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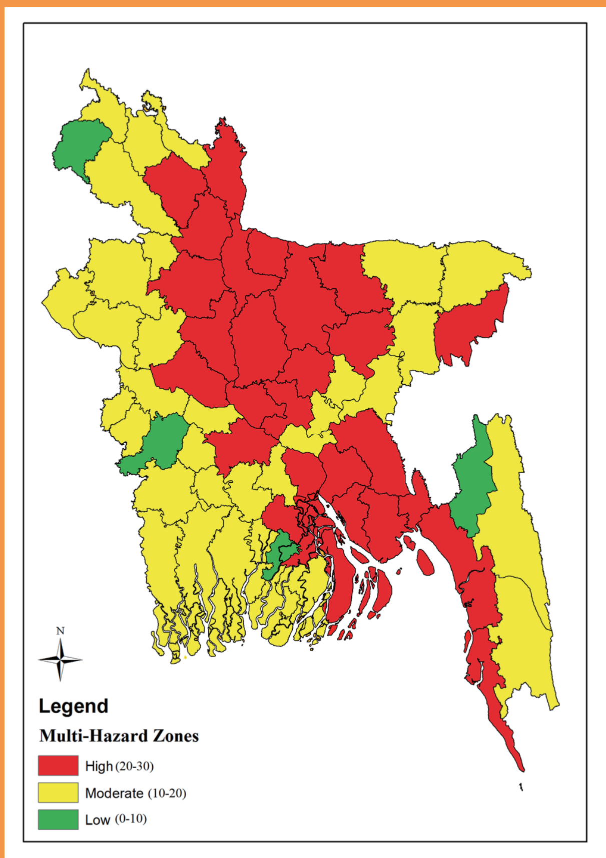

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INSTITUTE OF INDUSTRIAL SCIENCE THE UNIVERSITY OF TOKYO

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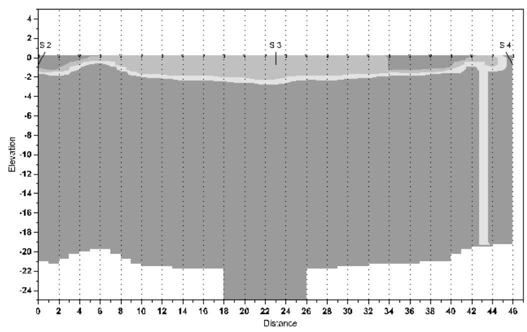
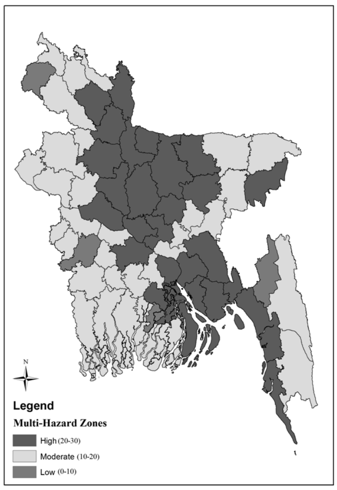
BUET, DHAKA, BANGLADESH

Prepared By:

Mehedi Ahmed Ansary





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CONTENTS

PART-I

LAND SUBSIDENCE BESIDE SUNDARBAN HOTEL ON BIR UTTAM CR DUTTA ROAD IN KATHALBAGAN, DHAKA ON 27 - 29 MAY, 2015

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

Prepared By: Uttama Barua

Mehedi Ahmed Ansary

At around 7:30am on 27 May 2015, some parts of a bye lane beside Sundarban Hotel on Bir Uttam CR Dutta Road in Kathalbagan near Sonargaon Intersection in Dhaka's Karwan Bazar and several parts of a piling structure of an under-construction building 'National Bank Limited Twin Tower' suddenly caved in. Witnesses said the iron structure erected for pilling work of the under-construction building near the SAARC Fountain fell to ground with huge sound. After that, at around 3:45pm, the northeast portion of the basement of the six-storey Sundarban Hotel partially fell down.

Figure 1: Boundary wall and basement of Sundarban Hotel

Figure 2: Bye lane beside the construction site

The NBL authorities contracted Korean firm, Donga, to build the 12-storey twin tower primarily with a three-storey basement on around 64 katha land. The Korean firm sub-contracted three Bangladeshi firms — Mum Impex, BD Construction and MS Construction. On the day of incident there was no official word on the exact reason behind the subsidence but BUET Professor Dr. Mehedi Ahmed

Ansari, after visiting the site, said that the three-tier under construction basement of the NBL twin tower is very weak and the method followed was not correct either. The shore piling of the under construction building failed due to the poorly-deigned groundwork of the under-construction building, i.e. lack of proper iron bracing to protect the piling, which is meant to protect the edge of the soil. Chairman of RAJUK said that the National Bank Limited (NBL) obtained approval from the RAJUK in December 2013, but he assumes that the pilling work has not been done according to the approved design. Concerns of MS Construction brushed aside poor construction measures and blamed the recent earthquake and rain for the collapse. According to them, the boundary wall of the hotel collapsed first and damaged the sewerage and drainage pipes beneath. When the pipes got broken, water came out and created pressure on the surrounding earth, eventually triggering the slide. Meanwhile, Bangladesh Bank officials said that NBL authorities did not take their permission to build their headquarters on the site.

The incident took down several tea stalls, rickshaw vans, trees and electricity poles. But, no report of injuries has been filed. As a result of the incident the water and gas supply system of the area collapsed. The entire area is stated to be very risky as the sand and mud of the ground are being washed away by the water coming out of the leakage in the water line of Hotel Sundarban. The restricted vehicular movement on the road near the subsidence site gave rise to hours of traffic congestions in the surrounding busy roads.

Mayors and high officials of two city corporations, RAJUK officials, officials and staff of WASA and DESCO, expert teams of Bangladesh University of Engineering and Technology (BUET) visited the spot. The mayors held the authorities of RAJUK and the construction company responsible for the incident. They said that due to lack of monitoring by RAJUK, the construction firm got the chance to violate the approved design. RAJUK said that they will sue the construction firm over the incident.

A team from Kalabagan Police Station and Tejgaon fire station officers rushed to the scene immediately after being informed, although the area falls under the Mohammadpur fire station's purview. Apart from the firefighters and police, additional law enforcers, including RAB and Ansar members have been deployed in the area in order to prevent further damage. Afterwards, they ordered to evacuate the Sundarban Hotel. There were a total of 50 guests inside the hotel, who had been moved away immediately afterwards. Utility authorities disconnected water, gas and power supply in the adjacent areas because some of these lines were also damaged in the incident. The authorities concerned restricted all type of vehicular movement on the road in front of the building. Law enforcers were deployed in the area to control an inquisitive crowd so that nobody got hurt in case there were any further shifts in soil.

As an immediate step to prevent any further disaster, Dr. Ansari said that the first thing that the authorities should do is filling up the excavated place with land. Experts said that the excavation hole must be fully filled up in the quickest possible time; otherwise the surrounding areas would also be at risk of subsiding. Moreover a heavy downpour might cause the hotel building to collapse at any time, which would put the nearby high-rise buildings and adjacent roads under threat. In a joint effort around 12:30pm, Dhaka north and south city corporations started filling up the void created by the slide with different kinds of sand and brick dust. Officials said the filling of land would continue for two days. According to their estimation, around 1,500 trucks of sand would be required immediately to fill up the site and save the hotel temporarily, and it would require two days to complete the work. Around 500 trucks of sand had been piled in after 10pm on the same day. The building still faces risk as several large cracks have developed on it.

Figure 3: Land filling work

Figure 4: Land filling by truck

Figure 5: Crack developed in Sundarban Hotel

National Bank Limited is not cooperating to make risk-free the area at Karwan Bazar after the street caved in due to a construction of its high-rise. GM of Sundarban Hotel filed a general dairy with Kalabagan police station narrating the incident against the construction firms. Meanwhile, RAJUK itself filed a case with the Kalabagan police station against NBL twin tower Project Director, MS Construction CEO, and NBL Deputy Director.

On the second day of the incident, 28 May 2015, another portion of the Bir Uttam CR Dutta Road - a few yards north of the spot where land subsided on the previous day – caved into the excavation site with a loud bang at around 10pm. In the process, anser camp, row house of the workers, a part of a wall, several billboards and trees, a portion of the pavement and an electricity pole also fell into the excavation site. Later, cracks were also seen on the road of Panthpath. Moreover, the sand filling work to prevent Sundarban Hotel from collapsing progressed at a sluggish pace on the second day of the incident due to lack of sand reinforcement in the ditch. Later the contractor MS Constructions and Development's Project Director was contacted to supply the required amount of sand. Experts fear that any untoward incident can take place in the advent of rain. In this situation, the SAARC Fountain is now in the risk, as it may face the fate of the hotel.

Figure 6: Second incident of land subsidence on 28 May 2015

The second subsidence put one half of the road leading from Karwan Bazar to Panthapath at risk. The authorities stopped vehicular movement on this half of the road, leaving the other half – adjacent to the Basundhara City Shopping Mall – open for vehicles in order to prevent further subsidence due to vibrations created by moving vehicles. A security cordon was put in place beside the tiger sculpture, making the mouth of the Bir Uttam CR Dutta Road fully off limits for people and vehicles as hundreds of curious people gathered near the spot of the accident. Billboards, makeshift shops and hawkers from the site were removed in apprehension of big incident. The National Bank Limited authorities were asked to clear the roads around Sundarban Hotel by Sunday.

Another land subsidence occurred at the Karwan Bazar construction site on 29 May, 2015 morning, following two similar incidents on consecutive days since Wednesday. The extent and damage caused by the latest land subsidence, which happened a little before 9am in the same north-west side as Thursday’s incident, was comparatively less than the previous days. Authorities working at the site stayed alert throughout the day for the possibility of further rain that might trigger yet another incident. Although there was some downpour in the afternoon, no more land subsidence happened.

Figure 7: Third incident of land subsidence on 29 May 2015

Following the brief spell of rain, the sand-dumping trucks were parking a bit further away from the site and maintaining caution while approaching the void left by the land subsidence at the under-construction NBL Twin Towers. After this incident until 10 pm on Saturday around 1000 trucks of sand have been dumped in the hole and till the third incident no other subsidence occurred. The western portions of the hotel and the construction site are still in danger of collapse as the truck of sand cannot reach that portion of the hotel. Commuters passing through the area continued to suffer as the adjacent Panthapath and Bir Uttam CR Dutta roads stayed out-of-bounds for vehicles because of safety reasons. The authorities concerned withdrew the restriction of vehicular movement on the roads four days after the land subsidence in front of Hotel Sundarban on 31 May, 2015 stating that the lane is primarily out of risk.

Figure 8: Closure in adjacent roads after the incident of land subsidence

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PART-II

APPLICATION OF SEISMIC REFRACTION METHOD TO INVESTIGATE SUB-SURFACE SOIL STRUCTURE

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

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Pushpendue Biswas
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1 INTRODUCTION

Seismic refraction is a commonly used geophysical technique to determine depth-to bedrock, competence of bedrock, depth to the water table, or depth to other seismic velocity boundaries. This method involves the analysis of the travel times of arrivals that travelled roughly parallel to the upper surface of a layer during their transmission through the subsurface. [1] Seismic refraction methods provide an effective and efficient means to obtain general information about large volumes of the subsurface in the two dimensions of depth and horizontal (or slope) distance. Information provided by seismic refraction includes compression wave (p-wave) velocities within the investigated subsurface profile. Traditionally, these velocities are interpreted to be present within layers or horizons whose depths are also interpreted. Newer interpretation methods are making it possible to interpret velocity changes as gradients as well as discrete layers. Seismic refraction measurements are applicable in mapping subsurface conditions for various uses including geological, geotechnical, hydrological, environmental, mineral and archaeological investigations.

2 STUDY BACKGROUND

The seismic refraction survey has application in a variety of geological exploration problems, where information on the depth and strength of subsurface materials is required. These surveys provide subsurface information over large areas at relatively low cost; locate critical areas for more detailed testing by drilling and can readily eliminate less favorable alternative sites. Seismic surveys can also reduce the number of boreholes required to test a particular site and improve correlation between boreholes.

2.1 Advantages / Disadvantages

- Difficulty of interpretation in areas morphologically rough or with many underground pipes
- Open spaces is needed for cables and electrodes array, the electrodes must be planted into the ground (can also be applied in paved areas or asphalt, drilling holes).
- Good vertical and lateral stratigraphic resolution.
- For best accuracy, a calibration reference stratigraphy is needed.
- Very useful for discrimination of metal, clay / sand and aquifers

2.2 Fundamentals Theory

The refraction method consists of measuring (at known points along the surface of the ground) the travel times of compressional waves generated by an impulsive energy source. The energy source is usually a small explosive charge and the energy is detected, amplified, and recorded by special equipment designed for this purpose. The instant of the explosion, or "zero-time," is recorded on the record of arriving pulses. The raw data, therefore, consists of travel times and distances, and this time-distance information is then manipulated to convert it into the format of velocity variations with depth. The interpretation of this raw data will be developed as we go along. The process is schematically illustrated in Fig. 1. The fundamental law that describes the refraction of light rays is Snell's Law (see Fig. 2), and this, together with the phenomenon of "critical incidence," is the physical foundation of seismic refraction surveys.

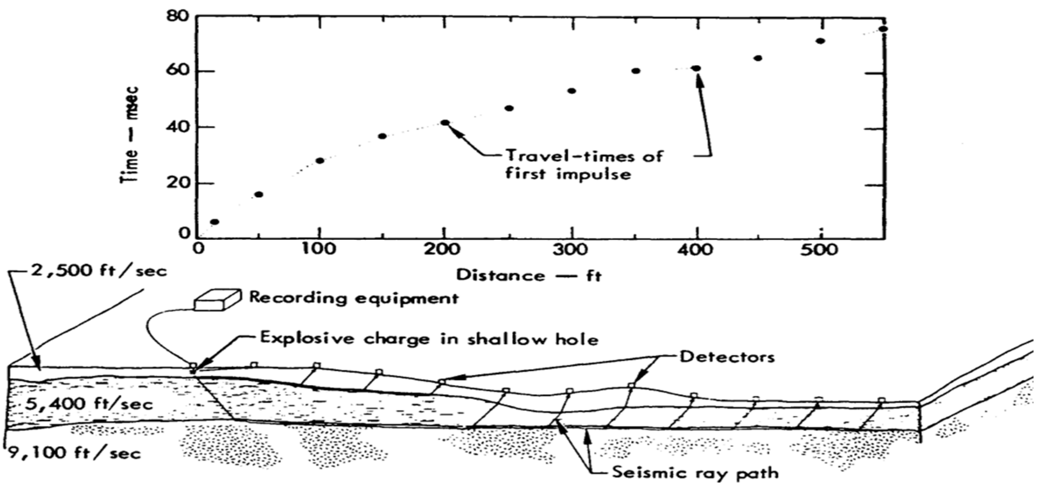

Fig 1: Schematic of seismic refraction survey

A small explosive charge is detonated in a shallow hole at A and the energy is detected by a set of detectors laid out in a straight line along the surface. The arrival times of the impulses are plotted against the corresponding shot-to-detector distances as shown in Fig. 3. The first few arrival times are those of direct arrivals through the first layer, and the slope of the line through these points, $\Delta T/\Delta X$, is simply the reciprocal of the velocity of that layer; i.e., V_1/V_2. The energy that arrives at the detectors beyond the critical distance will plot along a line with a slope of V_1/V_2.

The line through these refracted arrivals will not pass through the origin, but rather will project back to the time axis to intersect it at a time called the intercept time. Because both the intercept time and the critical distance are directly dependent upon the velocities of the two materials and the thickness of the top layer, they can be used to determine the depth to the top of the second layer.

The rock types can be found to know the seismic velocity transmitted to the soil. The verities of seismic velocity of different layers indicated different types of soil. [5]There is an approximate range to classify rocks depending on seismic velocities.

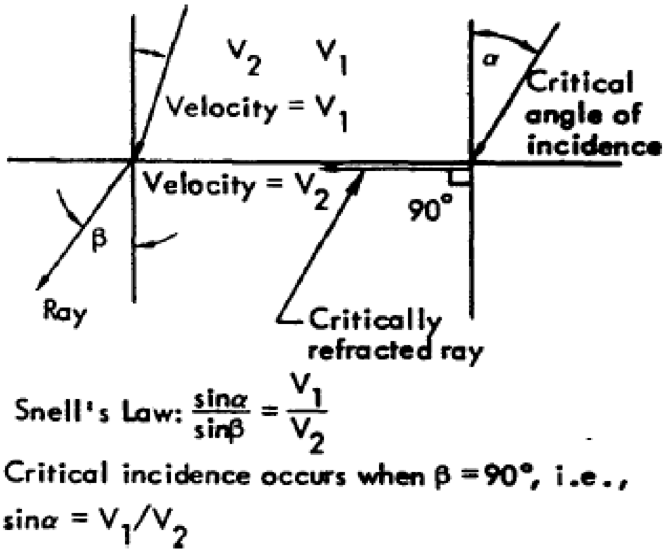

Fig 2: Snell's law and refraction of ray transmitted across boundary between two media with different velocities

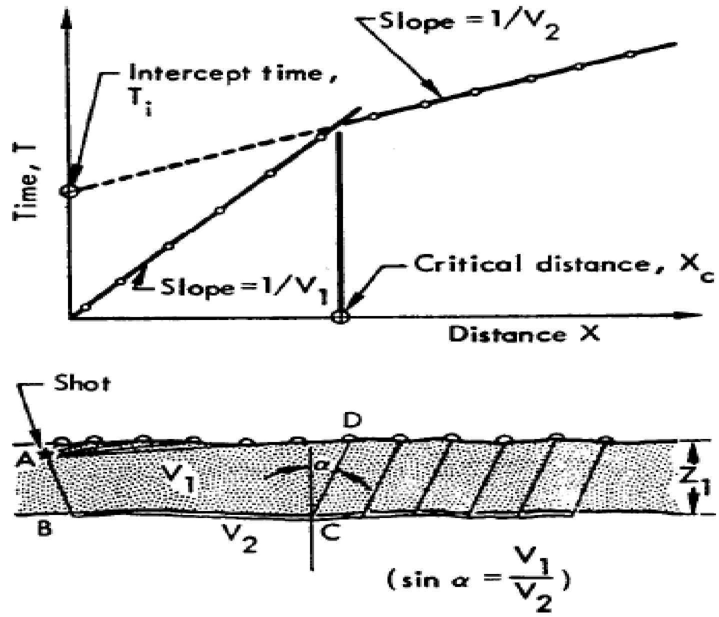

Fig 3: Simple two-layer case with plane, parallel boundaries and corresponding time-distance curve.

Table 1: Approximate seismic velocities for rocks

Rock type	V_p(km/sec)	Rock type	V_p(km/sec)
Unconsolidated sediment		sandstone	2.0-5.0
Clay	1.0-2.5	Others	
Sand, dry	0.2-1.0	Air	0.3
Sand, saturated	1.5-2.0	Natural gas	0.43
Sedimentary Rocks		Ice	3.4
limestone	3.9-6.2	Water	1.4-1.5
Salt	4.6	Oil	1.3-1.4

3 METHODOLOGY

Measurement of subsurface conditions by the seismic refraction method requires a seismic energy source, trigger cable, geophones, geophone cable, and a seismograph. The geophones and the seismic source must be placed in firm contact with the soil or rock. The geophones are usually located in a line, sometimes referred to as a geophone spread. The seismic sources may be a sledge hammer, a mechanical device that strikes the ground, or some other type of impulse source. Explosives are used for deeper refractors or special conditions that require greater energy. Geophones convert the ground vibrations into an electrical signal. This electrical signal is recorded and processed by the seismograph. The travel time of the seismic wave (from the source to geophone) is determined from the seismic wave form.

3.1 Study Area Selection

This machine is new one for finding soil profile. So it is needed to calibrate with another known value which has collected by other equipments like microtremor. For our justification we selected different locations of BUET ground as study area.

3.2 Data Collections and Results Analysis

The data of the different locations were collected using different combination of seismic impulse source and different spacing of geophones. Some specific software based on conventional method was needed to process seismic refraction.

3.2.1 *Seismic refraction result analysis for soil at BUET play ground*

The geophone spread and impulse source is shown in Fig. 4 and Fig. 5 respectively during seismic refraction test at BUET. Five shot points were selected during this test named middle shot, 1st offset shot, 1st end shot, last end shots and last offset shot. The position of two offset shots 23m away from 1st and last geophone, which is half of the total spread length 46m as shown in fig 6.

Fig 4: Spread of geophones during refraction test at BUET playground

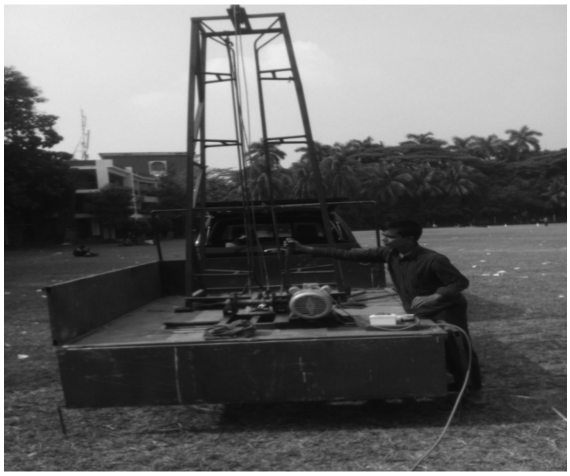

Fig 5: Using 140lb with 12 feet drop height hammer as impulse source

Fig 6: Layout of shots position during seismic refraction test at BUET

The soil profile of the seismic refraction test is shown in Fig. 7. It shows that the investigation depth of soil profile is about 20m. The seismic velocity ranges is about to 200m/s to 400m/s which range indicates the sub soil is dry sand according to Table 1.

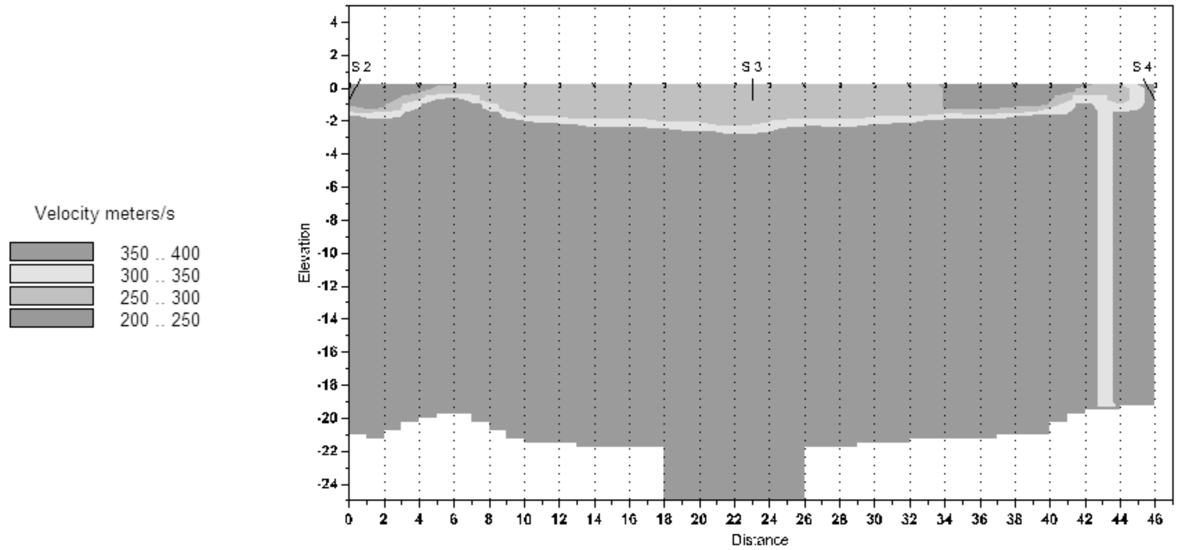

Fig 7: P-wave velocity profile at BUET playground

3.2.2 *Seismic refraction result for Red campus play ground*

The geophone spread and impulse source is shown in Fig. 8 and Fig. 9 respectively during seismic refraction test at BUET red campus. Five shot points were selected during this test named middle shot, 1st offset shot, 1st end shot, last end shots and last offset shot. The position of two offset shots 23m away from 1st and last geophone, which is half of the total spread length 46m as shown in fig 10.

Fig 8: Spread of geophones during refraction test at red campus playground.

Fig 9: Using 140lb with 12 feet drop height hammer as impulse source

Fig 10: Layout of shots position during seismic refraction test at BUET

The soil profile of the seismic refraction test is shown in Fig. 11. It shows that the investigation depth of soil profile is about 25m. The seismic velocity range is about to 100m/s to 500m/s which range indicates the sub soil is dry sand.

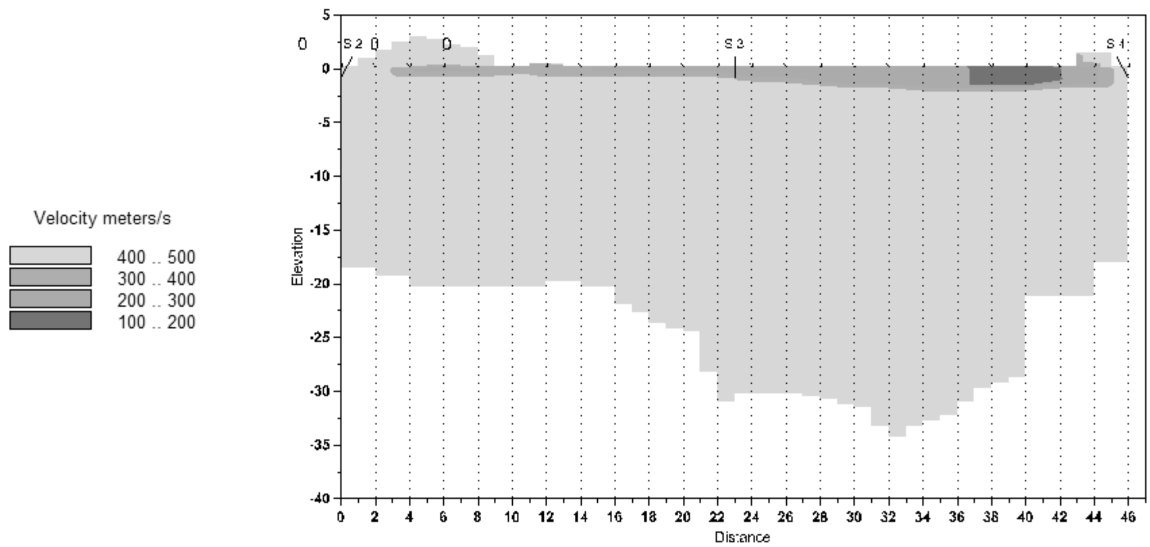

Fig 11: P-wave velocity profile at Red campus play ground

3.2.3 *Seismic refraction result in front of BUET JIDPUS*

The geophone spread and impulse source is shown in Fig. 12 and Fig. 13 respectively during seismic refraction test at BUET. Five shot points were selected during this test named middle shot, 1st offset shot, 1st end shot, last end shots and last offset shot. The position of two offset shots 12m away from 1st and last geophone, which is half of the total spread length 23m as shown in fig 14.

Fig 12: Data collection during refraction test at BUET JIDPUS

Fig 13: Using 140lb hammer as impulse source

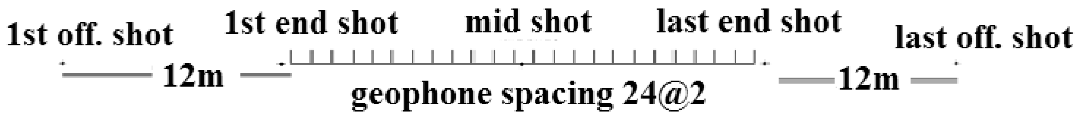

Fig 14: Layout of shots position during seismic refraction test at BUET

The soil profile of the seismic refraction test is shown in Fig. 10. It shows that the investigation depth of soil profile is about 25m. The velocity range is about to 200m/s to 1200m/s which range indicates the sub soil up to 3m dry sand and then clay soil.

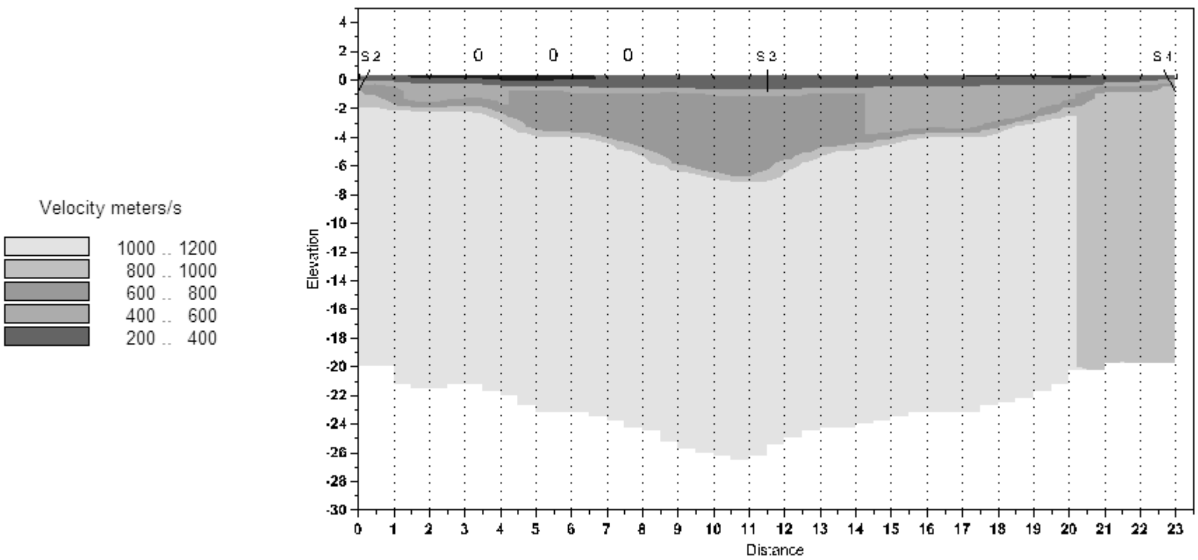

Fig 15: P-wave velocity profile in-front of BUET JIDPUS

4 CONCLUSION

The interpretation of the results showed that all areas having consisted of two layers with approximate velocity 100 to 1200 m/s underlie the study area. Table 1 lists approximate ranges for velocities of different types of soil. The upper layer consists of dry sand and for in-front of BUET JIDPUS 2nd layer consists of clay sol. The result of the investigation is therefore recommended as a useful guide for civil engineering planning and development of the area.

LIMITATIONS

A hidden layer, or blind layer, is one that is undetectable by refraction surveying. [2]A layer may simply not give rise to first arrivals, that is, rays traveling to deeper levels may arrive before those critically refracted at the top of the layer in question (see Fig. 16). This may result from the thickness of the layer or from the closeness of its velocity to that of the overlying layer. A more insidious type of hidden layer problem is associated with a low velocity layer, as illustrated in Fig. 17. Rays cannot be critically refracted at the top of such a layer and the layer will, therefore, not give rise to head waves. Hence, a low velocity layer cannot be detected by refraction surveying.

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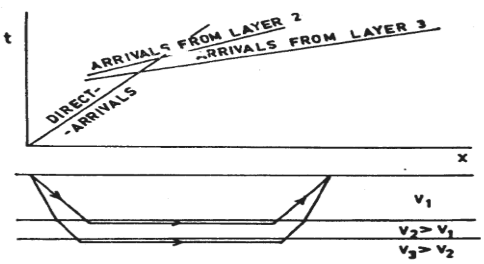

Fig 16: Hidden layer problem in seismic refraction

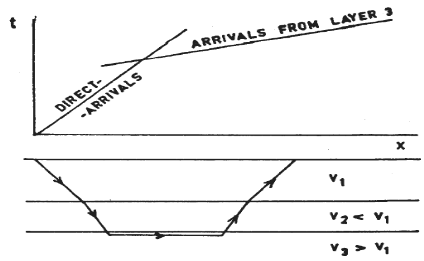

Fig 17: Blind zone problem in seismic refraction

Due to lack of available impulse source the seismic refraction test is difficult in maximum places. Also we have no sufficient financial help to buy such type of high cost impulse sources. Hence here in Bangladesh seismic refraction test will be preferable when sufficient funding will be provided by other to investigate subsoil characteristics.

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PART-III

VALIDATION OF CORRELATION BETWEEN INSITU CONCRETE STRENGTH AND UPV

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

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INTRODUCTION

Concrete is the most widely used construction materials. As a result, its quality is an important issue. Compressive strength is the most important property of concrete as it is the main criteria to judge the quality of concrete (Aydin and Saribiyil 2010). Direct determination of compressive strength requires that concrete specimen must be loaded to failure. It is required to collect concrete specimen according to ACI standards and specified requirements. This procedure may provide actual concrete strength for under construction and existing buildings. This procedure is time consuming and troublesome for existing buildings. Because of these problems some NDT methods have been developed to measure other properties of concrete other than strength and relate them with strength, durability or any other properties (Qasrawi 2000).

The nondestructive testing (NDT) is a direct method to find in situ compressive strength of concrete (Yuksel 1995). The NDT of concrete has scientific and practical importance especially for damaged concrete constructions (Turgut 2004). Malhotra (1976) has presented a literature survey for NDT used for evaluation and testing of concrete structures. Leshchinsky (1991) has summarized the advantages of NDT tests as reduction in labor cost of preparation and testing of samples, minimal structural damage, less costly, simple and quick usage, availability of test result on site, possibility of testing concrete strength where core drilling is impossible (thin-walled, densely reinforced etc.).

NDT methods can be employed for efficient time management of large scale construction project. Where knowing in-situ strength is necessary for removing formwork, releasing time for the wires in pre-stressed members and post-tensioned element loading time, to avoid unnecessary delay in the next stage of construction (Elvery and Ibrahim 1976; Karaesmen et al. 1996; Price and Hynes 1996). These advantages are of no use if the results are not representative and close to the actual tested part of the structure (Turgut 2004). The limitations of NDT are associated with material heterogeneity and anisotropy, test conduction area and its roughness, test direction, and different empirical equation for different types of materials (Yilmaz 2009; Yılmaz and Sendır 2002). To overcome these limitations, the test results have to be correlated with destructive tests. (Karaesmen et al. 1996).

EVALUATION OF CONCRETE STRENGTH BY DIFFERENT NDT

Various NDT that can be used for measuring concrete strength are shown and explained in Figure 1.

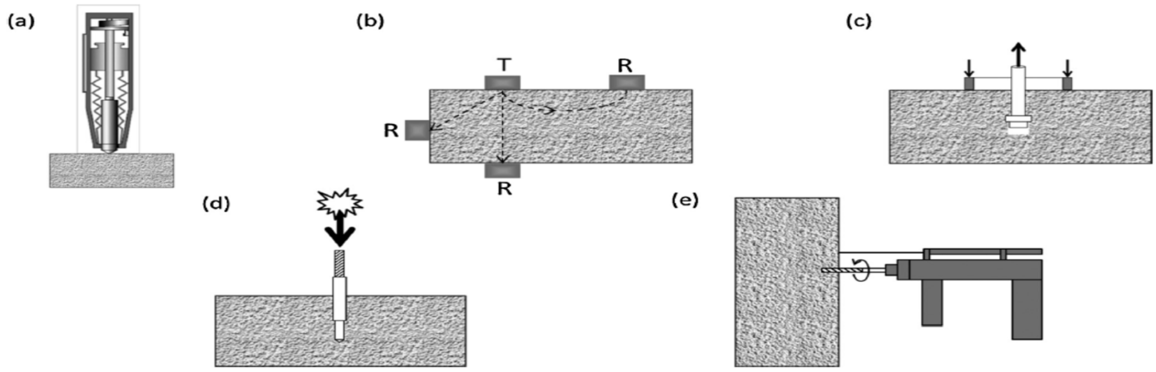


Fig 1: NDT techniques that have been or potentially can be used for in situ strength assessment of concrete: (a) rebound hammer; (b) Ultrasonic pulse velocity (UPV); (c) Pull-out-force; (d) Penetration Resistance ; (e) drilling resistance. (Gunes 2015)

The Rebound Hammer test, generally known as Schmidt hammer is one of the oldest, commonly used and most simple NDT method (Gunes 2015). The test method is described in ASTM (2008), BSI (1986) and TS (1978). The test is classified as a hardness test and based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges (Aydin and Saribiyil 2010). The energy absorbed by the concrete is related to its strength (ACI Committee 228 2003). Rebound hammer number is sensitive to local variation of concrete. For example, if a large aggregate falls under the tip of the plunger rebound number will be very high. On the other hand if any crack of void falls under the tip it will cause lower rebound number. Rebound number also varies with aggregate properties, mix proportioning, surface texture and wetness of concrete (Ariöz et al. 2009).

The Ultrasonic Pulse Velocity (UPV) test is a popular, fast and easy nondestructive test method (Ariöz et al. 2009). It has been first introduced by Long, Kurt and Sandenaw in 1945 for evaluating quality of concrete by transmitting an irrational pulse to travel a known distance through the concrete (Mahure et al. 2011). The ultrasonic pulse velocity (UPV) method makes use of the velocity of ultrasonic pulses obtained from direct (opposite faces), semi-direct (neighboring faces) and indirect (same face) arrangement of the transmitter (T) and receiver (R) transducers (Fig. 1b) to estimate concrete strength (Gunes 2015).

In the laboratory, access is generally available to opposite surfaces of a test specimen, and ultrasonic tests are commonly conducted using direct transmission. Direct transmission is defined as the propagation of ultrasonic stress waves along a straight-line path between the opposite surfaces of a specimen. In the field, however, access to opposite surfaces of a component may not be readily available (for example, concrete pavements and bridge decks), and tests may need to be conducted using indirect transmission. Indirect, or surface, transmission is defined as the propagation of ultrasonic stress waves between points that are located on the same surface of the material (Yaman et al. 2001). UPV test is prescribed in ASTM (2002) and BSI (1997) . The principle of test is that the velocity of sound in a solid material V, is a function of the square root of the ratio of its modulus of elasticity E, to its density ρ,

$$V=f\,(g\,E/\rho)^{1/2} \tag{1}$$

Where g is the gravity acceleration. In the test, the time the pulses take to travel through concrete is recorded. Then, the velocity is calculated as:

$$V = L/T \tag{2}$$

Where V= pulse velocity (m/s), L= Length of sample (m), and T= effective time (s), which is the measured time minus the zero time correction. Based on experimental results, Tharmaratnam and Tan (1990) have provided the relationship between the ultrasonic pulse velocity in a concrete V and concrete compressive strength f_c as:

$$f_c = ae^{bV} \tag{3}$$

Where a and b are parameters dependent upon the material properties. The ultrasonic pulse velocity results can be used to check uniformity of concrete, voids in concrete, quality of concrete and concrete products by comparing results to a similar made concrete, measure condition and deterioration of concrete, depth of surface crack, measure strength comparing with previous data (Qasrawi 2000).

Pull-out force method correlates concrete strength with the pull our force of a rod (Fig-1c). The penetration resistance technique is based on driving a steel probe or pin into concrete by applying a known amount of mechanical energy and the penetrated or exposed length is correlated with concrete strength (Fig -1d). The drilling resistant method (Fig-1e) is based on the ease of drilling a hole in concrete. It is not yet a fully established method of NDT but has the potential to become a rapid or reliable method of measuring concrete strength (Gunes 2015).

To use the above mentioned technique (Fig 1a-c) in conjunction with cores, TS (2010) has provided a formwork. An extensive list of NDT with references and standards has been provided in TS (2013). It is compiled from international standards and other resources. Current researches in the field of nondestructive evaluation of concrete strength are aimed for the improvement of the existing technique and developing new ones.

DIFFERENT EXISTING CORRELATIONS

Tumendemberel and Baigalimaa (2015) conducted a research to find a relation between compressive strength of cubes and UPV values by using statistical methods. They have collected data from 126 concrete cubes with the size of 150x150 mm with different mix ratio and curing condition prepared in the laboratory. Before determining the compressive strength of the cubes UPV test have been conducted with 54 kHz frequency, taking the average of three readings. The range of concrete strength is between 9.96 and 42.6 MPa for different curing conditions. The regression analysis method has been used to find the correlation. Their proposed equation is $S = 1.356*10{-}5V2 - 0.076V + 111.502$ Where: S = Compressive strength in MPa, V = UPV in m/ sec. The value of correlation coefficient (R^2) for this equation is 0.63. Similar study has also been conducted by Qasrawi (2000). He used linear regression method and proposed the following equation: S (MPa) = 36.72 USPV – 129.077, where USPV is the pulse velocity (km/s). The R^2 value was found to be 0.96.

Mahure et al. (2011) has taken true concrete cube specimen from Tehri Hydro Electric Project, Uttarakhand, India for interpreting relationship between UPV and the compressive strength of concrete. Cubes of three different grades of concrete M15, M20 and M35 were cast. Their w/c ratio ranges from 0.42 to 0.60. 43% to 45% of the total volume of concrete has been cement mortar. The volumetric ratio of fine aggregate to coarse aggregate is 38:62, 35:65 and 37:63 respectively. Water reducing admixtures have been used to prevent bleeding and segregation. 125 Nos. of concrete specimens for M15 grade of concrete, 200 Nos. for M20 grade of concrete and 45 Nos. for M35 grade of concrete have been cast and tested for both UPV and compressive strength. Nominal frequency of the transducer used for measuring UPV are 54 kHz.125 data points for M15 grade of concrete, 200 data points for M20 grade of concrete and 45 data points for M35 grade of concrete have been plotted for establishing relation between UPV and compressive strength. Linear regression is applied for establishing the relation. The correlation equations for the simulation curves for M15, M20 and M35 grades of concrete respectively are CS = 9.502PV - 18.89, CS = 2.701PV + 17.15, CS = 4.104PV + 19.23. Where CS and PV represent the compressive strength (MPa) and the ultrasonic pulse velocity (km/s), respectively. Their corresponding correlation coefficient (R^2) is 0.244, 0.027, and 0.025 indicating good relevance between data points and the regression curves. To validate the relationships, additional specimen have been prepared in the laboratory having same grade i.e. M15, M20 and M35. A total of 15 concrete specimens, 5 for each grade have been prepared. Pulse velocity has been measured and using the equation above compressive strength of concrete (M15, M20 and M35 grades) are measured. The results show that almost all the comparison results are between 5.96% and -4.33%.

Nash't et al. (2005) covers 161 test results from 161 concrete cubes with 150x150 mm. Compressive strength of them have varied from 15 to 25 MPa and age of them are 7 to 138 days. UPV tests have been carried out for each cube with the average of two reading with frequency of 54 kHz. Crushing strength of concrete is also recorded. Power equation has been used to predict the correlation between UPV and strength. Following exponential equation is proposed: S_c = 1.19 EXP 0.715U, where S_c= Crushing Strength N/mm^2, U= UPV (μm/sec) and R^2 for this equation is 0.59. Jain et al. (2013) used this equation to predict strength of M20, M30, M40, and M50 grade concrete in laboratory and has found a variation of 6%.

Shariati et al. (2011) has conducted a research taking UPV values from beam, column and slab of existing structures. Compressive strength of concrete are determined by using specimens tested at 1, 3, 7, 14 days interval. Two specimens have been tested and average strength results have been used. UPV values are measured in direct and semi direct method between opposite faces for column, adjacent faces for beam and indirect method for slab. There are 36 reading for beam, 12 reading for column and 20 reading for slab. The best-fit curve that represents the relationship has the following equation: fc =15.533V - 34.358 where, V is the ultrasonic pulse velocity (Km/s) and fc is the compressive strength (MPa). The R^2 value was found to be 0.92.

Turgut (2004) has made a correlation with the data obtained from previous studies which have been produced on specimens having dissimilar concrete mix ratios in the laboratory. To develop a correlation from existing structure, he has collected 82 cores from 30 existing concrete structures with the age varying from 28 days to 36 years. The best fit formula is obtained from the curve of existing reinforced structures and the curve obtained from previous studies in the laboratory. The best fit formula is found to be: $S_n = 0.3161e^{1.03V_n}$ Where, S_n is in KPa and V_n is in Km/s. R^2 value was found to be 0.80.

Lin et al. (2003) has established mathematical models for predicting pulse velocity in concrete based on aggregate content and water-cement ratio. Demirboğa et al. (2004) has developed an exponential relationship between compressive strength and UPV for mineral admixtured concrete.

Apart from these Amin (September, 2014) has also conducted laboratory experiment on strength-UPV relation using locally available aggregates brick and stone. He has used 3 to 180 days of concrete age and two different testing conditions saturated and air dry conditions. He has proposed two different relations for brick and stone aggregate concrete and has also provided a master equation for two different testing conditions.

Y= -64.687 + 21.411V, for brick aggregate and Saturated Condition, ($R^2 = 0.81$)

Y= -123.65 + 32.584V, for stone aggregate and Saturated Condition, ($R^2 = 0.87$)

Y= -34.678 + 12.648V, Combined Equation for Saturated Condition, ($R^2 = 0.61$)

Y= -59.409 + 20.251V, for Brick aggregate and Air dry Condition, ($R^2 = 0.79$)

Y= -120.34 + 33.414V, for Stone aggregate and Air dry Condition, ($R^2 = 0.87$)

Y= -42.581 + 15.263V, Combined Equation for Air dry Condition, ($R^2 = 0.66$)

The equation most commonly used is exponential form Trtnik et al. (2009) : $S = a.e^{b.V_p}$ Where a and b are empirical parameters determined by the least squares method.

RESEARCH SIGNIFICANCE

Earlier researchers have conducted in finding the relation between concrete strength and UPV are generally limited to specimens prepared in the laboratory. Only a few of those relations have been developed taking mix ratio into consideration. Most of them have neglected the mix ratios. Production of concrete in the laboratory has been done under good care, where as production of concrete in the field may face many variations in the condition of mixing, degree of compaction or curing in the field. In addition pulse velocity is influenced by path length, lateral dimensions of the specimen, presence of reinforcing steel and moisture content of concrete (Jain et al. 2013). These factors need to be addressed before using strength UPV relations developed in the laboratory, to predict field concrete strength. In this study, relationship is developed between strength and UPV by using data obtained from 2658 cores that are collected from elements (column, beam, and slab) of 825 reinforced concrete structures having different ages and unknown ratios of concrete mixtures.

EXPERIMENTAL METHODOLOGY AND DISCUSSION

In this study, the relations which are produced in the laboratory are compared with relations developed from core test of existing reinforced concrete buildings. For this process starting from June 2013 to February 2015, 2568 cores are collected from 825 reinforced concrete buildings from all over Bangladesh. The age of the buildings varied from 5 yrs. to 40 yrs. Stone chips and brick chips are the two types of aggregates commonly used. Fig. 2 shows the distribution of the compressive strength from core test results. Records containing the aggregate proportions, water-cement ratio and cylinder strength values for tested concrete are not available. Cores have been obtained from Column, beam and slab of the structures.

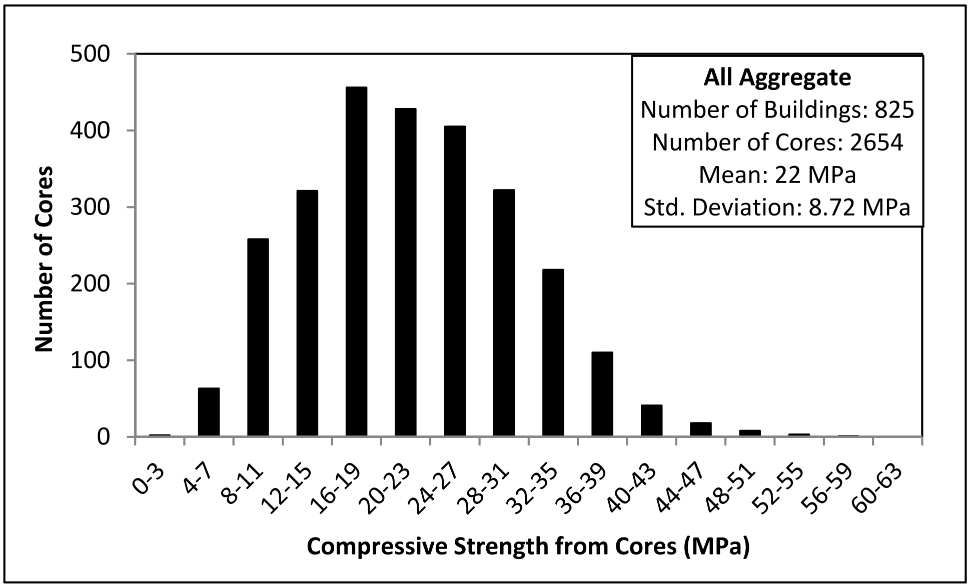


Figure 2: Compressive strength of cores.

Out of the total collected cores 1561 are of brick aggregate with mean strength of 21 MPa and standard deviation of 8.35 MPa. The diameter has varied between 44 mm and 104 mm. Length of the sample is in the range of 69 and 206 mm. Fig. 3 shows the distribution of core test result of brick aggregate.

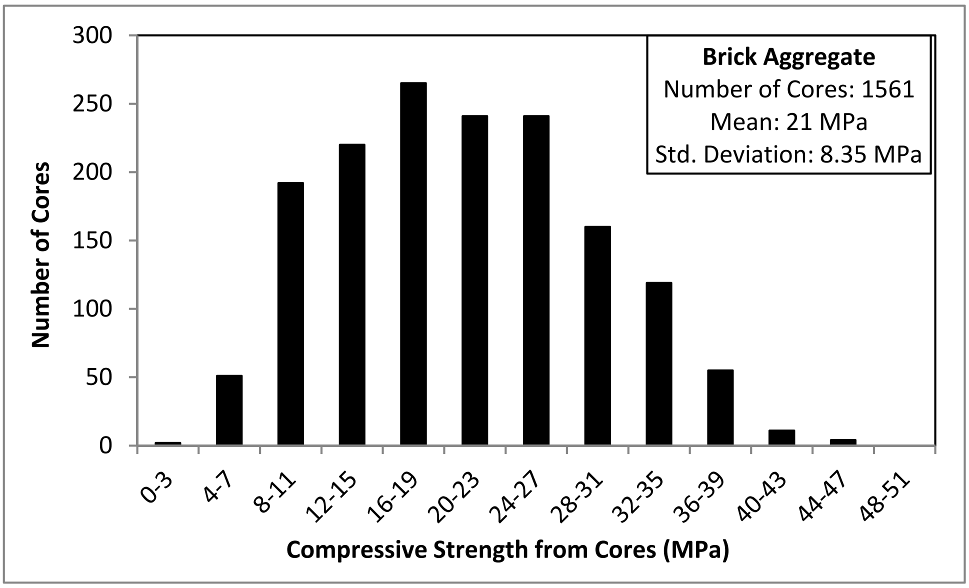


Figure 3: Core test result of brick aggregate

Number of core with stone chips are 1095. They have a mean strength of 21 MPa and standard deviation is 8.33 MPa. The diameter has varied between 44 to 112 mm. Length of the sample is in the range of 71 and 241 mm. Fig. 4 shows the distribution of core test result of stone aggregate.

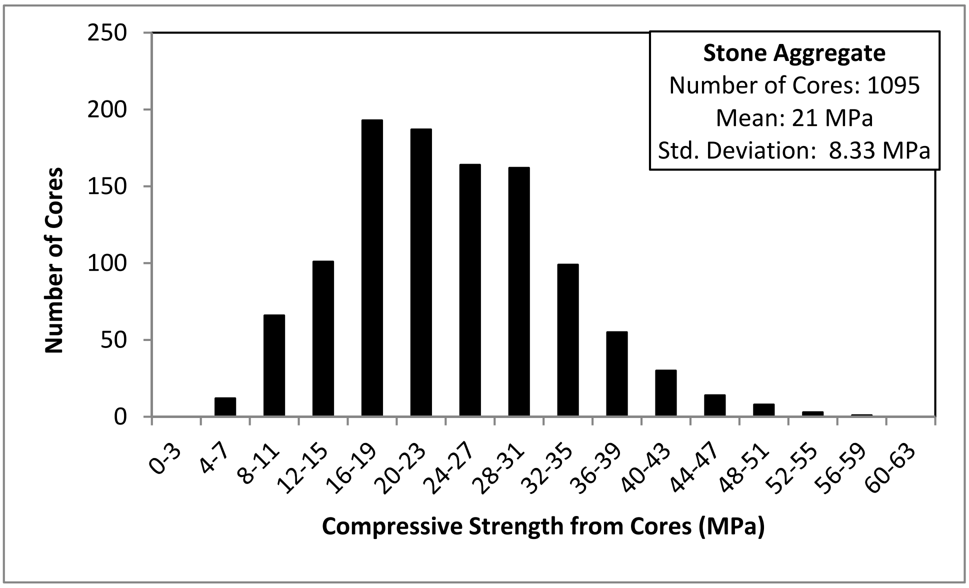


Figure 4: Core test result of stone aggregate

Fig. 5 shows year wise distribution of the buildings along with their storey numbers from which core samples are tested at BUET. Out of these 825 factory buildings, 12 are built before 1980, 198 are built between 1980 and 2000 and the rest after 2010. Approximately, 52% of those factory buildings are constructed after 2005. Most of the buildings constructed after 2005 are made of stone chips.

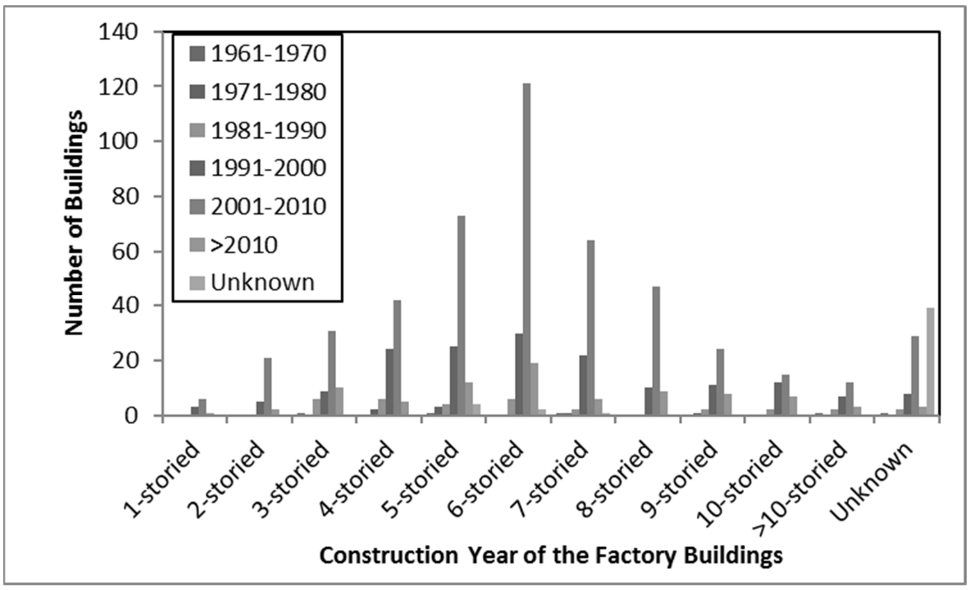


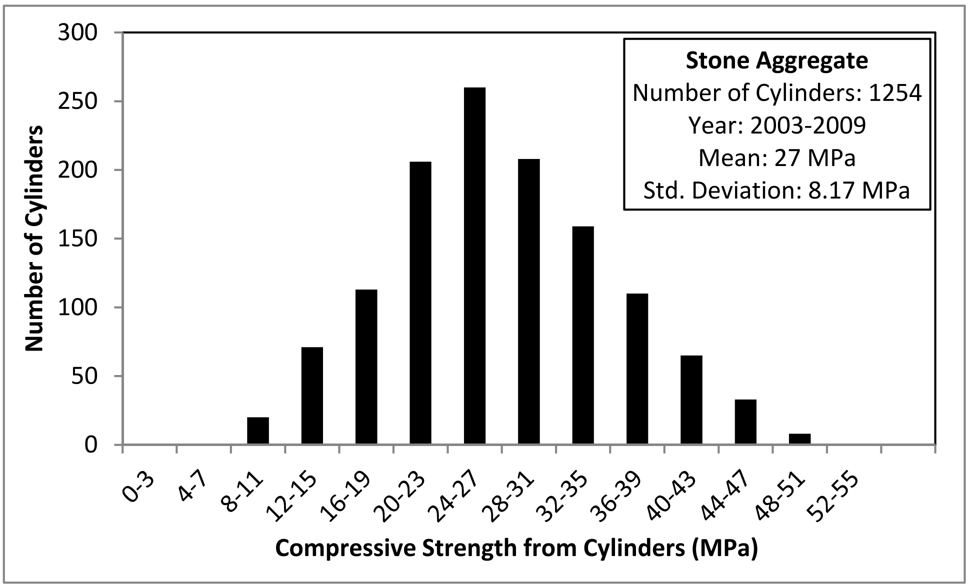
Figure 5: Year wise distribution of buildings from which cores are collected

Cores taken from column and beam have been drilled horizontally and slab has been drilled vertically. Before the execution of destructive compressive test, pulse velocity through the cores has been measured at the laboratory. The velocity of the propagating wave has been measured by direct transmission using a standard ultrasound device. The transducers used are 50 mm in diameter and had a maximum resonance frequency of 54 khz. The values of the ultrasound pulse velocity of brick aggregate lay between 1873 to 5264 m/s and concrete strength has varied between 3 to 47 MPa. For stone chips the pulse velocity has ranged between 1042 to 7143 m/s and concrete strength varied between 5 to 58 MPa.

There are many factors that affect core strength such as the diameter of the core, length to diameter ratio, presence of reinforcement, moisture condition at the time of testing, presence of reinforcement in samples. Based on these criteria some of the cores of brick and stone chips are discarded. Experimental evidence shows there is conflicting evidence concerning the strength of cores with different diameter. In practice, it is very difficult to obtain a 50mm diameter core without any defect. Considering these factor, the authors have discarded all the cores that has a diameter less than 68mm.

Specimens with small *l*/*d* fail at greater loads because the steel loading platens of the testing machine restrain lateral expansion throughout the length of the specimen more effectively and so provide confinement. The end effect is largely eliminated in standard concrete compression test specimens, which have a length to diameter ratio of two (ACI 2013). To minimize the effect of l/d ratio and to keep them within the provided limit in ACI (2013), all the samples that had length less than 127mm were discarded.

According to Neville (1995) Concrete strength of 40MPa or greater are high strength, 20MPa to 40MPa are medium strength and less than 20 MPa are low strength concrete. Fig. 6 shows the cylinder test result collected from BUET database between 2003 and 2009.



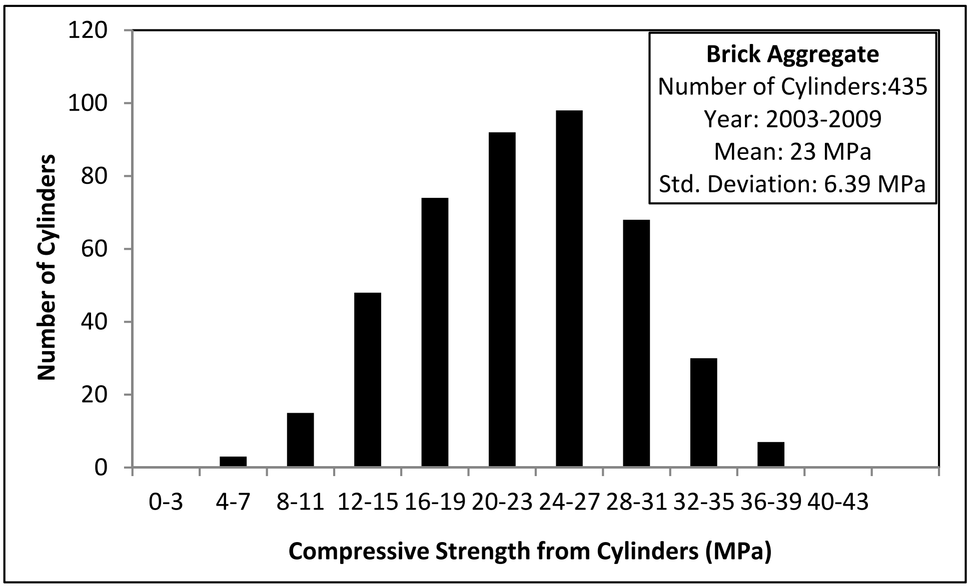
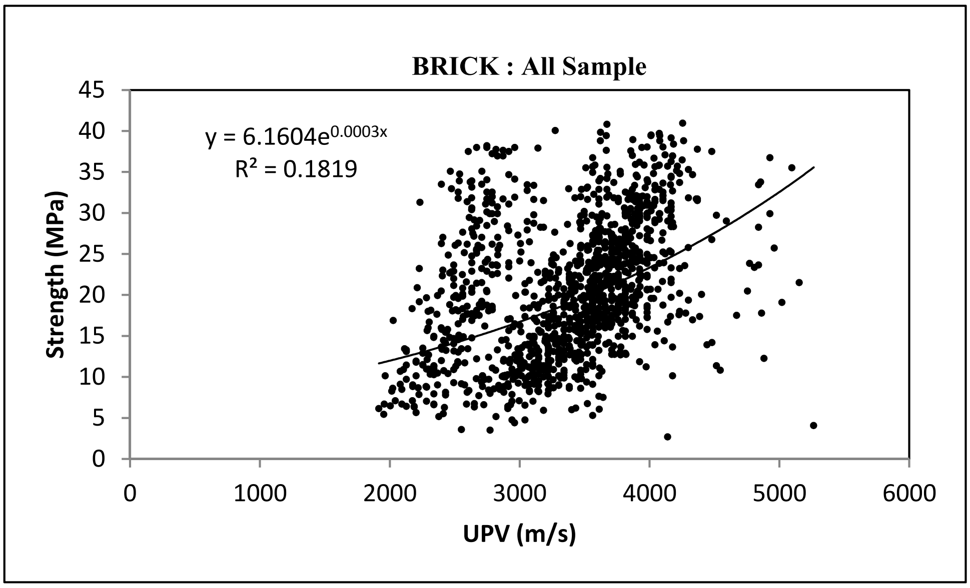


Figure 6: Cylinder test results collected from BUET database between 2003 and 2009

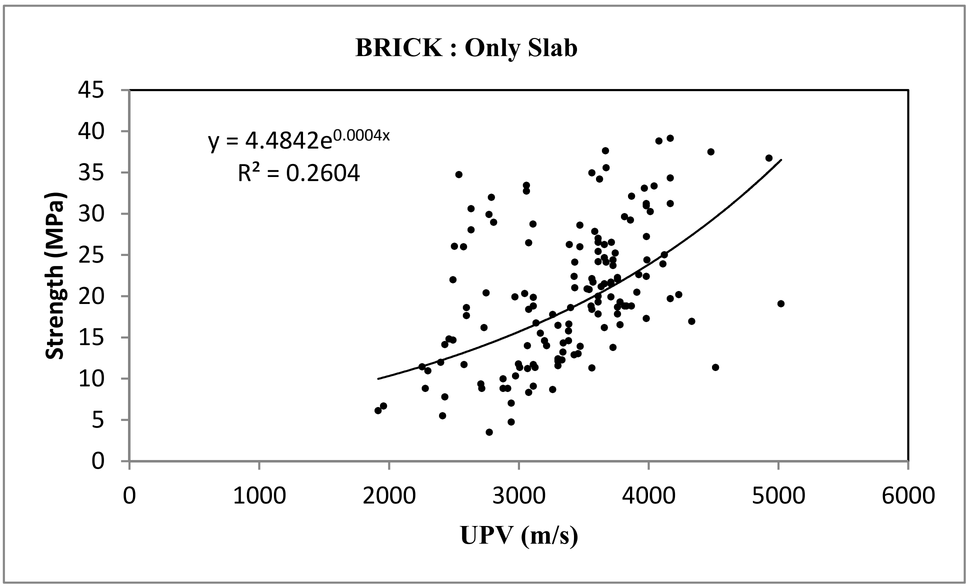
According to statistical rule, it is known that 95.45% of sample fall within 2 standard deviation and 99.73% of sample fall within 3 standard deviation. It can be seen from the figure that almost 95 % of samples have strength less than 40 MPa that are medium to low strength concrete. To remain consistent with the record core strength greater than 40 MPa have been discarded.

After discarding sample on the basis of diameter, l/d ratio and strength, they have been sorted into three different group column, beam and slab. They are then plotted to find a correlation between UPV and strength. Best fit curves for each type of cores are drawn using regression analysis. Correlation coefficient (R^2) values have been used for comparing the results with previous studies.

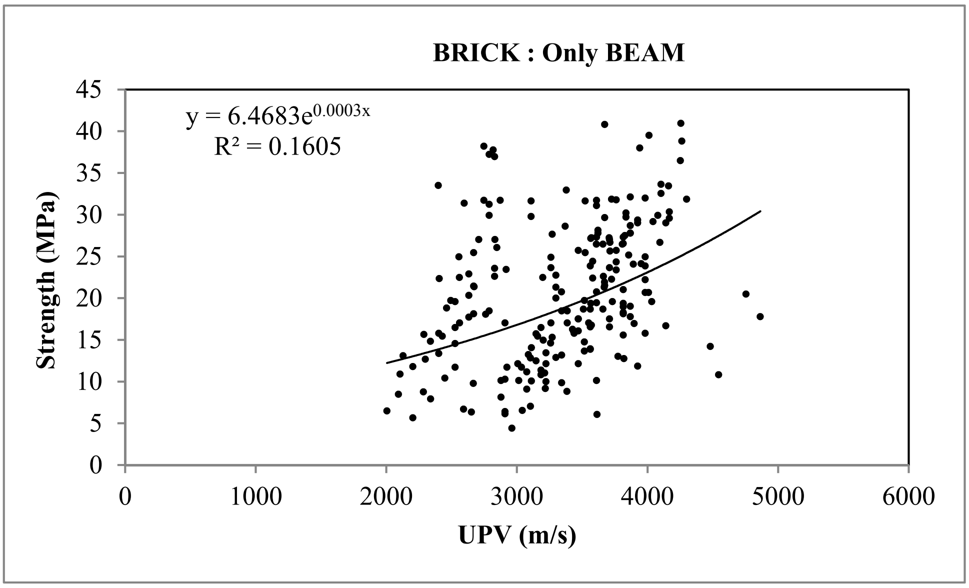
Fig. 7 shows the correlation between strength and UPV for brick aggregate concrete. Figure 7(a) has been drawn using all the cores of brick aggregate concrete after discarding the cores using the above criteria. There are 1237 cores out of 1561 initial samples. The correlation equation has been found to be $y = 917.26e^{0.0003x}$, where X= UPV in m/s and Y is strength in MPa. R^2 value for this equation is 0.17. This means that we can explain 17% of the variability for the data around the regression line and 83% remained without explanation. Fig. 7(b) was drawn using the cores taken from slab made of brick aggregate concrete. It contains 147 cores. Correlation equation has been found to be $y = 650.38e^{0.0004x}$, R^2 value for this equation was 0.26. It has showed a slightly good relation than the correlation from total brick cores. Fig. 7(c) shows correlation for cores taken from beams only. It contains 220 cores. Correlation equation was found to be $y = 938.14e^{0.0003x}$, R^2 value for this equation was 0.16. It is close to the relation obtained from all cores. Fig. 7(d) shows correlation for cores taken from column only. It contains 873 cores. The correlation equation has been found to be $y = 981.69e^{0.0003x}$, R^2 value for this equation was 0.16 which is similar to the relation obtained from beam element and close to the relation obtained from all cores.



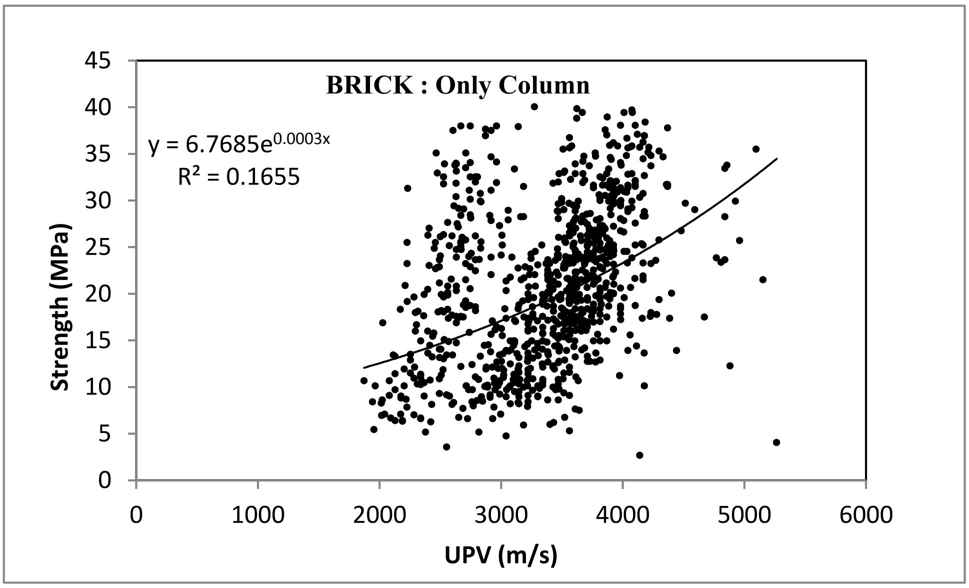
(a) Strength-UPV relation for all cores of brick aggregate concrete



(b) Strength-UPV relation for slab of brick aggregate concrete



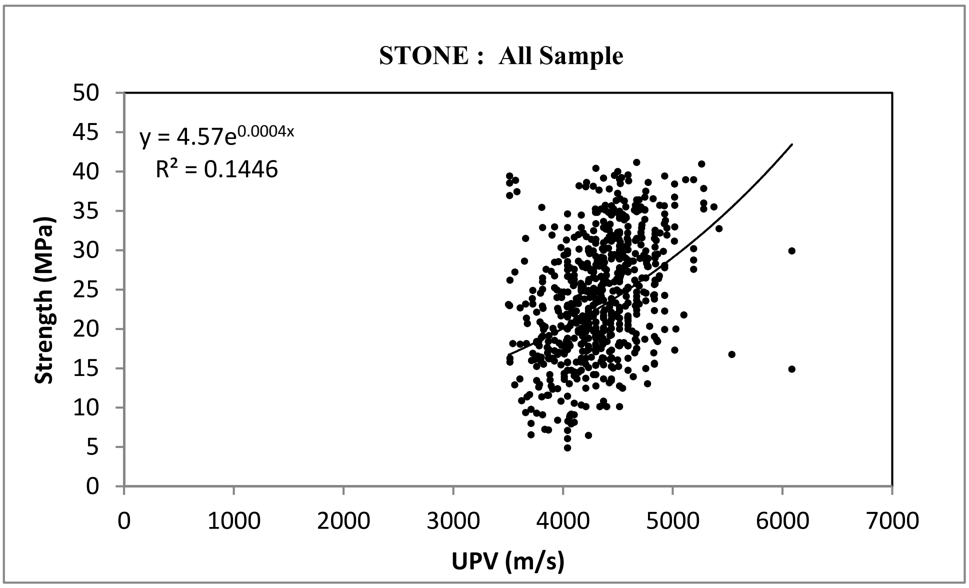
(C) Strength-UPV relation for beam of brick aggregate concrete



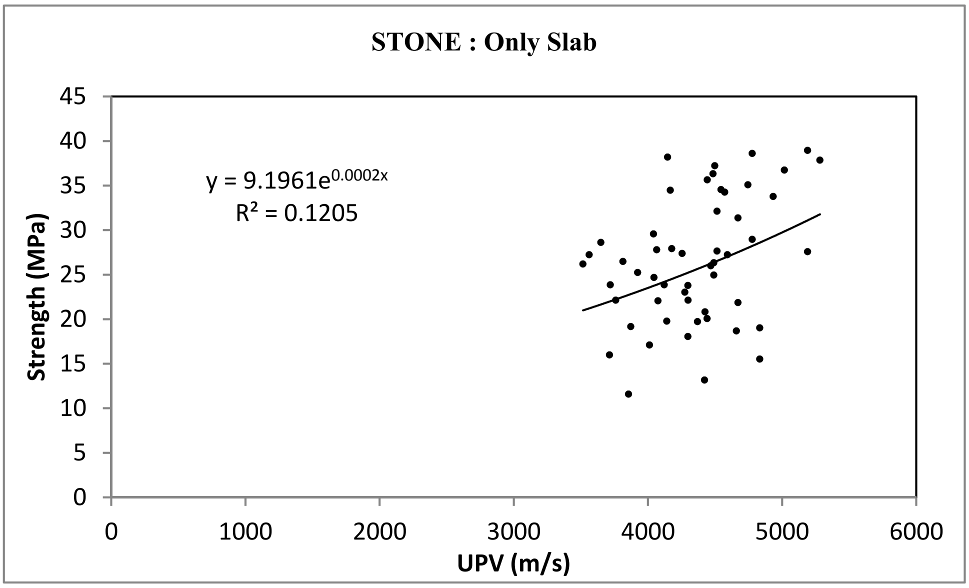
(d) Strength-UPV relation for column of brick aggregate concrete

Figure 7: Strength-UPV relation for brick aggregate concrete

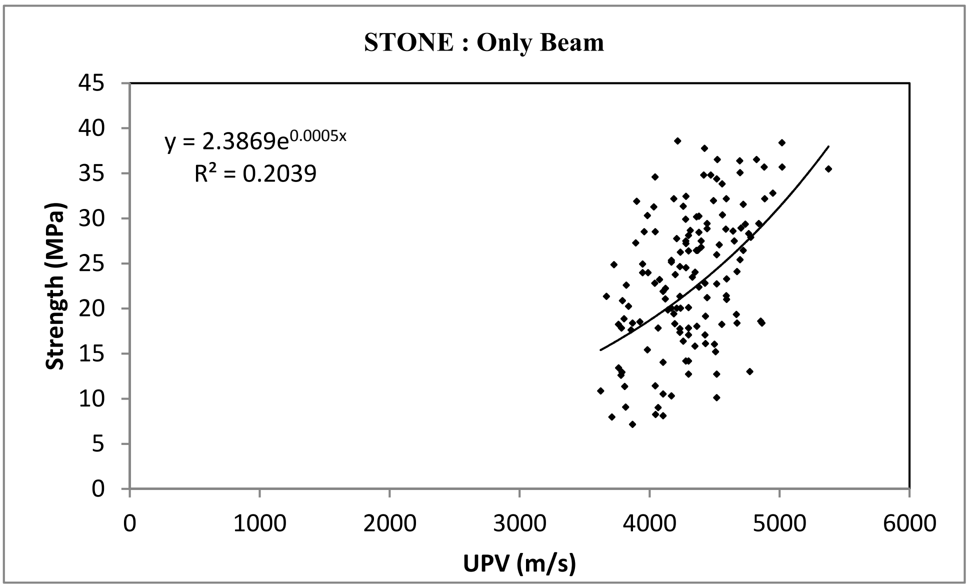
Fig. 8 shows the correlation between strength and UPV for stone aggregate concrete. Fig. 8(a) has been drawn using all the cores of stone aggregate. There are 647 cores out of 1095 initial samples. The correlation equation has been found to be $y = 662.81e^{0.0004x}$, where X= UPV in m/s and Y is strength in MPa. R^2 value for this equation is 0.14. This means that we can explain 14% of the variability for the data around the regression line and 86% remained without explanation. Fig. 8(b) is drawn using the cores taken from slab made of stone aggregate concrete. It contains 54 cores. Correlation equation is found to be $y = 1333.8e^{0.0002x}$, R^2 value for this equation was 0.12. It has showed a slightly less correlation value than the correlation from all the cores. Fig. 8(c) shows correlation for cores taken from beams. It contains 142 cores. Correlation equation is found to be $y = 346.19e^{0.0005x}$, R^2 value for this equation is 0.20. It is higher than the relation obtained from all cores. Fig. 8(d) shows correlation for cores taken from column. It contains total of 453 cores. The correlation equation is found to be $y = 713.71e^{0.0004x}$, R^2 value for this equation is 0.13 which is slightly higher than the relation obtained from slab element and close to relation obtained from all cores



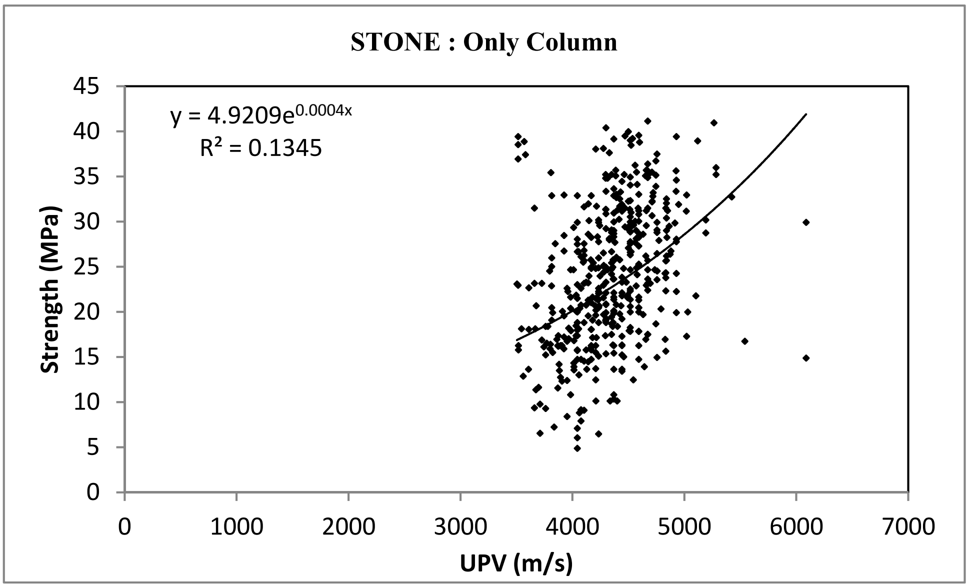
(a) Strength-UPV relation for all cores of stone aggregate concrete



(b) Strength-UPV relation for slab of stone aggregate concrete



(C) Strength-UPV relation for beam of stone aggregate concrete



(d) Strength-UPV relation for column of stone aggregate concrete

Figure 8: Strength UPV relation for stone aggregate concrete

Fig. 9 shows the bar diagram of the correlation coefficient obtained from the plot of the cores of brick and stone aggregate concrete. It is clear from the diagram that brick aggregate has a higher correlation than stone aggregate concrete. Only in case of cores obtained from beams, it has lower correlation than stone aggregate concrete, but it is not too low. The highest coefficient obtained is 0.25 which indicates poor correlation. It is clear from Figures 6 and 7 that there is a positive correlation between strength and UPV, with the increase of UPV concrete strength also increases. Depending on this, it may be claimed that for high strength concrete strength-UPV relation would be more reliable.

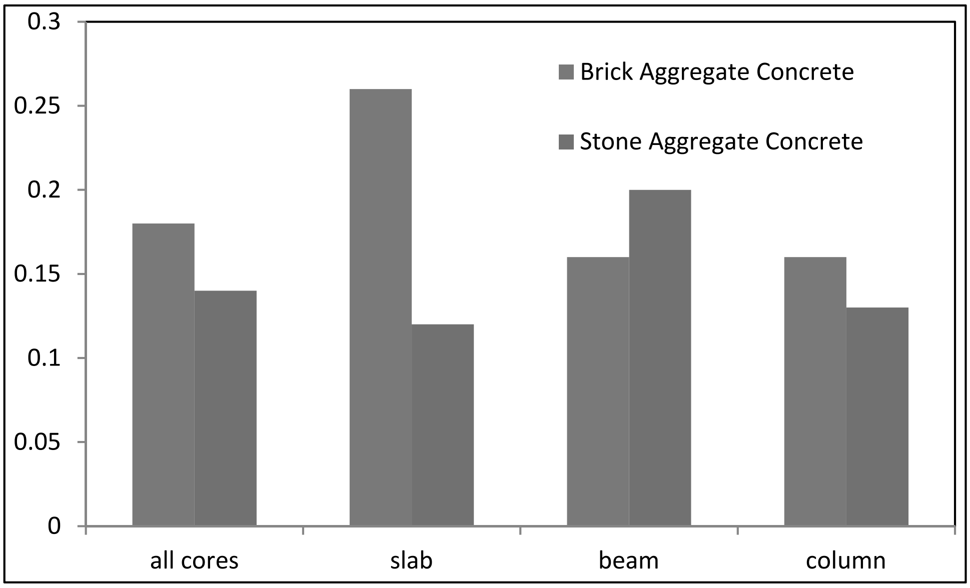


Figure 9: Comparison of correlation of brick and stone aggregate

Fig. 10 shows comparison among correlation values of the previous studies of strength –UPV established in the laboratory with the test result of cores obtained from existing reinforced concrete structures. Qasrawi (2000) and Shariati et al. (2011), show highest degrees of correlation 0.95 and 0.92. Kheder (1999) shows lowest value of 0.41. Among the cores obtained from existing reinforced concrete structures, cores obtained from slab of brick aggregate concrete shows highest value of 0.26 and cores from slab of stone aggregate concrete shows the lowest value of 0.12. There is a huge variation among correlations obtained in the laboratory and relations obtained from existing structures. The previous studies derived good correlation between strength-UPV in the laboratory with a particular mix proportion. No clear evidence has been provided about the effect of mix proportion on the correlations. Each study has obtained different strength-UPV relation. Therefore there exists a large uncertainty when one tries to use the developed relations to estimate concrete strength in the field condition. Instead of good care in concrete production in the laboratory many variations occur in the field such as variations of aggregate type, cement content, mixing, compaction and curing. These variations are not considered in the laboratory based relations.

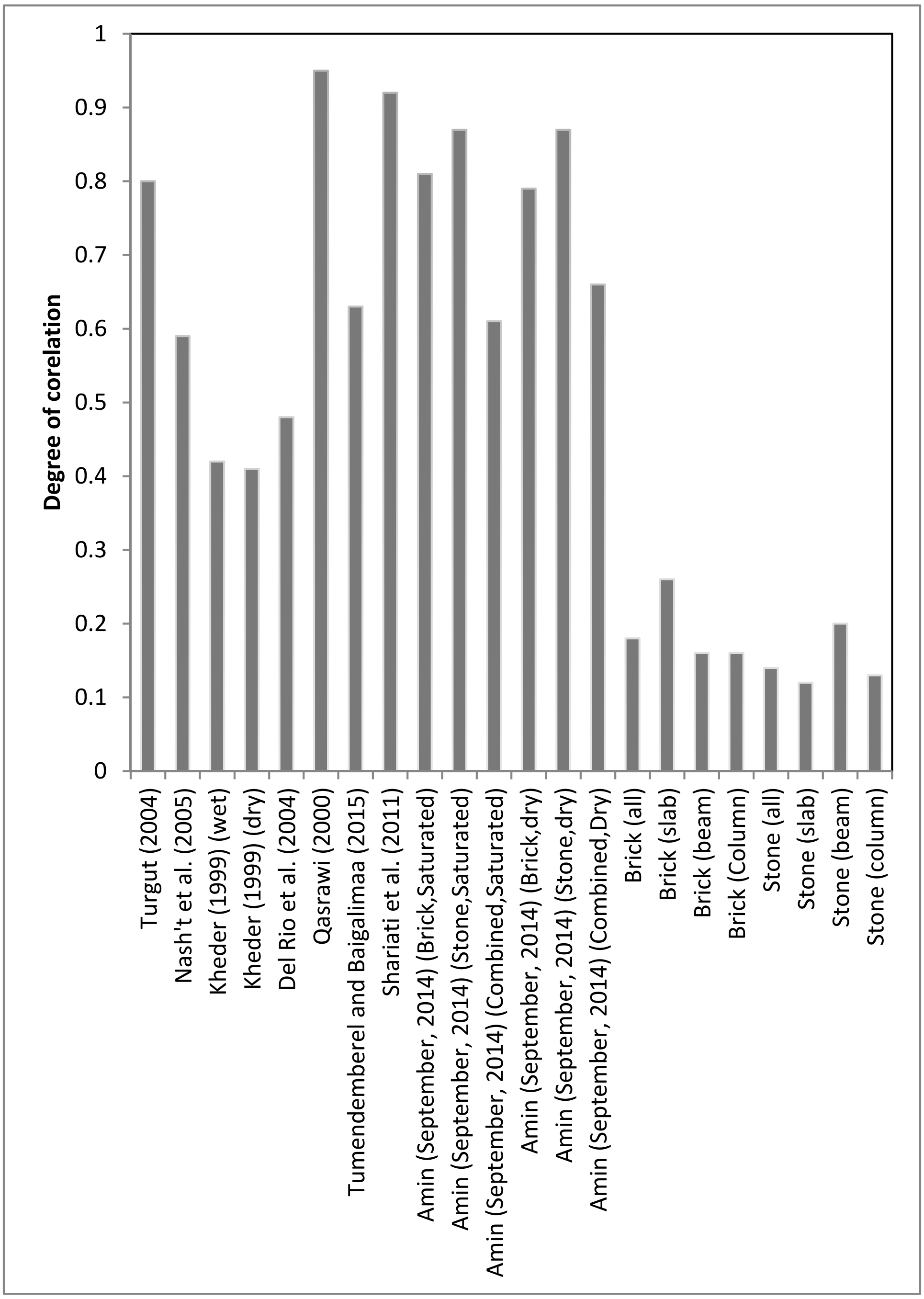


Figure 10: Comparison of correlation with previous studies

Conclusions

The ultrasonic pulse velocity (UPV) test has a strong potential to be used for predicting insitu concrete strength. The main problem in realizing this potential is that the correlation between compressive strength and UPV is low in the field due to different field variations. The correlation is high for the laboratory produced concrete specimen which cannot be directly used for the estimation of concrete strength in the field. The relation is influenced by a number of factors which would have to be taken in to account if a reasonable prediction of compressive strength has to be made from pulse velocity measurements. Thus the curve obtained from existing reinforced concrete structures and laboratory specimens can be used only to measure approximate values of concrete strength. These methods can also be employed for the efficient planning of the construction works in huge infrastructure projects, in which it may be necessary to know in-situ strength of concrete in order to determine the removal time of formwork, the stressing or releasing time for the wires in pre stressed members, the loading time for the system in post-tensional elements or the time for opening the structure to service safely. For economic and simplicity, a two stage method of concrete strength verification can be introduced by a combination of destructive and nondestructive method. Among the various methods employed for the assessment of concrete strength in situ, the classical method, involving compression tests on cylindrical specimens produced from cores drilled out of the structure, should surely be recognized as having primary importance on account of reliability and accuracy of the result.

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PART-IV

NDT AND DESTRUCTIVE TESTS AT OAB, BUET AND RETROFITTING PROPOSAL

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

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1. INTRODUCTION

Men with mainly four materials built the oldest constructions and these materials lasted thousands of years for construction purposes. These were earth (from which bricks come from, for instance), stone, wood and natural plants fibers. With these four elements men was able to build spectacular constructions some of which are still standing nowadays. Later in the 18th century, with the beginning of the industrial revolution in England, the iron is burnt with coal and its impurities decrease giving rise to cast iron, to be built in great quantities. While the iron from Nature is very brittle, the cast iron is resisting well to compression, although bad to tension, and can be used as a structural resisting element working in compression. With fewer impurities, later on, we have the forged iron/steel and later the steel, where carbon is mixed with iron is small quantities to make it become more malleable. The forged steel and the steel are used mainly in tension due to the phenomena of buckling. Steel structures are common nowadays. The last great change occurring in construction materials was the introduction of concrete.

Most unreinforced masonry (URM) buildings possess features that can threaten lives during earthquakes. These may include unbraced parapets, walls and roofs that are not well attached to each other, and walls that are poorly constructed. When earthquakes occur, inadequate connections in these buildings can allow masonry to fall. Floors and roofs may collapse leaving occupants and passers-by in harm's way. These risks to life can be significantly reduced with seismic retrofits.

The main objectives of the study was to make a basic structural checklist to assess the safety and vulnerability of the Old Academic Building (Masonry) of Bangladesh University of Engineering and Technology (BUET) and to provide an earthquake resistant design for retrofitting of the Old Academic Building.

2. BACKGROUND

Brick masonry buildings have large mass and hence attract large horizontal forces during earthquake shaking. They develop numerous cracks under both compressive and tensile forces caused by earthquake shaking. The focus of earthquake resistant masonry building construction is to ensure that these effects are sustained without major damage or collapse. Appropriate choice of structural configuration can help achieve this.

2.1 Earthquake Design and Construction Basics

2.1.1 Behavior of Brick Masonry Walls

Ground vibrations during earthquakes cause inertia forces at locations of mass in the building. These forces travel through the roof and walls to the foundation. The main emphasis is on ensuring that these forces reach the ground without causing major damage or collapse. Of the three components of a masonry building (roof, wall and foundation) (Figure 1a), the walls are most vulnerable to damage caused by horizontal forces due to earthquake. A wall topples down easily if pushed horizontally at the top in a direction perpendicular to its plane (termed weak direction), but offers much greater resistance if pushed along its length (termed strong direction) (Figure 1b). The ground shakes simultaneously in the vertical and two horizontal directions during earthquakes (IITK-BMTPC Earthquake Tip 5).

However, the horizontal vibrations are the most damaging to normal masonry buildings. Horizontal inertia force developed at the roof transfers to the walls acting either in the weak or in the strong direction. If all the walls are not tied together like a box, the walls loaded in their weak direction tend to topple (Figure 2a). To ensure good seismic performance, all walls must be joined properly to the adjacent walls. In this way, walls loaded in their weak direction can take advantage of the good lateral resistance offered by walls loaded in their strong direction (Figure 2b). Further, walls also need to be tied to the roof and foundation to preserve their overall integrity.

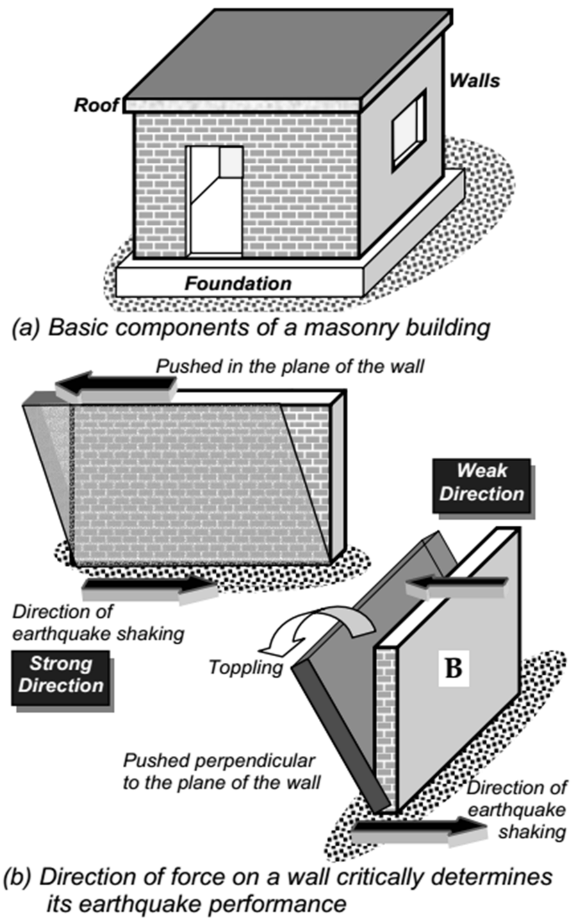


Figure 1: Basic components of a masonry building

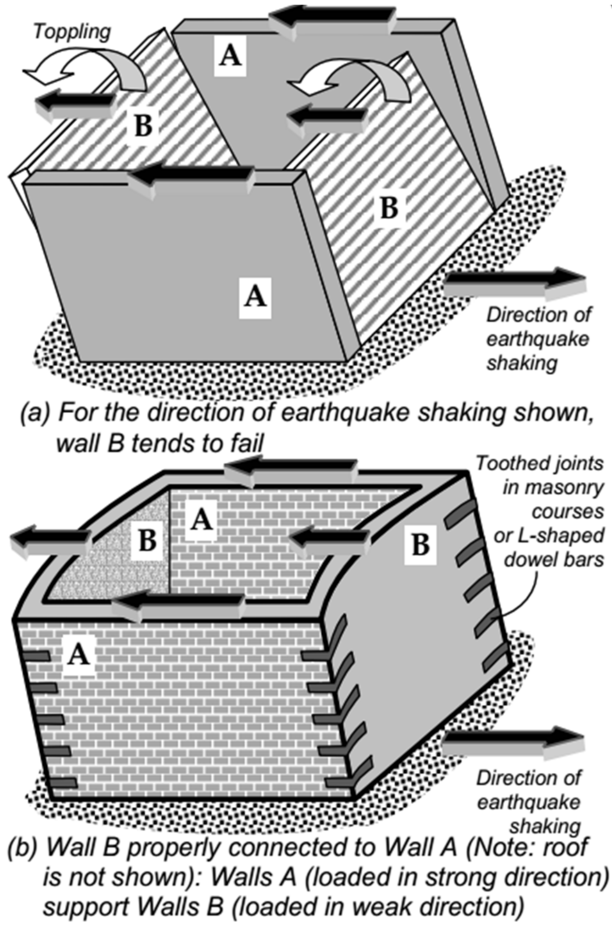


Figure 2: Advantage sharing between walls

2.1.2 How to Improve Behavior of Masonry Walls

Masonry walls are slender because of their small thickness compared to their height and length. A simple way of making these walls behave well during earthquake shaking is by making them act together as a box along with the roof at the top and with the foundation at the bottom. A number of construction aspects are required to ensure this box action. Firstly, connections between the walls should be good. This can be achieved by (a) ensuring good interlocking of the masonry courses at the junctions, and (b) employing horizontal bands at various levels, particularly at the lintel level. Secondly, the sizes of door and window openings need to be kept small. The smaller the openings, the larger are the resistance offered by the wall. Thirdly, the tendency of a wall to topple when pushed in the weak direction can be reduced by limiting its length-to-thickness and height-to-thickness ratios. Design codes specify limits for these ratios. A wall that is too tall or too long in comparison to its thickness is particularly vulnerable to shaking in its weak direction (Figure 3).

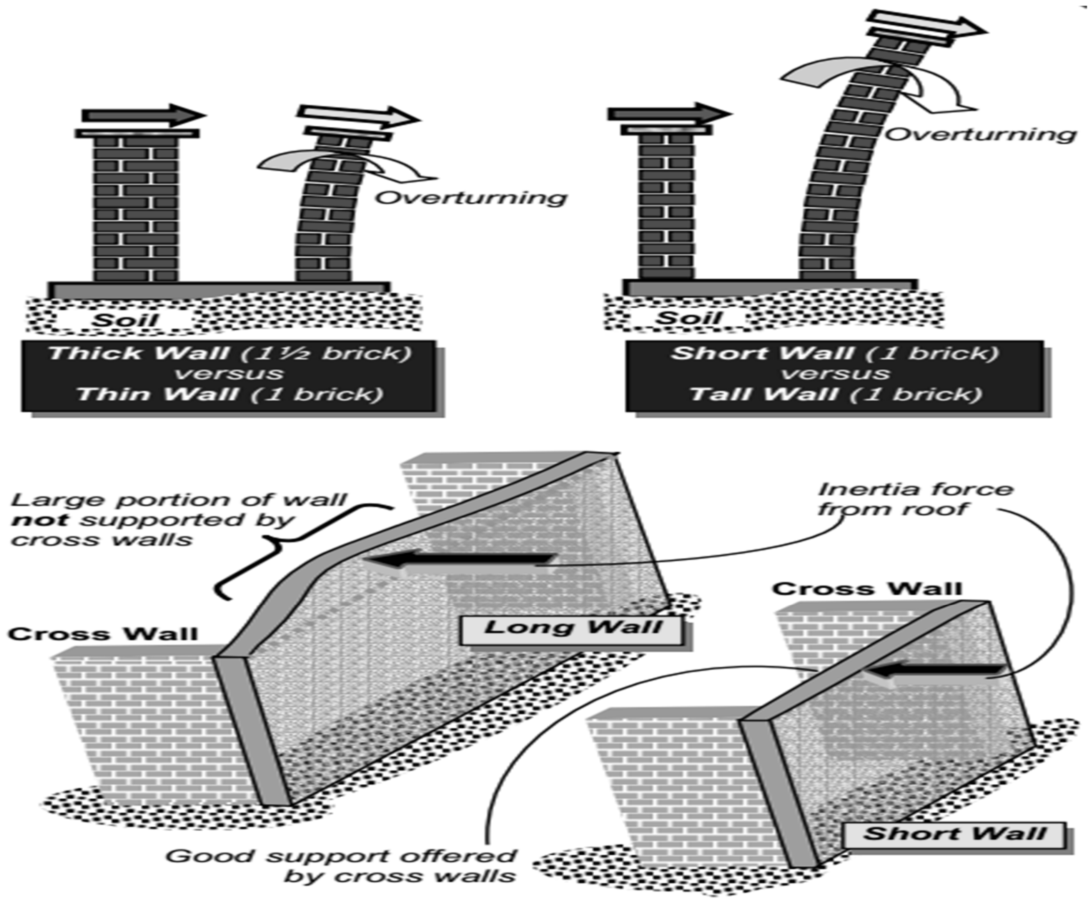


Figure 3: Slender walls are vulnerable – height and length to be kept within limits.

2.1.3 Choice and Quality of Building Materials

Earthquake performance of a masonry wall is very sensitive to the properties of its constituents, namely masonry units and mortar. The properties of these materials vary across India due to variation in raw materials and construction methods. A variety of masonry units are used in the country, e.g. Clay bricks (burnt and unburnt), concrete blocks (solid and hollow), stone blocks. Burnt clay bricks are most commonly used. These bricks are inherently porous, and so they absorb water. Excessive porosity is detrimental to good masonry behavior because the bricks suck away water from the adjoining mortar, which results in poor bond between brick and mortar, and in difficulty in positioning masonry units.

For this reason, bricks with low porosity are to be used, and they must be soaked in water before use to minimize the amount of water drawn away from the mortar.
Various mortars are used, e.g. mud, cement-sand, or cement-sand-lime. Of these, mud mortar is the weakest; it crushes easily when dry, flows outward and has very low earthquake resistance. Cement-sand mortar with lime is the most suitable. This mortar mix provides excellent workability for laying bricks, stretches without crumbling at low earthquake shaking, and bonds well with bricks. The earthquake response of masonry walls depends on the relative strengths of brick and mortar. Bricks must be stronger than mortar. Excessive thickness of mortar is not desirable. A 10mm thick mortar layer is generally satisfactory from practical and aesthetic considerations (IITK-BMTPC Earthquake Tip 12).

2.1.4 Box Action in Masonry Buildings

The structural configuration of masonry buildings includes aspects like (a) overall shape and size of the building, and (b) distribution of mass and (horizontal) lateral load resisting elements across the building. Large, tall, long and unsymmetrical buildings perform poorly during earthquakes (IITK-BMTPC Earthquake Tip 6). A strategy used in making them earthquake-resistant is developing good box action between all the elements of the building, i.e., between roof, walls and foundation (Figure 4). Loosely connected roof or unduly slender walls are threats to good seismic behavior. For example, a horizontal band introduced at the lintel level ties the walls together and helps to make them behave as a single unit.

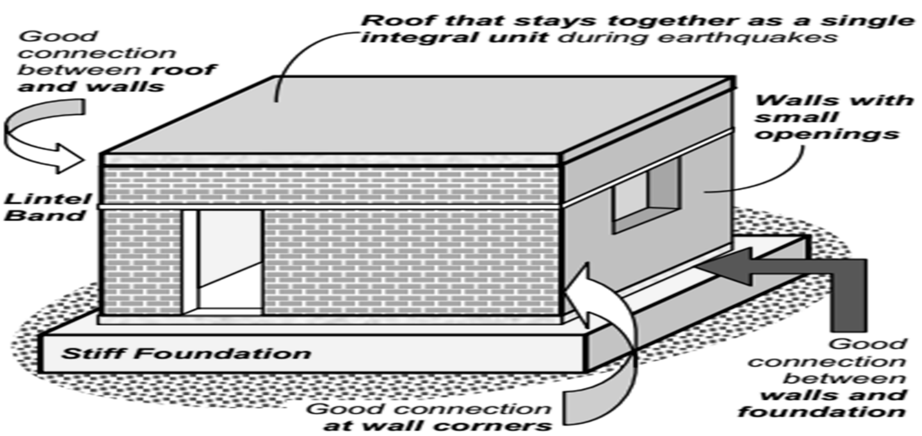


Figure 4: Essential requirements to ensure box action in a masonry building.

2.1.5 Influence of Openings

Openings are functional necessities in buildings. However, location and size of openings in walls assume significance in deciding the performance of masonry buildings in earthquakes. To understand this, consider a four-wall system of a single storey masonry building (Figure 5). During earthquake shaking, inertia forces act in the strong direction of some walls and in the weak direction of others (IITK-BMTPC Earthquake Tip 12).

Walls shaken in the weak direction seek support from the other walls, i.e., walls B1 and B2 seek support from walls A1 and A2 for shaking in the direction shown in Figure 2. To be more specific, wall B1 pulls walls A1 and A2, while wall B2 pushes against them. At the next instance, the direction of shaking could change to the horizontal direction perpendicular to that shown in Figure 2. Then, walls A and B change their roles; Walls B1 and B2 become the strong ones and A1 and A2 weak. Thus, walls transfer loads to each other at their junctions (and through the lintel bands and roof).

Hence, the masonry courses from the walls meeting at corners must have good interlocking. For this reason, openings near the wall corners are detrimental to good seismic performance. Openings too close to wall corners hamper the flow of forces from one wall to another (Figure 6). Further, large openings weaken walls from carrying the inertia forces in their own plane. Thus, it is best to keep all openings as small as possible and as far away from the corners as possible.

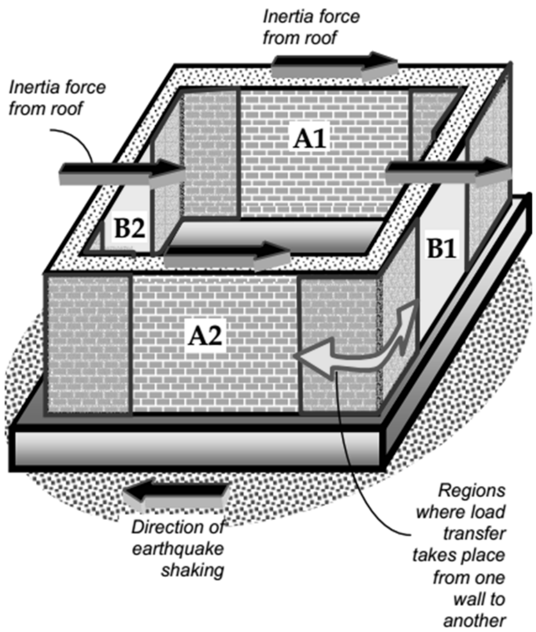


Figure 2: Regions of force transfer from weak walls to strong walls in a masonry building

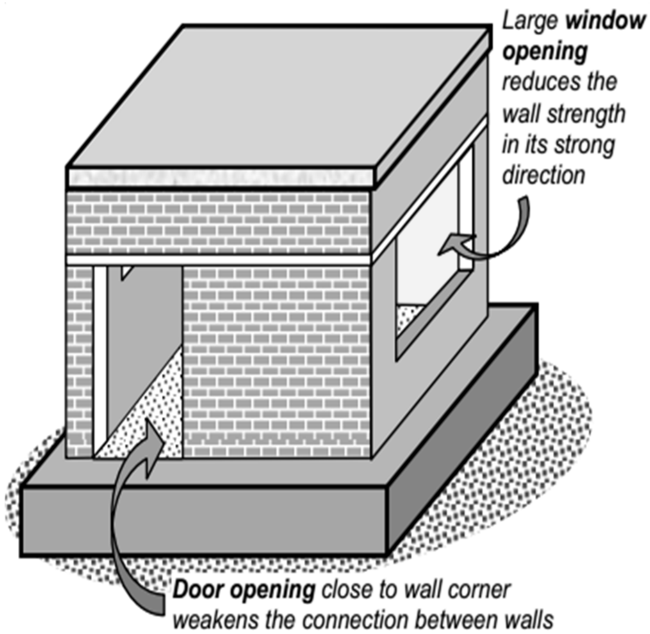


Figure 6: Openings weaken walls in a masonry building

2.1.6 Earthquake-Resistant Features

Indian Standards suggest a number of earthquake-resistant measures to develop good box-type action in masonry buildings and improve their seismic performance. For instance, it is suggested that a building having horizontal projections when seen from the top, e.g., like a building with plan shapes L, T, E and Y, be separated into (almost) simple rectangular blocks in plan, each of which has simple and good earthquake behavior (IITK-BMTPC Earthquake Tip 6).

During earthquakes, separated blocks can oscillate independently and even hammer each other if they are too close. Thus, adequate gap is necessary between these different blocks of the building. The Indian Standards suggest minimum seismic separations between blocks of buildings. However, it may not be necessary to provide such separations between blocks, if horizontal projections in buildings are small, say up to ~15-20% of the length of building in that direction. Inclined staircase slabs in masonry buildings offer another concern. An integrally connected staircase slab acts like a cross-brace between floors and transfers large horizontal forces at the roof and lower levels (Figure 7a). These are areas of potential damage in masonry buildings, if not accounted for in staircase design and construction. To overcome this, sometimes, staircases are completely separated (Figure 7b) and built on a separate reinforced concrete structure. Adequate gap is provided between the staircase tower and the masonry building to ensure that they do not pound each other during strong earthquake shaking (IITK-BMTPC Earthquake Tip 13).

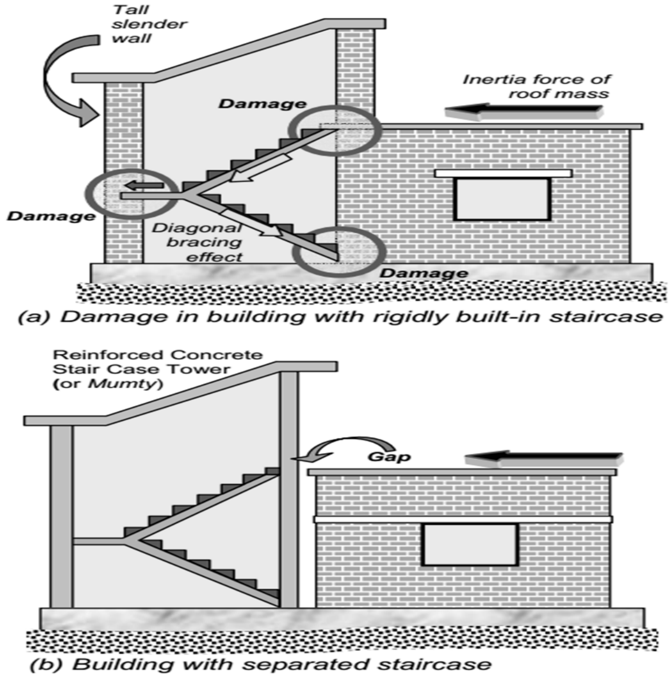


Figure 7: Earthquake-resistant detailing of staircase in masonry building

2.1.7 Role of Horizontal Bands

Horizontal bands are the most important earthquake-resistant feature in masonry buildings. The bands are provided to hold a masonry building as a single unit by tying all the walls together, and are similar to a closed belt provided around cardboard boxes. There are four types of bands in a typical masonry building, namely gable band, roof band, lintel band and plinth band (Figure 8), named after their location in the building. The lintel band is the most important of all, and needs to be provided in almost all buildings. The gable band is employed only in buildings with pitched or sloped roofs. In buildings with flat reinforced concrete or reinforced brick roofs, the roof band is not required, because the roof slab also plays the role of a band.

However, in buildings with flat timber or CGI sheet roof, roof band needs to be provided. In buildings with pitched or sloped roof, the roof band is very important. Plinth bands are primarily used when there is concern about uneven settlement of foundation soil. The lintel band ties the walls together and creates a support for walls loaded along weak direction from walls loaded in strong direction. This band also reduces the unsupported height of the walls and thereby improves their stability in the weak direction. During the 1993 Latur earthquake (Central India), the intensity of shaking in Killari village was IX on MSK scale. Most masonry houses sustained partial or complete collapse (Figure 9a). On the other hand, there was one masonry building in the village, which had a lintel band and it sustained the shaking very well with hardly any damage (Figure 9b) (IITK-BMTPC Earthquake Tip 14).

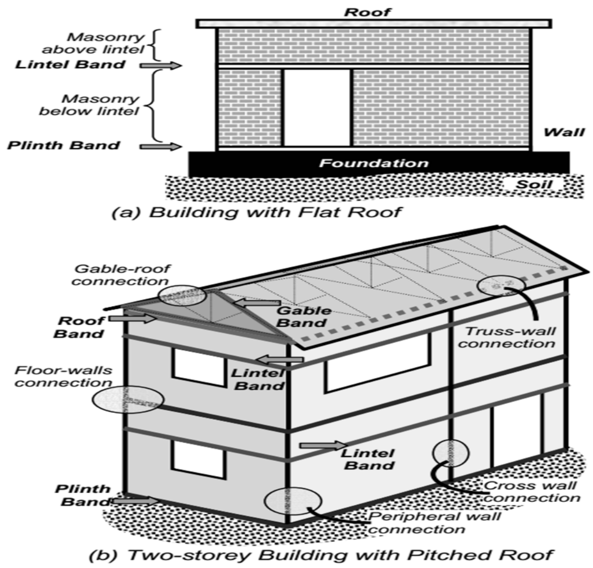


Figure 8: Horizontal Bands in masonry building

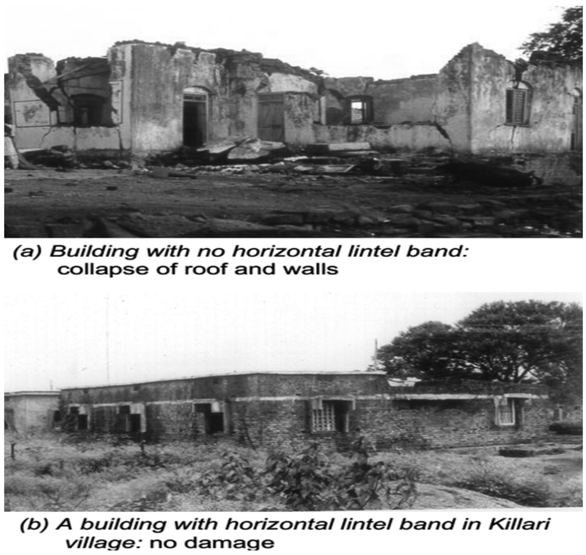


Figure 9: The 1993 Latur Earthquake (Central India)

2.1.8 Design of Lintel Bands

During earthquake shaking, the lintel band undergoes bending and pulling actions (Figure 10). To resist these actions, the construction of lintel band requires special attention. Bands can be made of wood (including bamboo splits) or of reinforced concrete (RC) (Figure 11); the RC bands are the best. The straight lengths of the band must be properly connected at the wall corners. This will allow the band to support walls loaded in their weak direction by walls loaded in their strong direction. Small lengths of wood spacers (in wooden bands) or steel links (in RC bands) are used to make the straight lengths of wood runners or steel bars act together. In wooden bands, proper nailing of straight lengths with spacers is important. Likewise, in RC bands, adequate anchoring of steel links with steel bars is necessary. The Indian Standards IS: 4326-1993 and IS: 13828 (1993) provide sizes and details of the bands. When wooden bands are used, the cross-section of runners is to be at least 75mm×38mm and of spacers at least 50mm×30mm. When RC bands are used, the minimum thickness is 75mm, and at least two bars of 8mm diameter are required, tied across with steel links of at least 6mm diameter at a spacing of 150 mm centers (IITK-BMTPC Earthquake Tip 14).

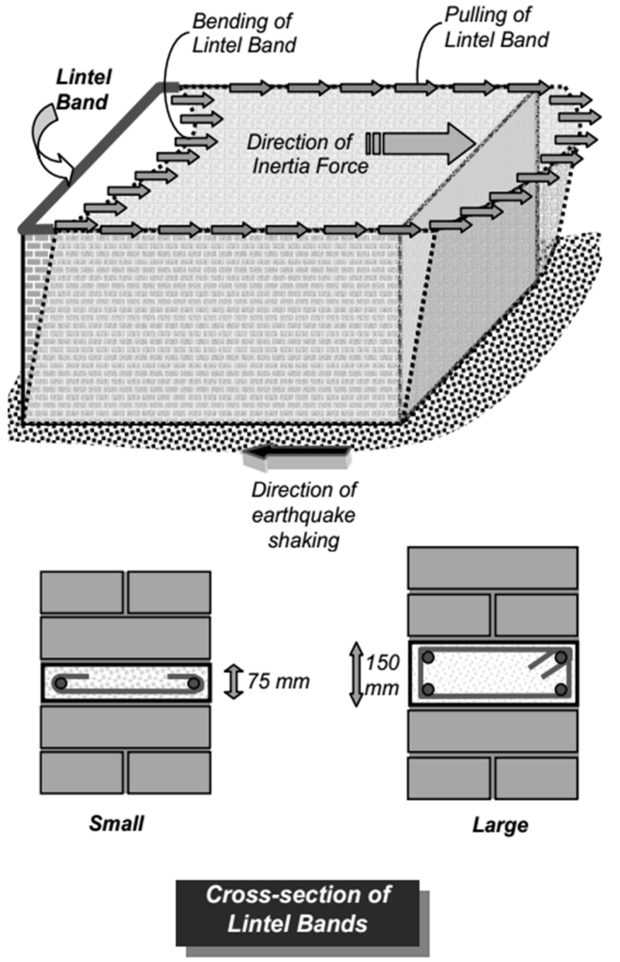


Figure 10: Bending and pulling in lintel bands

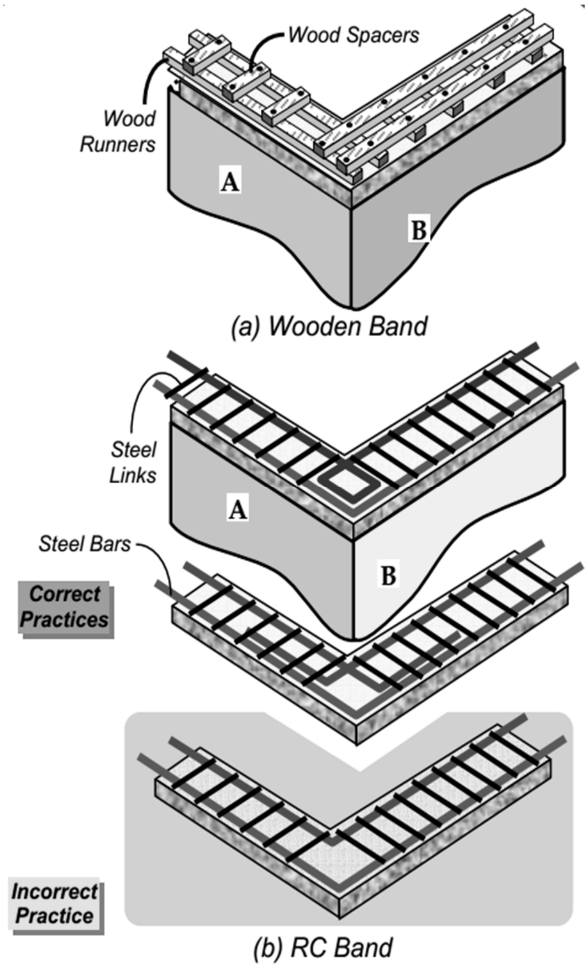


Figure11: Horizontal Bands in masonry buildings

2.1.9 Response of Masonry Walls

Horizontal bands are provided in masonry buildings to improve their earthquake performance. These bands include plinth band, lintel band and roof band. Even if horizontal bands are provided, masonry buildings are weakened by the openings in their walls (Figure 12). During earthquake shaking, the masonry walls get grouped into three sub-units, namely spandrel masonry, wall pier masonry and sill masonry.

Consider a hipped roof building with two window openings and one door opening in a wall (Figure 13a). It has lintel and plinth bands. Since the roof is a hipped one, a roof band is also provided. When the ground shakes, the inertia force causes the small-sized masonry wall piers to disconnect from the masonry above and below. These masonry sub-units rock back and forth, developing contact only at the opposite diagonals (Figure 13b). The rocking of a masonry pier can crush the masonry at the corners. Rocking is possible when masonry piers are slender, and when weight of the structure above is small. Otherwise, the piers are more likely to develop diagonal (X-type) shear cracking (Figure 13c); this is the most common failure type in masonry buildings.

In un-reinforced masonry buildings (Figure 14), the cross-section area of the masonry wall reduces at the opening. During strong earthquake shaking, the building may slide just under the roof, below the lintel band or at the sill level. Sometimes, the building may also slide at the plinth level. The exact location of sliding depends on numerous factors including building weight, the earthquake-induced inertia force, the area of openings, and type of doorframes used (IITK-BMTPC Earthquake Tip 14).

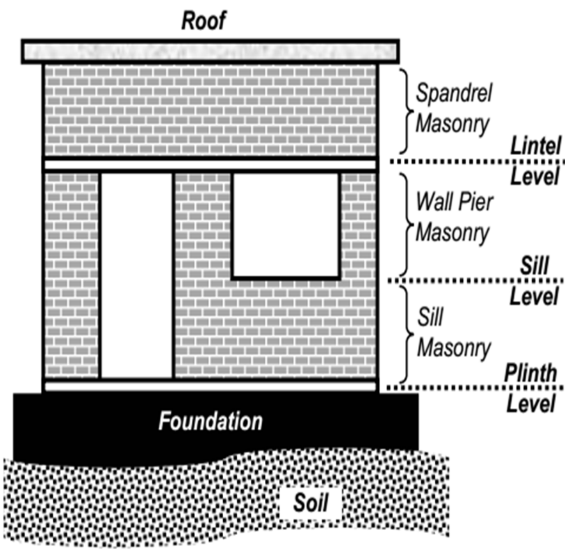


Figure 12: Sub-units in masonry building

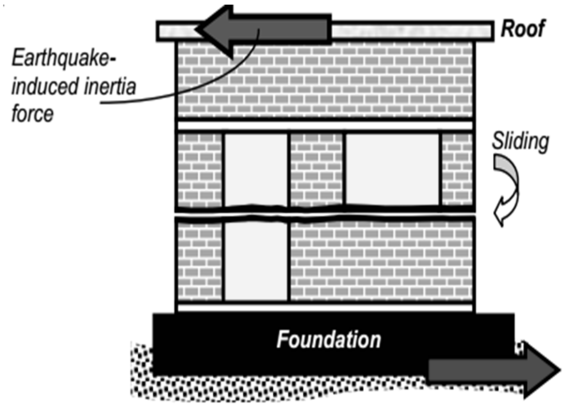


Figure 14: Horizontal sliding at sill level in a masonry building

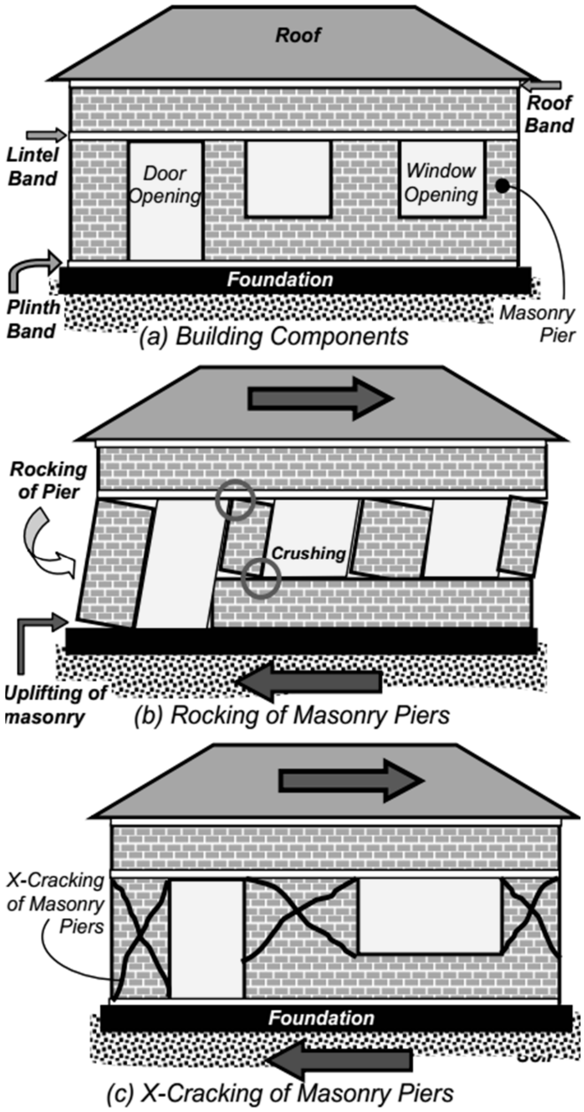


Figure 13: Earthquake response of a hipped roof
masonry building

2.1.10 How Vertical Reinforcement Helps

Embedding vertical reinforcement bars in the edges of the wall piers and anchoring them in the foundation at the bottom and in the roof band at the top (Figure 15), forces the slender masonry piers to undergo bending instead of rocking. In wider wall piers, the vertical bars enhance their capability to resist horizontal earthquake force sand delay the X-cracking. Adequate cross-sectional area of these vertical bars prevents the bar from yielding in tension. Further, the vertical bars also help protect the wall from sliding as well as from collapsing in the weak direction (IITK-BMTPC Earthquake Tip 15).

2.1.11 Protection of Openings in Walls

Sliding failure mentioned above is rare, even in unconfined masonry buildings. However, the most common damage, observed after an earthquake, is diagonal X-cracking of wall piers, and also inclined cracks at the corners of door and window openings. When a wall with an opening deforms during earthquake shaking, the shape of the opening distorts and becomes more like a rhombus- two opposite corners move away and the other two come closer. Under this type of deformation, the corners that come closer develop cracks (Figure 16a). The cracks are bigger when the opening sizes are larger. Steel bars provided in the wall masonry all around the openings restrict these cracks at the corners (Figure 16b). In summary, lintel and sill bands above and below openings, and vertical reinforcement adjacent to vertical edges, provide protection against this type of damage (IITK-BMTPC Earthquake Tip 15).

2.1.12 How to make Stone Masonry Buildings Earthquake Resistant

(a) Ensure proper wall construction: The wall thickness should not exceed 450mm. Round stone boulders should not be used in the construction. Instead, the stones should be shaped using chisels and hammers. Use of mud mortar should be avoided in higher seismic zones. Instead, cement -sand mortar should be 1:6 or richer) and lime-sand mortar 1:3 (or richer) should be used.(b) Ensure proper bond in masonry courses: The masonry walls should be built in construction lifts not exceeding 600mm. Through-stones (each extending over full thickness of wall) or a pair of overlapping bond -stones (each extending over at least ¾ths thickness of wall) must be used at every 600mm along the height and at a maximum spacing of 1.2m along the length (Figure 17). (c) Provide horizontal reinforcing elements: The stonemasonry dwellings must have horizontal bands (IITK-BMTPC Earthquake Tip 14for plinth, lintel, roof and gable bands). These bands can be constructed out of wood or reinforced concrete, and chosen based on economy. It is important to provide at least one band (either lintel band or roof band) in stone masonry construction (Figure 18). (d) Control on overall dimensions and heights: The unsupported length of walls between cross-walls should be limited to 5m; for longer walls, cross supports raised from the ground level called buttresses should be provided at spacing not more than 4m. The height of each story should not exceed 3.0m. In general, stone masonry buildings should not be taller than 2 stories when built in cement mortar, and 1 story when built in lime or mud mortar. The wall should have a thickness of at least one -sixth its height. Although, this type of stone masonry construction practice is deficient with regards to earthquake resistance, its extensive use is likely to continue due to tradition and low cost (IITK-BMTPC Earthquake Tip 16)

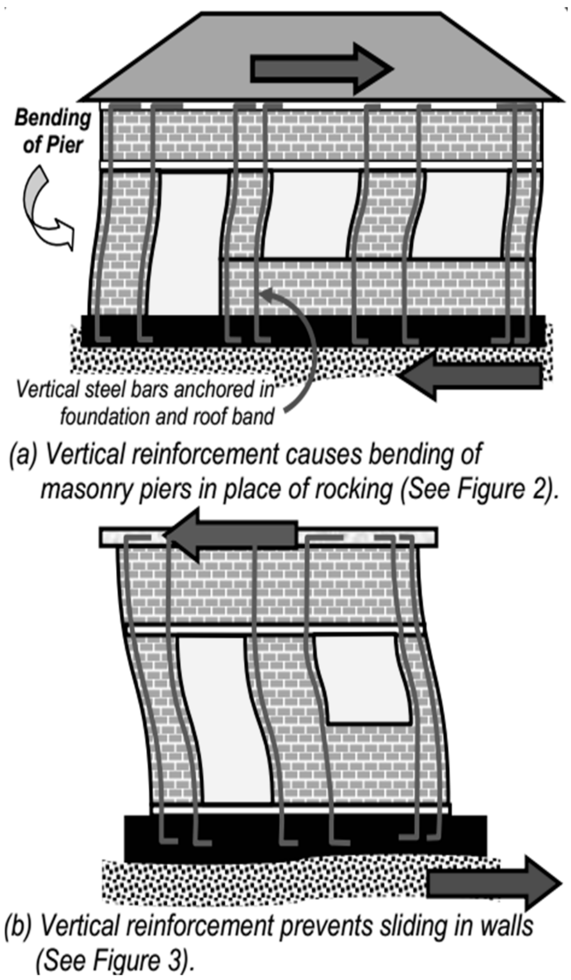


Figure 15: Vertical reinforcement in masonry walls

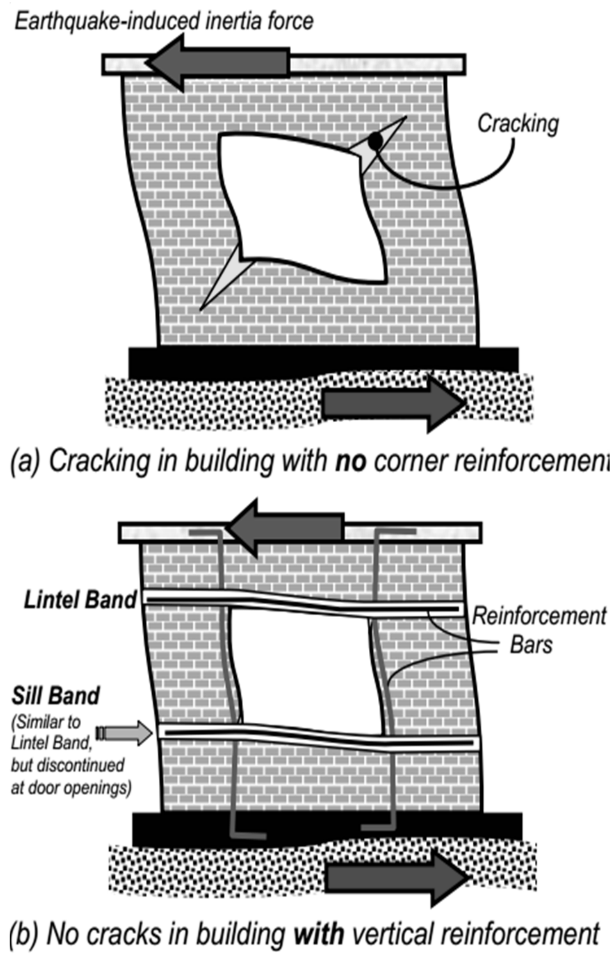


Figure 16: Cracks at corners of openings in a masonry building

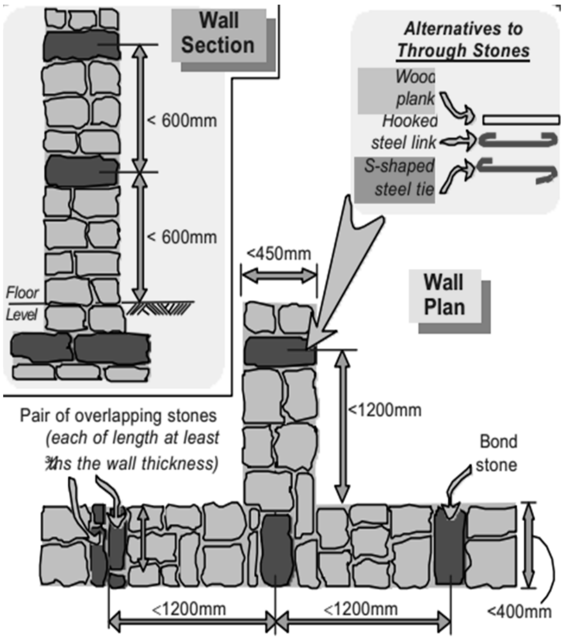


Figure 17: Use of "through stones" or "bond stones" in stone masonry walls

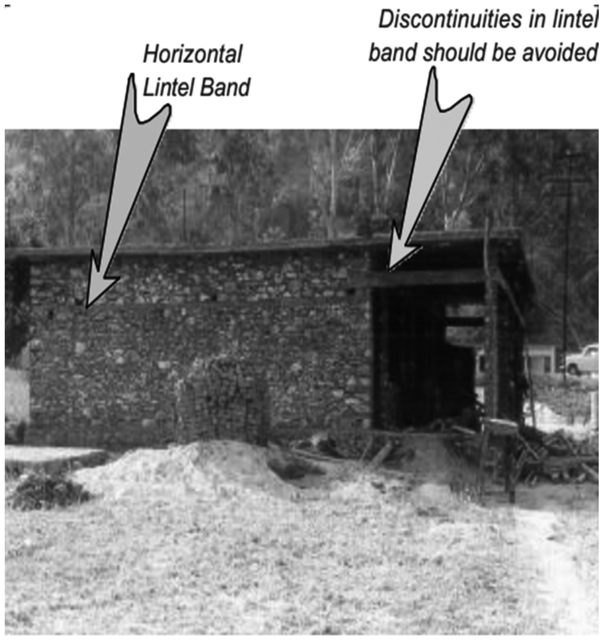


Figure 18: Horizontal lintel band is essential in
random rubble stone masonry walls

2.2 NON-DESTRUCTIVE TESTING EQUIOMENT

2.2.1 Ferroscan

Ferroscan is portable, non-destructive steel reinforcement detection system using electromagnetic pulse. It can reduce costly effort to drill, cut or physically break concrete surface to find out the bar. Ferroscan has been used for determining the position, depth and diameter of rebar in existing structure. This is a portable, quick and simple-to-operate system carrying out structural analysis quickly and exactly in a non-destructive manner. This also determines coverage coverage over the entire surface of the structure. The key element of the system is the scanner and the monitor. After scanning a structure data has been transferred to the monitor. Collected data can be analyzed by monitor or in a PC using the software PS 200. Maximum depth of scanning is 180 mm (at 36 mm rebar diameter) where rebar diameter range 6-36 mm. Accuracy of depth measurement for rebar is $\pm$ 1 mm, depending on the depth range and Scan mode used. Three types of scanning can be checked out by using Ferroscan device. Line scan is simple way to detect position and depth of rebar where Image scan provides detail information (diameter of bar, concrete cover, location etc.) with scanned image (2ft x 2ft grid) of any structure. Block scan is a combination of a set of image scan for a comparatively large area (Rahman et. Al, 2010). Figure 19 shows monitor and scanning device.

Figure 19: Monitor and scanning device of Ferroscan

2.2.2 Microtremor Instrument

Microtremor measurement has been done with five component of sensor. At each site microtremor ground motions were measured for five minutes. Each accelerometer recorded data in the direction two horizontal (N-S and E-W components) and one vertical direction (up-down). For free two fields near to building, First Fourier Transform (FFT) has been done in order to calculate H/V spectral ratio for microtremors. At the top and ground floors of the both buildings, horizontal X- and Y-component microtremor motions, which are in longitudinal and traverse direction of the buildings, were observed. Figure 20 shows the microtremor testing equipments.

Figure 20: Microtremor testing equipments

2.2.3 Ultrasonic Pulse Velocity (UPV) Instrument

Principle and Crack Depth Estimation

The ultrasonic pulse transmits a very small amount of energy through air. Therefore, if a pulse traveling through the concrete comes upon an air filled crack or a void whose projected are perpendicular to the path length is larger than the area of the transmitting transducer; the pulse will get diffracted around the defect. Thus, the pulse travel time will be greater than that through a similar concrete without any defect. The pulse velocity method, therefore, is effective in locating cracks, cavities, and other such defects. It should be pointed out that the application of this technique in locating flaws has serious limitations. For example, if the cracks and flaws are small or if they are filled with water or other debris, thus allowing the wave to propagate through the flaw, the pulse velocity will not significantly decrease, implying that no flaws exist.

Vertical crack depth

The experimental set up for estimating the vertical crack is as shown in the Figure 21.
The depth of an air filled crack can be estimated by the pulse velocity method.
The depth, h, is given by equation (1),

$$h = \frac{x}{T_2} \left(T_1^2 - T_2^2\right)^2 \qquad (1)$$

Where
x = distance of transducer from the crack (note that both transducers must be placed equidistant from the crack);
T_1= transmit time around the crack;
T_2= transmit time along the surface of the same type of concrete without any crack (note that surface path length for T_1 and T_2 must be equal).
It should be pointed out that for the above equation to be valid; the crack must be perpendicular to the concrete surface. A check should be made to determine if the crack is perpendicular to the surface or not. This can be done as follows. Place both the transducers equidistant from the crack and obtain the transit, time. Move each transducer, in turn, away from the crack. If the transmit time decreases, then the crack slopes towards the direction in which transducer was moved.

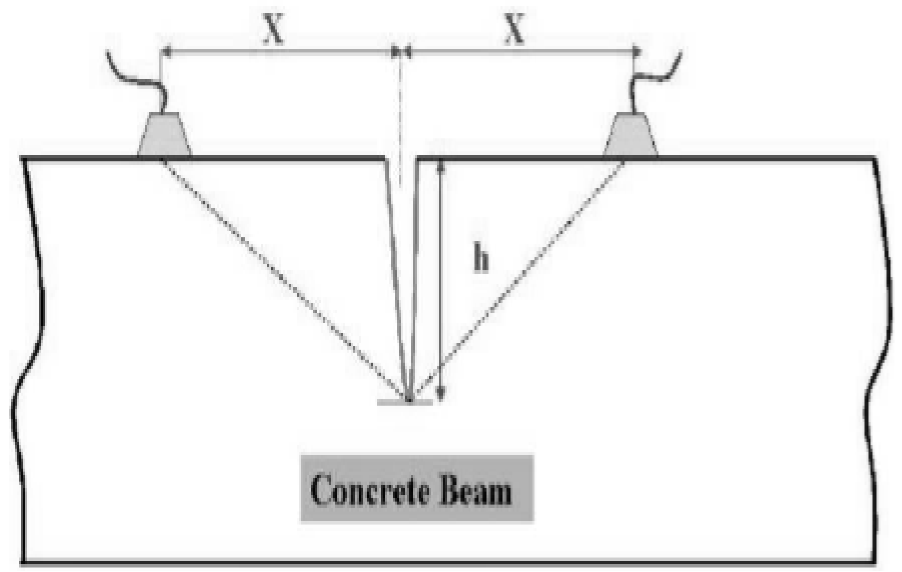


Figure 21: Experimental set-up for vertical crack depth estimation

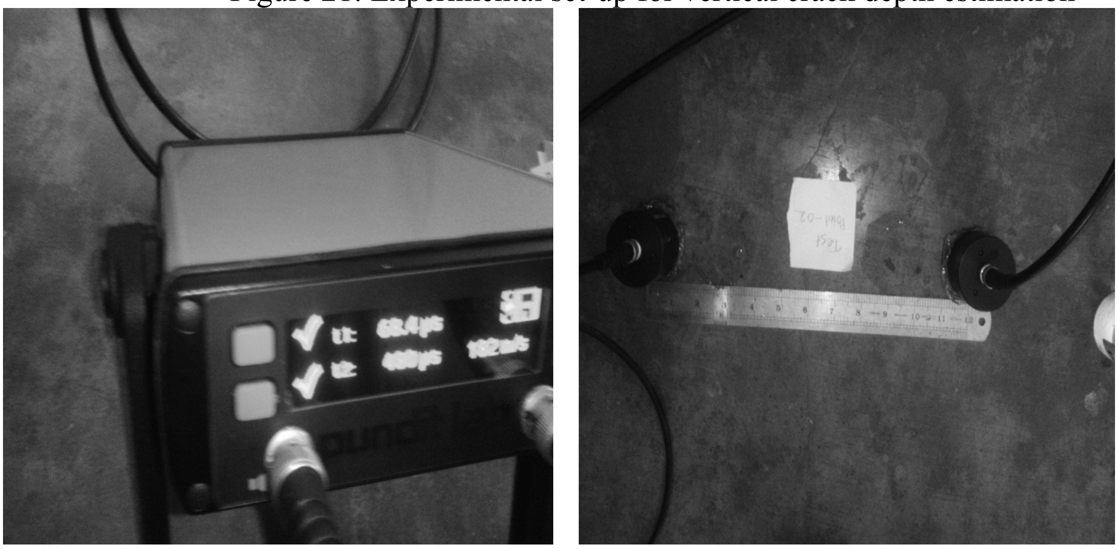


Figure 22: Ultrasonic Pulse Velocity Instrument

2.3 Moisture Content Analysis of OAB building

2.3.1 Introduction

Moisture, in all its physical forms, is commonly regarded as the single greatest threat to durability and long-term performance of the building stock. Excessive exposure to moisture is not only a common cause of significant damage to many types of building components and materials, it also can lead to unhealthy indoor living environments (Dacquisto et al., 2004). Bangladesh lies in the sub-tropical monsoon zone and receives approximately 2000 mm of rainfall annually, of which more than 80% occurs during the monsoon season (from June to September) (Dewan et al., 2007; Dewan and Yamaguchi, 2009a). So, climate of the city is characterized by subtropical, high rainfall, humid condition with cool and short winter; and long, humid and hot summer. Moreover, the buildings in this country are not constructed complying with the national building code. Due to such climatic condition and structural condition, excessive exposure to moisture is a common phenomenon in Bangladesh.

This study aims to assess building moisture content by detecting thermal or infrared radiation through thermal imaging or infrared (IR) camera. The Old Academic Building (OAB) in Bangladesh University of Engineering and Technology (BUET) was selected as the study area for this study.

2.3.2 Background of the study

2.3.2.1 Moisture Assessment

Some of the more serious effects resulting from moisture problems in houses include: decay of corrosion of metals, infestation by termites, carpenter ants and other insects, negative impacts on indoor air quality, the growth of mold, mildew and other biological contaminants, reduced strength in building materials, expansion/contraction damage to materials, reduced thermal resistance of wet insulation, premature failures of paints and coatings, damage to building contents, negative effects on building aesthetics, etc (Dacquisto et al., 2004). Considering the consequences several studies regarding moisture assessment have been undertaken. Colantonio (2008) discussed moisture detection methodologies for interior inspections in the paper. Dacquisto et al. (2004) carried out a project to develop a set of recommendations for future research on moisture problems in housing that will help to prevent such problems or resolve them once they have occurred through a review and analysis of the extensive technical literature concerning the problems created by bulk water and excessive water vapor in houses, and the solutions to those problems.

Some case studies providing information on specific occurrences of moisture problems in different courtiers are also found in the literature. Most case studies are anecdotal in nature and deal with a specific construction or a select group of structures that have experienced moisture-related performance problems (Dacquisto et al., 2004). Marshall Macklin Monaghan Limited (1983) studied indications of moisture problems in CMHC-financed housing built between the years of 1973 and 1981 (689,000 total housing units representing about 35% of housing production in Canada during that period). Later in 1998, 1999, and 2000, CMHC carried out similar studies for moisture assessment in British Columbia, Seattle, WA, Vancouver, B.C., and Alberta in Canada (Survey of Building Envelope Failures in the Coastal Climate of British Columbia, 1998; Comparative Analysis of Residential Construction in Seattle, WA and Vancouver, B.C., 1999; Wall Moisture Problems in Alberta Dwellings, 2000). Chouinard and Lawton (n.d.) revealed that in Canada, the primary source of moisture leading to performance problems was rainwater intrusion rather than interior sources of construction moisture. May (1991) demonstrated through several examples that moisture damage is more dependent on management of rainwater. Similar conclusion was drawn in the studies of U.S. Department of Housing and Urban Development (Assessing Housing Durability: A Pilot Study, 2001), Crandell (1996), Crandell (2003), Crandell and Kenney (1996), and Tsongas et al. (1998).

2.3.2.2 Thermal Image for Moisture Assessment

2.3.2.2.1 The Thermal Imaging Camera and How It Works

Infrared thermographic imagers have been used in the building industry since the 1980's, mainly for building envelope and heat loss analysis, which are now vital tools to determine performance characteristics of walls and roofs for both energy and structural integrity (Colantonio, 2008). A thermal imaging camera is a unique and non-contact tool utilizing infrared thermography which is the art of transforming an infrared image into a radiometric one allowing temperature values to be read from the image. Infrared radiation is an energy wave that lies between the visible and microwave portions of the electromagnetic spectrum where heat or thermal radiation is its primary source (Holland, 2008; FLIR, 2011a & 2011b). As a diagnostic technique, thermography captures two-dimensional images of the apparent temperatures of equipment and structures (FLUKE, n.d.). On the electromagnetic spectrum infrared has a lower frequency than the red part of the visible light, thus the designation infra (below) red (Holland, 2008). The tool produces thermal image indicating the exact location of energy losses through scanning and visualizing the temperature distribution of entire surfaces quickly and accurately providing precise and convincing argumentation (FLIR, 2011a & 2011b). It is also well suited to identifying wet spots in building envelopes (FLUKE, n.d.). Figure 1 shows thermal and visual image showing wet area of wall.

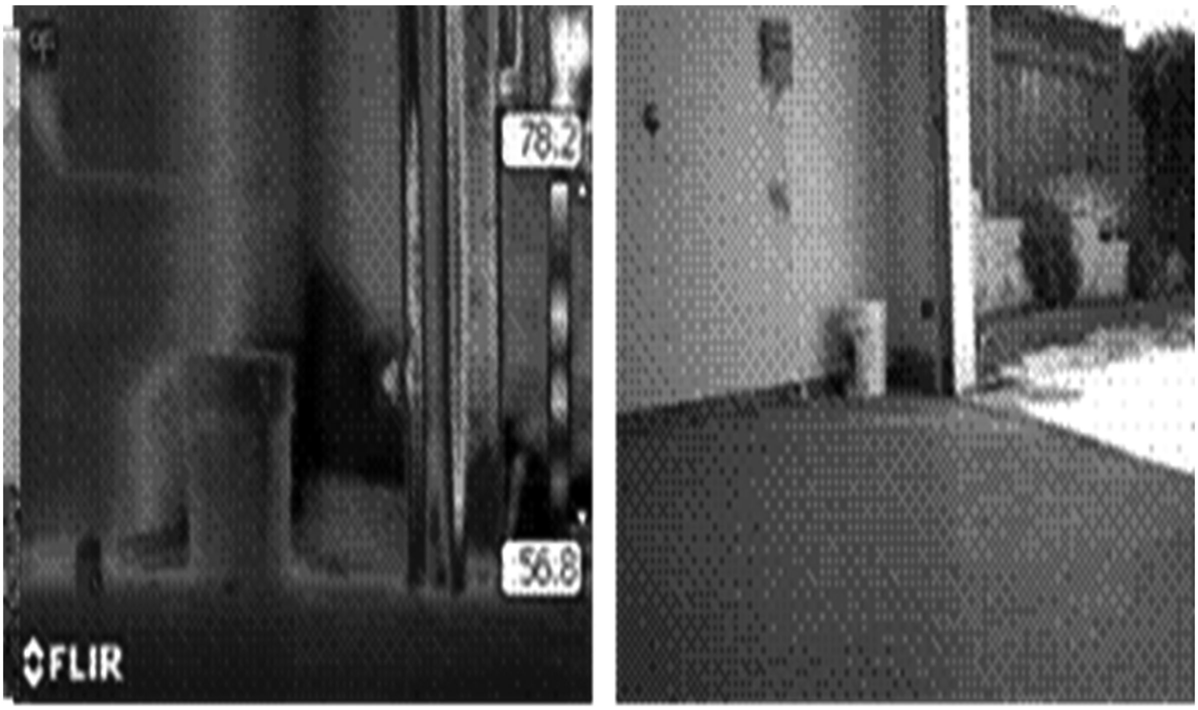


Figure 23: Thermal and visual image showing wet area of wall (Source: Hopkins, 2011a)

2.3.2.2.2 Use of Thermal Image for Moisture Assessment

The presence of moisture in building envelopes, whether from leakage or condensation, can have serious consequences. For example, moisture in insulation reduces its insulating capability, causing heating and/or cooling losses and wasting energy. Moisture can also cause structural deterioration and foster the growth of mold, while a serious roof leak can damage or destroy a building's contents (FLUKE, n.d.). The true culprits of moisture damage are design flaws, construction defects and mechanical or plumbing mistakes which allow for the intrusion of water. And a structure's age is definitely a factor too as components start to wear, like caulking and mastic, and in these cases deferred maintenance would be the true cause of a leak (Hopkins, 2011b). There are a number of areas where moisture can accumulate that are often overlooked in typical inspection processes, or require extensive damage to the property to find them. That is why many are turning to thermal imaging as part of their building inspection regimen (FLUKE, n.d.).

An infrared camera can see and measure heat differences in building materials on ceilings, walls and floors. Wet or moist areas and objects usually have a different temperature than dry areas (Hopkins, 2011b). Usually, the temperature of the damp areas are colder then dry ones (a), because of surface evaporation, or warmer (b), because of the higher thermal inertia of water versus building materials (Rosina and Ludwig, 1999). Infrared camera can be used to detect presence and extent of moisture by means of variances in heat transfer brought on by this capacitance of water and phase change heat loss or gain (Colantonio, 2008). The principle that allows locating moisture on the interior walls is evaporative cooling. Evaporative cooling can be very slight; there may only be a 1ºF temperature difference from wet to dry. A good IR camera easily shows even that slight temperature difference (Holland, 2008). Accordingly, the wet areas will appear relatively darker or lighter than the dry areas on an infrared picture, enabling us to locate them (Hopkins, 2011b). The process of finding all areas with moisture issues can be a long and tedious task when using only a moisture meter. The thermal imaging camera quickly and accurately shows all relevant thermal differences. The investigation results in the preliminary determination of the problem (Holland, 2008). Moreover, unlike other moisture-detecting technologies, such as meters, thermography requires no physical contact with roofs, ceilings, walls or floors. In addition, it is possible to check inaccessible areas and cover a large area in a single image (FLUKE, n.d.). Thus the infrared camera can be readily utilized to detect the extent of moisture intrusion in building structures in a much faster and convenient way than conventional moisture detection devices (Colantonio, 2008).

Using infrared cameras (or thermal imagers) to detect moisture is a relatively new but rapidly growing practice in inspection and insurance circles (FLUKE, n.d.). Realizing the importance of thermal imaging camera in building moisture assessment, several studies have been carried out on relevant subject. Hopkins (2011a and 2011b) showed the use of thermal imaging camera for identifying the indoor moisture content problems due to condensation leaks, slab leaks, poor roof design, etc. Rosina and Ludwig (1999) described optimal procedures to obtain reliable maps of moisture in building materials, at different environmental and microclimatic conditions, and the related energetic phenomena, which cause temperature discontinuities, and that are detected by thermography.

2.4 Direct Shear Test

Ancient masonry structures are partially vulnerable to dynamic actions, especially seismic actions. This building, as structure planned and constructed at past, is vulnerable to dynamic loads, which may unpredictably induce a collapse of a portion of the building or derive the whole structure to rapid failure. However, the high vulnerability of ancient masonry buildings to seismic actions is mostly due to insufficient connections between the various parts.

The old academic building of BUET, the bonding material is lime mortar so it was required to check the shear stress of the bonding mortar of masonry. And direct shear test has been carried out to find the best result for mortar strength.

3 METHODOLOGY OF THE STUDY

The study has been conducted with the following methodology:

3.1 Study Design

Masonry is the building of structures from individual units laid in and bound together by mortar; the term masonry can also refer to the units themselves. The common materials of masonry construction are brick, building stone such as marble, granite, travertine, and limestone, cast stone, concrete block, glass block, and cob. Masonry is generally a highly durable form of construction. However, the materials used, the quality of the mortar and workmanship, and the pattern in which the units are assembled can significantly affect the durability of the overall masonry construction.

Seismic retrofitting is the modification of existing structures to make them more resistant to seismic activity, ground motion, or soil failure due to earthquakes. With better understanding of seismic demand on structures and with our recent experiences with large earthquakes near urban centers, the need of seismic retrofitting is well acknowledged. Prior to the introduction of modern seismic codes in the late 1960s for developed countries (US, Japan etc.) and late 1970s for many other parts of the world (Turkey, China etc.), (NZSEE Bulletin 39(2)-June 2006), many structures were designed without adequate detailing and reinforcement for seismic protection. In view of the imminent problem, various research works has been carried out. State-of-the-art technical guidelines for seismic assessment, retrofit and rehabilitation have been published around the world - such as the ASCE-SEI 41 and the New Zealand Society for Earthquake Engineering (NZSEE)'s guidelines (NZSEE 2006). These codes must be regularly updated; the 1994 Northridge earthquake brought to light the brittleness of welded steel frames, for example (Reitherman, Robert (2012).

The retrofit techniques outlined here are also applicable for other natural hazards such as tropical cyclones, tornadoes, and severe winds from thunderstorms. Whilst current practice of seismic retrofitting is predominantly concerned with structural improvements to reduce the seismic hazard of using the structures, it is similarly essential to reduce the hazards and losses from non-structural elements. It is also important to keep in mind that there is no such thing as an earthquake-proof structure, although seismic performance can be greatly enhanced through proper initial design or subsequent modifications.

In many parts of developing countries such as Bangladesh, Iran and China, unreinforced or in some cases reinforced masonry is the predominantly form of structures for rural residential and dwelling. Masonry was also a common construction form in the early part of the 20th century, which implies that a substantial number of these at-risk masonry structures would have significant heritage value. Masonry walls that are not reinforced are especially hazardous. Such structures may be more appropriate for replacement than retrofit, but if the walls are the principal load bearing elements in structures of modest size they may be appropriately reinforced. It is especially important that floor and ceiling beams be securely attached to the walls. Additional vertical supports in the form of steel or reinforced concrete may be added.

In the western United States, much of what is seen as masonry is actually brick or stone veneer. Current construction rules dictate the amount of *tie–back* required, which consist of metal straps secured to vertical structural elements. These straps extend into mortar courses, securing the veneer to the primary structure. Older structures may not secure this sufficiently for seismic safety. A weakly secured veneer in a house interior (sometimes used to face a fireplace from floor to ceiling) can be especially dangerous to occupants. Older masonry chimneys are also dangerous if they have substantial vertical extension above the roof. These are prone to breakage at the roofline and may fall into the house in a single large piece. For retrofit, additional supports may be added; however, it is extremely expensive to strengthen an existing masonry chimney to conform to contemporary design standards. It is best to simply remove the extension and replace it with lighter materials, with special metal flue replacing the flue tile and a wood structure replacing the masonry. This may be matched against existing brickwork by using very thin veneer (similar to a tile, but with the appearance of a brick).

3.2 Study Area Selection

The Old Academic Building of Bangladesh University of Engineering and Technology (BUET) was selected as the study area.

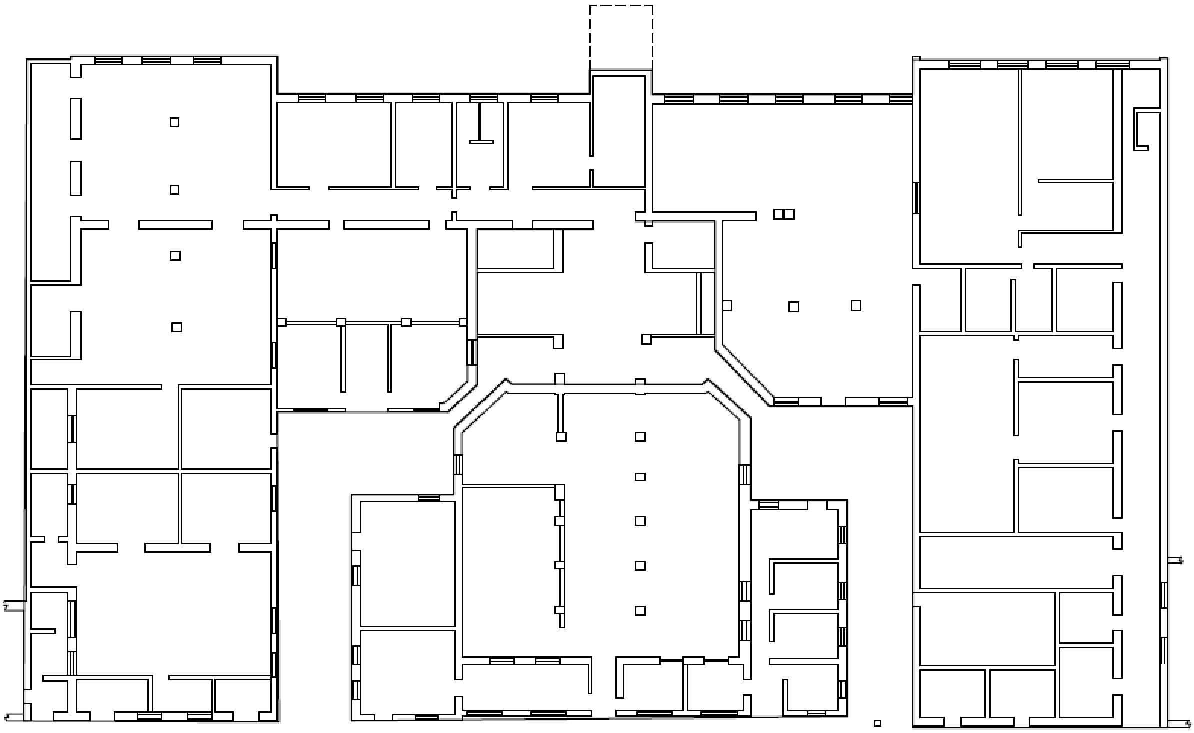


Figure 24: Ground Floor plan of Old Academic Building BUET

3.3 Preparation of Structural Checklist

A basic Structural checklist of masonry structure has been made by following the ASCE-SEI 31 and ASCE-SEI 41. To prepare this checklist, a detailed field survey was conducted.

3.4 Non-Destructive Tests

To assess the actual scenario of the of the masonry structure of Old Academic Building BUET, some basic Non-destructive tests were performed which includes Ferroscan, Microtremor, Ultrasonic Pulse Velocity (UPV), Thermal Imaging for Assessment of Moisture.

3.5 Direct Shear Test

Direct shear test is a destructive test. It has been conducted to measure the shear stress due to mortar bond only.

3.6 Data processing and analysis

The data collected from the survey have been analyzed with the relevant software to prepare the final report.

3.7 Preparation of Final Report

All information and findings were gathered and presented by tables and figures to prepare the final report.

4 ANALYSIS AND RESULTS

4.1 Structural Checklist

The following checklist has made based on ASCE-SEI 31 and ASCE-SEI 41. The checklist is given below-

i.	Building Usage Type	Academic building
ii.	Fire and Electrical Safety	Not in the scope of the report
iii.	Structural System	Unreinforced Masonry Bearing Walls with Stiff Diaphragms (Building Type 15 according to ASCE/SEI 31-03)
iv.	Floor System	First floor (2nd story) is slab supported on masonry walls, Ground floor (1st story) is slab on grade
v.	Floor Area	36000 s
vi.	No. of Stories	2-storied
vii.	Construction Year	Early 1940's (as reported)
viii.	Construction by	Owner of the building
ix.	Floor Load	Academic cum office load
x	Foundation Type	Shallow masonry strip foundation (assumed according to the usual practice)
xi.	Design Drawings	Not available (only architectural plan is available)
xii.	Soil Boring Report	Available
xiii.	Site Class	Class D
xiv.	Adjacent buildings or others	Adequate distance is maintained with other buildings
xv	Construction Materials	Unreinforced burnt clay brick masonry with lime mortar

Building plan dimension of the Academic building is roughly about 150 ft x 240 ft. Wall thickness is mostly 25 inches.

Reported Distress History:

Cracks in various positions both in ground floor and first floor of the building were reported.

Observations:

The observations of the visiting team members on the general physical condition of the superstructure, based on visual inspection of the exposed parts, are as follows:

- There is deviation in the arrangement of walls from the approved drawing.
- Both horizontal and vertical cracks in masonry wall were observed in the ground floor and first floor which is much greater than the permissible crack width 0.3mm.
- Dampness was observed in the wall which has mentioned in the moisture content analysis of the OAB.
- The non-structural members were not found in disordered or in distressed condition.
  The walls are not properly anchored with the concrete slabs.
- Bottom story has some portion as weak-story as well as a soft-story.

GENERAL RECOMMENDATIONS:

- Anchorage should be provided between masonry walls and the concrete slabs.
- Flexible couplings should be introduced in the fluid and gas piping.
- No construction beyond existing level should be made without any detail investigation.

Concluding Remarks:

- The building may be regarded safe for its present level (gravity load) of use. There is no immediate threat or risk in using the building at its normal working condition with existing loading status.
- However, measures mentioned in the General Recommendations should be taken to reduce seismic vulnerability.

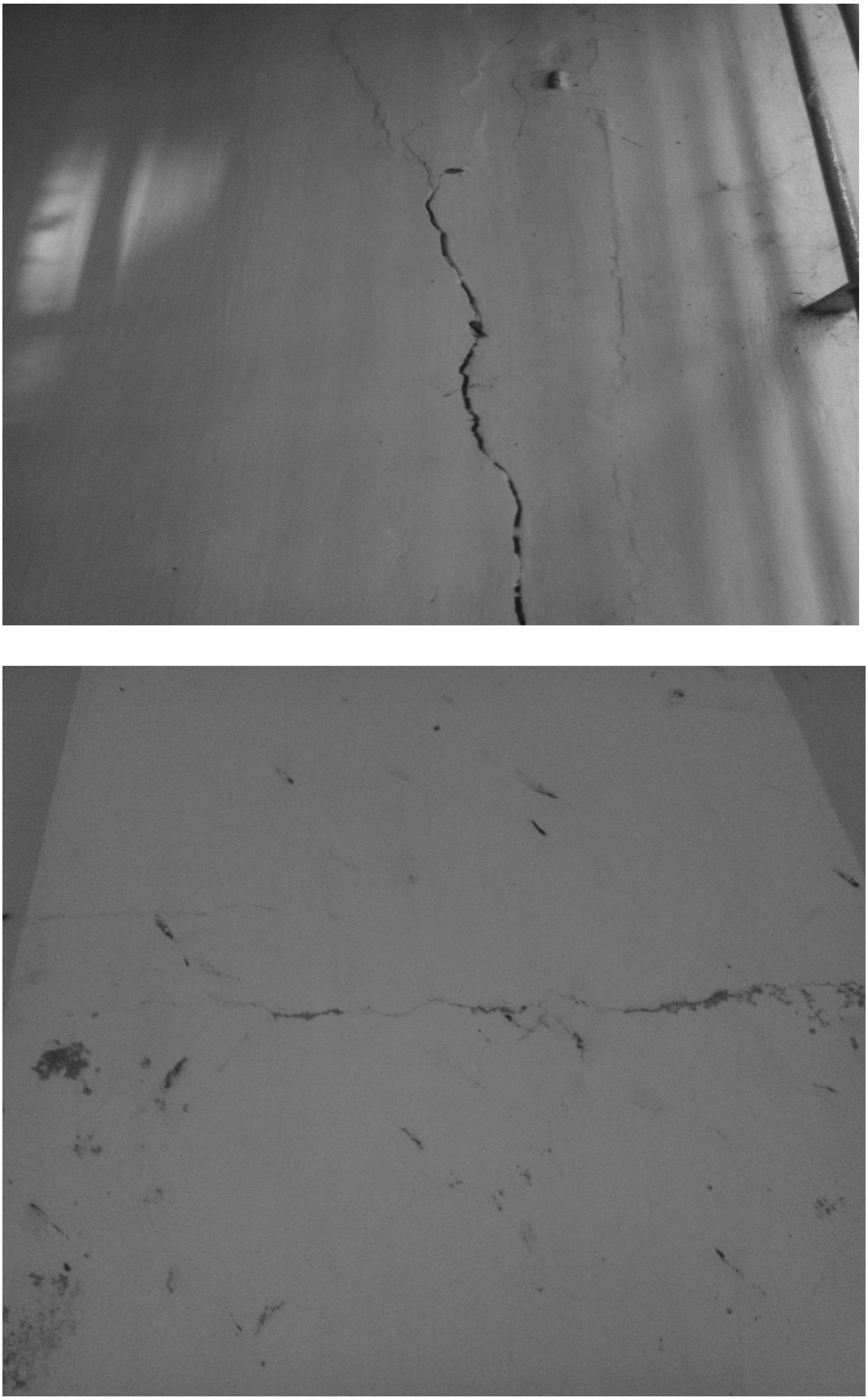


Figure 25: Major cracks in the wall

4.1.1 Seismic Performance Evaluation as per ASCE 31-03 Tier-1 Analysis

Level of Investigation

Only architectural plan is available. A site visit was made to verify the plan information and to assess the condition of the building.

Level of Performance

The building is evaluated to the ***Life Safety Performance Level (L.S).***

Level of Seismicity

The building is located in the region of ***moderate seismicity***. The parameters of level of seismicity are described in below-

According to BNBC (1993) and based on geotechnical investigation report

1. Zone coefficient for Dhaka = 0.15
2. Site Class = S3 (as per BNBC 1993)

Therefore,

Design short period response acceleration $S_{DS} = 2.5 \times 0.15g = 0.375g$
Design spectral response acceleration at 1 sec. $S_{D1} = 2 \times 0.15g = 0.300g$
Where, g = acceleration due to gravity

Building Type

As the description of types of building, the evaluated buildings are classified as **URMA (Unreinforced Masonry Bearing Walls with Stiff Diaphragms).**

Screening Phase (Tier 1)

The buildings are URMA type and the site is in a high seismicity zone. Thus the following checklists are associated for ***Tier 1*** evaluation.

- **Basic Structural Checklist**
- Geologic Site Hazards and Foundation Checklist
- Basic Nonstructural Checklist

The mentioned checklists are given below-

Basic Structural Checklist for Building Type URMA: Unreinforced Masonry Bearing Walls with Stiff Diaphragms

The following is the General Basic Structural Checklist with relevant clauses. **Each of the evaluation statements on this checklist shall be marked Compliant (C), Non-compliant (NC) or Not Applicable (N/A) for a Tier 1 Evaluation.** Compliant statements identify issues that are acceptable according to the criteria of this standard, while non-compliant statements identify issues that require further investigation. Certain statements may not apply to the buildings being evaluated. For non-compliant evaluation statements, the design professional may choose to conduct further investigation using the corresponding Tier 2 Evaluation procedure; corresponding section numbers are in parentheses following each evaluation statement.

Criteria	Description of Conditions	Remark	Comments
Load Path	The structure shall contain a minimum of one complete load path for Life Safety and Immediate Occupancy for seismic force effects from any horizontal direction that serves to transfer the inertial forces from the mass to the foundation	C	
Mezzanines	Interior mezzanine levels shall be braced independently from the main structure, or shall be anchored to the lateral-force-resisting elements of the main structure.	**N/A**	There is no mezzanine.
Weak Story	The strength of the lateral-force-resisting system in any story shall not be less than 80 percent of the strength in an adjacent story, above or below, for Life Safety and Immediate Occupancy.	**NC**	Some part of the building has weak story.
Soft Story	The stiffness of the lateral-force-resisting system in any story shall not be less than 70 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.	**NC**	Some part of the building has soft story.
Geometry	There shall be no changes in horizontal dimension of the lateral-force-resisting system of more than 30 percent in a story relative to adjacent stories for Life Safety and Immediate Occupancy, excluding one-story penthouses and mezzanines.	**NC**	There is more than 30 percent change in lateral dimension of lateral- force-resisting system of building.
Vertical Discontinuities	All vertical elements in the lateral-force-resisting system shall be continuous to the	**NC**	

	foundation.		
Mass	There shall be no change in effective mass more than 50 percent from one story to the next for Life Safety and Immediate Occupancy. Light roofs, penthouses, and mezzanines need not be considered.	C	
Torsion	The estimated distance between the story center of mass and the story center of rigidity shall be less than 20 percent of the building width in either plan dimension for Life Safety and Immediate Occupancy.	C	
Deterioration Of Concrete	There shall be no visible deterioration of concrete or reinforcing steel in any of the vertical- or lateral force-resisting elements.	**C**	
Masonry Units	There shall be no visible deterioration of masonry units	**C**	
Masonry Joints	The mortar shall not be easily scraped away from the joints by hand with a metal tool, and there shall be no areas of eroded mortar.	**C**	
Unreinforced Masonry Wall Cracks	There shall be no existing diagonal cracks in wall elements greater than 1/8 inch for Life Safety and 1/16 inch for Immediate Occupancy or out-of-plane offsets in the bed joint greater than 1/8 inch for Life Safety and 1/16 inch for Immediate Occupancy, and shall not form an X pattern.	**C**	Observed crack are not diagonal.

LATERAL FORCE RESISTING SYSTEM

Criteria	Description of Conditions	Remark	Comments
Redundancy	The number of lines of shear walls in each principal direction shall be greater than or equal to 2 for Life Safety and Immediate	**NC**	The Building does not have redundancy

	Occupancy.		
Shear Stress Check	The shear stress in the unreinforced masonry walls, calculated using the Quick Check procedure shall be less than the greater of 30 psi for clay units and 70 psi for concrete units for Life Safety and Immediate Occupancy.	C	
Wall Anchorage	Exterior concrete or masonry walls that are dependent on the diaphragm for lateral support shall be anchored for out-of-plane forces at each diaphragm level with steel anchors, reinforcing dowels, or straps that are developed into the diaphragm. Connections shall have adequate strength to resist the connection force.	NC	Walls are not properly anchored with the diaphragms.
Transfer to Shear Walls	Diaphragms shall be connected for transfer of loads to the shear walls for Life Safety and the connections shall be able to develop the lesser of the shear strength of the walls or diaphragms for Immediate Occupancy.	NC	Walls aren't properly connected to the diaphragms.
Girder/Column Connection	There shall be a positive connection utilizing plates, connection hardware, or straps between the girder and the column support.	N/A	????

Geologic Site Hazards and Foundation Checklist

The following is a geological site hazards and foundations checklist. **Each of the evaluation statements on this checklist shall be marked Compliant (C), Non-compliant (NC) or Not Applicable (N/A) for a Tier 1 Evaluation.** Compliant statements identify issues that are acceptable according to the criteria of this standard, while non-compliant statements identify issues that require further investigation. Certain statements may not apply to the buildings being evaluated. For non-compliant evaluation statements, the design professional may choose to conduct further investigation using the corresponding Tier 2 Evaluation procedure; corresponding section numbers are in parentheses following each evaluation statement.

Geologic Site Hazards

The following statements are completed as the building is in the high seismicity level.

Criteria	Description of Conditions	Remark	Comments
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.	C	Liquefaction susceptible soils do not exist in the foundation soils.
Slope Failure	The building site shall be sufficiently remote from potential earthquake-induced slope failures or rock falls to be unaffected by such failures or shall be capable of accommodating any predicted movements without failure.	C	The building is on a relatively flat site.
Surface Fault Rupture	Surface fault rupture and surface displacement at the building site is not anticipated.	C	Surface fault rupture and surface displacements are not anticipated.

Conditions of Foundations

The following statements shall be completed for Tier 1 building evaluation

Criteria	Description of Conditions	Remark	Comments
Foundation Performance	There shall be no evidence of excessive foundation movement such as settlement or heave that would affect the integrity or strength of the structure.	C	The structure does not show evidence of excessive foundation movement
Deterioration	There shall not be evidence that foundation elements have deteriorated due to corrosion, sulfate attack, material breakdown, or other reasons in a manner that would affect the integrity or strength of the structure	C	No evidences are found

Capacity of Foundation

The following statements shall be completed for Tier 1 building evaluation

Criteria	Description of Conditions	Remark	Comments
Pole Foundations	Pole foundations shall have a minimum embedment depth of 4 feet for Life Safety and Immediate Occupancy.	N/A	Foundation embedment depth is more than 4 feet.
Overturning	The ratio of horizontal dimension of the lateral-force-resisting system at the foundation level to the building height (base/height) shall be greater than $0.6S_a$.	C	The ratio of horizontal dimension of the lateral-force-resisting system at the foundation level to the building height (base/height) is greater than $0.6S_a$.
Ties between Foundation Elements	The foundation shall have ties adequate to resist seismic forces where footings, piles, and piers are not restrained by beams, slabs, or soils classified as Class A, B, or C.	C	Strip foundation
Deep Foundations	Piles and piers shall be capable of transferring the lateral forces between the structure and the soil. This statement shall apply to the Immediate Occupancy Performance Level only.	N/A	The building is evaluated for Life Safety Performance Level.
Sloping Sites	The difference in foundation embedment depth from one side of the building to another shall not exceed one story in height. This statement shall apply to the Immediate Occupancy Performance Level only.	N/A	The building is evaluated for Life Safety Performance Level.

Basic Nonstructural Component Checklist

This following is the Basic Nonstructural Component Checklist with relevant clauses. **Each of the evaluation statements on this checklist shall be marked Compliant (C), Non-compliant (NC) or Not Applicable (N/A) for a Tier 1 Evaluation.** Compliant statements identify issues that are acceptable according to the criteria of this standard, while non-compliant statements identify issues that require further investigation. Certain statements may not apply to the buildings being evaluated. For non-compliant evaluation statements, the design professional may choose to conduct further investigation using the corresponding Tier 2 Evaluation procedure; corresponding section numbers are in parentheses following each evaluation statement.

Partitions

Criteria	Description of Conditions	Remark	Comments
Unreinforced Masonry	Unreinforced masonry or hollow clay tile partitions shall be braced at spacing equal to or less than 10 feet in levels of low or moderate seismicity and 6 feet in levels of high seismicity.	N/A	The masonry walls are load bearing structural elements.

Ceiling System

Criteria	Description of Conditions	Remark	Comments
Support	The integrated suspended ceiling system shall not be used to laterally support the tops of gypsum board, masonry, or hollow clay tile partitions. Gypsum board partitions need not be evaluated where only the Basic Nonstructural Component Checklist is required	**N/A**	

Lighting Fixture

Criteria	Description of Conditions	Remark	Comments
Emergency Lighting	Emergency lighting shall be anchored or braced to prevent falling during an earthquake.	**C**	

Cladding and Glazing

Criteria	Description of Conditions	Remark	Comments
Cladding Anchors	Cladding components weighing more than 10 psf shall be mechanically anchored to the exterior wall framing at a spacing equal to or less than 4 feet. A spacing of up to 6 feet is permitted where only the Basic Nonstructural Component Checklist is required.	C	
Deterioration	There shall be no evidence of deterioration, damage or corrosion in any of the connection elements.	C	
Cladding Isolation	For moment frame buildings of steel or concrete, panel connections shall be detailed to accommodate a story drift ratio of 0.02. Panel connection detailing for a story drift ratio of 0.01 is permitted where only the Basic Nonstructural Component Checklist is required.	C	
Multi-Story Panels	For multi-story panels attached at each floor level, panel connections shall be detailed to accommodate a story drift ratio of 0.02. Panel connection detailing for a story drift of 0.01 is permitted where only the Basic Nonstructural Component Checklist is required.	N/A	
Bearing Connections	Where bearing connections are required, there shall be a minimum of two bearing connections for each wall panel.	N/A	
Inserts	Where insets are used in concrete connections, the inserts shall be anchored to reinforcing steel or other positive anchorage.	N/A	
Panel Connections	Exterior cladding panels shall be anchored out-of- plane with a minimum of 4	C	

	connections for each wall panel. Two connections per wall panel are permitted where only the Basic Nonstructural Component Checklist is required.		

Masonry Veneer

There is no masonry veneer; statements in this section are Not Applicable (N/A).

Parapets, Cornices, Ornamentation, and Appendages

Criteria	Description of Conditions	Remark	Comments
URM Parapets	There shall be no laterally unsupported unreinforced masonry parapets or cornices with height-to-thickness ratios greater than 1.5. A height- to-thickness ratio of up to 2.5 is permitted where only the Basic Nonstructural Component Checklist is required.	C	
Canopies	Canopies located at building exits shall be anchored to the structural framing at a spacing of 6 feet or less. An anchorage spacing of up to 10 feet is permitted where only the Basic Nonstructural Component Checklist is required	N/A	

Masonry Chimneys

There is no masonry chimney; statement in this section is Not Applicable (N/A).

Stairs

Criteria	Description of Conditions	Remark	Comments
URM Walls	Walls around stair enclosures shall not consist of unbraced hollow clay tile or unreinforced masonry with a height-to-thickness ratio greater than 12-to-1. A height-to-thickness ratio of up to 15-to-1 is	C	

	permitted where only the Basic Nonstructural Component Checklist is required.		
Stair Details	In moment frame structures, the connection between the stairs and the structure shall not rely on shallow anchors in concrete. Alternatively, the stair details shall be capable of accommodating the drift calculated using the Quick Check procedure of Section 3.5.3.1 without including tension in the anchors.	N/A	

Building Contents and Furnishing

Criteria	Description of Conditions	Remark	Comments
Tall Narrow Contents	Contents over 4 feet in height with a height-to- depth or height-to-width ratio greater than 3- to-l shall be anchored to the floor slab or adjacent structural walls. A height-to-depth or height-to-width ratio of up to 4-to-l is permitted where only the Basic Nonstructural Component Checklist is required	C	

Mechanical and Electrical Equipment

Criteria	Description of Conditions	Remark	Comments
Emergency Power	Equipment used as part of an emergency power system shall be mounted to maintain continued operation after an earthquake.	C	
Hazardous Material Equipment	HVAC or other equipment containing hazardous material shall not have damaged supply lines or unbraced isolation supports.	C	
Deterioration	There shall be no evidence of deterioration, damage, or corrosion in any of the anchorage or supports of mechanical or	C	

	electrical equipment.		
Attached Equipment	Equipment weighing over 20 lb that is attached to ceilings, walls, or other supports 4 feet above the floor level shall be braced.	C	

Piping

Criteria	Description of Conditions	Remark	Comments
Fire Suppression Piping	Fire suppression piping shall be anchored and braced in accordance with NFPA-13 (NFPA, 1996)	C	
Flexible Couplings	Fluid, gas, and fire suppression piping shall have flexible couplings	**NC**	Fluid and gas piping does not have flexible couplings.

Hazardous Materials Storage and Distribution

Criteria	Description of Conditions	Remark	Comments
Toxic Substances	Toxic and hazardous substances stored in breakable containers shall be restrained firm falling by latched doors, shelf lips, wires, or other methods.	N/A	

4.2 Ferroscan

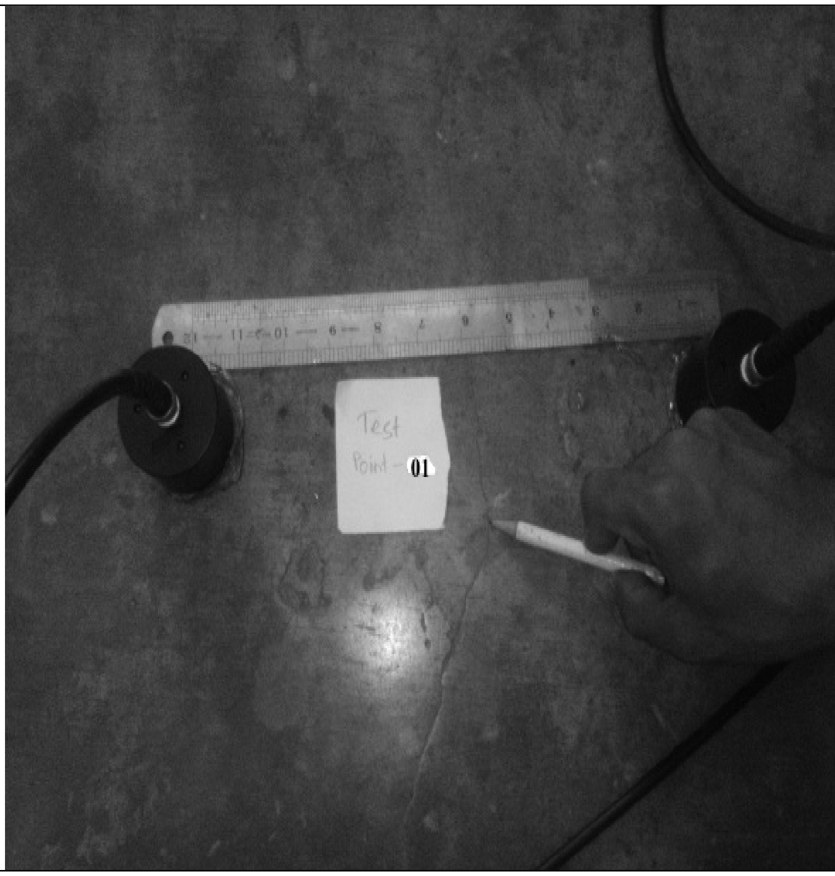
Though the Old Academic Building of BUET is basically masonry but it has columns in various positions in similar pattern of RC column. That why the Ferroscan test was performed to check if there’s any reinforcement present in the column. The line scan has confirmed that few columns have steel channel inside the masonry column.

Figure 25: Line scan operation of masonry column of OAB, BUET

4.4 Ultrasonic Pulse Velocity (UPV)

Using the UPV the depth of the cracks were measured which have given below-

Test point 01:

Point	01
Location	Slab
t_1 (μs)	88.90
t_2 (μs)	161.40
Depth (mm)	52 mm
Type of Crack	Linear Crack
Crack Width (mm)	0.45 mm
Comments	
Crack Image	

Test point 02:

Point	02
Location	Slab
t_1 (μs)	91.90
t_2 (μs)	158.40
Depth (mm)	57 mm
Type of Crack	Linear Crack
Crack Width (mm)	0.51 mm
Comments	
Crack Image	

4.5 Moisture Content Analysis of OAB building

Figure 26, Figure 27, Figure 28, Figure 29, and Figure 30 show the moisture content in different portions of OAB building.

Figure 26: Damped arch at the back of OAB building

Figure 27: Damped wall in OAB building

Figure 28: Possible leakage in OAB building

Figure 29: Damped wall in OAB building

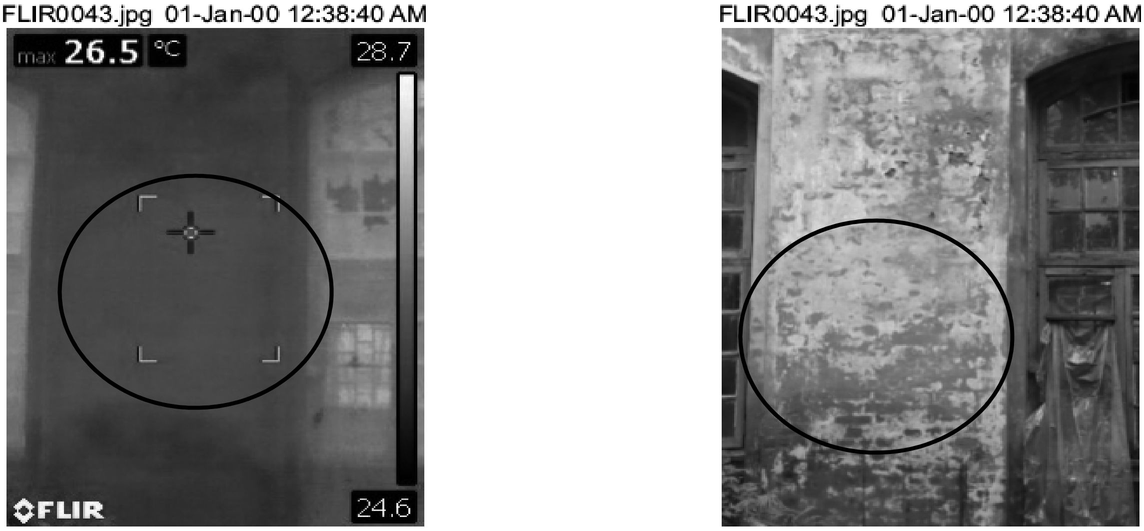


Figure 30: Damped wall OAB building

4.6 Direct Shear Test

As the Old Academic Building, BUET has to be retrofitted, the direct shear test was required to measure the shear stress due to mortar bond only. Destructive test has been performed using Hi-Force Hydraulic Jack. The result has given below. Figure 31 shows application of Direct Shear Test.

Direct Shear Test of Masonry				
Jack diameter	35	mm		
Area	962.12	mm^2		
	Length	Width	Height	
Brick Size	254	114.3	76.2	mm
Contact Area	77419.2			
	P (bar)	Force (N)	Shear Stress	N/mm^2
Dial Gauge Reading	190	18280.19	0.236119528	
Shear Strength of the Sample, τ	0.23612	N/mm^2		
Nos. of bricks above testing brick	100			
Height of wall above testing brick	9.15	m		
Unit weight of wall	19	KN/m^3		
Vertical Pre-stress on testing brick, σ	173.85	KN/mm^2		
σ* μ	0.17385			
Shear Stress due to mortar bond only	τ-σ* μ			
	0.06227	N/mm^2		

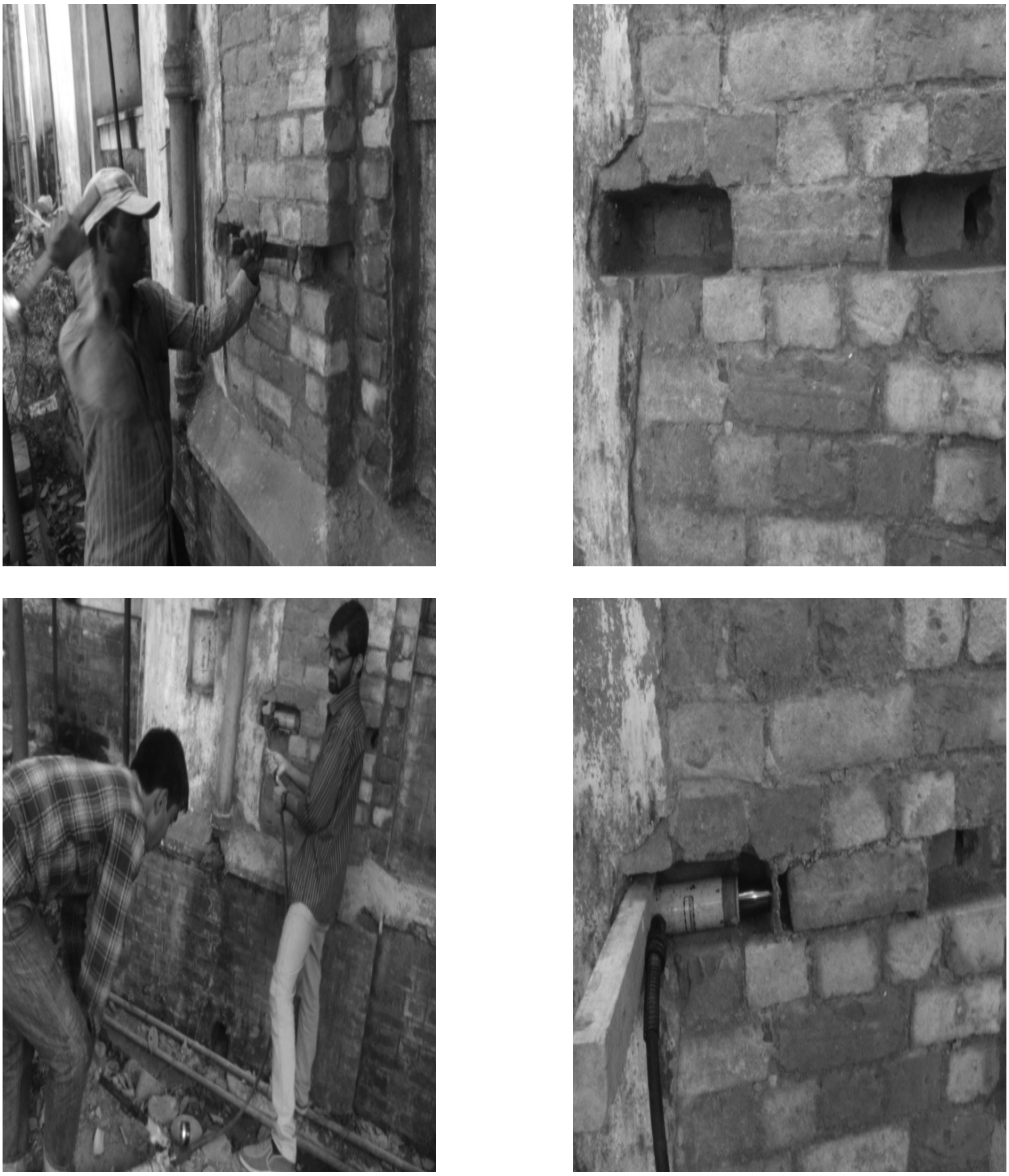


Figure 31: Application of Direct Shear test

5. Conclusions

The building has recommended for retrofitting after observing and analyzing all Destructive and Non-destructive test results. The proposed design of retrofitting has been presented below:

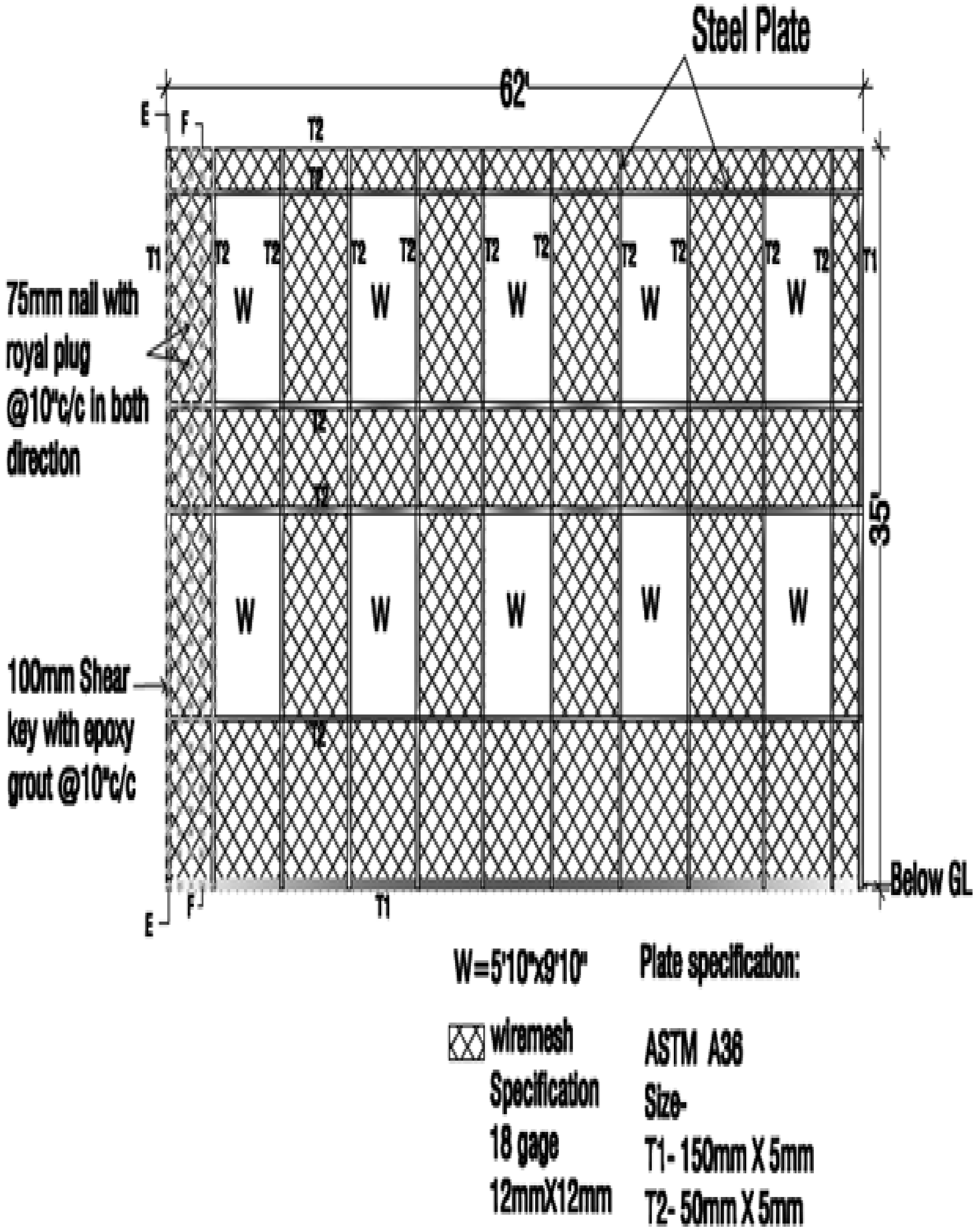


Figure 32: Vertical wall section for retrofitting

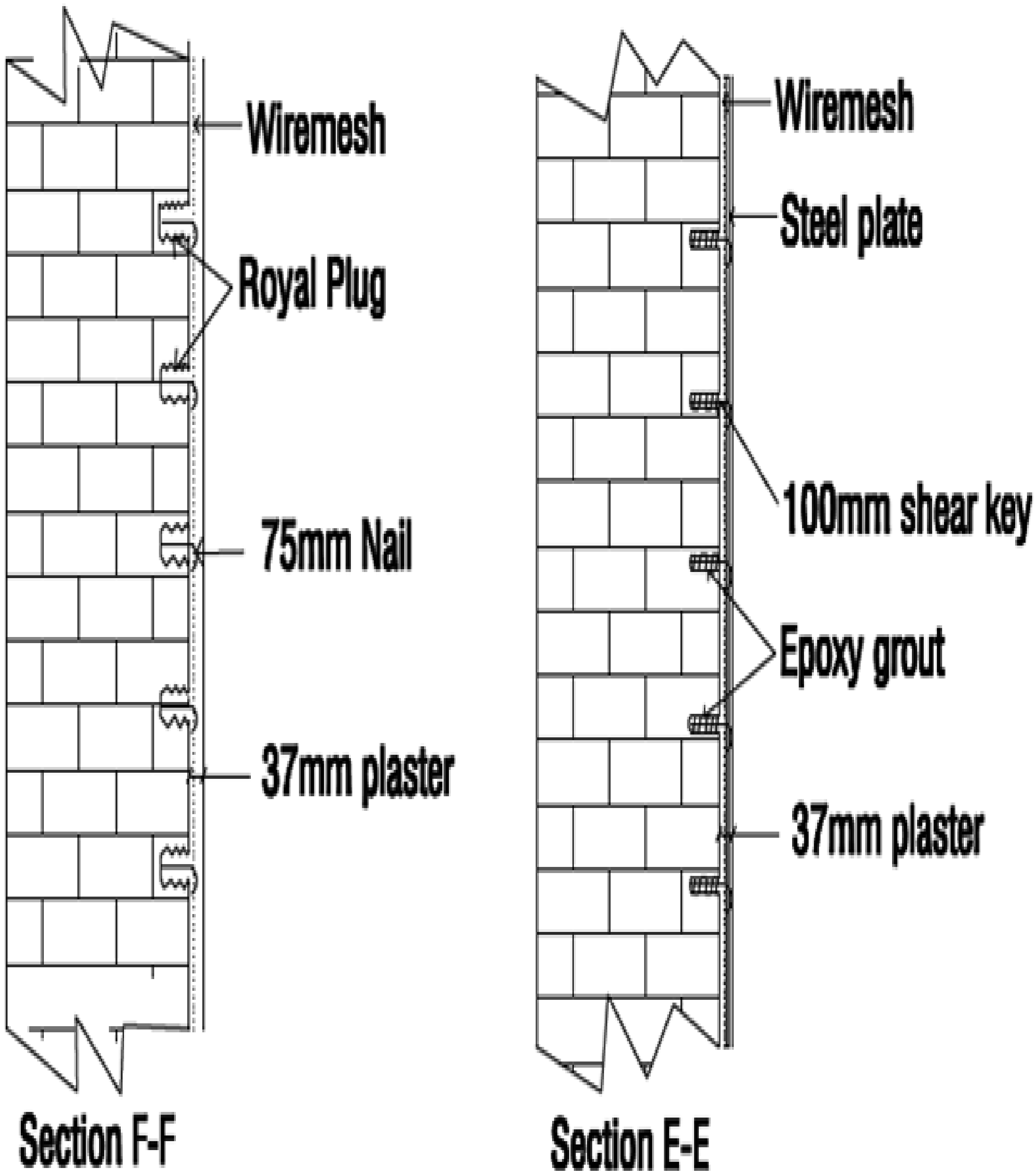


Figure 33: Vertical cross section of wall for retrofitting

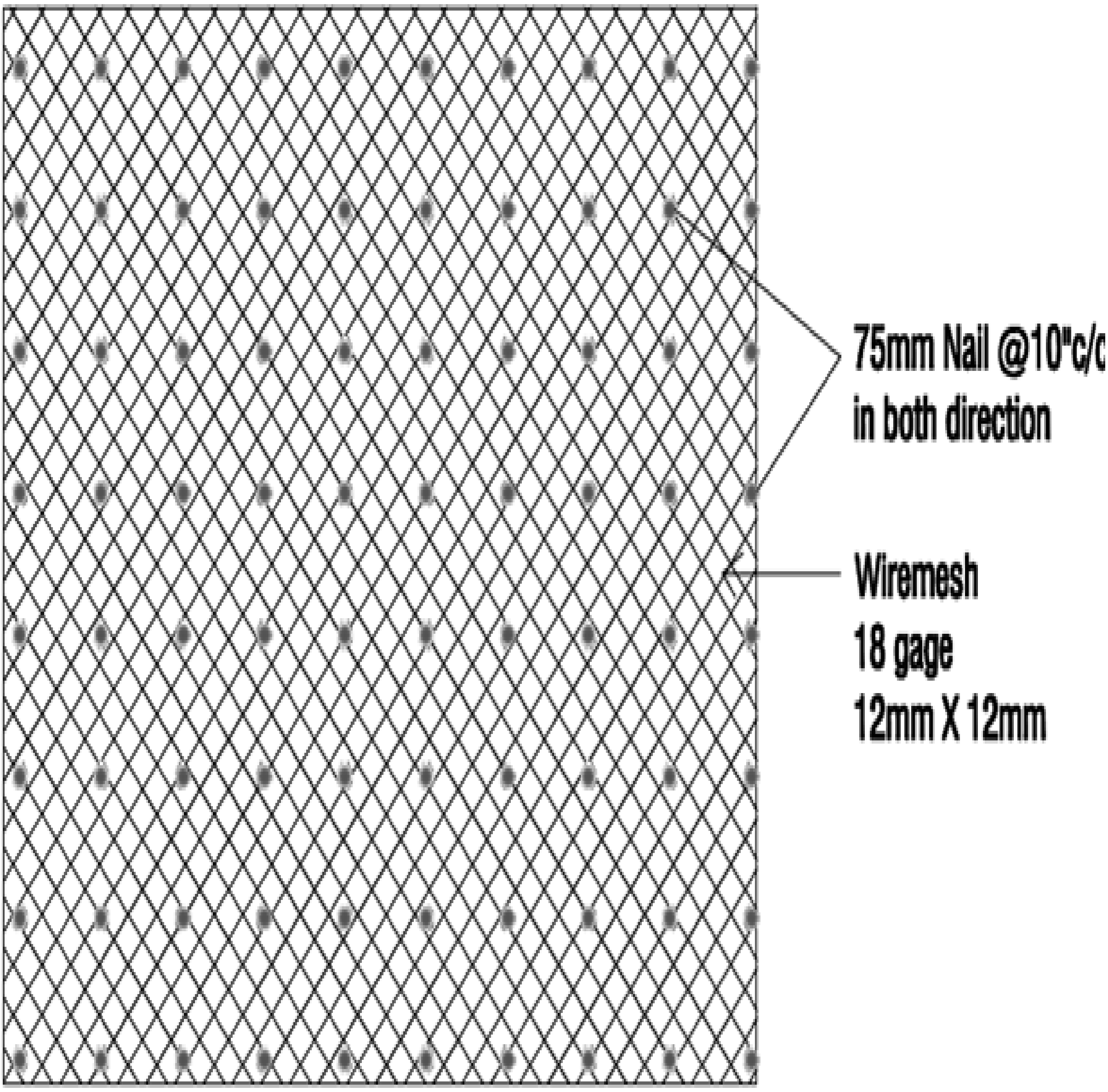
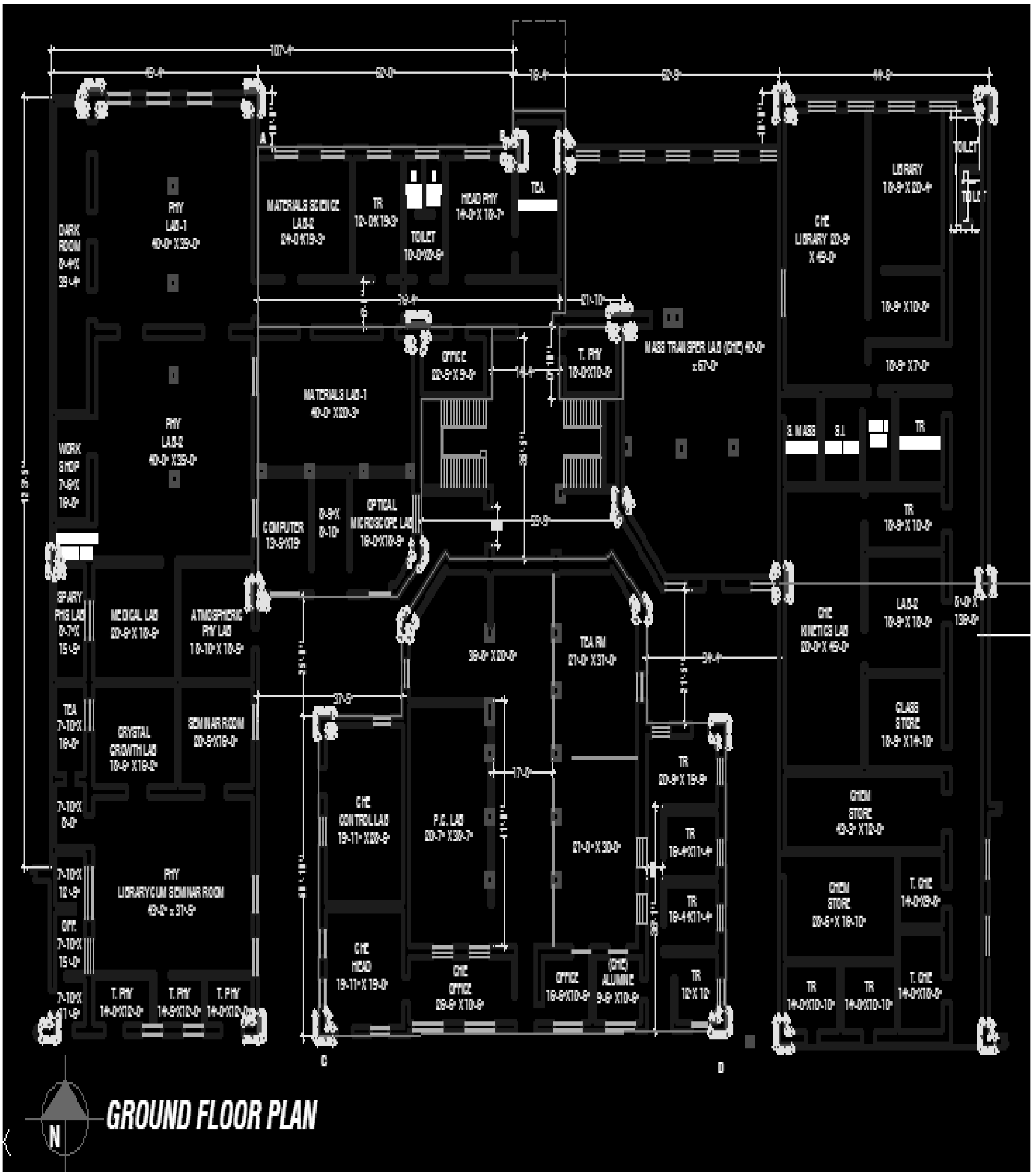


Figure 34: Typical section of slab for retrofitting



Yellow marked columns were recommended for retrofitting

Figure 35: Recommended retrofitted column layout

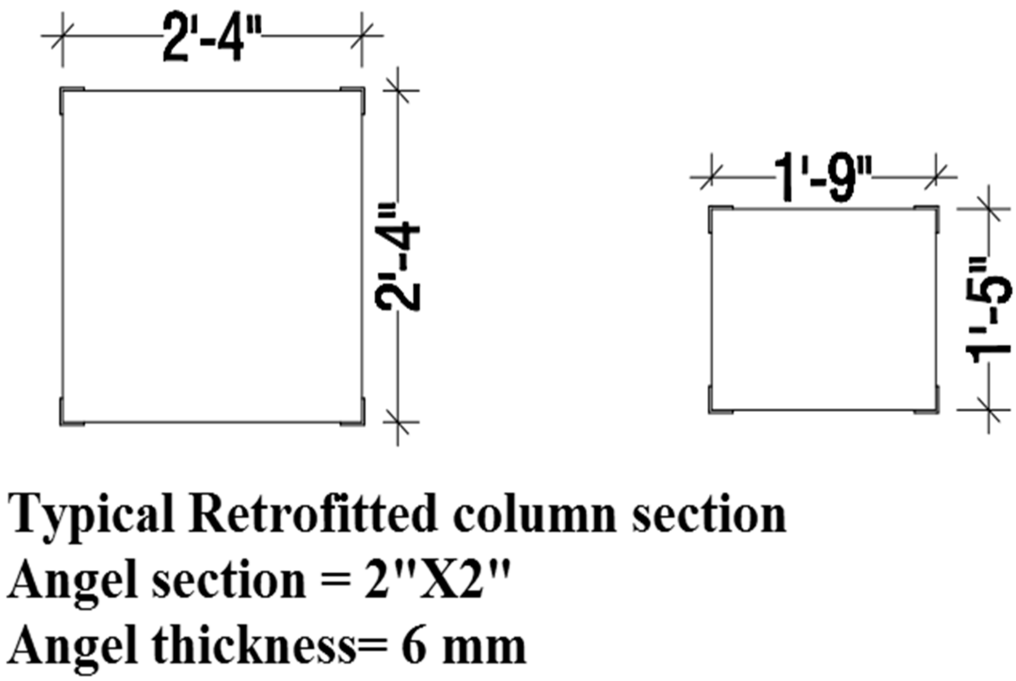


Figure 36: Typical section of column with retrofitted

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PART-V

FIRE INCIDENT IN READY-MADE GARMENT FACTORY 'DIGNITY TEXTILE LIMITED', GAZIPUR ON 31 MAY, 2015

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

Prepared By: Uttama Barua
Mehedi Ahmed Ansary

On 31 May 2015 Sunday at around 1:45pm a fire broke out at a ready-made garment factory 'Dignity Textile Limited' Betjuri area of Sreepur upazila of Gazipur. The fire was originated at the warehouse on the third floor of the seven-storey factory building and engulfed the whole floor. It is a complete composite factory owned by Deel Hue, a Mauritius citizen, where some 3000 workers were working in different units included knitting, dyeing, cutting and finishing section. The fire was sensed when the smoke began to pour through the window of the warehouse in the south of the third floor.

On information, 14 units of firefighters from Tongi, Mawna, Joydebpur, Kaliakoir and Bhaluka of Mymensingh rushed to the spot. The building is made of metals like iron and steel. So the efforts to douse the fire using water were not working accordingly. The firefighters were also facing difficulties as they could not go near the building due to excessive heat and the boundary wall was too strong to be bulldozed. The fire was finally brought under control after twenty hours of frantic efforts at around 9.30am on the next morning.

Figure 1: Before and after scenario of the RMG factory building, Gazipur

The cause of the fire and extent of damage could not be known immediately. It was initially suspected that the fire originated from an electric short circuit. There were flammable products on all floors which resulted in rapid spread of fire in the building. There were modern and sufficient fire extinguishing systems available in the factory building, but they lacked trained persons for the purpose. As a result immediate actions to douse fire could not be taken. Moreover the fire fighters did not have any experience to douse fire in metal structured building. This kind of metal structured building require concrete jacketing, fire proof painting and other preventive measures as metals become heated and thus melts rapidly. In case of this factory building, these measures were absent which resulted in greater consequence due to fire.

Huge amount of thread, cotton, clothes and others equipments were gutted in the fire. Administrative Manager of the factory said that the machines and other equipments on the third floor were completely burnt in the fire. The extreme heat, generated by prolonged fire, melted the steel-frame of the building, triggering its collapse at 11:00am. The blaze gutted most parts of the factory building. Some people sustained minor injuries but no worker was reported to be killed in the incident as all 3,000 workers of factory were out at lunch hours when the fire broke out.

PART-VI

DISTRICT WISE MULTI-HAZARD ZOANING OF BANGLADESH

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

Prepared By: Uttama Barua
M. Shammi Akhtar
Mehedi Ahmed Ansary

1. Introduction

Bangladesh is a developing country with numerous problems like overpopulation, poverty, complex socio economic structure, low level industrial base, and resource constrains, lack of appropriate infrastructural and institutional facilities, dearth of trained manpower, etc. 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 floods plains, low river gradients, funnel shaped and shallow Bay of Bengal etc. 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 natural hazards. Its physiography, river morphology, abnormal rainfall condition, and earthquakes in the adjacent Himalayan range also contribute to recurring disasters. For all these conditions Bangladesh is stated as one of the most natural disaster prone countries in the world (Choudhury 2002; Karim and Mimura 2008; Ali, Rahman and Chowdhury 2012).

Natural 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 like flood, cyclonic storm, tidal surge, drought, tornado, riverbank erosion, earthquake, etc. occur in Bangladesh regularly and frequently causing devastating consequences (Karim 1995). The 1988 flood killed 1517 people and nearly half of the population were affected (Hossain 2004). The 1970 cyclone killed almost 500,000 people (Karim 1996). About 1300 people were killed by tornado at Saturia of Manikganj district in Bangladesh in 1989 (EIA, 2004). The 1897 Great Indian Earthquake with a magnitude of 8.7 killed 1542 people and affected almost the whole of Bangladesh, which is one of the strongest earthquakes in the world (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 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 like 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 are much less. Thus, based on historical occurrences and potential damage of these hazards in Bangladesh, tornado, flood, earthquake, and cyclone are considered as focused hazards.

Total elimination of risks is difficult and impractical. So disaster management through proper hazard assessment is very essential to reduce loss of lives and sufferings of people. UNISDR (2007) defined hazard as "…..A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage….." . According to UNISDR (2007), quantitatively hazards in different areas are determined by "the likely frequency of occurrence of different intensities as determined from historical data or scientific analysis". So hazard scores can be calculated for identifying hazards through consideration of historical disaster data and their potential damage levels (Granger and Trevor 2000; Munich Reinsurance Company 2003; Bell and Glade 2004; UNDP 2004; Lavalle et al. 2005; Dilley 2005; Khatsu and Westen 2005; Schmidt-

Thomé 2006; Thierry et al. 2008; Kunz and Hurni 2008; SCEMDOAG 2009; Wipulanusat et al. 2009; Shi 2011; Siddique and Schwarz 2015).Thus, the first step for hazard assessment is the identification of hazards along with their intensity and their potential damage levels through analysis of historical data for evaluation of disaster condition. Here intensity refers to the damage generating attribute of a hazard (Deyle et al. 1998). Intensity scales represent the damage severity of disasters, which are subjective and dependent upon social condition and construction status of a country along with regional effects. Intensity scales are important and informative for decision makers as the scales give them ideas about the level of disaster and their magnitude of damage at a glance.

In any disaster management programme, the first and the foremost task is to identify the areas where hazards are probable to occur at disastrous magnitude (Cutter et al., 2000). Hazard maps provide clear and attractive pictures of the geographic distribution of potential hazards which play a key role in disaster risk identification (Tran et al., 2009). Some literatures focused on development of hazard specific zoning maps, i.e. flood (Büchele et al. 2006; Fuchs et al. 2009; Maantay and Maroko 2009; Meyer, Scheuer and Haase 2009; Tran et al. 2009; Pradhan 2010; Porter and Demeritt 2012), earthquake (Anbazhagan et al. 2010), and landslide (Abella and Westen 2007; Pourghasemi, Pradhan and Gokceoglu 2012; Pourghasemi et al. 2012; Xu et al. 2012; Tremblay, Svahn and Lundström 2013). Use of historical data in preparation of hazard specific zoning maps is the most common method in these literatures (Büchele et al. 2006; Abella and Westen 2007; Fuchs et al. 2009; Maantay and Maroko 2009; Meyer, Scheuer and Haase 2009; Tran et al. 2009; Anbazhagan et al. 2010; Pradhan 2010; Pourghasemi, Pradhan and Gokceoglu 2012). Some literatures adopted probabilistic analysis (Meyer, Scheuer and Haase 2009; Xu et al. 2012; Tremblay, Svahn and Lundström 2013) or statistical analysis (Fuchs et al. 2009) or both (Büchele et al. 2006; Pradhan 2010) to analyze different dataset and criteria. Some of the literatures utilized Geographic Information System (GIS) based methodology for preparation of hazard map (Büchele et al. 2006; Abella and Westen 2007; Meyer, Scheuer and Haase 2009; Tran et al. 2009; Anbazhagan et al. 2010; Pradhan 2010; Pourghasemi et al. 2012; Xu et al. 2012).

Although, some countries or regions may be highly vulnerable to specific hazard, but consideration of one hazard at a time is not sufficient for the purpose of disaster management. Multi-hazard zoning maps identify the vulnerable areas for multiple hazards considering their threat levels, which is important to aid and orient the authorities' decisions regarding hazard mitigation and preparedness (Thierry et al. 2008; Mahendra et al. 2011). Thus, multi-hazard zoning maps are practical tools in disaster management, which give a good indication on the extent of expected hazardous areas for overall natural disaster. The importance of addressing hazards collectively is now recognized in several literatures (Liu et al. 2014). According to Liu et al. (2014), two approaches exist to assess multiple-hazards, e.g. the index or scoring method and the mathematical statistics method. The index or scoring method identifies hazards and their potential damage levels (Granger and Trevor 2000; Munich Reinsurance Company 2003; Bell and Glade 2004; UNDP 2004; Lavalle et al. 2005; Dilley 2005; Khatsu and Westen 2005; Schmidt-Thomé 2006; Thierry et al. 2008; Kunz and Hurni 2008; SCEMDOAG 2009; Wipulanusat et al. 2009; Shi 2011; Siddique and Schwarz 2015). The mathematical statistics method integrates observations of past losses attributed to each hazard type (FEMA 2004; Grünthal et al. 2006; Westen 2008; Mahendra et al. 2011; Schmidt et al. 2011; Linares-Rivas 2012; Frolova et al. 2012; Liu et al. 2013). Thus, the task of multi-hazard assessment is dependent on the country's past disaster records and their characteristics.

In Bangladesh, studies for multiple-hazard assessment have not been done so far in Bangladesh. Moreover, there are no existences of individual hazard intensity scales to identify the characteristics of particular hazards. The zoning maps for some individual hazards are available for Bangladesh, but historical database for different hazards are not well organized. To make the information readily available to the planners, administrators and disaster managers, it is necessary to prepare multi-hazard map on larger scale (district-wise) for easy identification of the vulnerable districts. In this background, the main aim of this paper is the preparation of district wise multi-hazard zoning map for Bangladesh. To achieve this aim, the objectives of this paper are: firstly to organize the historical database for four major hazards in Bangladesh, i.e. tornado, flood, earthquake, and cyclone; secondly to propose suitable intensity scales and damage risk levels for those four major hazards; and finally to calculate district wise individual and multi-hazard scores based on historical data, intensity scales and damage risk levels to produce a district wise multi-hazard zoning map for whole Bangladesh presenting the relative estimate of multiple hazards. This study is done integrating scoring and mathematical statistics methods, where hazards scores are calculated based on historical database. The map will assist decision makers to determine areas susceptible to individual hazards or multiple hazards and take initiatives accordingly.

2. Methodology of the Study

Every community has unique or unusual hazards that need to be considered. So, for preparation of multi-hazard map of Bangladesh for four natural disasters, i.e. cyclone, tornado, flood and earthquake, were considered based on the disaster context of Bangladesh and their potential damage. Steps followed for the purpose of preparation of multi-hazard zoning map of Bangladesh were: organization of the historical database, development of intensity scales and damage risk levels, calculation of district wise individual and multi hazard scores, and preparation of district wise multi-hazard zoning map of Bangladesh. These steps are described in details below:

2.1. Organization of the Historical Database

The available historical database of the four hazards in Bangladesh were collected and compiled from different secondary sources. The secondary data sources were: Bangladesh Meteorological Department (BMD), Bangladesh Space Research & Remote Sensing Organization (SPARRSO), Disaster Management Bureau (DMB) and concerned non-government organizations (NGO), Cyclone Preparedness Programme (CPP), and geological information from the Geological Survey of Bangladesh (GSB). Moreover, information from local and environmental organizations, international journals, local newspapers and many study reports were collected. Frequency is the occurrence of a disaster in a particular area, which was defined based on the organized historical database of hazards in Bangladesh.

2.2. Development of Intensity Scales and Damage Risk Levels

Comparing scenarios of four hazards in Bangladesh and their corresponding scales all over the world, suitable intensity scales and their corresponding damage risk levels were proposed for four major hazards in Bangladesh for district wise hazard assessment in Bangladesh. For the purpose of decision making in this regard considering experts' opinion, key informant interviews were carried out.

2.3. Calculation of District Wise Hazard Scores

Hazard specific zoning maps considering disaster levels or intensities are suitable to represent district wise scenario of Bangladesh for particular hazard. But consideration of historical occurrences, i.e. frequency of that particular hazard, along with intensity provides true representation of hazard scenario. So, district wise hazard scores for four major hazards in Bangladesh were calculated by multiplying district wise hazard factors and weighting factors for particular hazards which represent the hazard scenario considering disaster context. Hazard factors for particular hazard in particular district were defined comparing district wise historical disaster database with corresponding intensity scales and damage risk levels.

Hazard factors were defined on the scale from one to five, where one was assigned for zones with no hazards and five was assigned for high risk zones. It was decided in consultation with the experts from relative fields through key informant interview. Weighting factors for particular hazards in particular district were defined based on frequency of particular disasters in different districts of Bangladesh. This was done through relative priority scoring system (higher scores for higher hazard prone areas), where the base point is considered 1.0 for locations with no occurrence of a disaster and increase in frequency of disasters adds a point, i.e. 0.1 (NOAA 2007). For the purpose of decision making regarding weighting factors, key informant interviews were carried out. Thus, for calculation of district wise hazard scores for individual hazards, equation (1) was followed.

$$TH\ (c/\ f/\ t/\ e) = WT \times H \tag{1}$$

Where,

TH (c/ f/ t/ e) = Hazard score of a particular district (for particular hazard e.g. Cyclone(c)/ Flood (f)/ Tornado (t)/ Earthquake (e))

H = Hazard factor

WT = Weighting factor = f (fr)

fr = frequency of particular disaster

2.4. Preparation of District Wise Multi-Hazard Zoning Map of Bangladesh

After calculation of district wise scores for four individual hazards in Bangladesh, combined hazard scores were calculated using equation (2).

$$TH = \sum_{k=1}^{n} TH_k \tag{2}$$

Where,

TH = Total hazard score of a particular district

TH_k = Hazard score of a particular district for individual hazard

k= 1 is for Cyclone

k=2 is for Tornado

k=3 is for Earthquake

k=4 is for Flood

To prepare a multi-hazard zoning map of Bangladesh, the district wise multi-hazard scores were categorized into three groups to classify the districts of Bangladesh into three multi-hazard zones, i.e. high, moderate and low. The classification of combined multi-hazard scores was done through equal interval classification method in consultation with experts from related fields through key informant interview. Then, districts corresponding to each hazard zones were classified accordingly.

3. Results and Discussion

3.1. Historical Database of Major Disasters in Bangladesh

Disaster Management Bureau (DMB) prepared a map identifying the areas affected by Tornadoes, where the basis of the map is not clear (DMB 1993). Moreover, data on district wise wind speeds during different tornados occurred in Bangladesh are not available. So, frequency of tornado is considered in this study for hazard assessment. Frequency of tornado in different districts of Bangladesh were organized based on the historical database of tornado from 1875-2007. Table 1 shows frequency of tornado in different districts of Bangladesh. Here maximum frequency is eight representing that the districts have been affected by tornado eight times within the time frame, and minimum is zero representing that the districts were not affected by tornado within the time frame.

In the history of flood in Bangladesh, the 1998 flood is the extreme. Thus, 1998 flood map prepared by Flood Forecasting & Warning Centre (FFWC) and Bangladesh Water Development Board (BWDB), is used as a reference in this study (FFWC 1998). In the map the districts of Bangladesh are divided in four zones based on water level, i.e. severe flooding area (above 50cm above DL), moderate flooding area (up to 50cm above DL), normal flooding area (within 50cm DL) and non flooding area (below 50cm DL). Again, data of seven years' historical floods, i.e. 1955, 1974, 1987, 1988, 1991, 1998 and 2004, of Bangladesh are considered for calculation of district wise flood frequency in Bangladesh. From the flood maps of 1955, 1974, 1987, 1988, 1991, 1998 and 2004 of Bangladesh, and from different data source (BWDB 1987 & 1991; WFP 2004; FFWC 2007), the flood affected area of different districts of Bangladesh of seven flood year are calculated (Islam & Sado 2000). Based on the calculated flood affected area of different districts, frequencies or occurrences of flood in corresponding districts of Bangladesh are determined in this study. Table 1 shows district wise flooding area zones based on water level data and frequency of flood occurrences in Bangladesh. Here maximum frequency is seven representing that the districts have been affected by flood during all of the seven flood events, and minimum is zero representing that the districts were not affected by floods during any of the seven flood events considered in this study.

Ansary and Sharfuddin (2001) proposed a seismic-zoning map for Bangladesh, where the districts of Bangladesh are divided into three zones based on Peak Ground Acceleration (PGA), i.e. zone 1 (0.075g), zone 2 (0.15g), and zone 3 (0.25g). Table 1 shows district wise earthquake zones based on PGA and frequency of earthquake (with earthquake magnitude greater than 5 Mw) in Bangladesh.

The cyclone map of Bangladesh prepared by SPARRSO in 1993 is considered as the basis of hazard assessment in this study, where the districts of Bangladesh are grouped into three zones based on height of storm surge, i.e. high risk area (above 1m), high wind area (storm surge buffer), and non affected area (SPARSO, 1993). The maximum extent of the hazard does not realistically include the entire country and is limited to proximity to coastal waters. Frequency of cyclone in different districts of Bangladesh are calculated based on the historical database of cyclone from 1584-2004. Table 1 shows district wise cyclone zones based on height of storm surge and frequency of cyclone in Bangladesh.

3.2. Intensity Scales and Damage Risk Levels for Major Disasters

In Bangladesh no tornado scale exists. Again, though damage risk due to tornado depends on wind speed (Fujita 1978), data on district wise wind speeds during different tornados occurred in Bangladesh are not available. So, frequency of tornado is considered in this study for hazard assessment. Thus, intensity scales and damage risk levels depending on wind speed are not considered for tornado hazard assessment in this study.

In this study, 1998 flood map prepared by FFWC and BWDB based on water level is used for hazard assessment. So, in this study it is considered that intensity of flood depends on flood level, i.e. water level during flood. Again, detailed building damage reports for flooding have not recorded so far in Bangladesh. So, flood intensity scale with damage risk for Bangladesh is prepared comparing the 1998 flood map and the Vulnerability Atlas of India developed by the BMPTC (1997), based on understanding of material behavior under submergence. Table 2 shows flood intensity scale with corresponding damage risk for Bangladesh.

Earthquakes are measured in terms of their magnitude and intensity. Magnitude is measured using the Richter scale, an open-ended logarithmic scale that describes the energy release of an earthquake through a measure of shock wave amplitude. There are several scales available for measuring earthquake intensity, i.e. Modified Mercalli Intensity (MMI) Scale (12-level scale), Japanese seismic intensity Scale (0-VII levels), MSK 1964, EMS 1998 (updated scale of MSK scale), etc. Among these, MMI Scale is considered suitable for Bangladesh. Table 3 shows MMI scale for earthquake. For Bangladesh, Ansary and Sharfuddin (2001) proposed a seismic-zoning map based on Peak Ground Acceleration (PGA). The PGA, i.e., maximum acceleration experienced by the ground during shaking, is one way of quantifying the severity of the ground shaking. To translate PGAs in terms of MMI scale, the approximate empirical correlations between the MMI and the PGA is considered in this study which is explained in Table 4 (Bolt 1993).

Cyclone map of Bangladesh based on height of storm surge prepared by SPARRSO in 1993 is considered for hazard assessment in this study. So, in this study it is considered that intensity of cyclone depends on storm surge. Debsarma's Storm Surge Forecast (SSF) model predicts highest storm surge based on Reid (1956) and Breitschneider (1966) empirical formula utilizing maximum expected wind speed, Expected Central Pressure (ECP) of the cyclone, point of intersection of the storm track and 200m bathymetric contour (Debsarma, 1993, 1995a & 1995b). Again, Saffir-Simpson Hurricane Scale is a 1-5 rating scale based on a hurricane's present intensity, which is used to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Thus, to develop cyclone intensity scale for Bangladesh, firstly highest storm surges were predicted for Chittagong, Cox's Bazar, Kutubdia, Sandwip, Hatia, and Khulna utilizing Debsarma's Storm Surge Forecast (SSF) model. The storm surge height obtained in the model is valid for the shoreline, which will decay as the surge advances into the coastal localities. Then comparing Saffir Simpson Hurricane Scale with the predicted highest storm surges, a cyclone intensity scale for Bangladesh is proposed (Table 5). Again based on intensity, damage risk levels were required to be defined for Bangladesh from previous damage study, which could not be done in this study for limitation of data. So Saffir-Simpson Hurricane Scale is adopted for Bangladesh with some modification suggested by experts based on cyclone damage data of 1991 (LGEB 1991). Table 5 shows cyclone intensity scale and damage risk levels for Bangladesh.

3.2 District Wise Scores for Individual Hazards in Bangladesh

3.2.1 District Wise Tornado Scores

Considering available database, hazard factors and weighting factors were decided based on the frequency or number of occurrence of tornado (Table 1). Tornado may always have damaging consequences for all the tornado prone areas. So, hazard factor is considered “five” for all districts which have been affected by tornado at least once, and “one” for the districts with no occurrence of tornado. Then, weighting factors are defined for corresponding frequency classes. Here highest frequency of tornado events is “eight”, so highest weighting factor is considered “1.8”. Table 6 shows frequency or number of occurrence of tornado and their corresponding hazard factors and weighting factors. Thus district wise tornado hazard factors and weighting factors are assigned considering corresponding frequency or number of occurrence of tornado (Table 1) based on Table 6.

Combining corresponding tornado hazard factors and weighting factors using equation (3), tornado hazard scores for all districts of Bangladesh are calculated (Table 13).

Tornado Hazard Factor, $H_t = f\,(fr)$

and

Tornado Weighting Factor, $WT_t = f\,(fr)$

Where,

fr = Frequency.

Tornado hazard score of a district, $TH_t = H_t \times WT_t$ (3)

3.2.2 District Wise Flood Scores

Considering the flood intensity scale and damage risk levels (Table 2), flood hazard factors are defined for corresponding flood zones in Bangladesh. Table 7 shows flood zones and their corresponding hazard factors. Then, weighting factors are defined for corresponding frequency classes. Here highest frequency of flood events is “seven”, so highest weighting factor is considered “1.7”. Table 8 shows frequency or number of occurrence of floods and their corresponding weighting factors. Thus district wise flood hazard factors and weighting factors are assigned considering corresponding flooding area zones, and frequencies or number of occurrence of floods (Table 1) based on Table 7 and Table 8.

Combining corresponding flood hazard factors and weighting factors using equation (4), flood hazard scores for all districts of Bangladesh are calculated (Table 13).

Flood Hazard Factor, $H_f = f\,(fz)$

Where,

fz= Flood zone

Flood Weighting Factor, $WT_f = f\,(fr)$

Where,

f_r = Frequency

Flood hazard score of a district, $TH_f = H_f \times WT_f$ (4)

3.2.3 District Wise Earthquake Scores

Comparing the seismic zones according to the seismic-zoning map for Bangladesh proposed by Ansary and Sharfuddin (2001), with MMI seismic intensity scale (Table 4), corresponding intensities are defined. Considering the intensities and their damage risk levels (Table 3), earthquake hazard factors are defined for corresponding seismic zones in Bangladesh. Table 9 shows seismic zones and their corresponding hazard factors. Then, weighting factors are defined for corresponding frequency classes. Here highest frequency of earthquake events is “21”. So the frequencies are classified through equal interval classification, where the interval is considered three. It is decided in consultation with experts through key informant interview. Thus, highest weighting factor is considered “1.7”. Table 10 shows frequency or number of occurrence of earthquakes (with magnitude greater than 5 Mw) and their corresponding weighting factors. Thus district wise earthquake hazard factors and weighting factors are assigned considering corresponding seismic zones and frequencies (Table 1) based on Table 9 and Table 10.

Combining corresponding earthquake hazard factors and weighting factors using equation (5), earthquake hazard scores for all districts of Bangladesh are calculated (Table 13).

Earthquake Hazard Factor, $H_e = f(sz)$

Where,

sz = Seismic zone

Earthquake Weighting Factor $WT_e = f(fr)$

Where,

fr = Frequency

Earthquake hazard score of a district, $THe = H_e \times WT_e$ (5)

3.2.4 District Wise Cyclone Scores

Considering the cyclone zones with cyclone intensity scale and damage risk levels for Bangladesh (Table 5), hazard factors are defined for corresponding zones. From the cyclone intensity scale and damage risk levels for Bangladesh (Table 5), it can be observed that, storm surges with height greater than one meter are categorized into different intensity levels which cause different levels of damage in the affected areas. Again, the areas affected by storm surges with height below one meter are also risk prone areas for cyclone. Thus, hazard factor is considered “five” for the cyclone surge high risk and risk areas for their high risk, “two” for the high wind areas for their lower risk, and “one” for the locations with no consideration of risk for cyclone (Table 11). Table 11 shows cyclone zones and their corresponding hazard factors. Then, weighting factors are defined for corresponding frequency classes. Here highest frequency of cyclone events is “32”. So the frequencies are classified through equal interval classification, where the interval is considered four. It is decided in consultation with experts through key informant interview. Thus, highest weighting factor is considered “1.8”. Table 12 shows frequency or number of occurrence of cyclone and their corresponding weighting factors. Thus district wise cyclone hazard factors and weighting factors are assigned considering corresponding cyclone zones and frequencies (Table 1) based on Table 11 and Table 12.

Combining corresponding cyclone hazard factors and weighting factors using equation (6), cyclone hazard scores for all districts of Bangladesh are calculated (Table 13).

For Cyclone:

Cyclone Hazard Factor, $H_c = f\,(cz)$

Where,

cz= Cyclone zone

Cyclone Weighting Factor, $WT_c = f\,(fr)$

Where,

fr = Frequency

Cyclone risk score of a district, $TH_c = H_c \times WT_c$ (6)

3.3 Multi-Hazard Risk Map of Bangladesh

Total multi-hazard scores for each of 64 districts are estimated by adding corresponding hazard scores for four individual hazards (tornado, cyclone, earthquake, and flood). Table 13 summarizes district wise individual hazard scores for tornado, cyclone, flood earthquake, and flood, as well as the combined multi-hazard scores. Table 14 shows an example illustrating the calculation of individual hazard scores for individual hazards, as well as the combined multi-hazard scores for “Chittagong” district. Table 15 shows districts corresponding to multi-hazard zones based on combined multi-hazard score. Fig 1 shows the proposed district wise multi-hazard zoning map of Bangladesh representing multi hazard scenario (cyclone, flood, tornado and earthquake) of Bangladesh at a glance.

4. Recommendation

The findings of this study can be used by decision makers as a reliable basis for district wise decision making considering individual hazards, as well as a multi-hazard approach. To disseminate and utilize the results regarding district wise individual hazard assessment and multi-hazard map of Bangladesh, the former Disaster Management Bureau (DMB) and now Department of Disaster Management (DDM) can make the results available in their website for all the respective decision makers including planners, administrators and disaster managers, and guide them to incorporate the information in their decision making and plan making process. Policy makers at the national and regional levels can use the multi-hazard map for formulation of development strategies in multi-hazard active zones, i.e. land use management, revision and enforcement of appropriate building codes, and formulation of plans for mitigating measures against hazard risks affecting the region considered. Moreover, the map can be used as a guideline by planners, administrators and disaster managers to make decisions regarding layout planning, updating building construction regulation for reducing probable damage, suggesting improvements for the building types, planning for disaster preparedness and response, etc., for different districts considering the different aspects of respective multiple hazards. The district level administrators can be made aware of the outcomes regarding their corresponding administrative units, so that they can disseminate the information to the local people to take preparedness measures according to the hazard condition of their locality.

Due to unavailability of historical records or database on past disasters in Bangladesh, some important factors could not be incorporated in this study. This includes but not limited to district wise variation of wind speed in case of tornados, district wise variation of flood duration, district wise wind disaster data in case of cyclones, etc. Moreover, the multi-hazard map is time-dependent and might be subjected to changes due to future events. So, updates and refinements to the database are necessary for updating the multi-hazard map. For the purpose, it is required to develop, maintain and update, recording and analysis system of historical disasters in Bangladesh by the Government of Bangladesh (GoB) involving respective agencies, institutions, departments and working levels ranging from districts and the central government. Also methodologies for rapid assessment of damage caused by hazards (earthquake, cyclone, tornado, and flood) considering more variables, i.e. duration, probability etc should be developed. For the purpose of recording of disaster information, intensity scales and damage risk levels for different disasters considering international standards should be followed ensuring compliance with local context. In this case, the intensity scales developed and proposed in this study for different hazards (earthquake, cyclone, tornado, and flood) can be considered by respective authorities with adequate adjustments and improvements. In this study, intensity scale for tornado is not proposed due to lack of historical database, but for future studies and data management Fujita-Pearson Tornado Scale can be utilized which measures the damage severity of a tornado with respect to wind speed (FEMA 1997). Proper historical data recording will open the scope for the preparation of sub-district based multi-hazard micro-zoning mapping of Bangladesh. Moreover, incorporation of vulnerability assessment with multi-hazard zoning map will result in multi-hazard risk map.

5. Conclusion

Bangladesh has suffered from some major natural disasters in the last decade. Among the hazards, earthquake, cyclone, tornado and flood, are most notable based on historical occurrences and their potential damage. An effort has been made to develop a multi-hazard zoning map of Bangladesh, considering earthquake, cyclone, tornado and flood. As a basic requirement in this regard, a complete database of those disasters of Bangladesh has been prepared. Then comparing the organized disaster database with international scales, damage scenario and models, intensity scales and damage risk levels for earthquake, flood, cyclone and tornado for Bangladesh have been developed and proposed. Then, district wise hazard scores of earthquake, cyclone, tornado and flood hazards have been calculated for Bangladesh. After that the districts of Bangladesh have been subdivided into three zones based on multi-hazard scores. Finally a district wise multi-hazard zoning map of Bangladesh has been prepared and proposed. The research findings are crucial and an important aspect for policy makers to take decision regarding disaster management strategy for planning disaster prevention, mitigation, and preparedness actions by identifying districts in high multi hazard zone. It can guide policy makers at the national and regional levels in the formulation of development strategies in multi-hazard active zones, i.e. land use management, revision and enforcement of appropriate building codes, and formulation of plans for mitigating measures against hazard risks affecting the region considered. It can guide planners, administrators and disaster managers to make decisions regarding layout planning, updating building construction regulation for reducing probable damage, suggesting improvements for the building types, planning for disaster preparedness and response, etc., for different districts considering the different aspects of respective multiple hazards. It can be helpful for the general people to take preparedness measures according to the hazard condition of their locality.

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Table 1 Historical database for four major hazards in Bangladesh

District Name	Historical database (Fr represents frequency)						
	Tornado	Flood		Earthquake		Cyclone	
	Fr	Flooding area zones based on water level data	Fr	Earthquake zones based on PGA	Fr	Cyclone zones based on height of storm surge	Fr
Bagerhat	2	Non flooding area	3	Zone 1	3	High risk area	6
Bandaban	0	Severe	2	Zone 3	8	High wind area	0
Barguna	0	Non flooding area	2	Zone 1	3	High risk area	1
Barishal	3	Severe	6	Zone 1	3	High risk area	21
Bhola	2	Moderate	4	Zone 1	3	High risk area	5
Bogra	1	Severe	6	Zone 3	10	Non affected area	0
Brahmanbaria	0	Severe	6	Zone 3	5	Non affected area	0
Chandpur	1	Severe	7	Zone 2	4	High wind area	2
Chittagong	1	Severe	5	Zone 2	6	High risk area	32
Chuadanga	0	Moderate	1	Zone 2	3	Non affected area	0
Comilla	4	Severe	5	Zone 2	4	High wind area	1
Cox’s bazar	1	Severe	3	Zone 3	6	High risk area	25
Dhaka	8	Severe	6	Zone 2	4	Non affected area	0
Dinajpur	0	Severe	3	Zone 2	3	Non affected area	0
Faridpur	5	Severe	6	Zone 2	4	Non affected area	0
Feni	1	Moderate	4	Zone 2	3	High risk area	1
Gaibandha	4	Severe	6	Zone 3	13	Non affected area	0
Gazipur	4	Moderate	6	Zone 3	8	Non affected area	0
Gopalganj	3	Moderate	6	Zone 1	3	High wind area	0
Habiganj	0	Severe	7	Zone 3	12	Non affected area	0
Jamalpur	4	Severe	7	Zone 3	19	Non affected area	0
Jessore	2	Non flooding area	1	Zone 1	2	Non affected area	0
Jhalkati	0	Non flooding area	1	Zone 1	3	High wind area	0
Jhenaidah	0	Non flooding area	0	Zone 2	2	Non affected area	0
Joypurhat	0	Moderate	3	Zone 3	8	Non affected area	0
Khgrachari	0	Non flooding area	0	Zone 3	5	High wind area	0
Khulna	3	Non flooding area	0	Zone 1	3	High risk area	19
Kishoreganj	5	Severe	7	Zone 3	10	Non affected area	0
Kurigram	1	Severe	7	Zone 3	16	Non affected area	0
Kushtia	2	Severe	2	Zone 2	5	Non affected area	0
Lakshmipur	1	Severe	5	Zone 2	1	High risk area	0
Lalmonirhat	2	Moderate	4	Zone 3	9	Non affected area	0
Madaripur	1	Severe	6	Zone 2	3	High wind area	0
Magura	2	Moderate	5	Zone 2	4	Non affected area	0
Manikganj	4	Severe	6	Zone 2	6	Non affected area	0
Meherpur	1	Non flooding area	1	Zone 2	4	Non affected area	0
Moulvibazar	1	Moderate	7	Zone 3	17	Non affected area	0
Munshiganj	2	Severe	5	Zone 2	4	Non affected area	0
Mymensingh	8	Moderate	7	Zone 3	11	Non affected area	0
Naogaon	0	Severe	6	Zone 2	4	Non affected area	0
Narail	4	Normal	6	Zone 1	4	Non affected area	0
Narayanganj	1	Severe	6	Zone 2	3	Non affected area	0
Narsingdi	0	Severe	6	Zone 3	5	Non affected area	0
Natore	0	Severe	6	Zone 2	6	Non affected area	0
Nawabganj	0	Severe	5	Zone 2	2	Non affected area	0
Netrokona	1	Moderate	6	Zone 3	19	Non affected area	0
Nilphamari	2	Moderate	5	Zone 3	3	Non affected area	0
Noakhali	6	Moderate	4	Zone 2	2	High risk area	18
Pabana	2	Severe	6	Zone 2	8	Non affected area	0
Panchagarh	1	Non flooding area	2	Zone 3	3	Non affected area	0
Pirojpur	1	Normal	2	Zone 1	3	High wind area	0
Potualkali	0	Non flooding area	0	Zone 1	3	High risk area	12
Rajbari	1	Severe	6	Zone 2	7	Non affected area	0
Rajshahi	1	Severe	5	Zone 2	4	Non affected area	0

Rangmati	0	Non flooding area	1	Zone 3	6	High wind area	0
Rangpur	4	Severe	6	Zone 3	7	Non affected area	0
Satkhira	0	Non flooding area	1	Zone 1	3	High risk area	5
Shariatpur	3	Severe	6	Zone 2	3	High wind area	0
Sherpur	1	Moderate	6	Zone 3	21	Non affected area	0
Sirajganj	4	Severe	6	Zone 3	8	Non affected area	0
Sunamganj	0	Severe	7	Zone 3	18	Non affected area	0
Sylhet	0	Severe	7	Zone 3	16	Non affected area	0
Tangail	2	Severe	7	Zone 3	9	Non affected area	0
Thakurgoan	0	Non flooding area	1	Zone 3	3	Non affected area	0

Table 2 Intensity scale and damage risk levels for flood in Bangladesh

Flood zone	Water level (DL represents Danger Level)	Intensity scale	Damage risk	Description
No Flooding Area	Below 50cm DL	1	Very Low Damage Risk	Fine cracks in plaster; fall of small pieces of plaster.
Normal Flooding Area	Within 50cm DL	2	Low Damage Risk	Small cracks in walls; fall of fairly large pieces of plaster.
Moderate Flooding Area	Up to 50cm Above DL	3	Moderate Damage Risk	Large and deep cracks in walls; bulging of walls; loss of belongings; damage to Electric fittings.
Severe Flooding Area	Above 50cm above DL	4	High Damage Risk (<3m above 50cm DL)	Gaps in walls; punching of holes through wall by flowing water; parts of buildings may collapse; light roofs float away; erosion of foundation, sinking or tilting; undercutting of floors, partial roof collapse.
			Very High Damage Risk (>3m above DL)	Total collapse of buildings; roof and some walls collapse; floating away of sheets, thatch, etc; erosion of foundation; severe damage to lifeline structures and systems.

Source: Adapted from BMPTC 1997

Table 3 Modified Mercalli Intensity (MMI) scale for earthquake

Intensity level	Explanation	Intensity level	Explanation
I	Only felt by instruments.	**VII**	Most people run outdoors. Damage to weakly constructed buildings. Felt by people in moving vehicles.
II	Felt by people at rest, especially on upper floors. Suspended objects may swing.	**VIII**	Considerable damage to most buildings. Heavy furniture overturned. Some sand fluidized.
III	Felt indoors. Vibrations like passing traffic.	**IX**	Even well-designed and sturdy buildings badly damaged, moved from their foundations. Ground cracks. Pipes break.
IV	Many people feel it indoors, a few outdoors. Crockery and windows rattle. Standing cars rock. Some sleepers awake.	**X**	Most masonry destroyed. Landslides occur. Water slops from reservoirs and lakes. Railway lines bend.
V	Felt by nearly everyone. Tall objects rock. Plaster cracks.	**XI**	Few structures remain upright. Bridges fall. Extensive fissures in the ground. Underground pipes totally out of action.
VI	Most people run outdoors. Damage to weakly constructed buildings. Felt by people in moving vehicles.	**XII**	Total destruction. Ground thrown into waves. Objects flung into the air. You would be lucky to survive this one.

Table 4 Peak Ground Accelerations (PGAs) during shaking at different intensities

MMI	V	VI	VII	VIII	IX	X
PGA (g)	0.03-0.04	0.06-0.07	0.10-0.15	0.25-0.30	0.50-0.55	>0.60

Table 5 Intensity scale and damage risk levels for cyclone in Bangladesh

Intensity	Expected central pressure		Wind speed		Maximum possible Storm Surge (MSL)		Damage risk level	Description
	(mbar)	(in)	(mph)	(kph)	(m)	(ft)		
Category 1	>=976	>=28.94	74-95	119-153	<7	<22	Very Low Damage Risk (VL)	No real damage to building structures. Damage primarily to fishing boats, trees near coastal. Some damage to poorly constructed signs. Also, some coastal road flooding and minor pier damage.
Category 2	966-975	28.50-28.91	96-110	154-177	8-9	23-29	Low Damage Risk (L)	Some roofing material, door, and window damage of buildings. Considerable damage

Intensity	Expected central pressure		Wind speed		Maximum possible Storm Surge (MSL)		Damage risk level	Description
	(mbar)	(in)	(mph)	(kph)	(m)	(ft)		
								to trees with some trees blown down. Some fishing boats missing. Considerable damage to poorly constructed signs, and piers. Small craft in unprotected anchorages break moorings.
Category 3	948-965	27.91-28.47	111-130	178-209	10-11	30-32	Moderate Damage Risk (M)	Tin roof, wooden supports blown off. Tin shed cottage industry totally damage. Crack in wall and beam and floor settled of some godown. Some structural damage to small residences and utility buildings with RCC roof and wall crack. Extensive damage to doors and windows of one storey buildings and General damage of doors-windows of some two storey residential buildings. Some damage of boundary wall and steel gate. Some retaining wall washed away and some damage to toe of wall. Wooden jetty totally damage. Some electrical works damage. Major damage to lower floors of structures near the shore.
Category 4	923-947	27.17-27.88	131-155	210-249	12-13	33-42	High Damage Risk (H)	More extensive curtain wall failures with some complete roof structure failures on

Intensity	Expected central pressure		Wind speed		Maximum possible Storm Surge (MSL)		Damage risk level	Description
	(mbar)	(in)	(mph)	(kph)	(m)	(ft)		
								small residences. Semi pucca tin roof totally destroyed. Roofs blown away and windows-doors damaged of dormitory and community centre. Single storey buildings totally collapse. General damage to interior of cyclone shelter. RCC pillars crack. Doors and windows of two storey cyclone shelter destroy. Complete roof failure of many residential and industrial buildings. Trees and all signs are blown down. Major damage to lower floors of structures near the shore.
Category 5	<924	<27.17	>155	>249	>13	>42	Very High Damage Risk (VH)	Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. All trees and signs blown down. Severe and extensive window and door damage. Stairs, auditorium and toilet block severely damage. Some one-storey buildings and boundary walls collapse. Some two storey buildings destroy.

Table 6 Tornado hazard factors and weighting factors based on frequency

No. of occurrence/ Frequency of tornado	Weighting factor	Hazard factor
0	1.0	1
1	1.1	5
2	1.2	
3	1.3	
4	1.4	
5	1.5	
6	1.6	
7	1.7	
8	1.8	

Table 7 Flood zones and their corresponding hazard factors for Bangladesh

Flood zone	Intensity	Hazard factor
No Flooding Area	1	1
Normal Flooding Area	2	2
Moderate Flooding Area	3	4
Severe Flooding Area	4	5

Table 8 Flood weighting factor with respect to frequency

Frequency/ No. of occurrence	Weighting factor
0	1.0
1	1.1
2	1.2
3	1.3
4	1.4
5	1.5
6	1.6
7	1.7

Table 9 Seismic zones and their corresponding hazard factors

Zone	PGA	Intensity	Hazard factor
Zone-1	0.075g	VI	3
Zone-2	0.15g	VII	4
Zone-3	0.25g	VIII	5

Table 10 Earthquake weighting factor with respect to frequency

Frequency/ No. of Occurrence	Weighting Factor
0	1.0
1-3	1.1
4-6	1.2
7-9	1.3
10-12	1.4
13-15	1.5
16-18	1.6
19-21	1.7

Table 11 Cyclone zones and their corresponding hazard factors

<table>
<tr><th>Cyclone zone</th><th>Intensity</th><th>Hazard factor</th></tr>
<tr><td>Non Affected Area</td><td>-</td><td>1</td></tr>
<tr><td>High Wind Area</td><td>-</td><td>2</td></tr>
<tr><td>Risk Area</td><td>-</td><td rowspan="2">5</td></tr>
<tr><td>High Risk Area</td><td>Category 1
Category 2
Category 3
Category 4
Category 5</td></tr>
</table>

Table 12 Cyclone weighting factor with respect to frequency

Frequency/ No. of occurrence	Weighting factor
0	1.0
1-4	1.1
5-8	1.2
9-12	1.3
13-16	1.4
17-20	1.5
21-24	1.6
25-28	1.7
29-32	1.8

Table 13 District wise individual hazard and multi-hazard scores

District name	Score for individual hazards				Multi-hazard score (T + E + C + F) (increasing order)
	Tornado (T)	Earthquake (E)	Cyclone (C)	Flood (F)	
Jhalkati	1	1.1	3.3	2	7.4
Jhenaidah	1	1	4.4	1	7.4
Thakurgoan	1	1.1	5.5	1	8.6
Khgrachari	1	1	6	2	10
Rangmati	1	1.1	6	2	10.1
Chuadanga	1	4.4	4.4	1	10.8
Barguna	1	1.2	3.3	5.5	11
Jessore	6	1.1	3.3	1	11.4
Satkhira	1	1.1	3.3	6	11.4
Potualkali	1	1	3.3	6.5	11.8
Meherpur	5.5	1.1	4.8	1	12.4
Dinajpur	1	6.5	4.4	1	12.9
Panchagarh	5.5	1.2	5.5	1	13.2
Pirojpur	5.5	2.4	3.3	2	13.2
Joypurhat	1	5.2	6.5	1	13.7
Nawabganj	1	7.5	4.4	1	13.9
Narail	7	3.2	3.6	1	14.8
Naogaon	1	8	4.8	1	14.8
Natore	1	8	4.8	1	14.8
Bandaban	1	6	6.5	2	15.5
Brahmanbaria	1	8	6	1	16
Narsingdi	1	8	6	1	16
Bagerhat	6	1.3	3.3	6	16.6
Habiganj	1	8.5	7	1	17.5
kushtia	6	6	4.8	1	17.8
Magura	6	6	4.8	1	17.8
Gopalganj	6.5	6.4	3.3	2	18.2
Khulna	6.5	1	3.3	7.5	18.3
Nilphamari	6	6	5.5	1	18.5
Sunamganj	1	8.5	8	1	18.5
Sylhet	1	8.5	8	1	18.5
Rajshahi	5.5	7.5	4.8	1	18.8
Narayanganj	5.5	8	4.4	1	18.9
Lalmonirhat	6	5.6	6.5	1	19.1
Munshiganj	6	7.5	4.8	1	19.3
Rajbari	5.5	8	5.2	1	19.7
Madaripur	5.5	8	4.4	2	19.9
Pabana	6	8	5.2	1	20.2
Manikganj	7	8	4.8	1	20.8
Bhola	6	5.6	3.3	6	20.9
Gazipur	7	6.4	6.5	1	20.9
Shariatpur	6.5	8	4.4	2	20.9
Chandpur	5.5	8.5	4.8	2.2	21
Feni	5.5	5.6	4.4	5.5	21
Faridpur	7.5	8	4.8	1	21.3
Moulvibazar	5.5	6.8	8	1	21.3
Netrokona	5.5	6.4	8.5	1	21.4
Sherpur	5.5	6.4	8.5	1	21.4
Bogra	5.5	8	7	1	21.5
Comilla	7	7.5	4.8	2.2	21.5
Tangail	6	8.5	6.5	1	22
Lakshmipur	5.5	7.5	4.4	5	22.4

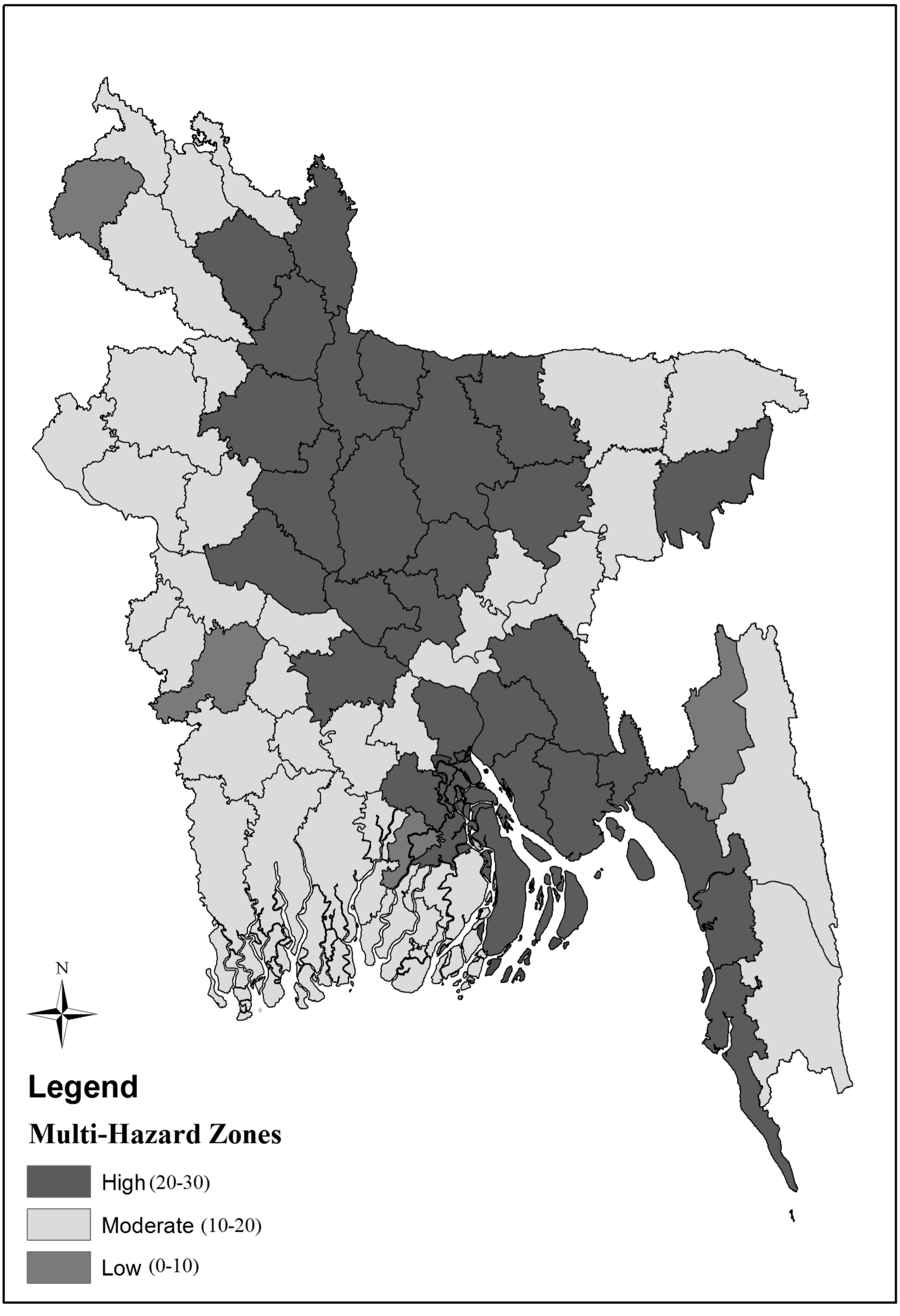
Rangpur	7	8	6.5	1	22.5
Sirajganj	7	8	6.5	1	22.5
Dhaka	9	8	4.8	1	22.8
Kurigram	5.5	8.5	8	1	23
Gaibandha	7	8	7.5	1	23.5
Mymensingh	9	6.8	7	1	23.8
Kishoreganj	7.5	8.5	7	1	24
Jamalpur	7	8.5	8.5	1	25
Noakhali	8	5.6	4.4	7.5	25.5
Barishal	6.5	8	3.3	8	25.8
Cox's bazar	5.5	6.5	6	8.5	26.5
Chittagong	5.5	7.5	4.8	9	26.8

Table 14 Calculation of individual and multi-hazard scores for "Chittagong" district

	Hazard zone	**Frequency**	**Hazard factor (H)**	**Weighting factor (WF)**	**Hazard Score (TH = H × WT)**
Tornado	-	1	5	1.1	5.5
Flood	Severe	5	5	1.5	7.5
Earthquake	Zone 2	6	4	1.2	4.8
Cyclone	High risk area	32	5	1.8	9
Multi-hazard score					26.8

Table 15 Districts corresponding to multi-hazard zones based on multi-hazard score

Multi-hazard score	**Multi-hazard zones**	**Districts**
1-10	Low	Jhalkati, Jhenaidah, Thakurgoan, Khgrachari
10-20	Moderate	Rangmati, Chuadanga, Barguna, Jessore, Satkhira, Potualkali, Meherpur, Dinajpur, Panchagarh, Pirojpur, Joypurhat, Nawabganj, Narail, Naogaon, Natore, Bandaban, Brahmanbaria, Narsingdi, Bagerhat, Habiganj, Kushtia, Magura, Gopalganj, Khulna, Nilphamari, Sunamganj, Sylhet, Rajshahi, Narayanganj, Lalmonirhat, Munshiganj, Rajbari, Madaripur
20-30	High	Pabana, Manikganj, Bhola, Gazipur, Shariatpur, Chandpur, Feni, Faridpur, Moulvibazar, Netrokona, Sherpur, Bogra, Comilla, Tangail, Lakshmipur, Rangpur, Sirajganj, Dhaka, Kurigram, Gaibandha, Mymensingh, Kishoreganj, Jamalpur, Noakhali, Barishal, Cox's bazar, Chittagong



Source: Prepared by authors

Fig. 1 Multi-hazard risk map of Bangladesh

PART-VII

WORKPLACE SAFETY COMPLIANCE OF RMG INDUSTRY IN BANGLADESH: STRUCTURAL ASSESSMENT OF RMG FACTORY BUILDINGS

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1. Introduction

Accidents in industry effect on the safety of workers, livelihood of the workers' families, those living in the vicinity of the industry and on the environment. Thousands of people are killed and injured in industrial accidents every year (Jaiswal, 2012). According to ILO, occupational accidents and work-related diseases cause over 2.3 million fatalities annually, of which over 350,000 are caused by occupational accidents, which result in immeasurable human suffering to victims and their families along with major economic losses for enterprises and economies as a whole, e.g. around 4 per cent of the world's gross domestic product (GDP), or about US$2.8 trillion, is lost annually in direct and indirect costs (ILO, 2014e). Among different types of hazards in textile industry, physical hazards i.e. fire, building collapse, etc, are dependent on the structural and workplace safety compliance issues. Different industrial hazards resulted in several initiatives worldwide to protect human life and reduce material damage from industrial accidents, both nationally and internationally.

Occupational hazards are common in China with the dramatic economic development over the past 20 years (Zhang, Wang, and Li, 2010). For the prevention of occupational hazards, especially occupational diseases several legislative measures have been promulgated in China. Other initiatives included enforcement and implementation of occupational health and safety research, capacity building, supervision team formation, basic occupational health services in collaboration with international organizations, etc (Zhang, Wang, and Li, 2010). The occupational hazards in Japan are characterized by health issues and industrial accidents resulting in several laws and acts (JISHA, 2010; Takahashi, and Ishii, 2013).

Manmade industrial disasters happen frequently in Europe, resulting in adoption of minimum requirements for safety and health protection at the workplace to prevent accidents and occupational diseases in Member States of European Union (EU), i.e. policies, legislation, convention, etc (European Commission, 2014a; Chambers, 2015; European Agency for Safety and Health at Work, n.d.). Among the industrial accidents influencing adoption of preventive measures, Seveso chemical accident in Italy (1976), Baia Mare industrial accident in Romania (2000) etc are significant (European Commission, 2014b; Ludwiczak, 2014; European Commission, 2015; Eves, 2015). The earlier poor working condition in industries of United Kingdom (UK) resulted in initiation of factory inspection and imposition of Factory Act in 1833, which amended several times afterwards to address industrial accident issues. Several initiatives were undertaken in response to industrial accidents, i.e. industrial explosion in Silvertown, East London killing 73 workers (1917), explosion and fire at Flixborough, Lincolnshire killing 28 workers and injuring 36 workers (1974), collapse of a four-storey factory building in Glasgow caused by a liquefied petroleum gas (LPG) explosion killing nine and injuring thirty three workers (2004), massive explosion and fire at the Buncefield Oil Storage Depot, Hemel Hempstead (2005), etc (McQuaid, 1991; Eves, 2015). In USA, unhealthy working conditions and frequent serious accidents with resulting economic and social losses influenced the government to undertake different actions, e.g. in 1877 the first Factory Act along with factory inspection initiative were enacted in Massachusetts in response to the tragic fire at the Granite Mills in Fall River (1875) (MacLaury, n.d.).

In 1919, following the end of the First World War, the International Labour Organization (ILO) was established in order to address all conceivable aspects of labor rights internationally. Occupational health and safety (OHS) is one of the ILO Constitution's main objectives, the concept of which was developed by the ILO and the World Health Organization (WHO) in 1950 as a building block for labour legislation (Muller, 2013; Nations Encyclopedia, n.d.).

The Ready Made Garment (RMG) industry in Bangladesh has been facing challenges regarding compliance with the international standard to ensure workplace safety and better working conditions for the millions of garment workers resulting in worst safety record in the world (CCC, 2012). Neglecting the importance, many employers did not comply with the basic regulations in Bangladesh, despite extensive global legislation on occupational health and safety and other workers' rights. Most garments factories in Bangladesh paid little attention to labor standards and labor rights, many of which did not meet the minimum standards prescribed in building and construction legislation (Ahmed, 2013). Such non-compliance resulted in numerous industrial accidents in RMG factories of Bangladesh like fire and building collapse resulting in the enormous sufferings to the workers and their families (Ahmed, 2013). One of the most deadly fire accidents in RMG sector Bangladesh is Tazreen Fashion fire on November 24, 2012, which resulted in death of 112 workers (ILO, n.d.a). Since Tazreen Fashion Factory fire to April 17, 2015, about 84 fire incidents have occurred in the sector leading to at least 31 deaths and 903 injuries (Solidarity Center, 2015). In 2005 Spectrum factory collapsed causing death of 64 garment workers and injury of 80 (CCC, 2012). In 2006, 22 workers died due to collapse of Phoenix Garments building. Just months after the fatal fire at Tazreen Fashions, Rana Plaza collapsed on 24 April 2013 resulting in 1134 deaths and more than 2500 injuries. It is the last most alarming accident in RMG sector in Bangladesh stated as one of the deadliest industrial disasters in the world, which resulted due to the reluctant attitude of the stakeholders towards the compliance issues.

Without workplace safety compliance, it is almost impossible to ensure business sustainability and thus to survive in global market competition (Rajon, 2014). Despite the challenges in RMG sector in Bangladesh McKinsey, a global management consulting firm, described Bangladesh as the next hot spot in apparel sourcing (Berg et al., 2011). The firm forecasted that the export-value growth will be

7-9% annually resulting in increase of apparel export double by 2015 and nearly triple by 2020, if the sector in Bangladesh can ensure total compliance with the international standard. Even after the Rana Plaza collapse, a study jointly conducted by the United States Fashion Industry Association (USFIA) and the University of Rhode Island (URI) revealed that, the US-based fashion companies are expected to boost their sourcing from Bangladesh by 2016 (Lu, 2014).

Considering the potentiality of RMG industry in Bangladesh, several and diverse national and international commitments and initiatives resulted as part of the reform and restructuring of the Bangladesh RMG sector aiming at improvement of workplace safety in Bangladesh's garment factories to safeguard the lives of over four million RMG workers and to retain the confidence of global buyers following the Rana Plaza accident (ILO, 2015a; Moazzem, & Islam, 2015). The initiatives include but not limited to, National Tripartite Action Plan (NTPA), the European Union Sustainability Compact, and the United States Trade Representative (USTR) Plan of Action. Though the targets and objectives of these initiatives are same, but they share some common courses of action (Moazzem, & Islam, 2015). Among the common actions considered in three initiatives, structural assessment of RMG factory buildings is significant to ensure a safe working environment for all in the sector preventing further accidents.

In this background, this paper aims firstly to discuss the history, potentiality and challenges of RMG industry in Bangladesh to bring out the importance of this industry in the economy of the country along with the challenges, secondly to review the initiatives taken after Rana plaza accident to overcome the challenges along with their progress in terms of achievement within two years, and finally to review and discuss in detail about the action regarding structural assessments of buildings housing RMG factories in Bangladesh including its progress, implementation mechanism, and outcomes within two years after Rana Plaza collapse. Assessment of buildings is not an end in itself, which requires further study to take corrective measures accordingly. So, along with the discussion, some recommendations have been suggested in this study to be incorporated in the structural assessment initiative to make the weak factory buildings resilient by addressing the structural issues. This study was done on the basis of review of secondary resources and field experiences of the authors.

2. Ready Made Garment (RMG) Industry in Bangladesh: History, Potentiality and Challenges

Ready Made Garment (RMG) industry sector of Bangladesh commenced its journey in late 1970s due to global garment chain and outside pressure rather than local demands and has come to the position it is in today (Rahman, 2004; Hasan, 2013). The industry emerged in Bangladesh at a time when it began its struggle for achieving economic emancipation after independence to lead the country to prosperity with its limited resources. At that time jute was the major foreign exchange earner of

Bangladesh contributing more than 50% of the country's total export earnings (Chowdhury, Ahmed, and Yasmin, 2014). But the jute market collapsed due to consequent decline in global demand for jute. The growth in the RMG sector has been a welcome change for Bangladesh's export market diversifying the economy of the country which has historically been dependent on agricultural sector. It has indeed emerged as a niche market for Bangladesh's export sector.

The history influencing the commencement of RMG industry in Bangladesh initiated in 1950 when cost of production increased in Western World due to increase in labour wage in RMG sector (Chowdhury, Ahmed, and Yasmin, 2014). As a result, retailers started searching for places where the cost of production was cheaper, i.e. Hong Kong, Taiwan and South Korea (Hasan, 2013; Chowdhury, Ahmed, and Yasmin, 2014). In 1974, Multi Fiber Agreement (MFA) was made by General Agreement on Tariffs and Trade (GATT) to control the level of imported RMG products from developing countries into developed countries, imposing six percent increase in export rate every year from a developing country to a developed country and quotas on countries that exported at a higher rate (Chowdhury, Ahmed, and Yasmin, 2014). Bangladesh was able to escape the MFA quotas as it was not perceived to be a particular threat to the industries of those countries (Khan, 2002). The MFA agreement led the producers to search for countries that were outside the umbrella of quotas and had cheap labour like Bangladesh. Thus, exemption of Bangladesh from MFA and cheap labour influenced the instigation of RMG sector in the country, when South Korean company Daewoo signed a five-year collaboration agreement with Desh, a Bangladeshi garment in 1974. Further the development and improvement of communication system and networking, flexible government policy toward the sector, and other factors persuaded the expansion and success of Bangladesh's entire garments export sector (Rahman, 2004; Yunus, and Yamagata, 2012; Chowdhury, Ahmed, and Yasmin, 2014). By late 1980s, the sector became the main export sector and a major source of foreign exchange in Bangladesh (Rahman, 2004; Chowdhury, Ahmed, and Yasmin, 2014). Thus, the MFA quota was a blessing to the RMG industry of Bangladesh. In 2005, phase out of the quota was completed under the Uruguay round of GATT (1994) (Razzaue and Eusuf, 2007; Yunus, and Yamagata, 2012; Hasan, 2013). At the end of the quota, it was predicted by many that the phase out would greatly affect the export of the country. However, the post MFA era is another storey of success proving all predictions wrong (Razzaue and Eusuf, 2007; Yunus, and Yamagata, 2012; Hasan, 2013).

In the recent years, RMG exports from Bangladesh have been growing at an impressive rate. In FY 1984-'85 the value of RMG export of Bangladesh was 116.20 million USD which was 3.89% of total export (BGMEA, 2014). It is now the biggest export earner in Bangladesh with an export earning of around 25 Billion USD which is 84.1 percent of the total export earnings of the country in FY2014-15 (May). Due to such growth in RMG export earning, Bangladesh became the second largest apparel exporting country in the world in 2010 just within a course of three decades despite other challenges in the sector (Islam, 2014; ILO, 2015b; Rahman and Hossain, 2010). Figure 1 shows comparative statement on share of different sectors in total export earning of Bangladesh, which represents the increasing superiority of export earnings of RMG sectors in Bangladesh in last eight fiscal years. Except 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 1978, there were only 9 export-oriented garment manufacturing units employing 0.12 million workers, which shot up to around 3500 employing more than 4.2 million workers in 2014 (BGMEA, 2014; ILO, 2015b). At present, European Union (EU including UK) and North America (the US and Canada) are the main buyers of RMG products of Bangladesh, where sixty percent of export contracts of western brands are with European buyers, and about 30 percent with North American buyers (Hasan, 2013; Hasan, 2014). Bangladesh is a participant in General System of Preferences (GSP) programs of both the EU's as well as that of the US.

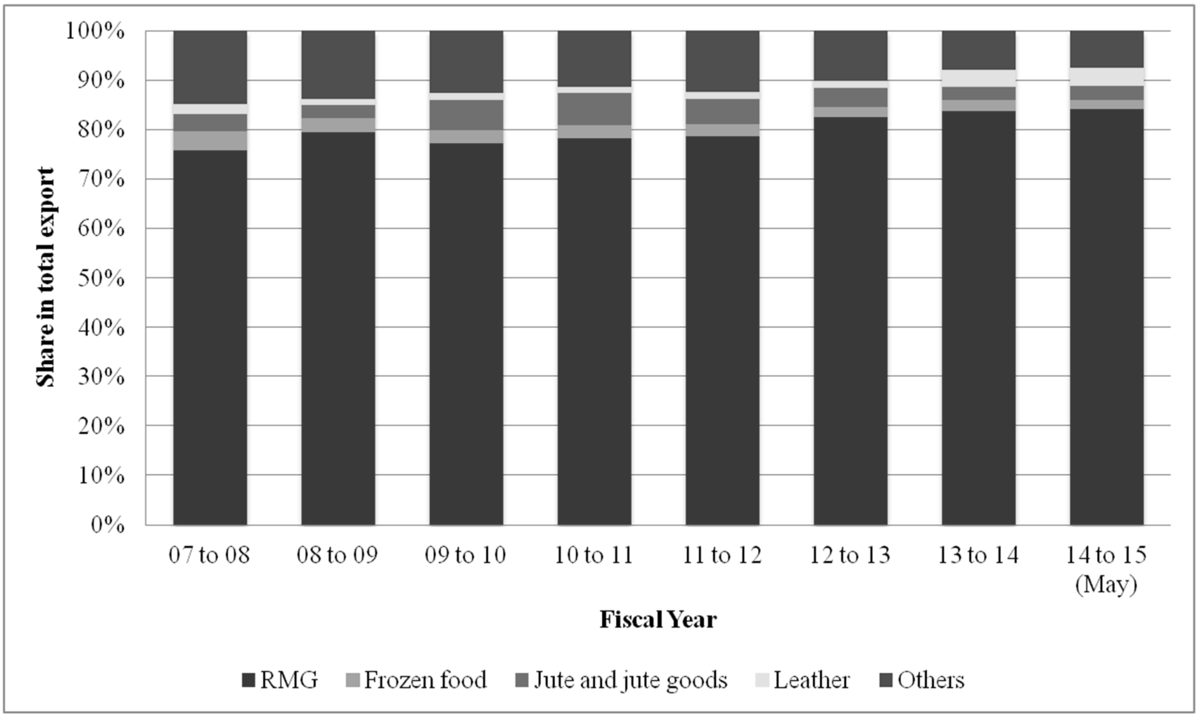


Figure 1: Share of different sectors in total export earning of Bangladesh (Source: Export Promotion Bureau, 2015)

It is apparent from Figure 1 that that the growth rate of RMG sector in Bangladesh has been around nine percent over the FY2013-14 which is slightly lower than the earlier five years average of around 12 percent (Anwar, 2014). This reduction has resulted due to several factors including image smearing due to industrial accidents, political turmoil, energy crises, physical distribution, and discriminatory treatment by some major global buyers. Industrial accidents are common in RMG factories of

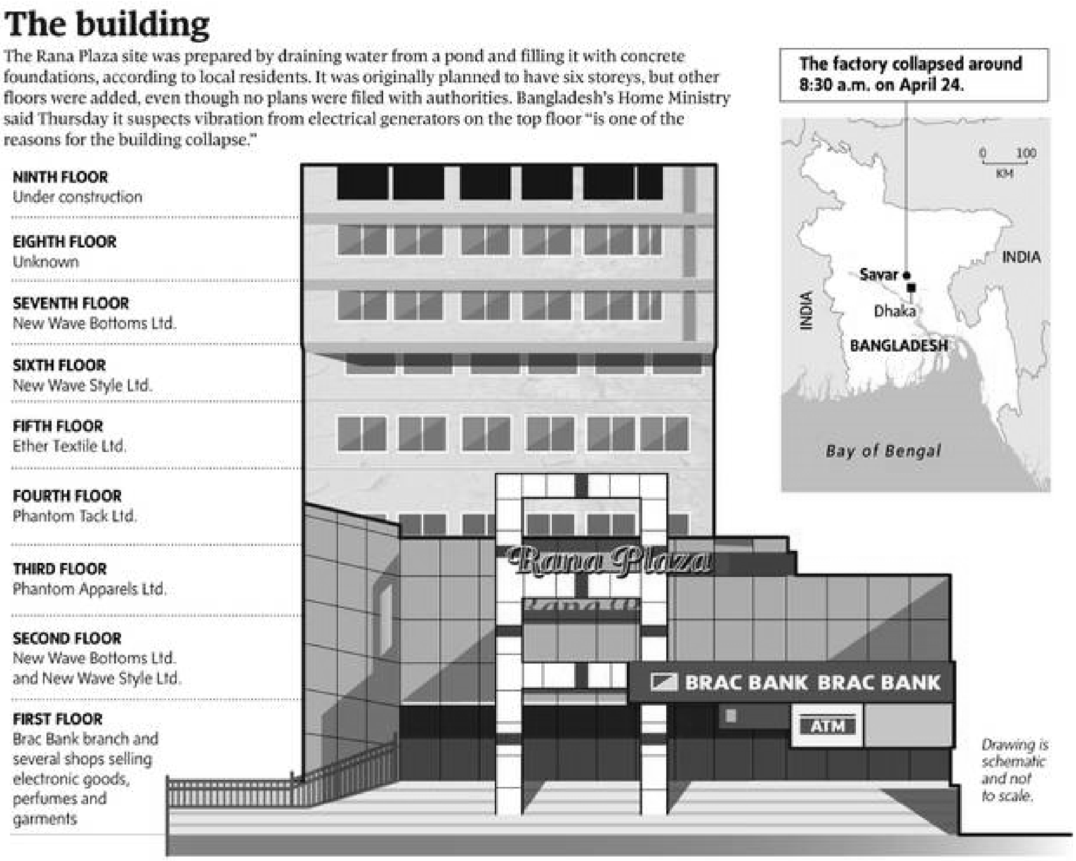
Bangladesh due to lack of compliance with the international standard. Many of the factories did not meet the minimum standards prescribed in building and construction legislation causing different accidents like fire and building collapse causing enormous suffering to workers and their families (Ahmed, 2013). One of the most deadly fire accidents in RMG sector Bangladesh is Tazreen Fashion fire on November 24, 2012. Just months after the fatal fire at Tazreen Fashions, Rana Plaza collapsed on 24 April 2013 at around 8:30 am, which was located at Dhaka-Aricha highway near Savar bus stand (Figure 2). It is the last most alarming accident in RMG sector in Bangladesh, which resulted due to the reluctant attitude of the stakeholders towards the compliance issues.

Rana Plaza housed five garment factories employing around 5,000 people, 300+ shops, and a bank. It was a 9-storied industrial building with a single basement. Figure 2 shows the schematic diagram, of the building and a photo before it collapsed. Instead of RAJUK (Capital Development Authority), local municipality (Savar) gave permission to the owner of Rana Plaza to construct a five storey commercial building with one basement in 2005 and later allowed the owner to extend it up to nine storey, without considering the structural design, though the foundation of the building was of 5 storey (Rahman, and Ansary, 2013). Moreover, the building was converted from commercial to industrial use, and power generators were placed at the higher floors. As a result of such violation in building construction, cracks developed on some pillars and a few floors of the building following a jolt on 23 April 2013, a day prior to the fateful day. After inspection of industrial police, they 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 of 24th April, 2013. As a consequence, the collapse resulted in the high death toll of 1,134 and more than 2500 people to be badly injured at the end of the rescue operation on 14 May 2013 (Osman et al., 2013; CPD, 2014a). It was a global tragedy emphasizing the importance of issues concerning millions of workers, employers, brands and consumers – the entire supply chain in the RMG sector of Bangladesh (ILO, 2014a).

After Rana Plaza accident, the US President suspended Bangladesh from participating in the GSP program on June 27, 2013, and the suspension order was to be implemented within 60 days after the announcement (Brooks, 2013). Many in the international community had wondered if the EU would soon follow suit, or if it would pursue a different approach toward spurring policy changes in the country (ICTSD, 2013). Convinced by ILO, the EU confirmed that it will be keeping Bangladesh in its Everything But Arms (EBA) scheme of GSP, which grants least developed countries, such as Bangladesh, duty-free, quota-free access to the EU market for all goods exports, with the exception of arms and ammunition (ILO, 2014d; ICTSD, 2013). Thus, the initial reaction of the trading partners and global business and investors after Rana Plaza collapse weakened confidence in Bangladesh (ILO, 2014c).

To safeguard the lives of over four million RMG workers and to retain the confidence of global buyers following the Rana Plaza accident, several and diverse national and international commitments and initiatives resulted as part of the reform and restructuring of the Bangladesh RMG sector aiming at improving workplace safety in Bangladesh’s garment factories (ILO, 2015a; Moazzem, & Islam, 2015). The initiatives include but not limited to, National Tripartite Plan of Action (NTPA), the European Union Sustainability Compact, and the United States Trade Representative (USTR) Plan of Action. Though the targets and objectives of these initiatives are same, but they share some common courses of action (Moazzem, & Islam, 2015).

After Rana Plaza accident, the Government of Bangladesh (GoB) put in place a number of incentives to ease the difficulties faced by RMG entrepreneurs, i.e. bringing down the advance income tax from 0.8 per cent of f.o.b. value to 0.3 per cent, arrangement of low-cost credit for struggling RMG units, etc (CPD, 2014b). But these incentives were not enough to satisfy the requirement of global buyers. Thus, tripartite partners, i.e. GoB, RMG workers, and RMG employers, signed a Joint Statement built upon NTPA on May, 2013 (ILO, n.d.b). The NTPA on Fire Safety was first outlined on March 2013 after Tazreen Fashion fire accident (Ahmed, n.d.). 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 on July 2013 (ILO, n.d.b). The NTPA on Fire Safety and Structural Integrity includes 25 commitments divided into the three categories, i.e. legislation and policy, administration, and practical activities, among which 16 have been fully or substantially completed and nine of the commitments have been partly completed within two years (Moazzem, & Islam, 2015). The National Tripartite Committee (NTC) was established in 2013 under NTPA commitment to ensure and monitor implementation of the NTPA (ILO, n.d.b; CPD, 2014a). The committee chaired by Labour Secretary includes Government agencies, employers, i.e. Bangladesh Employer's Federation (BEF), Bangladesh Garment Manufactures & Exporters Association (BGMEA) and Bangladesh Knitwear Manufacturers & Exporters Association (BKMEA), and trade unions.



(a) Rana Plaza

(b) Rana Plaza before collapse

(c) Rana Plaza after collapse

Figure 2: Rana Plaza before and after its collapse on April 24, 2013 (Source: bdnews24.com)

3. Initiatives after Rana Plaza Collapse: Workplace Safety Compliance Issues

Based on NTPA; the EU, GoB and ILO issued an agreement of time-bound actions, “The Sustainability Compact: Compact for Continuous Improvements in Labor Rights and Factory Safety in the Ready-Made Garment and Knitwear Industry in Bangladesh” on July 2013 to promote improved labor standards and responsible business conduct in the RMG and knitwear industry in Bangladesh (ILO, n.d.b; Joint Statement, 2013; Moazzem, & Islam, 2015). A total of twenty nine activities are listed in the EU Sustainability Compact, among which 15 actions have been fully or substantially completed, 13 actions have been partly completed, and one action regarding encourage retailers and brands to adopt and follow a unified factory audit code of conduct in Bangladesh has not been initiated yet (Moazzem, & Islam, 2015). 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 (Moazzem, & Islam, 2015; Brooks, 2013). The USTR Action Plan endorsed the EU Sustainability Compact particularly for trade union related activities. Substantial progress has been made in regards to twelve of the actions and greater progress is required in regards to four actions (Moazzem, & Islam, 2015). Table 1 shows the status of actions under three initiatives. From this review it is realized that Bangladesh has progressed a lot in terms of the achievement or completion of actions initiated under plans of actions.

Table 1: Status of actions under three initiatives

Initiative	Fully or substantially completed	Partly completed
NTPA	1. Submit the Bangladesh Labour Law Reform Package to Parliament. 2. Adopt a National Occupational Health and Safety Policy. 3. Establish a Task Force on Building and Fire Safety under the Cabinet Committee for the RMG sector. 4. Establishing a single resource for information on fire safety licensing and certification. 5. Recruitment of 200 labour inspectors	1. Review relevant laws, rules and regulations regarding fire, building and chemical safety. 2. Review and adjust factory licensing and certification procedures. 3. Develop a transparent and accountable industry sub-contracting system. 4. Develop and implement a factory fire safety improvement programme.

Initiative	Fully or substantially completed	Partly completed
	6. Upgrade the Department of the Inspection for Factories and Establishments (DIFE) to a Directorate. 7. Strengthen the capacity of the DIFE 8. Establish a publicly accessible database on safety issues in RMG factories. 9. Develop and introduce a unified fire safety checklist to be used by all relevant government agencies. 10. Conduct a factory level fire safety needs assessment. 11. Deliver a fire safety "crash course" for mid-level factory managers and supervisors. 12. Establish a fire safety hotline for workers. 13. Strengthen the capacity of the Bangladesh Fire Service and Civil Defence (FSCD). 14. Develop guidelines for the establishment of labour management committees on occupational safety and health and/or fire safety. 15. Develop and disseminate fire safety self-assessment and remediation tools. 16. Redeploy RMG workers that were rendered unemployed by the	5. Develop and deliver fire safety training to factory inspectors. 6. Develop and deliver fire safety training to union leaders. 7. Assess the structural integrity of all active RMG factories. 8. Develop and deliver mass worker education tools. 9. Develop a tripartite and protocol for compensation of the families of deceased and injured RMG workers.

Initiative	Fully or substantially completed	Partly completed
	incident, as well as rehabilitated disabled workers.	
EU Sustainability compact	1. Amend the Bangladesh Labour Law 2. The ILO is to provide technical assistance to Bangladesh towards implementation and follow-up concerning freedom of association and the right to collective bargaining 3. Ensure freedom of association, collective bargaining and the application of the Bangladesh Labour Law 4. Register independent trade unions and ensure protection of unions and their members from anti-union discrimination and reprisals. 5. Conduct a diagnostic study of the Labour Inspection System, followed by the development and implementation of an action plan with appropriate measures. 6. Conduct regular visits to assess industrial establishments 7. Upgrade the Department of the Chief Inspector of Factories and Establishments to a Directorate. Recruit 200 additional inspectors by the end of 2013. 8. Implement the National Action Plan on Fire Safety and Structural Integrity in the RMG industry in Bangladesh, with the support of the ILO, in accordance with established	1. Implement, enforce and monitor the Labour Law 2. Issue and implement all rules required by law 3. Develop and adopt additional domestic legislative proposals to address freedom of association and protection of the Right to Organise and Collective Bargaining 4. Establish Joint Committees for the improvement of occupational safety and health 5. Deliver education and training programmes on fundamental principles, rights at work and occupational safety and health 6. Extend technical assistance to address labour standards 7. The ILO is to assist Bangladesh in reviewing the adequacy of reforms in meeting ILO requirements 8. Align actions with the ILO Programme Outline 2013-2016, ‘Improving Working Conditions in the RMG Sector in Bangladesh’, and ‘Better Work’; to be

Initiative	Fully or substantially completed	Partly completed
	milestones and timelines as stipulated in the Programme of Action. 9. Assess the structural and fire safety of all active export-oriented RMG and knitwear factories and initiate remedial actions 10. Create a publicly accessible database 11. Achieve eligibility for the 'Better Work Bangladesh' (BWB) programme 12. Explore the possibility of reallocating funds under the current EU-funded 'Technical and Vocational Education and Training' (TVET) project implemented by the ILO. Implement the existing EU-funded 'Better Work and Standard' (BEST) cooperation programme. 13. Extend the social compliance component in the ongoing EU BEST programme with Bangladesh 14. Underline the importance of engaging with stakeholders to ensure effective implementation of and consistency among various initiatives 15. Implement the ILO's skills and training programme for injured workers. Rehabilitate and reemploy affected workers.	supported technically or financially by the EU under the next programming cycle (2014-2020). 9. Explore further funding possibilities within the upcoming programming period (2014-2020), including through the 'Thematic Programme Global Public Goods and Challenges' programme 10. Rehabilitate those who are permanently disabled as a result of the Rana Plaza Tragedy 11. Ensure a focus on skills development in future EU assistance to Bangladesh 12. Encourage other companies to expeditiously join the Accord within their respective capacities. 13. Take note of the steps taken by European social partners in the RMG sector to update their 1997 and 2008 Codes of Conduct on Fundamental Rights, within the framework of the European Sectoral Social Dialogue Committee for Textiles and Clothing

Initiative	Fully or substantially completed	Partly completed
USTR Bangladesh Action Plan	1. Develop a plan to increase the number of labour, fire and building inspectors, improve their training, establish clear procedures for independent and credible inspections and expand resources and their disposal, so as to conduct effective inspections 2. Increase fines and other sanctions for failure to comply with labour, fire or building standards to levels sufficient to deter future violations 3. Develop and implement a plan to assess the structural building and fire safety of all active RMG/knitwear factories in consultation with the ILO. Initiate remedial actions, or close or relocate inadequate factories, as appropriate. 4. Create a publicly accessible database of all RMG/knitwear factories as a platform for reporting labour, fire and building inspections 5. Establish an effective compliant mechanism 6. Continue to register unions to ensure protection of unions and their members from anti-union discrimination and reprisal 7. Publicly report information on the status and final outcomes of individual union registration applications	1. Enact and implement labour law reforms to address key concerns related to freedom of association and collective bargaining. 2. Develop and implement mechanisms to prevent harassment, intimidation and violence against labour activists and unions 3. Actively support the ILO and other worker-employer initiatives in the shrimp sector 4. Publicly report on complaints received of anti-union discrimination or other unfair labour practices in the shrimp sector

Initiative	Fully or substantially completed	Partly completed
	8. Register non-governmental labour organizations 9. Publicly report any complaints received of anti-union discrimination or other unfair labour practice 10. Bring the EPZ law into conformity with international standards 11. Issue regulations to ensure the protection of EPZ workers' freedom of association until the EPZ law has been repealed or overhauled 12. Issue regulations to ensure transparency in the enforcement of the existing EPZ law until the EPZ law is repealed or overhauled	

Source: Prepared by author on the basis of Moazzem, & Islam, 2015

In addition to these initiatives, two different factory inspection programmes have been established to make work place safer in Bangladesh: the Bangladesh Accord on Fire and Building Safety in Bangladesh, and the Alliance for Bangladesh, where ILO fulfills the role of neutral chair. The Accord on Fire and Building Safety in Bangladesh (the Accord) was signed 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, 2015a; Bangladesh Accord Secretariat, 2015). The Alliance for Bangladesh Worker Safety (the Alliance) officially launched its local operation in Dhaka on December 9, 2013, which is also a five year independent and legally binding agreement founded 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 initiatives and their achievements indicate that Bangladesh RMG sector is not only trying hard to maintain required global standards but in fact in some cases it was far exceeding the standards set by the competing countries (Anwar, 2014). Thus, despite the challenges, the RMG sector still held a competitive position in global RMG market showing impressive export performance afterwards in FY 2013-14 and FY 2014-15 (Figure 1).

4. Structural Assessments of Buildings Housing RMG Factories in Bangladesh

4.1 Progress of the Structural Assessment Initiative

After Rana Plaza accident, work-place safety was considered one of the most important challenges to sustain RMG industry in Bangladesh. Thus actions regarding structural and fire safety assessment of all active export-oriented RMG factories were addressed in all the action plans. The supporting actions included up-gradation 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 (Table 1).

The GoB has already upgraded Chief Inspector of Factories and Establishment office to Department of the Inspection for Factories and Establishments (DIFE), sanctioning 679 new staff positions including 392 new inspectors and also started organizing training program for the newly recruited inspectors for capacity building. 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. 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 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 was also established to handle urgent safety issues in garment factories. Finally on November 2013, assessments of the structural integrity and fire safety of RMG factory buildings officially commenced led by engineers from BUET (ILO, n.d.b; ILO, 2013; ILO, 2014b; ILO, 2014c). The BGMEA and BKMEA agreed to share necessary documents related to factory design and layout with the Committee to facilitate a smooth assessment process (ILO, 2013). A publicly accessible database of all RMG factories has also been created as a platform for reporting labour, fire and building inspections.

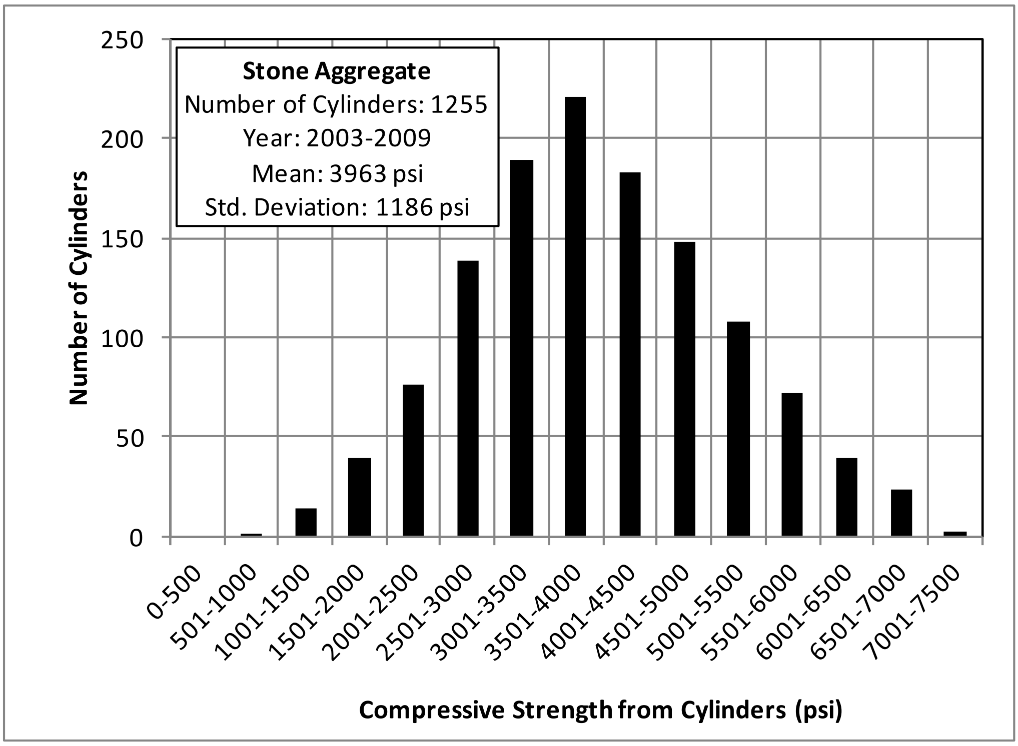
Among a total of 1,400 Accord member factories, 1,250 have been inspected till March, 2015. Moreover, among newly listed factories initial inspections of 250 factories have already completed. As of March 2015, the Accord has received and handed over 950 Corrective Action Plans (CAPs) to the respective factories. So far 683 CAPs have been published on the website (Bangladesh Accord, 2015c). The Alliance has already inspected all of its 647 factories (Alliance for Bangladesh, 2015). The NTPA has set a target to inspect around 1,500 factories that are neither part of the Accord or the Alliance with the support of the ILO. The Bangladesh University of Engineering and Technology (BUET) has inspected 471 factories, and rest of the factories in the initiative are to be inspected by two private sector companies, TUV SUD Bangladesh (Pvt.) Ltd and Veritas Engineering & Consultant (ILO, 2014c; ILO, 2015a; ILO, 2015b). Despite such progress in the assessment, the initiative is currently facing a number of difficulties in conducting the inspections. The difficulties include listing with incorrect address, factories in the list missing as a result of previous closures, and incomplete listing of factories (Moazzem, & Islam, 2015).

4.2 Implementation Mechanism of the Structural Assessment

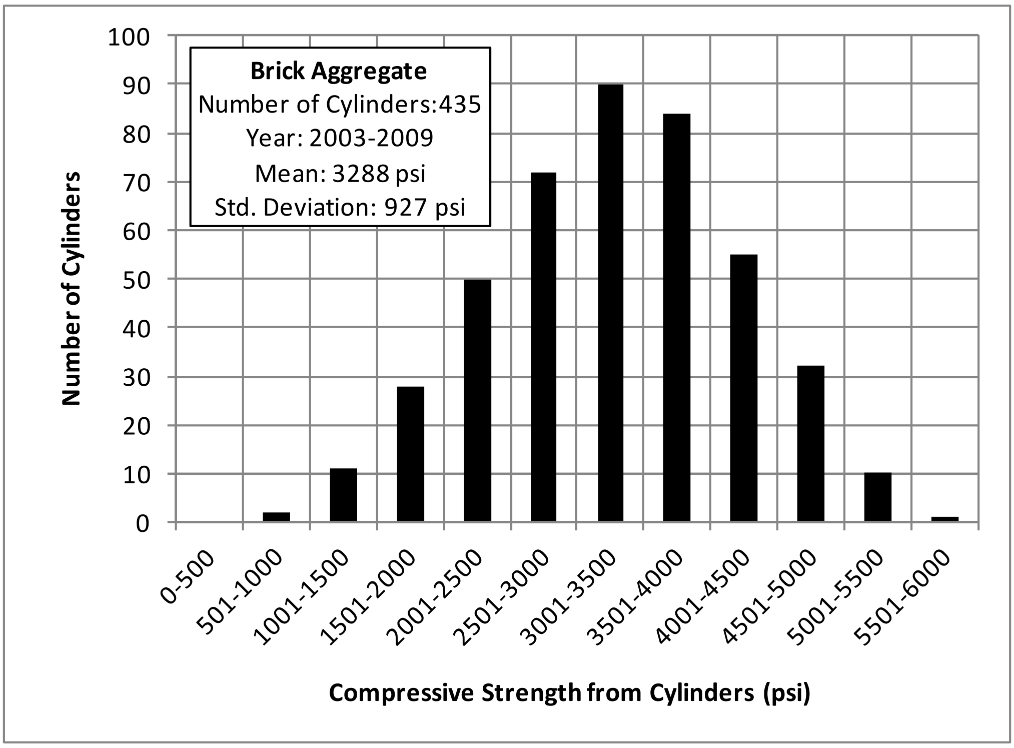
To undertake the structural assessment of factory buildings with common approach and standard, ILO brought together the technical experts (structural engineers, fire safety experts, etc.) from the BUET on behalf of the NTC, the Accord, and the Alliance. NTC endorsed 'Guidelines for Assessment of Structural Integrity and Fire and Safety' including harmonized standards developed by technical experts from the BUET, the Accord and the Alliance. The common steps for structural assessment of buildings housing RMG factories by team of expert are: visual inspection for identification of existence of any distress in the structure of a building, review of structural design drawings and soil investigation reports to assess the current use and loading pattern (if available), and assessment of immediate threat of collapse from current building use.

Firstly the columns for brick or stone aggregate concrete in the buildings were checked and recorded. In case of unknown column material, brick aggregate was assumed. For initial assessment of the column, equivalent concrete strengths for Stone Aggregate Concrete and Brick Aggregate Concrete were assumed 16.3 MPa (2365 psi) and 14.1 MPa (2045 psi) respectively. These two equivalent concrete strengths were estimated on the basis of the cylinder test results conducted at BUET Concrete Laboratory between 2003 and 2009 using equation (1). Figure 3 shows cylinder test results collected from BUET database between 2003 and 2009. Then the order of reinforcement is checked with a ferroscanner. In case of unknown number of reinforcement bar, it was assumed 1%.

$$f_{ceq} = Mean\ of\ the\ dataset - 1.34\ x\ Standard\ deviation\ of\ the\ data\ set \quad \text{..................} \quad (1)$$



(a) Cylinder test results for stone aggregate



(b) Cylinder test results for brick aggregate

Figure 3 Cylinder test results collected from BUET database between 2003 and 2009

For the assessment of immediate threat of collapse from current building use, the surveyors highlighted key columns and carried out simple calculations of working stresses to find out Factor of Safety (FOS). The FOS is Column Ultimate Strength divided by the Column Working Stress, where Column Ultimate Strength of the columns were calculated using equation (2) according to Bangladesh National Building Code (BNBC) (1993) and the Column Working Stresses were calculated comparing data set values and trigger points developed.

$$P_n = 0.8\phi[0.85f'_c(A_g - A_{st}) + f_y A_{st}] \quad \text{.......} \quad (2)$$

Here,

P_n = Ultimate Strength of a column

Φ = strength reduction factor (= 0.7)

f'_c = compressive (cylinder) strength of concrete

A_g = gross area of concrete section

A_{st} = area of reinforcement

f_y = assume 40 ksi (276 MPa) for steel before 2005 and 60 ksi (414 MPa) for steel after 2005

Based on FOS, four color codes have been proposed to be used indicating the required actions within certain time frame. After assessment if any factory is notified as hazardous, the respective assessment teams let the review panel of Bangladesh government know about the factories to carry on further assessment by inspection team and take final decision regarding the closure of the factory. Table 1 shows the color codes based on FOS of columns along with required actions within time frame.

Table 2: Color codes based on FOS of columns along with required actions within time frame structural assessment of buildings housing RMG factories

Factor of Safety (FOS) of column	**Color codes**	**Description**	**Required action**	**Time frame of action**
Below 1.25	Red	Critical visible defects resulting in immediate danger to structure and workers.	Require careful review. Take actions to increase FOS by reducing load less than the minimum load on any floor, i.e. 1kN/m² or 20psf. If FOS is still below 1.25, then evacuate the facility immediately considering expert opinion.	Start Detailed Engineering Assessment (DEA) immediately.
Between 1.50 and 1.25	Amber	Significant visible defects with no immediate danger to structure or workers.	No reason to suspend operations in the facility. Production may continue subject to agreement to address issues raised and actions prioritized locally in report.	Require DEA within six weeks
Between 1.86 and 1.5	Yellow	Limited visible defects with no immediate danger to structure or workers.	Production may continue subject to agreement to address issues raised and actions prioritized in report.	Actions and core test within 6 months
Better than 1.86	Green	No critical visible defects or structures and no visible immediate risks to workers.	Generally all clear subject to agreement to address prioritized comments. Production can continue.	No immediate actions required.

Requirement of Detailed Engineering Assessment is decided based on FOS values of factory buildings. Other 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. Core tests are essential actions for factory buildings falling under red, amber and yellow category to gradually improve the state of building and reach to green category. For the purpose of core test at least four, three inch diameter core samples have to be collected and tested, and ACI 562 (2013) will be used to estimate equivalent concrete strength from those core data.

After each inspection, preliminary assessment reports are prepared including the findings along with required recommendations for the building owner and user according to the assessment results, i.e. Detailed Engineering Assessment (DEA) of the building involving soil investigation, other non-destructive tests and 3D building modeling.

4.3 Findings from RMG Factory Buildings' Structural Assessments

Starting from June 2013 until February 2015, 4552 core samples of 825 factory buildings were collected and tested at BUET's Concrete Laboratory. Figure 4 shows year wise distribution of the buildings along with their storey numbers from which core samples are tested at BUET. Out of these 825 factory buildings, 12 are built before 1980, 198 are built between 1980 and 2000 and the rest after 2010. Approximately, 52% of those factory buildings are constructed after 2005. Figure 5 shows representative of factory buildings by their construction year. This represents the types of the factory buildings constructed at different time frames. Again, Figure 6 shows distribution of these core test results. Out of these data, 2673 are of brick aggregate with mean strength of 2805 psi (19.3 MPa) and standard deviation of 1231 psi (8.5 MPa), and 1823 are of stone aggregate with mean strength of 3312 psi (22.8 MPa) and standard deviation of 1320 psi (9.1 MPa).

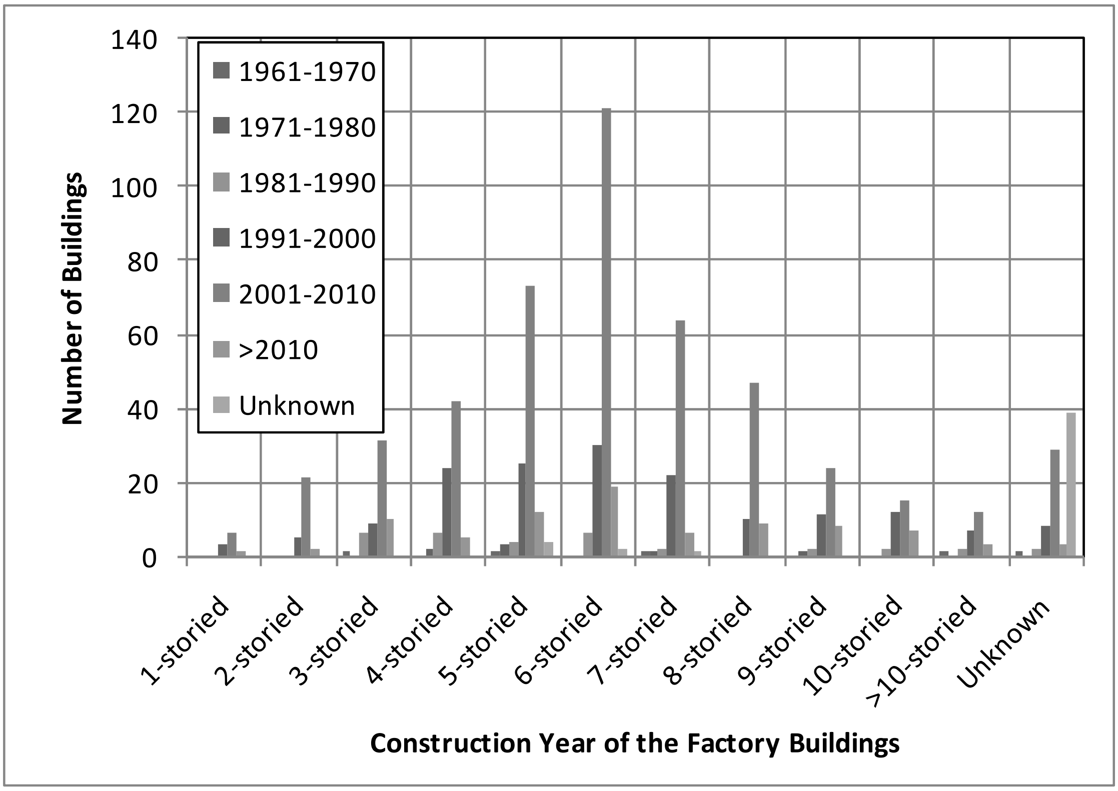


Figure 4: Year wise distribution of factories from which cores are collected

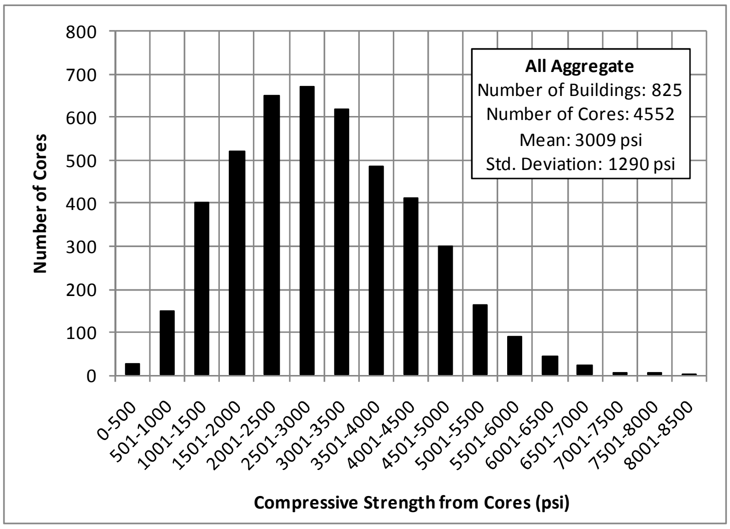
(a) Construction Year: 1984

(b) Construction Year: 1992

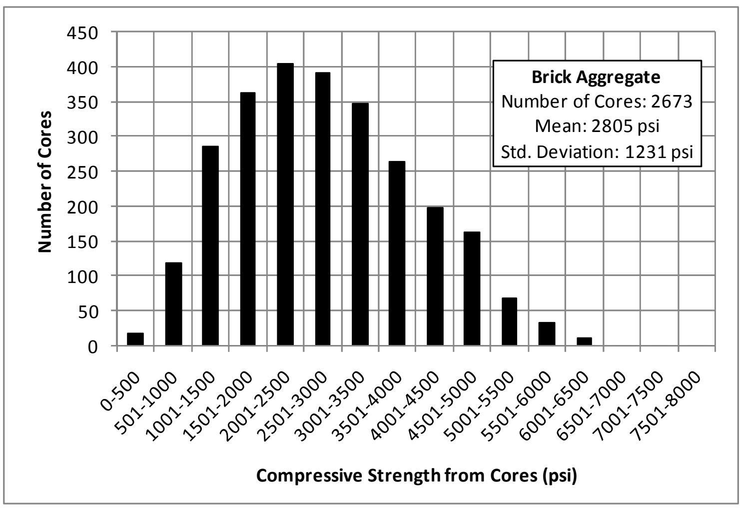
(c) Construction Year: 2002

(d) Construction Year: 2012

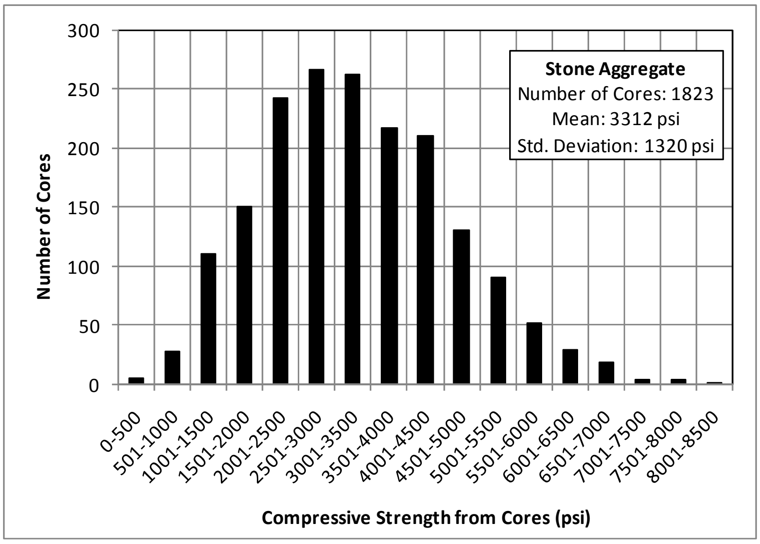
Figure 5: Representative of Factory Buildings by their Construction Year



(a) Core test results for all aggregates



(b) Core test results for brick aggregate



(c) Core test results for stone aggregates

Figure 6: Core tests performed at BUET Laboratory between 2013 and 2015

Figure 7 shows the structural assessment results conducted by different team and Table 3 shows Review Panel decisions to different cases. A total 65 factories were referred to Review Panel, out of which 29 factories located in 12 buildings were closed, 17 factories located in 10 buildings were partially closed and 19 factories located in 12 buildings were allowed to operate (Table 3). Till March 2015, summary reports of 474 RMG factories assessed by the Accord were available in DIFE website, among which majority (274) fall under amber category, and 11 fall under red category (Figure 7). The Accord brought 38 immediate risk cases to the review panel, elected to fully close eight factories, partially close 24 and allow six to operate with reduced loads (Table 2). Again, till March 2015, summary reports of 122 RMG factories assessed by the Alliance were available in DIFE website, among which majority (93) fall under amber category, and nine fall under red category (Figure 7). The Alliance brought 25 immediate risk cases to the review panel, elected to fully close four factories, partially close eight and allow 13 to operate with reduced loads (Table 2). Till December 2014, assessments of 618 factories have been conducted under the National Initiative by BUET covering 471 factory buildings. Among those, majority of the buildings (279) fall under green category, and four fall under red category (Figure 7). Among the immediate risk cases two were brought to the Review Panel which elected fully close one factory and partially close one (Table 2).

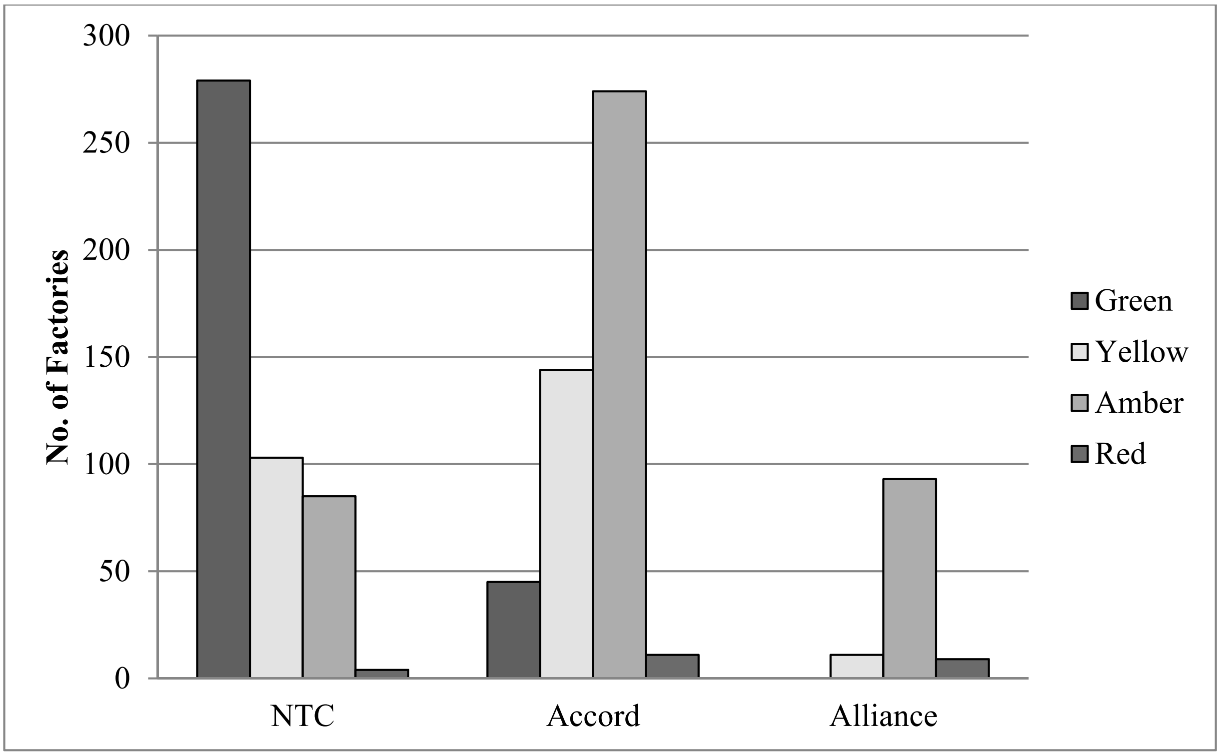


Figure 7: Structural assessment results by different team

Table 3: Review Panel decisions to different cases of Building Assessment

Decision	NTC		Accord		Alliance		Total		No. of workers affected
	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 Review Panel	2	2	38	18	25	14	65	34	20724
Partially closed	1	1	8	5	8	4	17	10	1530
Closed	1	1	24	9	4	2	29	12	15093
Decision pending	0	0	0	0	0	0	0	0	0

Inspection pending	0	0	0	0	0	0	0	0	0
Allowed operation	0	0	6	4	13	8	19	12	4101

Source: Adopted from DIFE, 2014

4.4 Recommendation Regarding Structural Assessment

According to the assessments by different parties, the common problems faced by the factories regarding safety hazards are: lack of fire doors and fire exits, inadequate fire alarm systems, inadequate fire separations and protected exits, lack of lateral stability in structure, lack of accurate structural drawing, inadequate space for electrical installations (i.e. substations), etc. To make the weak factory building resilient by removing the problems, the Corrective Action Plan, Detailed Engineering Assessment and Retrofitting have to be undertaken immediately in accordance with the initial assessment report under the NTC.

4.4.1 Corrective Action Plan (CAP)

Corrective Action Plan (CAP) is the plan for action to be prepared by each factory to address and correct the problems found out in the initial structural assessment of the factory building. It is very important to eliminate or reduce the problems within significant extent to ensure structural safety. Figure 7 shows comparative status of different issues of Accord, Alliance and NTC and Figure 9 shows the Assessment Workflow of Alliance. The Accord and The Alliance have already started this process. By now 598 CAP have been approved by Accord (Bangladesh Accord, 2015b). All factories under the Alliance are now in the process of addressing safety concerns and updating safety equipment and close to 300 factories have approved CAPs (Alliance for Bangladesh, 2015). Alliance has also published a protocol regarding this issue (Alliance for Bangladesh, 2014).

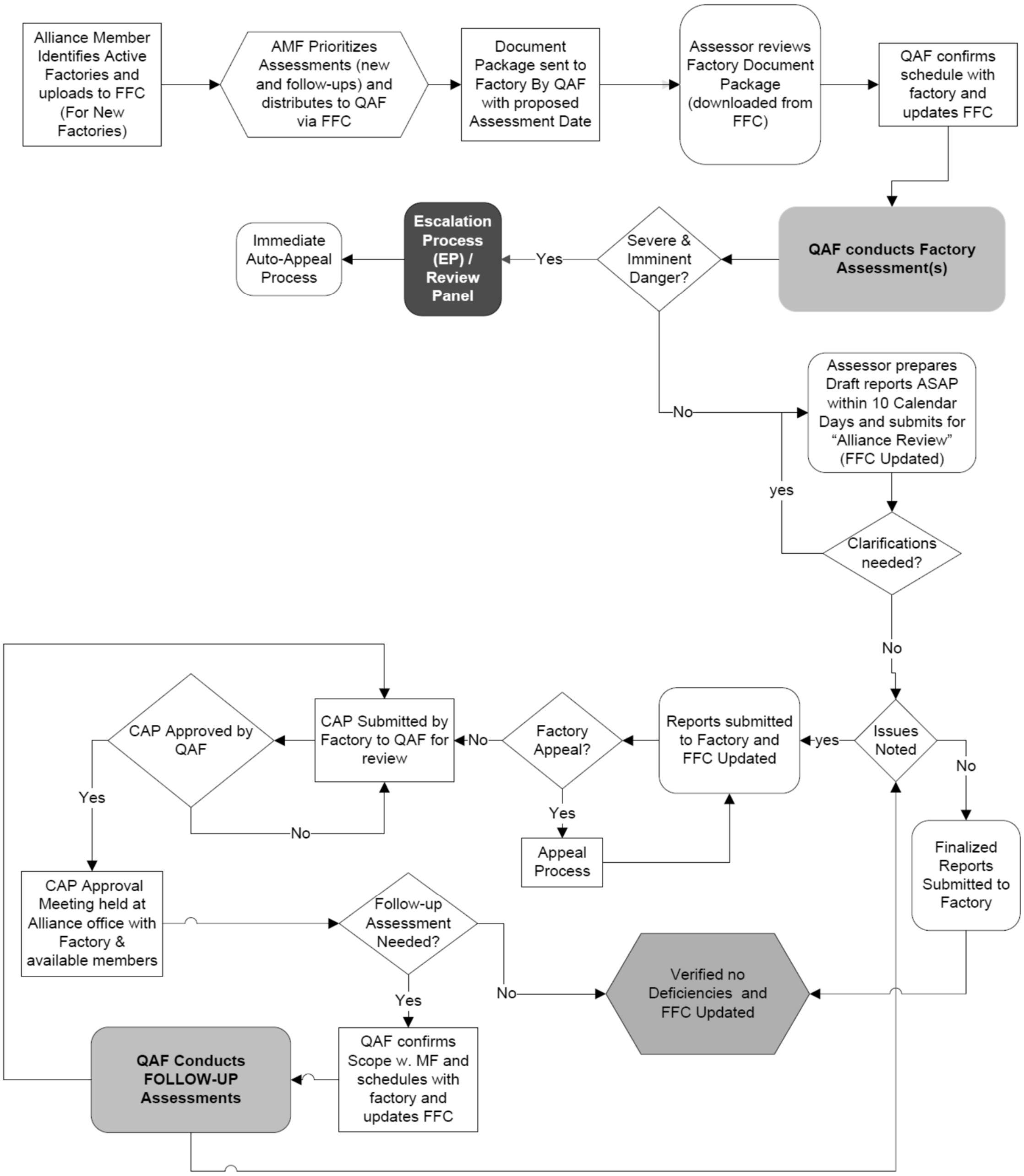


Figure 9: Assessment Workflow of Alliance (Source: Alliance for Bangladesh, 2014)

In contrary, no CAP has been prepared under National Initiative by now. Recently a task force has been formed at the beginning of January 2015 headed by Inspector General (Additional Secretary) of DIFE along with two professors from BUET, one director from RAJUK, and one director from Fire Service and Civil Defense (FSCD). The Terms of Reference (ToR) includes regular inspection of the factory buildings to inspect whether the factories follow the recommendations accordingly, Detailed Engineering Assessment (DEA), and preparation of CAP. The time limit has been bound to 30 March, 2015 for short listing of the firms or companies to undertake the activities.

NTC has also approved a CAP process for the NTC assessed factory buildings composed of five main steps. Firstly, the inspection reports will be shared with factory owners to propose an outline CAP and firm for DEA (within the short-listed DEA firms by the DIFE Task Force) after review of the inspection report within maximum two weeks. Secondly, the outline of the CAP will be approving with two weeks through joint meeting between Factory Technical Team and the Initial Assessment Team. Thirdly, the approved firm will conduct DEA to prepare report containing detail remediation scheme within six to twelve weeks and submit it for review and comments by the DIFE Task Force. Fourthly, the DIFE Task Force will review the DEA along with remediation scheme and send comments to the factory owner within two weeks after receiving the DEA report. After revision of DEA and remediation scheme by the approved firm, it will be submitted to DIFE Task Force for final approval within maximum two weeks.

4.4.2 Detail Engineering Assessment (DEA)

Detail engineering assessment is required to have in-depth understanding of the condition of the structure. It also identifies inadequate structural members (if any) with respect to capacity as per code. In addition to that the condition of the structure can be assessed for different loading conditions. As per Alliance, Accord, and NTC guideline (NTPA, 2013) DEA is required if the visual or initial assessment found structural distress in main load-carrying members, apparently inadequate main structural members for both vertical and lateral load, or extension beyond design drawing or permission. Accord (2014) and Alliance (2014) have published their own protocol regarding DEA. The typical Steps for the assessment are shown below. The steps may vary according to the level of assessment and information available.

- Prepare As-built Architectural and Structural drawings, if not available already. The as-built drawing shall show the structural, non-structural elements with dimensions at all levels, foundations and framing on plan, section and elevation, and cross-sectional drawings showing reinforcements in foundations, columns, beams, slabs etc. If as-built drawings are available – verify if it truly represents the structure. As-built drawing shall be prepared/ checked as per NTC Guideline (NTPA, 2013)

- Scanning of rebars in main structural elements of lower tiers to confirm as-built condition.
- Confirm bar size by drilling 50mmx 50mm holes at rebar location.
- Arrange confirmatory soil test (2 to 3 borings).
- Spot check of foundation by excavation, if necessary.
- Identify causes of any physical distress, dampness or any other abnormalities and suggest remedial measures.

- Work on specific items of concern identified in the initial structural assessment report
- Identify any overloading, additions, extensions, presence of water tanks, towers. Study their effect on the structure and suggest remedial measures.
- Arrange for core test by taking 4 Nos. 3 inch cores (preferably from columns) to assess in situ strength ensuring sample reliability, testing of cores in approved laboratories only, and proper interpretation of core test results considering various factors as per ASTM C42-90.
- Use ACI 562 to find equivalent concrete strength to be used in design checking
- UPV tests may also be conducted with proper calibration.
- Prepare structural model as per As-built drawing using appropriate software by following the standard practice and building code.
- Obtain reliable data on steel grade or arrange testing of steel rebar (if possible) or assume 40 grades conservatively for using in all analysis/design adequacies.
- Use loading and Load factors as per standard (NTPA, 2013).
- Check strength and serviceability requirements as per Bangladesh National Building Code (BNBC, 1993).
- Make recommendation(s) based on results of DEA– including restriction of loading, restriction on vertical extension.
- In case of deficiency in structural integrity of the structure(s), appropriate retrofitting scheme is to be designed.
- Prepare Load Plan and arrange posting of load plan and approve it.
- Submit report for review by the Engineering Team

4.4.3 Retrofitting

Retrofitting is the modification of existing structures to make them more resistant and safe. In case of factory buildings, retrofitting will have to be carried out as per the DEA. The DEA of factory buildings will incorporate a full structural evaluation of the building, as well as investigation of ways to improve the factory buildings based on several defining criteria (Accord, 2014). In case of retrofitting, the requirements of BNBC are to be adhered to as much as possible, although it recognized that in some cases a fair judgment must be made as to how much a building can be improved based on its existing condition, as well as how economical it will be to satisfy every design criteria as stipulated by code requirements. The overall strategy will be generally as follows based on a hierarchical principle of increasing compromises:

a) Follow strictly the code design requirements to assess the actual deficiency of the building under analysis.

b) Determine all possible requirements, and which compliant factors can be relaxed in order to achieve a minimum level of compliance of another factor which does not comply (for example, the relaxation of floor loading in order to achieve a reasonable level of punching shear resistance when taking into account lateral loads which cause unbalanced forces within the structural system)

c) Propose a comprehensive remedial plan based on the extent of works and the practicality of carrying them out cost-effectively. Prepare alternative retrofitting schemes to remedy the structural deficiency. Discuss with the owner about construction issues and cost. Decide the most optimum retrofitting option.

d) Submit Retrofitting Scheme for review by the Assessment Team.

e) Supervise retrofitting work during construction for quality control and certify the structural integrity/safety after construction as per the provision of the Remediation and Oversight Protocol.

In some cases, situation may arise at which the results of the analysis may have the possibility of rendering certain buildings completely unfit for purpose, and the extent of remedial works may be too much and too complicated to implement. In such cases, it should be decided whether or not partial or complete demolition and reconstruction should be considered as a single viable option.

5. Conclusions:

There is no denying that Bangladesh has progressed a lot since two years after Rana Plaza collapse in terms of achieving workplace safety compliance issues in RMG industry, under three plans of actions - National Tripartite Action Plan (NTPA), the European Union Sustainability Compact, and the United States Trade Representative (USTR) Plan of Action. Among 25 commitments under the National Tripartite Plan of Action on Fire Safety and Structural Integrity (NTPA), 16 have been fully or substantially completed and nine have been partly completed. Among a total of twenty nine listed activities in the EU Sustainability Compact, 15 actions have been fully or substantially completed, 13 actions have been partly completed, and one action regarding encourage retailers and brands to adopt and follow a unified factory audit code of conduct in Bangladesh has not been initiated yet. The United States Trade Representative (USTR) proposed a sixteen-point action plan, where substantial progress has been made in regards to twelve of the actions and greater progress is required in regards to four actions.

In all three plans of actions, structural assessments of buildings housing RMG factories have been given importance, with regard to which substantial progress has been made, i.e. up gradation of Chief Inspector of Factories and Establishment office to DIFE, sanction of 679 new staff positions including 392 new, organization of training program for capacity building of the newly recruited inspectors, development of Guidelines for Assessment of Structural Integrity and Fire and Safety including harmonized standards, establishment of a review panel along with a review mechanism to handle urgent safety issues in garment factories, initiation of assessments of the structural integrity and fire safety of RMG factory buildings, and creation of publicly accessible database of all RMG factories as a platform for reporting labour, fire and building inspections. Till December 2014, assessments of 618 factories have been conducted under the National Initiative by BUET covering 471 factory buildings. By March 2015, assessment of approximately 1500 factories have been done among 1600 factories by the Accord which houses approximately 1.9 million workers and 507 factory assessment summary reports are available in DIFE website which are housed in 474 buildings. To date, every factory producing for Alliance Members, i.e. 647 factories have been inspected which houses approximately 1.1 million workers. Among these 122 factory assessment summary reports are available in DIFE website which are housed in 113 buildings.

Still there are nearly 1000 factories remaining for assessment under national initiative. The reason for such delay is that NTC is facing a number of difficulties in conducting the inspection. The main difficulty remains in the list of factories provided by BGMEA and BKMEA, based on which the assessments have been carried out. The list contains factories with wrong address causing delay in locating the factories and some enlisted factories do not even exist. Moreover, there remain some factories which are not member of any organizations such as BGMEA and BKMEA. So, the list of factories is required to be updated and verified internalizing the remaining factories to ensure quick completion of the assessment.

On the other hand, structural 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 through different initiatives, i.e. preparation on Corrective Action Plan based on the assessment findings, Detailed Engineering Assessment as proposed in the initial assessment report, and retrofitting as requirement. The Accord and the Alliance have showed much progress in preparation of CAP, but no CAP has been prepared under National Initiative so far. So, immediate actions are required by NTC to address the issues.

After Rana Plaza tragedy, there was a strong apprehension that RMG sector would confront a challenging time, but the sector has performed better than other competing countries in post Rana Plaza Tragedy period. In the long run, the challenge is to maintain momentum already created for achieving sustainability in RMG sector in Bangladesh. The future competitiveness in the sector will depend on adjustment with rising operational cost towards maintaining compliance. If the industry wants to achieve the export target of USD $50 Billion by 2021, all the factory buildings identified to be structurally unsound will have to be structurally strengthened within the next five years.

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BANGLADESH NETWORK
OFFICE FOR URBAN SAFETY

PART-VIII

COMPARISON BETWEEN WEAK AND STRONG GROUND MOTIONS AT SELECTED LOCATIONS OF BANGLADESH

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

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DATA COLLECTION AND ANALYSIS

Damage in recent earthquakes showed that local site conditions have a significant effect on ground motion. Site response studies play an important role in seismic microzonation studies. The application of microtremor is to determine dynamic characteristics (predominant frequency and amplification factor). Microtremor measurements are usually used in site characterization due to their simplicity, low cost and minimal disturbance to other activities.

In the traditional spectral ratio method, H_S/H_r, site and source effects are estimated from observation at a reference site. In practice, adequate reference site are not always available especially in flat areas where exposed rock is not available. Therefore, methods have been developed that do not need reference sites (Bard 1994). Several recent applications of this technique have proved to be effective in estimating predominant frequency (Field and Jacob 1993; Ohmachi et al. 1994) and amplification factors (Lermo and Chavez-Garcia 1994; Konno and Ohmachi 1995).

Several methods have been proposed for spectral calculation of ground motions including microtremor. Fourier spectrum is the most convenient one that is used widely. Some investigations showed that different methods give similar results (Dimitriu et al. 1998). However some researchers declare that a suitable spectral method gives more reliable results (Ghayamghamian and Kawakami 1997). That's why five segments of spectra have been selected to compute the mean segmental cross spectra. Standard deviation of mean has also been calculated to show the deviation of mean value from Fourier spectra in East-West and North-South direction. Among these locations, empirical soil correlations developed by Ansary et al. (2010) and other empirical correlations (After TC4, ISSMFE, 1993) have been used to convert SPT-N value to shear-wave velocity.

STUDY LOCATIONS

29 SMAs have been deployed by BUET from 2003 to 2005 and all these digital seismic measuring device are located free-field stations around Bangladesh as shown Figure 3.1. Out of these 29 locations, 6 are selected for this research. Microtremor Array of six points have been collected.

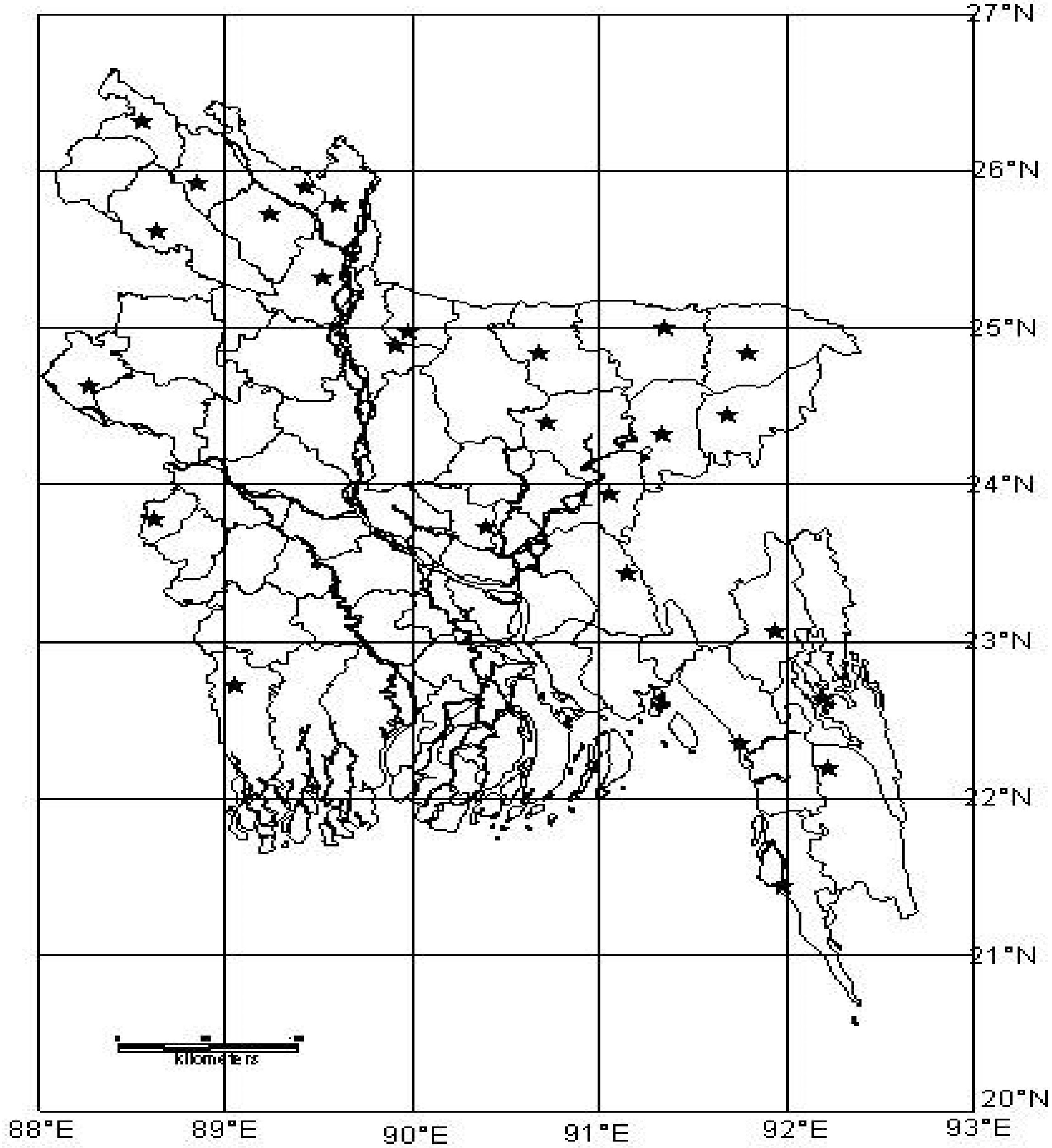

Figure 3.1 Location of Digital Seismic Measuring Devices (29-ETNA) in and around of Bangladesh

Location of Digital Seismic Measuring Device free-field Station (ETNA) as shown Table.1

Table 1 Location of Digital Seismic Measuring Device Station (ETNA)

SL.No	Model	Location	Latitude	Longitude
*1	ETNA (BUET)	LGED, Bogra	23.32^0N	88.45^0E *
*2	ETNA (BUET)	LGED, Natore	23.22^0N	88.35^0E *
3	ETNA (BUET)	Jamuna Bridge West-End	23.28^0N	88.25^0E
*4	ETNA (BUET)	Jamuna Bridge East-End	23.25^0N	88.20^0E *
5	ETNA (BUET)	LGED, Mymensingh	25.43^0N	90.65^0E

SL.No	Model	Location	Latitude	Longitude
*6	ETNA (BUET)	BUET-Dhaka	23.92^0N	90.25^0E *
7	ETNA (GSB)	PWD Office, Satkhira	23.85^0N	88.52^0E *
*8	ETNA (GSB)	PWD, Ashkona-Hajji camp	23.71^0N	90.38^0E *
*9	ETNA (GSB)	Pollice Staff College	23.72^0N	90.25^0E
10	ETNA (GSB)	GSB-Dhaka	23.75^0N	90.35^0E
11	ETNA (GSB)	GSB-Chittagong	22.15^0N	91.80^0E
12	ETNA (GSB)	PWD, Cox's-bazar	21.42^0N	91.89^0E
13	ETNA (GSB)	PWD, Bandarban	22.25^0N	92.32^0E
14	ETNA(JIDPUS)	PWD, Rangamati	22.72^0N	92.38^0E
15	ETNA (GSB)	PWD, Sunamganj	25.07^0N	91.32^0E
16	ETNA (GSB)	PWD, Sylhet	25.15^0N	91.25^0E
17	ETNA (GSB)	PWD, Moulvibazar	24.35^0N	91.72^0E
18	ETNA(JIDPUS)	PWD, Comilla	23.22^0N	91.35^0E
19	ETNA (GSB)	PWD, B.Baria	23.92^0N	91.25^0E
20	ETNA (GSB)	PWD, Kishoreganj	24.35^0N	90.92^0E
21	ETNA (GSB)	PWD, Netokona	24.72^0N	90.65^0E
22	ETNA(JIDPUS)	Haluaghat, Mymensingh	25.05^0N	90.25^0E
23	ETNA(GSB)	PWD, Jamalpur	25.15^0N	90.12^0E
24	ETNA(GSB)	PWD, Rangpur	25.80^0N	89.20^0E
25	ETNA (GSB)	PWD, Lalmonirhat	25.90^0N	89.35^0E
26	ETNA(JIDPUS)	PWD, Kurigram	25.60^0N	89.80^0E
27	ETNA (GSB)	PWD, Panchagarh	26.15^0N	88.25^0E
28	ETNA(GSB)	PWD, Meherpur	23.75^0N	88.62^0E
29	ETNA(JIDPUS)	Ruppur, Pabna	23.42^0N	88.75^0E

*Microtremor observations have been made

SOME EARTHQUAKES HAVE AFFECTED BANGLADESH OF THE LAST DECAY

On May 25, 2015 the major "Nepal earthquake" occurred in Pokhara province, Nepal. Its Magnitute is 7.8 and distance 741 km from Dhaka, Bangladesh. This earthquake been recorded by the free-field stations at Kurigram, Bogra, Natore, Sylhet, Ruppur at Pabna, Jamuna Bridge at Sirajganj, Police Staff College, at Mirpur, and BUET-Dhaka at 12:15:45 hrs BST (06:15:45 hrs GMT, May 25, 2015). The maximum acceleration of this earthquake recorded in Bogra with a values of 23.56 cm/sec.^{2} in East-west direction. Some major earthquakes that have affected Bangladesh recently is shown in Table 2

Table 2 Some earthquakes that have affected in and around Bangladesh

Date	Name	Epicentre	Magnitude (M)
14-02-2006	Sikim Earthquake	Bihar, India	5.9
16-11-2006	Bengal Earthquake	Jessore, Bangladesh	5.5
11-09-2010	Assam Earthquake	Shillong Plateau	5.1
18-03-2012	Sikim Earthquake	Jantia Hill, Assam	7.1
25-04-2015	Nepal Earthquake	Pokhara, Nepal	7.8

METODOLOGY OF EARTHQUAKE AND MICROTREMOR DATA ANALYSIS

At first, site is selected for data collection. There are six selected locations Bogra, Natore, Jamuna Bridge at Sirajganj, Haji-Camp at Ashkona, Police Staff College at Mirpur and BUET. Both microtremoe and earthquakes data have been recorded along three directions (x, y and z directions). Fast Fourier Transformation (FFT) along x, y, and z directions and their H/V Ratio analysis with frequency are conducted. Ultimate target is to etimation of predominant frequency of these site from HVR of Microtremor and Earthquakes analysis. The following flow chart (Figure 2) shows the outline of the Metholodogy.

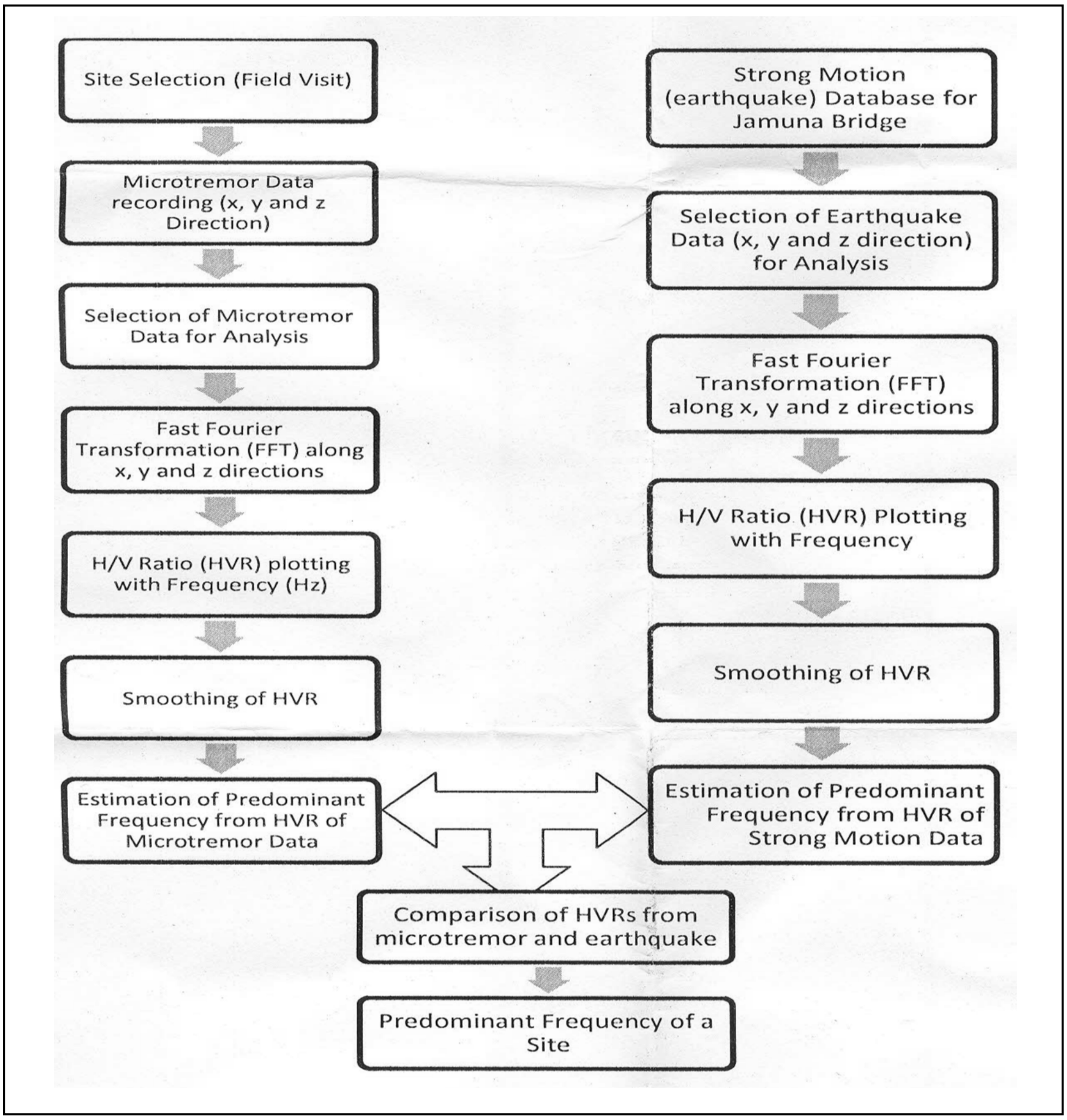

Figure 2 Flow Chart for Microtremor and Strong Motion Data Analysis.

MICROTREMOR AND EARTHQUAKE DATA ANALYSIS, RESULTS AND DISCUSIONS

The transfer function of the shear wave (the surface motion versus the incidental motion at depth) has been calculated using the soil models. For the calculation of transfer function of shear-wave and a damping ratio of 2% has been used, assuming input motion at the outcrop. Comparision between predonant frequency and H/V ratio six selected locations at Bogra as shown Figure 4.1. Similarly Natore, Jamuna Bridge East at Sirajganj, Haji-Camp at Ashkona, Police Staff College at Mirpur and BUET-Campus as shown Figure 4.2 to 4.6

Figure 4.1 and Figure 4.2 show the typical graphs for comparison of amplitude ratio between predominant frequency and H/V ratio of microtremor and earthquake. On the other hand, microtremor and earthquake H/V ratio curve has been found from the Horizontal to Vertical spectral ratio (H/V) of Fourier spectra.

From the comparison of microtremor and earthquake, four types of characteristics curves have been observed. These curves are classified as similar, dissimilar, right side shifted and left side shifted and compared to the microtremor and earthquake H/V ratio curve. Among four models two transfer function have been shifted in the right side of microtremor and only one has been shifted in the left side. There are two sites curves have similar pattern. The rest one site have been found where no similarity between microtremor within earthquake H/V ratio.

Figure 4.1 shows the comparison of amplitude ratio between predominant frequency and H/V ratio of microtremor and earthquake microtremor at Bogra. The amplitude ratio of earthquake is similar to microtremor H/V ratio. However, peak of H/V has been moved into right side slightly. The amplitude ratio of both curves is around 3.36 and 6.67. The predominant frequency of microtremor is 1.68 Hz and H/V ratio is 3.36. Similar curves between earthquake and microtremor have been found in four locations which are shown in Figure 4.1.

Figure 4.2 demonstrates that the peak amplitude ratio has been moved toward right side of microtremor at Natore. But, the peak value of transfer function is lower amplified than microtremor H/V ratio. The predominant frequency of microtremor is 1.07 Hz and H/V ratio is 3.68. On the other hand, peak H/V ratio of earthquake is 6.67 and predominant frequency is 2.10 Hz. The similar types of right shifted and lower amplified locations have been observed.

Figure 4.3 shows that amplitude ratio of microtremor is higher than earthquake at Jamuna Bridge East site. The predominant frequency of microtremor is 1.04 Hz whereas the earthquake is 0.83 Hz. The H/V ratio of microtremor is 4.66 and earthquake is 8.44.The similar pattern of curves between microtremor and earthquake have been observed.

The dissimilarity between earthquake and microtremor H/V ratio has been found in Figure 4.4 at Ashkona Haji-Camp, Dhaka. The predominant frequency and amplitude ratio of microtremor is 2.84

Hz and earthquake is 1.71 Hz where as H/V ratio is 3.02 and 11.41. Figure 4.5 demonstrates that amplitude ratio of transfer function is right shifted at Police staff college, Mirpur-Dhaka. The predominant frequency and H/V ratio of microtremor is 1.35 Hz and earthquake is 1.25 Hz. The H/V ratio of microtremor and earthquake have been found 3.24 and 7.65.

The similar predominant frequency but higher amplification has been found in Figure 4.6 at BUET-Campus. The predominant frequency in microtremor is 1.21 Hz and earthquake is 0.90 Hz. The peak H/V ratio of microtremor is 5.46 Hz whereas the earthquake is 6.32..

From these result, it can be said that although amplitude values of the ratios are close, the predominant frequency for the two cases differs slightly. The reason of this difference is that microtremor consists of different types of waves, but the earthquake based on shear-wave velocity only. Microtremor results may be more similar pattern of earthquake but more different its H/V ratio. Compare of average and smoothed HVR in Microtremor and Earthquake at Bogra as shows Figure 4.1 and Similarly at Natore, Jamuna Bridge East at Sirajganj, Haji-Camp at Ashkona, Police Staff College at Mirpur and BUET-Campus as shown in Figure 4.2 to 4.6

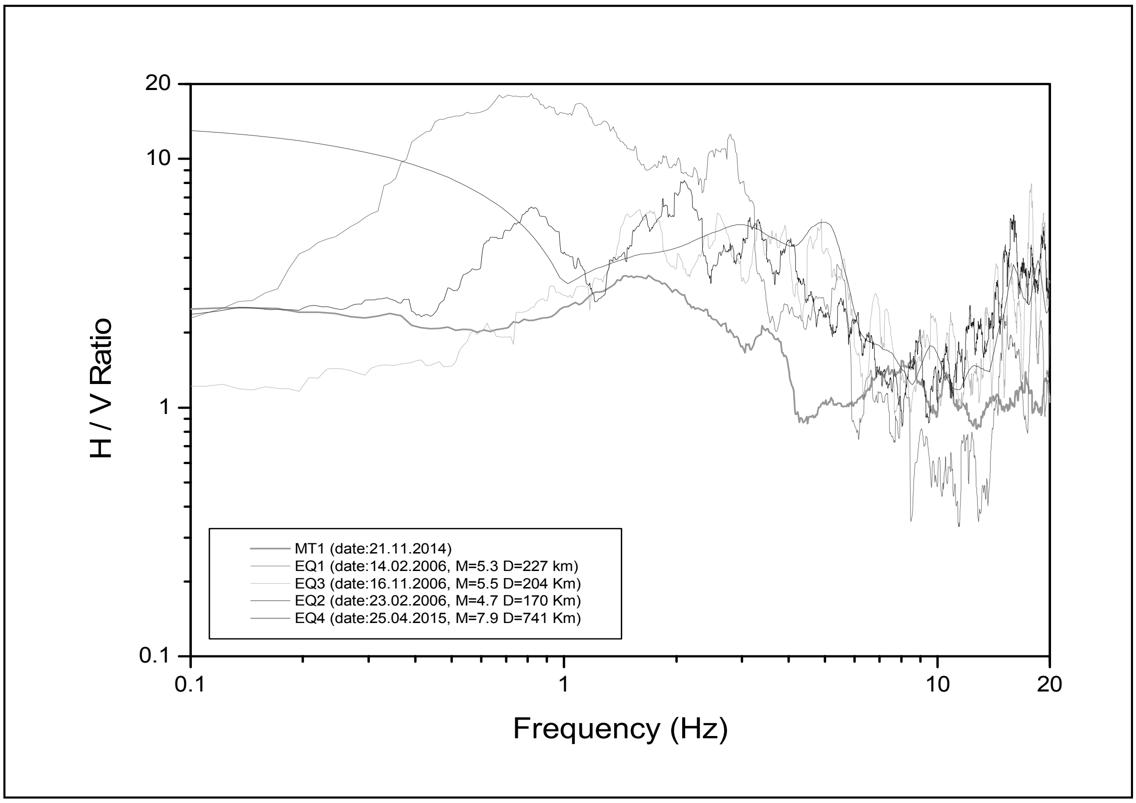

Figure 4.1 Compare of Average and Smoothed HVR in Microtremor and Earthquake at Bogra LGED office, Bogra.

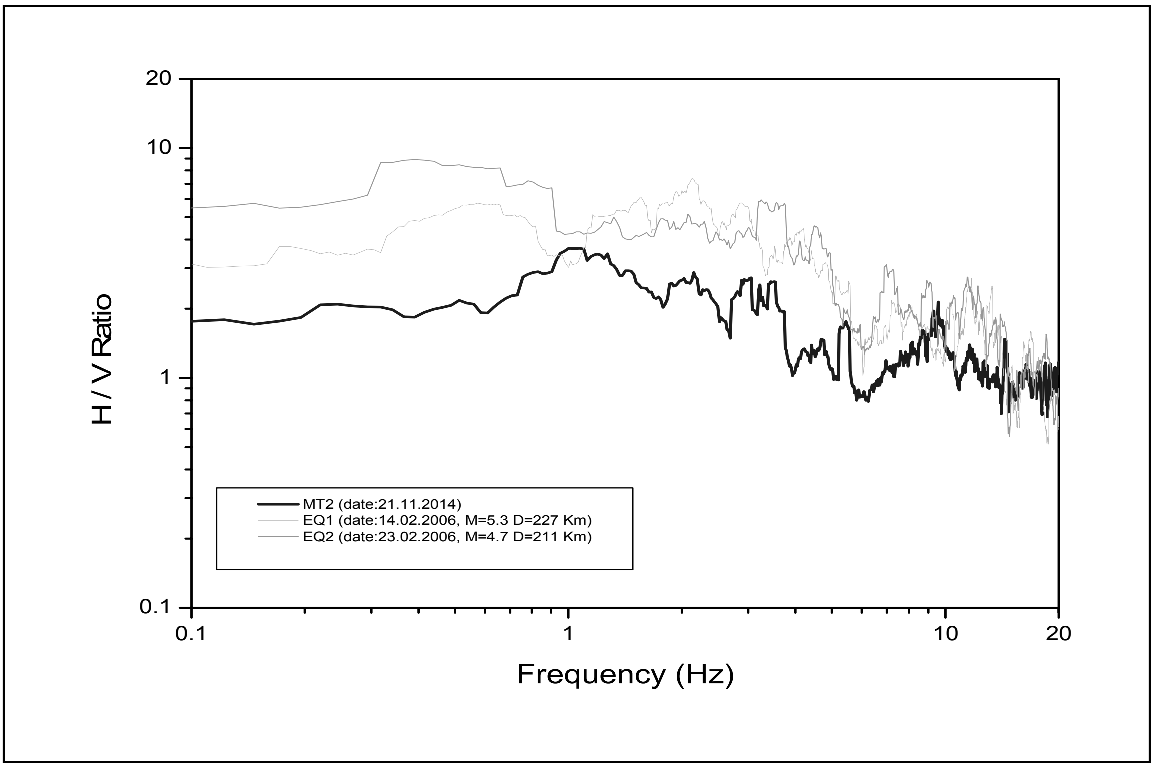

Figure 4.2 Compare of Average and Smoothed HVR in Microtremor and Earthquake at Natore

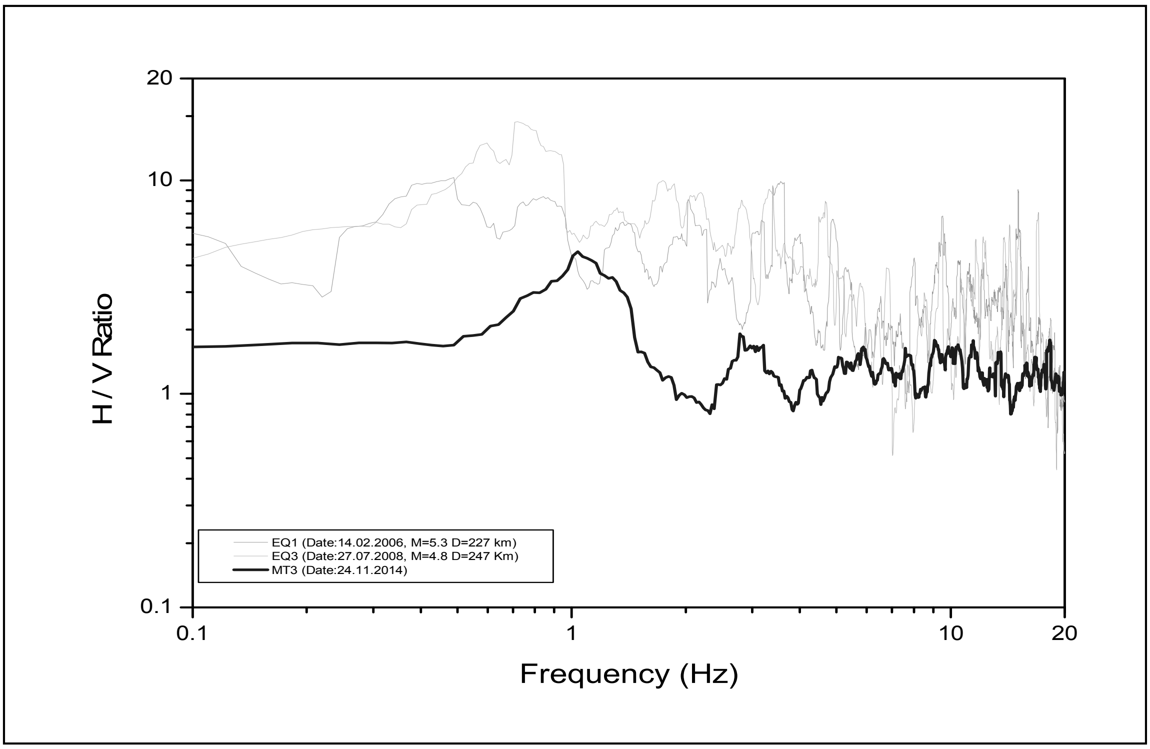

Figure 4.3 Compare of Average and Smoothed HVR in Microtremor and Earthquake in the Jamuna Bridge East at Sirajganj

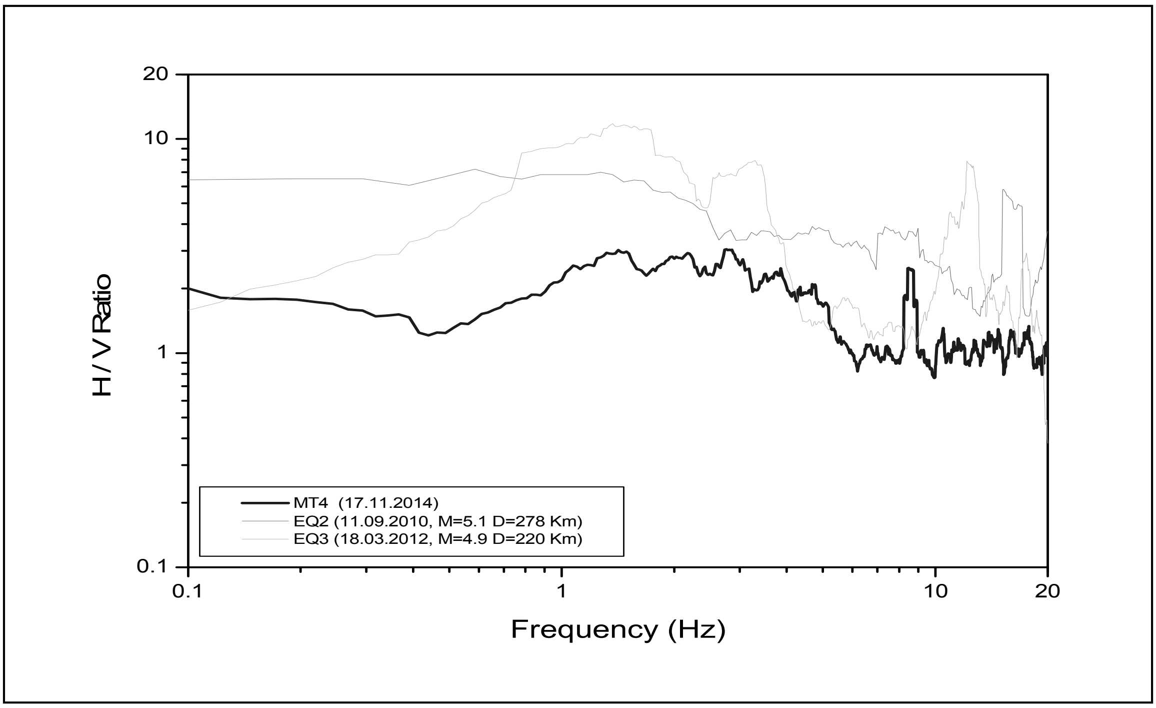

Figure 4.4 Compare of Average and Smoothed HVR in Microtremor and Earthquake in the Haji-Camp at Ashkona.

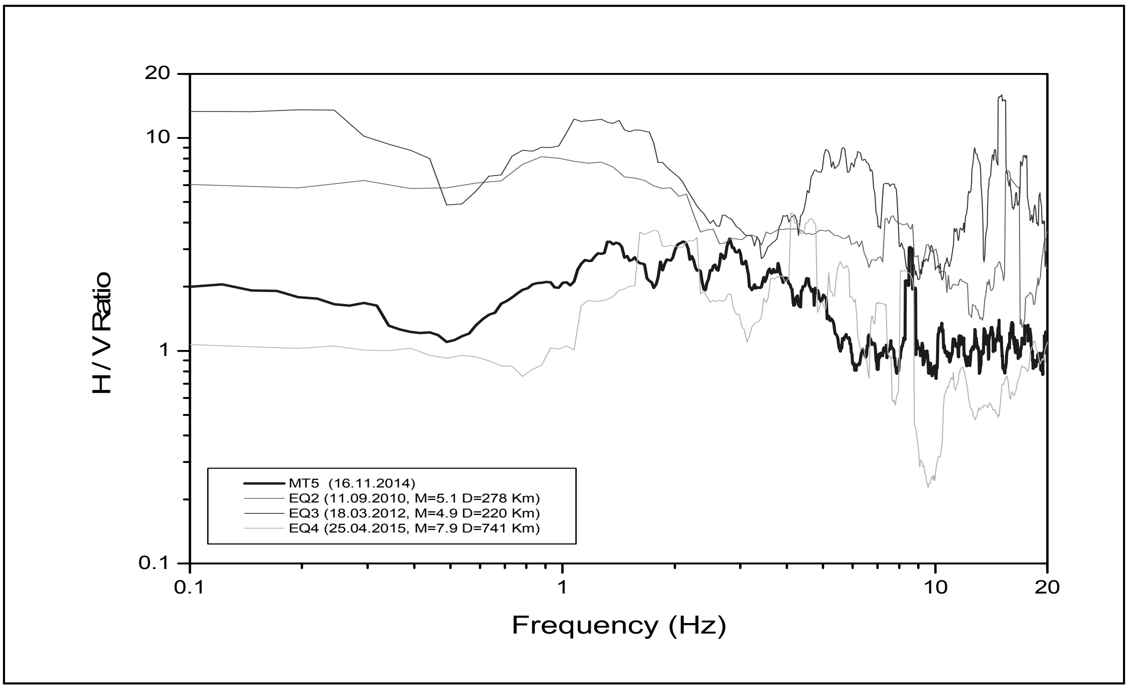

Figure 4.5 Compare of Average and Smoothed HVR in Microtremor and in the Police Staff College at Mirpur.

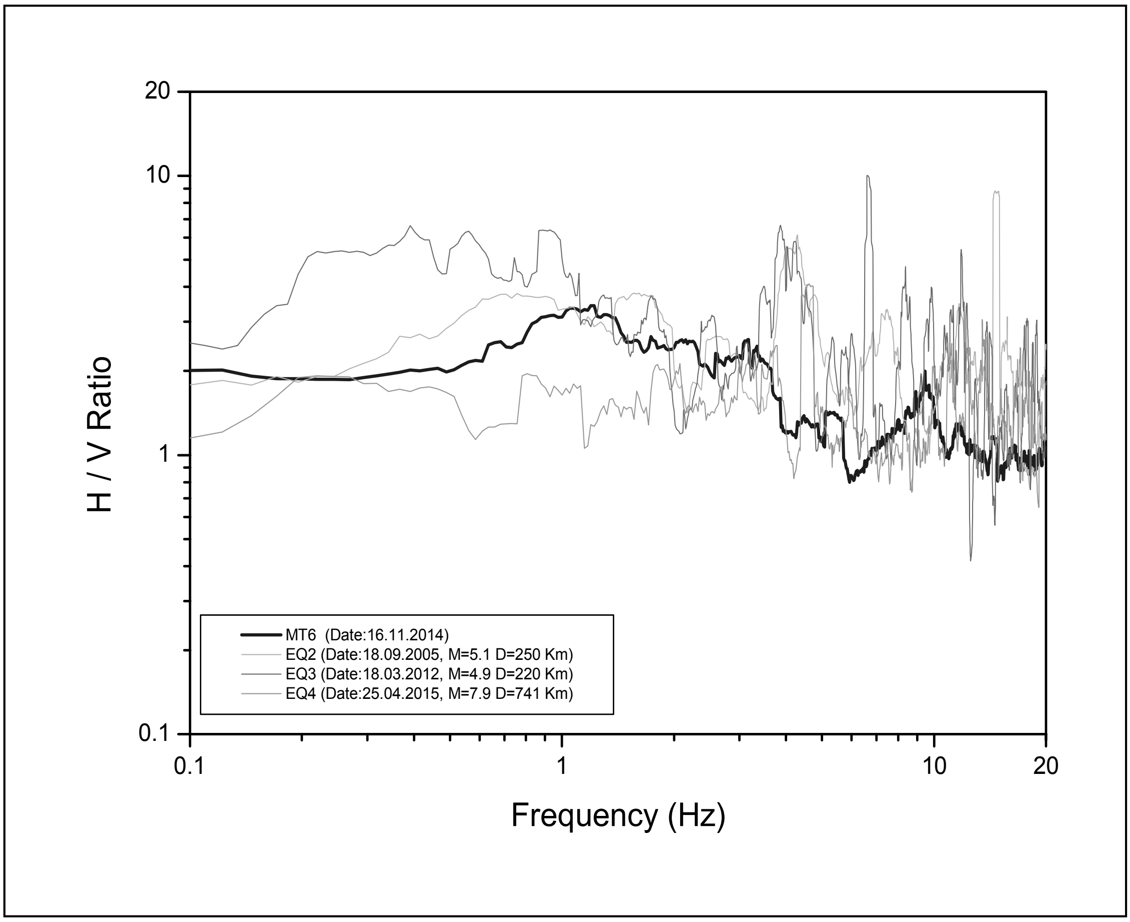

Figure 4.6. Compare of Average and Smoothed HVR in Microtremor and Earthquake at BUET-Campus.

VULNERABILITY ASSESSMENT

Earthquake and Microtremor data analysis and their vulnerability assessment of selected locations. Microtremor observation and earthquake data has been carried out at sixt selected locations of Bangladesh which has been discussed in Chapter 3. The Horizontal to Vertical spectra ratio (H/V) of these locations have been compared with the predominant frequency of selected site in EW and NS direction, respectively. The mean square root of H/V ratio (RM) obtained from microtremor observations and earthquakes data analysis and found that which nearby soils has been compared with Fourier spectra at the sites soils. The damage assessment of consolidated soil using Nakamura's Seismic Vulnerability Index (Kg) has been included in article 4.3.1.

Seismic Damage assessment of soil using Nakamura's Technique

Seismic vulnerability index (Kg) is an index indicating the level of vulnerability of a layer of soil to deform. Therefore, this index is useful for the detection of areas that are weak zone (unconsolidated sediment) at the time of occurrence of earthquakes. Some studies like Daryono (2009) and Nakamura (2000) showed a good correlation between seismic vulnerability index (Kg) and the distribution of earthquake disaster damage. This index is obtained from the peak value of HVSR squared, divided by the value of the predominant frequency. For this research area (Kg) values for six locations are shown in Table 4.1.

The seismic vulnerability index has been classified into four major types. Article 2.9.1 Vulnerability Index (Kg) of Loma Preta Earthquake (after Nakamura et al., 1990). These are Low (0-5), Moderate (6-10), High (11-20) and Very High (>20). Table 4.1 demonstrates the highest (Kg) value in the Jamuna Bridge East at Sirajganj, Police Staff college at Mirpur and Haji-Camp at Ashkna. Most of the zones having higher Vulnerability Index (Kg) are situated in reclaimed areas

Table 4.1 Damage assessment of site soil using Nakamura's empirical formula

SL. No	ID	Location	Predominant Frequency (MT), F_g(Hz)	Predominant Frequency (EQ), F_g (Hz)	H/V Ratio (MT), A_g	H/V Ratio (EQ), A_g	Vulnerability Index, $K_g = \frac{A_g^2}{F_g}$ (MT)	Vulnerability Index, $K_g = \frac{A_g^2}{F_g}$, (EQ)	Remarks
1	MT1 & EQ1	LGED Office at Bogra	1.68	2.06	3.36	9.02	6.72	39.49	Low to Moderate
2	MT2 & EQ2	LGED Office at Natore	1.07	2.09	3.68	6.56	12.65	20.59	Low to Moderate
3	MT3 & EQ3	Jamuna Bridge East Side at Sirajganj	1.04	1.77	4.66	11.52	20.88	74.97	Moderate to Very High
4	MT4 & EQ4	Haji-Camp at Ashkona	0.84	1.45	2.99	7.75	10.64	41.42	Moderate to High
5	MT5 & EQ5	Police Staff College at Mirpur	1.35	1.48	3.24	7.67	7.77	39.74	Medium to High

SL. No	ID	Location	Predominant Frequency (MT), F_g(Hz)	Predominant Frequency (EQ), F_g (Hz)	H/V Ratio (MT), A_g	H/V Ratio (EQ), A_g	Vulnerability Index, $K_g = \frac{A_g^2}{F_g}$ (MT)	Vulnerability Index, $K_g = \frac{A_g^2}{F_g}$, (EQ)	Remarks
6	MT5 & EQ6	BUET-Campus	1.21	2.06	3.41	4.16	9.61	8.40	Low to Moderate

Table 4.1 shows the classification of vulnerability site at six locations using Nakamura's Vulnerability Index (Kg). Figure 4.3 demonstrates three major and three minor in between vulnerability type. The number of low vulnerability type locations, which is 3, is the most common among 3 locations. The second most predominant number of vulnerability type is moderate type which varies between 10 and 15. The number of very high type vulnerable site is Jamuna Bridge East site at Sirajganj, Haji-Camp at Ashkona and police staff college at Mirpur, Dhaka.

To further ensure this, research on the acceleration of seismic waves in the basement need to be estimated. Vulnerability Index together with the acceleration of seismic waves in the basement has been suggested by Nakamura (2000) to calculate the value of shear strain (γ) of surface soil layers. Damaging earthquakes will occur when the limits are exceeded due to the shear strain deformation surface layer of soil. Soil is plastic at $\gamma = 1000 \times 10^{-6}$, whereas at $\gamma > 10.000 \times 10^{-6}$, the ground will deform. Only predominant frequency is not effective to classify a site due to Nakamura's vulnerability index. Both predominant frequency and H/V ratio are required to estimate vulnerability type.

CONCLUDING REMARKS

This chapter shows the comparison of theoretical analysis with microtremor observation and earthquake data analysis results. The theoretical analysis and has been compared with the microtremor and earthquake ground motion of H/V ratio. From these result, it can be said that although amplitude values of the ratios are close, the predominant frequency for the three cases differs slightly. The reason of this difference is that microtremor and earthquake consists of different types of waves, but the H/V ratio based on shear-wave only.

In addition to this, the seismic vulnerability of soil has been analyzed at the study points using the Nakamura's (2000) Vulnerability Index (Kg). The Vulnerability Index of six selected locations has been classified into four types which are Low, medium, high and very high vulnerable. Most of the reclaimed sites fall within high medium to high vulnerability range.

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