.5 Exit discharge

Statement of BNBC (1993) and Accord and Alliance (2014) are similar for termination of exit discharge, which is also supported by other standards. This issue is not complied in almost 33.2 percent buildings. Accord and Alliance (2014) state other standards for exit discharge regarding re-entry provision, fire separation, opening condition and conditions for interior building exit discharge.

3.4 Condition of means of egress for fire: Comparison of standards and non-compliance

3.4.1 Exit enclosure

Accord and Alliance (2014) provide superior general fire separation standard for exits based on a number of storey, which is not complied in around 7 percent buildings. It also provides standards for opening and penetration into and from exit enclosure, where about 11 percent buildings have noncompliant opening into exit enclosure. For door assemblies opening on to the means of egress, BNBC (1993) specified standard (at least 20 minutes fire resistance) is followed by other standards. Among analyzed factory buildings, 13.4 percent buildings do not comply with this standard.

3.4.2 Number and arrangement of exits

BNBC (1993) provides standard for a minimum number of staircases and number of means of egress from any floor, story or portion thereof based on the number of storey and occupant load which is followed by other standards with slight modification in Accord and Alliance (2014) and BNBC (draft 2018) for single exit condition. Minimum requirement of exit is defined by NTPA (2013) which is followed by Accord and Alliance (2014). For more than one exits, their arrangement is important to ensure access to all the occupants. Though BNBC (1993) specified a standard for the arrangement of exits is followed by NTPA (2013) and BNBC (draft 2018), Accord and Alliance (2014) provide more detailed and specified standard considering the condition whether there is automatic sprinkler system or not.

3.4.3 Distance

Travel distance means straight line distance between the remotest point of an area of the incident and the entrance point of a separated area as per BNBC (draft 2018). NTPA (2013) and BNBC (draft 2018) provides superior standard for maximum travel distance based on the availability of automatic fire detection system, portable fire extinguishers, and standpipe system. On the other hand, Accord and Alliance (2014) provide a standard for the maximum length of the common path of travel considering the condition whether there is automatic sprinkler system or not. BNBC (1993) provides a superior standard for the maximum length of the dead-end corridor.

3.4.4 Walking surface

Accord and Alliance (2014) and BNBC (draft 2018) provides a similar standard for levels of walking surfaces and changes in level. BNBC (draft 2018) provides additional standard for steps in walking surface. Accord and Alliance (2014) provide a higher standard for changes in elevation with lower allowable change. About 20 percent factory buildings are non-compliant regarding this issue. Accord and Alliance (2014) provide a superior standard for slip resistance stating that walking surfaces stating that stairway treads shall be uniformly slipping resistant, but in some of the buildings glassy tiles have been used with no slip resistant measures.

3.4.5 Reliability

All the issues of BNBC (1993) regarding reliability are addressed by other standards. According to these issues, about 22 percent buildings are non-compliant because egress path in these buildings is obstructed and interfered by alternate uses. In addition to these issues, Accord and Alliance (2014) specifies that the capacity of the means of egress shall not be reduced along the path of travel, which has not been maintained in 6 percent buildings. It also addresses issues related to visibility obstruction and BNBC (draft 2018) provides standard for accessibility of the exits. All paths of egress shall be provided with illumination as per Accord and Alliance (2014), which has not been maintained in 25 percent buildings. Moreover, according to this standard, all occupiable roofs shall be provided with parapets or guards with a minimum mentioned height, which has not been provided in around 21 percent buildings.

3.4.6 Occupancy load

In case of minimum space requirement for each occupant, NTPA (2013) provides a superior standard, whereas Accord and Alliance (2014) allow an increase of occupant load if all other means of egress requirements for that higher occupant load are met. It also mentions that occupant load should be posted at appropriate locations in the building. In almost 70 percent factory buildings, occcupant load information is not posted in any floor as per standard.

3.4.7 Marking and signage

All the issues of BNBC (1993) regarding marking and signpost and sign illumination are addressed by other standards. Additionally, Accord and Alliance (2014) state that floor entrance from the stair, stair name and floor name and door location shall be provided accordingly. About 40 percent factory buildings do not have required markings and signpost. About 58 percent buildings do not have stair designation sign, whereas 47 percent buildings do not have floor designation sign. Additionally, about 34.6 percent buildings do not have required directional signs where there is a change in the direction for the path of travel and the direction to an exit is not obvious.

According to Accord and Alliance (2014), signs should be provided with appropriate language (English and Bengali) and graphics, which have not been provided in about 17.5 percent buildings. Moreover, according to this standard, all lighted exit signs shall be provided with either battery backup or emergency power to keep them continuously illuminated, which has not been complied in 26 percent buildings.

In addition to these issues, BNBC (draft 2018) states that presence and location of steps or ramps in the walkways shall be readily apparent, and similarly Accord and Alliance (2014) state that changes in slope or elevation shall be marked. But about 15 percent of the buildings do not have required marking indicating changes in slope or elevation.

4. Conclusion

From the above discussion, it can be observed that BNBC (1993) standard has been considered as the basis for other standards. This standard is not in line with modern fire safety concepts.

Therefore, it was considered an insufficient basis for the inspections that were carried out in the wake of the fire at Tazreen Fashion. Thus, NTPA (2013) and Accord and Alliance (2014) added upgraded issues. BNBC standard has also been improved and in some cases upgraded in BNBC (draft 2018). But among these standards, Accord and Alliance (2014) provide most superior standards compared to others. The difference among the standards is alarming. The reason is that the final findings of the factory buildings are compared at national level considering all factories under all initiatives together. Such comparison may remain inconsistent because some factory buildings may have been identified safe under one initiate considering a certain fire safety issue and in contrary in the same condition for the same safety issue other factory building may have been identified non-compliant under another initiative.

In case of compliance issue, factory buildings do not comply with BNBC (1993) standard. Thus, automatically they remain non-compliant to Accord and Alliance (2014). The most important non-compliance issues observed in means of egresses in the factory buildings are: noncompliant fire resistance of exit doors with improper type and locking features, non-compliant exterior stair, handrail not provided in both sides of stairways, improper termination of stairways and exit passageways, slippery walking surface, obstructed egress path hampering continuity, lack of proper illumination in egress path, unprotected rooftop, absence of occupancy load posting, and insufficient marking and signage with insufficient illumination.

The findings of this study will enable policymakers to understand the differences among the standards based on which the factory buildings have been assessed. This will encourage them to take initiative to work together to make a single and efficient standard for all. Additionally, the non-compliant fire evacuation safety issues in RMG factories in Bangladesh related to means of egress that have been identified in this study will help policymakers to understand the issues which have been mostly ignored by the factory owners. This will help them to take necessary initiatives to ensure compliance in regard to these issues.

In this research only means of escape component of fire safety has been considered. Moreover, this research could not consider the whole document of the standards. So if there are some issues mentioned in other chapters of the considered standards, then they have not been considered here. In future, this study will be extended to other portions of the issues related to fire safety considering other components. After that, a complete scenario can be established. Further analysis is required to analyze the components of means of egress.

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PART-IV

INTERPRETATION OF GEOTECHNICAL PARAMETERS FROM CPT AND SPT FOR THE RECLAIMED AREAS OF DHAKA, BANGLADESH

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1 INTRODUCTION

Soil sampling combined with laboratory testing is the most reliable method to determine soil properties. Sometimes due to limited budgets, tight schedules, or lack of concern, projects do not receive proper laboratory recommendation. However, in many cases subsoil investigation data like SPT blow count or CPT cone resistance and sleeve friction along with soil type and depth of water table are available to judge the subsurface soil characteristics. Therefore, when laboratory data are not available it is common practice to estimate the soil properties from the SPT-CPT results. Many empirical correlations have been created between the SPT N-value and CPT cone resistance with other engineering properties of soils. But due to variability of soil properties for same type of soil from place to place it is very difficult to predict the outcome of those relations without justifying them for local soil. The local soil may follow previous correlations with slight deviation or may not follow the trend at all. For the latter case new correlations for local soil must be provided to fulfill the above-mentioned purpose.

The Standard Penetration Test (SPT) is the most common in situ test for site investigations in Bangladesh and most of foundation designs have been based on SPT-N values and physical properties of soils recovered in the SPT sampler. The SPT has some disadvantages such as potential variability of measured resistances depending on operator variability and possibility of missing delicate changes of soil properties owing to the inevitable discrete record. Around the world the Cone Penetration Test (CPT) is becoming increasingly popular as an in-situ test for site investigation and geotechnical designs, especially in deltaic areas since it provides a continuous record which is free from operator variability. For economic consideration it is unlikely that both CPT and SPT are done for investigation. So, it is important to establish correlation between soil parameters individually with CPT and SPT along with interrelation between these investigation methods.

2 FIELD INVESTIGATIONS

2.1 General

Field investigations were carried out mainly through the application of cone penetration testing (CPT) and standard penetration testing (SPT). A total of six pairs of CPT and SPT were performed in different locations within the study area and each pair of CPT and SPT was carried out as close as possible; the maximum horizontal distance was not greater than 1m. In this research, field investigations were carried out in Uttara Residential Model Town (3rd Phase), Dhaka, Bangladesh as shown in Figure 1.

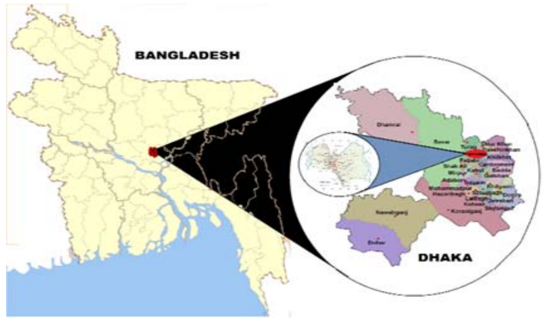

Fig 1: Study location

The geologic formations of the research site are mainly consisting of alluvial silt and clay. The alluvial silt and clay part has medium to dark grey silt; the color is darker as amount of organic material increases. A combination of alluvial and paludal deposits has been observed there including flood-basin, back swamp silty clay, and organic rich clay in sag ponds and large depressions. Some depressions contain peat. Large areas underlain by this unit are dry only a few months of the year; the deeper part of depressions and bils contain water throughout the year.

2.2 Cone Penetration test

CPT soundings were advanced using a Hogentogler type piezocone penetrometer with a cross sectional area of 10 cm^2 and which can measure the pore water pressure (u_2), as well as the cone tip resistance (q_c) and sleeve friction (fs). To perform the test, the cone was pushed vertically into the ground at a constant rate of approximately 20mm/sec. During the advancement, measurements of dynamic pore water pressure, tip resistance and sleeve friction were recorded continuously at 10 mm depth increments. The typical penetration depth for this study was approximately 12-14 m below the ground surface.

2.3 Standard Penetration test

SPT were conducted according to ASTM D1586. Boreholes for the SPT were advanced by wash boring. The split spoon sampling method was used to obtain soil samples from boreholes and disturbed representative samples were collected. Samples recovered from boreholes were stored in plastic bags which were used for laboratory testing. Potential source of uncertainty which may affect SPT N-value has been carefully taken into account. Borehole drilling, soil sampling and SPT N-value recording procedures were observed by an experienced geologist during the entire test program and this individual provided visual descriptions of the collected samples. The SPT N-value and samples were every .45 m intervals. Rope and cathead SPT hammer-release was used and the efficiency of the hammer was 60%. The corrected tip resistance (q_{c1}) and corrected SPT value $N_{1,60}$ values are presented in Figure 2.

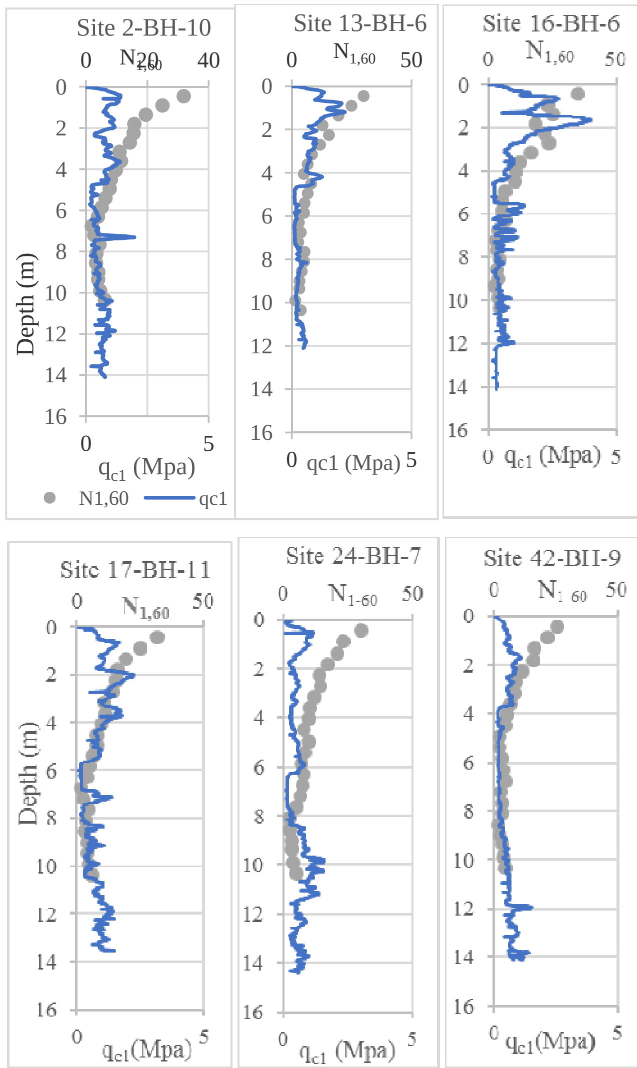

Figure 2. Depth versus corrected cone tip resistance (q_{c1}), SPT N_{60} and $N_{1,60}$ values for all boreholes

Based on the results of the subsurface explorations, the subsoil profile at the study area can be divided into three strata. The soil primarily comprised fine sand and silt clay particles. The top layer consists of light grey to grey medium to loose fine sand trace mica with a total thickness of approximately 4.75 m to 7.5 m. Immediately below this layer, a layer of dark grey silty clay with organic matter is extended to a depth of 7.65 m to 9.45 m. The bottom layer consists of high plastic grey medium stiff clay or medium plastic soft to medium stiff clay up to the depth of 10.35 m. Ground water table is located at 2.3-2.7 m below EGL. There was considerable variability in the measured SPT N-value in different boreholes at different depths, ranging from 2 to 18 and the maximum corrected cone tip resistance (q_{c1}) was close to 4 MPa.

3 LABORATORY INVESTIGATIONS

3.1 Sieve Analysis

Soil samples recovered from different bore holes were individually assessed and classified based on dry sieve analysis according to ASTM C136. There is appreciable amounts of fines (fc) ranging from 2.3 to 96.4 %, fineness modulus ranging from 0.02 to 1.02 and mean grain size (d_{50}) ranging from 0.12 to 0.19 mm. Based on the sieve analysis results, the soils are generally classified into two groups; either well graded sands with little silt or poorly graded sands with silt. According to the unified soil classification system, the soils can be symbolized as SW and SP-SM, respectively. The mean grain size (d_{50}), fines content (fc) for all six boreholes are given below:

Table 1: Sieve Analysis Results

Depth	Borehole 2-10		Borehole 13-16		Borehole 16-6	
m	d_{50}	fc	d_{50}	fc	d_{50}	fc
0.45	0.14	5.3	0.2	10	0.2	7.1
0.9	0.14	10	0.2	8.1	0.2	12.7
1.35	0.14	7.3	0.2	8.8	0.2	13.3
1.8	0.14	10	0.2	8.6	0.2	9.8
2.25	0.14	6.8	0.2	5.6	0.2	14.6
2.7	0.15	7.2	0.2	6.9	0.1	18.4
3.15	0.14	7	0.2	7.1	0.1	17.4
3.6	0.15	4.2	0.2	7.6	0.1	16.6
4.05	0.15	6.3	0.2	6.8	0.2	15.2
4.5	0.15	3.1	0.2	6.4	0.1	19.9
4.95	0.14	8.1	0.2	6	0.2	8.7
5.4	0.17	10	0.2	6.9	0.2	6.3
5.85	0.12	2.3	0.2	6.8	0.2	5.3
6.3	ND*	13	ND*	29	ND*	8.3
6.75	ND*	91	ND*	29	ND*	69.1
7.2	ND*	ND*	ND*	ND*	ND*	ND*

Depth	Borehole	Borehole	Borehole 42-9

	17-11		24-7			
m	d_{50}	fc	d_{50}	fc	d_{50}	fc
	mm	%	mm	%	mm	%
0.45	0.15	4.8	0.2	5.6	0.16	14
0.9	0.17	3.4	0.2	5.6	0.16	15
1.35	0.17	6	0.2	4.1	0.14	15
1.8	0.16	8.6	0.2	3.4	0.15	9.5
2.25	0.17	10	0.2	3.7	0.14	7.1
2.7	0.17	9.9	0.2	2.9	0.14	16
3.15	0.17	9.8	0.2	3.4	0.14	9.2
3.6	0.17	8	0.2	3.4	0.14	8.2
4.05	0.17	8.2	0.2	3.9	0.15	7.1
4.5	0.16	8.9	0.2	7.2	0.16	16
4.95	0.17	8.6	0.2	3.6	ND*	53
5.4	0.15	11	0.2	3.4	ND*	79
5.85	0.13	14	0.2	3.9	ND*	79
6.3	ND*	53	0.2	4	ND*	79
6.75	ND*	96	0.2	11	ND*	79
7.2	ND*	96	0.2	8.8	ND*	79

3.2 Direct shear test

Direct shear testing was done per ASTM standard D-6528, "Standard Method for Direct Simple Shear Test on Soils under Consolidated Undrained Conditions". The internal friction angle and shear strength for different bore holes are summarized below in the table.

Table 2: The internal friction angle and shear strength for different bore holes

Sample	Shear strength (c_u)	Internal friction angle (φ)
No	kPa	Degree(°)
BH 2-10	14.8	11
BH 13-6	20	30
BH 17-11	25	32
BH 24-7	41	20
BH 42-9	22	19

3.3 Unconfined compression test

Unconfined compression tests on four remolded sample were done as per ASTM D 2166 - Standard Test Method for Unconfined Compressive Strength of Cohesive Soil. As for the results, the axial stress was plotted versus the axial displacement. The maximum axial stress, or the axial stress at 15% axial strain if it occurs earlier, was reported as the unconfined compressive strength σ_c. The undrained shear strength was obtained as $c_u = \sigma_c / 2$

Table 3: Undrained shear strength obtained for different bore holes

Sample No	BH 2-10	BH 17-11	BH 24-7	BH 42-9
c_u kPa	27.58	39.44	28.75	23.17

4 Results Comparison and Discussions

In this Section, comparisons between soil parameters obtained from field investigation results and parameters directly obtained from laboratory tests are illustrated. Existing correlations will be used to obtain different soil parameters from SPT and CPT results to justify their applicability for local soils and new correlations will be proposed if local soils show deviation maintaining a particular pattern.

4.1 Correlation between CPT Cone Resistance q_c and SPT blow count N_{60}

Three approaches have been taken here to correlate CPT cone resistance ($q_{c)}$ and SPT blow count ($N_{60)}$ based on three different soil parameters, Mean grain
size (d_{50}), Fines content (f_c) and Soil Behavior Index (I_c). Also, an approach to establish a direct linear relationship between normalized cone resistance q_{c1} and $N_{1,60}$ has been made in this study.

A total of 75 data points for the sand deposits from the 6 boreholes presented in Table 1 were selected for this study to perform comparative analysis with mean grain size (d_{50}) and percent finer (fc) based on CPT-SPT correlations. In the case of Soil Behavior index I_c based correlations, I_c was determined for all the boreholes using the equation provided by Robertson (1990),

$$\mathrm{ISBT} = [(3.47 - \log(qc/pa))\char`^2 + (\log \mathrm{Rf} + 1.22)\char`^2]\char`^0.5$$

(1)

Calibrations were performed on recorded cone tip resistance data to eliminate pore pressure effect on tip resistance by a calibration factor of 0.32, as provided by the cone manufacturer to get normalized cone tip resistance q_{c1}. Furthermore, the cone tip resistance was normalized to an overburden stress level of 100 kPa. The SPT energy corrections and overburden pressure corrections were applied to the recorded field N-values to calculate $N_{1,60}$. It should be noted that, in this study the same CPT equipment and SPT rig were used in all tests to minimize inherent test variability.

All the bore holes had similar type of variation in behavior index(I_c) and it reached a peak value of about 5 to 4 in all the bore holes at a depth greater than 5m. Calculated CPT based Ic was plotted against the ratio of CPT cone resistance q_c to SPT blow count N_{60} [q_c/N] and compared to the existing correlation between q_c/N and I_c provided by Jefferies & Davies (1993) which was modified by Robertson and Wride (1998) and Robertson(2012). Fig 3 shows that the average linear trend line of the plotted study data is close to the existing correlations. The q_c/N ratio for selected data points varies from 0.6 to 10 with a variation of SBT index from 1.9 to 3.9 whereas existing correlations suggest that with similar a variation of SBT index q_c/N has a range of 1 to 5. From the graph, we can see the number of data points showing deviation is much less and about 85% of the data points fall within the range of existing correlations. So, we can conclude that CPT data are reliable to calculate the SBT index and also that SBT indices based CPT-SPT correlations are fairly applicable for the local soil.

Mean grain size (d_{50}) based correlations illustrated by Robertson et al. for north American soil (1983), Burland and Burbidge for London soils (1985), Kulhawy & Mayne for soils of California (1990), Canadian foundation engineering manual (Canadian Geotechnical Society 1992) and Anagnostopoulos for Greek soils (2003) are shown in Figure 4. The data sets selected for this study are plotted on the same figure to evaluate the applicability of these correlations to the local soils. q_c/N_{60} ratio of selected data set are less scattered and varies from 1-11 for a variation of d_{50} from .14-.19 mm and surprisingly 71.4% of the data fall within the range of existing co-relationships. The upper and lower range for the study soil was provided using regression analysis. The proposed upper range nearly coincides with the upper range of Robertson et al (1983). The available correlations prove to be useful for the local soil.

The fines content based correlations proposed by Chin et al. (1988) and Kulhawy & Mayne (1990) are presented in Figure 5 along with collected data sets of this study. The collected data sets showed a poor fit to the fines content based correlations and cannot substantiate a general trend between fines content and q_c/N ratio. There exists a range of q_c/N ratio for the same value of fines content.

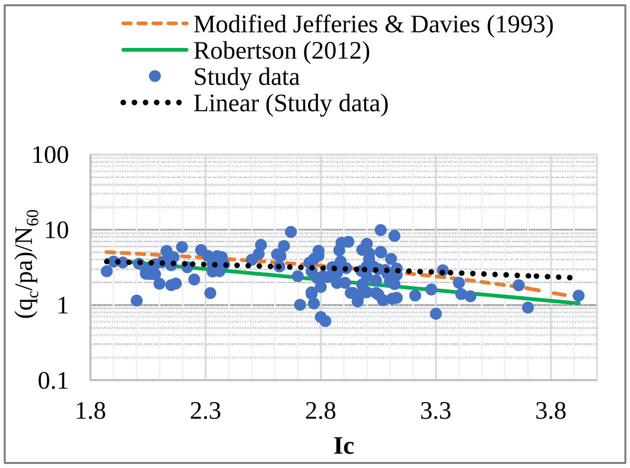

Figure 3: (qC/pa)/N60 Vs CPT-based SBT index Ic comparison with existing correlations

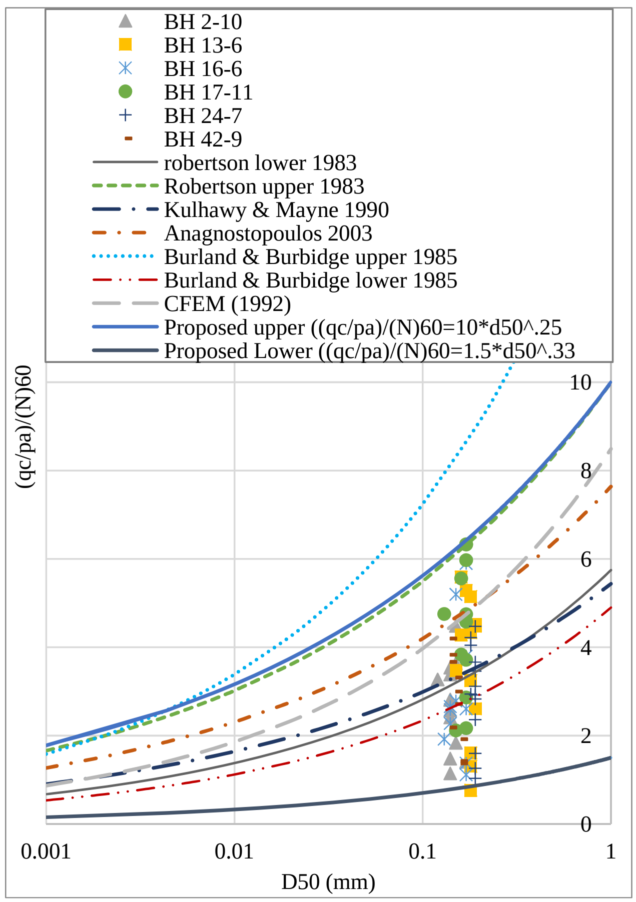

Figure 4: Variation of ratio $(q_c/pa)/N_{60}$ with mean grain size, d_{50} comparison

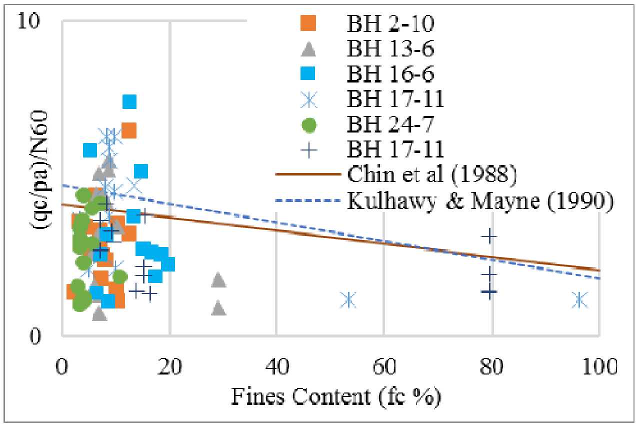

Figure 5: Variation of ratio $(q_c/pa)/N_{60}$ with Fines content, f_c comparison

Figure 6 compares the measured data with the single value of $q_{c1}/N_{1,60}$ ratio of 0.45 suggested by Elbanna et al. (2011) for sands. The plotted data shows significantly lower values than the average value of 0.45 as the study soil was not pure sand, but they show a similar linear relationship and nearly maintain a $q_{c1}/N_{1,60}$ ratio of 0.0569. It is believed that the proposed correlation between normalized cone tip resistance and normalized SPT $N_{1,60}$ can serve as a better relationship for the local soils. The main advantage of this relationship is that it can be used in the absence gradation results. Therefore, there is a need to collect additional high-quality CPT and SPT data to develop a better relationship.

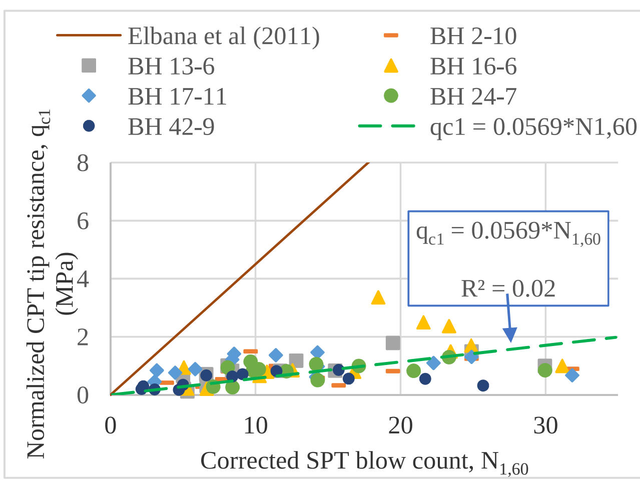

Figure 6: Variation of normalized cone tip resistance (q_{c1}) with normalized SPT blow count $N_{1,60}$ comparisons.

4.2 Correlation of SPT with undrained shear strength Su or c_u

Shear strength obtained from laboratory tests were compared with shear strength obtained from SPT based correlation provided by Kulhawy and Mayne (1990). From Table 4 it may be observed that three out of four unconfined compression test results coincide with SPT derived shear strength but direct shear test results show deviation. This is mainly because Kulhawy and Mayne established the empirical correlation between SPT and undrained shear strength for pure clay sample based on unconfined compression test results. Besides the direct shear test is suitable for fine grained soil not pure clay. A slight variation in moisture content can significantly affect direct shear test. Only a single compaction test was done to determine the optimum moisture content for all the sample remolding. Thus, some samples may have a moisture content more than necessary which may cause the deviations.

Table 4: Comparison of shear strength parameter (c_u) from laboratory test results with SPT based shear strength

Sample No	Unconfined Compression test (kPa)	Direct Shear test (kPa)	SPT N_{60}	Kulhawy &Mayne (1990) (kPa)
BH 2-10	27.58	14.8	5	30.40
BH 13-6	ND	20.1	4.38	26.6
BH 17-11	30.44	25	5	30.4
BH 24-7	28.75	41	4.57	27.78
BH 42-9	23.17	22	3.87	23.53

Unconfined compression test results were plotted against SPT on the same graph with relationship provided by Kulhawy-Mayne (1990)

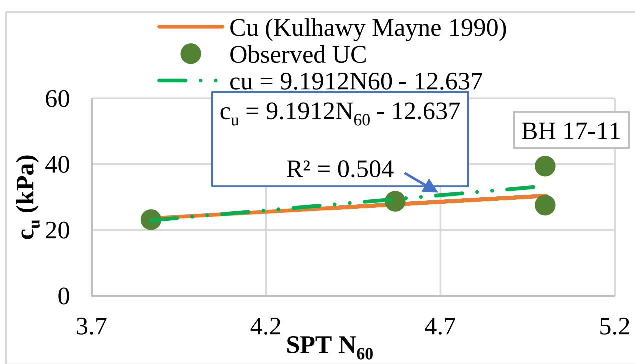

Figure 7: c_u Vs SPT blow count N_{60}curve for comparison of unconfined compression test results

From figure 7 we see that only Shear strength obtained from the sample of BH 17-11 shows deviation, yet the mean line of unconfined compressive results was very close to that of Kulhawy and Mayne and has a R^2>0.3 which ensures good applicability of this correlation for local soil.

4.3 Correlation of CPT with undrained shear strength Su or c_u

Shear strength obtained from direct shear test and unconfined compression test were compared with shear strength obtained from CPT based correlation provided by Robertson (2012).

Table 5: Comparison of shear strength from laboratory test results with CPT based shear strength

Sample No	UC (kPa)	DS (kPa)	qc (kPa)	$Cu=(q_c-\sigma_{vo})/N_{kt}$ (Robertson 2012) (kpa)
BH 2-10	27.58	14.8	310	13
BH 13-6	ND	20.1	310	15
BH 17-11	39.43	25	730	35
BH 24-7	28.75	41	650	36.55
BH 42-9	23.17	22	597	29.32

We observe from Table 5 that with a variation of q_c from 310 to 730 kPa the existing correlation gives a c_u range of 13 to 29 kPa where laboratory test results give a c_u range of 23.17 to 39 kPa for Unconfined compression test and 14.8 to 41 kPa for direct shear test.
Both laboratory test results were plotted against SPT on the same graph with relationship provided by Robertson (2012) to justify the applicability this correlation to local soils.

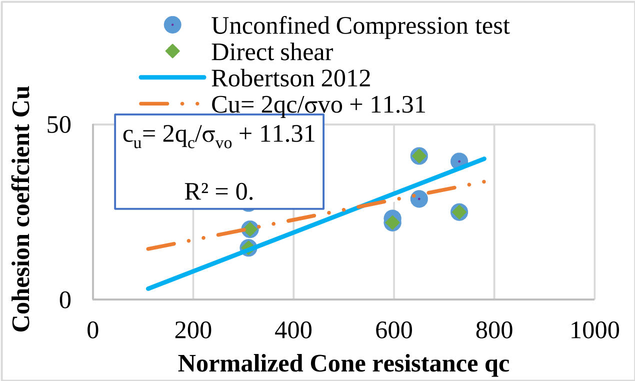

Figure 8 : c_u Vs CPT cone resistance qc curve for comparison laboratory test result

The study data points follows a similar linear pattern as correlation stablished by Robertson (2012) but better suits with $c_u = 2q_c/\sigma_{vo} + 11.31$ rather than $c_u = (q_c - \sigma_{vo})/N_{kt}$. The proposed correlation has $R^2 > 0.3$ and has a scope of development when large amount of data points are available.

5 CONCLUSIONS

This paper presents that developed correlations for q/N_{60} with d_{50} and I_c show good applicability to local soils whereas available relationships between q/N_{60} and Fine content do not fit them well. New correlation ranges $(q_c/p_a)/(N)_{60} = 1.5d_{50}^{0.33}$ to $10d_{50}^{0.25}$ have been proposed. Moreover, the CPT and SPT data used for this study better suit with $(q_{c1}/N_{1,60})$ ratio of 0.0569 instead of 0.45 proposed by Elbana (2011). A comparative analysis of Laboratory obtained shear strength parameter (c_u) and parameter obtained from existing correlations have been done in this study. Interpretation of soil shear strength parameters from both CPT and SPT data shows great potential. Two new correlations $Cu = 9.1912N_{60} - 12.637$ and $Cu = 2q_c/\sigma_{vo} + 11.31$ has been proposed for local soil. Yet, the available data sets which exist for the study area falls within a relatively narrow range for developing good correlations.

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PART-V

INTERPRETATION OF SOIL STRATIGRAPHY AND GEOTECHNICAL PARAMETERS FROM CPTU AT BHOLA, BANGLADESH

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Mehedi Ahmed Ansary

INTRODUCTION

Soil Investigations has evolved to improve understanding of soil type, stratigraphy and its strength and sustainability as a structural element or a resisting element in facing erosion. The Standard Penetration Test (SPT) is widely employed in-situ test. Even though there have been many attempts to standardize the SPT process, it is still a problem for geotechnical engineers to gather reliable and repeatable SPT results. A significant experience related to the design methods from the local SPT correlation has been built. However, in future, it is expected that more CPT will be performed thus improving local experience and the reliability of site investigation data. However, until a reliable CPT database has been created, it is necessary to be able to correlate between SPT and CPT in order to use SPT-based data that already exist.

The Cone Penetration Test (CPT) has become a significantly popular in-situ test to do site investigation and do geotechnical design. It is useful for stratigraphy delineation and continuous fast record of parameters such as cone tip resistance (q_c) and sleeve friction (f_s). The merits of the CPT are the repeatability, continuous measurement, and simplicity (Robertson et al, 1983).

In this study an approach has been taken to obtain soil profile based on cone tip resistance(q_c), friction ratio (R_f), Soil behavior index (I_c) and pore water pressure (u) to depths up to 30 m. SPTs tests have been done in the same location (within 2m to 3m of CPT locations) to interpret Geotechnical parameters such as grain size, fines content and behavior index from available CPT-SPT based correlations. Also, an approach has been taken to interpret SPT blow count (N_{60}) from CPT cone tip resistance (q_c). Interpreted results have been compared with laboratory obtained results and new correlations have been proposed where laboratory obtained data deviated from existing correlations.

FIELD INVESTIGATIONS

General

Field investigations were carried out mainly through the application of Cone Penetration Testing (CPT) and Standard Penetration Testing (SPT). A total of three pairs of CPT and SPT were performed in different locations within the study area and each pair of CPT and SPT was carried out as close as possible (SPT were performed within 2m to 3m of CPT locations), maximum horizontal distance between each CPT locations was not greater than 500m. In this research, field investigations were carried out in Charfasson, Bhola, Bangladesh as shown in Figure 1.

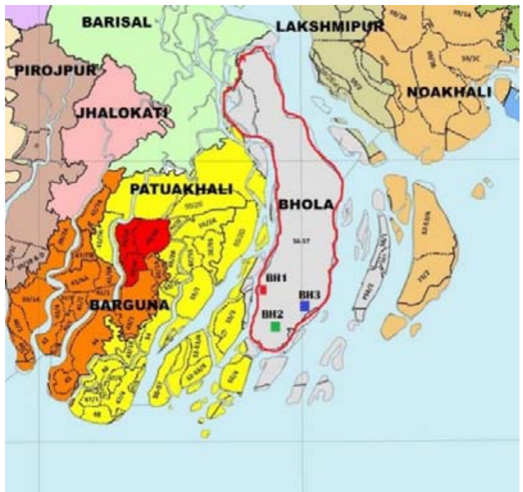


Figure 1: Study location

The geologic formations of the research site are loamy to clayey, calcareous and poorly drained. Calcareousness decreases from west toward east of the Meghna confluence while the silt content in soil decreases both toward the east and the west of Bhola district.

Cone Penetration test

CPT soundings were advanced using a Hogentogler type piezocone penetrometer with a cross sectional area of 10 cm^2 and which can measure the pore water pressure (u_2), as well as the cone tip resistance (q_c) and sleeve friction(fs). To perform the test, the cone was pushed vertically into the ground at a constant rate of approximately 20mm/sec. During the advancement, measurements of dynamic pore water pressure, tip resistance and sleeve friction were recorded continuously at 10 mm depth increments. The typical penetration depth for this study was approximately 28-32 m below from ground surface.

Standard Penetration test

SPT were conducted according to ASTM D1586. Boreholes for the SPT were advanced by wash boring. The split spoon sampling method was used to obtain soil samples from boreholes and disturbed representative samples were collected. Samples recovered from boreholes were stored in plastic bags which were used for laboratory testing. Potential source of uncertainty which may affect SPT N-value has been carefully taken into account. Borehole drilling, soil sampling and SPT N-value recording procedures were observed by experienced geologist during the entire test program and this individual provided visual descriptions of the collected samples. SPT N-value and a sample were taken at every 0.45 m intervals. Rope and cathead SPT hammer-release was used and the efficiency of hammer was estimated to be 60%.

SOIL STRATIGRAPHY

Based on the results of the subsurface explorations, the subsoil profile at study area can be divided into three strata. The soil within the test area is primarily comprised of grey medium stiff to stiff clayey silt of medium plasticity with traces of fine sand and loose to medium dense fine sand with trace of silt and mica. The soil strata of borehole 1 and 3 are interbedded with the aforementioned two types of soil whereas borehole 2 is single layered comprising only grey medium stiff to stiff clayey silt. The ground-water table is located 4.5 m below from EGL in all the boreholes. Note that, there was considerable variability in the measured SPT N-value between boreholes, at different depths ranging from 3 to 16 and maximum corrected cone tip resistance (q_{c1}) was close to 12 MPa.

CPT-SPT profile

Cone Tip resistance q_{c1} (normalized) and SPT blow count N_{60} and $N_{1,60}$ (normalized) have been plotted along with depth for all three bore holes. It observed that q_{c1} varies from 0.5 to 12 MPa and peak values are reached below 15m depth. SPT blow count N_{60} varies from 3 to 16. On Figure 2, it may be observed that CPT and SPT values seems to be proportional in most of the cases.

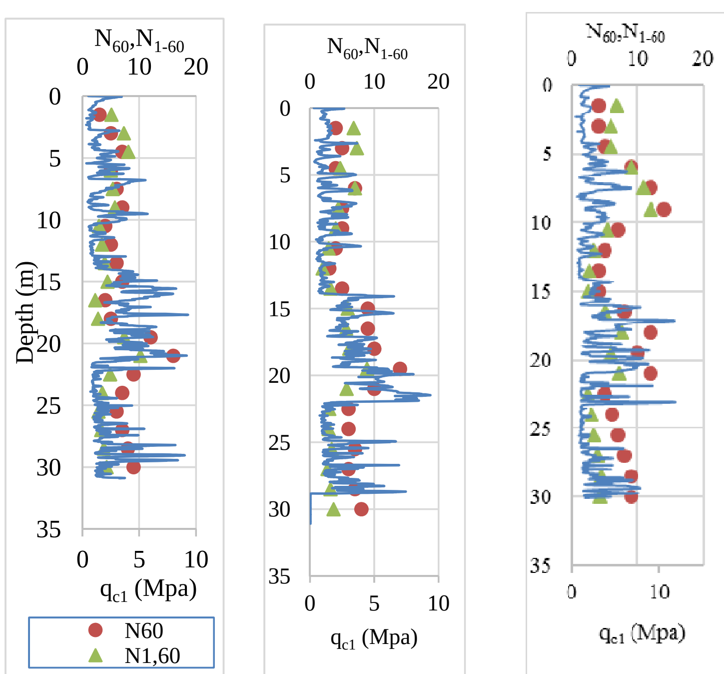


Figure 2: CPT-SPT profile of Borehole 1, 2 and 3 respectively

SBT profile

Soil Behavior index I_c was determined for all the boreholes using the equation provided by Robertson (1990)

$I_{SBT}= [(3.47 - \log(qc/pa))^2 + (\log Rf + 1.22)2]^{0.5}$

All the boreholes have similar trends of variation in behavior index(I_c) and varying from 0 to about 3.5 for all the boreholes.

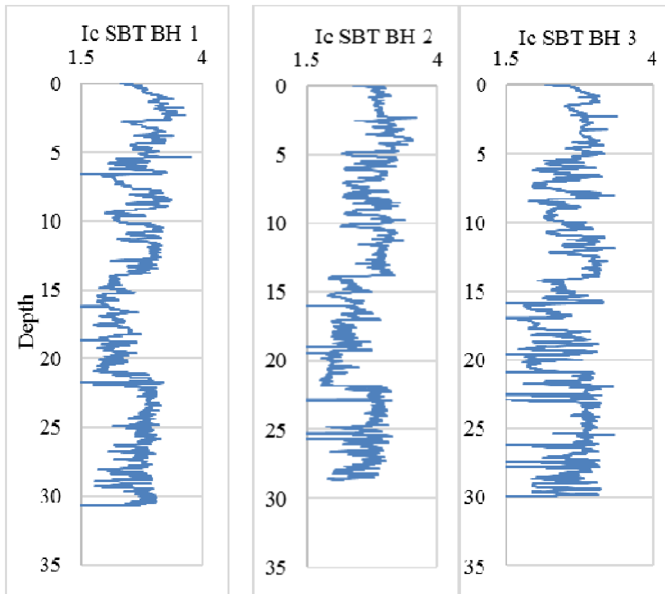


Figure 3: SBT profile for all the bore holes

Variation of friction ratio

Friction ratio (Rf or f_r) is defined as the ratio of sleeve friction (fs) to cone tip resistance (q_c)

Rf %= $100*f_s/q_c$

Friction ratio of all three boreholes has similar pattern and most cases it varies between 0 to 5. The peak value of friction ratio for all three bore holes varies from 9 to 12.

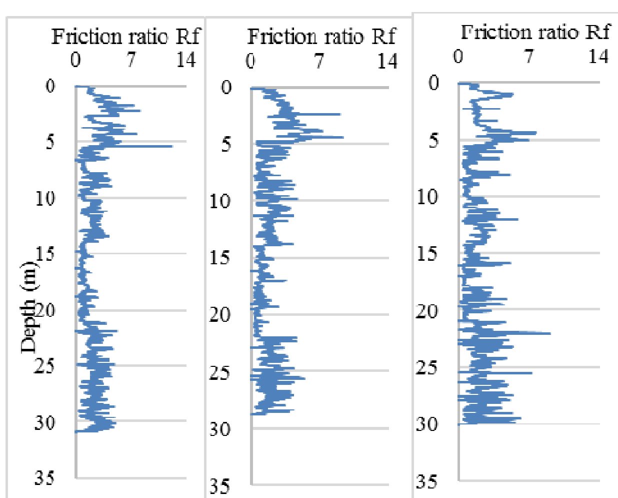


Figure 4: Variation of friction ratio with respect to depth

Variation of pore pressure

Pore pressure varies from 0 to 0.4 MPa bellow 20m depth and suddenly increases up to 0.85MPa after 20m. All three boreholes show similar var

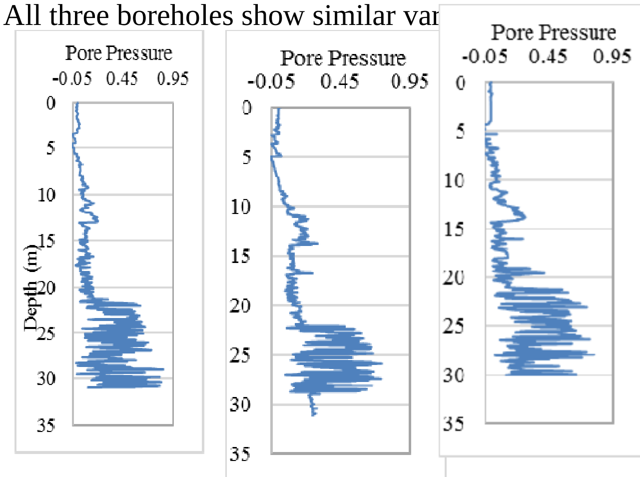


Fig 5 : Variation of pore pressure with respect to depth for all three bore holes

LABORATORY INVESTIGATION

4.1 Sieve Analysis

Soil sampled recovered from the three boreholes were individually assessed and classified based on dry sieve analysis. Sieve analysis was performed according to ASTM C136 on 20 disturbed soil sample from 3 boreholes. These soils contain reasonable amounts of fines (fc) ranging from 5 to 26%, fineness modulus ranging from 0.49 to 1.36 and mean grain size (d_{50}) ranging from 0.14 to 0.25.

Table 1: Soil Gradation chart

Depth	Bore hole 1		Bore hole 2		Bore hole 3	
	d_{50}	f_c	d_{50}	f_c	d_{50}	f_c
1.50	0.18	8.90	0.25	10.00	0.19	15.56
4.50	0.14	15.62	ND	ND	ND	ND
9.00	ND	ND	0.16	15.00	0.14	7.90
12.00	0.17	11.12	ND	ND	0.16	15.00
15.00	0.18	6.34	0.17	9.30	ND	ND
16.50	ND	ND	ND	ND	0.22	2.77
18.00	0.18	4.77	0.19	6.62	ND	ND
21.00	0.14	8.50	ND	ND	0.18	10.21
24.00	ND	ND	0.19	26.00	ND	ND
25.50	0.18	10.52	ND	ND	0.22	4.29
28.50	ND	ND	0.20	6.72	ND	ND
30.00	0.20	5.00	ND	ND	ND	ND

ND=Not Determined

Interpretation of Mean Grain Size from the ratio of Cone Tip Resistance (q_c) to SPT blow count (N_{60})

A range for Mean grain size (d_{50}) was determined based on correlations presented by Robertson et al. for North American soil (1983), Burland and Burbidge for London soils (1985), Kulhawy & Mayne for soils of California (1990), Canadian foundation engineering manual (Canadian Geotechnical Society 1992) and Anagnostopoulos for Greek soils (2003) and are shown in Figure 6. The laboratory obtained results are plotted on the same figure to compare the interpreted results to the actual results. The qc/N_{60} ratio of selected data set are less scattered and vary from about 2-12 for a variation of d_{50} from 0.14-0.25 mm whereas the available correlations give a range of d_{50} from 0.06 to 0.5 for the same variation of qc/N_{60} ratio.

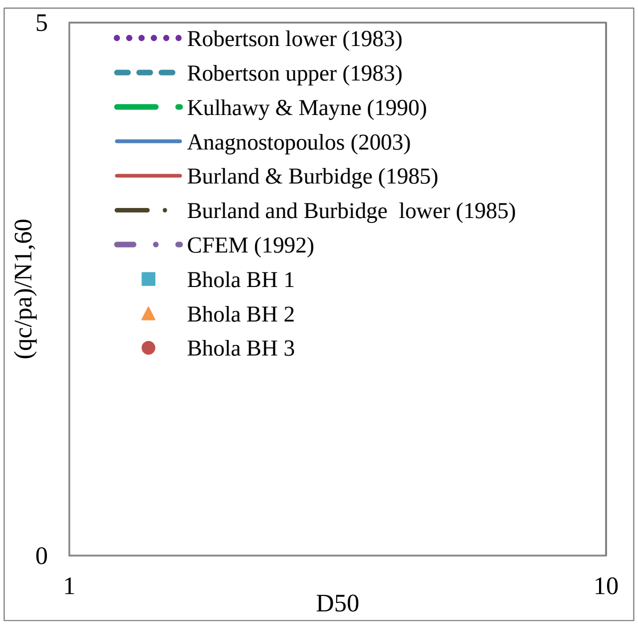


Figure 6: Variation of ratio $(q_c/pa)/N_{60}$ with mean grain size, d_{50} comparison

Interpretation of Fines Content Size from the ratio of Cone Tip Resistance (q_c) to SPT blow count (N_{60})

The fines content based correlations proposed by Chin et al. (1988) and Kulhawy & Mayne (1990) are presented in Figure 7 along with collected data sets of this study. Laboratory obtained data are a little scattered but appeared to be a logarithmic relationship unlike the interpreted values from available linear correlations. But the trend line of plotted data set shows that with increasing qc/N ratio, fines content decreases as indicated by previous researchers. The determination factor (R^2) based on 20 data points is 0.344>.3 which although relatively poor, considered to provide a starting point for the CPT database.

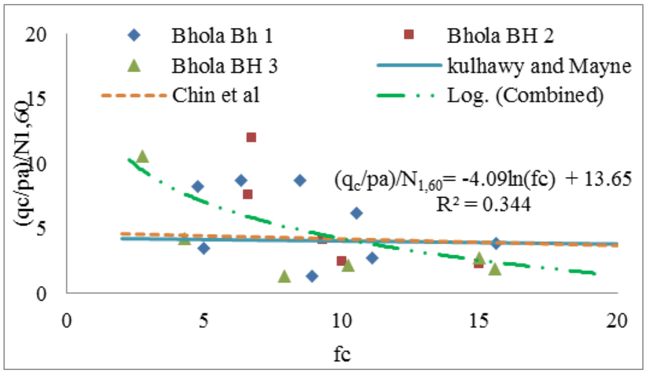


Figure 7: Variation of ratio $(q_c/pa)/N_{60}$ with fines content, f_c comparison

Interpretation of behavior index from the ratio of Cone Tip Resistance (qc) to SPT blow count (N60)

Calculated CPT based Ic was plotted against the ratio of CPT cone resistance q_c to SPT blow count N_{60} and compared to the existing correlation between q_c/N and Ic provided by Jefferies & Davies (1993) which was modified by Robertson and Wride in (1998) and Robertson (2012). Fig 8 shows that q_c/N ratio for 54 study data points show the same pattern as existing correlations. q_c/N ratio for selected data points varies from 1 to 7 with a variation of SBT index from 1.8 to 3.3 whereas existing correlations suggest that with similar variation of SBT index q_c/N has a range of 1.5 to 5.

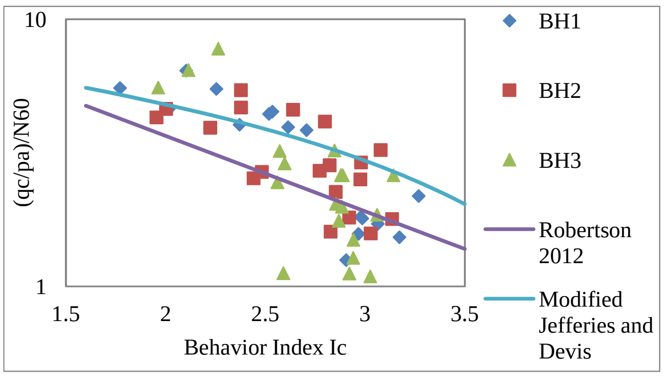


Figure 8 :$(q_c/pa)/N_{60}$ Vs CPT-based SBT index Ic comparison

5.4 Interpretation of SPT blow count (N_{60}) from CPT cone tip resistance

Elbana et al (2011) proposed a linear relationship between SPT blow count and CPT cone tip resistance which is q_{c1}=0.45*$N_{1,60}$. To establish a linear relationship between qc and N60, normalized cone tip resistance was plotted against SPT blow count for 55 data points. On Figure 9 we observe that, although the data points are scattered, the linear average trend line gives a relationship between CPT and SPT close to Elbana et al which is q_{c1}=0.42*$N_{1,60}$ with a coefficient of determination (R^2)=0.1327.

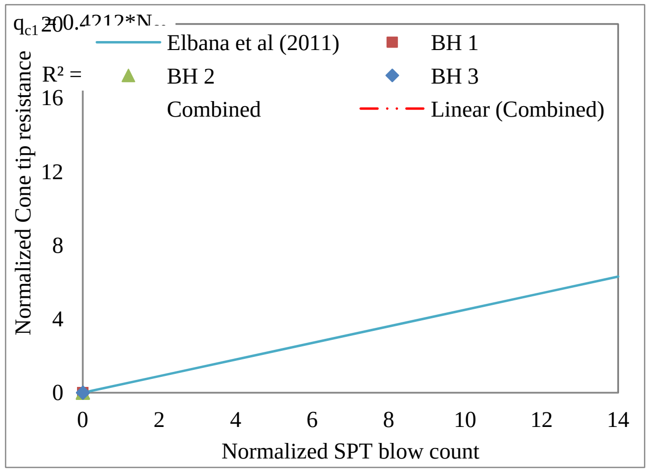


Figure 9: Variation of normalized cone tip resistance (q_{c1}) with normalized SPT blow count $N_{1,60}$ comparisons

Interpretation of Shear Strength Parameter (ϕ) from SPT and CPT

Drained friction angle obtained from direct shear test was compared with SPT based friction angle provided by Wolff (1989), Kulhawy and Mayne (1990) and Hatanaka and Uchida (1996) respectively and CPT based friction angle provided by Robertson and Campenella (1983), Kulhawy and Mayne (1990) and Minmura (2003), these values are shown in Table 2.

Table 2: Comparison of drained friction angle from direct shear test results with SPT & CPT based friction angle

	Sample	Bhola 1	Bhola 2	Bhola 3
	Direct shear test	31	30.5	30
From SPT	SPT N60	6	4.5	4.5
From SPT	Kulhawy & Mayne 1990	27.3	25.08	25.08
From SPT	Hatanaka & Uchida 1996	29.95	28.62	28.62
From SPT	Wolff 1989	28.88	28.44	28.44
From CPT	CPT qc	1.8	1.1	1.17
From CPT	Robertson & Campanella 1983	27.47	23.65	24.22
From CPT	Kulhawy & Mayne 1990	25.08	22.71	23.04
From CPT	Mimura 2003	30.59	28.21	28.54

From above table we observe that for a variation of SPT from 4.5 to 6, the interpreted drained friction angle of internal friction remains within the range of 25-30° whereas results obtained from direct shear test shows a variation of ϕ of 30-31°. For a variation of cone resistance from 1.1-1.8MPa existing correlations provides a range of 23-31^{o} whereas drained friction angle from direct shear test varies from 30 to 31°. Hatanaka & Uchida 1996 and Mimura 2003 are in best agreement with the laboratory test results.

CONCLUSIONS

This study was intended to assess the best way possible to evaluate the use of correlations between laboratory and field investigation data so that it serves in various ways from saving time to saving money.

This study suggests that CPT data can be utilized to obtain high quality soil stratigraphy. Interpreted mean grain size and fines content from available correlations deviate from actual values. But better fines content values can be interpreted for local soil using $(q_c/pa)/N_{1,60} = -4.09\ln(fc) + 13.65$. On the other hand, behavior index based correlations gives values close to the real values. Also, interrelation between CPT and SPT proposed by Elbana et al (2011) may prove to be very useful for the local soil types. Drained friction angles interpreted from both CPT and SPT give values reasonably close to laboratory investigations, with more recent correlations giving better agreement.

Very little researches have been conducted with CPT-SPT data interpretation in our country, this study was a small part of an extensive research to profile, characterize and analyze soils from the northern-most riverine embankment to the southern-most coastal embankmen

PART-VI

ASSESSMENT OF FLOOD RISK IN THE EASTERN PART OF JAMUNA FLOODPLAIN

BANGLADESH NETWORK OFFICE FOR URBAN SAFETY (BNUS), BUET, DHAKA

Prepared By: Maruf Biullah
Mehedi Ahmed Ansary

Introduction

Risk assessment is becoming popular in the management and policies of all the major countries especially in disaster management sector like a flood (Meyer et al., 2009). In the context of Bangladesh, risk assessment is even more important as she faces different natural calamities on a regular basis and flood is one of them. It noticiably damage humanlives, properties, environments and conributed about 39.26% of worldwide natural disasters and coused about USD 397.3 billion worth damage between 2000 and 2014 (Em-dat, 2010). As Bangladesh is part of the world's most dynamic hydrological and the biggest active delta system, the landscape, position, and outfall of the three major rivers shape the annual hydrological cycle of the land. Too much rain in rainy season and too little water in the dry season is the annual phenomenon in a hydrological cycle. Here regular monsoon event, flood, the depth, and duration of inundation are the deciding factors whether it is affecting beneficially or adversely. Monsoon inflow along with rainfall historically shapes the civilization, development, environment, ecology and the economy of the country. Extreme events of flood adversely affect the development, economy, poverty and almost every sector. The quick advancement of satellite-based innovations and the remarkable advancements in spatial data examination and demonstration have empowered various improvements in exact flood risk evaluation and also rational flood management.

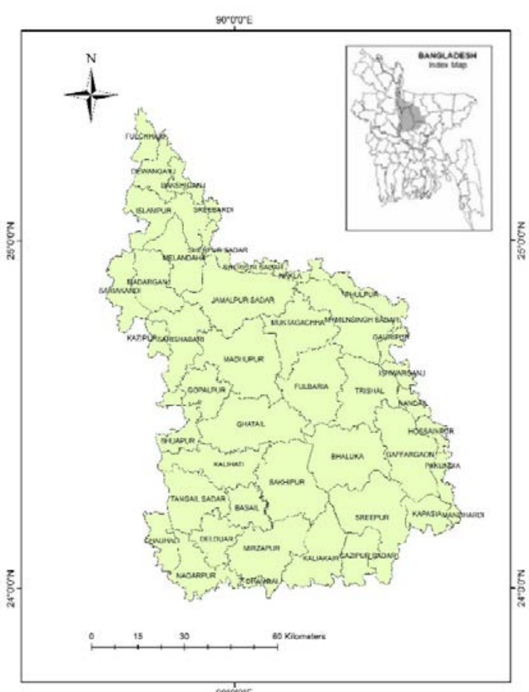


Fig 2: study area (Karzakram, 2011)

Materials and Methods

Concept of risk: A risk is observed as the likelihood of occurrence or the gradation of loss of a specified element expected from a specific hazard (Schneiderbauer and Ehrlich, 2004). While risk measurement varies according to discipline, in hazard research, risk is equal to the product of two or three factors (Crichton, 2002; UNISDR, 2009; Wisner et al., 2004) , though dissimilar views exist (Chakraborty et al., 2005) . For example, (Crichton, 2002) summaries chance with a three-way relationship in which risk, presentation, and helplessness contribute freely. On the other hand, Asian Disaster Reduction Center (Center, 2005) defines hazard as the coverage areas of three factors—hazard, exposure, and vulnerability—that act simultaneously to generate the risk of natural hazards, which can be expressed as:

Risk = hazard x vulnerability …………. (Equation: 1)

Risk = hazard x exposure x vulnerability......... (Equation: 2)

While hazards are a probable threat to inhabitants and the surroundings, a risk is an interplay between hazard and vulnerability. Elements at risk, a commonly used term in hazard research, allows the assessment of economic losses from a life-threatening event (Meyer et al., 2009). But it is usually not included in the risk equation; it is considered as a part of the vulnerability and exposure analysis.

However, according to the United Nations Disaster Relief Coordinator Office (United Nations Development Program (Peduzzi et al., 2009), a risk is the function of elements at risk (e.g., population), hazards, and vulnerability. It varies from the concept of others, who describe risk as a production of hazard and vulnerability (Wisner et al., 2004). The risk to a specific community varies over time and time and depends on their socioeconomic, traditional, and other characteristics(Cannon, 2000; Wisner et al., 2004), moreover the risk of the natural hazards relay on both the hazard and the capability of the community to withstand shocks from disaster.

Risk assessment: Refers to the evaluation of the capacity of the estimated risks based on the local society's suitability criteria. The assessment of the estimated risk with acceptable ones results in the decision of what risk will be acceptable in the particular affected system and what risk reduction measures will be applied; if needed.

For the present study, risk analysis has been done mainly in structural and non- structural measures that are the human settlement, flood frequency, and occurrence, evacuation policy, adaptation measures, coping strategy etc. Physiographic conditions and hydrological parameters have also been taken into consideration to depict the real scenarios of the study area. The variables of the study area taken into consideration analyzed in detailed. Processed data and information have been used in the developed model and finally a risk map has been prepared using the following speculation:

$$Risk = \frac{\text{Hazard x Vulnerability}}{\text{Coping capacity}} \text{ ………… (Equation: 3)}$$

Concept of Flood Risk Assessment: Flood risk assessment is an interdisciplinary task. It combines various types of source, information and models. Some assessment attempts to estimate many possible hazard factors like flood extent and inundation depth, how probable they are and what may be the consequence (de Moel et al., 2015).

Integrated Risk Assessment Model: Risk is the product of hazard, exposure, vulnerability, and coping capacity. First, a hazard is the probability or severity of an event. Second, exposure characterizes structure, population, and economy. Third, Conceptual framework for disaster risk reduction, vulnerability encompasses physical, social, economic, and environmental aspects. Fourth, capacity and mitigation measures include physical planning, social capacity, economic capacity, and management. Using these four measures, it is possible to determine community's vulnerability to hazards and take the necessary actions to lessen the risk of disaster. The proposed model was mainly developed to assess the flood risk of the Jamuna Floodplain; hence, all these above-mentioned components are applicable to single hazard investigation.

The assessment of risk rather than vulnerability, and risk is seen as the product of hazard and vulnerability. The model is based on three important principles.

First, a single hazard perspective is used rather than a multi-hazard.

Second, it is only applicable for hazards that have spatial relevance, such as flood. Spatially non-relevant hazards such as disaster earthquake or cyclone cannot be used.

Third, the model may be useful to determine community risk by integrating hazard and vulnerability; however, it is unable to recognize individuals' risk. An important Pitfall of this model is that it requires copious data to operationalize the concept.

Analysis of variables of the proposed model

Topographic analysis: For the purpose of using geographical data in the planned model, upazilla map are constructed from an administrative shape file provided by government of Bangladesh. GPX converter (an online open source) has been used to obtain elevation data

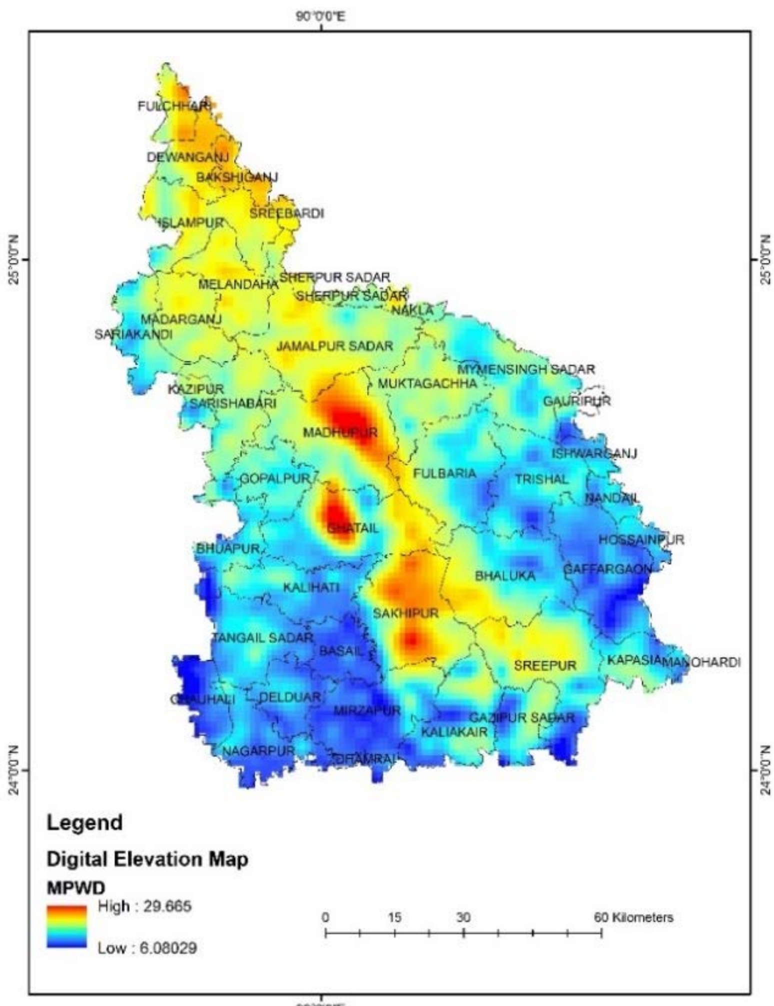


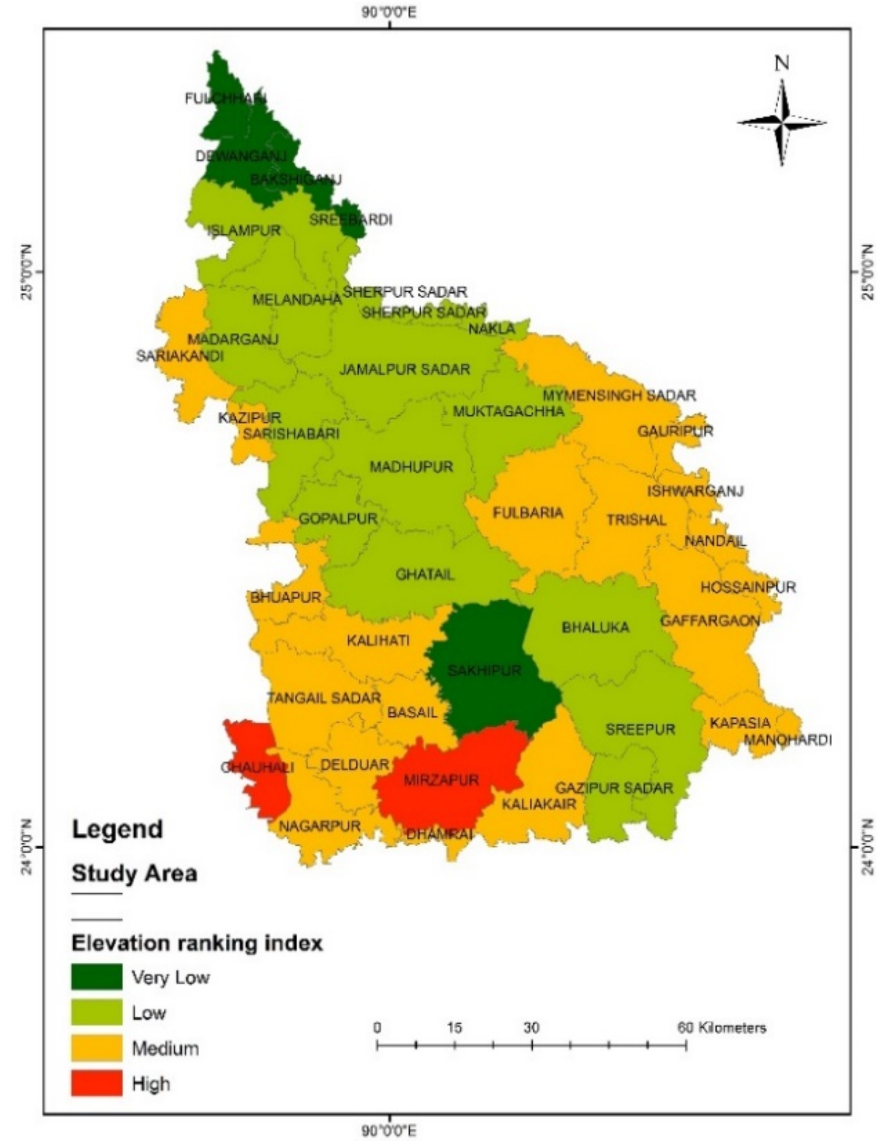
Fig 2: Digital elevation map

for particular are using GIS and image processing (fig 2). According to the elevation of the study area risk index has been prepared and shown on a map (fig

3). Raster elevation ranked as 20 meters and above height from the sea level is 5 in values, and 1 is in risk rank while very low in risk index. The estimated values, ranks and risk index are given in the table1.

Table 1: Elevation value, rank and index used in the model

Elevation in meter	Values	Rank	Risk Index
1-5	1	5	Very High
6-10	2	4	High
11-15	3	3	Medium
16-20	4	2	Low
20+	5	1	Very Low



Source: (Tingsanchali and Karim, 2010)

Fig3: Elevation Ranking

Analysis of population density of human settlement: The population density of the study area provided further evidence of the problems especially in the case of losses of life due to flooding. In 1901on an average of 216 inhabited in one square kilometer in Bangladesh. By 1951 that number had reached to 312 per square kilometer and, in 1988, reached 821. By the year 2000, population density was expected to exceed 1,000 persons per square kilometer. But in some portion of the study area experience the population more than 2000 per square kilometer. To assess the flood risk on population settlement, Upazila wise population density statistics and the prepared index used in the model as follows: (table 2) and a population Density index map has been developed for better visualization (fig 4).

Table 2: Upazila wise Population density in the study area

SL. No.	Name of the Upazila	Area (Sq. km)	Total population	Density per sq. km	Density rank (*)
1	Basail	157.78	148555	941	2
2	Bhaluka	444.05	264991	596	2
3	Delduar	184.54	175684	952	2
4	Fulbari	402.41	345283	858	2
5	Gafargaon	401.16	379803	946	2
6	Ghatail	451.30	341376	756	2
7	Gopalpur	193.37	252747	1307	3
8	Jamalpur Sadar	489.56	501924	1025	3
9	Kaliakair	414.14	232915	741	2
10	Kalihati	301.22	354959	1178	3
11	Madargonj	225.38	24306	107	1
12	Madhupur	500.67	375295	749	2
13	Melandaha	239.65	262478	1095	3
14	Mirzapur	373.89	337496	902	2
15	Muktagacha	314.71	321759	1022	3
16	Sakhipur	429.63	220281	512	2
17	Sharishabari	263.48	289106	1097	3
18	Tangail Sadar	334.26	680518	2035	5
19	Trisal	338.98	336797	993	2

*** Population Density Index, 100-500=1, 501-1000=2, 1001-1500=3, 1501-2000=4, 2000+=5**

Source: (Bangladesh Bureau of Statistics, 2012)

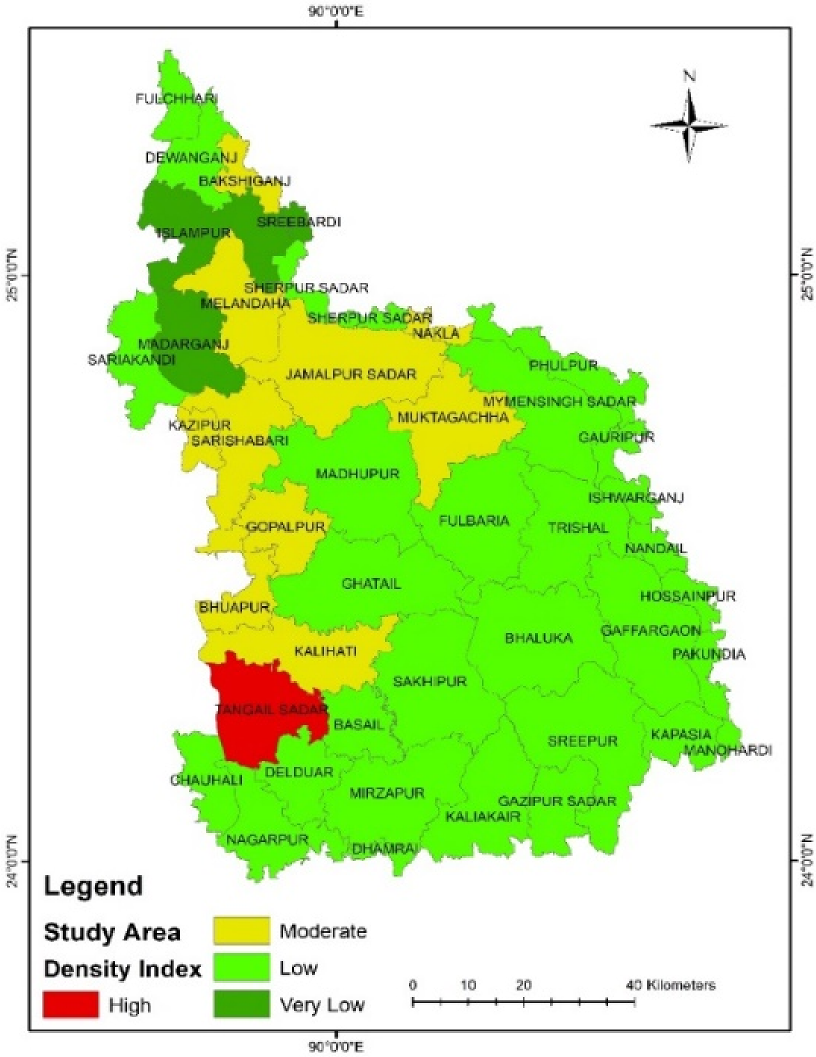


Fig 4: Population density index.

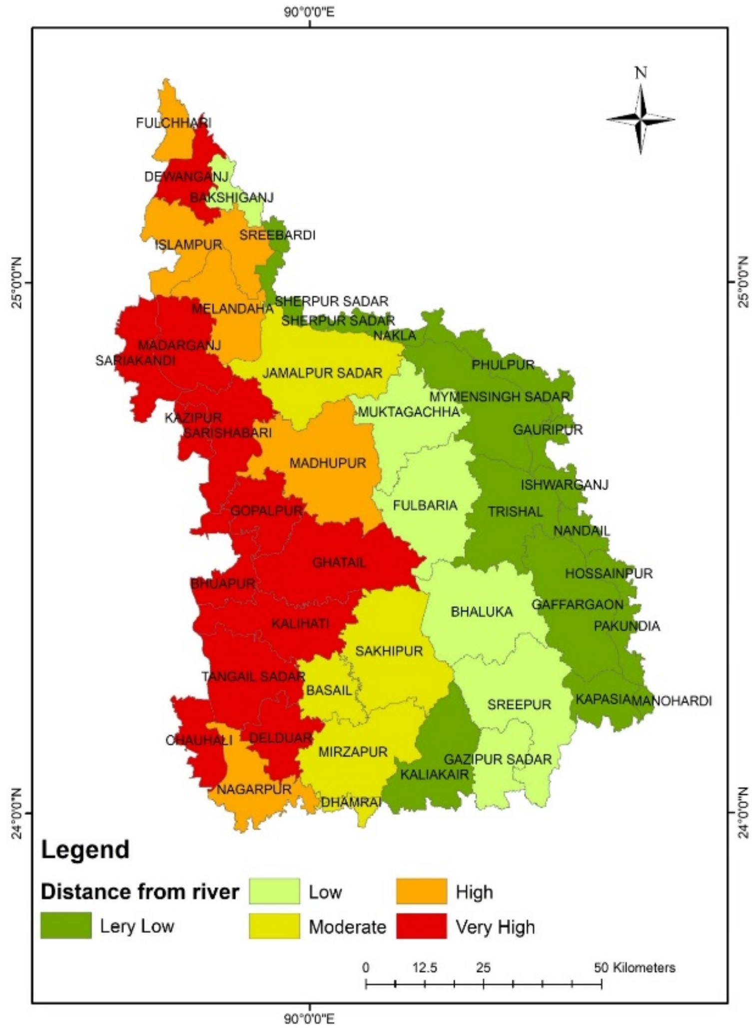
Hydrological analysis: The vulnerability of flood in any catchment or basin area or floodplain depends on the hydrological characteristics of its own. To determine the actual scenario of hydrological risk, distance from the river of each unit of land (Upazila) calculated and in this case the river Jamuna has been taken into consideration as a river. Upazila wise hazard index has been prepared on the basis of a distance from the river. The distance has been calculated use proximity toolset in Arcgis 10.1 version. Figure 5 represent the distant ranking.

Table 3: Hydrological data used in the model

SL. No.	Name of the Upazila	Area (Sq. km)	Average Distance from the river (Km)	Distance rank *
1	Basail	157.78	38.62	3
2	Bhaluka	444.05	51.49	4
3	Delduar	184.54	24.14	1
4	Fulbari	402.41	54.71	4
5	Gafargaon	401.16	86.90	5
6	Ghatail	451.30	32.18	1
7	Gopalpur	193.37	8.04	1
8	Jamalpur Sadar	489.56	40.23	3
9	Kaliakair	414.14	65.98	5
10	Kalihati	301.22	6.43	1
11	Madargonj	225.38	9.65	1
12	Madhupur	500.67	37.01	2
13	Melandaha	239.65	25.74	2
14	Mirzapur	373.89	41.84	3
15	Muktagacha	314.71	59.54	4
16	Sakhipur	429.63	45.06	3
17	Sharishabari	263.48	14.48	1
18	Tangail Sadar	334.26	17.70	1
19	Trisal	338.98	67.59	5

*** Distance index, 0 -16 = 1, 17 -32 = 2, 33 – 48 = 3, 49 – 64 = 4, 65 + = 5**

Average Vulnerability Index: To calculate the average vulnerability of the selected area, population density and the distance from the river has been considered because flood will affect more if it sticks in a dense populated area rather than an area which has less dance. On the other hand distance from the river is another parameter as in our country maximum flood



occurs when the river can’t contain the excessive water flow comes down from the upward in moon soon period. A vulnerability index map (fig 6) has been develop using the average score of the distance from the river and population density.

Fig 5: Distant rank from the river

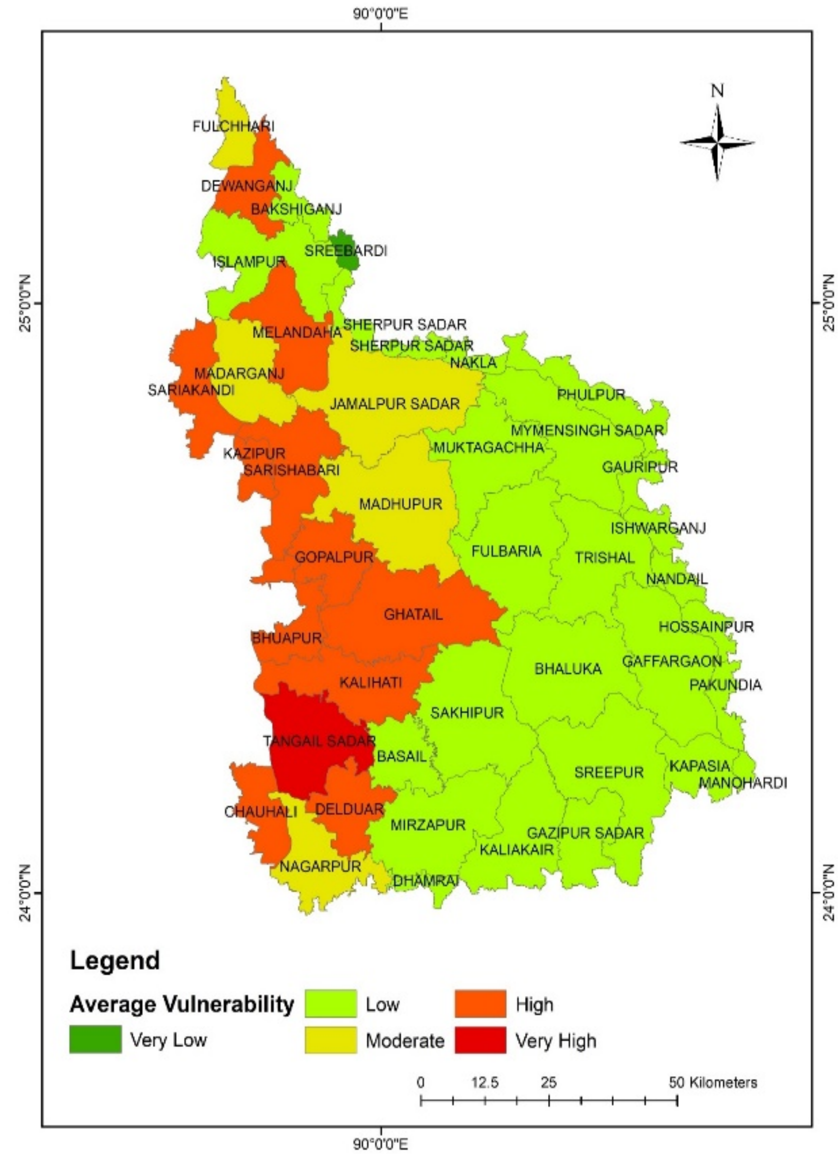


Fig 6: Average vulnerability index

Coping capacities or coping strategies: Coping capacities or coping strategies are highly complementary since greater resilience is achieved when the vulnerability is reduced. Flood vulnerability of the study area found more severe than previous. People of the study area adapted various strategies to cope with the flood of their own and also with the help of different organizations. Focus group discussion (FGD), Key informant interview (KII) have been conducted in very upazilla. Coping strategies of the local people used in the developed model as furnished in the table below: (table 4) and the map (fig 7) symbolizes the overall capacity scenario of that specific area.

Table 4: Coping capacity, variables and index (upazila wise)

SL. No.	Name of the Upazila	Variables of measuring coping capacity				
		Awareness	**Relief system**	**Economic Strength**	**Use of indigenous knowledge**	**Education level**
		Index	**Index**	**Index**	**Index**	**Index**
		Very high=5 High=4 Medium=3 Low=2	Very good=5 Good=4 Satisfactory=3 Not good=2 Bad=1	High=3 Medium=2 Low=1	High=3 Medium=2 Low=1	Very high=5 High=4 Medium=3 Low=2 Very low=1
1	Basail	4	4	1	2	2
2	Bhaluka	4	5	2	2	2
3	Delduar	4	4	2	2	2
4	Fulbari	3	3	3	3	3
5	Gafargaon	4	2	2	2	2
6	Ghatail	4	4	2	1	2
7	Gopalpur	3	4	1	1	2
8	Jamalpur Sadar	3	3	3	1	3
9	Kaliakair	4	5	3	2	4
10	Kalihati	4	4	1	2	2
11	Madargonj	4	4	2	1	2
12	Madhupur	5	4	2	3	2
13	Melandaha	4	5	1	1	2
14	Mirzapur	5	3	2	3	2
15	Muktagacha	3	3	2	3	2
16	Sakhipur	4	3	2	2	2
17	Sharishabari	4	4	2	3	2
18	Tangail Sadar	4	2	3	1	2
19	Trisal	3	3	2	2	2

Index of economic based on monthly income taka 15000 + = 3, 10000 – 15000 = 2, 0 – 10000 = 1

Index of education (%), 0 – 20 = 1, 21 – 40 = 2, 41 – 60 = 3, 61 – 80 = 4, 80 + = 5

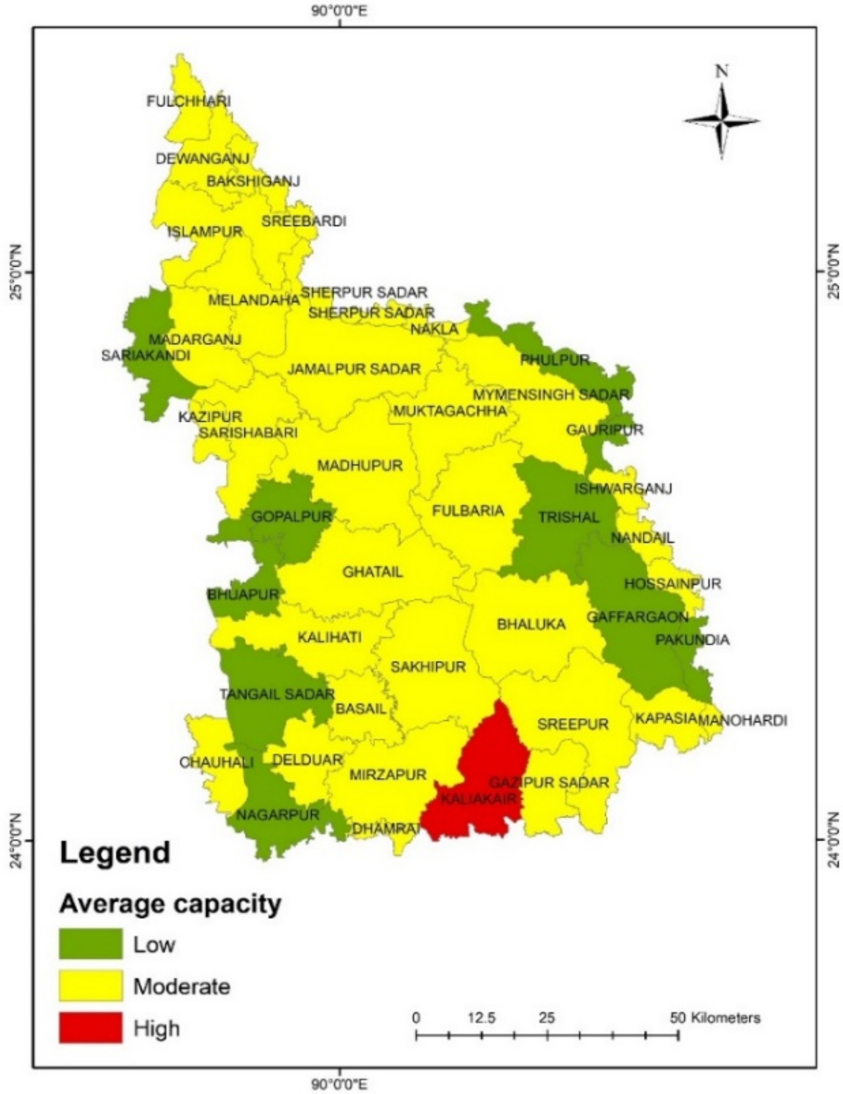


Fig 7: Average capacity ranking

Flood Risk Ranking Map: Based on the assessment of final risk has been calculated through the equation (equation 3). Calculation of data and procedures of data and information input are described in details in the methodology of this study. The developed model has run using Arc GIS and final flood risk map have been produced. In the case of the final output of the flood risk map, three major variables Hazard, Vulnerability and Capacity have been considered. Similarly, in scheming hazard, vulnerability and Capacity both ordinal and nominal values were calculated through the model. Figure 8 is the final yield of flood rink valuation of the study area.

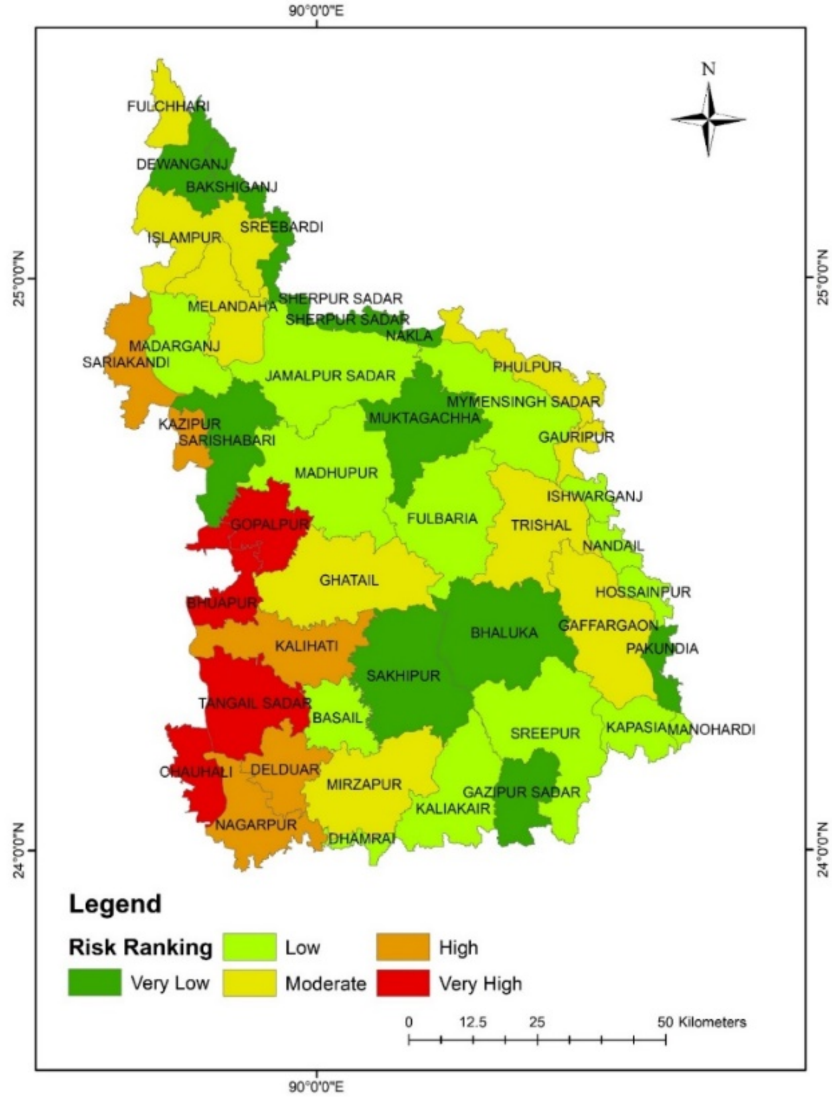


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Fig 8: Flood risk ranking.

Conclusion

After analyzing all variables stated above, final flood risk has been assessed and is shown in the final map (fig 8) which shows the index of flood risk of the Jamuna floodplain. The proposed model could also be applicable for the assessment of flood risk for the whole country as well as for the world as both social and topographical factors has been considered here. This assessment has been conducted to identify the priority areas which should give more emphasis for flood mitigation procedures. This type of work is helpful for the planners, disaster management organizations and also for the government to think about the future plan in the considered area.

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PART-VII

VULNERABILITY ASSESSMENT OF EDUCATIONAL FACILITIES DUE TO CYCLONE AND STORM SURGE AT KALAPARA UPAZILA, PATUAKHALI BANGLADESH

BANGLADESH NETWORK OFFICE FOR URBAN SAFETY (BNUS), BUET, DHAKA

Prepared By: Maruf Biullah

Mehedi Ahmed Ansary

BACKGROUND OF THE STUDY

Bangladesh is a developing country with numerous problems such as over population, poverty, complex socio-economic structure, low-level industrial base, resource constrains, lack of appropriate infrastructural and institutional facilities. These problems are complicated and compounded with the occurrences of regular and frequent disasters impeding the overall socio-economic development efforts of the country (Haque, 1997). The geographical setting of Bangladesh makes the country vulnerable to natural hazards (Karim and Mimura, 2008). Major factors responsible for natural hazards in Bangladesh are flat topography, heavy monsoon rainfall, rapid run-off and drainage congestion, enormous discharge of sediments, low relief of the floodplains, low river gradients, and funnel-shaped and shallow Bay of Bengal. The mountains and hills bordering almost three-fourths of the country along with the funnel-shaped Bay of Bengal in the south not only make the country a meeting place of life-giving monsoon rains, but also make it subject to the catastrophic ravages of nature. For all these conditions, Bangladesh is stated as one of the most natural disaster-prone countries in the world (Ali et al., 2012; Choudhury, 2002; Karim and Mimura, 2008).

As a disaster prone country the damage from multi hazards (cyclone and storm surge) in coastal area is very high. In this article, we have considered the damage and vulnerability of school buildings as a disruption on educational facilities. Poor construction of school buildings due to poor implementation of building codes and safety standards, unplanned, haphazard development, a large number of school buildings will be affected by floods, cyclone and storm surge. This will ultimately reduce the sheltering capacity of the local community during any disaster. The southern part of Patuakhali district like Kalapara upazila (Figure 1), school buildings are vulnerable to floods, cyclone and storm surge due to their geological feature. The Bay of Bengal and many rivers in this location, make them vulnerable. Past experiences and based on the available evidences in Bangladesh, the education sector has been found to be hardest hit along with other sectors in the event of any disaster (Tatebe and Mutch, 2015). During the Cyclones of 1970, 1991, 2007, 2009 and floods of 1988, 1998, 2004, schools have been found to be damaged due to structural failure. In the flood plain areas, majority of schools have been closed for more than three months (Tatebe and Mutch, 2015). An estimated 5,927 educational institutions have been fully or partially damaged during Cyclone Sidr in 2007, resulting in a total value of damage and losses of USD 70 Million (Dasgupta et al., 2010).

This paper aims to identify multi hazard (Cyclone and Storm surge) risk of school buildings through GIS and to assess the structural vulnerability of those buildings due to those hazard.

Global Scenario

School children and school buildings have been greatly affected during all major disasters. A devastating fire claimed 94 lives of young children at the Sri Krishna Primary School in Kumbakonam (Tamil Nadu, India) on 16 July 2004 (Satapathy and Walia, 2007). The Bhuj earthquake that occurred on the 26 January 2001 in India has claimed about 1000 student lives, 15000 educational facilities have been affected (Rai et al, 2002) and has incurred USD 144 Million loss in the educational sector (Vatsa, 2002). At least 1884 school buildings collapsed and 5950 classrooms have been destroyed in the earthquake (Rooze et al., 2006). 17,000 children died and 2,448 schools have collapsed in the 2005 Kashmir earthquake in both India and Pakistan (Aid and Kwatra, 2005). Typhoon Linda (1997) has razed 2,254 schools and damaged 4,022 schools in Vietnam ("Vietnam Typhoon Linda Situation Report No.4," 1997). 74% of all schools have been damaged in the 1999 Colombia earthquake (Wisner et al., 2004). 441 school children have died in a stampede at a school function in Mandi Dhabwali (India) in December 1995 (Srinivasan et al., 2006). Out of 200,000 buildings brought down by the Great Sichuan Earthquake on May 12, 2008 in China, nearly 7,000 schools, many recently built, have been destroyed and several thousand school children have been killed (Yong and Booth, 2011). In the town of Mianzhu seven schools have collapsed, burying 1,700 people. Roughly one billion children aged 0-14 live in countries with high seismic hazard zones. Several hundred million are at risk when they are attending school. More than 200 million people are affected by disaster every year world over, a third of them are children ("Horror and hope," 2017).

Major Events of Cyclones and Storm surges in Bangladesh

Any hazards become disasters when they intersect with the human environment. In Bangladesh, historical natural disasters have left a profound imprint causing devastating loss of life, property, economy, and community. From historical evidences, it can be observed that different types of disasters such as flood, cyclonic storm, tidal surge, drought, tornado, riverbank erosion, and earthquake occur in Bangladesh regularly and frequently causing devastating consequences (Karim, 1995). The 1988 flood killed 1517 people, and nearly half of the population in the country have been affected (Hossain, 2004). The 1970 cyclone has killed almost 500,000 people (Karim, 1996). About 1300 people have been killed by tornado at Saturia of Manikganj district in Bangladesh in 1989 (Islam, 2004). The 1897 Great Indian Earthquake with a magnitude of 8.7 Mw has killed 1542 people and has affected almost the whole of Bangladesh (Oldham, 1899). Drought is a recurrent phenomenon in some parts of Bangladesh, which leaves a permanent damage, i.e. damages agricultural production and encourages the desertification process that is going on in some parts of North Bengal (Shahid and Behrawan, 2008). River erosion takes away thousands of hectares of land every year in the country resulting in displacement of a huge number of people (Mutton and Haque, 2004).

Depending upon their potential to cause damage to human life and property, these natural calamities may be broadly grouped into major and minor types. Natural hazards such as earthquake, drought, flood, tornado, and cyclone can be regarded as major for their greater impact, whereas landslide, riverbank erosion, groundwater contamination, fire, tsunami, etc., can be categorized as minor hazards, whose impacts are localized and intensity of the damages is much less. Thus, based on historical occurrences and potential damage of these hazards in Bangladesh, tornado, flood, earthquake, and cyclone are considered as major disasters in Bangladesh (Barua et al., 2016).A list of major cyclone and storm surge events from 1960-2013 are presented in Table 1.Figure 1 also shows some historical cyclone tracks affecting Bangladesh.

Table 1: Major events of cyclones and storm surges in Bangladesh

Month	Year	Max. Wind Speed (km/h)	Storm Surge Height (meter)	Human Deaths
October	1960	210	4.5-6	5149
May	1961	146	2.5-3	11466
May	1963	203	4-5	11520
May	1965	162	3.5	19279
December	1965	210	4.5-6	-
October	1966	146	4.5-9	850
November	1970	223	6-9	500000
May	1985	154	3-4.5	11069
April	1991	225	6-7.5	138000
May	1994	200	-	170
May	1997	225	2.5-4	126
November	2007	223	3-4	3363
May	2009	92	3+	190
May	2013	88	1.5-2	17

Source: (Nizamuddin, 2001)

In the recent past, Bangladesh has faced some devastating natural calamities and those have a huge impact on the structural facilities of education sector. This has become one of the major causes for school drop out after a major disaster.

METHODOLOGY OF THE STUDY

To conduct the study at first the authors have used risk ranking method to assess the vulnerability of individual school buildings that has been surveyed through extensive field visit. The collected school building data has been presented using GIS to develop hazard maps. The coastal area of Kalapara upazilla of Barguna district, Bangladesh has been selected for this study (Figure 1).

Location of Kalapara Upazila

The study area is located between 21º48´ and 22º05´ north latitudes and between 90º05´ and 90º20´ east longitudes. The upazila is bounded on the north and west by Amtali upazila of Barguna zila, on the east by Galachipa and Rangabali upazilas and on the south by the Bay of Bengal. The major rivers are the Andharmanik, Nilgang and Dhankhali (Figure 1).

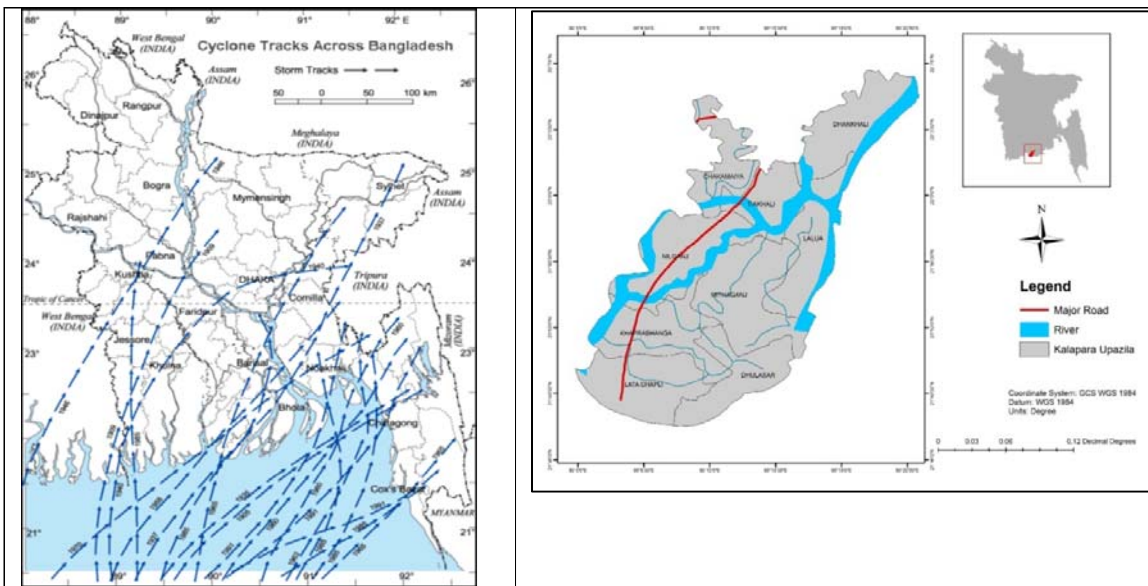


Figure 1: (a) Cyclone Tracks in Bangladesh and (b) Study Area (Kalapara Upazila)

Surveyed Schools of Kalapara

Kalapara upazila has around 110 schools having around 160 buildings, out of those 30 schools having 59 buildings have been assessed in this research as shown in Figure 2. These schools are located within 50 km from the coast. Some of the surveyed school buildings are shown in Figure 3. The buildings mainly consist of RC (Reinforced Concrete) frame, URM (Unreinforced Masonry) with roof slab, URM with tin roof and buildings with tin wall and roof.

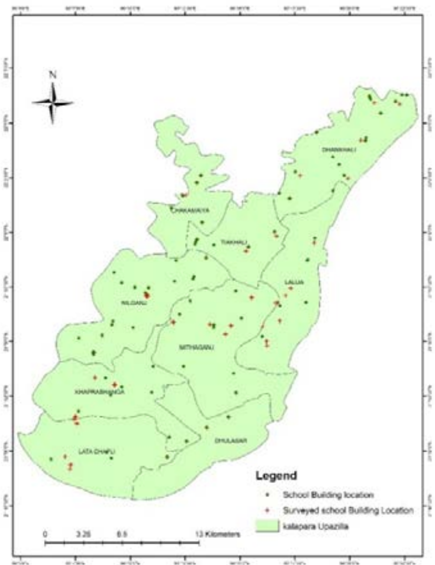


Figure 2: Position of Surveyed School Buildings

Figure 3: Some of the existing school buildings in the study area

RESULTS AND DISCUSSIONS

Multi hazard assessment becomes an influential tool to the decision makers for future planning initiatives because it can provide a composite hazard profile for the target area. To perform this assessment, it is required to prepare individual hazard analysis that might cause risk to the region. In this study attempts has been made to assess educational buildings for cyclone and storm surge, this will ultimately yield composite vulnerable situation of the educational buildings of the study area. Weighting factors of vulnerability to cyclone and storm surge have been determined through expert opinion by the authors. Panels of 10 experts have been consulted to determine the combined vulnerability score of cyclone and storm surge. Table 1 presents hazard wise vulnerability score of Cyclone/ Storm surge.

Table 1: Hazard wise vulnerability score of Cyclone/ Storm surge

Scale	Score
Very Low	1
Low	2
Moderate	3
High	4
Very high	5

Vulnerability to Cyclone of Kalapara School Building Structure

Cyclone is always ranked as top most natural hazard for any coastal area. It possesses devastating impact on coastal communities. The different factors and weightage used to estimate the cyclone vulnerability has been provided in Table 2. Position of the building can play a vital role to withstand the wind speed. An isolated building or the building which is situated at the corner has to face the devastating wind of the cyclone. Primary structural system is another vital factor as it provides the strength of the building to withstand the natural calamities. Frame structure and steel structure can resist more live and dead load to withstand as well as resist the wind load than any other structures. On the other hand timber, wooden and other structure is more vulnerable to cyclone hazard. Roof structure and roof cover is other criteria to sustain when the rotating wind strike the area. Roof pitch, condition, structural condition and connection quality are the other important factors which can enhance the vulnerability of school buildings. To assess the existing vulnerability of the school buildings, the above mentioned criteria have been considered for quick survey.

Table 2: Cyclone hazard vulnerability (CHV) score based on various structural parameters

Criteria	Weightage	Sub-criteria	Score
Position of building (C2)	2	Isolated	5
		Corner	5
		Mid-block	1
Primary Structural system (E2)	5	Steel and RC frame	1
		Masonry	2
		Timber	5
Roof structure and cover (F2)	3	RC slab	1
		Steel truss	2
		Timber frame	3
		Straw and Other	5

Criteria	Weightage	Sub-criteria	Score
Roof Pitch (G2)	3	Flat	1
		Multi Pitch	2
		Mono Pitch	3
Roof Condition (H2)	3	Excellent	1
		Fair	2
		Deteriorated	5
Structural Condition (I2)	3	Excellent	1
		Fair	2
		Deteriorated	5
Connection quality (J2)	2	High	1
		Moderate	3
		Low	5

Expert opinion has also been considered while assessing the scores of Table 2. In Table 2, 1 has been selected for very low vulnerability and 5 for very high vulnerability as presented in Table 1. Based on weightage and individual scores of different variables, Cyclone Hazard Vulnerability (CHV) score has been calculated as:

CHV = (Score of C2 x 2)+(Score of E2 x 5)+(Score of F2 x 3)+(Score of G2 x 3)+(Score of H2 x 3)+(Score of I2 x 3)+(Score of J2 x 2).

CHV for every single surveyed school building has been estimated. After estimating individual school building vulnerability, all values have been converted into a normalized value ranging from 0 - 1. For normalization, following equation has been used.

$$\text{Normalized Cyclone Hazard Vulnerability (NCHV)} = \frac{CHV_{actual} - CHV_{minimum}}{CHV_{maximum} - CHV_{minimum}}$$

Here,

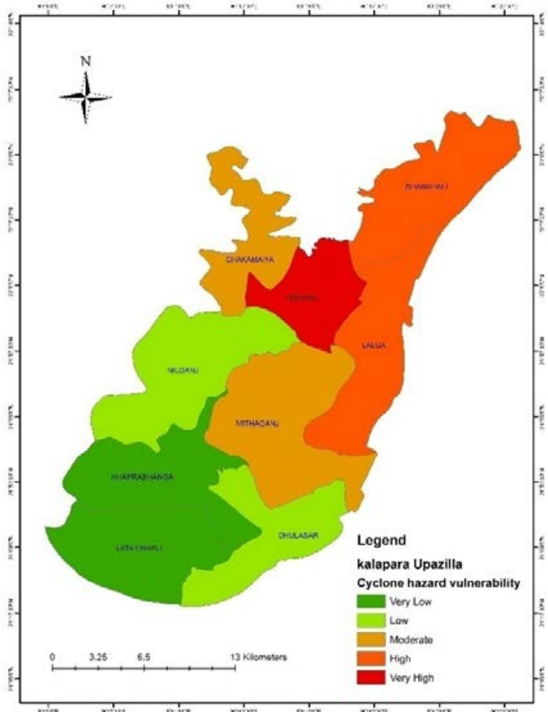
CHV_{actual} = Vulnerability value of individual building

$CHV_{minimum}$ = Lowest vulnerability value among all buildings

$CHV_{maximum}$ = Highest vulnerability value among all buildings

Using the normalized value of cyclone hazard vulnerability (NCHV), map for educational facilities have been developed using Inverse Distance Weighted (IDW) interpolation method of vulnerability mapping (Figure 4).

It is clear from the hazard map that the lower part of Kalapara upazila is less vulnerable rather than the upper part. This is due to the fact that the structural developments and qualities of educational facilities in the lower part (near the coast) are relatively better than in the upper part. In the lower part of the upazila, close to the sea most of the school buildings



have been converted into multipurpose cyclone shelters (see Figure 3), which reduce the vulnerability of the educational facilities as well as the reduction of vulnerability of the nearby community people who will use them as shelters.

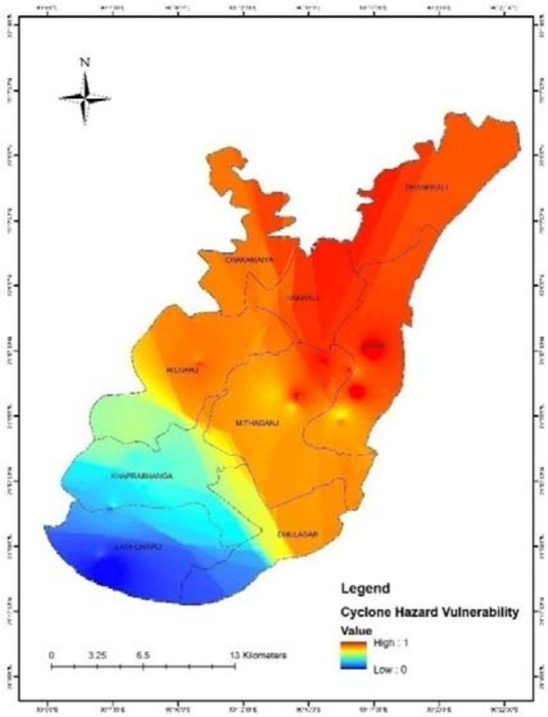


Figure 4: Normalized Cyclone hazard vulnerability of educational facilities IDW (left) and union wise vulnerability mapping (right)

Vulnerability to Storm surges of Kalapara School Building Structure

Due to geographical and topographical settings of Kalapara upazila, it is also vulnerable to storm surge hazard. Storm surge is not a single hazard. It comes with a huge water wave while the cyclone strikes the area. The main difference between the storm surge and the cyclone is that the size of the affected area of the storm surge is relatively less than the affected area of the cyclone. The consequence of the storm surge is relatively higher than the cyclone. The different factors and their corresponding weightage used to estimate the storm surge vulnerability has been provided in Table 3. Three factors for storm surge vulnerability are similar to the cyclone vulnerability factors, namely, primary structural system, structural condition and connection quality. For storm surge vulnerability assessment, additional three parameters namely, floor material, elevation irregularity and mass irregularity have been added, according to the experts opinion.

Table 3: Storm surge hazard vulnerability score based on various structural parameters

Criteria	Weightage	Sub-criteria	Score
Primary Structural system (PS)	4	Steel and RC frame	1
		Masonry	2
		Timber	5
Floor material (FM)	4	RC slab and Reinforced brick concrete	1
		Timber and Wooden floor	3
		Mud	5
Structural Condition (ST)	3	Excellent	1
		Fair	2
		Deteriorated	5
Connection quality (CQ)	2	High	1
		Moderate	3
		Low	5
Elevation irregularity (EI)	5	Yes	3
		No	1
Mass irregularity (MI)	2	Yes	3
		No	1

For storm surge, primary structure plays a vital role as it is the main elements of a building, similar for cyclone. To prevent the wash out and severe damage of the ground floor, floor material, condition of the structure, elevation and mass distribution are important criteria. Storm Surge Vulnerability (SHV) has been estimated using the following equation:

SHV =(Score of PS x 4)+(Score of FM x 4)+(Score of ST x 3)+(Score of CQ x 2)+(Score of EI x 5)+(Score of MI x 2)

SHV for every single surveyed school building has been estimated. After estimating individual school building vulnerability, all values have been converted into a normalized value ranging from 0 - 1. For normalization, following equation has been used.

$$\text{Normalized Storm Surge hazard Vulnerability (NSHV)} = \frac{SHV_{actual} - SHV_{minimum}}{SHV_{maximum} - SHV_{minimum}}$$

Here,

SHV_{actual} = Vulnerability value of individual building

$SHV_{minimum}$ = Lowest vulnerability value among all building

$SHV_{maximum}$ = Highest vulnerability value among all building

Similar to cyclone, using the normalized value of storm surge hazard vulnerability (NSHV), map for educational facilities have been developed using Inverse Distance Weighted (IDW) interpolation method of vulnerability mapping (Figure 5).

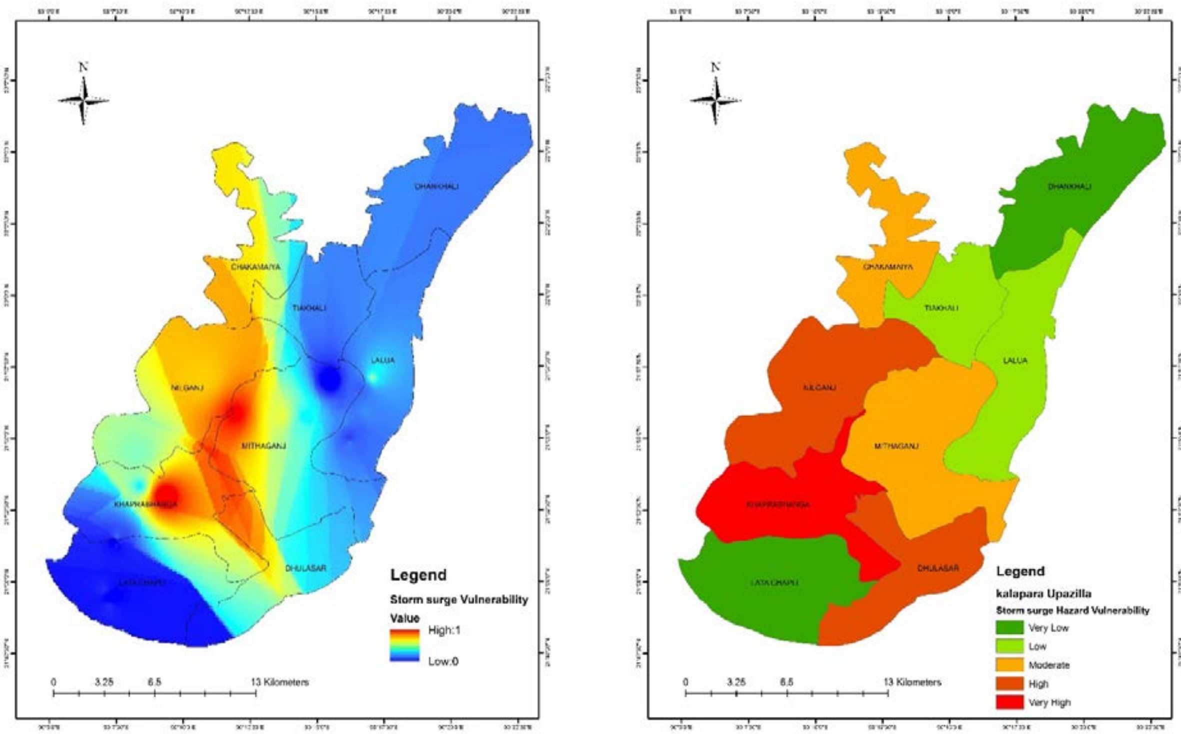


Figure 5: Storm surge hazard vulnerability on educational facilities IDW (left) and union wise vulnerability mapping (right)

Unlike cyclone hazard vulnerability map of Figure 4, the storm surge hazard map (Figure 5) show low values in the lower and upper part of the upazila and high values in the middle part. The reason behind this is the presence of several small and medium size rivers located in the middle part of the upazila which allows water wave to damage the weak educational facilities of these locations.

Multi Hazard of Kalapara School Buildings

The multi hazard analysis performed in this study clearly shows that disasters are not separated but strongly interconnected. Different disasters can interfere among them and results in multi hazard vulnerability for any structures. The energy of storm surge helps the cyclone to damage a structure more severely than it can do for cyclone alone. To understand the vulnerability of educational facilities of the study area, a multi hazard vulnerability analysis has been carried out by combining the effect of two disasters (cyclone and storm surge) based on the following equations. The weighting factors have been obtained by consulting the relevant experts.

$$Normalised\ Multi\ Hazard\ Vulnerability\ (NMHV) = \left(\frac{0.5}{NCHV_{maximum}} * NCHV^2\right) + \left(\frac{0.5}{NSSV_{maximum}} * NSSV^2\right)$$

Here,

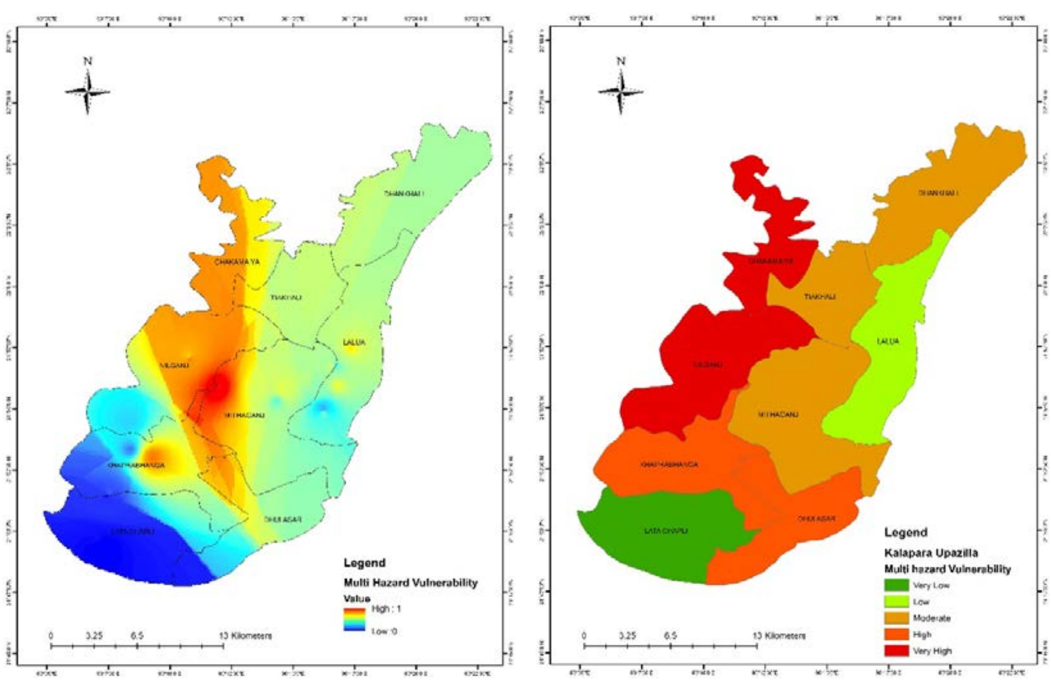
NCHV =Cyclone vulnerability value for specific school building (normalized)

NSSV= Storm surge vulnerability value for specific school building (normalized)

$NCHV_{maximum}$= Maximum cyclone vulnerability value among all school buildings (normalized)

$NSSV_{maximum}$= Maximum storm surge vulnerability value among all school buildings (normalized)

Figure 6 presents the multi hazard vulnerability map for educational facilities using Inverse



Distance Weighted (IDW) interpolation method.

Figure 6: Normalized Multi hazard vulnerability on educational facilities IDW (left) and union wise vulnerability mapping (right)

Figure 7 presents frequency distribution of normalized hazard vulnerability values for different hazards. The figure clearly shows that in the study area, the cyclone hazard vulnerability has more influence than the storm surge hazard. For cyclone hazard vulnerability, most of the buildings are within the range of 0.5 to 1 in a scale of 0 to 1 (0 for low vulnerability and 1 for very high vulnerability) (Figure 7a) but for the storm surge hazard we have a different scenario, a large portion of school buildings fall within 0 to 0.6 within the vulnerability scale (Figure 7b). This is happening due to the following reasons. The affected area of the storm surge is relatively less than the cyclone; on the other hand, the damaging capacity of the storm surge is relatively higher than the cyclone. In general, less school buildings will be affected by the storm surge than the cyclone. School buildings which are located near the coast or rivers are more likely to be affected by the storm surge. Figure 7c shows the multi-hazard vulnerability distribution of the assessed school buildings of the study area.

Figure 7d shows comparison of different normalized hazard vulnerability for individual schools. In this case for each of the 59 assessed school buildings. The red line indicates cyclone hazard vulnerability for different school building where as blue and green color indicate storm surge and multi hazard vulnerability respectively. Kuakata Municipality which is located within Latachapli Union is a well known tourist spot. This city has observed rapid developments in the recent times. Most of the school buildings of this area have been converted into multipurpose cyclone shelters which ultimately reduce the multi-hazard vulnerability. In this figure, it can be observed that the same school building have different vulnerability for different hazard which depends on structural, roof and floor condition of existing structures. Table 4 presents information about seven assessed school buildings: school ID, school name, their normalized CHV, SHV and MHV values, union where they are located and their photograph. It can be seen that the school buildings of Latachapli union are mostly new buildings having the ground floor open. On the other hand, the unions located in the middle (Mithaganj) and upper part (Chakamaiya) of the study area have mostly old buildings having poor maintenance and those schools are relatively weak against cyclone and storm surges.

CONCLUSIONS

Disasters such as cyclones, floods, landslides, fire and water logging are regular features in Bangladesh. Schools in different parts of Bangladesh suffer differently. Kalapara Upazila in Patuakhali district is more vulnerable to cyclone and storm surge. Lower part of the study area (such as Latachapli union) which is closer to the coast is less vulnerable in terms of educational facilities than the other part of Kalapara Upazila. Rapid urbanization has occurred in this union based on the tourism center located at Kuakata in Latachapli union. Government agencies pay more attention in this area than the other part of the upazila. Number of cyclone shelters which are also used as school buildings are more in this union than in other unions of the upazila. Population of this union is also increasing day by day due to the presence of tourism related activities. The cyclone and storm surge hazard assessments carried out in this paper show that building location, building materials and type have significant effect on hazard values. The multipurpose cyclone shelters which are also used as school buildings are less vulnerable than the ordinary school buildings. It is advisable to construct more multipurpose cyclone shelters in the coastal areas of Bangladesh which will help to protect the local community during emergency situations as well as will be used as educational facilities. These resilient cyclone shelters will be able to withstand the natural calamities more efficiently. The study will also help the policy makers to rethink about the vulnerability of the existing school buildings and to take proper measures to safeguard those against hazards.

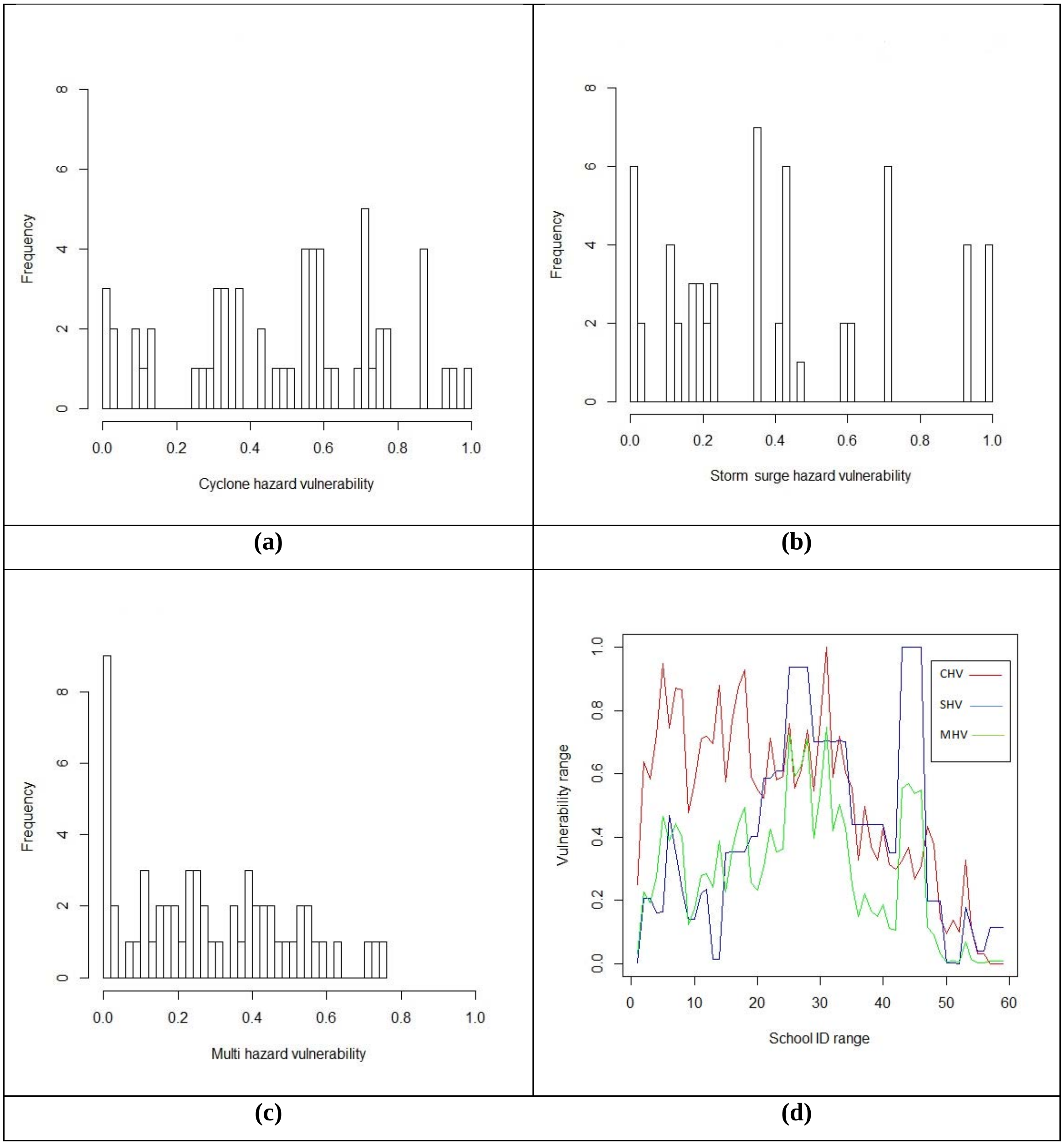


Figure 7: Frequency of different school building vulnerability for cyclone hazard (NCHV) (a), Frequency of different school building vulnerability for storm surge hazard (NSHV) (b), Frequency of different school building vulnerability for multi hazard (MHV) (c), Comparison of different hazard vulnerability.

Table 4: Several assessed school buildings information

School ID	School Name	Normalized CHV value	Normalized SHV value	Final MHV	Union Name	Photograph
27	Tegasia Secondary School (Two-storied)	0.611	0.936	0.624	MITHAGANJ	
28	Tegasia Secondary School (Single storied)	0.738	0.936	0.711	MITHAGANJ	
30	43 Pakhimara Government Primary School (Single storied: new)	0.766	0.702	0.540	CHAKAMAIYA	
31	43 Pakhimara Government Primary School (Single storied: old)	1.000	0.704	0.748	CHAKAMAIYA	
52	117 Amjedpur Government Primary School (Three-storied)	0.101	0.000	0.005	LATA CHAPLI	
53	117 Amjedpur Government Primary School (Single storied)	0.327	0.177	0.069	LATA CHAPLI	
56	Kuakata Banga Bandhu Secondary School	0.032	0.040	0.001	LATA CHAPLI	

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PART-VIII

DYNAMIC BEHAVIOUR OF UNREINFORCED MASONRY BUILDING

BANGLADESH NETWORK OFFICE FOR URBAN SAFETY (BNUS), BUET, DHAKA

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Raquib Ahsan

Mehedi Ahmed Ansary

Introduction

One of the prime causes of mass casualties in an earthquake around the world is collapse of the non-engineered structures (Macabuag et. al., 2012). Many advanced researches have been conducted in the field of earthquake engineering; yet non-engineered structures often remain outside the scope. Along with many architectural heritage structures, there are many residential buildings in Bangladesh, which are non-engineered unreinforced masonry (URM) buildings. Those buildings are vulnerable due to lack of lateral load resisting system. Figure 0.1 shows some common failure of URM in Bangladesh. Rather than demolishing those URM buildings, we need to seek a favorable option for the improvement of their seismic performance. However, before adopting any retrofitting or rehabilitation technique, it is essential to understand the seismic behavior of URM buildings. A number of experimental researches e.g. In-plane tests (Elgwady et. al., 2002; Russwll et. al., 2007; Fam et. al., 2002; Capozucca, 2011), out of plane tests (Derakhshan and Ingham, 2008; Simsir et. al., 2004) and shake table tests (Elgwady et. al., 2002; Simsir et. al., 2004; Hanazato et. al., 2008; Ersubasi and Korkmaz, 2010) were conducted in different countries using their indigenous materials and testing equipment.

a) Damage at Rangpur, 1897 earthquake

b) Damage due to 2003 Rangamati Earthquake

Figure 0.1 Common Failure of Unreinforced Masonry Building

In Bangladesh, there are very few (Das, 2016; Asif et. al., 2017) experimental evidence of lateral load resistance capacity of URM wall and no actual dynamic loading test have been conducted. The exact crack pattern will, of course, depend on the wall boundary conditions and the aspect ratio of the URM elements. Seismic actions are bidirectional and the URM can perform in both in-plane and out-of-plane direction. Therefore, the objective of this research is to understand the overall dynamic behavior, in-plane and out of plane behavior of walls as well as the failure pattern of masonry structures with retrofit (using wire mesh) and without retrofit under shaking table tests in context of Bangladesh.

Specific Objectives of the Study

The total analysis on the dynamic behavior of masonry building/room is done based on the experimental results. Shaking table test is carried out with the following specific objectives:

1. Investigation of the system (overall building) response of bare masonry building/room and retrofitted masonry building/room over a range of real earthquake scenario in shaking table.
2. Investigation of in-plane deformation characteristics of URM wall for bare model and retrofitted model.
3. Investigation of out-of-plane deformation characteristics of URM wall for bare model and retrofitted model.
4. Investigation of the lateral load resistance capacity of URM wall and comparison with Bangladesh National Building Code (BNBC 1993).
5. Investigation of lateral load variation with deformation for both in-plane and out-of-plane wall (for bare model and retrofitted model).

Experimental Program

Due to the size and payload of the shaking table, the experimental model was built using a 1:2 reduced scale, taking in account Cauchy's law of similitude law. Table 3.1 shows the scale factors of the Cauchy similitude law. Compressive strength and prism test of full scale brick and half scale brick were determine. Compressive strength of mortar used for the construction was also determined. A reinforced concrete foundation pad was designed and constructed on which to build the model structure. The pad formed the shape of a rectangular ring and had dimensions of 7' x 6' with 8" thickness. The rectangular ring was 16" wide. To serve the interface requirements, the pad had 24 holes for bolting to the simulator platform (shaking table) and was roughed on its top surface along the footprint of the structures to increase the bond with the base mortar joint. Amount of reinforcement was more than required to prevent the premature failure of the foundation pad before the failure of structure. Figure 0.1 shows the foundation pad detailing and cross section foundation pad on shake table. Total weight of the foundation pad is 1.24 ton.

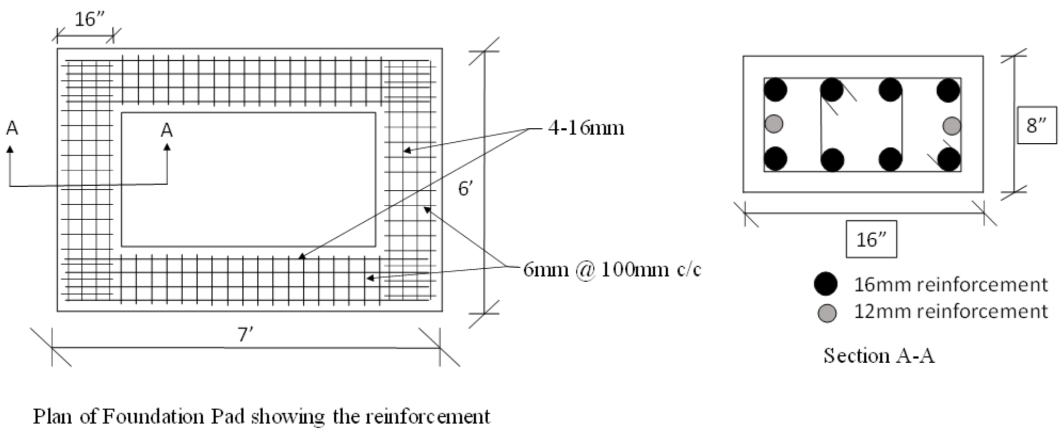


Figure 0.1 Detailing of foundation pad and cross section

Masonry room was constructed on the foundation pad after placing the foundation pad on the shake table. The geometric properties of the experimental model result directly from the application of the scale factor to the prototype. The material properties of the experimental model should be equal to the prototype, namely in terms of compressive strength, shear strength and modulus of elasticity. The mortar used fine sand to comply with the reduced scale of the bed joints and also in local practice fine sand is commonly used for mortar preparation. A cement mortar of a mix 1:4 (cement : sand) with a water/cement ratio of 0.7 was used so that appropriate flow ability and workability was achieved. The model represents the typical room size of the Bangladeshi masonry structure. The prototype was 12' x 10' (length x width) with 10' height. Typical wall thickness of a masonry building in Bangladesh is 5". Keeping this dimensions in mind, the size of model was kept 6' x 5' (length x width) with 5' height and 2.5" wall thickness. Walls were constructed in stretcher bond. The thickness of mortar used in the construction is 10mm. No openings were kept because opening in one or two side may create torsion and stiffness degradation. Walls were constructed in three days, one-third in a day. In future, author have intention to perform shake table test of masonry building keeping window, door and lintel. Figure 0.2 illustrate the constructed masonry model. Total weight of the masonry model is 1.24 ton.

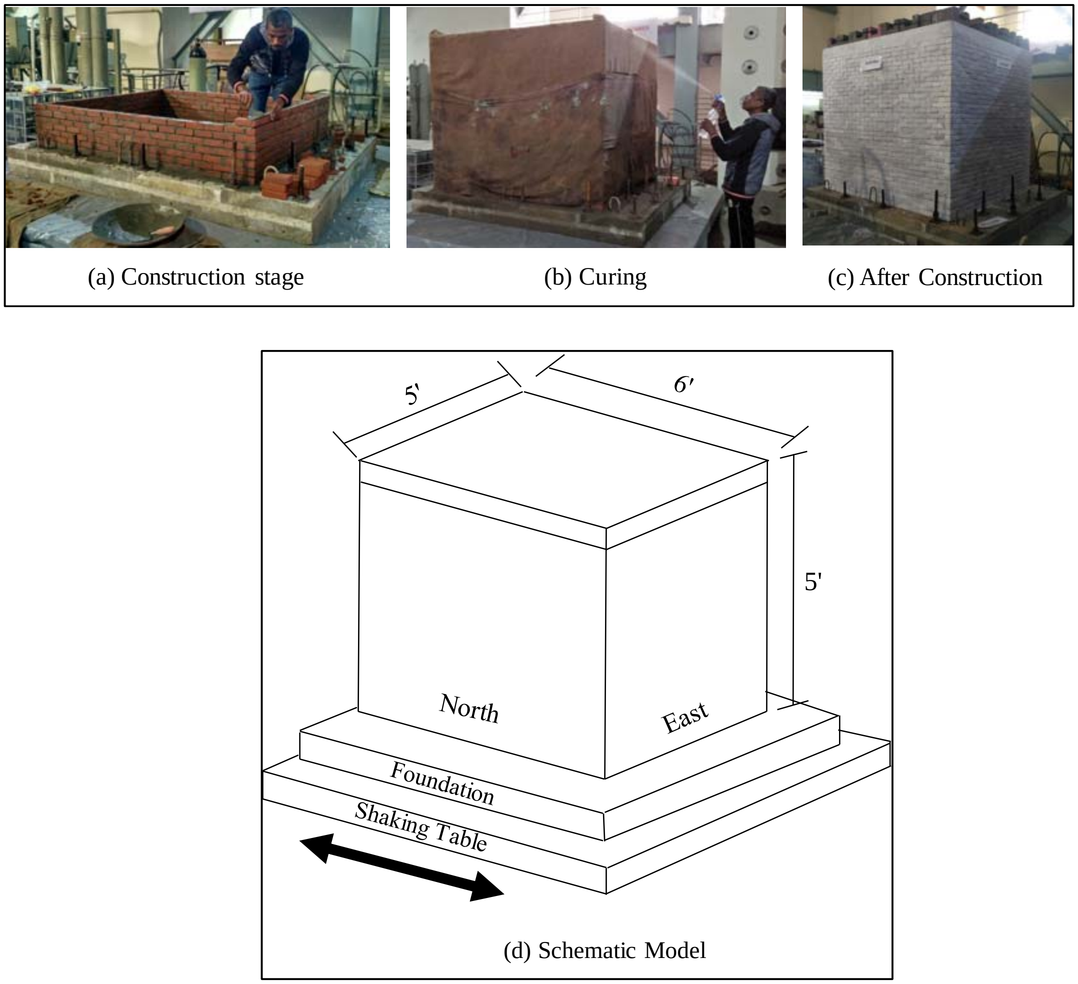


Figure 0.2 Unreinforced Masonry Room

Size of the slab is 6' x 5' (length x width) with 3" thickness. The slab was design considering 20 psf (20 nos weight =20*20 kg/weight=400 kg) live load on the slab and 220 lb/ft (100kg/ft) load on the wall as axial compression and those loads was calculated according to the rules of scaling. The model was tested considering two storey building and 220 lb/ft comes from the upper storey.

6 mm reinforcement was provided at 4" c/c in both direction. This reinforcement is more than calculated reinforcement as per the rules of scaling. This is because, the purpose of this test is to see the performance of masonry building not the slab. The reinforcement is cranked at L/4 distance from the edge of the slab. The extra top is 6" more than the calculated length. Total weight of the slab is 0.52 ton.

At first, the bare URM specimens (reference specimen) were tested without allowing collapse. Then, the reference specimen was upgraded using wire mesh and retested. For upgradation or retrofitting purpose 18 gauge wire mesh with 12mmx12mm (1/2" x 1/2") opening was used.

Table 3.1 Scale factors of the Cauchy similitude
(where p and m designate prototype and experimental model, respectively)

Parameter	Symbol	Scale Factor
Young's Modulus	E	$E_p/E_m=\lambda=1$
Specific Mass	ρ	$\rho_p/\rho_m=\lambda=1$
Stress	σ	$\sigma_p/\sigma_m=\lambda=1$
Strain	ε	$\varepsilon_p/\varepsilon_m=\lambda=1$
Length	L	$L_p/L_m=\lambda=2$
Area	A	$A_p/A_m=\lambda^2=4$
Volume	V	$V_p/V_m=\lambda^3=8$
Mass	m	$m_p/m_m=\lambda^3=8$
Displacement	d	$d_p/d_m=\lambda=2$
Velocity	v	$v_p/v_m=\lambda=1$
Acceleration	a	$a_p/a_m=\lambda^{-1}=1/2$
Weight	W	$W_p/W_m=\lambda^3=8$
Force	F	$F_p/F_m=\lambda^2=4$
Moment	M	$M_p/M_m=\lambda^3=8$
Time	t	$t_p/t_m=\lambda=2$
Stiffness	K	$k_p/k_m=\lambda=2$
Damping	C	$C_p/C_m=\lambda^2=4$
Frequency	f	$f_p/f_m=\lambda^{-1}=1/2$

To retrofit the model, firstly, the previous cracks were sealed by epoxy grout and then the white wash of the model was removed. The wire mesh was wrapped along the whole length of the wall. Wire mesh was applied to the all four walls. The wire mesh was attached to the wall with royal bolt. After that, plaster was applied on all four walls. For rapid strength gain of the plaster, cement grout was used with chemical. After eight days retrofitted sample was retested. Figure 0.3 shows the application process of wire mesh and plastering. Wire mesh was applied only on the wall. Wire mesh was not extended to connect with the base.

(a) Wrapping and bolting of Wire Mesh (b) Plastering

Figure 0.3 Retrofitting Procedure

Instrumentation

Two piezo-resistive accelerometers (500mV/g) were used during the dynamic testing of masonry building. One accelerometer mounted to the earthquake simulator while the other was attached to the slab of the building. The accelerometers were positioned to record motions in the direction of testing. Table 3.2 summarizes the accelerometer locations and their sign conventions.

Table 4.1 Accelerometer locations

Accelerometer No.	Location	Direction of Positive Acceleration
1	Attached on Shake Table	Loading Direction (W-E)
2	At top of the model	Loading Direction (W-E)

The displacement response of the models at critical locations was measured using laser displacement sensor (LDSs) and acquired in data-acquisition system at a sampling rate of 200 Hz to capture deformation in the direction of loading and. One LDSs was built into the hydraulic actuator that drove the earthquake simulator. Two LDSs were positioned to the building to record motions of the wall in the direction of testing while two additional LDSs were added to measure out of plane displacements of the wall. Figure 0.1 illustrates their locations on reference sample and on retrofitted sample.

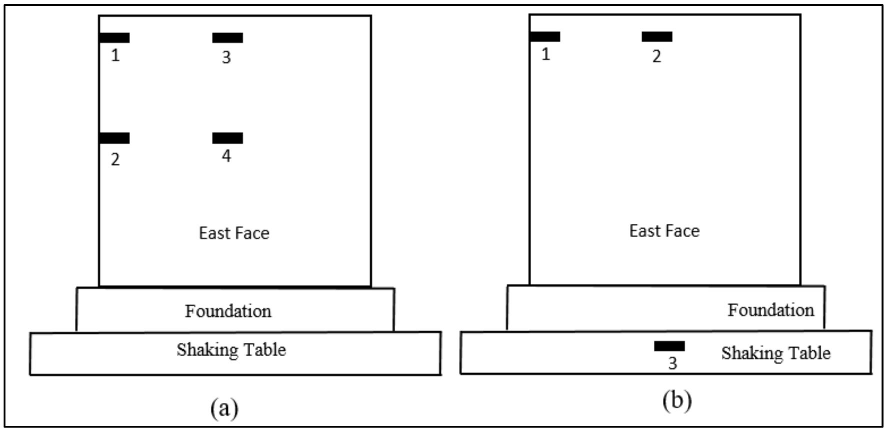


Figure 0.1 Locations of LDSs

Earthquake simulator

The earthquake simulator used in this dynamic testing of masonry room is resident in the Earthquake Engineering Laboratory of BUET-JIDPUS, BUET. The platform measures 3mx3m (10' x 10') and is supported by six bearing pad for the movement of shaking table. Total platform height of the shaking table is 15". The platform itself is a 38mm solid MS plate supported by/welded with six (6) nos longitudinal T-beam and three (3) nos transverse T-beam in multiple bay. Platform are threaded which form an $7\frac{3}{3}^{"}x7\frac{3}{3}^{"}$ center to center bolting pattern. The hole of the shake table is 20mm in diameter. An instrumentation datum is attached to one end of the simulator platform for collecting measurements relative to the platform base. The simulator is driven by a 25 ton hydraulic actuator driven hydraulic power system (HPS) attached to three-stage electro-hydraulic servo-valve with a total capacity of 200 gallon per minutes (gpm). Table 3.9 shows the specification of shake table. The simulator is controlled via DANCE (Version 632.2) software which was supplied by ANCO Engineers Inc. DANCE is also capable of providing rapid graphical display of the data once the test is complete. After a test had been completed, the data from the various channels was exported in a text format.

Table 5.1 Specification of Shake Table of BUET-JIDPUS

Shake Table Specification
Size: 3m x 3m (10'x10')
Actuator: 25 ton$ Servo Hydraulic Actuator
Acceleration Capacity: 1.6g maximum acceleration with 10ton payload
Bare table Acceleration: 4.0g
Velocity Capacity: 100 cm/s (40 inch/sec)
Displacement Capacity: +/- 100mm (±4 inch)

Dynamic Testing

The test was conducted with incremental acceleration ranging from 0.27g to 1.05g using Imperial Valley Earthquake. Between each earthquake simulation, visible damage was noted and recorded. Prior to their testing, model structure was painted white to facilitate crack identification and marking. Cracks were marked with colored pens, with a different color used for each run that induced new cracks. The retrofitted model was tested in the same procedure. Figure 0.1 shows the complete model with instrument.

Figure 0.1 Complete Experimental Setup

Experimental Results

In-plane, out of plane and overall behavior of URM model was observed through eyewitnesses and recording devices. During the testing, notes were made on the visually-observed behavior of the test structures. The seismic action was applied to the structure in a phased procedure, with a sequence of incremental amplitude levels of accelerograms imposed. Table 7.1 summarizes the test sequence with the actual Peak Ground Acceleration (PGA) measured from the base of the models, corresponding to distinct acceleration value of the seismic input.

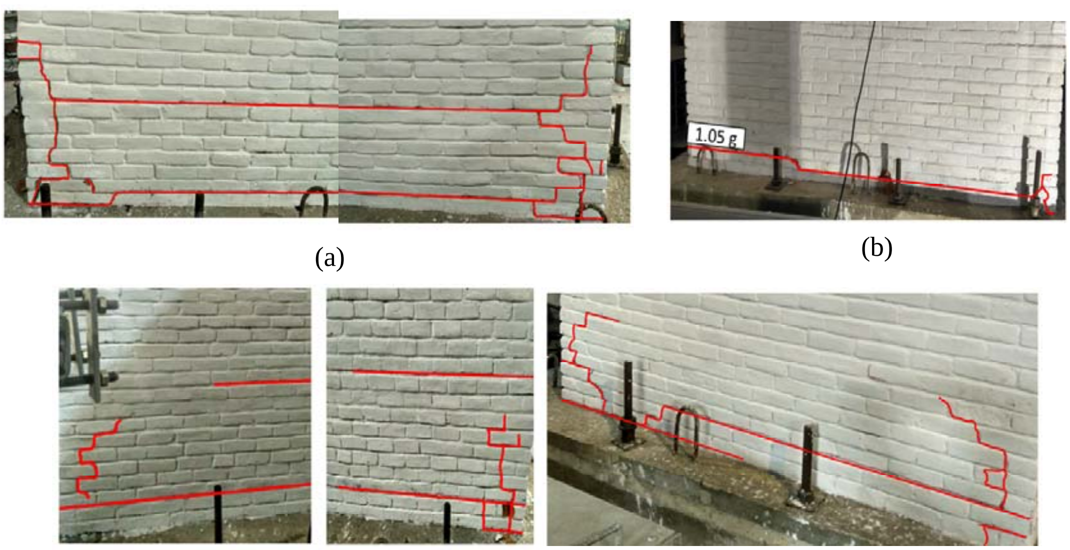
Table 7.1 Seismic Input and corresponding Peak Acceleration at Shake Table

Run	Table Acceleration (g) of Reference Model	Table Acceleration (g) of Retrofitted Model
1	0.27	0.195
2	0.36	0.25
3	0.41	0.328
4	0.59	0.38
5	0.66	0.52
6	0.76	0.77
7	0.83	0.9
8	0.92	1.02
9	1.05	1.15
10	-	1.24
11	-	1.34
12	-	1.45
13	-	1.49
14	-	1.45

It is clear from the recorded acceleration that retrofitted mode can sustain more than 1.4 times acceleration than reference model. First crack was initiated at 0.83g in reference model while in retrofitted model first crack was initiated at 1.49g, which is approximately 1.8 times more than 0.83g. Shear diagonal stepped cracks developed at the unit mortar interface even in the bricks, starting from the corner of the wall. In the east wall (out of plane wall-perpendicular to the direction of loading), both horizontal and stepped cracks developed at the lower part. Horizontal cracks also developed at the height of L/4 of height from the bottom. Mostly all the cracks developed along the unit-mortar interface, some bricks also were also cracked. Due to the lack of low flexural resistance and low vertical compression, These horizontal cracks were developed. For retrofitted model, total fourteen seismic motion were run and no visible cracks were observed in the wall for the first eleven run in which acceleration range was from 0.27g to 1.45g. In twelve run at an acceleration of 1.49g, which is the maximum acceleration, cracks develop at the base of the model in all wall. This is due to the sliding of the wall. After retrofitting, model become stiff- this stiffness as well as low vertical compression accelerate the sliding of the wall. In the next following run, a vertical crack developed at the bottom of north-west corner of the north wall and no other visible cracks were observed in any other wall. The cracks along the base was further extended and the model was totally separated from the base. The cracks distribution in in-plane walls and out of plane walls are shown in Figure 0.1.

Table 7.2 Crack Distribution in different acceleration of Reference Model

Run	Table Acceleration (g) of Reference Model	Crack Distribution
1	0.27	no crack
2	0.36	no crack
3	0.41	no crack
4	0.59	no crack
5	0.66	no crack
6	0.76	no crack
7	0.83	visible crack in out of plane wall (east) in bed joint
8	0.92	visible crack in out of plane wall (east), in-Plane wall (north, south) along the head and bed joint
9	1.05	visible crack in out of plane wall (east), in-Plane wall (north, south) along the head and bed joint. Previous cracks were extended



(a) (b)

(c) (d)

Figure 0.1 Cracks in in-plane wall (a,b) and out-of-plane wall (c,d)

Displacement Characteristics

For each test run, displacements at four points of the structure were measured by the laser sensors; two at mid heights of the two walls (In-plane and Out of plane) and two at the top of the two walls. It is to be noted that all the values of the displacements were relative to the base of the structure. This relative displacement was measured by subtracting base displacement from the recorded displacement at top. Approximate deflected shape of the in-plane wall and out of plane wall is shown in Figure 0.1and Figure 0.2.

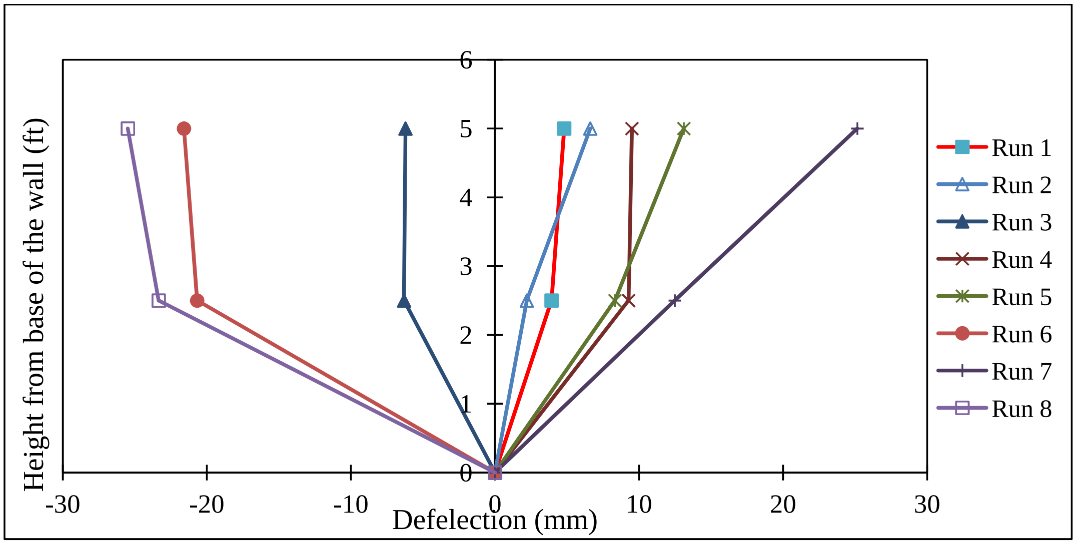


Figure 0.1 Approximate deflected shape of In-Plane wall for maximum top deflection

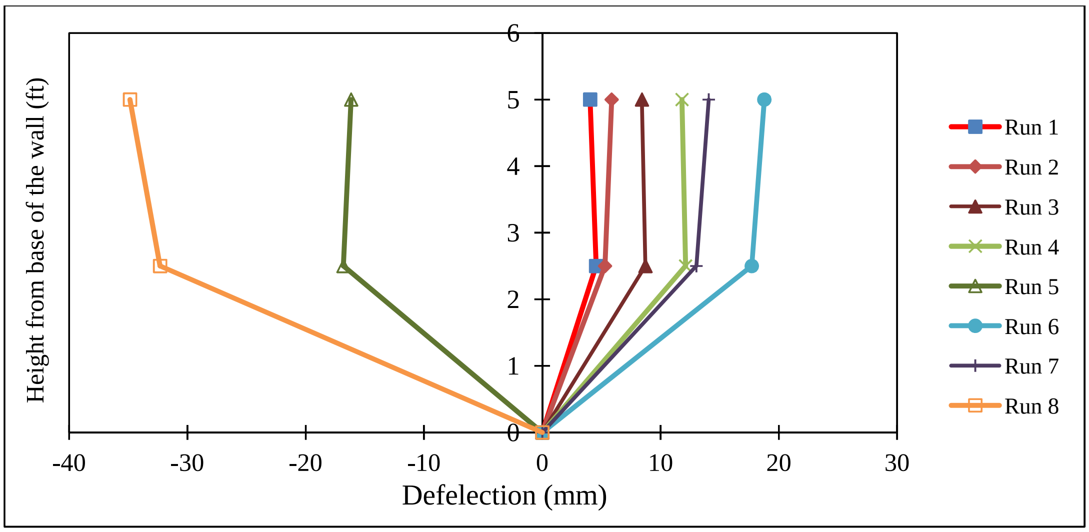


Figure 0.2 Approximate deflected shape of Out-of-Plane wall for maximum top deflection

During the tests conducted after retrofitting, the displacement data of walls were taken with one laser sensor for each wall. Two sensors were placed to record the wall top displacements, each at the top of one In-plane and one Out of Plane walls; one sensor was placed to record the displacement of the shake table. The displacements of one wall top relative to the table was found by subtracting the table displacement from the recorded displacement at wall top. Afterwards, the maximum displacement at wall top of in-plane and Out of plane wall for each run are plotted in Figure 0.3 and Figure 0.4 respectively.

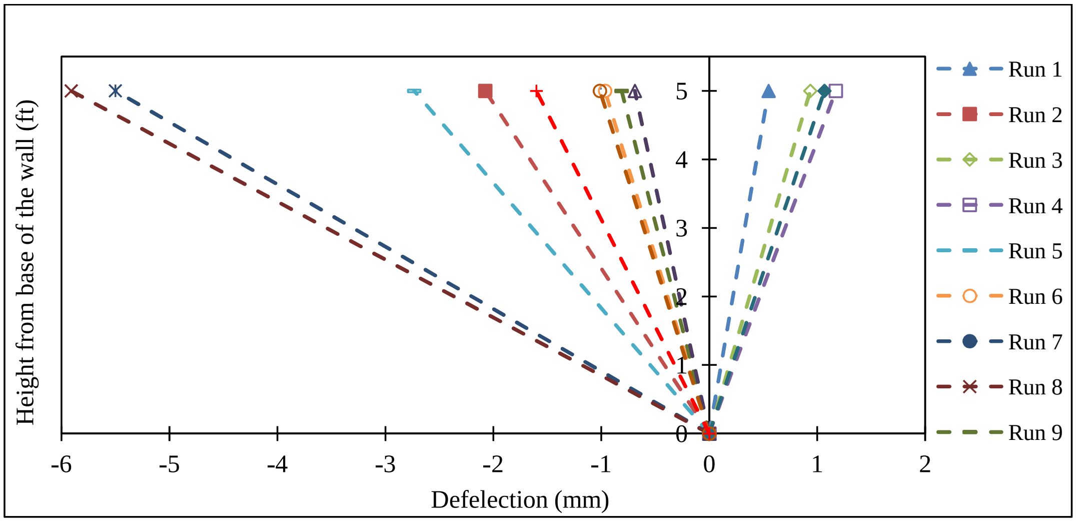


Figure 0.3Approximate Deflected shape of In-Plane wall for maximum top deflection

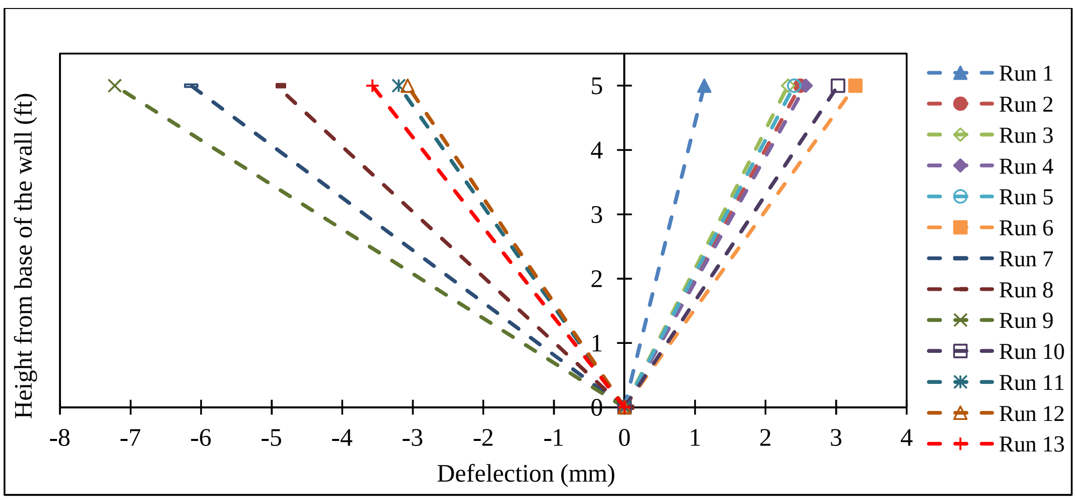


Figure 0.4 Approximate Deflected shape of Out-of-Plane wall for maximum top deflection

Load Characteristics

The lateral force was computed as a multiple of the roof mass (2.08-tons), slab weight and weight of upper half of the walls times the measured roof acceleration/total acceleration ignoring damping force. Since the motion is unidirectional, the lateral force will mostly be carried by in-plane wall. Therefore the force is divided by two. The lateral force is plotted versus the measured relative lateral displacement producing what are commonly referred to as hysteresis loops. Figure 0.1and Figure 0.2 depicts the lateral force vs relative displacement for reference model.

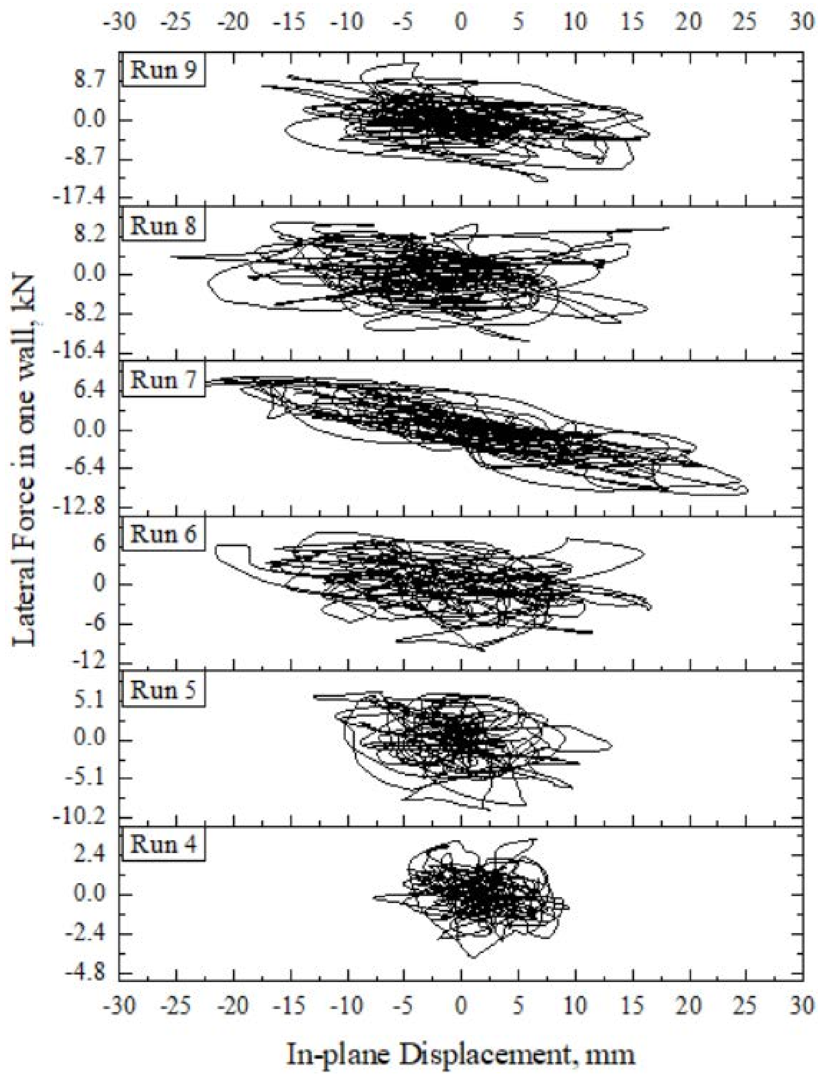


Figure 0.1 Lateral Force vs. Relative Lateral Displacement of in-plane wall for reference model

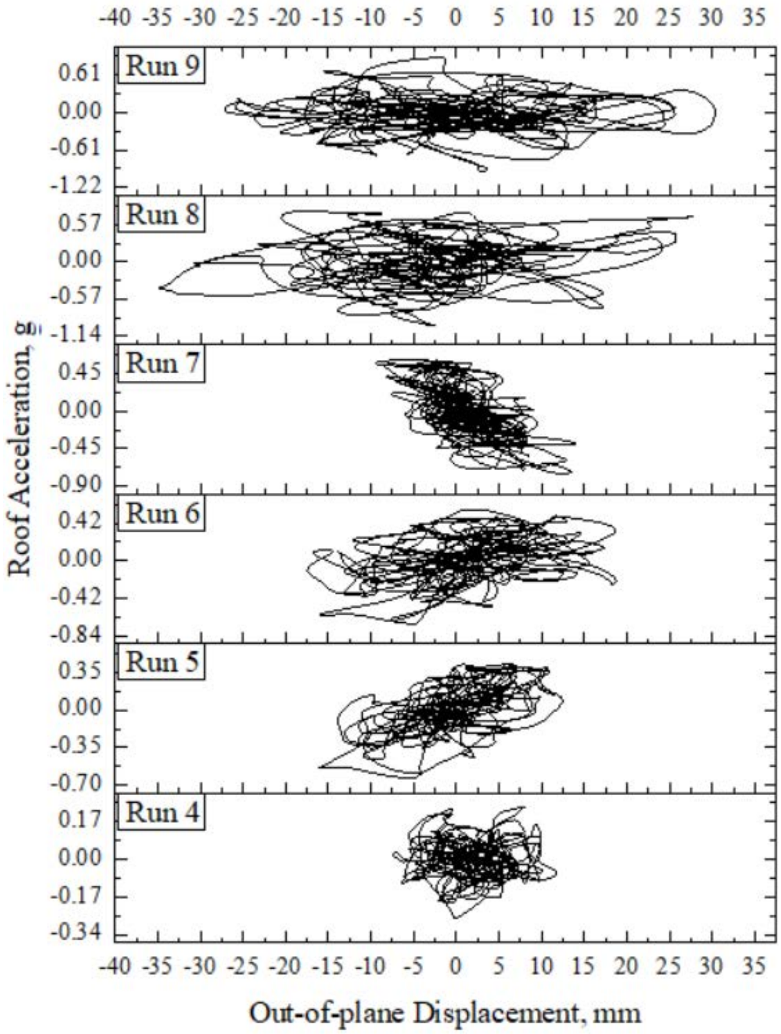


Figure 0.2 Roof Acceleration vs. Relative Lateral Displacement of out-of-plane wall for reference model

For the retrofitted model, lateral force is calculated multiplying the load of the upper half of the model with roof acceleration ignoring damping force. Lateral force at roof level is computed multiplying roof acceleration by roof mass, weight of slab and half of walls weight. The lateral force is then plotted versus measured relative displacement. Using in-plane wall displacement data following hysteresis loop was derived which is depicted in Figure 0.3and Figure 0.4.

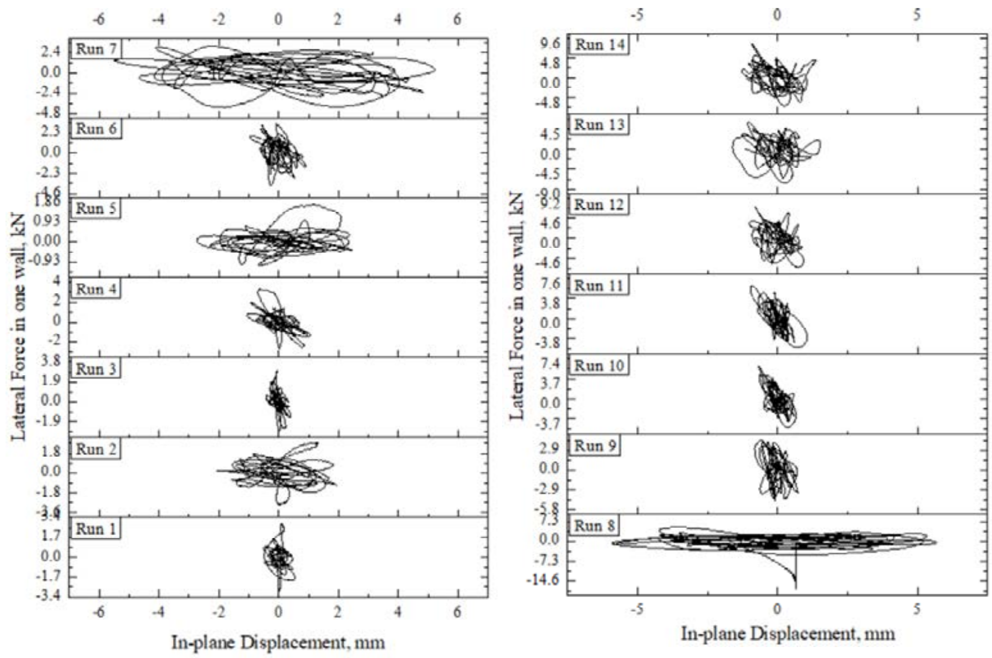


Figure 0.3 Force-Displacement relationship for in-plane wall of Retrofitted Model

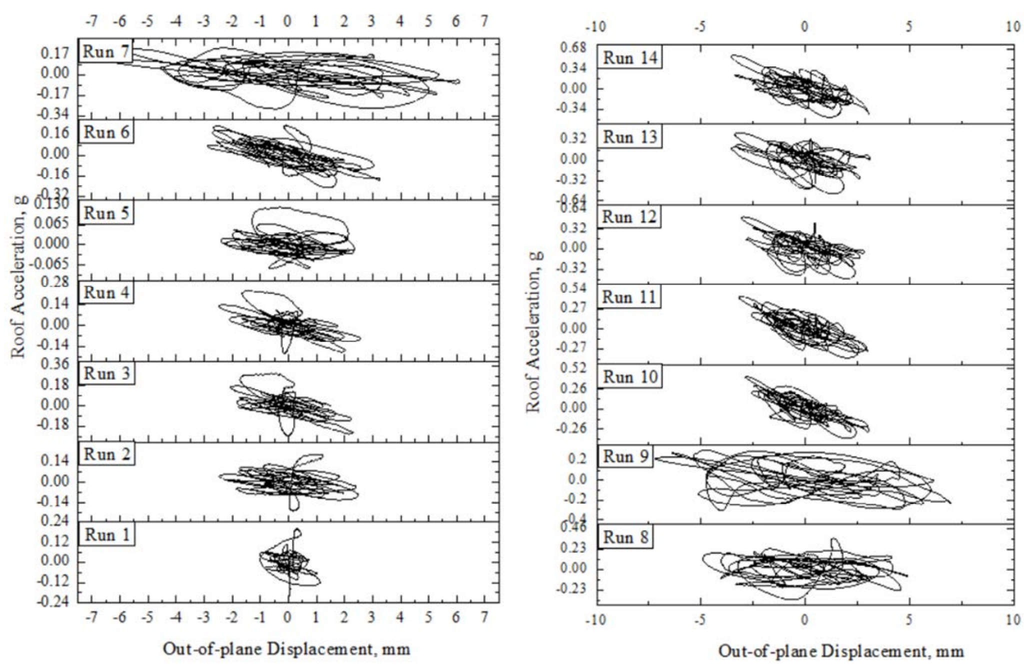


Figure 0.4 Force-Displacement relationship for out-of-plane wall of Retrofitted Model

Conclusions

Behavior of unreinforced masonry room (bare and with retrofit) under dynamic loading were investigated in this study. Based on the results obtained from the experiment of the specimens, the following observations can be drawn:

i. The cracks in the bare sample are mostly localized in the corner of the wall and those are stair-stepped cracks. Lateral sliding along the bed joints are also visible in the in-plane and out of plane wall. Cracks are mostly generated in the lower 1/3 length of the walls (both in-plane and out of plane wall). Therefore, corners are mostly vulnerable in earthquake.

ii. First crack was observed in the out-of-plane wall. So special consideration need to be taken in case of design of masonry buildings.

iii. In retrofitted sample, no visible cracks was observed in the wall exce[illegible]rtical crack in the in-plane wall. The failure was initiated along the intersection of base. So proper precautionary measures should be taken in the base-wall connection.

iv. The retrofitted model masonry structures was able to sustain 1.42 times more acceleration than bare model structure.

v. Retrofitting using wire mesh decrease the deformation of the structure around 4.3 to 4.8 times and increase the capacity of the structure to undergo more acceleration.

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PART-IX

SEISMIC LOSS ESTIMATION FOR WARD 14 OF MYMENSINGH, BANGLADESH

BANGLADESH NETWORK OFFICE FOR URBAN SAFETY (BNUS), BUET, DHAKA

Prepared By: Tamanna Akhter

Mehedi Ahmed Ansary

1. Introduction

Mymensingh district is located at 24°45' north latitude and 90°25' east longitude in Dhaka division on the west bank of Old Brahmaputra River. The municipality of Mymensingh was established in 1869 and its jurisdiction area covers 21.73 sq. km. with a total population of 258,040 people and density of 9,414 persons per sq.km (BBS, 2011). Among the 21 wards of Mymensingh Pourashava, Ward no. 14 has been selected as study area for this research which has an area of 0.54 sq. km. Figure 1 shows location of the study area in Mymensingh district and Mymensingh municipality. The study area lies in one of the earthquake prone areas of Bangladesh. The seismic zoning map of Bangladesh in which Mymensingh falls in Zone 3 with a seismic coefficient of 0.25g in BNBC 1993 (Table 1). However in the draft version Bangladesh National Building Code falls in Zone 4 with a seismic coefficient of 0.36g (Two-third of the value is .24g) which is shown in Figure 2 (Proposed BNBC, 2017). In this paper a comprehensive loss assessment of 14 no. ward, Mymensingh is presented. The purpose of the study is to evaluate the potential losses of earthquake based on Bangladesh National Building Code 2017 using Geographical Information System and to provide a basis for the study area to plan and prepare effectively for future damage of earthquake and to raise public awareness of the study areas' earthquake risk.

2. Geology of Study Area

Mymensingh district lies in the northern outlier of Madhupur Tract and within old Brahmaputra flood plain. Old Brahmaputra flood plain is located in the northeastern part of the Indian Plate which comprises low-lying alluvial plain of the latest Holocene period. The plain is bordered by Modhupur Tract and the Sylhet Depression in the East which is shown in Figure 3. Mymensingh is situated on the bank of Brahmaputra River and alluvial deposit of this area consists of flood sand to overbank silt and ponded clay (Sarker *et. al.*, 2010). The colors of the deposited materials are yellowish brown or gray to reddish-gray silt to clay. Oxidized upper 0.5m unit includes highland alluvial (Alam *et.al*., 1990) and some Holocene slope wash deposit adjacent to higher ground. According to PWD, the average elevation of the floodplain is less than 15m (Sarker *et. al.*, 2010). Other than Brahmaputra River, numerous channels; Sutia and Khiro River are the prominent one that drains this flood plain. Old Brahmaputra River and these channels have formed the drainage network of Mymensingh. In Figure 4 the Rivers in and around Mymensingh can be seen. Mymensingh is situated in the south of Sutia River, east of Khiro River and south-western of Old

Brahmaputra River. The out fall of Sutia River and Khiro River is the Banar River which is at the southern part forms the outlier of Mymensingh.

3. Tectono-Geomorphic Features of Study Area

Tectonic activities of an area convey some expressions to the geomorphology of that area. Tectono-geomorphic evidence of past and present is important for the understanding of tectonic activities of an area. Mymensingh lies in the eastern part of Jamuna valley which is situated in the central part of the Bengal Basin. On the regional context, the Bengal Basin lies to the northeastern part of the Indian Plate which is characterized by complex tectonic environment. Some tectonic elements are active and are creating many tectono-geographic features. The examples of some lineaments produced by these features are Madhupur lineament, Manikganj lineament, Nagarpur lineament. These lineaments depict four tectonic blocks e.g. Nagarpur block, Saturia block, Jamalpur block and Madhupur block which is shown in Figure 5. Madhupur block is the raised one on the east of Jamuna valley. Each block is characterized by certain tectonic geomorphic features (Islam *et. al.,* 1995). Mymensingh is located on the northeastern part of the above-mentioned block.

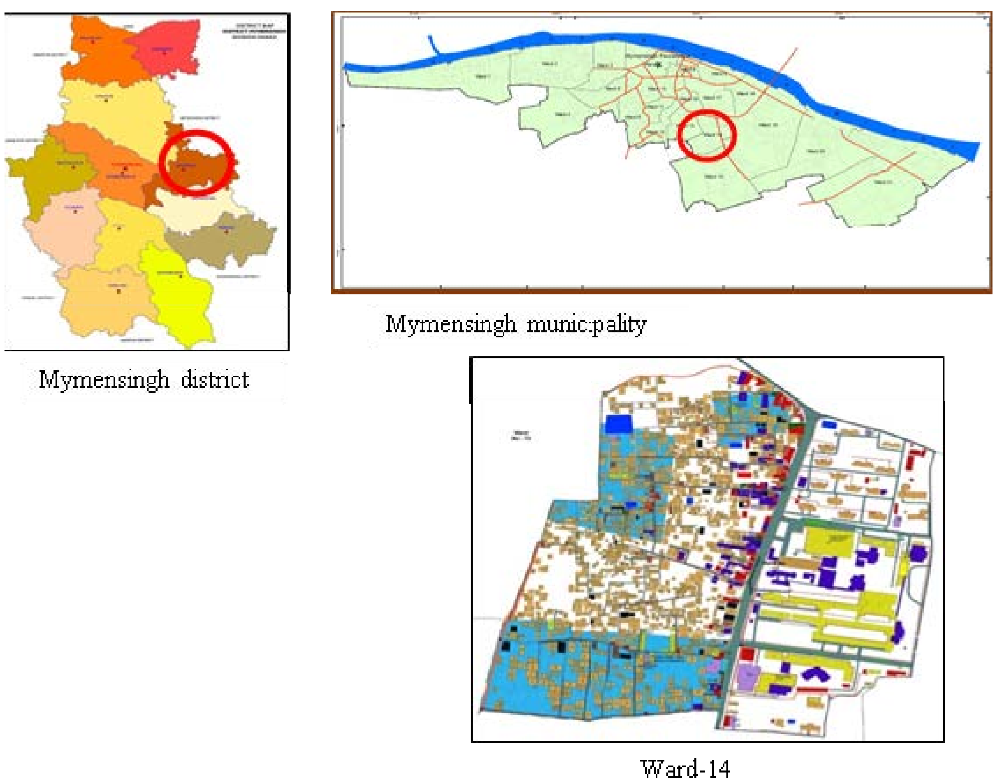
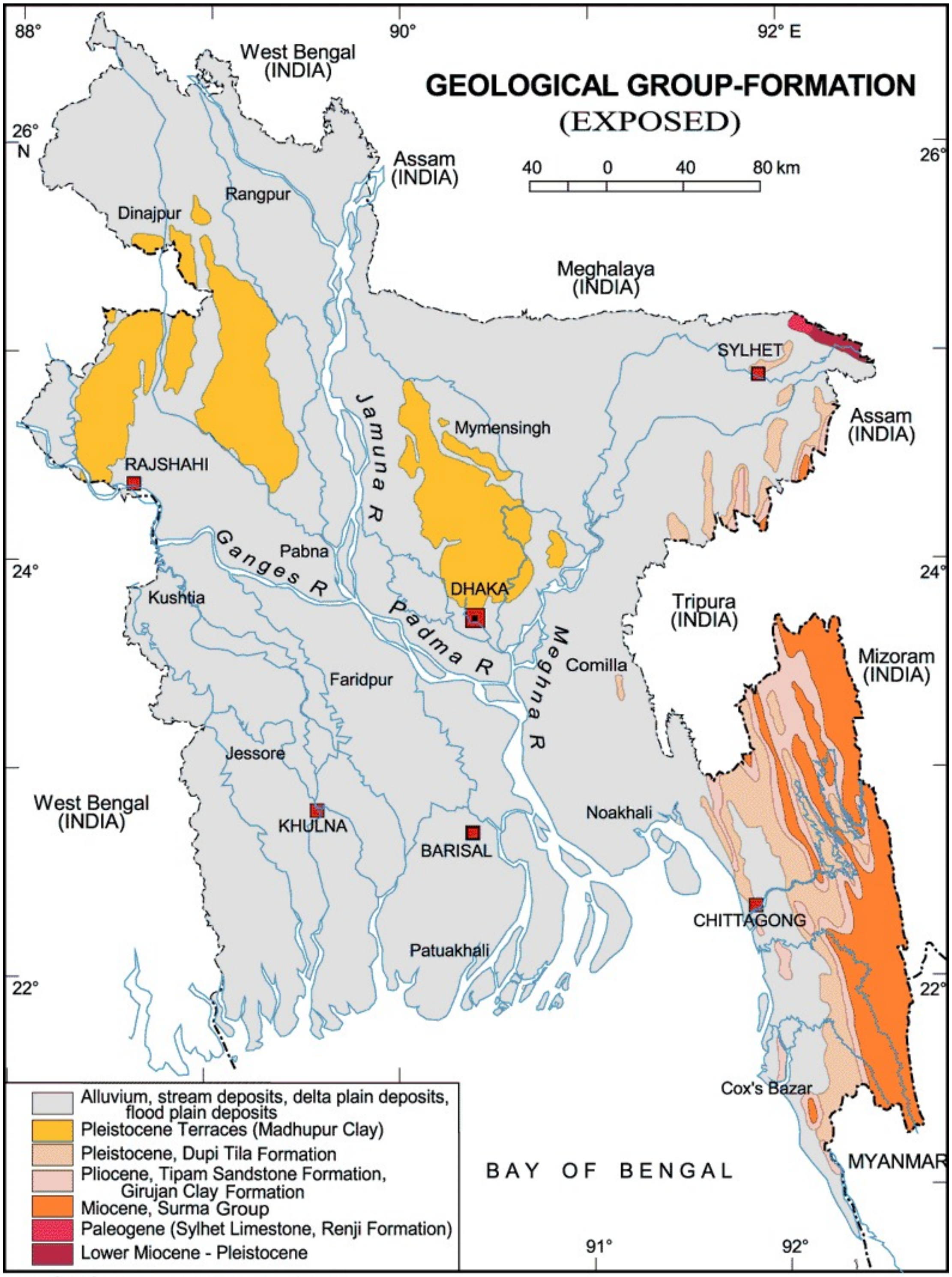


Figure 1: Location map of Ward No. 14 of Mymensingh Municipality (Source: Mymensingh Pourashava, 2017)

Table 1: Seismic zones of Bangladesh in BNBC 1993

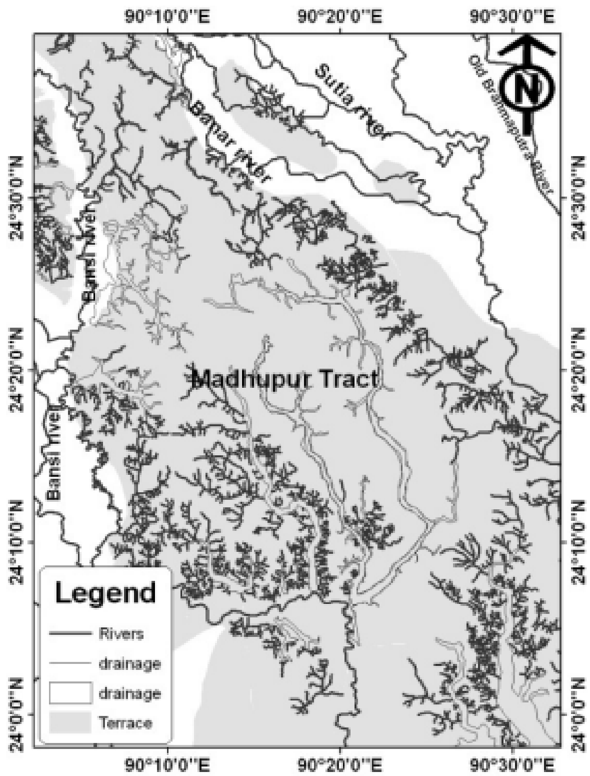
Zone	Area
I	South-East Bangladesh (Seismically least active)
II	Dhaka, Comilla, Noakhali and Chittagong
III	North and Eastern regions of Bangladesh (Seismically most active)

Figure 2: Proposed seismic zoning map for Bangladesh (Source: Proposed BNBC, 2017)



Modified from *Reimann, Klaus-Ulrich,* 1993

Figure 3: Madhupur Tract and its surrounding floodplains (Source: Geological Group Formation (Exposed): Bangladesh, 2015)



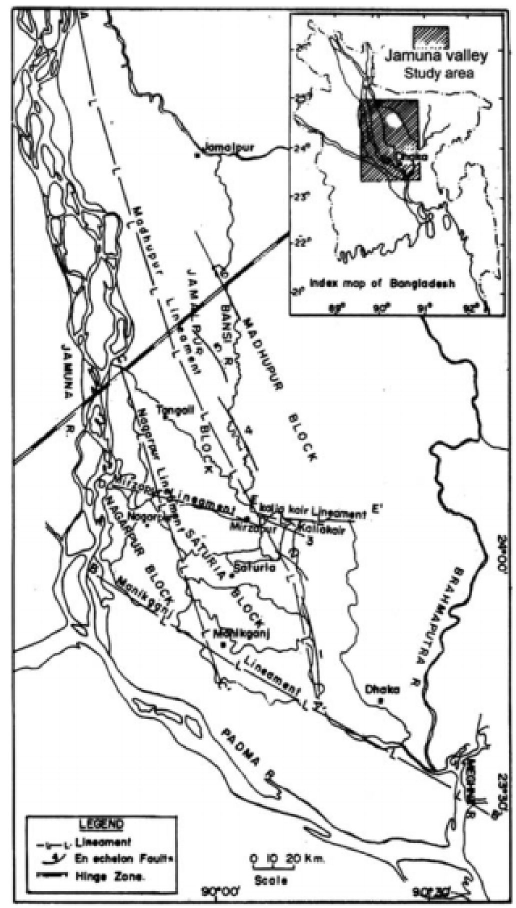


Figure 4: Madhupur Tract and Rivers in and around Mymensingh

Figure 5: Tectonic and lineament map of the eastern part of Jamuna valley (Islam *et. al.*, 1995)

4. Study Area Profile

4.1 Demographic Profile of Study Area

The total population of 14 no. ward, Mymensingh is 12,142 and the population density is 22,485 per sq. km. The male and female population ratio of the study area is 47.06 percent and 52.94 percent respectively. The total number of households in the area is 2,194 and average family size is 4.5 (BBS, 2011). The percentage of population aged below 30 years is 63.3% and 36.7% people of the study area are aged above 30 years (Field Survey, 2017). The literacy rate of study area is 75.1%. The primary occupations of people in the study area are: service (80.6%), agriculture (11.7%) and industry (7.6%). Mymensingh Medical College and Hospital which is a regional health facility is situated in this area (BBS, 2011).

4.2 Land use Characteristics of Study Area

Figure 6 shows the existing land use of Ward No. 14, Mymensingh Pourashava. The major land use of study area is agricultural use, open space, barren land, water body etc. (38.8%).

Road network covers a large portion of the land parcel (21.8%). Another major land use of the study area is residential land use (15.1%). The share of land for health facility is 13.3% as Mymensingh Medical College and Hospital is situated in the study area occupying a large portion of the area.

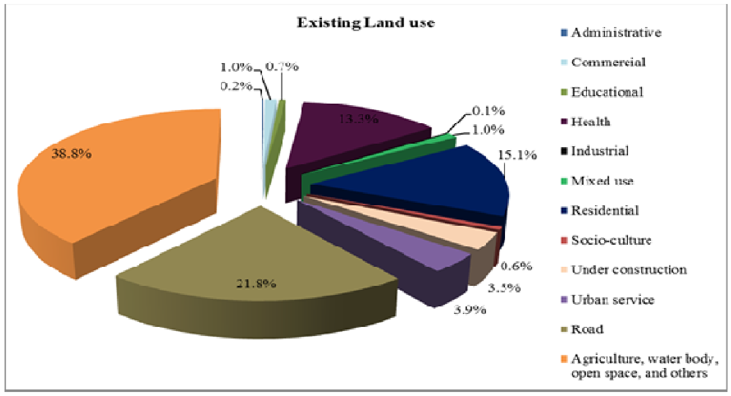


Figure 6: Existing land use of Ward no. 14, Mymensingh Municipality (Source: UDD, 2016 and Updated GIS Map, 2017)

4.3 Building Characteristics of Study Area

In the study area there are 1,611 buildings where 535 building are RCC structure, 208 of them URM structure and rest semi-pucca, kutcha and under-construction buildings. Most of the buildings in the study area lack setback space around them and the adjacent road networks in the study are too narrow for vehicular movements (Field Survey, 2017).

4.4 Storey and Average Floor Area of the Buildings of the Study Area

Figure 7 shows the cluster wise numbers of buildings with respect to number of storey. From this figure it can be seen that most of the buildings are one or two storied (58%). The percentages of two and three storied buildings are also prominent 17% and 16.7% respectively. The high rise buildings (i.e. six storied or higher) are situated along the Mymensingh- Dhaka highway.area (including 6 to 10 storey buildings). Figure 9 shows the numbers of buildings with respect to average floor area. From the field survey it can be seen that buildings having an average floor area of 500-1500ft are dominant. It has also been seen from the field survey that among RCC structures, the percentage of Soft storey is about 4%, which are vulnerable in Earthquake.

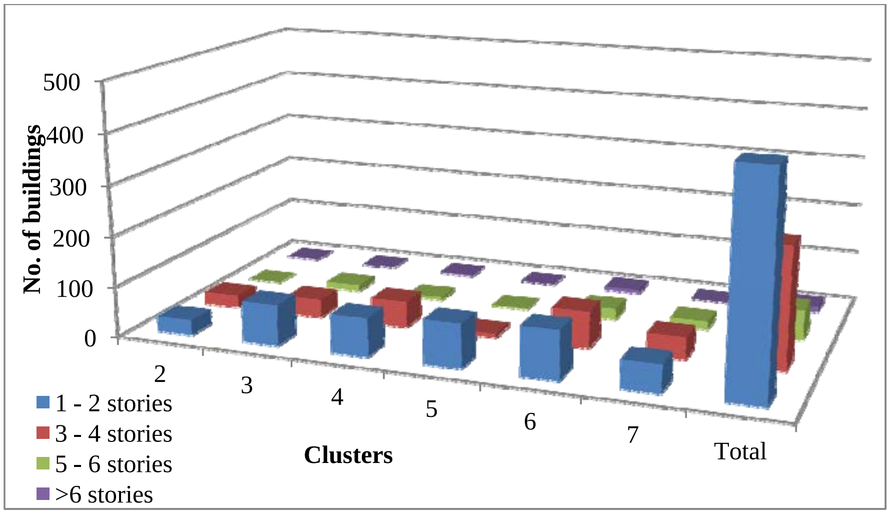


Figure 7: Cluster wise distribution of building according to storey (Source: Field Survey, 2017)

Figure 8 shows the floor area of buildings with respect to building storey and number of buildings of 14 no. ward, Mymensingh. From the figure it is visible that the number of one storied buildings is prominent in this area and the floor area is below 2500 ft. There are a few multi-storied buildings found in the study area. For most of the 6 or more storied buildings the floor area is >8500ft.

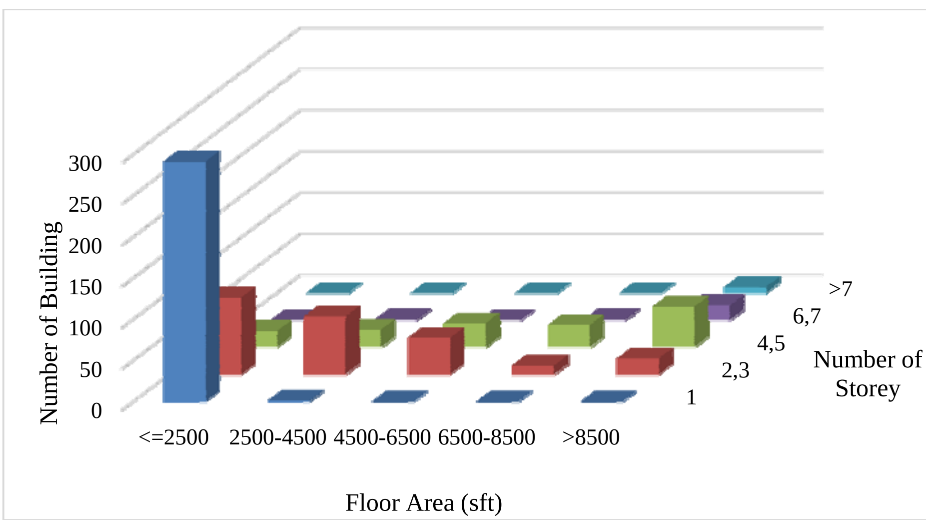


Figure 8: Cluster wise distribution of building according to storey and floor area (Source: Field Survey, 2017)

From Figure 09 the average floor area of buildings within different clusters of 14 no. ward Mymensingh can be seen. In most cases the average floor area of one storied buildings are less than 150 sq.m. For two and three storied buildings the average floor area is below 500 sq.m. On the other hand most of the buildings having four stories and more their average floor area is greater than 500 sq.m. For cluster 2, the average floor area of any storied buildings are greater than other clusters as the area is the property of Mymensingh Medical College and other clusters are basically privately owned land.

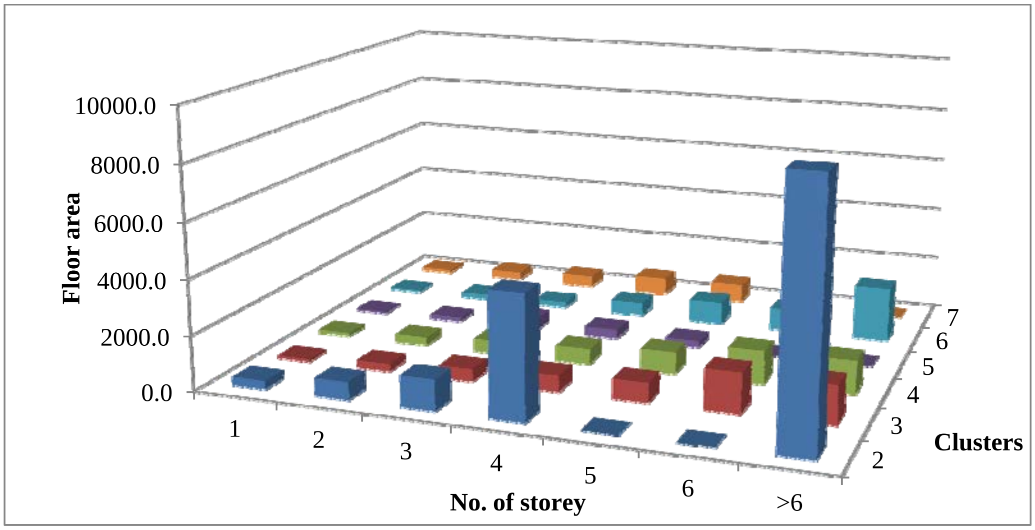


Figure 9: Cluster wise distribution of average floor area of buildings

4.5 Construction Year of buildings of the Study Area

From figure 10 it can be seen that, among the surveyed buildings, major portions (58%) of building were constructed after 2000 indicating that the area is new development area of the pourashava. Although the construction of URM buildings have been decreased after 2015 which was high before 2005. Almost two thirds of the buildings are less than 20 years old while around 16% is built before 1990.

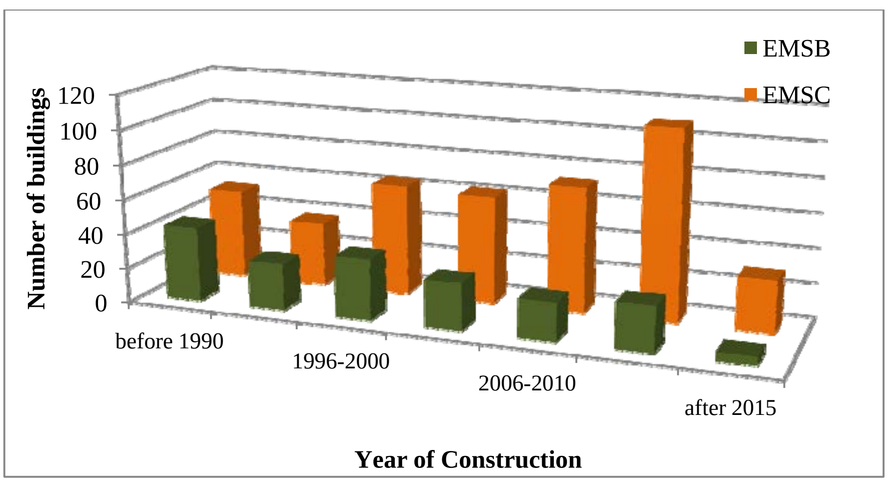


Figure 10: Construction year of the surveyed buildings

(Source: Field Survey, 2017)

5. Methodology of the Study

5.1 Selection of Study Area

Among 21 wards of Mymensingh municipality, ward no. 14 has been selected as study area. The area has density of 22,485 people per sq.km (BBS, 2011). In this region Mymensingh Medical College has been located which is a regional health facility. The population density of this area has been increased over time and the construction of buildings has been taken placed without considering the vulnerability of earthquake. The road network of the study area is too narrow for any rescue mission at any emergency situation (Field Survey, 2017). In this regard the study aims to assess the potential loss of the study area after occurrence of any earthquake event. To conduct the study the area has been divided into 7 clusters.

5.2 Seismic Exposure Assessment

For the purpose of seismic exposure assessment, data on ten (10) boreholes up to 100 ft. depth and undisturbed soil samples of the study area and five Microtremor tests with five sensors were collected from Bangladesh University of Engineering and Technology. From previous studies it has been found that the area is not susceptible to liquefaction (Sarker *et. al.,* 2010). So the liquefaction analysis is excluded from the study.

5.3 Building Vulnerability Assessment

In study area, 1611 buildings have been found in the field survey among them semi-pucca buildings are predominant (52%). The percentages of pucca and katcha buildings are respectively 38.5% and 9.5%. For building vulnerability assessment, 735 buildings were surveyed among them 517 buildings were RCC buildings, 206 of them were URM buildings and 12 of them were tin-shade structures.

Table 2: Building Classification (Field Survey, 2017 & BBS, 2011)

Cluster	Housing Unit	EMSB1	EMSB2	EMSC	EMSF
2	56	0	35	22	0
3	131	21	26	84	2
4	136	8	15	110	3
5	97	31	28	34	5
6	198	27	19	150	2
7	117	0	0	117	0

Total	**735**	**80**	**126**	**517**	**12**

Table 3: Definition of Building Classifications (Sarkar *et. al.*, 2010)

No.	Type	Description
1	EMSB1	1-storied brick masonry of fired bricks with cement or lime mortar, roof is either of GI sheets or other materials
2	EMSB2	2-storied or taller brick masonry of fired bricks with cement or lime mortar
3	EMSC	Reinforced concrete frame with low ductility, designed for vertical load only
4	EMSD	Reinforced concrete frame with moderate ductility, designed for both vertical and horizontal loads
5	EMSF	Mainly bamboo, wooden and steel structures

6. Assessment of Seismic Hazard

For the assessment of seismic hazard HAZUS a post-earthquake management model have been used in US (Schneider and Schauer. 2005). HAZUS can develop a risk management tool. It is not suitable for Bangladesh to use the tool because of lack of data availability. For the assessment of seismic hazard in 14 no. ward of Mymensingh Microtremor test has been done in nine locations to calculate the Peak Ground Acceleration (PGA value).

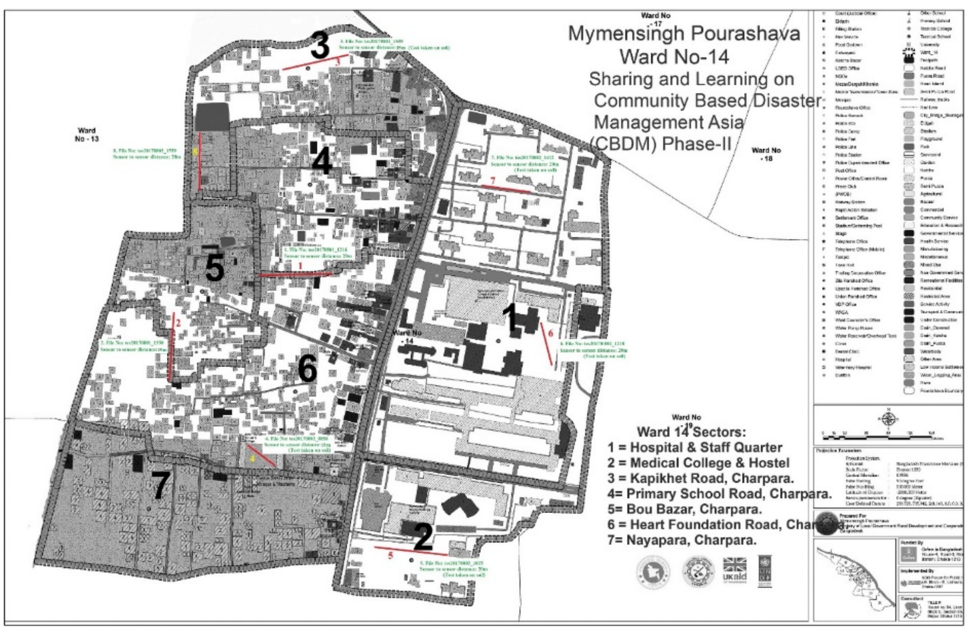


Figure 10: Location of Microtremor test 14 no. ward of Mymensingh (Map Source: UDD, 2016)

From the test it has been cluster 6 has the highest PGA value (0.68g) whereas the average PGA value lies between 0.4-0.5g. By using the following equation (Equation 1) the intensity of earthquake in the clusters of the study area have been determined by using PGA value.

$$\log(PGA) = 0.014 + 0.3\,(MMI) \qquad (1)$$

As the PGA value is high for the clusters of the 14 no. ward, Mymensingh; the area is highly susceptible to a disaster event like earthquake. From Figure 12 it is visible that, the occurrence of an earthquake event will have an intensity of VIII-IX in the study area. It can also be seen that cluster 2A and cluster 6 are the most vulnerable areas resulting in severe damage to structures and high fatality and injury level.

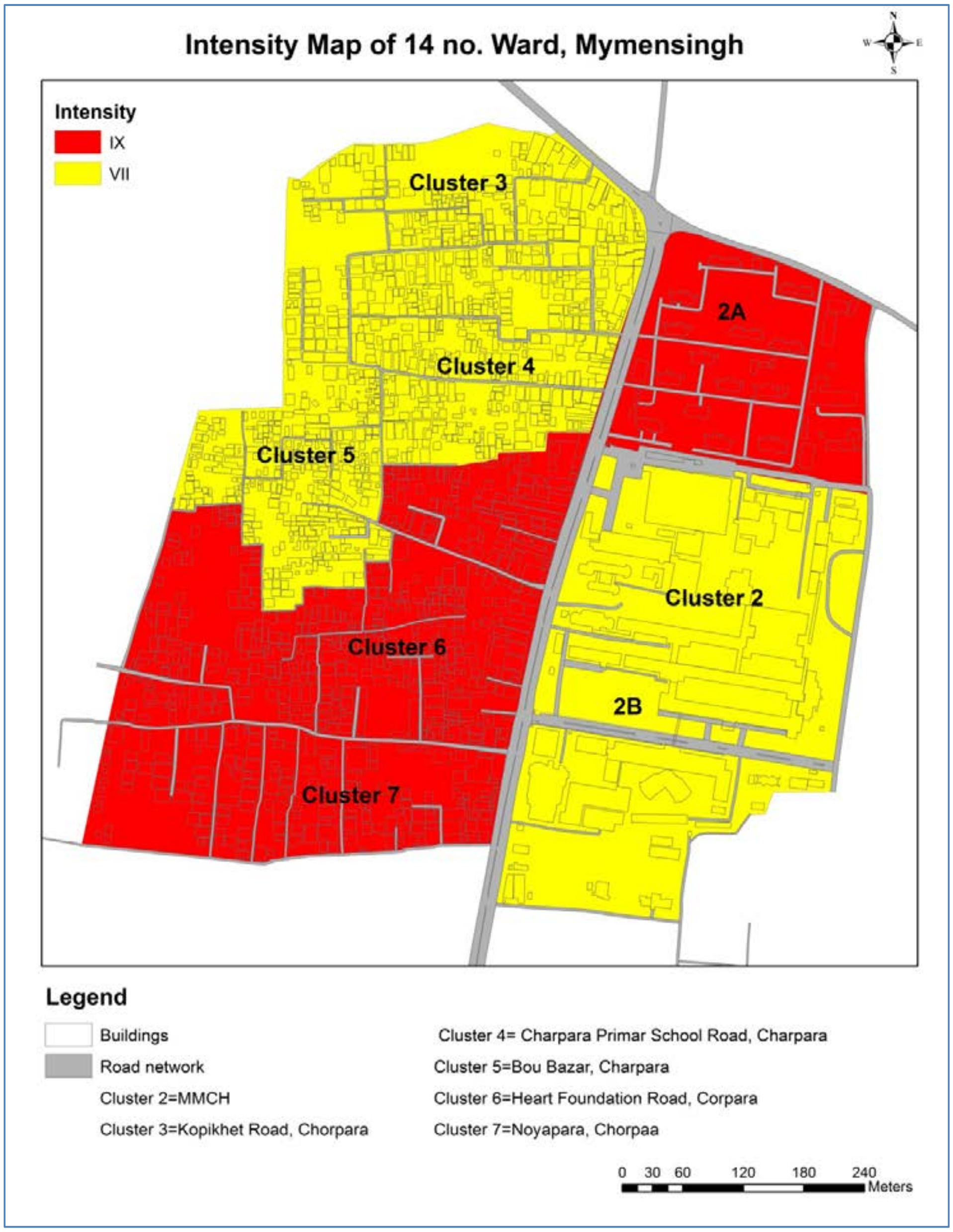


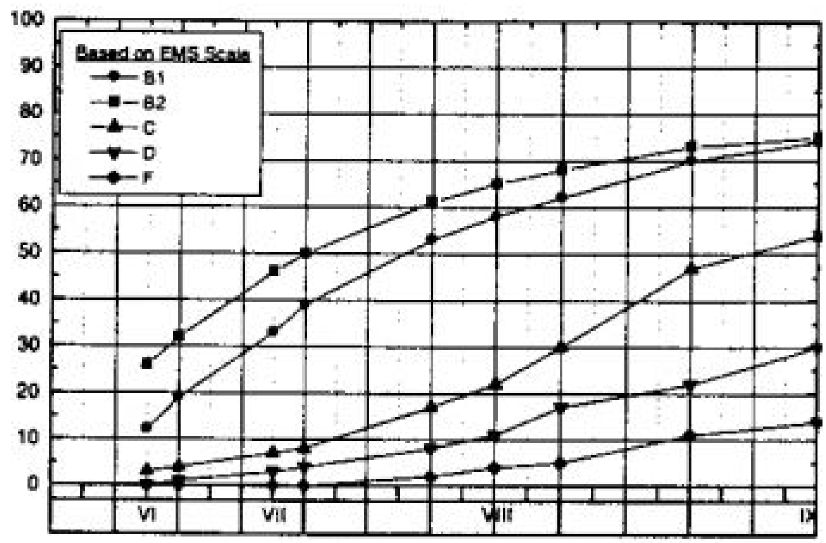
Figure 11: The intensity map of 14 no. ward, Charpara

7. **Assessment of Seismic Damage**

7.1 Distribution of Damage

In this study, fragility curves are used in the FEMA/NIBS methodology to estimate building damage from ground shaking of earthquake (Whitman *et. al.,* 1997). Fragility curves are log-normal functions that can predict the probability of structural and non-structural damage states for a given level of earthquake response. For Indian Buildings, a number of fragility curves are prepared by Arya (2000) and for Nepalese buildings prepared by Bothara *et. al.,* (2000). A number of fragility curves are also prepared for different types of structure and for different earthquake intensities (Kircher *et. al.,* 1997; Fah *et. al.,* 2001; Yamazaki and Murao, 2000; Yamaguchi and Yamazaki, 2000; Bommer *et. al.*, 2002). As there are no fragility curves available for structures of Bangladesh, Indian and Nepalese curves may be the most suitable for Bangladesh. In this study, fragility curves for the buildings of study area were prepared by calibrating the existing fragility curves of Arya (2000) and Bothara *et. al.*, (2000). But they didn't mention the type of damages to be estimated by these fragility curves which was quoted for heavily damaged structures by Segawa *et. al.*, (2002).

Average Loss Ratio (%)



Intensity caused by earthquake

Figure 12: Fragility curves for different type of buildings based on EMS intensity (Source: Ansary, 2004)

From the previous section it has been found that the clusters of 14 no. ward, Mymensingh are located in severe earthquake zone. Incidence of an earthquake at the intensity of VII-IX will result in heavy damage of life and property. The table below shows the possible damage of different types of structures in the clusters of the area. From the table it can be seen that 51% of the surveyed buildings will be affected by earthquake. As cluster 2A and cluster 6 are more vulnerable to earthquake, there is a probability of heavy damage of buildings 73% and 58%. The other clusters will also face severe destruction to earthquake. About half of the buildings are estimated to be affected at an event of earthquake having VIII intensity level. From the map it is also visible that cluster 3 and cluster 4 will be less affected to earthquake compared to other clusters. When the damage is estimated in terms of number of buildings, it has been found that cluster 6 will have highest number of buildings susceptible to be damaged. As the cluster is large compared to others and densely populated and the roads are too narrow for vehicular movement (Field Survey, 2017). On the other hand the buildings of cluster 2A are URM structures which made the cluster vulnerable to earthquake.

Table 4: Estimation of Building Collapse as a result of earthquake

Cluster	Total No. of Buildings	Possible No. of Destroyed Buildings					Cluster wise Total No. of Destroyed buildings/ Cluster wise Total No. of buildings	Cluster wise Total No. of Destroyed buildings/ Total No. of buildings
		B1	B2	C	F	Total		
2A	18	0	13	0	0	13	73%	2%
2B	38	0	12	9	0	21	53%	3%
3	131	13	18	25	0	55	42%	8%
4	136	5	11	47	0	64	47%	9%
5	97	19	19	10	0	49	50%	7%
6	198	20	14	81	0	116	58%	16%
7	117	0	0	59	0	59	50%	8%
Total	**735**	**58**	**87**	**230**	**1**	**376**	**51%**	**51%**

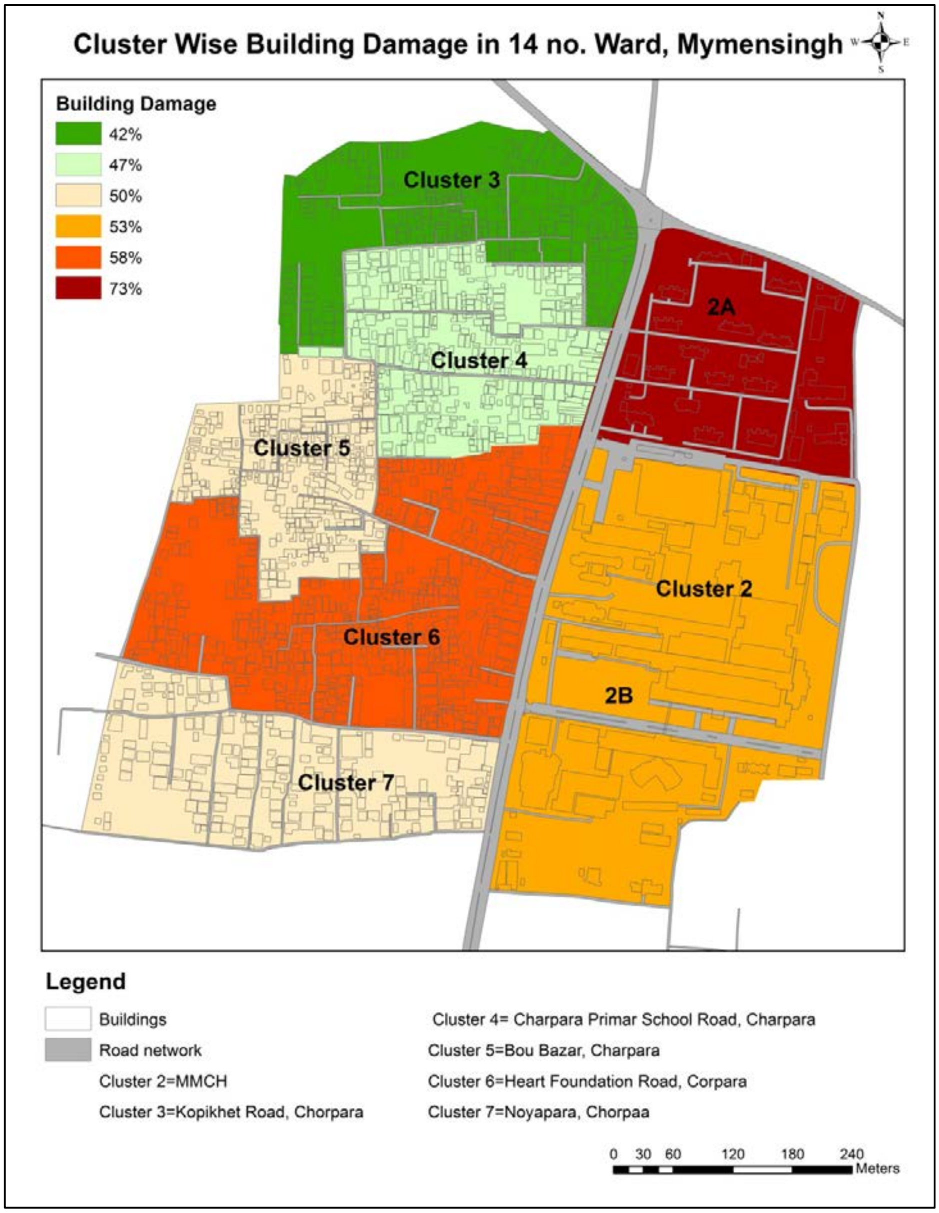


Figure 13: Building damage of 14 no. ward Mymensingh

7.2 Human casualty

To assess the levels of human casualty as a result of earthquake, the estimation of average fatality and injury levels have been used. To derive these figures, mortality prediction model for different types of structures has been used. This prediction model is prepared based on the investigation of human casualty of previous century due to occurrence of several major earthquakes (Coburn *et. al.*, 1992). The total number of people that may be killed due to building damages can be represented by:

$$Ksb = Db*[M1b * M2b * M3b * M4b]$$

Where Db= Total number of damaged household of type b,

M1= Occupant density (Population per household)

M2= Occupancy of buildings at the time of earthquake

M3= Proportion of occupants trapped by collapse of buildings

M4= Proportion of occupants killed or injured in the earthquake.

The occupancy cycle proposed by Coburn and Spence (1992) shown in Figure 14 for residential and business structures. The occupancy rate can vary for these buildings depending on the occurrence time of the earthquake. Depending on the time of earthquake the occupancy rate can be found (Figure 14). Human casualty also depends on the type of building. It has been observed that the number of death of trapped occupants due to building collapse of multi-storied masonry and reinforced concrete buildings are high compared to masonry buildings. For the purpose of the determination of occupancy rate, the figure is not used as the occupancy of the clusters are available for 14 no. ward of Mymensingh.

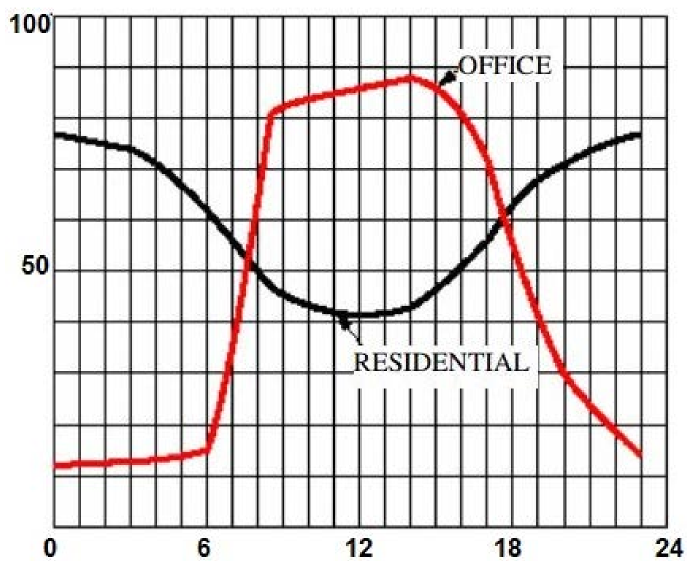


Figure 14: Building occupancy at the event of earthquake (Coburn *et. al.*, 1992)

From Table 5 the potential death of the occupants at the event of earthquake can be seen. In the study area Mymensingh Medical College is located which is a regional health facility. People from all over Mymensingh come for medical treatment. So the occupancy at the day is high in this cluster compared to night. The occurrence of earthquake at night will cause more death and injury to the residents as most people will be at their house and have a chance to get trapped. The injury and death rate is found to be high in cluster 6 as the occupancy at the day time and night are high in this cluster.

Table 5: Possible human casualties on different clusters of Mymensingh 14 no. ward at the event of earthquake (UDD, 2016 & Sarkar *et. al.*, 2010)

Clusters	Occupancy/ Day	Injury/Day (6.6% of total population)	Death/Day (5.5% of total population)	Occupancy/ Night	Injury/Night (8.3% of total population	Death/Night (7% of total population)
2	4161	275	229	373	31	26
3	2006	132	110	1837	152	129
4	1635	108	90	1607	133	112
5	362	24	20	691	57	48
6	2719	179	150	2900	241	203
7	1323	87	73	2480	206	174
Total	**12206**	**806**	**672**	**9888**	**821**	**692**

8. Economic Loss Estimation

The potential damage of buildings and human casualty have been calculated in the preceding section of the article. The economic loss of such damages will be calculated in Table 5. The estimation is done based on the following assumptions-

- New construction cost of fully collapsed buildings- BDT 2000 per sq.ft
- Retrofit of partially collapsed building- BDT 400 per sq.ft
- Subsidy to the family members for one fatality- BDT 1000000
- Medical bills for a hospitalized person- BDT 50000

In this study 376 buildings are estimated to be affected by an event of earthquake (Table 6). In the field survey 269 buildings have been found to be vulnerable which are considered to collapse totally. The remaining 107 buildings are considered to be partially collapsed. For the purpose of economic loss estimation, cluster wise average floor area has been calculated. As a result of partial and total collapse of buildings a monetary value has been estimated which is 92369.3 lakhs and 7347.6 lakhs respectively (Table 5).

Table 6: Economic loss estimation of 14 no. ward, Charpara

Cluster	Number of building	Possible no. of collapsed building	Possible no. of partially collapsed building	Average floor area	Cost of retrofitting (In lakhs)	Possible no. of totally collapsed building	Average floor area	Cost of new construction (In lakhs)
2	56	33	0	10953.7	0.00	33	10953.7	7229.4

3	131	55	12	1316.7	63.20	43	1316.7	1132.3
4	136	64	14	1532.4	85.81	50	1532.4	1532.4
5	97	49	16	748.4	47.90	33	748.4	493.9
6	198	116	44	1146.8	201.84	72	1146.8	1651.4
7	117	59	21	1469.4	123.43	38	1469.4	1116.7
Total	**735**	**376**	**107**	**17167.4**	**7347.62**	**269**	**17167.4**	**92360.3**

On the basis of the assumptions in this section, potential economic loss at the event of an earthquake occurrence in 14 no. ward of Mymensingh has been calculated. The direct economic loss is estimated to be **114161.4** lakhs in the study area which is vigorous for a ward. The Mymensingh Municipality in co-ordination with Government should encourage the residents and other stakeholders to follow the earthquake resistance guideline in order to construct buildings provided in national building code. An earthquake event may result in massive destruction of lives and properties in the area so it is necessary to ensure minimum loss to the individuals, society and nation.

Table 7: Total Economic loss of 14 no. ward, Mymensingh

Item		Physical Damage	Loss (In lakhs)
Human Injury	Day	806	403
	Night	821	410.5
Loss of human lives	Day	672	6720
	Night	692	6920
Total collapse of buildings		269	92360.3
Partial collapse of buildings		107	7347.6
Total Loss		**114161.4**	

9. Major Findings and Recommendations

- Almost 70% area will be affected by intensity level of VIII whereas 30% of study area will be affected by intensity IX. Cluster 2A and Cluster 6 will be mostly affected by earthquake compared to other clusters.
- Occurrence of earthquake at night time will cause more casualties which is more than 12% of total population (Table 5).

- About 376 buildings including RCC, URM and tin shade buildings are estimated to be damaged.
- A number of educational institutions and health facilities located in study area including Mymensingh Medical College are found to be vulnerable (Field Survey, 2017). Immediate actions should be taken to retrofit the buildings to reduce vulnerability of the locality.
- After occurrence of earthquake a large number of population will require temporary shelters because of massive destruction of their residence. In this regard, potential temporary shelters should be identified within the locality and facilitated with necessary amenities.
- For safe and immediate evacuation of the residents and others, Evacuation Route Planning should be introduced for the study area.
- Many people will require medical facilities after earthquake. To provide medical treatment to the injured people by an earthquake the safe and non-vulnerable health facilities should be identified.
- The massive destruction of an earthquake event will result in generation of tons of debris which should be removed for rapid evacuation. So Debris Management Plan should be introduced in the study area.
- Earthquake may also affect the utility lines of the study area. It may also cause damage to emergency services. Proper planning and act should be introduced to respond during disaster.
- From field survey it is found that the roads of study area are too narrow for vehicular movement. For proper evacuation roads should be widened so that vehicular movement is possible within the ward.
- Community level training and awareness program should be introduced. People of all ages and socio-economic groups should trained to be responsive during earthquake. The location of children, aged and disabled people within the community should be identified for the rapid evacuation and the data base should be continuously updated.

10. Conclusion

In recent times earthquake has become a regular phenomenon in Bangladesh. The impact of an earthquake having such high intensity will result in vigorous destruction to cities like

Dhaka, Chittagong, Mymensingh. The impact of such events should be reduced for both structural and non-structural features by taking initiatives. Immediate response to affected communities should be ensured by proper planning, response and management. The local, central government and other agencies should collaborate with each other for proper functioning during disaster. Emergency vehicles should be ensured for the rescue and transporting injured to the hospitals considering the road width of the area. Regular maintenance of the electricity, water and gas pipelines should be ensured and the firefighting and rescue teams should be well aware of the connectivity lines. Debris removal should be done within the shortest hours for the evacuation of the trapped people. In this study the potential damage caused by earthquake has been estimated for 14 no. ward of Mymesingh. Such studies should be introduced for the other wards of Mymensingh and integrated Earthquake Management Plan should be introduce to reduce the potential loss. Regular workshop and training should be held for awareness raising and capacity building of these localities. Government, public and private sectors and the individuals should come forward to ensure the minimum loss of life and property at the event of an earthquake.

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PART-X

VULNERABILITY OF READY MADE GARMENTS FACTORY BUILDINGS IN BANGLADESH: AN ASSESSMENT UNDER VERTICAL AND EARTHQUAKE LOADS

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1. Introduction

The safety of workers is endangered by accidents in an industry, which in turn adversely affect livelihood of their workers, their families, and those living in the vicinity of the industry. According to the International Labour Organization (ILO) every year over 0.35 million fatalities are caused by occupational accidents, and about 2.8 trillion (10^{12}) USD (around 4 per cent of the world's gross domestic product or GDP) is lost annually in direct and indirect costs (ILO 2014). Among different types of hazards in industry, building collapse is strongly related to structural safety.

In Bangladesh, Ready Made Garment (RMG) industry is one of the most important sectors, which emerged as a niche market for Bangladesh's export sector (Ansary and Barua 2015). The RMG sector has enjoyed a significant growth in Bangladesh for the last three decades resulting in impressive growth of RMG exports from Bangladesh (Wadud, Huda, and Ahmed 2014). Since this is a highly labor intensive industry (hence Bangladesh's competitive advantage through its abundant supply of unskilled cheap labor), the sector is also the largest industrial employer in the country with around 3.6 million people directly working in these factories. Thus, apart from its contribution in export earning, the RMG industry emerged as an important player in the economy in terms of employment generation, poverty alleviation and empowering of women (Rahman and Hossain 2010).

In recent years the sector is facing challenges regarding compliance with the international standard to ensure workplace safety and better working conditions for the millions of garment workers. Among different factors responsible for such condition the most important factor is the violation of the RMG factory buildings from minimum standards and construction legislation to ensure structural safety. RMG is a highly competitive industry and cost-saving is highly valued. Consequently, given the lack of a safety culture in the country in general, cost-cutting measures often affect the structural safety RMG buildings. The reluctant attitude of the stakeholders towards the structural and workplace safety compliance issues resulted in different occupational disasters in RMG factories in Bangladesh resulting in significant losses of lives, livelihoods (through injuries), equipment's and materials (Ahmed and Hossain 2009). Among different occupational disasters in RMG factories in Bangladesh Rana Plaza accident is one of the most significant. Rana Plaza collapsed on 24 April 2013 due to violation in building construction and occupancy resulting in 1,134 deaths and more than 2,500 injuries. It is the most fatal industrial accident in the history of Bangladesh RMG sector, and one of the deadliest industrial disasters in the world. This tragic accident received global attention, and brought forward diverse issues concerning millions of workers, employers, brands and consumers in Bangladesh RMG sector.

After Rana Plaza accident, several diverse national and international commitments and initiatives resulted as part of the reform and restructuring of the RMG sector aiming at improvement of workplace safety to safeguard the lives of over four million RMG workers and to retain the confidence of global buyers following the Rana Plaza accident. Among different initiatives, actions regarding structural safety of all active export-oriented RMG factories were addressed in all the action plans with a vision to ensure a safe working environment for all in the RMG sector. For this purpose, representatives of the Government of Bangladesh (GoB), employers' and workers' organizations, and the ILO agreed on initial structural integrity assessments of buildings housing RMG factories.

Bangladesh University of Engineering and Technology (BUET) and two private engineering firms TUV SUD Bangladesh (Pvt.) Ltd and Veritas Engineering & Consultant on behalf of the National Tripartite Committee (NTC), the Accord, and the Alliance are responsible for conducting structural and fire safety assessment of RMG factory buildings. To carry out the assessment with common approach, Guidelines for Assessment of Structural Integrity and Fire and Safety including harmonized standards have been developed by the technical experts (structural engineers, fire safety experts, etc.) from the BUET on behalf of the NTC, the Accord, and the Alliance. A review panel along with a review mechanism has also been established under Department of Inspection for Factories and Establishments (DIFE) to handle urgent safety issues in garment factories. Finally, in November 2013, the assessment activity has been officially commenced, led by professors from BUET.

Bangladesh is possibly one of the most vulnerable countries to potential earthquake threat and damage. An earthquake of even medium magnitude on Richter scale can produce a mass graveyard in major cities of the country, particularly Dhaka, Sylhet and Chittagong. Thus, assessment alone is not enough to ensure a safe working environment for all in Bangladesh RMG sector (Barua and Ansary 2016). The weak factory buildings are required to be strengthened to withstand both vertical and earthquake loads and consequently to prevent them from collapse. For this purpose it is necessary to understand the factors that are responsible for vulnerability of RMG factory buildings in Bangladesh to collapse due to vertical and earthquake loads.

Several studies have been carried out worldwide to understand vulnerability of buildings. Some researchers have focused on vulnerability assessment of buildings particularly for earthquake (Hassan and Sozen 1997, Porter, Kiremidjian, and LeGrue 2001, Cardoso, Lopes, and Bento 2005, Lagomarsino and Giovinazzi 2006, Lourenço and Roque 2006, Michel, Guéguen, and Bard 2008, DeJong and Vibert 2012, Wieland et al. 2012, Lagomarsino et al. 2013, Betti, Galano, and Vignoli 2014, Penna, Lagomarsino, and Galasco 2014, Chian 2016), tsunami (Dall'Osso et al. 2009, Dall'Osso et al. 2010, Suppasri et al. 2013), windstorm (Khanduri and Morrow 2003), hurricane (Pinelli et al. 2004), etc. Some studies focused on vulnerability assessment of particular building structure type, e.g. masonry buildings (Cardoso, Lopes, and Bento 2005, Lourenço and Roque 2006, Caliò, Marletta, and Pantò 2012, Lagomarsino et al. 2013), unreinforced masonry buildings (Betti, Galano, and Vignoli 2014), stone masonry structure (DeJong and Vibert 2012), reinforced concrete building (Hassan and Sozen 1997), etc.

Some researchers have studied structural behaviors or vulnerabilities using different models. Orsini (1999); Lagomarsino and Giovinazzi (2006); Lourenço and Roque (2006); Michel, Guéguen, and Bard (2008); and Lagomarsino et al. (2013) have developed and used models for the seismic analysis of buildings. Dall'Osso et al. (2009) and Dall'Osso et al. (2010) have developed and applied enhanced version of Papathoma Tsunami Vulnerability Assessment (PTVA) model that takes account of new understanding of the factors that influence building vulnerability. Lagomarsino and Giovinazzi (2006) have presented macro seismic and mechanical models for the vulnerability and damage assessment of buildings. DeJong and Vibert (2012) have created and used physical model and a discrete element computational model to investigate collapse under constant horizontal acceleration, impulse base motion, and earthquake ground motion for stone masonry structure. Caliò, Marletta, and Pantò (2012) have presented an innovative discrete-element model for simulation of the in-plane behavior of masonry buildings. Zhang et al. (2013) have applied automated safety rule checking using Building Information Models (BIM) for analyzing a building model to detect safety hazards and suggest preventive measures to users. Betti, Galano, and Vignoli (2014) have reported a comparison among different methods of analysis and different numerical models to estimate the seismic behavior of unreinforced masonry buildings. Chian (2016) have proposed engineering based building damage estimation model based on established theories of seismic wave propagation and structural resonance. None of these studies have focused on modeling vulnerability of buildings to understand the factors that increase vulnerability considering particular use of the building, especially for industrial use. In Bangladesh, some studies have been carried out focusing on structural assessment of RMG factory buildings in Bangladesh (Ansary and Barua 2015, Hodgson et al. 2016). But hardly any of these studies have focused on understanding the factors responsible for vulnerability of buildings to vertical and earthquake loads in Bangladesh considering particular use of the building.

There are many statistical modeling techniques that have been utilized by researchers to model different contexts, e.g. regression model, conditional logit model, multinomial logit model, multinomial probit model, ordered probit model, etc. Among them, the ordered probit model is most suitable when the specification of the utility is defined on a discrete and ordered scale to score the severity of factors (Daykin and Moffatt 2002, Greene and Hensher 2008, Garrido et al. 2014, Russo et al. 2014, Ye and Lord 2014). Ordered probit model has been utilized by researchers in different fields of researches for modeling injury severity in accident researches (O'donnell and Connor 1996, Duncan, Khattak, and Council 1998, Kockelman and Kweon 2002, Abdel-Aty 2003), impact of factors on transit use (Eboli et al. 2016), economic researches (Winkelmann 2005, Pietrovito, Pozzolo, and Salvatici 2016), household electricity saving behavior (Nakamura 2016), impact of family background, cohort and gender on educational attainment (Lauer 2003), job grading (Pudney and Shields 2000), firm relocation decision analysis (Van Dijk and Pellenbarg 2000), poverty analyses (Guagnano, Santarelli, and Santini 2016), consumer and consumption analysis (Huang, Kan, and FU 1999, Verbeke and Ward 2006, Harris and Zhao 2007, Jiang et al. 2016), hazard evacuation researches (Sadri, Ukkusuri, and Murray-Tuite 2013), risk assessment (Sakaguchi, Miyauchi, and Misawa 2013, Cameletti et al. 2016), etc. Considering the application of ordered probit model in such wide range of research fields and its suitability for application in this research, this statistical modeling technique is considered in this research.

In this background, this study aims to develop two separate models to explore and determine the key variables influencing RMG factory buildings' "Vertical Load Vulnerability" and "Earthquake Load Vulnerability" using ordered probit model.

2. Methodology

2.1 Sampling and data collection

In Bangladesh, BUET and two private engineering firms TUV SUD Bangladesh (Pvt.) Ltd and Veritas Engineering & Consultant on behalf of the NTC, the Accord, and the Alliance have been responsible for conducting structural vulnerability assessment survey of the RMG factory buildings due to vertical loads. Till March, 2016 survey and assessment of 3,746 factories have been completed. Among these factory buildings, Accord assessed 1,368 factories, Alliance assessed 829 factories and NTC assessed 1,549 factories, which includes 164 common factories assessed by both Accord and Alliance (DIFE 2016).Thus, structural vulnerability assessment data of all these 3,746 RMG factory buildings have been used in this research to understand the vulnerability of buildings to vertical loads. Among, these 3,746 RMG factory buildings, 478 buildings have been assessed by BUET experts. For structural assessment of RMG factory buildings, building vulnerability to earthquake loads have been considered by BUET along with the vertical loads. Thus, structural vulnerability assessment data of all these 478 RMG factory buildings have been used in this research to understand the vulnerability of buildings to earthquake loads.

2.2 Variables for Modeling Structural Vulnerability of RMG Factory Building

2.2.1 Variables for Assessing Vulnerability to Vertical Loads

To ensure uniformity of the data collection and assessment, Guidelines for Assessment of Structural Integrity and Fire and Safety has been developed by the technical experts (structural engineers, fire safety experts, etc.) from the BUET on behalf of the NTC, the Accord, and the Alliance including harmonized standards to understand building vulnerability to vertical loads for RMG factory buildings. All the responsible groups carried out data collection and assessment of RMG factory buildings on the basis of this guideline. Thus in this research, variables have been decided on the basis of this guideline. Based on the guideline four variables have been selected for modeling building vulnerability to vertical loads. They are:

a) Reduction in Column Capacity: Column capacity is one of the most important structural qualities of buildings that determine safety of buildings from any type building collapse due to vertical loads (Ansary and Barua 2015). Greater capacity of columns represents greater capacity of the buildings to withstand vertical loads and vice-versa. For understanding the vulnerability of RMG factory buildings, firstly the key columns of the buildings were highlighted to calculate their column capacity which was represented by Factor of Safety (FOS) of columns. FOS was calculated for each of the factory buildings, which is Column Ultimate Strength, divided by the Column Working Stress. Here, the Column Working Stresses were calculated comparing data set values and trigger points developed. Column

Ultimate Strengths of the key columns were calculated using equation (1) according to Bangladesh National Building Code (BNBC) (BNBC 1993).

$$P_n = 0.8\phi[0.85 f_c^{'}(A_g - A_{st}) + f_y A_{st}] \text{ ………………………………………………… (1)}$$

Where,

P_n = Ultimate Strength of a column

ϕ = strength reduction factor (= 0.7)

$f_c^{'}$ = compressive (cylinder) concrete strength

A_g = gross area of concrete section

A_{st} = area of reinforcement

f_y = steel strength

Based on FOS, the column capacity of the RMG factory buildings were categorized into three scales, where lower value of FOS were identified through higher scale which represents greater vulnerability. They are: low (1) for FOS value greater than 1.86, medium (2) for FOS value between 1.50 and 1.86, and high (3) for FOS value less than 1.50.

b) Structural System: In Bangladesh, generally two types of structural system are used to construct a RCC building, i.e. (i) Beam-Column and (ii) Flat Plate. Inherently, Flat Plate system lacks alternate load path making this system weaker than the Beam-Column system (Durrani and Du 1992). Combination of both of the systems makes it weaker to withstand vertical loads. Moreover, tin shed structures have least capacity to withstand vertical loads. Based on these findings, the RMG factory buildings were categorized into three scales based on structural system where higher scale represents greater vulnerability. They are: Beam-Column (1), Flat Plate (2), and Mixed (3).

c) Construction Materials: Structural capacity of a building to withstand vertical loads is greatly affected by ultimate strength since the elastic modulus is related to the ultimate strength. This ultimate strength largely depends on the properties of construction materials used (Kwon and Elnashai 2006). Thus, it can be said if the concrete strength is lower, the building will be more vulnerable. Generally in Bangladesh, two types of construction material are used, i.e. Brick, or Stone, or their combination. Average strength of Stone (3312 psi) is higher than the average strength of Brick concrete (2805 psi) (findings from laboratory test in BUET Lab).Thus, the RMG factory buildings were categorized into three scales based on construction materials where higher scale represents greater vulnerability. They are: Stone (1), Brick (2), and Mixed (3).

d) Bearing Capacity of Soil: The RMG factory buildings were categorized into three scales based on bearing capacity of soil where higher scale represents greater vulnerability. They are: Good (1), Fair (2), and Poor (3).

Table 1 shows summary of the variables and associated likert scales of measurement for modeling vulnerability to vertical loads for RMG factory buildings in Bangladesh. The model frameworks used to assess the RMG buildings' vulnerability to vertical loads is shown in Figure 1.

Table 1: Variables for modeling vertical loads vulnerability of RMG factory buildings

Name of Variables	**Scale (Greater value represents greater vulnerability)**		
	1	**2**	**3**
Reduction in Column Capacity	Low	Moderate	High
Structural System	Beam-Column	Flat Plate	Mixed
Construction Materials	Stone	Brick	Mixed
Bearing Capacity of Soil	Good	Fair	Poor

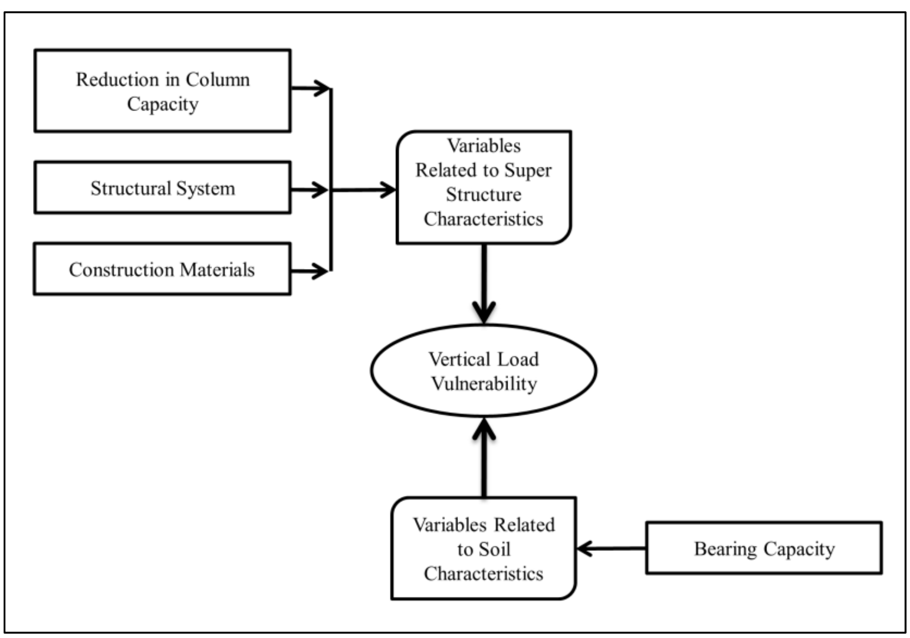

Figure 1: Model framework to assess RMG buildings' vertical load vulnerability

2.2.2 Variables for Assessing Vulnerability to Earthquake Loads

BUET experts have carried out the assessment of RMG factory buildings for vulnerability to earthquake loads on the basis of the standards mentioned for TIER-1 analysis in ASCE31-03 (ASCE 2003). This outline was used in this research to decide on the model Variables for modeling vulnerability of buildings to earthquake loads. Thus, twelve variables have been selected for modeling vulnerability of buildings to earthquake loads in this research. These twelve variables include four variables used for modeling building vulnerability to vertical loads, i.e. reduction in column capacity, structural system, construction materials and bearing capacity of soil. The reason is that, if the column capacity, structural system and construction materials of building do not have the capacity to withstand imposed live and dead loads certainly it will not have the capacity to withstand lateral loads like earthquake loads. Additionally, post-earthquake observations and experimental testing have shown that in such structures, lateral movements induced by earthquake ground motions combined with gravitational pull can make the connections between slabs and columns susceptible to punching shear failures (where the slab fractures around the column as if the column were punching through the slab), which can consequently cause floors or entire buildings to collapse (Durrani and Du 1992). Rests of the nine variables are:

a) Column slenderness: A column is identified as slender when, l/r ratio is greater than 35 (where "l" represents column height and "r" represents minimum dimension of column). Column slenderness reduces capacity of columns to withstand loads by a factor 1.18-0.009*(l/r) (Nilson 1997).Thus, the RMG factory buildings with l/r ratio greater than 35 have been identified to have column slenderness and consequently have been categorized as vulnerable.

b) Building shape: Building with equal or close to equal proportional width, length and height dimensions is identified as regular shaped building for which effect of lateral loads will be minimal. If the proportion varies, then the building is identified as slightly irregular shaped building for which the effect of lateral loads will be high. In case of, buildings with greater variation in the proportion of the dimensions (e.g. L-shaped building) the effect of lateral loads will be much higher which may cause building damage (FEMA 2015, 1998).Thus, the RMG factory buildings have been categorized into three scales based on building shape where higher scale represents greater vulnerability. They are: Regular (1), Slightly Irregular (2), and Irregular (3).

c) Soil liquefaction: Liquefaction-susceptible, saturated, loose granular soils that could jeopardize the building's seismic performance shall not exist in the foundation soils at depths within 50 feet under the building for life safety and immediate occupancy (ASCE 2003). If foundation soil is susceptible to liquefaction, then the building is considered as vulnerable. If soil beneath the building is loose sand and water table is shallow, the probability of occurrence of liquefaction is high. If soil beneath a building is liquefiable, the building is most vulnerable to earthquake loads. Liquefiable soil will not have any stiffness in case of lateral loads such as earthquake loads (Bird et al. 2006). Soil liquefaction cause serious damage to structures in case of earthquake loads. O'Rourke et al. (1991) provides an overview of areas in San Francisco which have been affected by soil liquefaction and significant ground deformation as a result of the Loma Prieta earthquake. Thus, the RMG factory buildings with liquefiable soil beneath have been categorized as vulnerable.

d) Building adjacency (pounding): There should be minimum distance between adjacent buildings for life safety and immediate occupancy. The clear distance between the buildings being evaluated and any adjacent building should be greater than 4 percent of the height of the shorter building. If the actual clear distance is less than this minimum distance, then there shall be pounding effect (FEMA 2015, 1998). The phenomenon is mostly observed in the old buildings that have been constructed before the advent and popularity of earthquake have been categorized as vulnerable.

e) Irregular Internal Frame: Building with beam-column system placed in a regular grid will behave well during an earthquake, whereas if the beams are not placed in a regular grid, the building will behave poorly (Yee et al. 2011). This condition is termed as irregular internal frame which increases vulnerability of a building to earthquake. Irregular frame structures lead to torsion, instability and localized damage (FEMA 2006). Thus, the RMG factory buildings with irregular internal frame have been categorized as vulnerable.

f) Column Shear Stress: The shear stress in the concrete columns should be less than the greater of 100 psi or $2\sqrt{f_c^`}$psi ($f_c^` =$ equivalent compressive cylinder concrete strength) for life safety and immediate occupancy in context of Bangladesh (Ansary and Barua 2015). If the shear stress in the concrete columns is greater than the maximum value, then the building is considered as vulnerable. Thus, the RMG factory buildings with column shear stress greater than the maximum value have been categorized as vulnerable.

g) Soft Storey: The stiffness of the lateral-force-resisting system in any story shall not be less than70 percent of the lateral-force-resisting system stiffness in an adjacent story above or below, or less than 80 percent of the average lateral-force-resisting system stiffness of the three stories above or below for life safety and immediate occupancy. If it is not so, then it should be notified as soft storey (FEMA 2015, 1998). Presence of soft storey represents that the building is vulnerable (Dolšek and Fajfar 2001). Thus, the RMG factory buildings with soft storey have been categorized as vulnerable.

h) Site Amplification: Ground shaking is the primary cause of earthquake damage to man-made structures, but at such event some place in the same area may experience stronger seismic shaking than others. The effect of local soil conditions on the amplitude and frequency content of earthquake motions define the characteristics of the seismic motions that can be expected at the free surface (or at any depth) of a soil stratum, which is called the soil amplification effect (USGS 2016). Hough et al. (2010) have found site amplification to be one of the most important variables to assess vulnerability of structures to earthquake loads. Thus, the RMG factory buildings with site amplification effect have been categorized as vulnerable.

Table 2 shows summary of the variables and associated likert scales of measurement for modeling vulnerability to earthquake loads for RMG factory buildings in Bangladesh. The model frameworks used to assess the RMG buildings' vulnerability to earthquake loads is shown in Figure 2.

Table 2: Variables for modeling earthquake loads vulnerability of RMG factory buildings

Name of Variables	**Scale (Greater value represents greater vulnerability)**		
	1	**2**	**3**
Reduction in Column Capacity	Low	Moderate	High
Structural System	Beam-Column	Flat Plate	Mixed
Construction Materials	Stone	Brick	Mixed
Column slenderness	≤ 35	>35	N/A
Site Amplification	Negligible	Moderate	High
Building shape	Regular	Slightly Irregular	Irregular

Soil Liquefaction	Negligible	Moderate	High
Building adjacency (pounding)	No	Yes	N/A
Bearing Capacity of Soil	Good	Fair	Poor
Irregular Internal Frame	No	Yes	N/A
Column Shear Stress	Low	Moderate	High
Soft Story	No	Yes	N/A

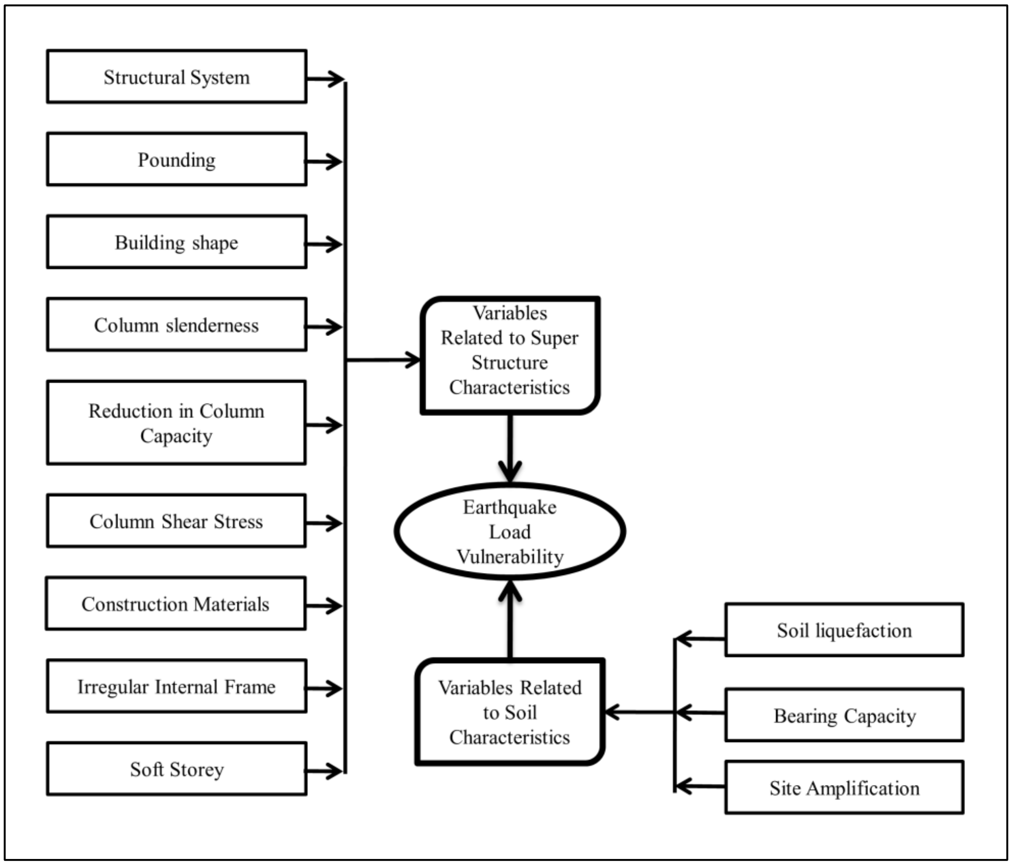

Figure 2: Model framework to assess RMG buildings' earthquake load vulnerability

2.3 Modeling Structural Vulnerability of RMG Factory Building

The collected data have been used to estimate key factors responsible for vulnerability of RMG factory buildings in Bangladesh to vertical and earthquake loads using ordered probit model. The model proposed by McKelvey and Zavoina (1975) adapts random utility theory to discrete and ordered answers, such as, those delivered by the qualitative scale offered in this research to express the severity level of factors responsible for vulnerability of RMG factory buildings in Bangladesh to vertical and earthquake loads.

The models are based on random utility theory explained in equation (2):

$$Q_i = \beta x_i + \varepsilon_i \text{...}(1)$$

Here,

i = index for each observation (each RMG factory buildings interviewed),

Q_i = vector form of vulnerability of RMG factory buildings (unobserved);

x_i = K-dimensional vector of factors (observed),

β =K-dimensional vector of coefficients that affect the observed attributes,

ε_i = error term (assumed to be a random variable, normally distributed in the ordered probit model, with mean zero and unit variance).

Since the dependent variable Q_i is unobserved, here standard regression techniques cannot be applied to compute equation (2). Yet, as suggested by O'donnell and Connor (1996), it can be reasonably assumed that high vulnerability (Q_i) is related to a high level of observed parameters (x_i). According to Ye and Lord (2014), this relationship can be translated as follows:

$$y_i = 1, \text{ if } Q_i \le \mu_{1,}$$

$$y_i = k, \text{ if } \mu_{k-1} < Q_i < \mu_{k,} \text{...}(2)$$

$$y_i = K, \text{ if } Q_i > \mu_{k-1}$$

Here,

μ = threshold values for all vulnerability severity levels threshold values for all vulnerability severity levels (where K is the highest vulnerability severity level) = [μ_1, μ_2, ...,μ_{k-1}, ..., μ_k].

The thresholds values (μ) are unknown parameters to be estimated jointly with the model parameters (β), which have been estimated through the maximum likelihood method in this research. In turn, the probability that RMG factory building surveyed is i and building vulnerability *level* k is equal to the probability that the unobserved severity of building vulnerability (Q_i) assumes a value between two fixed thresholds. In other words, given the value of x_i, the probability that the vulnerability of RMG factory building i related to observed parameter is:

$$P(y=1)=\phi(-\beta x_i);$$
$$P(y=k)=\phi(\mu_{k-1}-\beta x_i)-\phi(\mu_{k-2}-\beta x_i);\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$
$$P(y=K)=1-\phi(\mu_{K-1}-\beta x_i)$$

Here,

ϕ = cumulative normal distribution function

According to Washington, Karlaftis, and Mannering (2010), the relation can be represented as:

$$P(y=k)=\phi(\mu_k-\beta x_i)-\phi(\mu_{k+1}-\beta x_i)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Here,

μ_k = lower threshold for the building vulnerability severity level k

μ_{k+1} = upper threshold for the building vulnerability severity level k

For all the probabilities to be positive, the thresholds values must satisfy the restriction $\mu_1 <$ .... $\mu_{k-1} <$ ....$<\mu_k$. Computation of these probabilities allows the understanding of the effect of individual estimated parameters. Indeed, a positive value of β implies that an increase in x_i will clearly generate the increase of the probabilities of the highest ordered building vulnerability severity levels and vice versa. However, it is not obvious what effects a positive or negative β will generate on the probabilities of the intermediate levels. For this reason, the computation of marginal effects for each level is suggested. According to Washington, Karlaftis, and Mannering (2010) these marginal effects provide the direction of the probability for each level as follows:

$$P(y=k)/\partial x=[\phi(\mu_k-\beta x_i)-\phi(\mu_{K-1}-\beta x_i)]\beta\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

The computation of equation (6) is appropriate only if the variable is continuous. The variables considered in this research support this condition. In this research variables having Z value greater than 1.64 at 90 percent confidence level is considered significant.

2.4 Reliability of the Developed Models

Reliability test is done to assess the precision of the measurement procedure. Although, there exist a number of different reliability tests, one of the most frequently used is the Cronbach's alpha (Rahman et al. 2016). It quantifies internal consistency of dataset, i.e. how closely related a set of items are as a group. According to Byrne (2016), the minimum acceptable limit for Cronbach's alpha value is 0.60. This means that if Cronbach's alpha value for a model exceeds acceptable limit of 0.60, then it can be remarked that the model dataset is satisfactorily consistent.

2.5 Model Validation

To investigate the validity of the model specification, firstly both the datasets (structural vulnerability assessment data of 3,746 RMG factory buildings for vertical loads and structural vulnerability assessment data of 478 RMG factory buildings for earthquake loads)have been split into two parts (i.e. Sample 1 and Sample 2) each having about half of the observations. For each dataset, two separate models have been estimated with the same specification using these two samples. The hypothesis for this specification test is that model parameters are equal for the models estimated on these two samples for each dataset. It has been assumed that, if we fail to reject the hypothesis, the validity of the specification is established. A test statistics has been calculated for each dataset based on likelihood ratio (LR) as shown in equation (7):

$$LR = -2[LL(\beta_{full-data}) - LL(\beta_{sample1}) - LL(\beta_{sample2})] \quad (6)$$

Here,

$LL(\beta_{full-data})$ = log-likelihood at convergence of the model estimated using the full data,

$LL(\beta_{sample1})$ = log-likelihood at convergence of the model estimated using Sample 1, and

$LL(\beta_{sample2})$ = log-likelihood at convergence of the model estimated using Sample 2.

This whole process is done for both of the models to validate them.

3. Results and Discussions

Readymade garments (RMG) sector is one of the most important export sectors in Bangladesh. Yet the working conditions and safety records in the factories are often not up to the standard. The battle of business is won to some extent; however, the battle for the safety of workers' has not been fully won yet. This research generates two separate ordered probit models to assess the vulnerability of RMG factory buildings to vertical and earthquake loads respectively.

3.1 Model Representing Building Vulnerability to Vertical Loads

Table 3 shows parameter estimates of indicator variables for building vulnerability to vertical loads in Bangladesh RMG sector including parameter estimates, z-statistics and marginal effects for each indicator variables considering total dataset as well as parameter estimates and z-statistics for two samples (Sample 1 and Sample 2). Table 4 shows correlation matrix for building vulnerability to vertical loads in Bangladesh RMG sector showing correlation among indicator variables as well as correlation of indicator variables with vulnerability of the factory buildings considering vertical loads.

Table 3: Parameter Estimates Considering Vertical Loads

Indicator Variable	**Total Sample**			**Sample 1**		**Sample 2**	
	Estimated Parameter	**Z Statistics**	**Marginal Effect**	**Estimated Parameter**	**Z Statistics**	**Estimated Parameter**	**Z Statistics**
Reduction in Column Capacity	4.142	10.72	0.0879	4.147	10.75	4.171	10.74
Structural System	2.671	5.67	0.0161	2.379	5.60	2.485	5.48
Construction Materials	0.924	6.62	0.0364	0.906	6.47	0.981	6.74
Bearing Capacity	0.517	2.09	0.0281	0.505	1.99	0.521	2.11

Table 4: Correlation Matrix Considering Vertical Loads

Indicator Variable / **Indicator Variable**	Reduction in Column Capacity	Construction Materials	Structural System	Foundation Type	**Vertical Load Vulnerability**
Reduction in Column Capacity	1				
Construction Materials	0.125	1			
Structural System	0.381	0.293	1		
Foundation Type	0.120	0.118	0.188	1	
Vertical Load Vulnerability	**0.724**	**0.383**	**0.424**	**0.314**	**1**

From the results it is seen that “Reduction in Column Capacity” is directly related to vulnerability of the RMG factory buildings’ to vertical loads (estimated parameter or co-efficient 4.142; Table 3). This result is also supported by high correlation of “Reduction in Column Capacity” with building vulnerability to vertical loads (correlation value 0.724: Table 4). From the inspection of RMG factory buildings it was observed that with the increase of “Reduction in Column Capacity”, critical visible defects in the factory buildings were noticed which may result in immediate danger to structure and workers. Thus, RMG factory buildings with low “Column Capacity” were found to be vulnerable to vertical loads, which hardly have any capacity to withstand the imposed dead load and live load on it. Marginal effect values of Table 4 show that one unit increase in “Reduction in Column Capacity” increases the increases probability of building vulnerability to vertical loads by 0.0879. This result is supported by Ansary and Barua (2015), where the authors suggest that “Column Capacity” is the most important structural quality of the factory buildings that determines the workplace safety of RMG factories in Bangladesh from any type of building collapse due to vertical loads.

According to the model estimation, “Structural System” plays a significant role in determining the vulnerability of RMG factory buildings’ to vertical loads (estimated parameter or co-efficient 2.671; Table 3). The correlation value of “Structural System” with building vulnerability to vertical loads is 0.383 which indicates that RMG factory buildings’ vulnerability to vertical loads increase with the increasing disintegration in “Structural System”. Thus in Bangladesh RMG factory buildings with flat plate or mixed (combination of beam-column and flat plate) are more vulnerable to vertical loads than that of beam-column structural system. This finding is consistent with that of Durrani and Du (1992) who have mentioned about the low resistance of flat plate structures.

“Construction Materials” influences the RMG factory buildings’ vulnerability to vertical loads significantly where “Construction Materials” has a coefficient value of 0.924 (Table 3) and a corellation value of 0.383 (Table 4) with vulnerability of RMG factory buildings to vertical loads. Thus, it can be said that in Bangladesh RMG factory buildings’ vulnerability to vertical loads largely depends on “Construction Materials” used. That means buildings with brick or mixed (stone and brick) construction materials are more vulnerable than that of stone. Therefore, to reduce buildings’ vulnerability to vertical loads stone concrete is more preferable then brick concrete. This result is consistent with the findings of Kwon and Elnashai (2006).

From the above discussion it is clear that, “Reduction in Column Capacity”, “Structural System” and “Construction Materials” are the most significant variables that influence the vulnerability of RMG factory buildings to vertical loads.

3.2 Vertical Load Vulnerability Model Reliability and Validation

The Cronbach's alpha value for the dataset used to model building vulnerability to vertical loads is 0.781, which exceeds Byrne (2016) acceptable limit of 0.60. Therefore, it can be said that the dataset used in this research is satisfactorily consistent. For the developed model representing vulnerability of RMG factory buildings to vertical loads in Bangladesh, LR is found to be 11.78 by using equation (7), degrees of freedom is 4 and $\chi^2_{4,0.10} = 13.277$. Thus, we fail to reject the hypothesis that the parameters across different samples are equal. Thus, this test confirms the model measurement proposed in this paper.

3.3 Model Representing Building Vulnerability to Earthquake Loads

Table 5 shows parameter estimates of indicator variables for building vulnerability to earthquake loads in Bangladesh RMG sector including parameter estimates, z-statistics and marginal effects for each indicator variables considering total dataset as well as parameter estimates and z-statistics for two samples (Sample 1 and Sample 2). Table 6 shows correlation matrix for building vulnerability to earthquake loads in Bangladesh RMG sector showing correlation among indicator variables as well as correlation of indicator variables with vulnerability of the factory buildings considering earthquake loads.

Table 5: Parameter Estimates Considering Earthquake Loads

Indicator Variable	Total Sample			Sample 1		Sample 2	
	Estimated Parameter	**Z Statistics**	**Marginal Effect**	**Estimated Parameter**	**Z Statistics**	**Estimated Parameter**	**Z Statistics**
Reduction in Column Capacity	3.142	7.72	0.0678	3.137	7.75	3.171	7.74
Column Slenderness	0.446	1.93	0.0128	0.414	1.89	0.467	2.01
Structural System	2.321	4.67	0.0155	2.479	4.69	2.385	4.42
Building Shape	0.346	1.83	0.0228	0.314	1.79	0.367	1.91
Soil Liquefaction	0.702	3.41	0.0139	0.699	3.20	0.712	3.48
Pounding	0.271	1.74	0.0101	0.265	1.66	0.279	1.80
Construction Materials	0.824	5.61	0.0261	0.806	5.47	0.871	5.74
Bearing Capacity of Soil	-0.317	-1.89	-0.0181	-0.305	-1.82	-0.321	-1.91

Irregular Internal Frame	0.602	3.21	0.0127	0.587	3.25	0.612	3.49
Column Shear Stress	*0.101*	*1.09*	*0.0014*	*0.099*	*1.08*	*1.102*	*1.12*
Soft Story	0.291	1.89	0.0092	0.290	1.85	0.287	1.82
Site Amplification	*0.122*	*1.25*	*0.0033*	*0.121*	*1.19*	*0.137*	*1.34*

Italic numbers indicate 1.00 <Z_value< 1.64

Table 6: Correlation Matrix Considering Earthquake Loads

Indicator Variable / **Indicator Variable**	Reduction in Column Capacity	Column Slenderness	Structural System	Building Shape	Soil Liquefaction	Pounding	Construction Materials	Bearing Capacity of Soil	Irregular Internal Frame	Column Shear Stress	Soft Story	Site Amplification	**Earthquake Load Vulnerability**
Reduction in Column Capacity	1												
Column Slenderness	0.120	1											
Structural System	0.281	0.188	1										
Building Shape	0.035	0.089	-0.289	1									
Soil Liquefaction	0.024	-0.114	-0.024	0.014	1								
Pounding	0.040	0.216	0.313	0.13	-0.012	1							
Construction Materials	0.078	0.002	0.083	0.009	0.290	-0.019	1						
Bearing Capacity of Soil	0.008	-0.011	-0.081	-0.002	-0.014	-0.012	-0.141	1					
Irregular Internal Frame	0.210	0.119	0.230	0.121	0.017	-0.045	0.182	-0.261	1				
Column Shear Stress	0.055	0.054	0.123	0.021	-0.001	0.008	0.008	0.008	0.035	1			
Soft Story	0.089	0.084	0.078	0.058	0.002	0.045	0.007	0.004	0.201	0.008	1		
Site Amplification	0.025	0.011	0.121	0.022	-0.005	0.018	0.022	-0.010	0.102	0.001	0.078	1	

Earthquake Load Vulnerability	**0.62**	**0.127**	**0.328**	**0.247**	**0.304**	**0.014**	**0.317**	**-0.241**	**0.409**	**0.006**	**0.105**	**0.002**	**1**

From the results it is seen that "Reduction in Column Capacity" is directly related to vulnerability of the RMG factory buildings' to earthquake loads (estimated parameter or co-efficient 3.142; Table 5). This result is also supported by high correlation of "Reduction in Column Capacity" with building vulnerability to earthquake loads (correlation value 0.62: Table 6). Marginal effect values of Table 6 show that one unit increase in "Reduction in Column Capacity" increases the increases probability of building vulnerability to earthquake loads by 0.0678. This finding is similar to that of vertical loads as discussed earlier. If the building does not have the capacity to withstand imposed live and dead load certainly it will not have the capacity to withstand lateral loads like earthquake loads.

Similarly, RMG factory buildings' vulnerability to earthquake loads is positively correlated to "Column Slenderness" and "Column Shear Stress". Model results show that "Column Slenderness" has positive correlation with both "Reduction in Column capacity" (correlation value 0.120; Table 6) and building vulnerability to earthquake loads (correlation value 0.127; Table 6). Likewise, increase in "Column Shear Stress" reduces column capacity (correlation value 0.055; Table 6) and increases building vulnerability to earthquake loads (correlation value 0.006; Table 6). However, the model results show that "Column Shear Stress" (estimated parameter or co-efficient 0.101; Table 5) affects building vulnerability to earthquake loads less significantly than "Column Slenderness" (estimated parameter or co-efficient 0.446; Table 5).

"Structural System" plays a significant role in determining the vulnerability of RMG factory buildings' to earthquake loads. This statement is also supported by model results for earthquake loads (estimated parameter or co-efficient 2.321; Table 5). The correlation value of 0.328 with building vulnerability to earthquake loads indicates that RMG factory buildings' vulnerability to earthquake loads increase with the increasing disintegration in "Structural System". This finding is similar to that of vertical loads as discussed earlier. Additionally, "Irregular internal Frame" increases building vulnerability to earthquake loads. From the marginal effect values of Table 5 the above mentioned statement is justified, where, one unit increase in internal frame irregularity increases probability of vulnerability of RMG factory buildings' to earthquake loads by 0.0127. This result is consistent with the findings of Yee et al. (2011). Likewise, "Construction Materials" influences the RMG factory buildings' vulnerability to earthquake loads significantly. This statement is supported by the model results where “Construction Materials” has a coefficient value of 0.824 (Table 5) and a correaltion value of 0.317 (Table 6). It is true for vertical as well as earthquake loads. This finding is similar to that of vertical loads as discussed earlier.

If the building is robust having a good structural system with good construction materials and having columns with sufficient capacity, the building will not fail. But if the soil beneath a building is liquefiable then it will cause serious damage to structures in case of earthquake loads increasing building vulnerability. The model results show that “Soil Liquefaction” affects building vulnerability to earthquake loads significantly (estimated parameter or co-efficient 0.702; Table 5) and has a positive correlation with building vulnerability to earthquake loads (correlation value 0.024; Table 6). Thus result implies that with the increase of soil liquefaction RMG buildings’ vulnerability to earthquake loads increases significantly. This result is consistent with the findings of Bird et al. (2006) and O'Rourke et al. (1991) who concluded that soil liquefaction causes serious damage to structures in case of earthquake loads. The reasoning used to understand the relationship between “Soil Liquefaction” and building vulnerability to earthquake loads can be used to determine the relationship between “Bearing Capacity of Soil” and building vulnerability to earthquake loads. “Bearing Capacity of Soil” affects negatively (estimated parameter or co-efficient -0.317; Table 5) to building vulnerability to earthquake loads. This result implies that the increase in “Bearing Capacity of Soil” reduces building vulnerability to earthquake loads.

“Building Shape” influences building vulnerability to earthquake loads significantly (estimated parameter or co-efficient 0.346; Table 5). This statement is supported by the correlation value of 0.247 (Table 6). This value signifies that buildings with irregular shape increase the RMG buildings’ vulnerability to earthquake loading. “Soft Story” also plays a vital role for determining the vulnerability of RMG factory buildings’ to earthquake loads (estimated parameter or co-efficient 0.291; Table 5). The marginal effect value (0.0092; Table 5) and positive correlation (correlation value 0.105; Table 6) with buildings’ to earthquake loads indicates that creation of soft story increase building vulnerability to earthquake loads significantly. Similar results were found by Dolšek and Fajfar (2001), who showed that seismic response of RC frames are worst where a soft story is created by infilling only the upper part of the structure, whereas the bottom story remains bare. Pounding is one of the main causes of severe building damages in earthquake. From model results it is seen that “Pounding” increases building vulnerability to earthquake loads significantly (estimated parameter or co-efficient 0.271; Table 5). The principle reason for the “Pounding” effect for

RMG factory buildings in Bangladesh is insufficient separation in between the adjacent buildings.

According to the model results “Site Amplification” acts as a less significant variable to model vulnerability to earthquake loads of RMG factory buildings (estimated parameter or co-efficient 0.122 with z-statistics 1.25; Table 5 and correlation value 0.002; Table 6). This result is dissimilar with that of Hough et al. (2010) who found “Site Amplification” to be one of the most important variables to assess the earthquake load vulnerability to structures. The reason behind such inconsistency is that, the sites of the RMG factory buildings surveyed showed very low characteristics of site amplification and well compacted. Thus, well compaction of the soil surveyed is the main reason of less significance of “Site Amplification” to building vulnerability to earthquake loads for RMG factory buildings in Bangladesh.

From the above discussion it is clear that, “Reduction in Column Capacity”, “Structural System”, “Construction Materials”, “Soil Liquefaction” and “Irregular Internal Frame” are the five most significant variables influencing the vulnerability of RMG factory buildings to earthquake loads.

3.4 Earthquake Load Vulnerability Model Reliability and Validation

The Cronbach’s alpha value for the dataset used to model building vulnerability to earthquake loads is 0.714, which exceeds Byrne (2016) acceptable limit of 0.60. Therefore, it can be said that the dataset used in this research are satisfactorily consistent. For the developed model representing vulnerability of RMG factory buildings to earthquake loads in Bangladesh, LR is found to be 35.25 using equation (7), degrees of freedom is 12 and $\chi^2_{12,0.10} = 37.566$. Thus, we fail to reject the hypothesis that the parameters across different samples are equal. Thus, this test confirms the model measurement proposed in this paper.

4. Conclusion

Workplace safety is considered as an important aspect in international industrial sector for ensuring safety of the workers. Workplace safety is greatly endangered by occupational accidents among which building collapse is strongly related to structural safety. In Bangladesh, Ready Made Garment (RMG) industry is one of the most important sectors, which emerged as a niche market for Bangladesh’s export sector. Apart from its contribution in export earning, the RMG industry emerged as an important player in the economy in terms of employment generation, poverty alleviation and empowering of women. Despite such contribution, the sector is facing challenges regarding compliance with the international standard to ensure workplace safety. The reluctant attitude of the stakeholders towards the structural and workplace safety compliance issues resulted in different occupational disasters in RMG factories in Bangladesh resulting in significant losses of lives, livelihoods (through injuries), equipment's and materials. Additionally, Bangladesh is possibly one of the most vulnerable countries to potential earthquake threat and damage. In order to reduce the loss of lives and to ensure sustainable development, an in-depth understanding of the determining variables governing work-place safety in RMG industry is needed. Thus, the purpose of this research was to develop two separate models to explore and determine the key variables influencing RMG factory buildings' "Vertical Load Vulnerability" and "Earthquake Load Vulnerability".

For this purpose, ordered probit model was used in this research. A number of variables are found to influence the RMG buildings' "Vertical Load Vulnerability" and "Earthquake Load Vulnerability". If a structure is vulnerable to vertical loads (imposed dead load and live load) that structure is sure to be vulnerable to lateral loads (e.g. earthquake loads combined with imposed dead load and live load). The above statement is very much prominent in the model results where "Reduction in Column Capacity", "Structural System" and "Construction Materials" are the three most significant variables that influence the RMG buildings' "Vertical Load Vulnerability" as well as "Earthquake Load Vulnerability" most significantly. In addition to the above mentioned three factors, "Soil Liquefaction" and "Irregular Internal Frame" are the significant variables that influence the RMG buildings "Earthquake Load Vulnerability". Model results show prominently that "Reduction in Column Capacity" is the most determining variable to measure both RMG buildings' "Vertical Load Vulnerability" and "Earthquake Load Vulnerability". However, to reduce "Earthquake Load Vulnerability", structures must have enough lateral force resistance. In that case "Structural System" and "Irregular Internal Frame" play a vital role. To get the design strength of the structural members and thereby to get proper resistance against "Vertical Load Vulnerability" and "Earthquake Load Vulnerability" the best quality of "Construction Materials" should be chosen. In spite of a superstructure having adequate resistance to "Vertical Load Vulnerability" and "Earthquake Load Vulnerability", the soil beneath the superstructure must possess enough support for the proper transfer of load from superstructure to foundation and then to soil. Thus, "Soil Liquefaction" has a significant role to measure "Earthquake Load

Vulnerability” of RMG buildings. Superstructure having adequate resistance to lateral loads will collapse due to “Soil Liquefaction” in case of an earthquake.

The findings of this research will enable factory owners to better weigh the influencing factors increasing building vulnerability and thus make a decision better informed to increase the workplace safety. It will also aid corresponding authority to conduct a successful inspection of factory buildings and thus reducing both vertical and earthquake load vulnerability. In this research only material vulnerability (inherent weakness of the built environment) was considered to assess the “Vertical Load Vulnerability” and “Earthquake Load Vulnerability”. However, attitudinal vulnerability (fatalism, ignorance, and low level of awareness) can cause serious loss to human resources in an event of disaster. In future, researches should be carried out to incorporate both material vulnerability and attitudinal vulnerability to assess the RMG factories vulnerability in case of an event of disaster.

To increase the workplace safety of RMG factories BGMEA (Bangladesh Garment Manufacturers and Exporters Association) and corresponding authorities should be proactive to improve its rules for constructing buildings and continue the good practice. As, RMG industry is the single largest export sector in Bangladesh as well as for many developing countries, proper strengthening of the variables considered in this research should be made to reduce both “Vertical Load Vulnerability”, and “Earthquake Load Vulnerability”. Reduction in vulnerabilities will result in sustainable growth of RMG industries in the developing countries.

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BANGLADESH NETWORK
OFFICE FOR URBAN SAFETY

PART-XI

ASSESSMENT OF PREDOMINANT FREQUENCIES IN DHAKA CITY, BANGLADESH USING AMBIENT VIBRATION: IMPLICATIONS FOR EARTHQUAKE HAZARDS

BANGLADESH NETWORK OFFICE FOR URBAN SAFETY (BNUS), BUET, DHAKA

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INTRODUCTION

Bangladesh is a moderately seismic country of the world. The country is divided into four seismic zones (Figure 1) according to the latest Building Code of Bangladesh (Draft BNBC, 2017). Figure 2 shows the scenario earthquake fault model of Bangladesh (CDMP, 2009). Bangladesh is located close to the seismically active convergent plate boundary between the Eurasian and the Indian Plates (Figure 3). Two major active tectonic belts are responsible for the large and damaging earthquakes in Bangladesh, Northeast India, Nepal, Bhutan, and Myanmar. The tectonic elements are the Himalayan system in the north and the Arakan subduction–collision system in the east (Figure 3). The Himalayan Frontal Thrust and the Dauki Fault are the main components of the Himalayan system. The Chittagong–Tripura Fold Belt and underlying megathrust are the manifestation of the Arakan subduction–collision system (Steckler et al. 2008; Maurin and Rangin 2009; Wang et al. 2014).

Several historical earthquakes have occurred in Northeast India, Nepal, Myanmar, and Bangladesh along these tectonic belts in the last 255 years (Ambraseys and Douglas 2004; Szeliga et al. 2010). Among them, the 1762 Bengal-Arakan, 1869 Cachar, 1885 Bengal, 1897 Great Indian, 1918 Srimangal, 1930 Dhubri, 1934 Nepal–Bihar, 2015 Nepal Earthquakes are prominent in Bangladesh (Figure 3). The 1897 Great Indian Earthquake, epicenter located in Assam (see Figure 4), has caused huge damage to buildings in Dhaka City killing 1542 people in the region (Oldham 1899).

The April 25, 2015, Nepal earthquake of Mw 7.8 and May 12, 2015, aftershock of Mw 7.3 that are located in the west of the 1934 Nepal–Bihar earthquake, also occurred along the Himalayan Frontal Thrust (Figure 3). The 2015 Nepal earthquake that occurred approximately 80 km to the northwest of the Nepalese capital of Kathmandu, has killed 8790 people, has injured 22300 people and has caused an economic losses of US dollar seven billion (Lizundia et al., 2017). This earthquake has occurred as the result of the thrust fault along the main boundary thrust interface between the subducting Indian Plate in the south and the overriding Eurasian plate in the north (Lizundia et al., 2017). As the Indian Plate is moving northward at a rate of 4 cm/year and northeastward at a rate of 6 cm/year, large-magnitude earthquakes between M 7.5 and M 8.5 are expected to occur in the tectonic belt of Himalayan System (Bilham and Hough, 2006). Recent paleo-seismological investigation has revealed that the Dauki fault, which has been considered as the source of the 1897 Great Indian earthquake (Oldham, 1899), has been activated three times in the last thousand years

(Yeats et al. 1997; Morino et al. 2011, 2014). Therefore, the rate of plate movement and frequent occurrence of large-magnitude earthquakes along the plate boundary indicate that northern and northeastern India including Bangladesh, Nepal, Bhutan, and Myanmar are seismically active (Rahman and Siddiqua, 2017).

In the present study, we have analyzed the ambient vibration data recorded by triaxial velocity sensors at 105 sites to study the predominant frequency to characterize ground conditions of Dhaka city, Bangladesh (Figure 6). The reliability of the observed predominant frequency is corroborated with recorded earthquake data at three strong motion accelerometer (SMA) sites (Figure 6) and existing geological conditions. Finally, a map of the predominant frequency distribution for Dhaka city, Bangladesh has been presented.

GEOMORPHOLOGY AND GEOLOGY

Dhaka, the capital of Bangladesh is situated in the central part of the country at the bank of the river Buriganga (Figure 5a). The city having a population of around 9 million covers an area of 321 sq km. Tongi Khal is located in the north, the Buriganga River is located in the south and south-west, the Turag River is situated in the west and the Balu River is situated in the east of the city. Dhaka has been established as the capital of Bengal by the Mughals, a little over 400 years earlier (Mamoon, 2010). Many buildings in the old part of the city are non-engineered due to the unplanned civilization. The recent buildings, which are mostly engineered and some non-engineered, have been constructed on the artificial sand fillings of the recent floodplains of the four surrounding rivers. Dhaka and its surrounding areas are relatively flat. There exist some depressions as can be seen from Digital Elevation Model (DEM) of Figure 5b. The general slope of the city is from the north to south and south-east.

The southern part of the Pleistocene Terrace and the surrounding Holocene floodplains mainly covers the Dhaka city. Six geological units based on geomorphology, stratigraphy and geotechnical properties mainly cover the city. These units are Pleistocene terrace deposit, Holocene Alluvial valley fill deposit, Holocene Alluvial channel deposit, Holocene Alluvium, Holocene terrace deposit and Artificial fill (Figure 6) (after CDMP, 2009).

The central part of the city is generally composed of brown to reddish brown stiff silty clay and medium dense to dense silty sand from the Pleistocene Modhupur terrace deposit. The depressions or valleys of the Pleistocene terrace deposit, consisting of dark gray to gray soft silty clay, and yellowish brown, loose to medium dense silty sand of the Holocene Alluvial valley fill deposit. The present river channels are formed of gray loose to loose silty sand of the Holocene Alluvial channel deposit. The point bars, channel bars consisting of loose to medium dense silty sand, and soft to stiff silty clay of the Holocene terrace deposit. The eastern, southeastern and northwestern parts of the city where the Holocene Alluvium is located is composed of gray very soft to medium stiff silty clay, clayey silt and loose to loose silty sand. The artificial fills in the western and eastern parts of the city are composed of gray clayey silt, silty sand and sand. Hydraulic dredging from the river has been mainly used to emplace the artificial fills in the western and eastern parts of the city.

SEISMOTECTONICS

Figure 3 presents the plate boundaries and faults surrounding Dhaka region according to Maurin and Rangin (2009) and Steckler et al. (2008). The figure also shows the locations of some historical earthquakes which have occurred in the northeastern parts of India, Nepal, Myanmar, and Bangladesh during the last 250 years (Table 1). Among these earthquakes, the 1762 Bengal-Arakan, 1869 Cachar, 1885 Bengal, 1897 Great Indian, 1918 Srimangal, 1930 Dhubri and 1934 Nepal-Bihar Earthquakes are important for Bangladesh. In a megacity of this region, an earthquake of magnitude 8 or larger may cause one million casualties according to Bilham (2009). He has predicted this high level of casualties, since developed countries of this region are less vulnerable than those of developing countries due to high population density, unplanned urbanization, non-engineered construction practices, inadequate knowledge of the seismic design of structures, ignorance of building codes and poor monitoring system of the concerned government authorities during any structural construction.

According to Sabri (2002), the most critical earthquake for Dhaka City is the 1885 Bengal Earthquake and the epicenter of this seismic event has been relocated near Sherpur Upazila of Bogra District. Middlemiss (1885) has located this event near Atia in Manikganj District. The intensity of this earthquake at Dhaka City is VII in European Microseismic Scale (Ansary and Meguro, 2003). A recent study indicated that this earthquake might have originated due to the Madhupur Fault (CDMP, 2009). Due to this fact, for Dhaka City, the Madhupur Fault is one of the important seismic sources (Figure 2). In the seismic zoning map, Bangladesh is divided into three seismic zones based on peak ground acceleration (BNBC, 1993). The zones are Zone I, Zone II and Zone III, where the values are 0.075g, 0.15g and 0.25g respectively

(Figure 1a). The location of Dhaka City is in Zone II, where the peak ground acceleration is 0.15g. Recently (BNBC Proposed, 2017), this map has been updated (Figure 1b) and the zone factor of Dhaka has been upgraded to 0.20g.

METHODOLOGY AND INSTRUMENTATION

The horizontal-to-vertical spectral ratio (HVSR) experiment consists of recording ambient vibration with a three-component digital seismograph. In this study, GeoSIG Ltd's VE-23 triaxial velocity sensor with a modulur multi-channel (fifteen) digital acquisition system (24 bit) designed for ambient vibration measurement has been used. Study by Duval et al. (2004) has revealed that the HVSR of ambient vibration is not dependent on the type of velocity sensors.

In Dhaka city, seismic data recorded at 3 strong motion stations (SMAs) out of the existing 5 SMAs (Figure 6) using Kinemetrics triaxial accelerometer ETNA have also been used. The data sets have been acquired and processed according to the recommendation of the SESAME European project (D23.12, 2005). At each of the 105 sites, ambient vibrations have been registered during the daytime for 30 minutes at 200 samples per second. For reliable experimental conditions, the guidelines proposed by Koller et al. (2004) have been followed in the framework of SESAME (WP02 of SESAME Project).

The ambient vibration HVSR technique (Nakamura 1989) is a widely used technique for the estimation of the predominant vibration frequency of the soils, mainly for seismic microzonation purposes (Nogoshi and Igarashi 1971; Nakamura 1989; Lachet et al. 1996; Bonilla et al. 1997; Bour et al. 1989; Parolai et al. 2001; Pando et al. 2008; Rodriguez and Midorikawa 2003). The technique gives a reliable estimate of natural predominant ground frequencies of the investigated sites. The amplification factor estimated from ambient vibration HVSR curve is not reliable, since often the ambient vibration HVSR predominant frequency amplitude is lower than that estimated from earthquake recording. In order to compute the ambient vibration HVSR, time series has been tapered with a 5 % cosine function. The FFT is calculated for each component, and spectra are smoothed followed by Konno and Ohmachi (1998). The instrumental response correction has been carried out. The spectra of the NS and EW components have been merged to obtain the horizontal component spectrum by means of computing their root-mean-square average. Then, the spectral ratios between the horizontal and the vertical components have been calculated. Finally, the HVSR using ambient vibrations have been estimated computing the arithmetical mean of all the spectral ratios calculated for a given site. Figure 6 show the locations of 105 ambient vibrations measurement sites. Figure 7a shows an example of ambient vibration waveform recorded at station Hazicamp, where a SMA is located.

Furthermore, we have used 3 permanent accelerometer stations with 24-bit digital recording with internal hard disk (64 MB) and GPS timing systems to record local earthquake signals maintained by the first author. Table 2 shows 12 earthquake events recorded by these accelerometers from 2005 to 2017. The table presents the date of the event, name of the event, epicenter, magnitude, depth and stations those recorded that event. Recordings are continuous at a sampling rate of 200 samples per second. We have used single-station estimate of HVSR. The time window of 5.0 s with start of 0.5 s before the S-wave arrival is used for all components following Bonilla et al. (1997). Figure 7b shows a record of earthquake (Date: 10-09-2010; M=5.1) at Hazicamp station, which is located on Holocene Alluvial Valley Fill Deposit. This time length has been chosen to contain most of the high-amplitude direct S-wave energy. Bonilla et al (1997) and Field and Jacob (1995) have however found no statistical variations in site response computed with spectra of different time window lengths. Castro et al. (1997) has suggested that S-waves could be contaminated by surface waves at a larger epicenter distance. The 5.0-s time traces for each station have been detrended, 10% cosine tapered, and Fourier transformed using the FFT. The resulting H/V spectra for all events recorded at each site have been smoothed following Konno and Ohmachi (1998). Then, the final HVSR has been obtained by arithmetic averaging the H/Vs of earthquakes at each site. The estimate of the HVSR using S-wave has been made for the selected time window in this study.

COMPARISON OF HVSR WITH THE AMBIENT NOISE AND EARTHQUAKE RECORDINGS

In order to validate predominant frequency estimated from ambient vibration recording, it has been compared with predominant frequency estimated from earthquake records (Figures 7 and 8). For this purpose, the authors have used the data of different accelerometer stations as illustrated in Figures 7 and 8. It is observed that the estimated predominant frequencies by the two methods are similar at the three SMA sites. Figure 9 presents predominant frequency estimated from ambient vibration recordings at six sites. The results obtained from all the 105 sites have been presented in Table 3.

RESULTS AND DISCUSSIONS

It is commonly accepted that the single components of ambient vibration can show large spectral variations as a function of natural and cultural disturbances in which the HVSR tends to remain invariant, preserving the predominant frequency peak of the site (Field and Jacob 1993; Bard and Bouchon 1985; Parolai et al. 2001). Figure 9 shows that the predominant frequencies of the sites are relatively stable, while the peak amplitudes of the HVSR, representing the amplification factors, are found to vary. Similar observations have also been reported from other parts of the world (e.g., Lermo and Chavez-Garcia 1993; Field and Jacob 1995; Mucciarelli and Monachesi 1998; Horike et al. 2001; Mucciarelli, et al. 2003; Sukumaran et al. 2011). Table 3 summarizes the HVSR of 105 sites along with its geographical position and the corresponding predominant frequency and amplification.

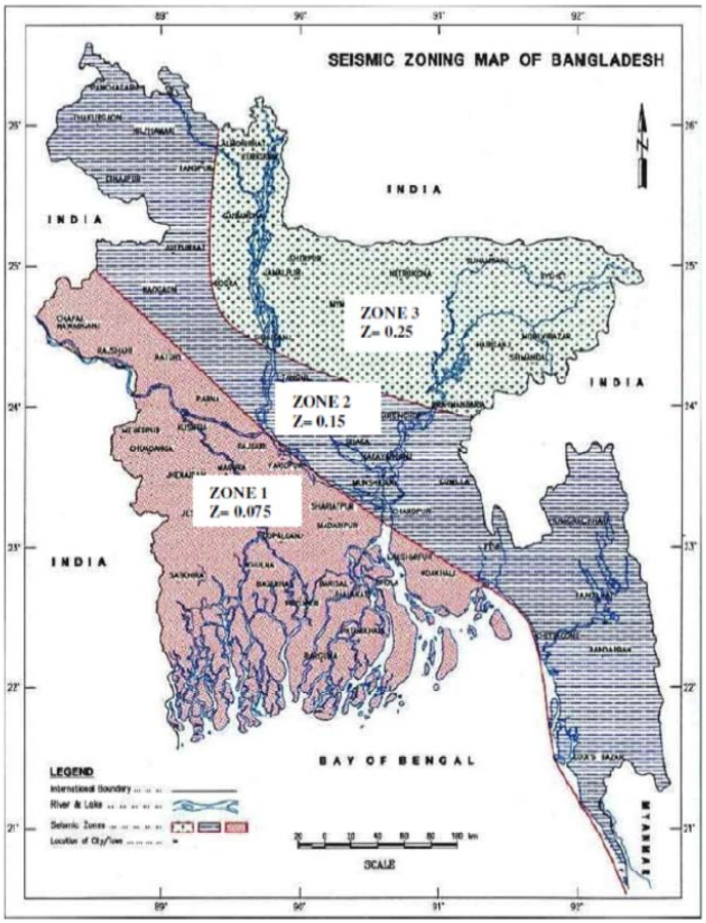
In the present study, the spectral ratios are presented in the 0.1–20 Hz frequency range, which include the natural frequencies of buildings in the region. Figure 9 and Table 3 show the resonance peaks are mostly in the range of 0.40–1.6 Hz. Figure 10 shows the map of the predominant frequency over the subsurface geology of Dhaka city. The geology of Dhaka is basically Quaternary (composed of both Holocene and Pleistocene deposits) in nature and the average shear-wave velocity of the top 30 m varies from 127 m/s and 320 m/s (Rahman et al., 2018). According to Singh et al. (2014), lower predominant frequency at soft sediment sites has greater potential for seismic hazard than that of hard sediments.

The HVSR results are presented in Table 3 and Figure 10; since many measurements do not evidence clear peaks in the analyzed frequency range, only examples of HVSR curve showing clear peaks are used. It is believed that no sharp velocity contrast is observed at depth at such sites.

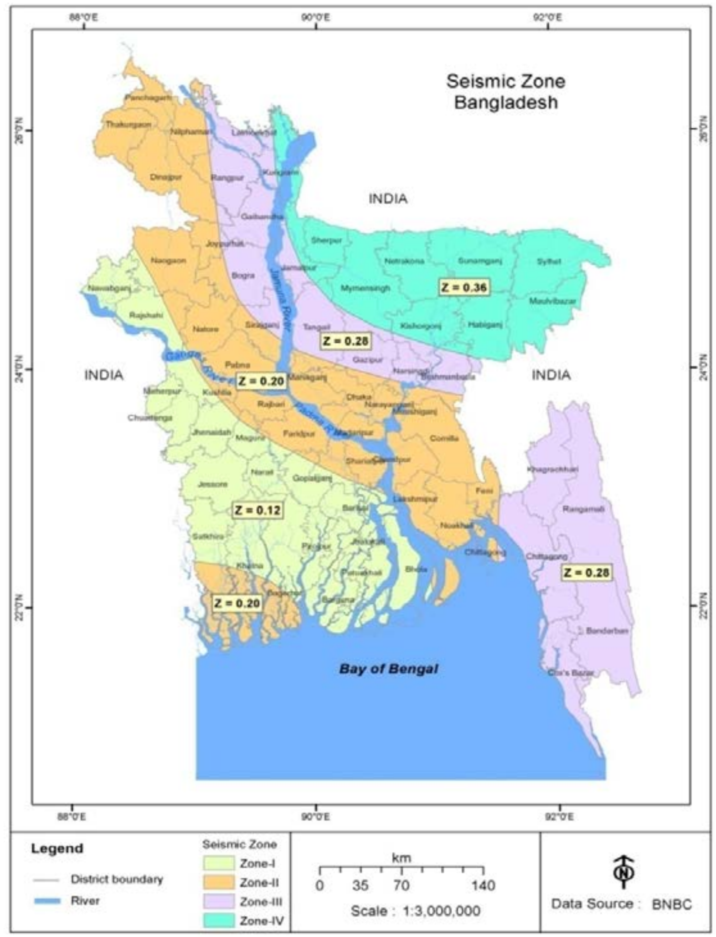
To a first approximation, the relationship between the height of a building and its fundamental period of vibration can be expressed as T = (number of stories)/10, we can expect that in this area, the natural frequency of the soil matches the frequency of buildings with six to twenty-five stories. This means that most of the buildings of Dhaka city may fail due to resonance and the buildings greater than five-storied need to be properly designed, and existing structures may be retrofitted to avoid resonance.

CONCLUSIONS

The predominant frequency map obtained in this study is useful for ground improvement as well as structural retrofitting and for future development of Dhaka city, Bangladesh. The HVSR results using ambient vibrations and earthquake records in Dhaka city, Bangladesh are consistent. The results reveal that weak-motion measurements can be used to estimate the predominant frequency of sites with acceptable reliability. From the results of these ambient vibration measurements, the predominant frequency determined at Quaternary sites is 0.4-1.6 Hz. In case of the Quaternary sites, the predominant frequency is due to deeper layers with lower resonance frequencies. We have presented the distribution of the detailed map of fundamental frequency for the city of Dhaka, which shows important characteristics requiring consideration in a study focusing on the mitigation of the seismic risk. The results of this study may be taken into consideration for civil engineering and for future planning in this region for making the new urbanization as earthquake risk resilient.



(a) Existing BNBC (1993)



(b) BNBC Proposed (2017)

Figure 1. Seismic zoning maps of Bangladesh

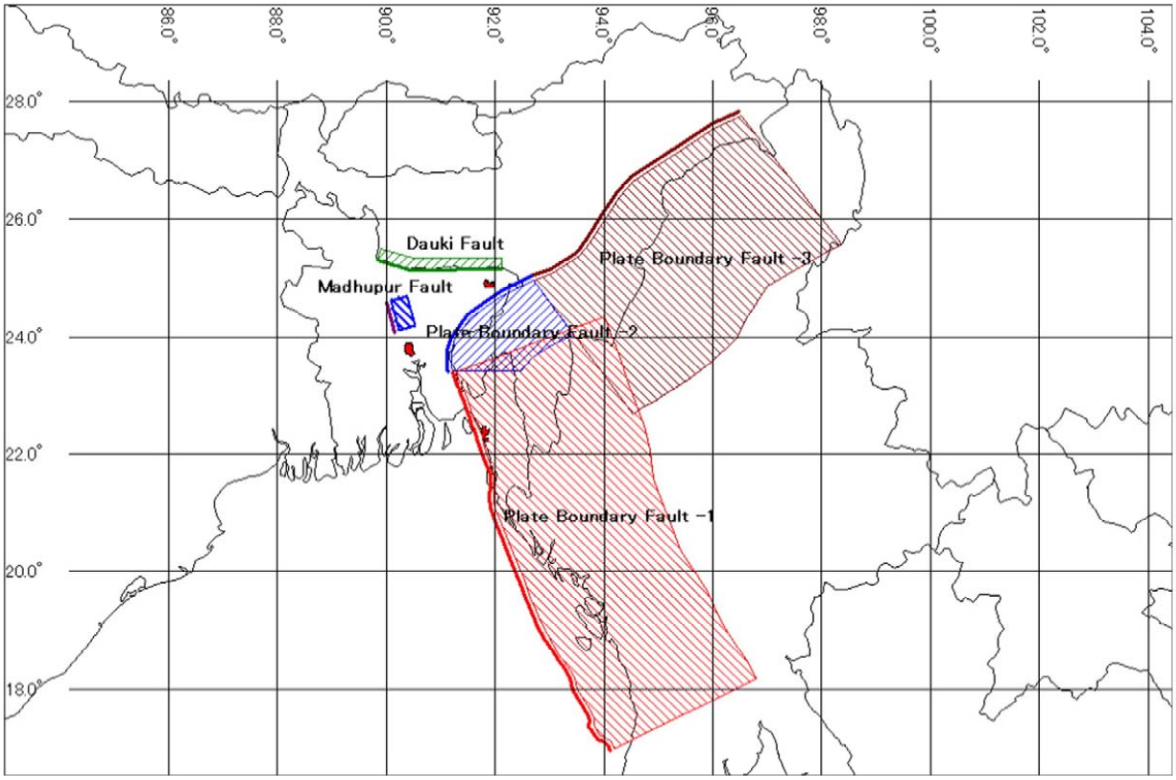


Figure 2. Scenario earthquake fault model of Bangladesh (CDMP, 2009).

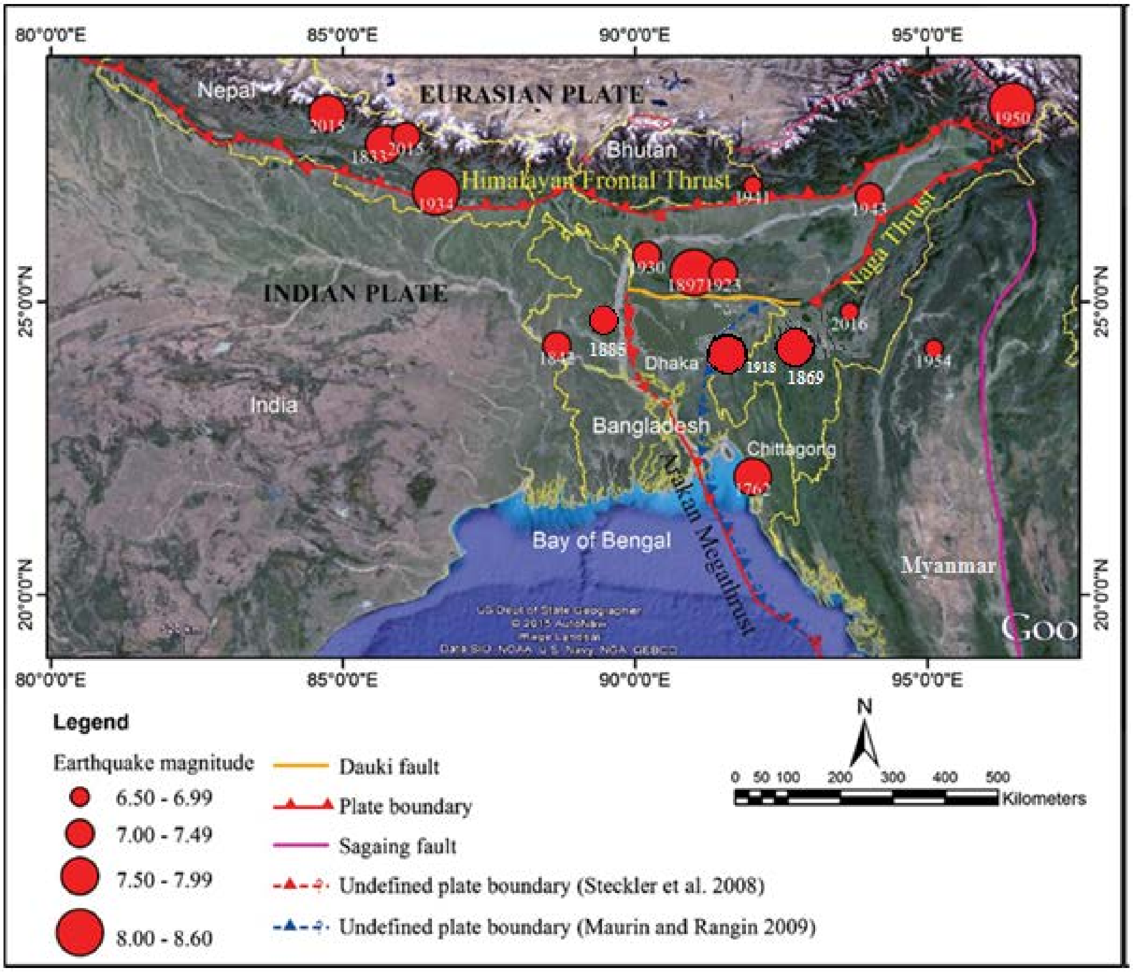


Figure 3 Recent and Historical large earthquakes in the surrounding area of Bangladesh (after Rahman et al., 2018 and Sabri, 2002)

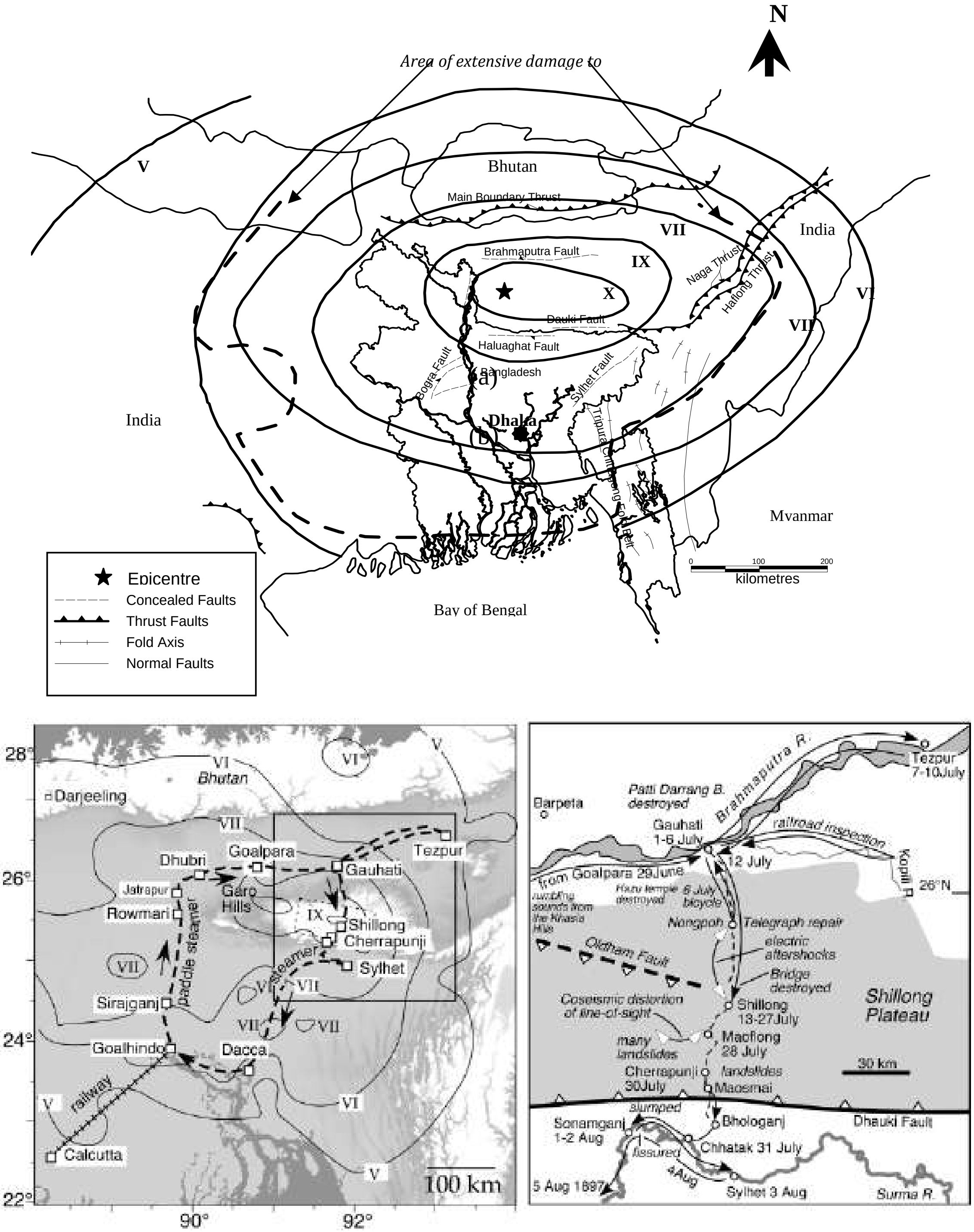
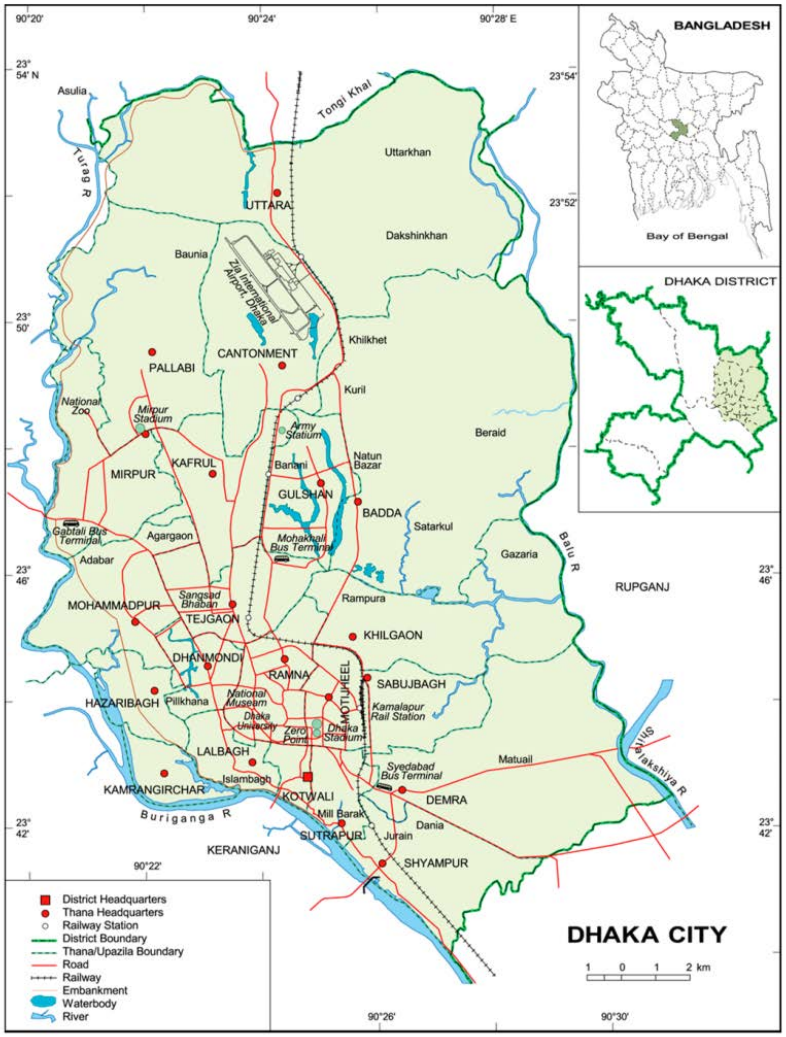
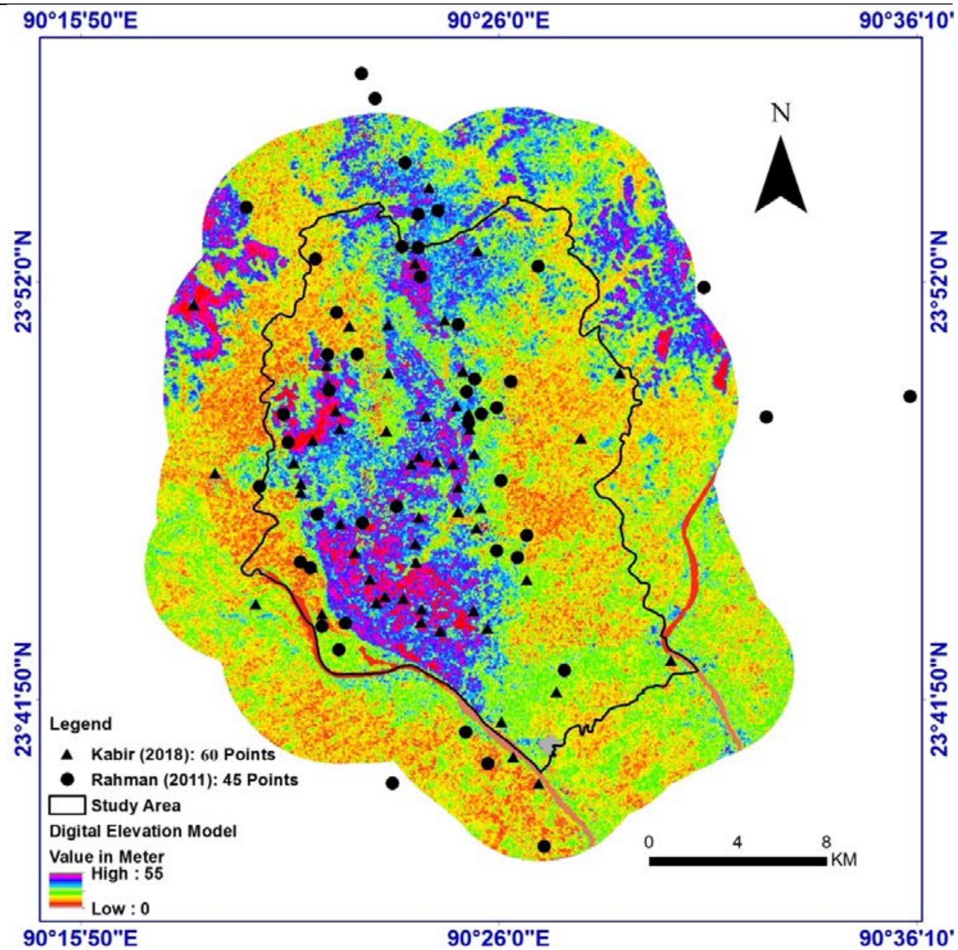


Figure 4 (a) Isoseismal map of 1897 Great Indian earthquake and (b) La Touche's epicentral route superimposed on an isoseismal map of the 1897 earthquake (after Bilham, 2008)





(a) Dhaka city (Islam, 2012)	(b) Digital Elevation Model of the study area

Figure 5 Location map of the study area

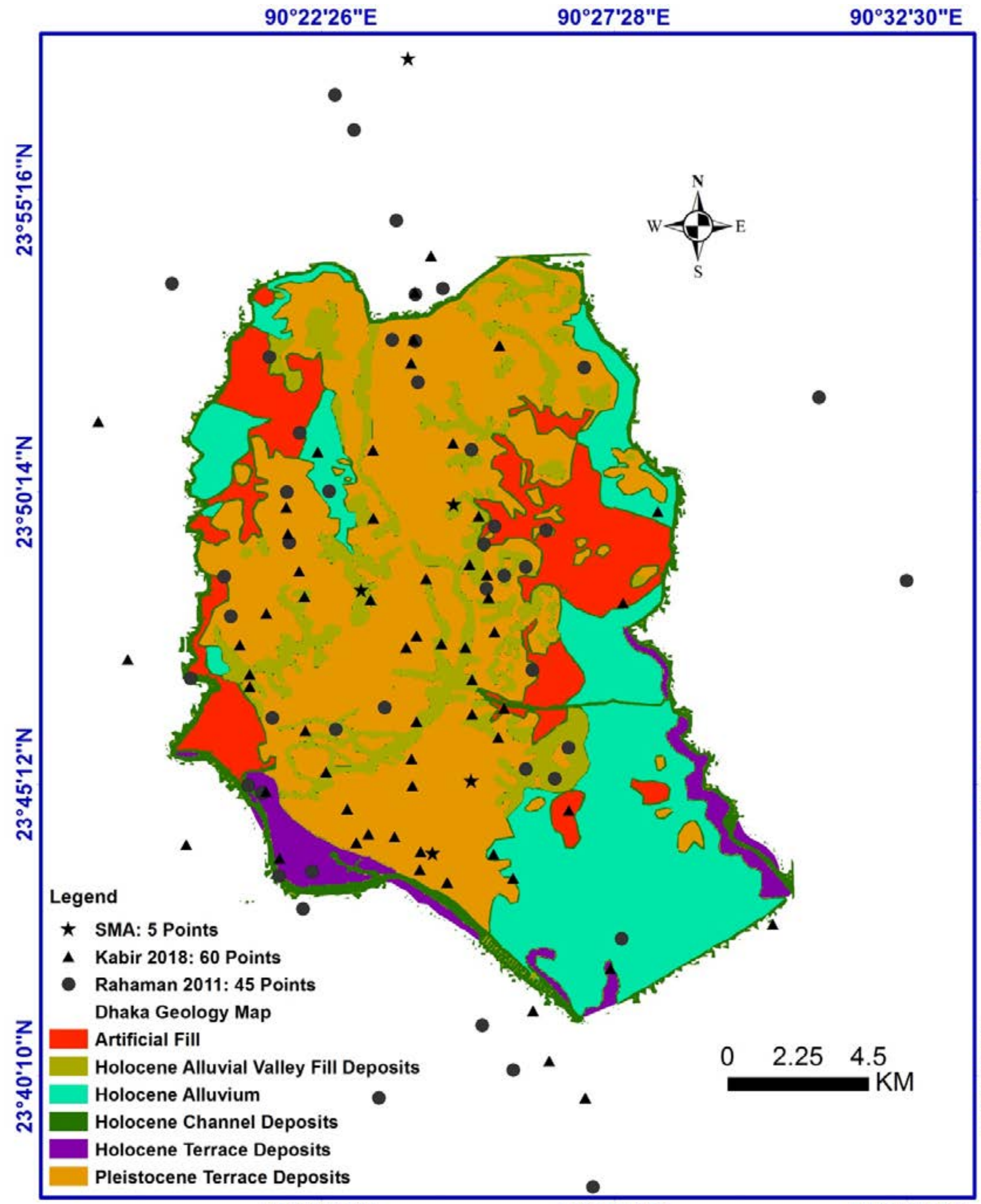


Figure 6 Surface geological map of Dhaka City (modified from geomorphological map of CDMP (2009)) with locations of microtremor observations

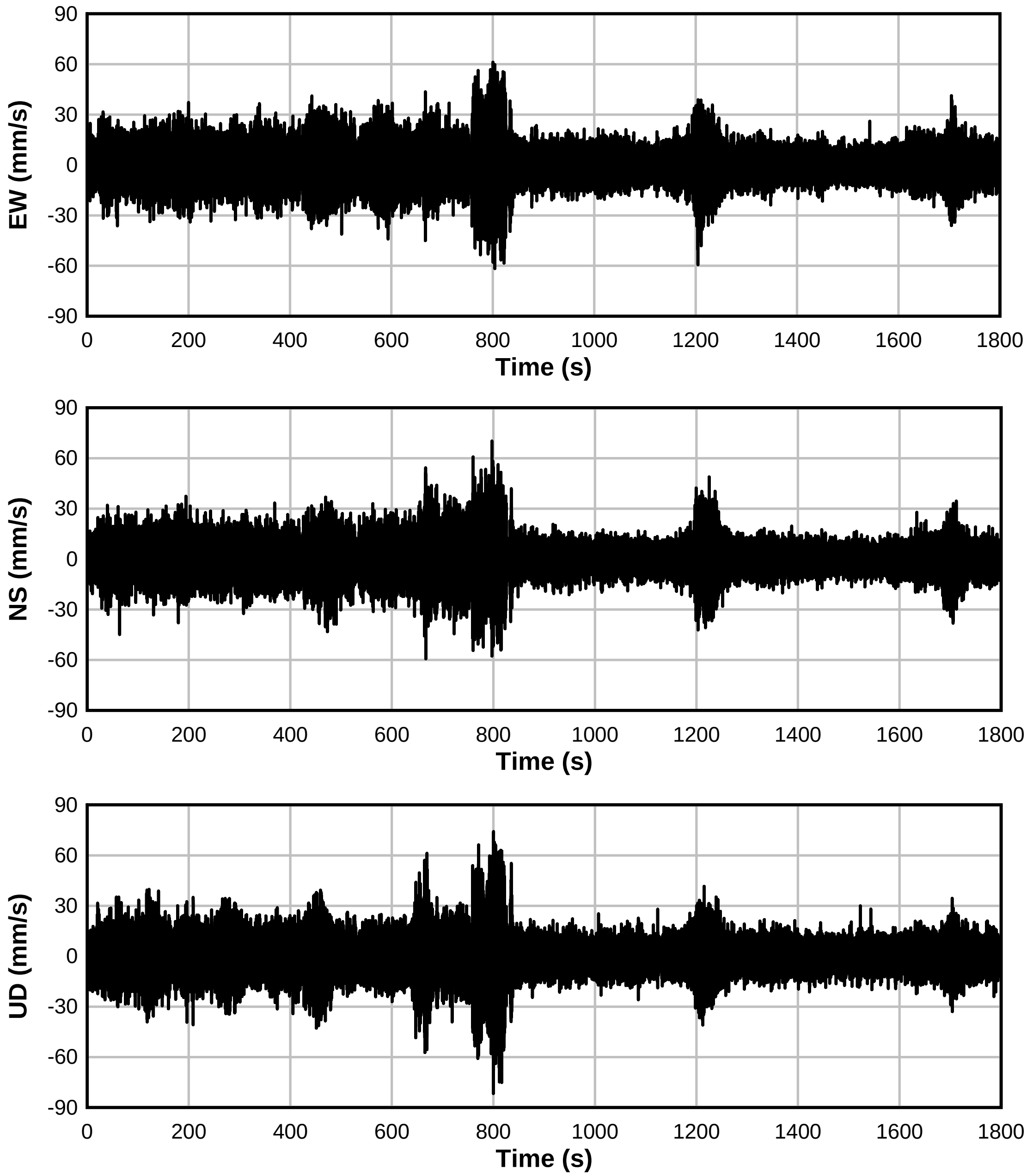


Figure 7 (a) An example of waveform recorded at Hazicamp station by microtremor. x-axis shows the time, and y-axis shows the different components of amplitude namely, UD vertical, NS north-south, and EW east-west. (b) Recording earthquake at three components (UD vertical, NS north-south, and EW east-west); ETNA accelerometer station at Hazicamp.

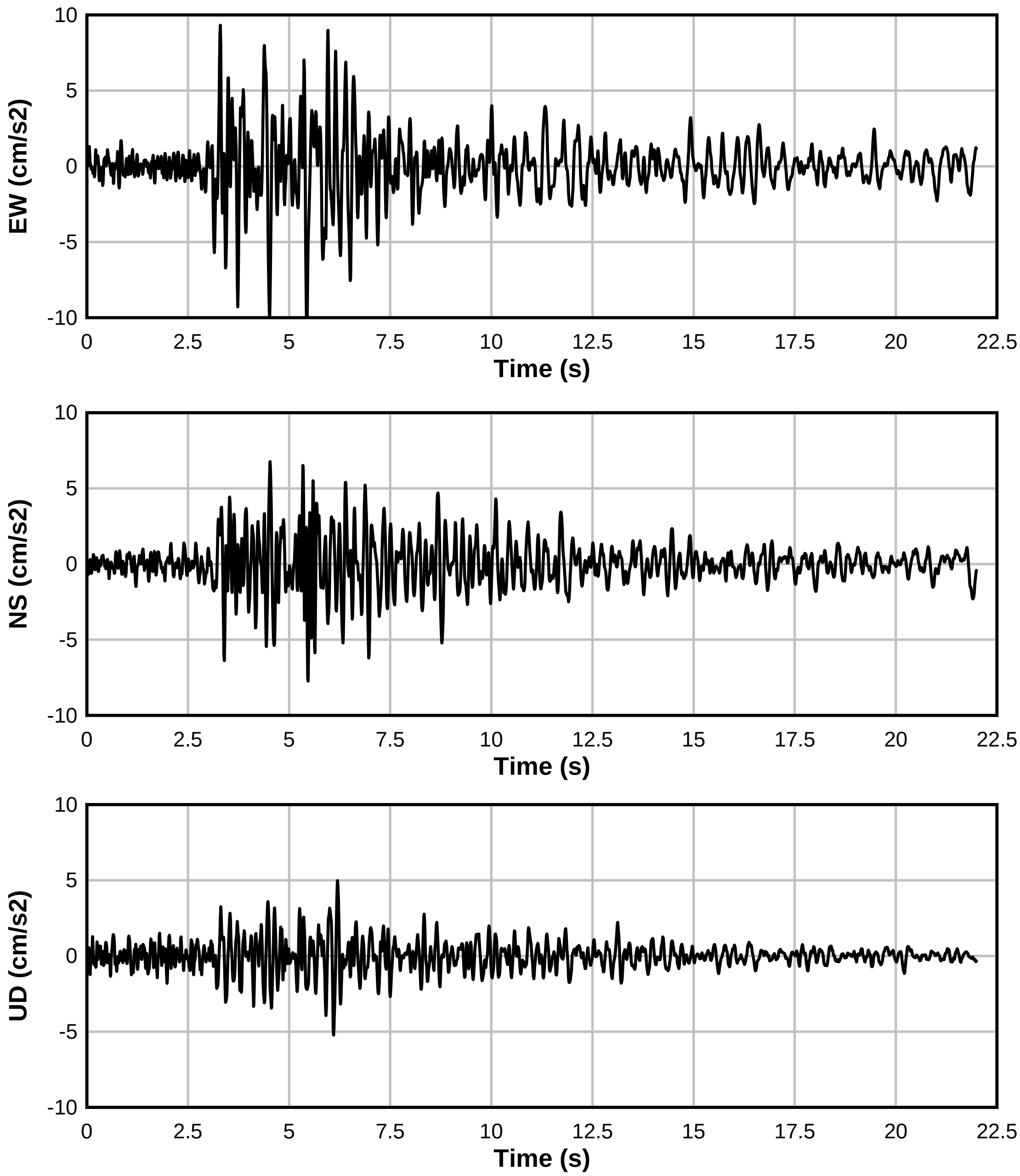


Figure 7 (contd.) (a) An example of waveform recorded at Hazicamp station by microtremor. x-axis shows the time, and y-axis shows the different components of amplitude namely, UD vertical, NS north-south, and EW east-west. (b) Recording earthquake at three components (UD vertical, NS north-south, and EW east-west); ETNA accelerometer station at Hazicamp.

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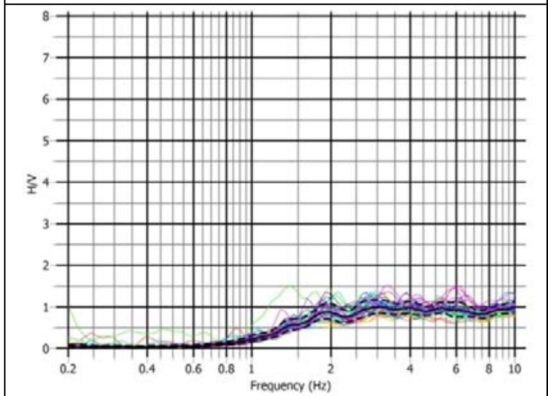
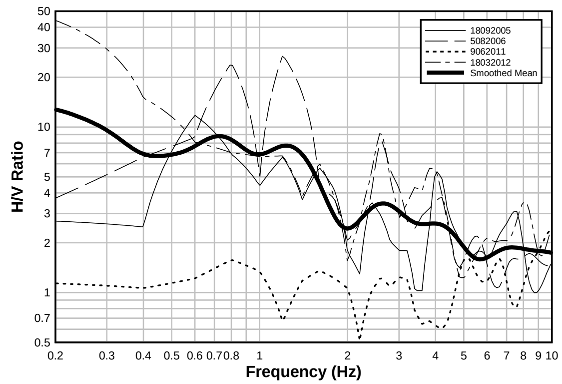
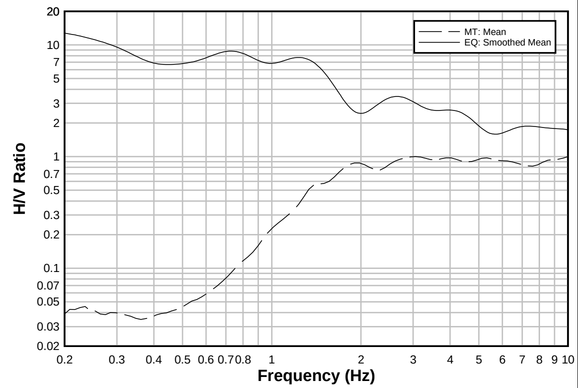
<tr><td>
</td><td>
</td><td>
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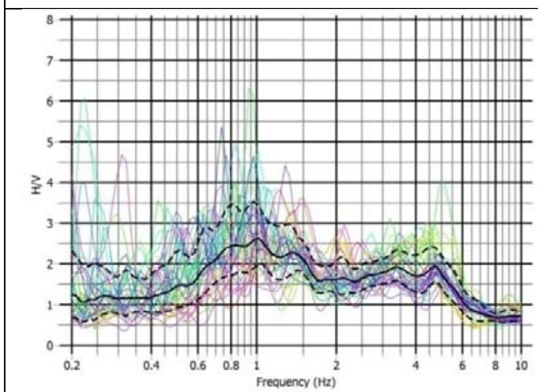
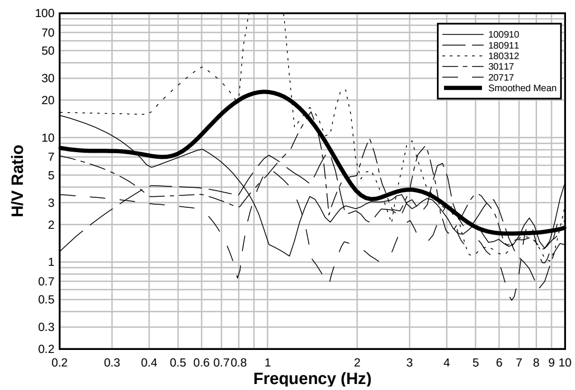
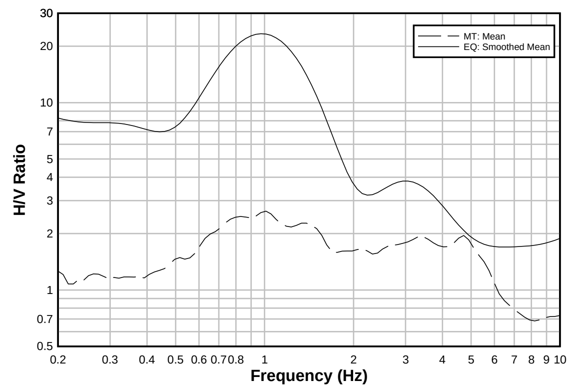
<tr><td>
</td><td>
</td><td>
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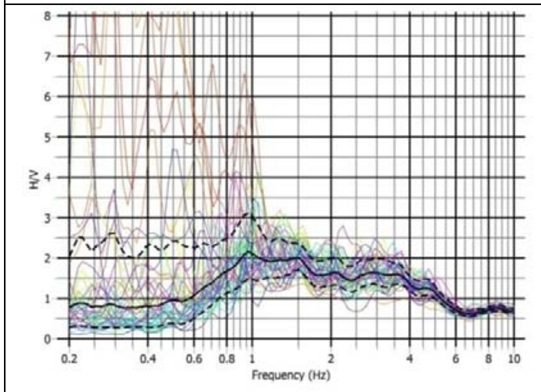
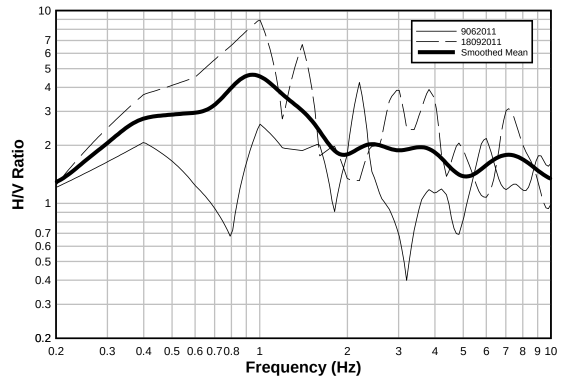
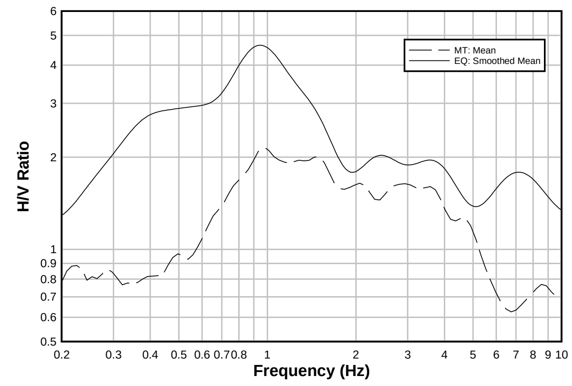
MT	EQ	Comparison
		
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Figure 8 Comparison of HVSR computed from earthquakes and ambient vibrations at three sites in and around Dhaka city

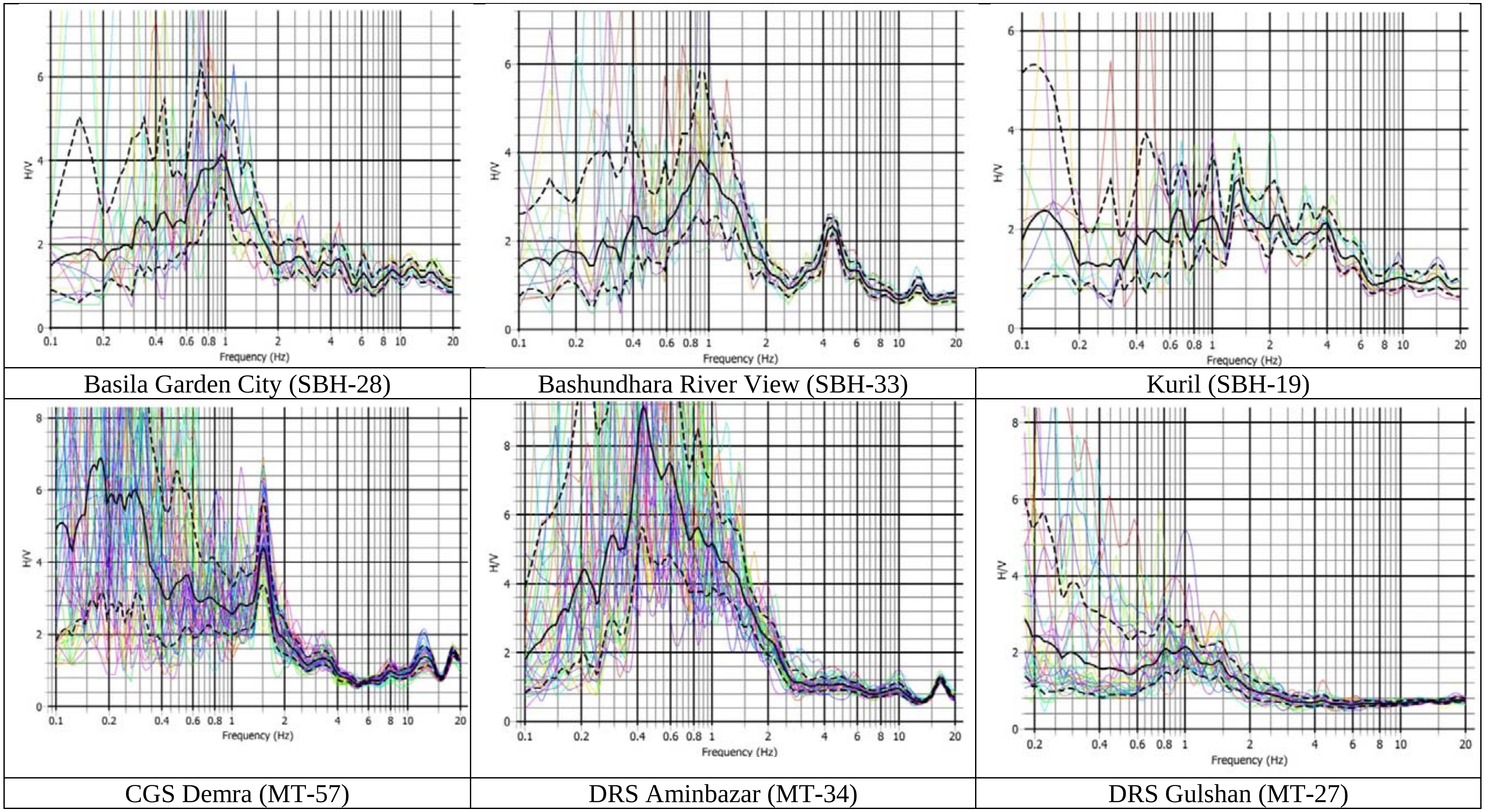

Figure 9 HVSR computed from ambient vibrations at six sites in and around Dhaka city. The continuous solid line is the average spectral curves; dotted lines are ±1 standard deviation

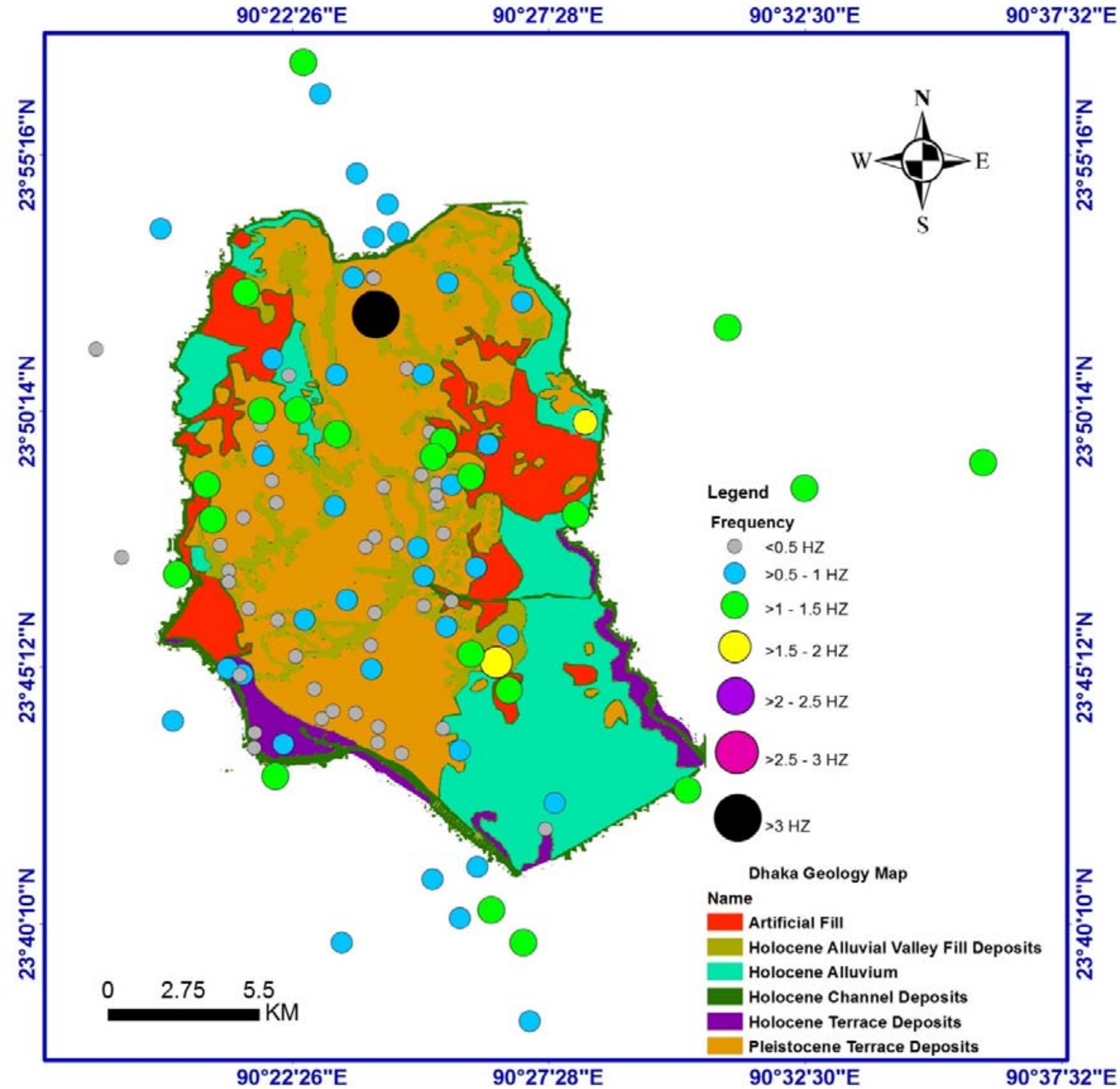

Figure 10 Map of the predominant frequency over the subsurface geology in Dhaka city

Table 1 List of historical earthquakes occurred in Bangladesh and NE India (Ansary and Meguro, 2003)

Date	Name of earthquake	Magnitude (Richter)	Intensity at Dhaka (EMS)	Epicentral distance from Dhaka (km)
10/01/1869	Cachar Earthquake	7.5	V	250
14/07/1885	Bengal Earthquake	7.0	VII	170
12/06/1897	Great Indian Earthquake	8.7	VIII+	230
08/07/1918	Srimangal Earthquake	7.6	VI	150
02/07/1930	Dhubri Earthquake	7.1	V+	250
15/01/1934	Bihar–Nepal Earthquake	8.3	IV	510
15/08/1950	Assam Earthquake	8.5	IV	780

Table 2 Earthquakes recorded by the free field stations

SL No.	Date	Name of the Earthquake	Epicentre	Magnitude	Depth (km)	Recorded by Stations
1	18-09-2005 (07:27:37 UTC)	-	Local	-	-	BUET
2	05-08-2006 (14:39:18.49 UTC)	Faridpur, BD EQ	23.662N,89.885E	4.2	`10	BUET, Gazipur
3	21-09-2009 (19:38:42.33 UTC)	MR EQ	20.404N,94.793E	5.7	84.2	BUET
4	22-09-2009 (08:27:59.31 UTC)	Bhutan EQ	27.289N,91.526E	4.0	27.9	BUET
5	10-09-2010 (17:24:16.61 UTC)	BD EQ	23.407N,90.648E	5.1	50	BBaria, Dhaka GSB and Hazicamp
6	09-06-2011 (07:34:27.43 UTC)	Madaripur BD EQ	23.602N,89.655E	4.4	35	BUET and PSC
7	18-09-2011 (12:40:51.83 UTC)	Sikkim, ID EQ	27.73N,88.155E	6.9	50	Bogra, Khagrachari, Kurigram, Hazicamp, Meherpur, Natore, PSC, Netrokona, Ruppur
8	18-03-2012 (2:56:13.39 UTC)	BD EQ	23.662N,90.259E	4.5	44	Hazicamp and BUET
9	25-04-2015 (6:11:25.95UTC)	NP EQ	28.2305N,84.731 4E 36km E of Khudi, Nepal	7.8	8.22	Bogra, BUET, Natore, JMB West, Ruppur and Sylhet
10	26-04-2015 (7:09:10.67UTC)	NP EQ (after shock)	27.7711N, 86.017 3E21km SSE of Kodari, Nepal	6.7	22.91	Bogra, BUET, JMB West, PSC and Ruppur
11	03-01-2017 (9:09:02.08 UTC)	Ambasa, ID EQ	24.015N, 92.018E 20 km ENE of Ambasa, India	5.7	32	Comilla and Hazicamp
12	25-07-2017 (09:09:01.96 UTC)	Hajiganj, BD EQ	23.376N,90.742E 18km NW of Hajiganj	4.4	10	Hazicamp

Note: BD=Bangladesh; ID=India, NP=Nepal

Table 3 Results of the microtremor stations in Dhaka city

Borehole No	Latitude	Longitude	Frequency (Hz)	Amplification
SBH-01	23.9512	90.3776	1.4	2.3
SBH-02	23.9412	90.3831	0.85	2.6
SBH-03	23.8273	90.4234	1.05	2.2
SBH-04	23.9151	90.3952	0.65	3.8
SBH-05	23.8956	90.4086	0.95	2.7
SBH-06	23.8805	90.4007	0.45	2.3
SBH-07(A)	23.8940	90.4007	0.52	4.3
SBH-07(B)	23.8809	90.3940	0.72	2.8
SBH-08	23.8970	90.3309	0.85	3.0
SBH-9	23.8729	90.4491	0.95	2.5
SBH-10(A)	23.8972	90.2829	1.1	3.1
SBH-10(B)	23.8418	90.3724	0.95	3.8
SBH-11	23.8687	90.4014	3.2	1.6
SBH-12(A)	23.8372	90.3638	1.2	2.6
SBH-12(B)	23.8374	90.3759	1.4	2.0
SBH-13	23.8493	90.4168	0.9	3.0
SBH-14(A)	23.8118	90.5416	1.1	3.4
SBH-14(B)	23.8203	90.6000	1.5	4.1
SBH-14(C)	23.8643	90.5164	1.3	2.3
SBH-15	23.8129	90.3459	1.24	3.0
SBH-16	23.8227	90.3645	1	2.2
SBH-17(A)	23.8132	90.4262	0.85	2.9
SBH-17(B)	23.8157	90.4324	1.45	5.5
SBH-17(C)	23.8263	90.4382	0.85	3.2
SBH-18	23.7754	90.3919	0.55	2.9
SBH-19	23.8222	90.4203	1.45	2.4
SBH-20	23.8015	90.3478	1.05	3.0
SBH-21	23.7861	90.4342	0.81	3.0
SBH-22	23.7837	90.3362	1.11	4.1
SBH-23	23.7724	90.3597	0.45	2.5
SBH-24	23.7690	90.3779	0.72	2.3
SBH-25	23.7638	90.4446	0.85	2.6
SBH-26	23.8095	90.4210	-	-
SBH-27	23.7549	90.4407	1.6	3.4
SBH-28	23.7530	90.3528	0.85	3.8
SBH-29	23.7508	90.3568	-	-
SBH-30	23.7282	90.3711	0.81	3.6
SBH-31	23.7175	90.3684	1.4	1.9
SBH-32	23.7269	90.3616	0.45	6.0
SBH-33	23.6713	90.4288	0.95	3.5

Borehole No	Latitude	Longitude	Frequency (Hz)	Amplification
SBH-34	23.7090	90.4598	0.72	2.5
SBH-35	23.6841	90.4198	0.85	4.0
SBH-36	23.6633	90.3902	1	3.8
SBH-37	23.6377	90.4516	1	3.6
SBH-38	23.7576	90.4324	1.05	2.6
MT1	23.8940	90.4005	0.42	5.7
MT2	23.9049	90.4052	0.51	2.8
MT3	23.8808	90.4003	0.48	4.2
MT4	23.8741	90.3995	-	-
MT5	23.8792	90.4248	0.75	2.7
MT6	23.8487	90.3728	0.41	3.9
MT7	23.8511	90.4115	0.44	2.4
MT8	23.8492	90.3885	0.59	2.9
MT9	23.8303	90.4191	-	-
MT10	23.8296	90.3886	1.48	4.9
MT11	23.8327	90.3637	0.46	3.1
MT12	23.8573	90.3098	-	-
MT13	23.8251	90.3642	0.46	2.7
MT14	23.8144	90.3674	0.44	2.6
MT15	23.8062	90.3878	0.58	2.8
MT16	23.8071	90.3689	0.46	4.0
MT17	23.8023	90.3580	0.44	2.8
MT18	23.8122	90.4038	0.5	7.9
MT19	23.7958	90.4010	0.46	3.2
MT20	23.7936	90.4083	-	-
MT21	23.8163	90.4163	0.44	2.5
MT22	23.8133	90.4213	-	-
MT23	23.8068	90.4218	-	-
MT24	23.7969	90.4234	-	-
MT25	23.7749	90.4262	0.45	3.4
MT26	23.7832	90.4170	0.92	2.1
MT27	23.7925	90.4151	1	2.1
MT28	23.7733	90.4170	0.4	5.1
MT29	23.7711	90.4011	0.42	4.5
MT30	23.7605	90.3996	0.46	2.7
MT31	23.7848	90.3532	0.42	3.5
MT32	23.7813	90.3533	0.44	3.2
MT33	23.7931	90.3504	0.46	4.6
MT34	23.7891	90.3183	0.44	9.1
MT35	23.7686	90.3692	0.42	3.0
MT36	23.7567	90.3752	0.48	3.2

Borehole No	Latitude	Longitude	Frequency (Hz)	Amplification
MT37	23.7461	90.3811	0.41	6.5
MT38	23.7528	90.3999	0.56	2.8
MT39	23.7667	90.4245	0.63	3.1
MT40	23.7365	90.3838	0.36	2.3
MT41	23.7390	90.3873	-	-
MT42	23.7338	90.4022	-	-
MT43	23.7382	90.3948	0.49	2.9
MT44	23.7281	90.4020	0.41	2.5
MT45	23.7250	90.4098	0.42	2.7
MT46	23.7332	90.4232	-	-
MT47	23.7262	90.4288	0.53	2.6
MT48	23.7511	90.3579	0.88	3.2
MT49	23.7359	90.3352	0.9	3.8
MT50	23.7653	90.3618	0.41	3.9
MT51	23.7925	90.3980	0.4	2.7
MT52	23.6881	90.4346	0.92	3.2
MT53	23.7457	90.4448	1.06	3.5
MT54	23.7003	90.4568	-	-
MT55	23.6737	90.4392	1.36	3
MT56	23.6632	90.4495	1.3	2.8
MT57	23.7130	90.5033	1.5	4.4
MT58	24.0088	90.4151	1.5	12.1
MT59	23.8296	90.4825	1.6	3.9
MT60	23.8033	90.4667	1.45	4.2

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BANGLADESH NETWORK
OFFICE FOR URBAN SAFETY

PART-XII

SHAHEED SUHRAWARDY MEDICAL COLLEGE AND HOSPITAL FIRE INCIDENCE: 14-02-2019

BANGLADESH NETWORK OFFICE FOR URBAN SAFETY (BNUS), BUET, DHAKA

Prepared By **Ayaz Mahmud**

Mehedi Ahmed Ansary

Shaheed Suhrawardy Medical College and Hospital in Dhaka’s Sher-e-Bangla Nagar caught fire on Thursday evening, leaving Around 1,200 patients, including those at the intensive care unit (ICU) and the surgery ward, under the open sky in dire situation for hours. The massive fire broke out around 5:50pm on 14th February 2019. It has originated in the storeroom on the hospital’s ground floor from an electric short circuit and then moved upwards.

The massive fire broke out at the Shaheed Suhrawardy Medical College Hospital.

A massive amount of smoke billowing from an under-construction part of the hospital.

Firefighters of 16 units have brought the flames under control around 9:00pm.Though it had take more time to put out all the small fires. The flames were completely doused around 11:30pm. The children’s ward on the second floor was damaged most.

A patient is being evacuated from the hospital.

An ambulance takes away patients from the premises of the Shaheed Suhrawardy Medical College Hospital.

Many of the patients found themselves under the open sky on the Suhrawardy Medical College Hospital premises.

Some patients managed space on the outside corridor of the Suhrawardy Medical College Hospital.

Some patients returned home after the Suhrawardy Medical College Hospital caught fire.

Evacuated patients in front of the hospital Building.

A fire broke out at the hospital forcing patients to be relocated

Patients are being brought out from the Suhrawardy Medical College Hospital.

The fire caused immense suffering to the patients and their relatives at the Suhrawardy hospital. The patients were evacuated and sent to different government hospitals, including the Dhaka Medical College Hospital (DMCH) and Mitford hospital. A child patient has died during evacuation. The child was given oxygen, but the oxygen mask was removed during the transfer. Relatives brought the child to the CARE Hospital, The CARE Hospital authorities declared the child as dead on arrival.

Child patient being transferred to another facility.

An emergency patient being wheeled out of the Hospital while an attendant squeezes the bag valve mask to help the patient breathe.

A patient is waiting to be relocated.

People waiting during relocation period.

Fire Service officials are saying that they had warned Shaheed Suhrawardy Medical College and Hospital three times, immediately before the devastating fire incident. The firefighting authorities had requested the hospital to upgrade their firefighting system and make several other changes. Eventually Fire Service issued a letter that it would not take any responsibilities in case of fire incidents, since the hospital had not paid heed to repeated warnings.

Children's ward on the second floor of the new building of the hospital was burnt.

Fire burnt the patient files and document.

Among the total, 1,174 patients -- 526 male, 576 female and 72 child patients were shifted to other government hospitals. Four wards, out of total 13 wards and a burn unit, bore the strain in the fire which will remain closed for investigation. Meanwhile, the hospital currently is not receiving child patients as the children's ward was severely affected.

According to Fire Service sources, they had inspected the hospital on November 16, 2017. They found a number of faults in the hospital buildings which made the hospital vulnerable to fire, and increased possibilities of high causalities. In a report based on the inspection, the firefighters said they found no fire hydrants, manual call points, alarms, emergency exit lights and aviation lights at the hospital. The building also did not have a basement and ramps. Fire Service also found no safety lobby on any floor, pump room, sprinkler heads, hose reels with hydrants, smoke- heat- or multi-detectors with main panel and repeater panel boards on any floor or basement. The hospital did not have the requisite number of portable fire safety equipment. It did not have a fire control room, according to the inspection report. An administrative officer of the hospital was present during the inspection, the report said. The inspection team suggested installing proper firefighting systems in the hospital and regular maintenance of electrical wiring. The team also suggested that the hospital authority clean the store room, where the fire would eventually take place. But necessary measures were not taken by the hospital. On October 21, 2018, the Fire Service sent a letter to the hospital authorities mentioning previous inspections and warnings and requested them to implement a fire safety plan to ensure public security. In the letter, the Fire Service wrote that its inspection had found fire and public safety measures to be very poor at the hospital.

To develop fire resistance, firefighting capacity and public safety of the hospital, the Fire Service recommended necessary steps in a previous letter. But they made no development on fire resistance, firefighting capacity and public safety. Therefore the hospital was always at high-risk. The hospital did not obtain a no-objection certificate from the fire authorities, which is also a must by law.Deadly fires are a persistent problem in Bangladesh yet for some reasons concerned officials are not taking required actions or failed to do so. It’s a colossal failure on their part and as a result people are suffering

PART-XIII

RIVERBANK EROSION IN LOWER PADMA USING REMOTE SENSING TECHNIQUES AND TERRESTRIAL LASER SCANNING

BANGLADESH NETWORK OFFICE FOR URBAN SAFETY (BNUS), BUET, DHAKA

Prepared By **Maruf Bilah**

Sudipta Chakroborti

Mehedi Ahmed Ansary

Bangladesh has a unique hydro-geological setting and deltaic floodplain which is jointly formed by the deposition of the Ganges (Padma), Brahmaputra (Jamuna) and Meghna River. The physical characteristics of the geographic location, river morphology, and the monsoon climate render Bangladesh highly vulnerable to natural disasters, primarily, floods, cyclones and bank erosion. In recent the lower Padma has been experienced massive river erosion. Padma River was in a rising trend and speedy current is engulfing houses and establishments rapidly in the Naria upazila of Shariatpur district. The erosion swallowed houses, schools, dams, roads, business establishments, mosques. The residents of riverbank are going through days of fear of further erosion while several more houses are still at greater risk. Victims have to live under the open sky as their dwellings were washed away by river waters. They face huge losses as their croplands have also been washed away. Now, they are seeking assistance to reconstruct their houses. In this report, we have tried to denote the present scenario of the affected area. This report has been developed based on the assessment of this massive disruption in Shariatpur district with the assist of Geographic Information System (GIS), terrestrial laser scanning and on field validation with transect walk.

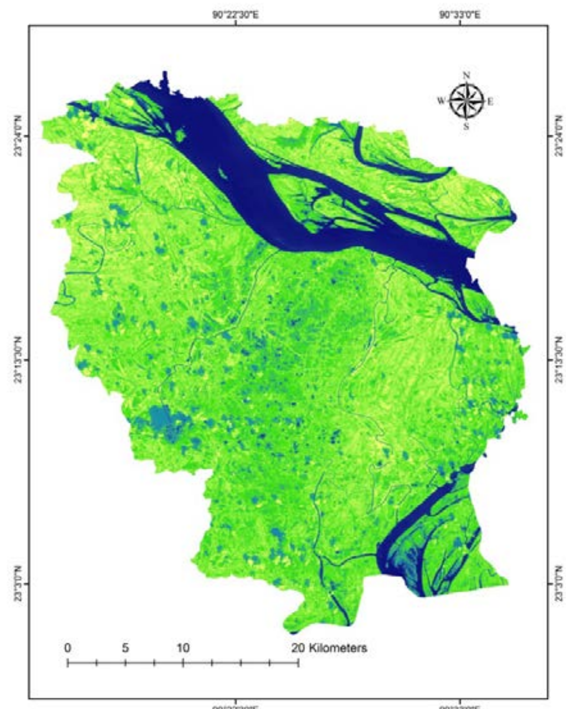


Figure 5: Study area map (Shariatpur district)

Present situation of the study area:

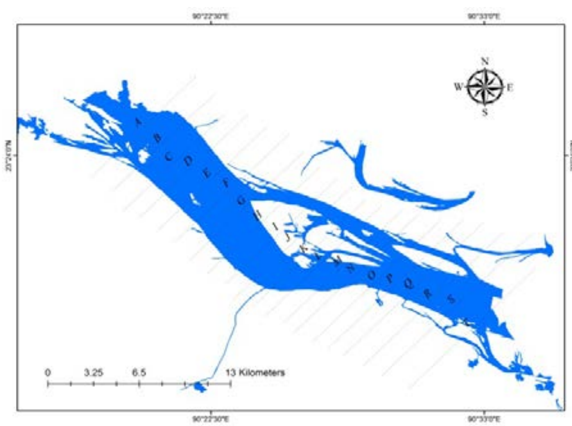
Enormous erosion has been taken place in Shariatpur district in recent days. To assess the situation, initially Landsat 8 (OLI) image has been used which is available in USGS earth explorer website (http://earthexplorer.usgs.gov) then a field observation has been conducted later. For detecting the erosion two images, one is before the incidence and another is after the incidence has been cast off. Modified normalized different water index (MNDWI) has been carried out to detect the bank shifting during this time (Pal, R. and Pani, P., 2016; Pal, R. and Pani, P., 2018; Islam, M.K., Dustegir, M.M., Rahman, M.M. and Rahman, M., 2018). Two different bands, band 3 (green) with the wavelength of 0.53-0.59 µm and band 6 (short wave infrared 1) as MIR with the wavelength of 1.57-1.65 µm have been used in this study.

$$\text{MNDWI} = \text{Green-MIR/Green+MIR}$$

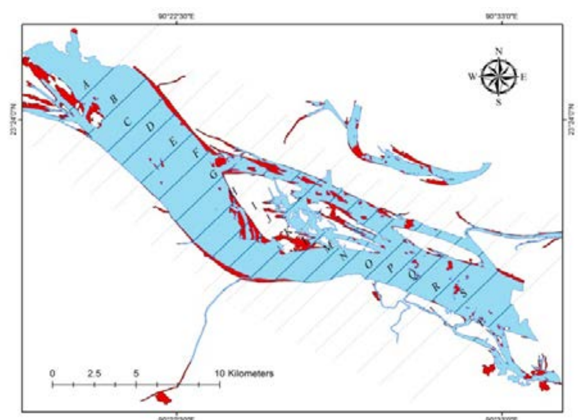
Table 1: General information on used satellite data

Acquisition Date	Path	Row	Land Cloud Cover	Scene Cloud Cover	Center Latitude	Center Longitude	Grid Cell Size Reflective	Grid Cell Size Thermal
10/3/2018	137	44	4.06	4.1	23°06'44.86"N	90°24'21.96"E	30	30
5/12/2018	137	44	1.59	1.9	23°06'44.86"N	90°24'21.96"E	30	30

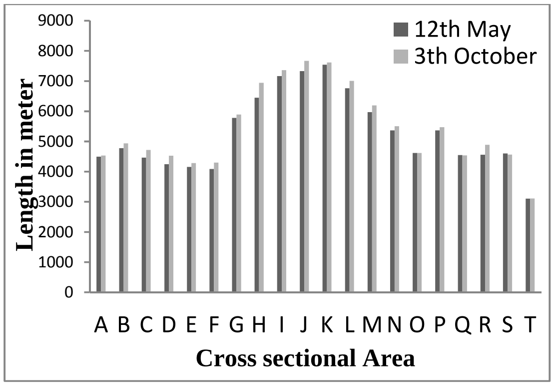
By image analysis it has been seen massive erosion in Sariatpur district basically in Naria Bazar, Mulfat and Bashtala area. Huge landmass has been lost within a shorter period of time. To detect the bank shifting along the river 20 cross sections have been analyzed with Arc GIS measurement tools.

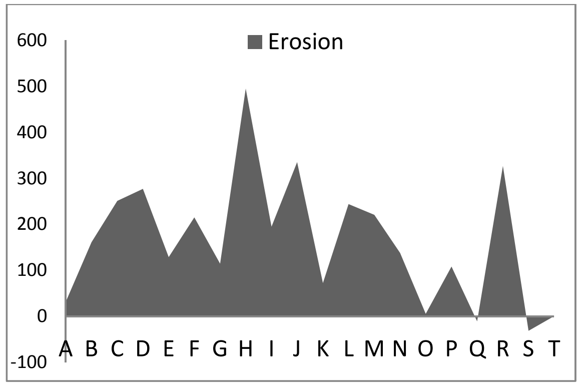


(a)



(b)





(c) (d)

Figure 2: 20 cross section to detect the bank shifting (a), cross section with eroded and shifted land mass in red marked (b), length of the cross sections in meter (c), length of the eroded area with respect to 20 cross sections (d).

The government has distributed relief among the victims in the affected areas, but these are not adequate, said the victims, adding that they are seeking financial assistance to build their dwellings. Kabir Bin Anwar, Secretary of the Ministry of Water Resources, visited the area on September 15 and declared that immediate steps will be taken over the issue. Meanwhile, Cabinet Committee on Economic Affairs on Wednesday approved a proposal to award a contract to Bangladesh Navy-run Khulna Shipyard to protect the Zajira and Naria upazilas in Shariatpur from river erosion at a cost of Tk1077.58 crore (Dhaka Tribune, 19th September 2018).

A total of 5081 families have been rendered homeless in Naria Upazila due to the violent erosion of Padma River in the district in recent weeks (Green Watch, 27th November 2018).“We don’t want help, we want the embankment, people could make their livelihood by driving rickshaw or three-wheeler if there was an embankment here,” said mother of two Mahamuda Begum, who has already been displaced four times previously due to river erosion. Another victim of Padma erosion Azizul Madbar said “My house was 5 km away, this is the fourth time, I have brought down my house and rebuilt for river erosion, I have become depleted. Our rescue is only possible if the Prime Minister looks upon us. Otherwise, there is no one to save us.” Juwel Bepari of the same area said he and his family were passing their days only half-a-kilometre away from the point at which the river is now, renting a place for Tk 6,000. Sufia Begum of Kedarpur village in the upazila had a large house and owned a shop at the historic but fast-disappearing Mulfatganj bazar, both of which were engulfed by the Padma. “Within two months our wealthy condition turned into poverty,” she said. Within one week different government and private buildings of Mulfatganj Bazar were vandalized. Most of the parts of the new building of Naria Upazila Health Complex went under the Padma water. Emergency and Exterior departments of the hospital were operating in a residential building of the hospital campus but its main entrance was lost creating disruption in service. No patients were seen taking treatment there due to the erosion fear. Eleven more buildings of the hospital complex were under erosion threat while a crack has occurred in one building, witnesses said.

Detail Assessment with TLS

Terrestrial laser scanning TLS provides a rapid, remote sensing technique to model 3D objects (Olsen, M.J., Kuester, F., Chang, B.J. and Hutchinson, T.C., 2009). Terrestrial laser scanning TLS provides dense range measurement data to model an object in three dimensions 3D. There are two common types of laser scanning technologies and they are 1 phase-based scanners and 2 time-of-flight based scanners (Maas, H.G., Bienert, A., Scheller, S. and Keane, E., 2008). High speed, phase-based scanners compare phase shifts in a modulated laser beam to determine distances to objects at close range. Instead, TLS provides an excellent mechanism for pre- and posttest modeling and analysis. Terrestrial laser scanners typically use low power lasers so that they are human safe. For this study, a RIEGAL was used, which utilizes a class 3R laser. This means that there is potential for eye-safety damage if the laser remains fixed at a location for several seconds and the person is in front of and close to the scanner within 1 m. Operators, however, must remain behind the scanner to avoid interfering with data collection. In this study to perform the detail assessment of riverbank erosion, a work flow of laser scan survey has been followed.

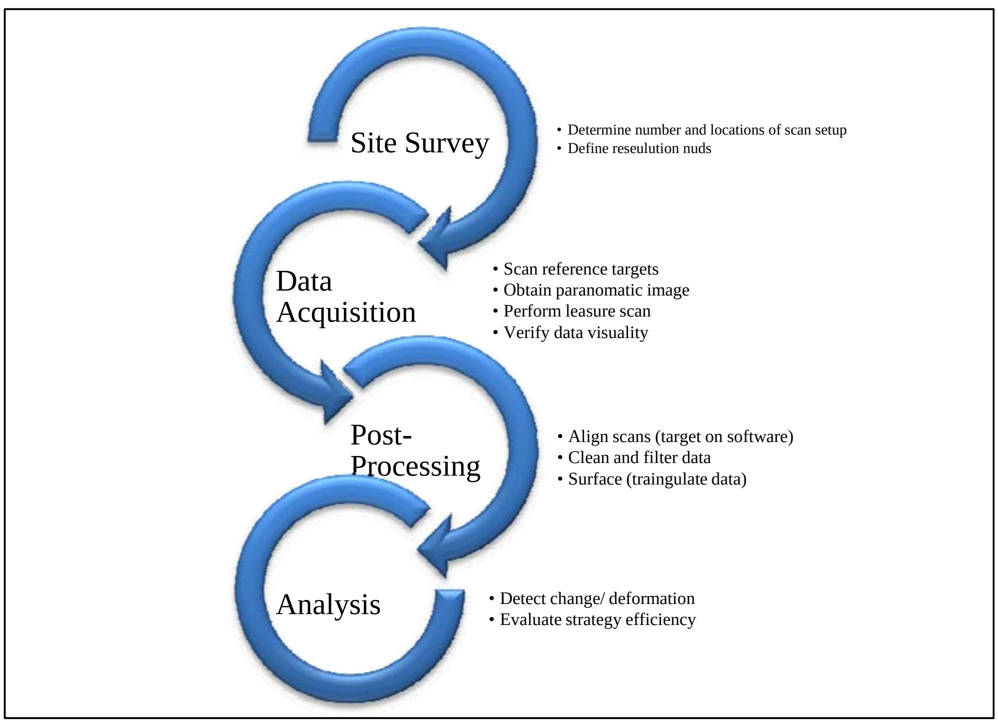
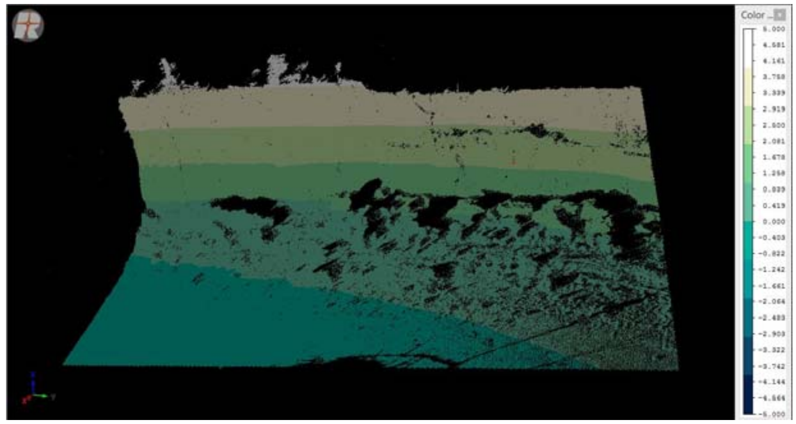
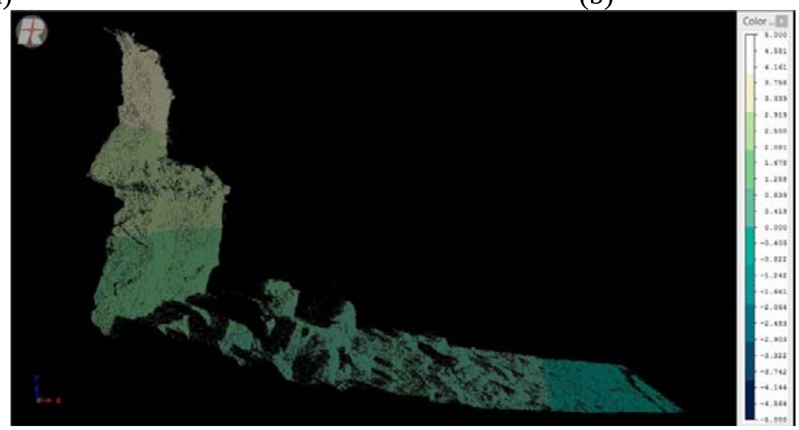


Figure 3: Workflow for laser scan survey project

(a)



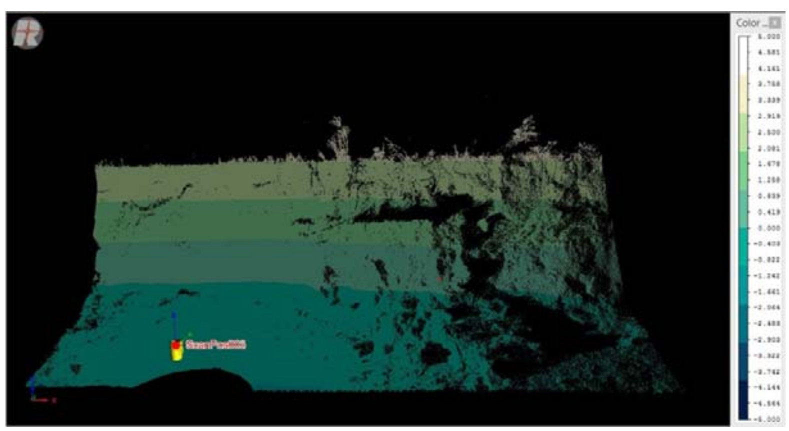
(b)



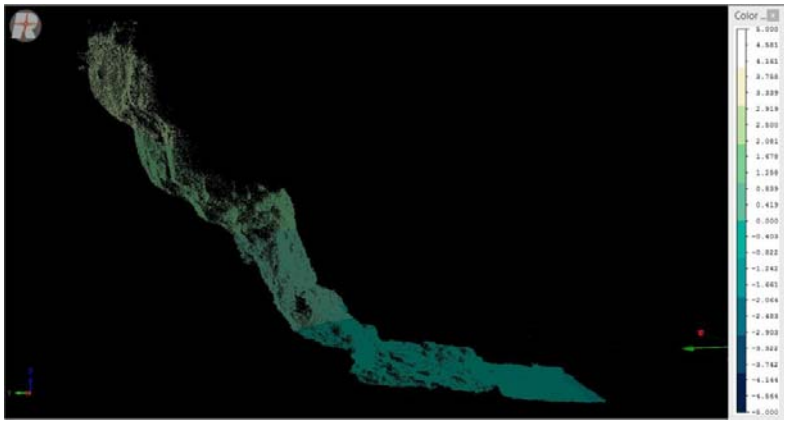
(c)

Figure 4: Detail assessment of Naria bazar river bank slope. Real picture of the present situation (a), detail scan (b), slope elevation and angle (c)

(a)



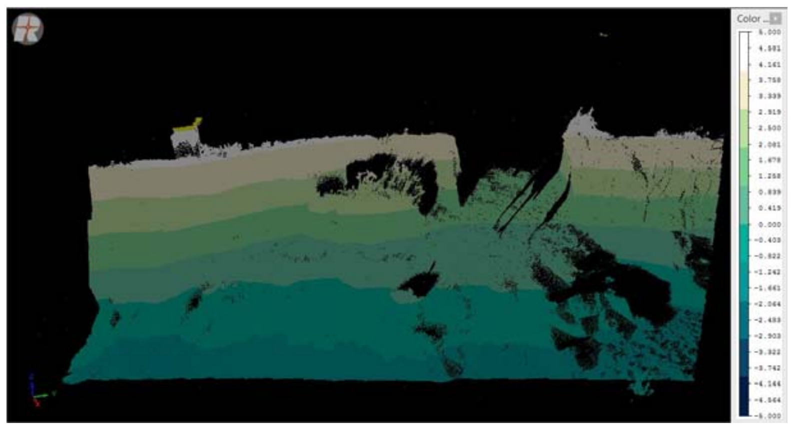
(b)



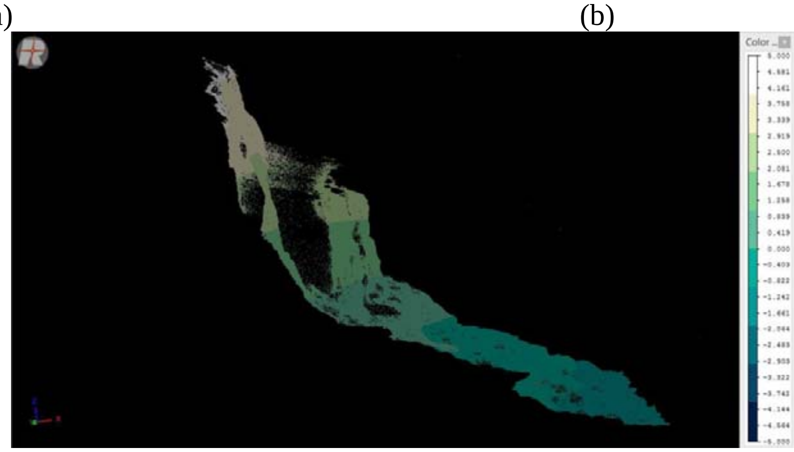
(c)

Figure 4: Detail assessment of Bashtola river bank slope. Real picture of the present situation (a), detail scan (b), slope elevation and angle (c)

(a)



(b)



(c)

Figure 4: Detail assessment of Mulfat river bank slope. Real picture of the present situation (a), detail scan (b), slope elevation and angle (c)

Photographs of the Field Visit

(a)

(b)

(c)

(d)

(e)

Figure 3. Figures show the river erosion at the a) Noriabazar, b) Mulfat, c) Bashtola, d) Bilashpur and e) Jajirabazar.

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PART-XIV

CHURIHATTA, CHAWKBAZAR FIRE INCIDENCE: 20-02-2019

BANGLADESH NETWORK OFFICE FOR URBAN SAFETY (BNUS), BUET, DHAKA

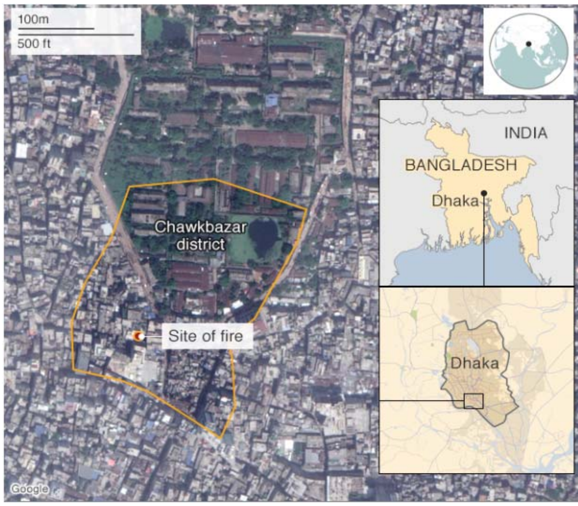
Prepared By **Maruf Bilah**

Sudipta Chakroborti

Mehedi Ahmed Ansary

Chawkbazar is a standout amongst the most imperative territories in Old Dhaka, an architecturally significant area built up around 400 years back amid the Mughal tradition. The area is crammed with buildings separated by narrow alleys, with residences commonly above shops, restaurants or warehouses on the ground floors. It is a hub of chemical businesses and local perfume factories. There are thousands of chemical warehouses in old Dhaka, most of which are in residential buildings. Only 2 percent of these warehouses have the city corporation's permission. The avenues are pressed with rickshaws, little vehicles and individuals strolling around amid the day. The paths are narrow to the point that traveler transports can't get past. Electrical, phone and web links hanging over the restricted paths represent a genuine risk. In any case, the most genuine risk originates from the way that private structures are utilized for business purposes, with ground floors filling in as chemical warehouses. More than one fire takes place a day in old town mainly because of numerous chemical storage, plastic and other factories. Fire service data show at least 468 fire incidents struck the old town's Lalbagh, Hazaribagh, Sadarghat and Siddique Bazar, where more than 500 chemical warehouses and factories operate illegally.

On the night of 20th February, 2019 around 10:30pm at Nanda Kumar Lane in Chawkbazar’s Churihatta area of Old Dhaka a colossal fire broke out. The affected area is under Dhaka south city corporation at ward no. 64. The fire has originated from a compressed natural gas or CNG cylinder explosion of a pick-up van first and then the fire spread to the vehicles and buildings on the street and spread to a chemical warehouse on the ground floor of a four-stored building named Hazi Wahed Mansion. There also were expired perfume can, air freshener and electrical equipment’s on the 1st floor of Hazi Wahed Mansion which further fed the fire. Hazi Wahed Mansion has caught fire first among the other buildings and has been affected most by the fire. The flames then quickly spread through three other buildings nearby.



Site location from google map.

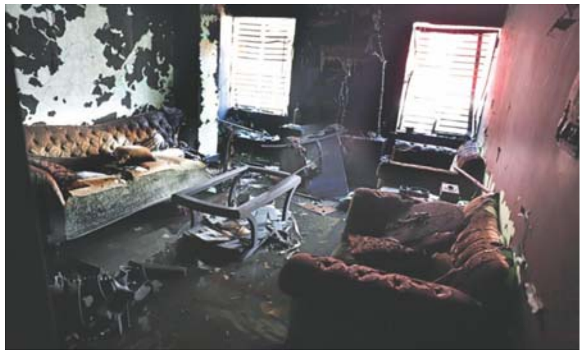

Hazi Wahed Mansion on Fire.

The Fire lasted 12 hours before completely doused off. Thirty-seven units of firefighters from 13 fire stations brought the fire under control around 3:00am. 67 people were burned alive within very short period of time and 41 people got injured. Amongst the injured, 7 people were in critical condition, 4 of them has died within 11 days from the incident. So, in total 71 people has died as of today when the report is being prepared (03 March 2019).


Ruins of Hazi Wahed Mansion.


Ground floor and 1st floor wall came outward
Due to explosion inside.

Charred remains of a dining table on the second floor of Hazi Wahed Mansion.



Charred remains of a drawing room on the second floor of Hazi Wahed Mansion.

Charred wreckages of vehicles are piled up for disposal.

A dead body is carried out from a burnt warehouse of wahed mansion.

Containers of chemicals found stacked in the basement of Haji Wahed Mansion.

Sacks of melted plastic beads on the ground floor of the building.

Burnt containers of perfumes stored on the 1st floor of Wahed Mansion.

Small explosion due to the perfume, air freshener can at 1st floor of Wahed Mansion.

Nasrin breaks down in tears holding the photo of her missing father.

Relatives rummaging through the charred bodies at Dhaka Medical College morgue in a desperate bid to identify their near and dear ones.

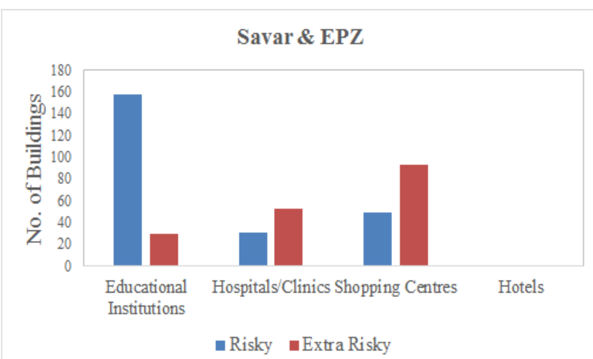
The injured at Dhaka Medical College Hospital.

Prime Minister Sheikh Hasina consoles a relative of a Chawkbazar fire victim being treated at the burn unit of Dhaka Medical College Hospital.

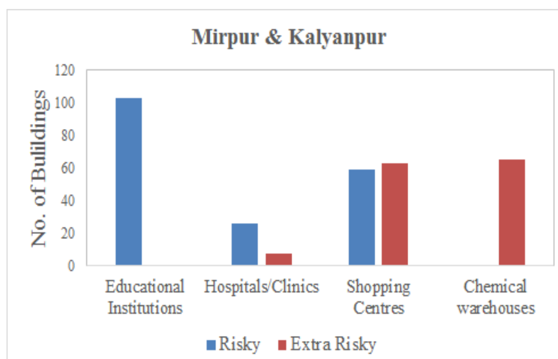
The chemical business in Old Dhaka has been a family business. It's like a family tradition. They don't want to go far. A lot of issues are related to this. One of the main reasons behind the concentration of chemical storehouses in Old Dhaka is their cheaper rent compared to those in other parts in the city. Besides, their locations also help businesses cut the chemical transportation costs. Storehouses are built in some almost unreachable and undiscoverable rooms and buildings, meaning these are inaccessible to firefighters. Around 98 percent of the chemical warehouses are illegal and they operate at night.

In 2017, the Fire Service Department did a city wide inspection of over 5000 markets, schools, hospitals, banks, hotels and chemical warehouses to find that an over overwhelming number of them do not meet the basic criteria of fire safety. To date, this is the most extensive database of fire safety violations. (Star weekend, March 1, 2019, The Daily Star)

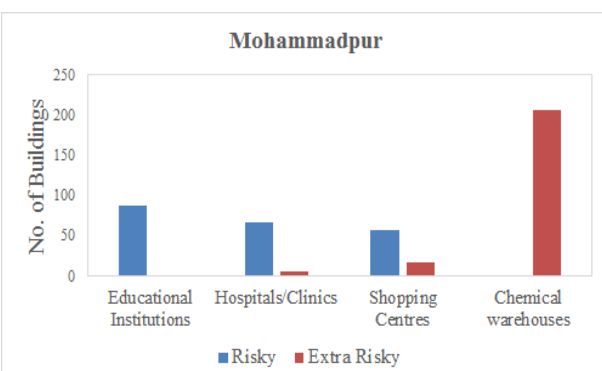
Some bar charts showing the probability of fire accident in terms of risky and extra risky cases are shown below for 10 separate areas. The no. of major fires that happened in each area are of between '2012 to 2019'.



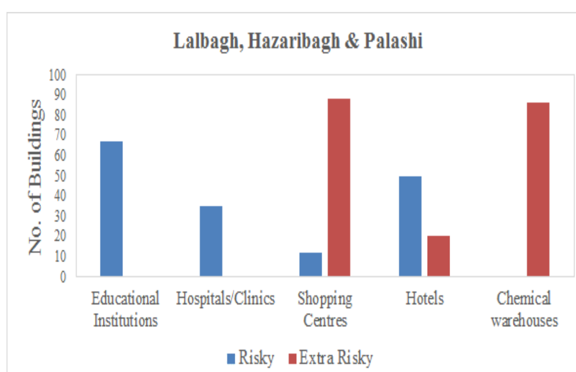
The no. of major fires =14



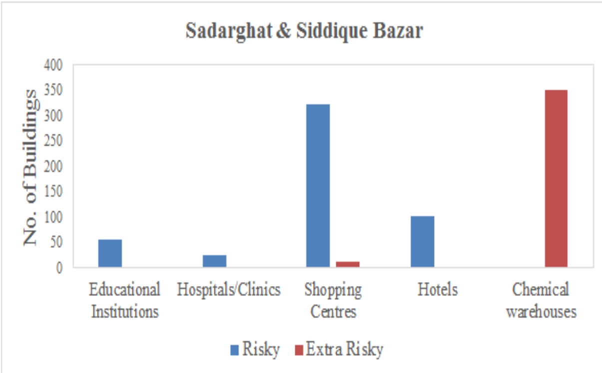
The no. of major fires =36

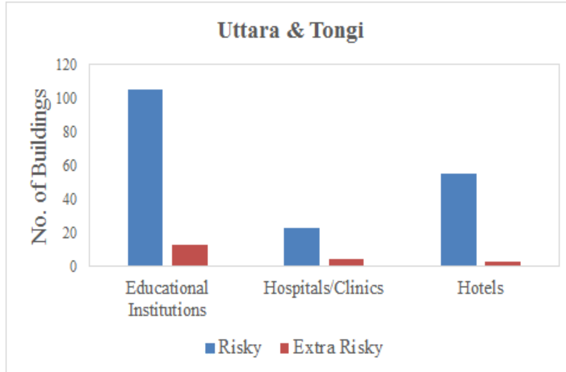


The no. of major fires =16



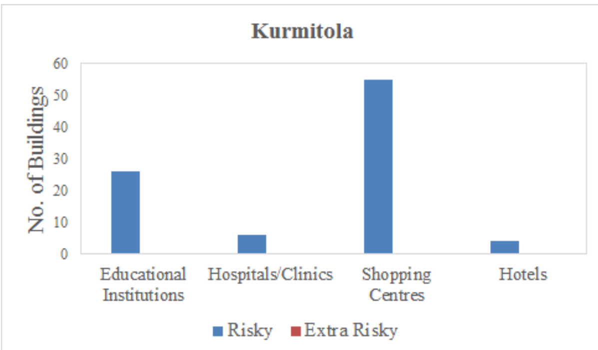
The no. of major fires =20

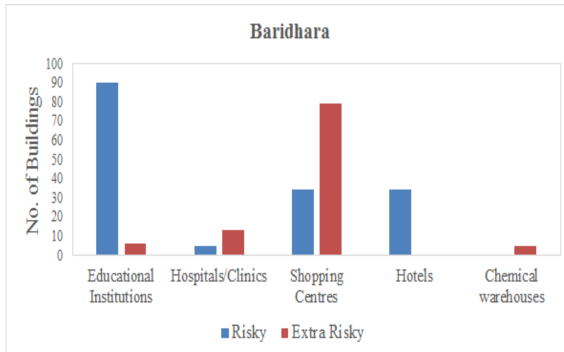




The no. of major fires =18

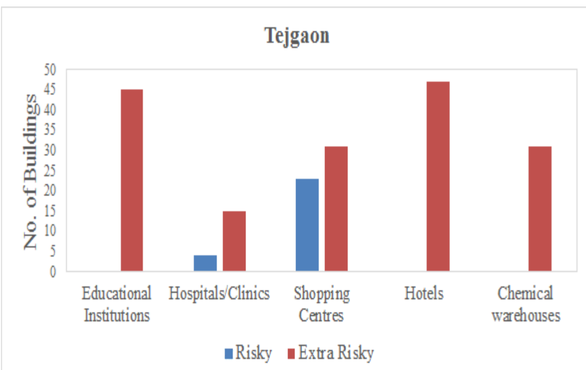
The no. of major fires =28

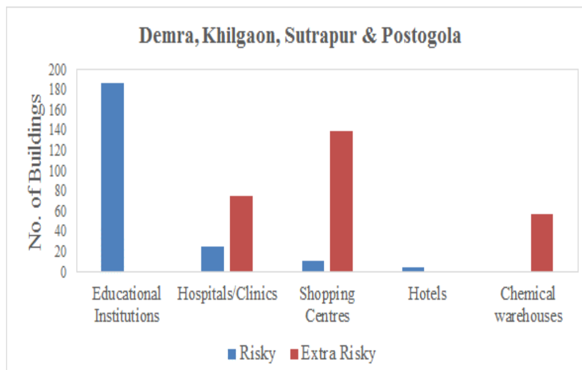




The no. of major fires =4

The no. of major fires =9





The no. of major fires =22

The no. of major fires =26

After the Nimtoli fire in 2010, the government had pledged to relocate chemical warehouses from Old Dhaka to a thinly populated area in Keraniganj. But it is yet to procure land to set up a chemical warehouse zone. It is not possible to eliminate all the sources of fire hazard in the area but at least some initiatives can be taken to minimize the loss. For example shifting warehouses to nonresidential areas, enforcing Fire Prevention and Extinguishing Rules 2003 and Bangladesh National Building Code, installing separate hydrant points in the city's different areas, forming a cross-functional license issuing body and updating school and college textbooks to raise awareness from an early age.