BNUS ANNUAL REPORT-2019

BANGLADESH NETWORK OFFICE FOR URBAN SAFETY

BUET, DHAKA, BANGLADESH

Edited By:

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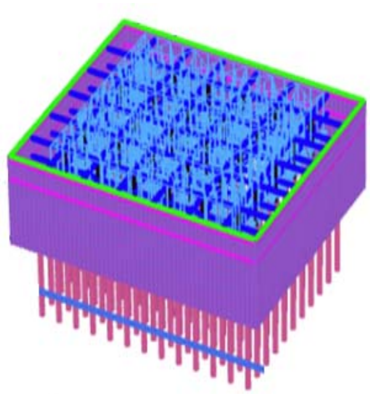

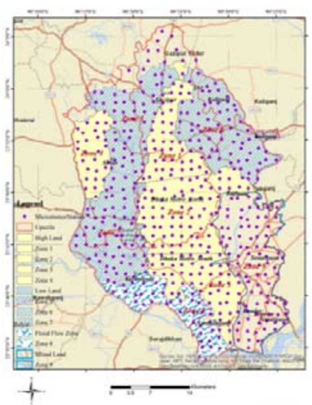

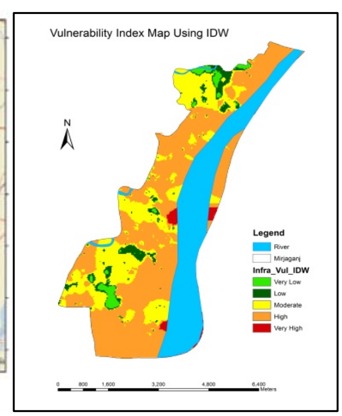

April 2020

BANGLADESH NETWORK
OFFICE FOR URBAN SAFETY

CONTENTS

PART-I

CYCLONE FANI, 3RD MAY, 2019

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

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Introduction:

Bangladesh is one of the most disaster prone countries due to its geological position and climatic condition. In every year the coastal part of Bangladesh has to face severe calamities like cyclone and storm surge and cause various damage and causalities. Proper warning and management can reduce the impact but cannot be avoided completely. As Patuakhali is a coastal arever, it is more vulnerable to climate change. Patuakhali is being affected almost every year by natural disasters like cyclones, floods and storm surge due to climatic impact. In this year 2019, cyclone FANI affect the coastal part of Bangladesh basically Patuakhali and Barguna badly. The IMD began tracking a depression located west of Sumatra on 26 April, classifying it as BOB 02. Later that day, the Joint Typhoon Warning Center (JTWC) issued a Tropical Cyclone Formation Alert on the system (JTWC, 2019). Afterward, the storm slowly coalesced while moving northward, and was upgraded to a deep depression at 00:00 UTC on 27 April (IMD report, 2019). At the same time, the JTWC began warning on the system, designating it 01B (JTWC, 2019). Six hours later, the IMD upgraded the system to a cyclonic storm and gave it the name *Fani*. The India Meteorological Department tracked the storm and issued numerous yellow warnings for much of the south-eastern portion of India when the cyclone started to intensify (CBS News, 2019; Wright, 2019). In preparation for the storm's impact, the state government of Odisha evacuated over 1.2 million residents from vulnerable coastal areas and moved them to higher ground and into cyclone shelters built a few miles inland. The authorities deployed around a thousand emergency workers and 43,000 volunteers in this effort. It sent out 2.6 million text messages to warn of the storm in addition to using television, sirens and public-address systems to communicate the message. About 7,000 kitchens were operated to feed evacuees in 9,000 storm shelters (Mohanty, 2019).

The Indian Navy readied naval ships and aircraft at Arakkonam and Visakhapatnam air-bases to prepare for the storm's aftermath and aid in reconnaissance, rescue and relief operations (The Hindu, 30 April 2019). The Odisha government staged "300 power boats, two helicopters and many chain saws, to cut downed trees" for the purpose *(Kumar, 2019).*

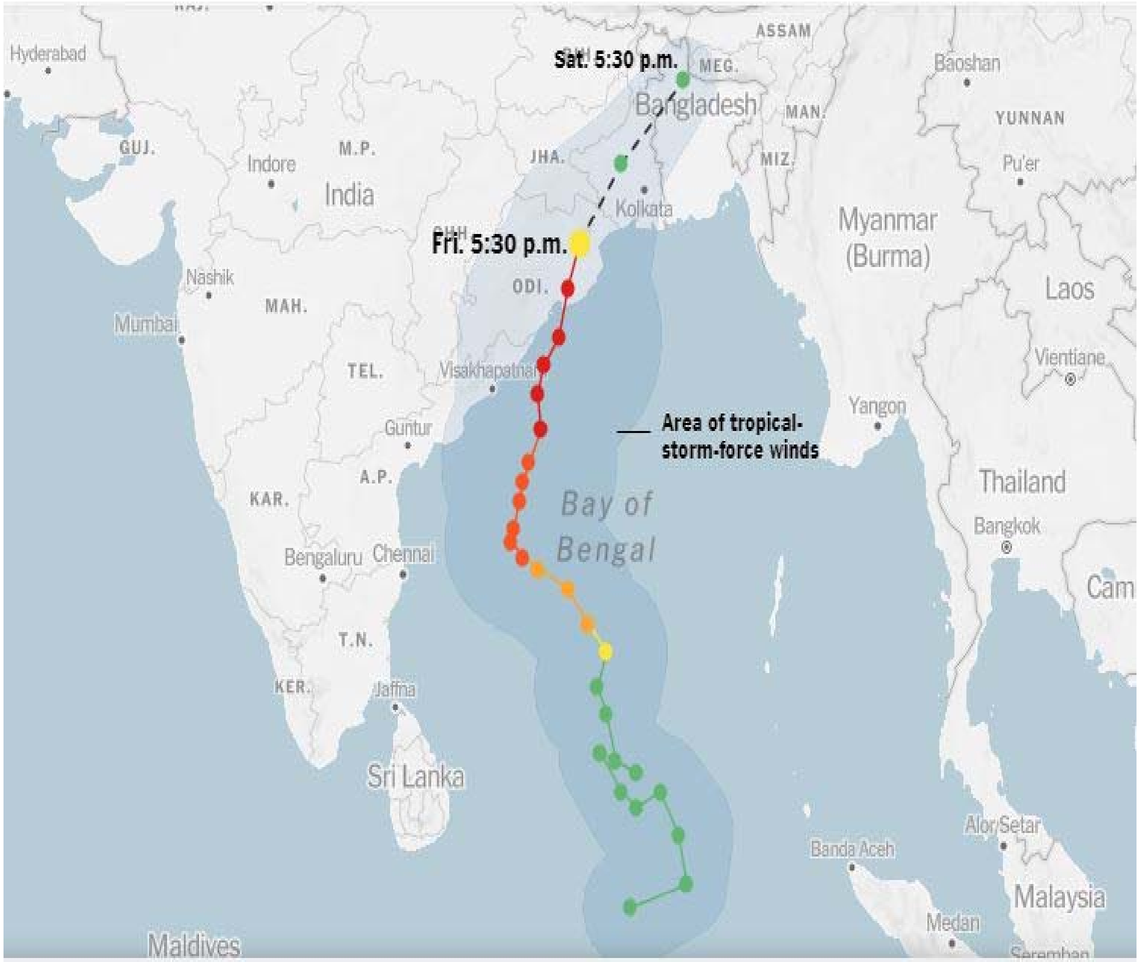
Authorities in Bangladesh were ordered to open shelter areas as well in 19 coastal districts (Dhaka Tribune, 1 May 2019). Bangladesh Navy deployed 32 naval ships to provide emergency relief and medical assistance to the coastal areas in case of any emergencies (Dhaka Tribune. 4 May 2019). More than 1.2 million people were evacuated in Bangladesh and moved to the cyclone shelters in coastal areas

Villagers suffer as tidal water enters adjacent areas through the damage portions of dikes, polders and embankments. Around 60 kilometers of flood control embankments in Patuakhali and Barguna got badly damage due to tidal surge caused by impact of cyclone FANI. Moreover thousands of people of different villages in those two districts have been suffering a lot as their dwelling, houses and agriculture land remain inundate under saline water for several days due to the impact of recent cyclone FANI. An emergency team was fielded by Bangladesh Network of Urban Safety (BNUS), BUET to assess the huge polder damage, surge monitoring and assessment posed by Fani and to observe and document the humanitarian conditions in the affected areas. The team focused on Patuakhali and Barguna district as all the organizations involved in the survey team mainly work within Mirzaganj upazila, Lalua and Mohipur union, and hold special interest in the humanitarian conditions and polders damage situation in the region. In this report several field visit, focus group discussion and key informant interview has been conducted to evaluate the present scenario of suffering due to cyclone attack and how people think on this matter of sufferings and management to reduce it. Demographic representation of Mirjagonj upazila, Lalua union and Mohipur union.

The purpose of this report is to provide a preliminary understanding of the polder damages and humanitarian conditions in the Fani affected areas of Khulna District. This report also assessed the needs to support an effective and timely humanitarian response for the cyclone victims. There is also a preliminary analytical report added to this document which attempts to answer the question why Cat-1 cyclone like Fani inflicted such a heavy damage in the coastal region of Patuakhali and Barguna district.

Cyclone Fani Tracking Path:

Cyclone Fani made landfall near Puri, India, around 8 a.m. on Friday, after more than a million people were evacuated. The fast moving storm lashed the coast with gusts of more than 120 m.p.h. Fani made landfall near north-west part of Bangladesh around 6.00 p.m. on Saturday. Four category have been selected for cyclone Fani. Red color is the category 4, yellow is the category 1 and green is the tropical storm. Bangladesh faced tropical storm during cyclone Fani.

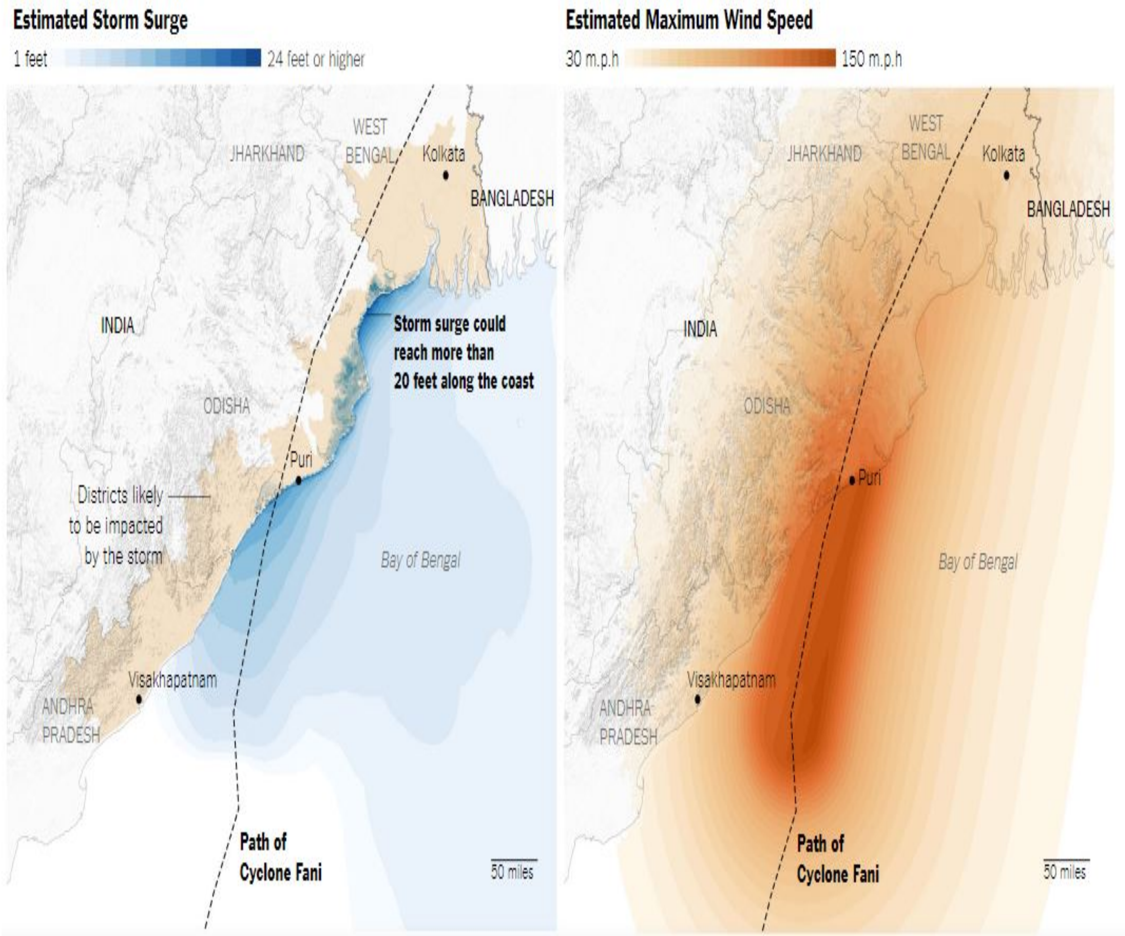


Source: (The New York Times, Asia Pacific; 03 may 2019)

Figure 1: Live tracking map: Cyclone Fani.

Threat of Storm Surge and sustained Wind:

Cyclones, sometimes associated with storm surge have been a cause of concern for Bangladesh. From 1891–98, approximately 178 severe cyclones with wind speeds of more than 87 kilometers per hour (km/h) formed in the Bay of Bengal, causing extensive loss of life and destruction of property. Estimated storm surge could reach more than 20 feet along the coast in India and Bangladesh. Districts likely to be impacted by the storm. High wind speed is another root cause the formation of cyclone. For cyclone fani estimated maximum wind speed was measured through kinetic analysis. Where 30 m.p.h was the lowest speed and 150 m.p.h was the highest value.



Source: (Kinetic Analysis; The New York Times, Asia Pacific; 03 may 2019)

Figure 2: Estimated storm surge and maximum wind speed.

Methodology and structure of the report:

The assessment team was consisted of 6 members representing Bangladesh Network of Urban Safety (BNUS), BUET. Members of the assessment team visited the most vulnerable area like Mirzaganj upazila, Lalua union, Mohipur union and assessed the situation between 20 May and 1 June 2019. The assessment report is based on the following methodology:

1. **Analysis and interpretation of primary data**

- Area survey by the survey team and collection of information from households with the help of the affected communities
- Observations and experience of each members of the survey team and interpretation and integration of those observation and experiences
- Interviews of the UP Chairman, members in affected areas
- Personal interviews of the communities in the affected areas
- Community Focused Group Discussions (FGDs)

- Key informative Interviews (KII) from different GO and NGO.

2. Analysis and interpretation of secondary data

- Basic data from the GoB district authorities
- Damage data from division, district and upazila administrations
- Analysis and integration of published reports in national and local level dailies
- Satellite imagery collected from Sentinal-1 and analyze the image through Arc-gis 10.1 software.

Description of the Study Area

Bangladesh is a densely-populated, low-lying, mainly riverine country located in South Asia with a coastline of 580 km (360 mi) on the northern littoral of the Bay of Bengal. The delta plain of the Ganges (Padma), Brahmaputra (Jamuna), and Meghna Rivers and their tributaries occupy 79 percent of the country. Bangladesh has a tropical monsoon climate characterized by wide seasonal variations in rainfall, high temperatures, and high humidity. Straddling the Tropic of Cancer, Bangladesh has a tropical monsoon climate characterized by heavy seasonal rainfall, high temperatures, and high humidity. Natural disasters such as floods and cyclones accompanied by surges periodically affect the country. Most of the country is intensively farmed, with rice the main crop, grown in three seasons. Rapid urbanization is taking place with associated industrial and commercial development. Patuakhali District (Barisal division) area of 3220.15 sq. km, located in between 21°48′ and 22°36′ north latitudes and in between 90°08′ and 90°41′ east longitudes. It is bounded by Barisal district on the north, Bay of Bengal on the south, Bhola district on the east, Barguna district on the west. The land of the district is composed of alluvial soil of the meghna basin and of a number of small char lands. Total population is about 1460781 including male 739331, female 721450; Muslim 1350968, Hindu 107893, Buddhist 391, Christian 1338 and others 191. Water bodies are Andharmanik, Agunmukha, tentulia, Galachipa, Rajganj; Rabnabad channel are notable (Banglapedia, 2006). In this study, six specific locations, one from each upazila are selected and studied. So, six specific areas except Galachipa of the district of Patuakhali are the study area of this research which is shown in Figure 3. Mirjagonj is one of the most vulnerable upazila under Patuakhali district. Mirzaganj is located at 22.3625°N 90.2417°E .

According to the 1991 Bangladesh census, Mirzaganj had a population of 110,763. Males constituted 50.06% of the population, and females 49.94%. The population aged 18 or over was 56,446. Average literacy rate is 42.1%; male 48.6%, female 35.6%. Another most vulnerable upazila is Kalapara under Patuakhali district. Kalapara is located at 21.9861°N 90.2422°E . It has 31324 households and total area 483.08 km^2. The major rivers are the Andharmanik, Nilganj, and Dhankhali. As of the 1991 Bangladesh census, Kalapara has a population of 174921. Males constitute 50.89% of the population, and females 49.11%. This upazila's eighteen up population is 82394. Kalapara has an average literacy rate of 34.9% (7+ years), and the national average of 32.4% literate.

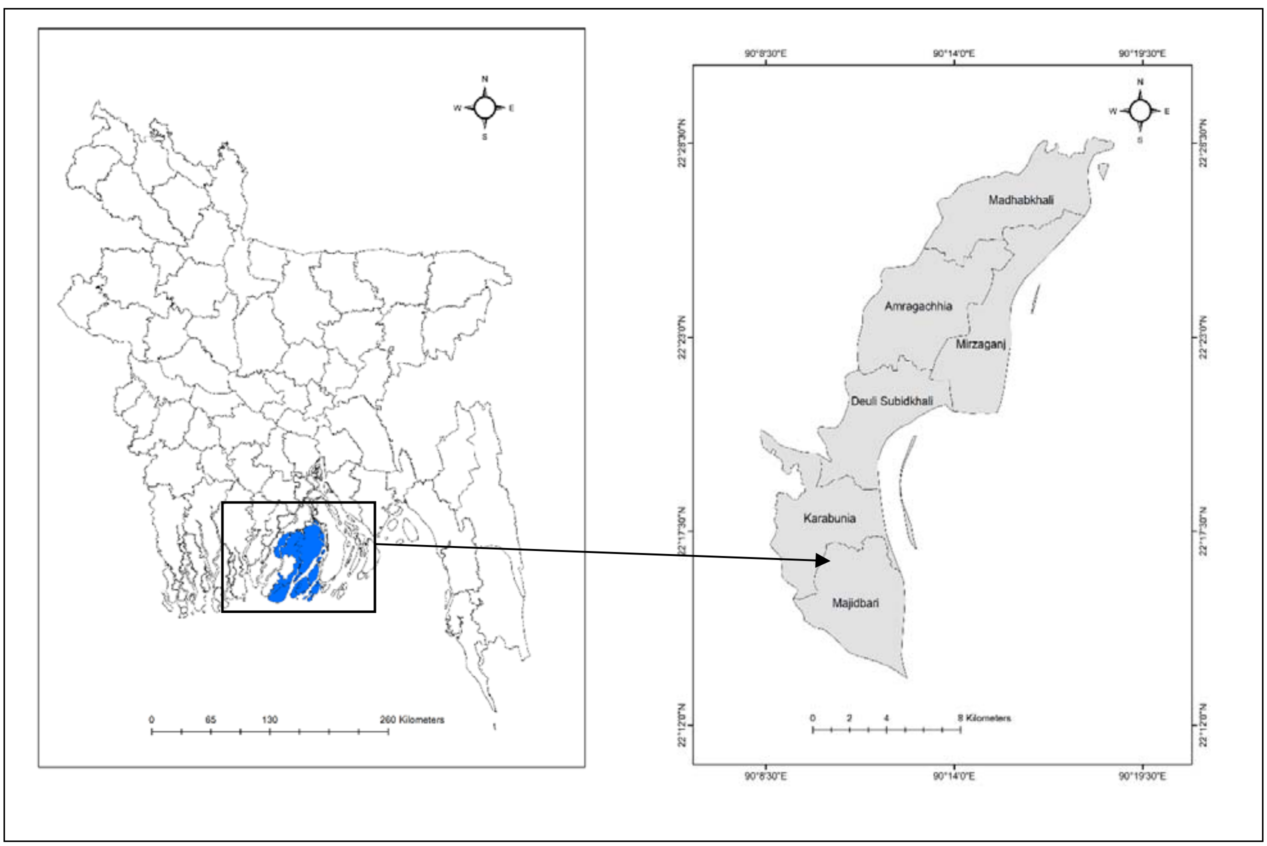
Data Collection Method

Primary data collection

Deriving accurate information is highly dependent upon the survey method (Ahmed et al, 2011). Reconnaissance survey was carried out to ascertain the primary idea about the locality, community hazard related risk and impact on crop production and farmers perception about climatic event like cyclone Fani and find out an approach of the study area.

Secondary data collection

Books, journals, report, internet documents, union praised office records, NGO office report, and records and published reports were used as secondary sources of data supporting or supplementing the empirical findings of the study. Related web sites were also searched to collect latest information about the research issue.



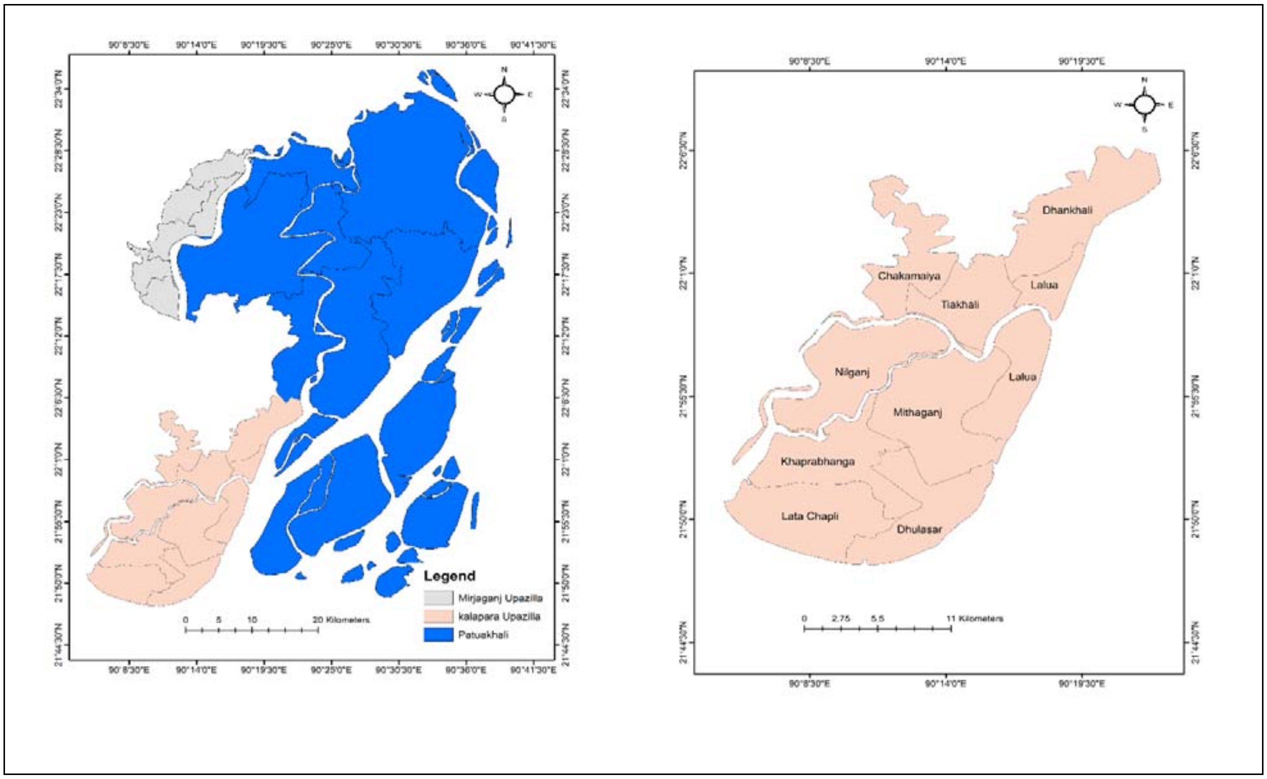


Figure 3: The Study Area Map (Patuakhali, Mirzaganj and Kalapara upazila); (Source: Arc GIS, 10.3).

Focus Group Discussion

Focus Group Discussion was conducted on both male and female. It was helped to gather a wide range of information in a short time (Kothari, 2011). The participants of the FGD have 6 to 10 people engaging different occupations. The participants would be asked question about the rural condition, which type of hazard related risk they face, for polders which type of problems and benefit they are faced on community. Due to climate induced disaster which kind of approach are fruitful to enhance the community resilience against this. Based on the objectives of the study, 20 Focus Group Discussion (FGD) was conducted.

Figure 4 Focus Group Discussion in the study area.

Key Informants Interview

A key informant is an individual who has a great depth of knowledge about a specific field and can offer perceptive information to the researcher (Kothari, 2011) relate to the research questions and problem solving suggestions related to any problem. The key informants include sub-divisional engineer (WDB), Patuakhali, NGO members, and community leaders, school teachers were selected from three unions for KII to conduct a qualitative assessment. The interviews were conducted in a natural and relaxed situation and the interview process must be kept flexible and more open than the structured interviewing with open questions (Kumar, 2011). Key informants were interviewed face to face and over cell phone using semi-structured questionnaire and were recorder and documented as per procedure. Total 5 (five) key informant interviews were conducted.

Figure 5 Key Informative Interview in the study area.

Results and Discussion:

Demographic and Socio-Economic Condition

It was needed to have a clear concept of demographic and socio-economic condition of respondents to understand their actual various existing local risk factors impact on their livelihood and their resilient mechanisms. This part considers the socio-demographic status of entire unions of the study area.

Gender ratio

Total no of respondents is 120 and among 120 respondents 84% are male and 16% are female farmer. Basically women organize the homestead gardening and in some case accompanying with male farmers where economic status is poor. Women help in irrigating the vegetables garden during Rabi season (mid-September to mid-march) by traditional method using bucket, jar etc.in some case where female headed house exist all of the responsibility goes for them. The respondent's gender division is shown in Figure (02).

Information collected from male and female respondent was very much helpful to reveal the community people's perception about different hazard like cyclone Fani, knowledge and level of understanding regarding the various existing local risk factors, impact on agriculture sector and their resilient mechanisms (Ali, 2012) reported that the male and female farmer ratio of coastal area is 6:1.that means female are less encouraged in crop production. Researchers (Hossain and Roy, 2010) found that female farmer engagement with homestead cultivation reduce the impact of hazard as they are first responder. Again the association of male and female farmer into crop field increases the crop production by reducing the risk factor (Hossain and Roy, 2010), This study concluded that a large number of female have included here but actually this happen due to less availability of female farmer during survey time.

Age of the respondents

Respondent's age ranged from 20 to 80 years. The age distribution of respondents is shown in Figure (03).

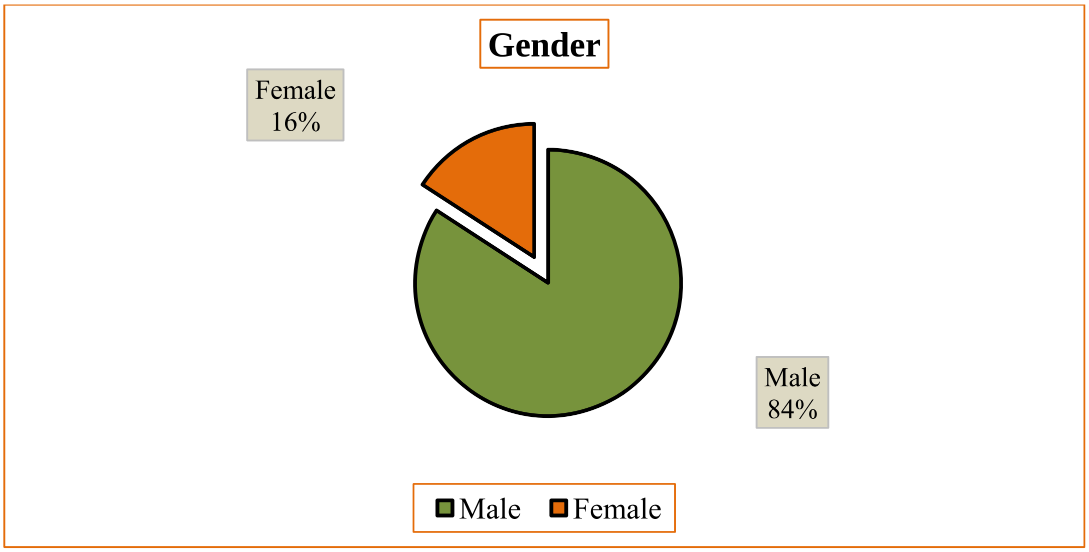


Figure 6: Gender ratio of Mirzaganj, Lalua and Mohipur Union.

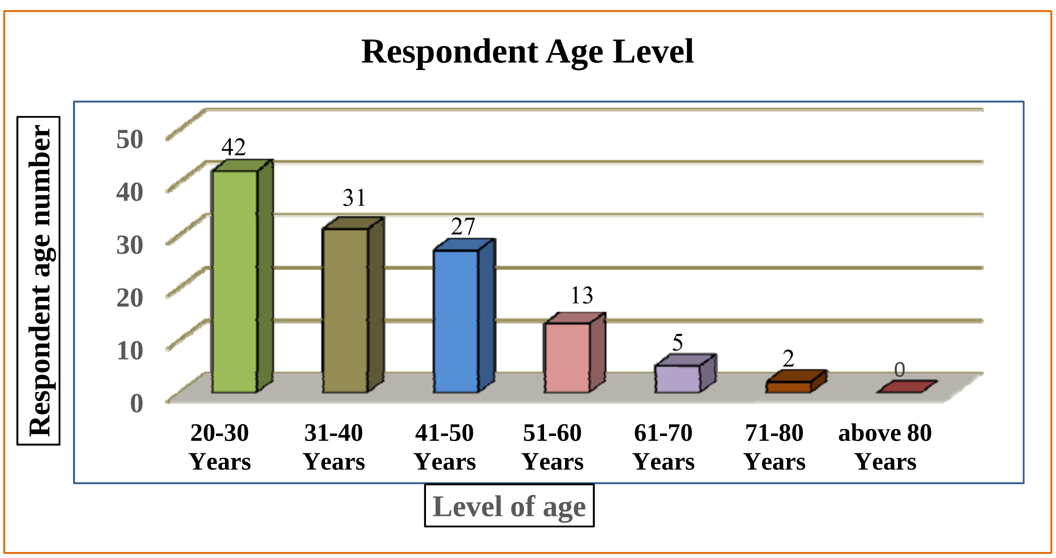


Figure 7: Respondent Age level of Mirzaganj, Lalua and Mohipur Union.

The research shows that among 120 respondents 42 respondent’s age between 20-30years, 31 is range of 31-40 years, 27 respondent’s age lies between 41-50 years where 13 respondent’s age is between 51-60 years and only 5 respondents’ age is between above 61 years and at last only 2 respondent’s age is around 71-80 years. Respondent’s age shows a variant result as maximum people 73 have in less than 40 years age (Biswas et al. 2015a) reported that age distribution of farmer-17 farmer age is above 50 years at coastal region. Another study Billah, (2013) found that elderly farmer’s distribution is only 17%.Respondents age have greater influence on risk perception and prediction of climatic hazard (Biswas et al, 2015a). Researcher (Biswas, 2015) found that farmer age distribution between 40-60 years have greater influence on climate change conception.

Primary occupation

People’s occupation of this region is farming in a larger rate. In Figure it specify that about 49 respondents said that farming is their main source of income, day laborer is common types of livelihood and 11 respondents indicate that. Fishing as a primary occupation is occupies by 21 respondents. Local business is very common in this locality. In this regard women plays key role. Primary occupation of the respondents is shown in Figure 04.

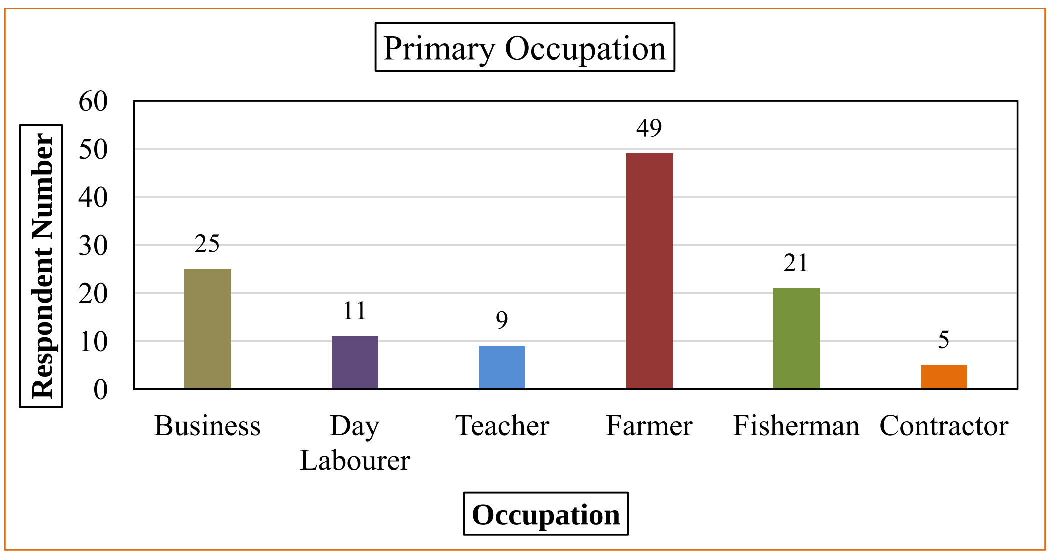


Figure 8: Primary Occupation of Mirzaganj, Lalua and Mohipur Union.

Billah et al (2013) found that in coastal area the primary occupation of the people is non-farm activities like fishing, day labor, small traders etc. Diversified livelihoods have greater influence on adaptation to climate change (Khaled, 2009).

Housing pattern of the study area

The household condition of the study area is very poor. The pie chart (Figure 05) represents the existing housing pattern of the study area. In the study it is found that most of the houses are katcha and the rest are semi-pucca and pucca types. In the pie chart it is indicated that the 46% respondent's house is kutcha, besides 36% household condition in that village is semi-pucca type. The rest respondent's house is pucca type. This poor housing condition makes this area is more vulnerable to natural disasters. Recurrent natural disasters are occurred in this area for this reason these types of houses are seriously affected by the violent cyclone, flood, irregular rainfall etc. which increase community risk. During cyclone Fani most of the houses were severely affected and some are partially affected due to the poor housing condition of this area.

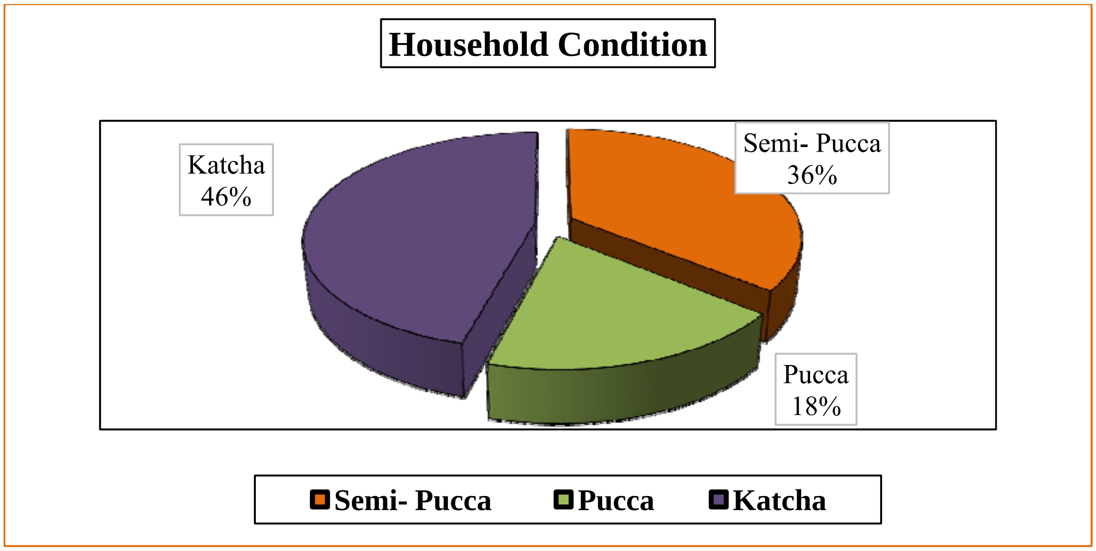


Figure 9: Household condition of Mirzaganj, Lalua and Mohipur Union

Overview:

In Patuakhali and Barguna district 1 upazila and 2 unions have been hit by Fani. Reports say Around 60 km of flood control polders in Patuakhali and Barguna district got badly damaged due to tidal surge caused by cyclone Fani Moreover, thousands of people are different villages in those districts have been suffering a lots as their dwelling houses and vast tracts of agricultural lands remained inundated due to the impact of this cyclone. Besides, tidal water keeps entering those villages through the damaged portion of the polder since the cyclone hit the southern region**. 14 killed and 45 injured** due to lightning, falling trees and house collapses (Health Emergency Operations Centre and Control Room of the Directorate General of Health Services). Major affected areas are Mirzagonj upazila, Mohipur union and Lalua union. Satellite data available on 05 May 2019 confirmed at least 40 percent of the district's total populated area was submerged under 1-3 feet of water. About 60 km in the polders around the district were reported through which water is freely flowing into the low-lying regions. The government officials reported about 60 km of embankment been damaged due to the breaches. In terms of number of people affected Lalua tops the list with Chairpara, Nawapara, Chowdhuripara, Nayakata, Munshipara, Chandupara, Hasnapara, Pashurparabunia to follow. In most of the area water is yet to recede, and with the full moon approaching, there is a possibility that water level will hoist. Migration from the affected areas due to waterlogged conditions has been a feature of the post Fani scenario. Fani also features a severe damage of the earth-made structures (mostly households and polders) and massive death of livestock. In this time of the rainy season, it is not possible to repair polder properly as commented by the locals. There is a possibility of permanent waterlogging in the area which is already forcing large scale migration and heaving the number of homeless and unemployed people. Social unrest is increasing throughout the area and harassments of the relief workers and others are increasing rapidly.

Damage Information

Food security

Cyclone Fani had the worst impact on the local food security in situation Patuakhali and Barguna Districts. Damage of 15,688 acres of standing crops has been reported officially (DAE Deputy Director Hridoyeswar Dutta), the main crops damaged are dry season vegetables, sesame, pulses and *Boro* paddy. A complete official estimate of total agricultural land being damaged is not yet available. However, information is available from the Upazila Agricultural Offices and local journalists, UP Chairman, members and locals.

Local food markets in the Fani affected areas are not functioning well as many food markets are still under water. The survey team observed a shortage of food in the markets which are still functioning and the price range is quite high that that of usual. In Mirzagonj upazila only one food market was found functioning on 20 May 2019 which is at the center of the upazila. Most of the shops were found closed during the time of high tide, as the market place went under two feet of water. In Lalua and Mohipur some scattered food shops were found functioning rather than in a market as a whole. There is a serious scarcity of dry foods among the affected dwellers. Cooking fuels are short or almost non-existing and dry places are rare in the affected areas. Lack of fuel is also restricting people to cook foods that are sought from elsewhere. Md Joynal Abedin, Assistant Head Teacher, Charkhali Hgh School said local administration is distributing rice among the affected people, but they cannot cook due to lack of fuel, and because there are no high lands nearby.

Roads and Polders

Roads and Polders' is one of the worst affected sectors in Fani. Of the 60 Kilometer damaged polder, around 30 Km is under Patuakhali Water Development Board (WDB), 10.5 Km under

Figure 10: Damaged polders after cyclone Fani at the study area.

Kalapara WDB in Patuakhali and 18.5 Km Is in Barguna, according to the Patuakhali and Barguna WDB offices. The local Sub- divisional Engineer of Patuakhali WDB Md. Shah-Alam said that among the 30 km polder, about 5.5 km was damaged fully and 24.5 km partly over this area. Meanwhile, in Kalapara, around 10.5 kilometer polder was badly damaged and tidal water keeps entering through the damaged portion in different villages. Kumar Sastik, acting executive engineer of Kalapara WDB, said in Barguna, due to lack of repair around 18 kilometre of the flood control polder at 37 spots under threats. The government has taken initiatives to repair the polders. However, reports from mirzagonj, Lalua and Mohipur divulge that in those places most repairs haven't been successful due to high pressure of tidal prism and continuous water flow through the breaches.

According to the people of Mirjagonj, Lalua and Mohipur union, polders were presented in that area. Community people were highly benefited by these polders. As those polders has higher elevation so people were using this in many aspects, such as for communication purpose, shelter during flood situation, prevent saline water intrusion and finally protect their crops. Although those unions had polder but it didn't cover all the areas. Thus various situations were occurred such as, salinity intrusion, flooding and many seasonal crops were highly damaged.

Before the occurrences of FANI cyclone the polders of that area were moderate condition. People's opinion about the polder condition are represented in Figure (06).

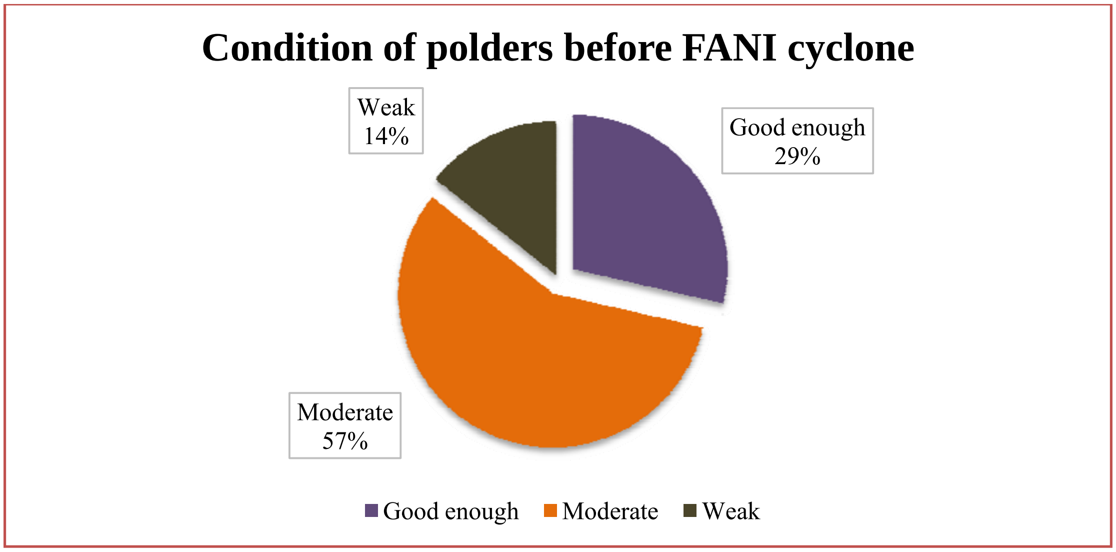


Figure 11: Condition of polders before cyclone FANI at Mirzaganj, Lalua and Mohipur Union

Cyclone FANI had devastating impact on physical aspects over this area. Around 60 km of polders over this area got badly damaged due to tidal surge caused by cyclone fani. From the Key informative interview

The most affected villages are mehendiabad, Ranipur, Golkhali, Hazikhali and Charkhali, all along the Payra river in Mirzagonj upazila.

Of the villages, Kamarpur, Nizampur, Puran Mahipur, Yusufpur, Monoharpur, Najibpur under Mohipur union and Chairpara, Nawapara, Chowdhuripara, Nayakata, Munshipara, Chandupara, Hasnapara, Pashurparabunia under Lalua union are most vulnerable.

Lalua union parishad chairman shawkat Hossain said alleast 16 villages under this union have been inundated after a portion of the polder along the Ramnabad river broke down.

Surge Monitoring and Assessment using (SAR) from sentinel-1 at Mirzaganj, Lalua and Mohipur union:

Patuakhali and Barguna districts face severe weaknesses and high-risk situations due to coastal threats like erosion and storms and due to an increasing intensive occupation. Tropical storms events can contribute to the occurrence of these situations, by causing storm surges with high water levels and, consequently, episodes of waves overtopping and coastal flooding.

To assess the project location’s exposure to storm surge in the Historical/Current time-frame, a conservative screen of 10 meters is applied. That is, if the project elevation is 10 meters above the present maximum high tide level, then the project will not likely be exposed to storm surge.

The 10 meter elevation threshold indicated above is roughly the elevation of the greatest historical storm surge and wave run-up heights.

The highest storm surge in the past century occurred during the Great Bhola Cyclone of 1970 in the Bay of Bengal, when a storm surge of 10.6 meters occurred during one of the highest high tides of the year.10 The highest storm surge on record in the United States was from Hurricane Katrina in 2005, measured at 8.4 meters above the normal astronomical tide level.

There are many sophisticated techniques for estimating maximum storm surge involving numerical modeling. To assess whether the project will be exposed to future storm surge, the tool helps the user to identify whether the project elevation is within 11 meters' elevation of the present maximum high tide level. Storm surge height is likely to be increased by sea level rise. The 11 meter threshold is based on a combination of the maximum present day surge values (10 meters) and the upper end of sea level rise projections for 2050 (0.6 meters). (See "Historical/Current" section, above, and "Sea Level Rise," preceding page). More precise estimates of changes in the magnitude of future storm surge are difficult to make and are relatively uncertain. There is high confidence that storm surge extremes will increase with sea level rise, yet there is low confidence in region-specific projections in storminess and storm surges.

For this report purpose, shows the surge inundation areas in Mirzaganj and Lalua union from Patuakhali district. In the period of cyclone Fani the selected area were inundated through storm surge. Deuli village from Mirzaganj upazila was severe affected by the inundated water. Many other villages were seriously affected by surge water. On the other hand, in Lalua union most of the villages were serious damaged by inundated water. Lalua was one of the most severe affected village due to surge water. Through satellite image analysis from (Arc-gis 10.1) inundated villages are given in figure (07, 08).

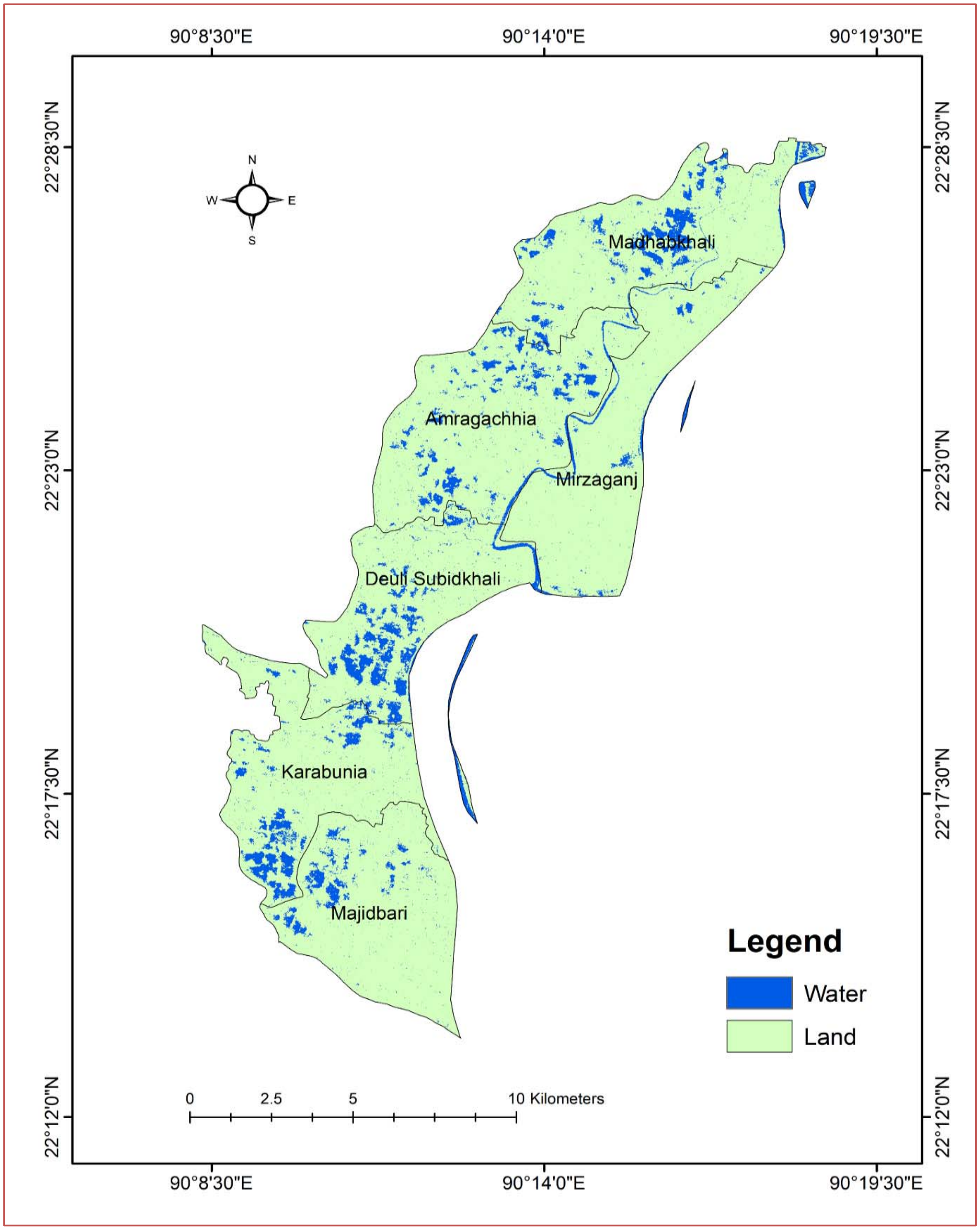


Figure 12: Inundated area due to surge water at Mirzaganj Upazila.

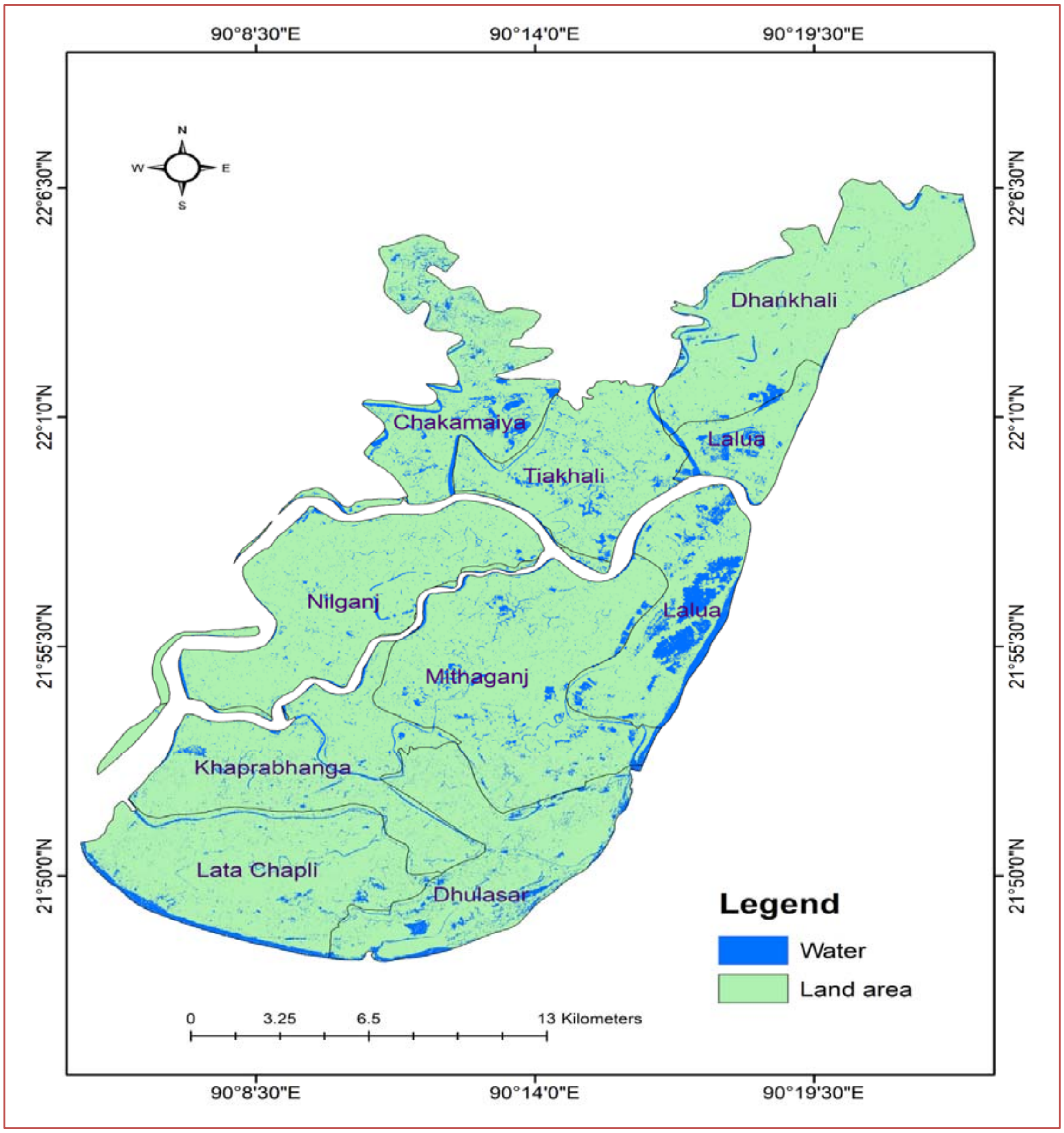


Figure 13: Inundated area due to surge water at Lalua Union.

Conclusions

It has been cleared from the assessment that not only from the cyclone FANI, most of the cyclones affect the coastal part of Bangladesh has more or less influence on this particular area. When a cyclone makes its landfall we all are concern about the hit area but most of them have the influence through a large part of the coast. The focus of this study was to identify the effect of cyclone FANI but we also found some information related to other cyclones from the past. However the polders in our coastal area to protect the surge water but sometimes it make the situation worse by retaining the saline water when it overtops. Sea level rise and excessive river siltation are also exhilarating the surge height. Only proper maintenance can solve this types of problems which are not seen in most of the area.

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PART-II

CYCLONE EVACUATION ROUTE IDENTIFICATION USING GIS FOR COASTAL COMMUNITIES IN BANGLADESH

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

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Maruf Billah
Mehedi Ahmed Ansary

Introduction

Different natural disasters, such as cyclones, droughts, and floods are increasing globally in recent years (IPCC 2001a, b; Khan and Rahman 2007). Cyclones are considered as the world's leading natural disasters that even exceed the effects of earthquakes (Murty and El-Sabh 1992; Finkl 1994; Dube et al., 1997; Zerger et al., 2002; Benavente et al., 2006).Bangladesh is the most vulnerable area to cyclones because of its geographical location at the triangular shaped head of the Bay of Bengal (Neralla, 1992), due to its high population density and the absence of effective coastal protection systems. In the pre-monsoon (April–May) or post-monsoon (October–November) seasons, at least one major tropical cyclone hit the Bangladesh coastal region each year (Mooley 1980; Haque 1997). Approximately one-tenth of global tropical cyclones occur in the Bay of Bengal (Choudhury, J. R. 1994). About one-sixth of the total cyclones developing in the Bay of Bengal make landfall on the coastal parts of Bangladesh (Quadir and Iqbal, 2008).If a cyclone occurs in tropical regions, it is known as a tropical cyclone. Cyclones occurring elsewhere are known as extra-tropical cyclones (Fritz et al., 2008; Fritz et al., 2007).

Existing literature shows that several devastating cyclones have stuck Bangladesh in 1822, 1876, 1961, 1965, 1970, 1991 and 2007 (Blaikie et al., 1994; Dube et al., 1997; GOB 2008). Among the 64 districts of Bangladesh, 19 are the located in the coastal areas. The population of this area is near about 36.8 million and more than half of the population (52%) are poor and about 41% is under the age of 15 (Islam, 2008). In spite of the poverty and being the most vulnerable to different kinds of coastal disasters, with their traditional indigenous knowledge and perceptions, these coastal people are coping with different kinds of disasters and passing their lives with relentless struggle (Parvin et al., 2008). Two destructive cyclones occurred in 1970 and 1991, with more than 500000 and 140000 causalities, respectively. However, in the last 20 years, Bangladesh has been able to reduce deaths and injuries from the cyclones. For example, the recent major cyclones like Sidr of 2007 and Aila of 2009 caused 3406 and 190 deaths only, about a 100-fold reduction of lives compared to the deadliest 1970 and 1991 cyclones (Ali 1980; Haider et al., 1991; GOB 2008; Paul 2009a; Haque et al., 2012).

As controlling the occurrence of natural disasters is almost impossible, the loss of life and property from these disasters can be minimized or prevented if proper precautions and preventive initiatives are taken timely. For saving human lives the fictitious solutions is to build the habitation above the surge level and construct them strong enough to resist high wind speed and the surges (Mallick et al., 2011). Nevertheless, the majority of coastal residents are living under poverty level in poorly constructed houses that are vulnerable to cyclone (Paul and Dutt, 2010).Existing literatures shows the importance of constructing raised platforms, reinforcement of homestead structures, overall cyclone proof houses in reducing casualties (Irteja et al., 2017; Ahmed et al., 2012). Besides, focus has been given on infrastructures stability and different infrastructures types to respond to cyclone like temple shaped house and elevated houses (Paul and Routray, 2011).Locations and pattern of settlements are the most important factor to decrease vulnerability of the coastal people. Scattered settlements in the coastal areas are more susceptible to cyclone (Alam and Collins, 2010).In the recent past, GIS and RS technology have increased the accessibility in the cyclone occurrence stage in order to develop map and assess the vulnerability of lives and infrastructures of cyclone-prone areas (Chisty et al., 2015; Rana et al., 2010).

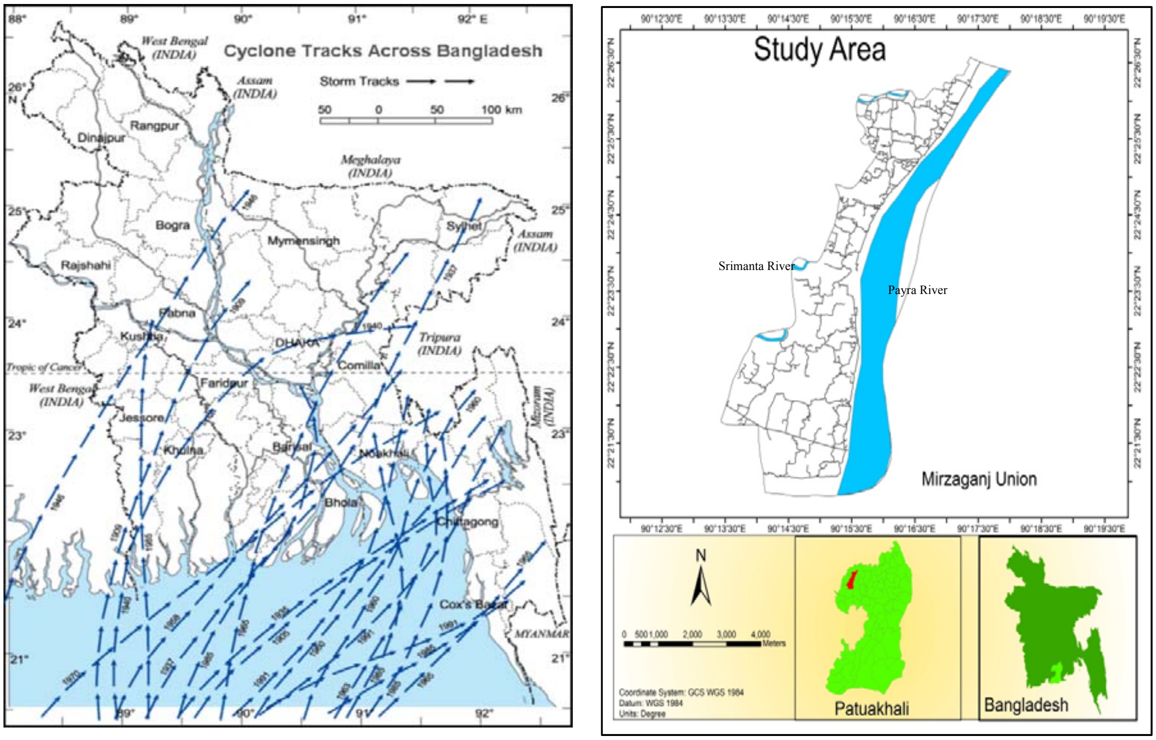
The next solution is evacuation of the coastal people to the high ground above the surge level (Mallick et al., 2011). Evacuation is considered as the primary protective action against any large-scale disasters like the cyclone. An early warning system plays a valuable role in the evacuation of vulnerable people during the occurrence of the disasters along with minimizing the loss (Dhar and Ansary, 2012). The effective early warning system provided by the government in advance of Cyclone Sidr, Aila, Mohasen, Komen, Roanu, Mora in 2007, 2009, 2013, 2015, 2016 and 2017 enabled successful evacuation of coastal communities that resulted in fewer than expected deaths. Besides the early warning systems, different activities like construction of cyclone shelters, embankment, and timely evacuation have contributed to decreasing the death rates in the coastal areas (Haque et al., 2012; Islam et al., 2010).In spite of the improvements in early warning systems, pre-cyclone evacuation remains a challenge (Dhar and Ansary, 2012). Some factors like illiteracy, lack of awareness, structural vulnerability and communication problems including poor road networks are the obstacles that hamper the evacuation system. Instead of moving to cyclone shelters, people in coastal areas still believe in a wait-and-see approach (Bern et al., 1993; Chowdhury et al., 1993; Paul and Routray, 2013).On the other hand, access to road network, distance of cyclone shelters from the homestead, and access to cyclone shelters are the factors that influence the evacuation decision (Paul, 2014).

Cyclone shelters play an important role during the evacuation. It has been estimated that around 1.5 million people have been evacuated by CPP (Cyclone Preparedness) volunteers to the multi-purpose cyclone shelters (MPCS) when Cyclone Sidr hit the coastal parts of Bangladesh in 2007 (Nateque Mahmood et al., 2014; Paul, 2009). Before the destructive cyclone of 2007, Bangladesh had only 1500 cyclone shelters in the coastal districts as the infrastructural support during cyclone. After Sidr, Bangladesh Government has constructed around 2000 new cyclone shelters for the population of the coastal belt (Das, 2017). The World Bank surveyed and further estimated that there is still a need for 5500 new MPCS(Multi-Purpose Cyclone Shelter) facilities for the purpose of a disaster management strategy (Nateque Mahmood et al., 2014; The World Bank, 2010; Islam et al., 2010).GIS-based map has been produced to know about the coverage area of a shelter and need for new shelters (Mallick, 2014).

Despite of completing these initiatives, the evacuation route to cyclone shelters from any community remains a challenge and is not well defined. People living in the coastal areas are not aware of the appropriate evacuation plan and route during cyclones. They can't take the decision during cyclones in which shelter they should go and which shelter is within their reachable distance. It is common that computing shortest paths over a network is an important task for evacuation. With the development of geographic information systems (GIS) technology, network and transportation analyses within a GIS environment have become a common practice in many application areas. Different factors like easy accessibility of the community people to the shelter with maximum walking distance for an individual is restricted to 2.25 kilometers, covering the entire population of the region by producing safe zones and evacuation zones, suitability of the shelters for other community activities are needed to follow (Dalal, 2007;Gupta et al., 2017). There exists digitized road map including road class, distance and shortest optimum route (Devlin, 2008).Many network flow model including logistics coordination model has been built for identifying optimal lane-based evacuation routing plans in a complex road network by using mixed-integer programming solver (Cova and Justin, 2003; Murray and Mahmassani,2003; Yi and Ozdamar,2007). There exist gaps in the above papers for identifying the shortest distance analysis which is needed during a evacuation process. In the reviewed papers, shortest distance have been analyzed in a map for a vast area without presenting numerical values of the distance from evacuation point to the shelters. Even how many people could be evacuated from each point has not been defined. As Bangladesh is a cyclone prone country, proper evacuation route is a need to reduce the number of affected people. This paper presents an evacuation model for Mirjaganj union of Patuakhali, Bangladesh for identifying evacuation route including the shortest distance analysis for each shelter.

Study Area

Figure 1(a) shows the past records of cyclones that hit Bangladesh. Among the Unions of Patuakhali district, Mirzaganj Union is one of the most vulnerable unions to cyclone hazard. Area of Mirzaganj Union is 34 square km, located in between 22°13' and 22°29' north latitudes and in between 90°08' and 90°19' east longitudes. Total amount of road is near about 90 kilometers, among these paved roads are 20 km, herring bond roads are 10 km and earthen roads are 70km. There are07secondary schools, 23primary schools, and 16madrasa. Main source of income is agriculture with 8527 acres of cultivable land. Due to the geographical location that union has been severely affected by 2007 cyclone Sidr and 2009 Aila. Figure 1(b) shows the location of the union.



(a) (b)

Figure1: (a) Cyclone Tracks in Bangladesh and (b) Study Area (Mirzaganj Union)

Methodology

The research is based on both secondary and primary data collected through focus group discussions and a household questionnaire survey. As there are no databases accessible with the level of details to be used in this particular study area for this research, the detailed area plan of the study location has been mapped in Esri shape file format using GIS. By using 97% confidence interval, the total sample size for the household questionnaire survey has been considered 830 out of 3200 households. Samples are taken proportionately from four zones of Mirzaganj union.

After collecting the data, GIS and Microsoft excel have been used to analyze the collected primary data. GIS has been used in developing maps, geographic data analysis, editing, data management, and geo-processing activities. ArcGIS has been used in finding the closest shelter facility location, origin-destination (O-D) distance generation and location allocation. A realistic evacuation model with the shortest route to shelters has been proposed in this study and has been validated using field data.

Result and Discussion

Mirzaganj union is bounded by the Payra River on the south and east, the Srimanta River on the west as can be seen in Figure 1(b).According to the Jatiyo Batayon, there are 11 villages in this union. Total population is 22100. Among them male is 11073 (50.10%), female is 11027 (49.89%). After surveying 830 households, it has been found that average 7 people live each in household. The literacy rate of the union is 70% including 13033 voters. Most of the people are farmers and small shopkeepers.

Condition of the Existing Cyclone Shelters and Infrastructures

In Mirzaganj area there are only two usable cyclone shelters (Figure 2). The shelters are designed to withstand a wind speed of 260 km/hour and placed on a higher ground to avoid the effect of the maximum expected surge level. Shelters have been constructed with the required facilities (Table 1). The shelters buildings are primarily used as schools. Shelters are designed in such a way that both human and livestock can take refuge there.

(a) (b)

Figure 2: (a) Cyclone Shelter no 1; (b) Cyclone Shelter no 2.

Table 1: Details about Existing Cyclone Shelters

Different Attributes	Cyclone Shelter no 1	Cyclone Shelter no 2
Name	Vazna Monoharkhali Govt. Primary School cum Cyclone Shelter	Vikakhali Govt. Primary School cum Cyclone Shelter
Location	5 minutes walking time from Mirzaganj ferry ghat	5 minutes walking time from Vikakhali ferry ghat
Date of completion	January, 2018	February, 2014
Type of Shelter	LGED type 3	
Source of Fund	GoB and World Bank	
Structure	• Three storied building • Open ground-floor structure to avoid flooding from the storm surges • Open first floor with tube-well facilities is kept for cattle with ramp to move on it. • Second floor with room and bathroom facilities for human shelter	
Capacity	1300	
Total Room	In total 6 rooms, 4 large size rooms and 2 extra rooms with attached bathroom for pregnant women and children.	

Facilities:	•Total 4 bathrooms (2 attached) •Two motors for drinking water •Four tube-wells •4 water tanks capacity with 2000 liters •4 water tanks capacity with 7000 liters (especially in cyclone shelter no 1) •Solar system is installed •Rain water harvesting system (especially in cyclone shelter no 1)
Livestock Capacity	200

Source: Field Survey, May 2018.

The official capacity of each cyclone shelter is 1300 people. A large amount of people (about 19000) have to stay at their own place due to lack of space in the shelters. That's why a survey has been conducted on the condition of households and their vulnerability to test if they can withstand cyclone or not. The survey has been conducted through a semi-structured questionnaire to measure the vulnerability of the existing households.Table 2 presents the criteria used in the questionnaire to assess the vulnerability of the infrastructures. Scoring has been done depending on the criteria. There are individual houses, schools, mosques and others structures of the assessed infrastructures, some of which are shown in Figure 3.

(a) (b) (c)

Figure3: (a) Homestead; (b) Mosque and Madrasa and (c) School

Table 2: Infrastructure Vulnerability Scoring

Criteria	Sub-Criteria	Score
Width of the house is perpendicular to nearest river's length	Yes	1
	No	4
House is in the safe distance from the biggest trees	Yes	1
	No	4
There is sufficient amount of trees around the house	Yes	1
	No	4
Which type of house that is?	Concrete	1
	Tin	5

Size of house(floor area)	Square	1
	Rectangular or L shape	4
Plinth level	4′	1
	Less than 4′	4
Ridge level	High	1
	Low	4
Wall	Concrete	1
	Wood	3
	Tin	5
'J' hook presence	Yes	1
	No	5
Post of house	Concrete	1
	Bamboo	2
	Wood	3
The thickness of tin	Above 0.35 mm	2
	Less than 0.35 mm	5
Window	Size above 4′*4′	2
	Less than 4′*4′	5
Door	Size above 3.6′*6.6′	1
	Less than 3.6′*6.6′	4

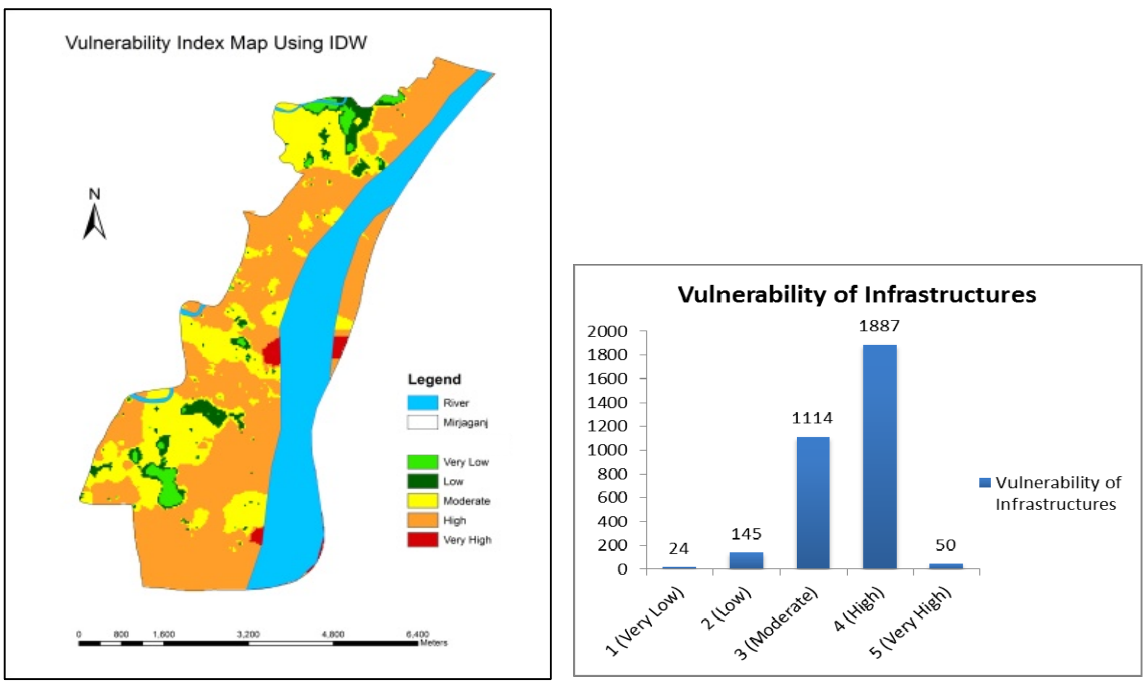
**Analysis has been based on criteria collected from "Construction Manual on Shelters for Cyclone-Prone Coastal Areas of Bangladesh" proposed by Disaster Management Bureau (DMB) of the Ministry of and Disaster Management and Relief (MODMR) and the Bangladesh University of Engineering & Technology (BUET).*

Figure 4(a) shows the vulnerability map of the studied union. Figure 4(b) indicates that among 3220 surveyed infrastructures 24 are with very low vulnerability (1%), 145 are with low vulnerability (4%), 1114 are with moderate vulnerability (35%), 1887 are with high vulnerability (59%) and 50 are with very high vulnerability (1%). It also shows that about 5% households are with low to very low vulnerable to cyclone and 95% households are not strong enough to withstand cyclone.

Existing Road Network System

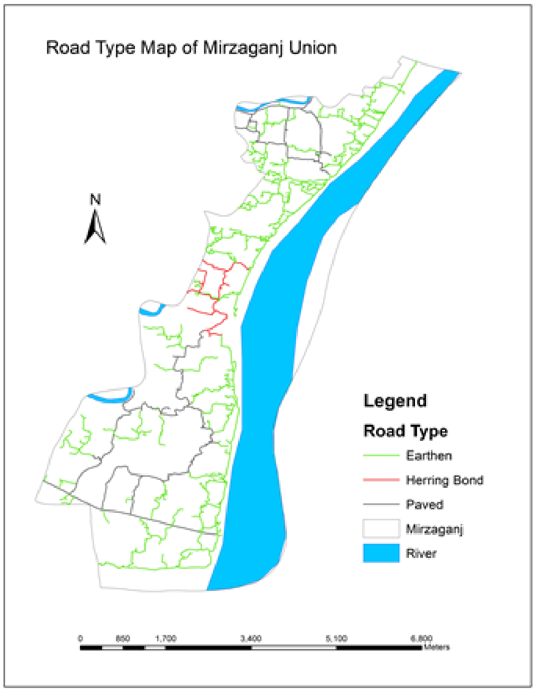
Network Analysis in GIS is based on graph theory and topology. It is often used to find solutions to transportation problems by using either vector or raster models to represent the real world. The vector-based model appears to be more suited to analysis of precisely defined paths such as roads and rivers (Bukholm, 2003). For a proper evacuation, a good road infrastructure is needed. Road network in coastal villages are still in rudimentary stage and path to the cyclone shelters remain unsafe prior to the landfall of cyclone because of excessive rainfall, high wind velocity, flooded terrain and tidal waves. Most of the time, roads are damaged by storm surge and make an obstacle for community people from going to safer places.

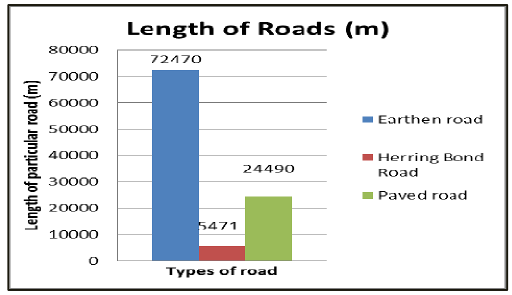
Figure 5(a) presents the map of road types of Mirzaganj Union. In this map three types of roads (earthen road, herring bond road, and paved road) have been shown. In Figure 5, three types of roads and lengths of the particular roads are presented. Among those 72.47 kilometers are earthen road (71%), 24.49 kilometers are paved roads (24%) and 5.4 kilometers are herring bond roads (5%). It can be clearly seen that half of the total road is of earthen type and is the most vulnerable during a cyclone. For this reason during a cyclone earthen road may be a snag for community people for evacuation. Besides width of roads play an important role during evacuation. Wider roads allow more people to evacuate than congested roads.



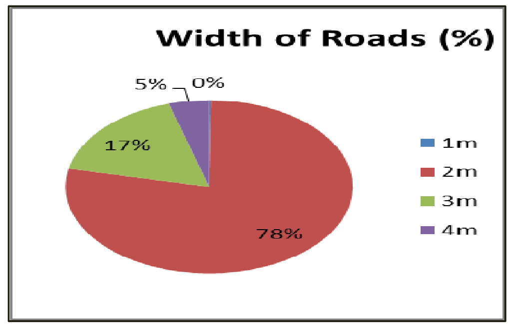
(a) (b)

Figure 4: (a) Map of vulnerability of infrastructures; (b) Infrastructures with various vulnerability ranges.





(b)



(a) (c)

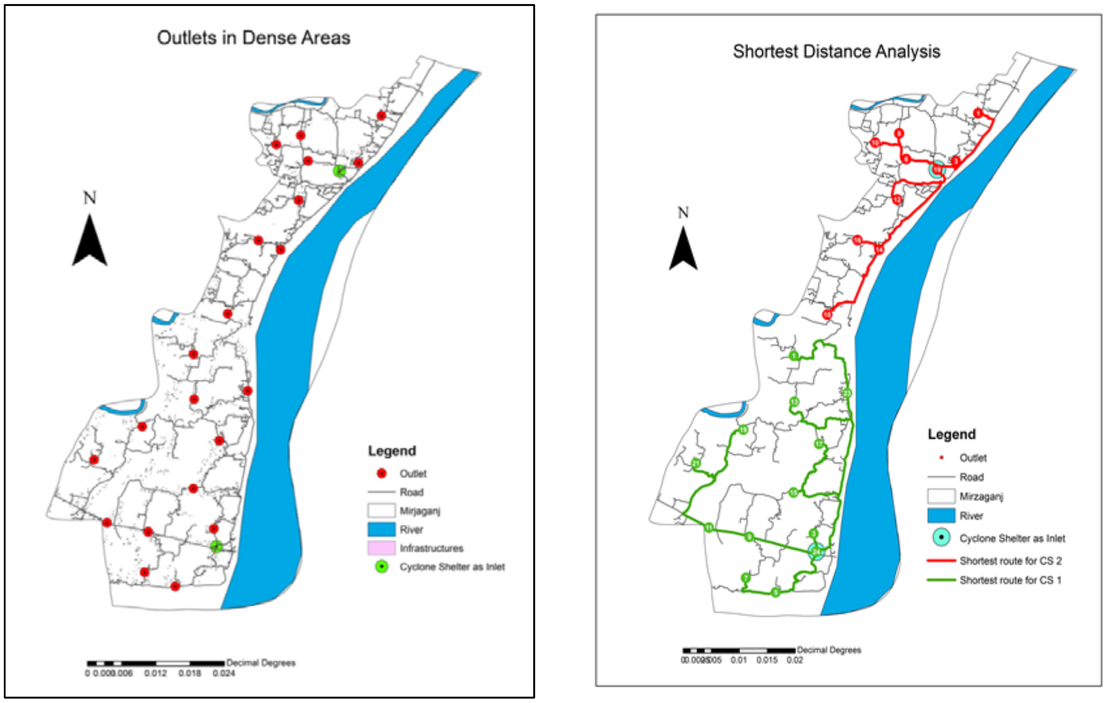
Figure 5: (a) Road types of the Union; (b) Length of Roads in meters; (c) Width of Roads in percentages.

Evacuation Route Analysis

It has been already mentioned that there is no delineated evacuation plan in this union. While warning system of Bangladesh is improving day by day but evacuation remains as a challenge because of lack of government plan. If there is a shortest route earmarked for every dense area, people will be able to reach to the cyclone shelters properly. Before analyzing the shortest distance we have considered cyclone shelters as inlet where people will take refuge and in every dense area we assumed a point as outlet from where maximum people can gather and evacuate to the shelters. In this study, based on the accessibility to shelters and distance from the main roads, 21 evacuation points (outlets) are marked around the study area. These outlets are situated at or near to the significant roads.

(a)

Figure 6(a) shows the outlets in the densely populated areas from where maximum people can be evacuated to the shelters and 6(b) shows the shortest distance from every outlet to the nearest shelter. From every outlet to inlet shortest distance has been analyzed using Network Analysis Tool in ArcGIS 10. As there are two inlets, the total outlets are divided into two areas as can be seen in Figure 6. Green colored routes are presented as the shortest distances to cyclone shelter no 1 and red colored routes are presented as the shortest distances to cyclone shelter no 2.



(a) (b)

Figure 6: Outlets and Inlets in Mirzganj Union (Left), Shortest Distance Analysis of Mirzaganj Union (Right)

Figure 7 presents the shortest distances from the different outlets to the shelters. The shortest distances for shelter no 1 are colored with green and the shortest distances for shelter 2 are colored with red. For shelter no 1, the shortest distance is 351 meters from outlet which is marked as CS1O3 (which means, CS1 is Cyclone shelter 1 and O3 is outlet 3) and for shelters no 2, the shortest distance is 518 meters from outlet which is marked as CS2O3.

In Figure 8 buffer zones have been developed keeping the outlets as the centers with 600 m radius to assume how many people are covered for evacuation. It shows that 16465 people (based on field survey) can be evacuated to shelters, which is70% of total population. Time is also an important factor for real time evacuation. The shortest distance along with the shortest time can be the best solution for assuming how much time it will take to move to the shelters through the shortest distance from each outlet. However, from the field survey we have found that during cyclone different types of factors like connectivity nodes and bent nodes may affect the travel time.

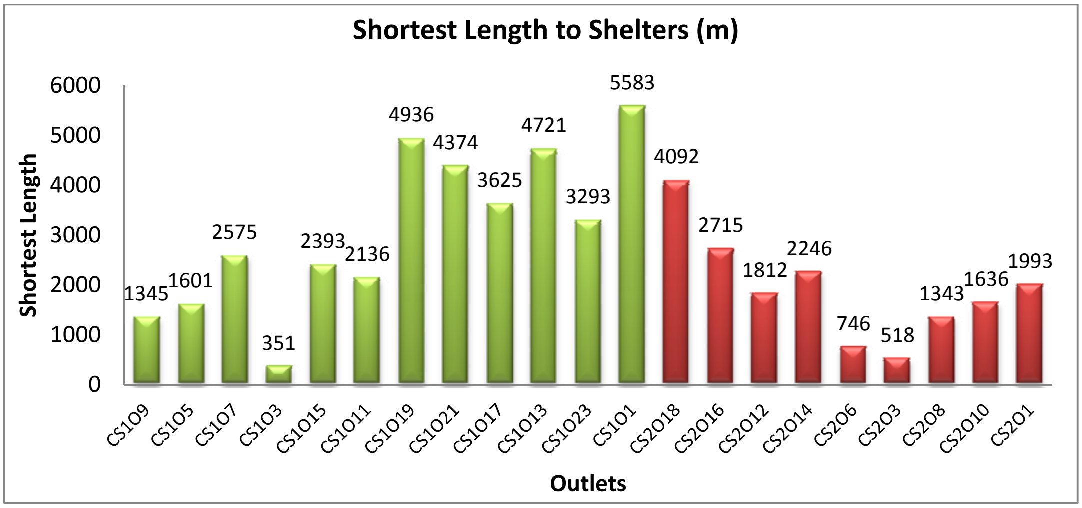
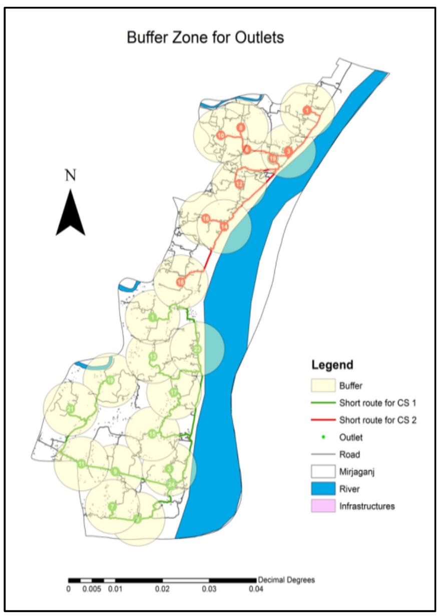
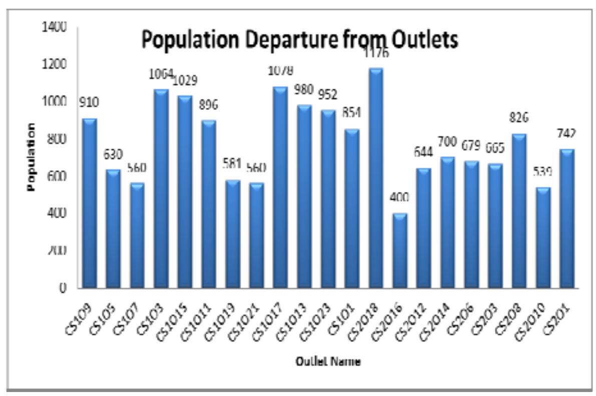


Figure 7: Shortest length to Shelters



(a)

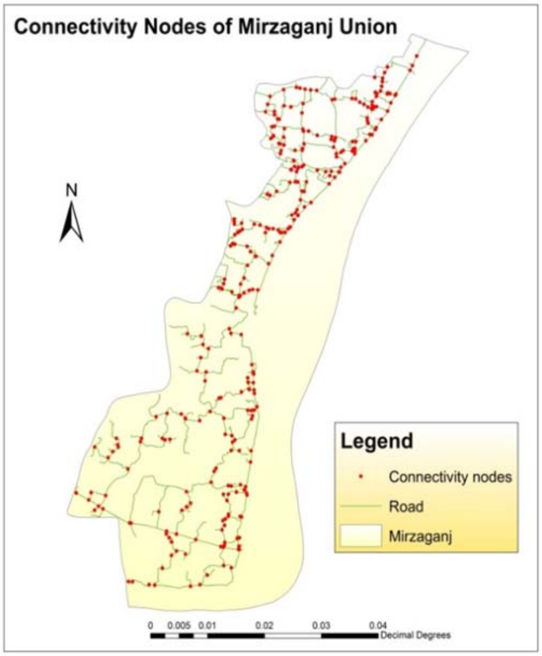


(b)

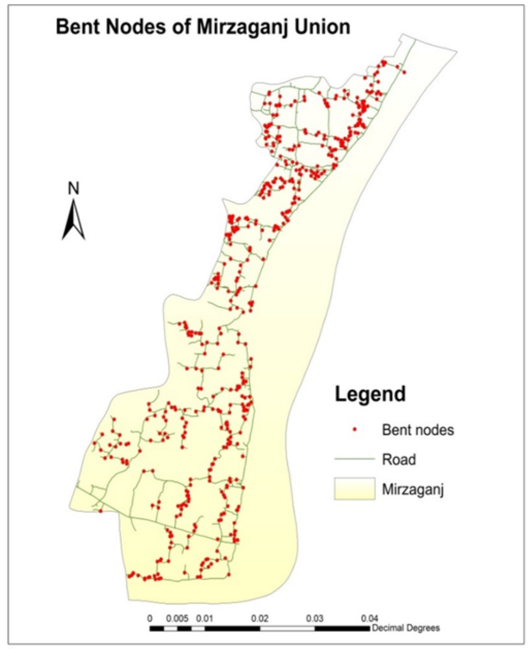
Figure8: Buffer Zones for Outlets (a), People departing from each Outlet in Bar Chart (b).

Figure 9shows the various bent nodes and connectivity nodes of the road network that cause delays. The placement of bent nodes and connectivity nodes are put in those places from where people would take turn to other roads and where roads have crossed each other.

In Table 3, we have developed a map of bent node network in which we have assumed 2 seconds delay for the bent nodes and in the map of connectivity node network we have assumed 4 seconds delay for the connectivity node for every shortest length to shelter. In Table 3, walking distance has been assumed 3.6 kilometers per hour or 60 meters per minute.



(a)



(b)

Figure 9: Connectivity Nodes Map (a) and Bent Nodes Map (b)

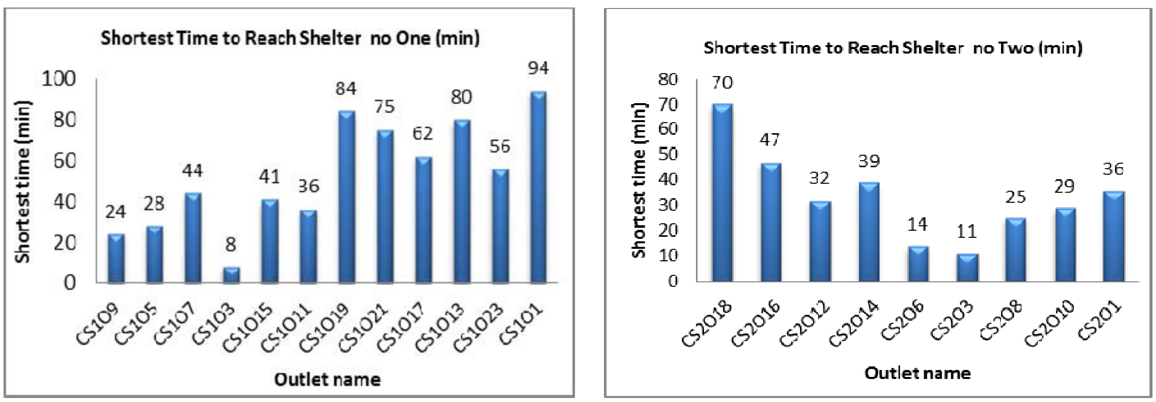
Table 3: Shortest Time Analysis considering factors

SL No.	Outlet name	Shortest length (m)	Walking speed= 60 m/min*	Shortest time without bents (min)	Time consuming for bent node (s)	Time consuming for connectivity node (s)	Total time consumed due to the bents (min)	Final shortest time (min)
01	CS1O9	1345	60	22.40	15*2= 30	9*4= 36	1.1	24
02	CS1O5	1601	60	26.70	14*2= 28	5*4= 20	0.80	28
03	CS1O7	2575	60	42.91	13*2= 26	5*4= 20	0.77	44
04	CS1O3	351	60	5.85	21*2= 42	14*4= 56	1.63	8
05	CS1O15	2393	60	39.88	25*2=50	8*4= 32	1.37	41
06	CS1O11	2136	60	35.60	1*2= 2	6*4= 24	0.43	36
07	CS1O19	4936	60	82.26	17*2= 34	10*4= 40	1.23	84
08	CS1O21	4374	60	72.90	18*2= 36	17*4= 68	1.73	75
09	CS1O17	3625	60	60.41	18*2= 36	8*4= 32	1.13	62
10	CS1O13	4721	60	78.70	16*2= 32	14*4= 56	1.47	80
11	CS1O23	3293	60	54.88	18*2= 36	14*4= 56	1.53	56
12	CS1O1	5583	60	93.05	19*2= 38	9*4= 36	1.23	94
13	CS2O18	4092	60	68.20	26*2= 52	15*4= 60	1.87	70
14	CS2O16	2715	60	45.25	28*2= 56	15*4= 60	1.93	47
15	CS2O12	1812	60	30.20	25*2= 50	13*4= 52	1.7	32
16	CS2O14	2246	60	37.40	19*2= 38	19*4= 76	1.9	39

17	CS2O6	746	60	12.40	18*2= 36	7*4= 28	1.1	14
18	CS2O3	518	60	8.60	38*2= 76	17*4= 68	2.4	11
19	CS2O8	1343	60	22.38	22*2= 44	20*4= 80	2.1	25
20	CS2O10	1636	60	27.30	17*2= 34	12*4= 36	1.17	29
21	CS2O1	1993	60	33.20	34*2= 68	25*4= 100	2.8	36

*Walking speed 3.6 km/h or 60 m/min (Hasnat, 2016).

Figure 10 shows time to reach to the shelters from the outlets using the shortest routes consdering bents along the path for the two shelters.



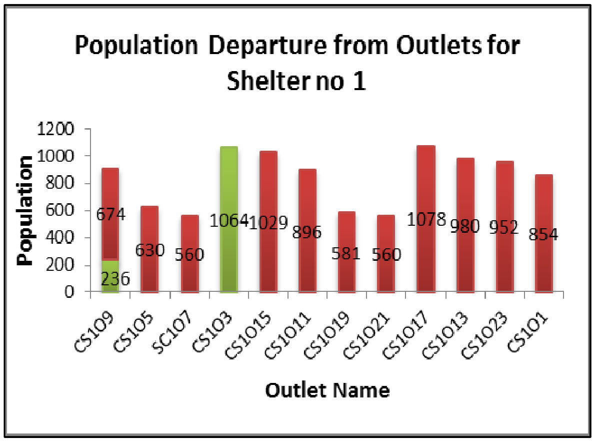
(a) (b)

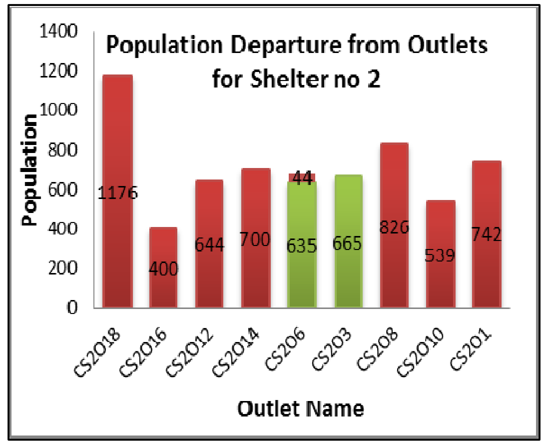
Figure10: Shortest Time (minutes) from each Outlet

It has already been mentioned that 1300 people can take shelter in each cyclone shelter. In reality about 4000 people take shelter in each of them and there is always overcrowding as reported by LGED (2014). Maximum 8000 people can use two shelters. On the basis of these data, two scenarios(with 1300 capacity and with 4000 capacity) have been developed to show how many people can be safe from cyclone by taking asylum in the shelters separately.

Figure 11 shows population departure from different outlets for the shelters (having 1300 capacity). In this figure,Green color represents the outlets from where people will be able to take refuge to the shelters since the time for evacuation from these outlets are the shortest. On the other hand, Red color represents the outlets from where people will be unable to take refuge to the shelters since the time for evacuation from these outlets are relatively high that means the shelters will be fully occupied before the people from these outlets reach the shelters.

Figure 11(a) shows the number of people departing from each outlet that cover the capacity (1300 people) of the cyclone shelter number one. It is observed that 1064 people can depart from outlet CS1O3 and only 236 people can departfrom outlet CS1O9 to fully occupy shelter one. Similarly for Figure11(b), it is observed that 665 people can depart from outlet CS2O3 and only 635 people can depart from outlet CS2O6 to fully occupy shelter number two.

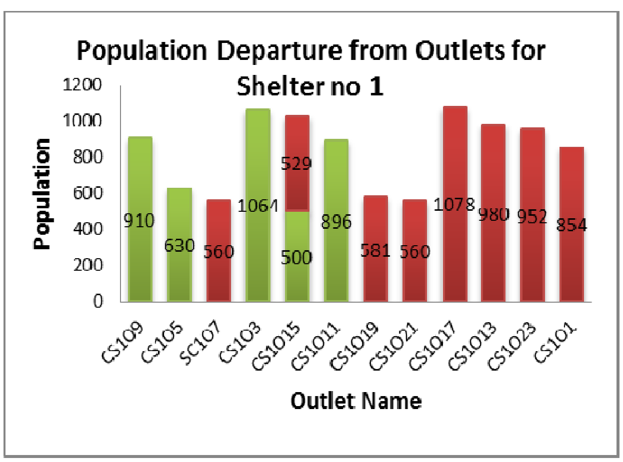


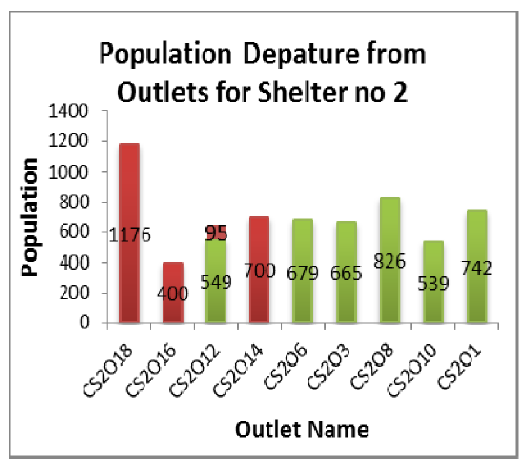


(a) (b)

Figure11: Population from outlets that cover (a) Cyclone Shelter number 1; (b) Cyclone Shelter number 2;when capacity is 1300 people in per shelter.

Figure 12 shows population departure from different outlets for the shelters (having 4000 capacity). Figure 12(a) shows the number of people departing from each outlet that cover the capacity (4000 people) of the cyclone shelter number one. It is observed that 3500 people can depart from outlet CS1O5, CS1O3, CS1O15, CS1O11 and only 500 people can departfrom outlet CS1O9 to fully occupy shelter one. Similarly for Figure 12(b), it is observed that 3451 people can depart from outlet CS2O1,CS2O3, CS2O6, CS2O8, CS2O10 and 549 people from CS2O12 to fully occupy shelter numbertwo.





(a) (b)

Figure12: Population from outlets that cover (a) Cyclone Shelter number 1; (b) Cyclone Shelter number 2; when capacity is 4000people in per shelter.

Figure 13 show that having capacity of 1300 people in each cyclone shelters can cover only 12% of the total population of the union. On the other hand, if the capacity is 4000 persons per shelter, it may cover 36% of the total population union. From Figure 4, it has been seen that about 5% (169 infrastructures) of total infrastructures are of low and very low vulnerability that can also be used as shelter during cyclones. These infrastructures include primary schools, mosque, homesteads (high plinth level with sturdy construction, as can be seen in Figure 3a).It has been assumed that average 50 persons can take shelter in these low vulnerable infrastructures covering 39% of the total population. If the capacity of the cyclone shelter has been considered as 1300 then with low vulnerable infrastructures, the capacity can be increased up to50% of the total population. And if we consider maximum capacity of the shelters to be 4000, along with low vulnerable infrastructures the capacity can be increased up to 75% the total population.

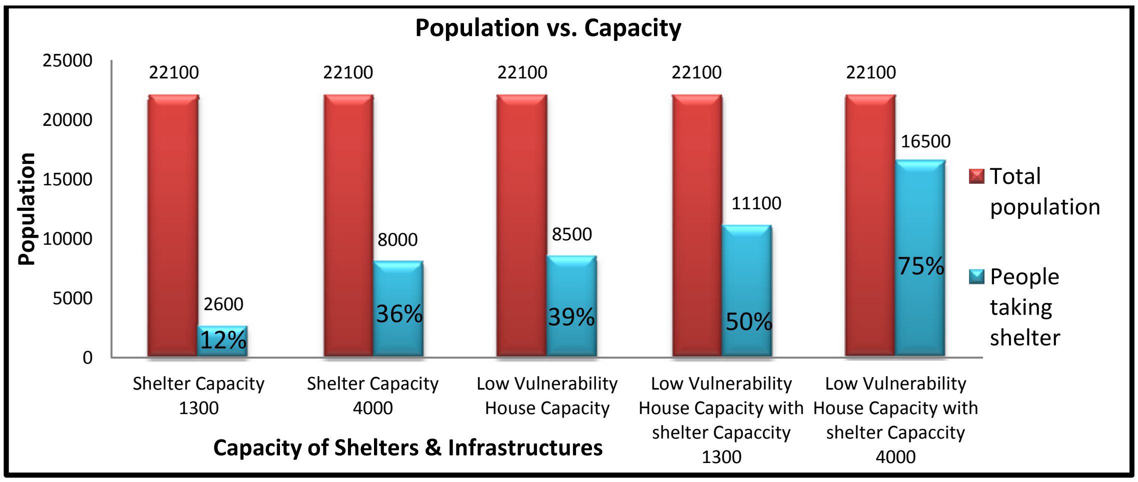


Figure13: Population demand versus capacity under various scenarios

Conclusions

For a developing country like Bangladesh, the death rate due to cyclone is reducing day by day. The 2007 Cyclone SIDR is not less devastating than the cyclone of 1991but the death toll has been reduced due to proper early warning dissemination. It is a clear indication that we are improving ourselves in disaster management sector. Hence, death rate could be reduced more if the evacuation has been conducted in a scientific manner. For a proper evacuation, departure route need to be developed and followed. Interview with people affected by cyclones has showed that the number of cyclone shelters in the study area is inadequate. The household condition is also vulnerable. The different existing road types have been considered for the development of evacuation route. More outlets have been suggested in the dense areas from where more people may go to the shelters. Analyzing the shortest distance and time from every outlet to shelters, it has been found that if we consider the shelter capacity to be 1300, only 12% of the total population can be accommodated into the shelters. If we consider, the shelter capacity to be 4000, only 36% of the total population can be accommodated into the shelters. If we consider the low vulnerable infrastructures, 75% of the total population can be accommodated. This study provides us an idea how we can manage our population to find out suitable nearby shelters. This study can be used as a role model for coastal belts of Bangladesh for developing a detailed cyclone evacuation plan for the coastal community.

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PART-III

SOFT SOIL TREATMENT WITH PREFABRICATED VERTICAL DRAIN (PVD) FOR THE CONSTRUCTION OF THE NEW RAILWAY EMBANKMENT OF KASHIANI-GOPALGANJ ROUTE IN BANGLADESH

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1. INTRODUCTION

Transportation plays a significant role in the progress of a country. In the construction of road, railway, airway, the alignment may have to be fixed through the soils which may not bear the traffic loads. In most cases, ground improvement is needed. In a broad sense, ground improvement refers to the incorporation of different techniques employed for modifying the properties of a soil to improve its engineering performance.

The soft Bangkok clay foundations at the site of the Second Bangkok International Airport (SBIA) have been improved using PVD (Bergado and Patawaran, 2000). Three full scale test embankments have been constructed in stages on soft Bangkok clay with prefabricated vertical drains (PVD) installed to 12 m depth in a square pattern. The rate and amount of settlement has been predicted by Asaoka's method proved to be in excellent agreement with the observed values.

Performance of an 80 km long road embankment (Bangkkok-Chonburi New Highway) has been constructed on improved soft marine clay in Bangkok (Ruenkrairergsa et al. 2001). The site has been evaluated during and after construction. PVDs has been associated with preloading and found to be effective to accelerate the consolidation settlement on soft Bangkok clay. In general, soft clay thickness has been varied from 6 m to 14 m. PVD spacing has been designed to be 1.2 m triangular grid pattern with varied length at each contracted section. PVD have been installed for the areas encountered with more than 6 m thick soft clay but have been limited to the maximum depth of 12 m below the original ground.

Shen et al. (2005) has presented a case history of the performance of two full-scale test embankments constructed on soft clay deposit in the eastern coastal region of China. One embankment has been constructed on natural subsoil and the other has been constructed on PVD improved subsoil. The soil profile consists of a thin weathered crust from about 1–1.5 m thick overlying a silty clay deposit of approximately 4 m thick. The third layer is very soft clay (MC, in China it is called mucky clay) with a thickness of approximately 10 m for the PVD-improved case and 11.5 m for the unimproved case. Below the clay is a silty clay layer called mucky-silty clay (MSC) approximately 4 m thick for PVD-improved case and 2.7 m for the unimproved case followed by a medium to stiff silty clay layer from 3 to 5 m thickness extending down to 23 m depth, which is in turn underlain by a layer of loose clayey sand. The thickness of the soft clay deposit without PVD-improvement is 19 m and with PVD-improved case is 23 m. The PVDs have been installed to a depth of 19 m with spacing of 1.5 m in a triangular pattern. Field performance of the two embankments has been analyzed using the finite element method. The analytical results show that PVDs has increased the bulk vertical hydraulic conductivity of soft subsoil by about 30 times compared to the original non-treated subsoil.

The vacuum-PVD system has been applied for soft Bangkok clay combining capped PVD with vacuum pressure and embankment loading whereby the PVD has been connected by HDPE tubes to a vacuum pipe (Saowapakpiboon et al., 2008). The soil profile at the project site (section EW-4, a part of the third runway of Suvarnabhumi International Airport, Thailand) can be divided into 8 sub-layers. It consists of a 2 m thick weathered clay layer overlying very soft layer which extends from 2 m to 10 m depth. Underneath the soft clay layer, a 2 m thick medium clay layer has been found. The light brown stiff clay can be encountered at 15 m to 30 m depth. The groundwater level has been found at about .50 m depth. The vacuum PVD has been installed into 10 m depth with spacing of 0.85 m and arranged in a triangular pattern. The final settlement of 0.91 m to 1.21 m with a degree of consolidation of 66% to 80% has been achieved. The vacuum-PVD system has reduced the time of consolidation by more than 50%.

The rail track of the Sandgate Rail Grade Separation Project (Sandgate between Maitland and Newcastle, in the Lower Hunter Valley of New South Wales, Australia) has been stabilised using short PVDs in the soft subgrade soil (Indraratna et al., 2011). Site investigation included 6 boreholes, 14 piezocone (CPTU) tests, 2 in-situ vane shear tests and 2 test pits. Laboratory testing such as soil index property testing, standard oedometer testing and vane shear testing were also performed. The groundwater level is at the ground surface. The soil profile at the project site consists of soft compressible soil (4 m-30 m), soft residual clay, and shale bedrock. Unit weight of the soil has been varied from 14-16 kN/m^3. Undrained shear strength has been varied from 10-40 kPa. The PVD has been installed into 8 m depth with spacing of 2 m and arranged in a triangular pattern. The formation has been separated into 3 distinct layers, namely ballast and fill, Soft soil-1 and Soft soil-2.

The Ballina Bypass route in Ballina (New South Wales, Australia) has been built to reduce local traffic jams (Indraratna et al., 2012). The soil profile at the site consists of very thick clay (more than 40 m), soft silty clay layer (20 m thick, water content 80-120%) and a firm clay layer. Shear strength has been varied between 5 and 40 kPa. To ensure ground stability and improvement, PVDs combined with surcharge and vacuum preloading has been utilized to consolidate the soft soils before the construction. A trial embankment has been built to the north of Ballina to evaluate the effectiveness of the technique in this area.

The railway embankment along the alignment of the project for the construction of double line track from Tongi to Bhairab Bazzar (including signaling on Dhaka- Chittagong main line) on soft ground between chainage 29+300 m to 64+265 m has been completed recently (BRTC, 2013). Depending on the soft ground treatment, 29 sections have been identified; among which in 13 sections no treatment is required, surcharge loading in 2 section, remove and replacement technique for 7 sections and PVD installation in 7 section (for 10.86 km) of the embankment is used. The PVD has been installed with spacing of 1.8 m c/c and arranged in a square pattern.

North-South Expressway (NSEW) project at Dong Nai Province, Cai Mep International Terminal (CMIT) project at Baria-Vung Tau provine, and 3 test embankments (TS1, TS2 and TS3) at Suvarnabhumi Bangkok International Airport (SBIA) project in these three projects of Thailand, PVD with or without vacuum consolidation is used for soft soil improvement (Long, P.V. et al. 2013). In the NSEW project PVD has been installed with spacing of 0.9 m and arranged in a triangular pattern. In the CMIT project PVD has been installed with spacing of 0.9 m and 1.2 m arranged in square pattern. In the SBIA project PVD has been installed into 12 m depth with spacing of 1.5 m, 1.2 m and 1.0 m.

Reddy et al. (2013) has proposed finite element modeling (FEM) for a portion of new road at Kakkanad, Thankalam new road, India where ground improvement (1000m and road width is expected to be 1.2m) has been done by preloading with PVD. Part of the road alignment goes through low lying water logged area. The primary consolidation of soil will continue for a longer period of time it is about 2.36 years from preliminary calculations which results in uneven settlement and severe cracking of the pavement surface. These PVDs are placed at a distance of 1.3m spacing. FEM analysis for the field conditions is done using PLAXIS. Using the FEM the flow of the pore water has been seen. After preloading the consolidation time has been reduced and the % reduction in time after preloading is up to 30%. As the settlement of soil has been observed by preloading hence the bearing capacity of the soil is improved.

Sari and Lastiasih (2014) has conducted analysis to determine the stability of the embankment by height variation of highway embankment on soft soil. The fundamentals of preloading techniques without and with PVD as ground improvement measures have been included. The analysis has been performed by comparing the slope stability without PVD and with PVD where the soil subgrade under embankment has been experiencing an increase in bearing capacity. The paper is devoted to determine the influence in subgrade improvement on the stability of embankment using PVD.

Bo et al. (2015) has described selection of PVDs against the comprehensive specification and the selection of the PVD installation rig and accessories based on the in-situ ground conditions. The quality management of PVD material installation in ground improvement works in land reclamation projects is a critical task for designers, contractors and clients alike. Only if a good quality management system is established, can the expected performance of the PVD improvement works in the field be ensured. A case study of quality management of PVD materials in the mega Changi East land reclamation Project in the Republic of Singapore is presented in this technical report. The quality management of PVD works consisted of several processes, starting from selection of the type of PVD, properties of the PVD materials and ultimate performance verification in the field.

PVD combined with staged construction of embankment has been considered as a common technique to reduce both the time for full consolidation and the excess pore water pressure (Al-Soud, 2016). A 3D software has been used to analyze the embankment and the underlying soft soil which has been chosen to be at Basra region. The numerical analysis has showed that the PVD is very effective in accelerating the consolidation process and increasing the long term stability of the embankment. It is interesting to note that installing the PVD with spacing (1 m) leads to a rapid dissipation of most of the excess pore water pressure at the end of each stage. The length of PVD sheets can significantly accelerate the consolidation more than the spacing.

Recently, Bangladesh Railway (BR) has taken up a decision to construct a new 32.365 km long railway track along Kashiani-Gopalgang-Tungipara section. Along this track the soft soil thickness varies from 5 to 16 m. PVD in triangular pattern has been used to obtain quick consolidation settlement due to soft soil. This paper aims to discuss on the soil profile of the Kashiani-Gopalganj railway project, techniques used for soil improvement and presents analysis of the monitored settlement data.

2. PROJECT DESCRIPTION AND LOCATION

Bangladesh Railway has started construction work of a new BG track along Kashiani-Gopalganj section. Construction of the 32.365 km railway embankment of Kashiani-Gopalganj resting on soft soil required soil treatment, is the major challenge for this project. Project has started on 30.08.2015 and will be fully completed on 28-12-2018. The latitude and longitude of the site is between 23.20°N & 23°13′N and between 89.80°E & 89°42′E, respectively. The location of the site is presented in Figure 1.The alignment of the site is shown in Figure 2.

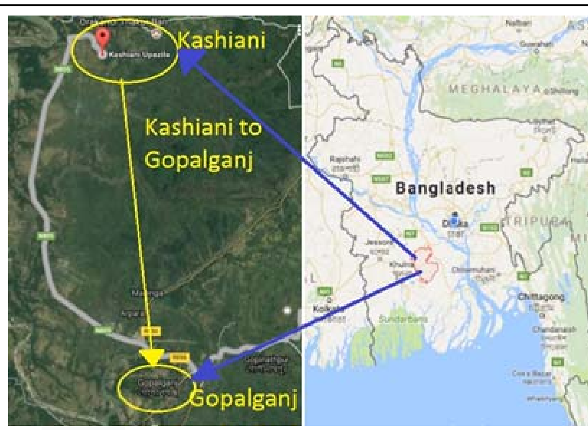


Figure 1 Project locations on the map.

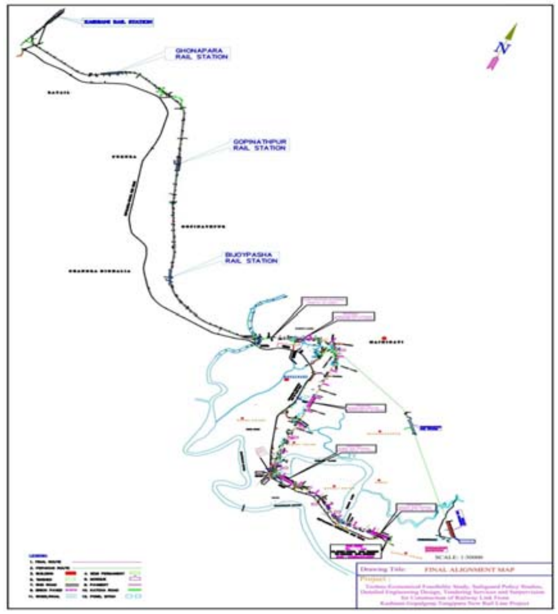


Figure 2 The alignment of Kashiani-Gopalganj section

3. GEOLOGY OF THE SITE

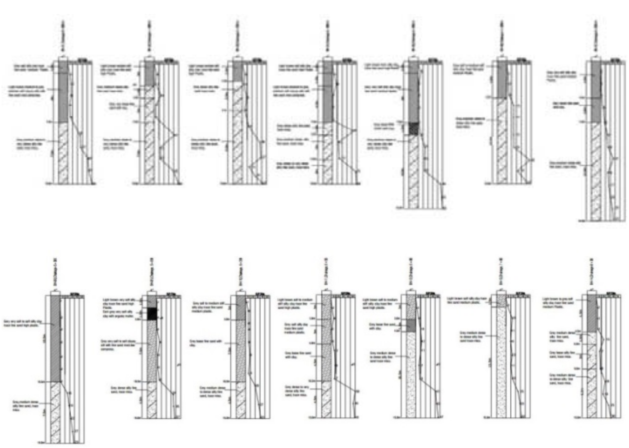
The geology of the project site comprises of Deltaic silt (dsl) and Paludal Deposits (ppc). Geologically the site comprises of light-grey to grey, fine sandy silt to clayey silt. Fine overbank sediments deposited by distributaries in flood basins. Also this site consists of grey or bluish-grey clay, black herbaceous peat, and yellowish-grey silt. Alternating beds of peat and peaty clay common in bils and large structurally controlled depressions; peat is thickest in deeper parts.

4. SUB-SOIL CONDITION AND GEOTECHNICAL PROPERTIES OF SOIL

The sub-surface investigation work includes execution of 52 borings extending to the depth of 15.0 m to 19.5 m, performance of the required field and laboratory tests, evaluation of the bearing capacity and finally recommending for the safe and appropriate type of foundation suited to the subsoil conditions. Boreholes have been drilled vertically using wash boring technique. Several laboratory tests have been conducted at Geotechnical Engineering Laboratory of BUET on disturbed and undisturbed samples of sub-soils of Kashiani-Gopalganj section on samples collected from 52 numbers of exploratory boreholes. The density and stiffness characteristics of the subsoil layers in the boreholes have been measured by performing Standard Penetration Test (SPT). Figure 3 shows all the borelogs along the alignment.

Thickness of soft compressible layers (silty clay, clayey Silt and fine silty sand) varies from 4.5 to 16.0 m as can be seen from Figure 3. Based on the provided elevations (RL) of existing ground and embankment top, the height of embankment fill has been found to vary from 0.9 m to 10.74 m. Considering the variation of fill height and the thickness of soft compressible layer total length of track alignment has been divided into 18 sections for design of PVD spacing and stage construction of embankments.

A detailed laboratory investigation has been carried out on disturbed and undisturbed tube samples collected from the 52 boreholes. Liquid limit (LL), Plastic limit (PL) and Plasticity index (PI) of 25 samples retrieved from various boreholes have been determined. Besides Shrinkage limit (SL) of 12 samples and Linear shrinkage (LS) of 20 samples have been done. The values of liquid LL of the samples varied between 31 and 94 with PI varying from 8 to 60. SL and LS of the samples has been varied from 12% to 20% and 4% to 18% respectively. Specific gravity values of the solid constituents of 20 samples have been determined. Values of specific gravity of the solid constituents of sub-soil have been found to vary between 2.65 and 2.76. Organic matter content of 4 selected samples of sub-soil has been determined. Organic matter content of the samples varied between 3.5% and 42.7%. Unconfined compressive strength tests have been carried out on 7 undisturbed samples obtained from different depths of various boreholes. On the basis of the value of undrained shear strength, which is half of the unconfined compressive strength, three of the samples tested have been found to be very soft in consistency. The values of q_u of these samples varied between 12 kN/m^2 and 38 kN/m^2 while the values of axial strain at failure (ε_f) of these samples have been found to vary between 2% and 6%. Three of the rest four samples were found to be soft to firm in consistency and values of q_u of theses samples varied between 45 kN/m^2 and 99 kN/m^2. Values of ε_f of these samples have been found to vary between 5% and 15%. One of the samples has been found which is firm in consistency and values of q_u of two specimen of this sample are 129 kN/m^2 and 159 kN/m^2. The values of ε_f of these two specimens have been found 10% and 13%. Consolidated drained direct shear test have been carried out on six undisturbed samples. The value of dry density for the six samples has been varied from 6.64 kN/m^3 to 15.41 kN/m^3. The values of effective cohesion (c') and internal friction (ϕ') has been varied from 0.0 kN/m^2 to 16 kN/m^2 and 17.2° to 43.7°. Moisture density relationships of three sub-soil samples obtained from pits have been determined.



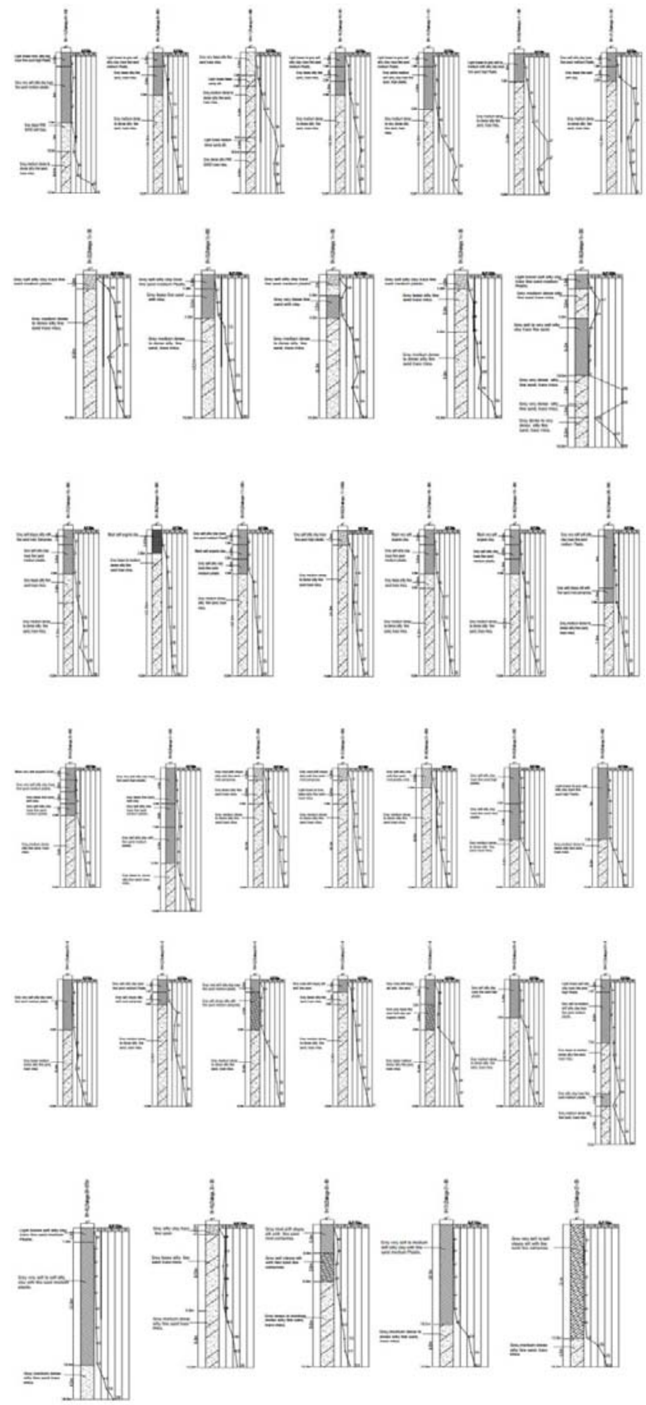


Figure 3 Soil profile with SPT values in the 52 boreholes.

The moisture content and maximum dry density values of the samples tested varied from 20.7% to 24.0% and 14.32 kN/m^3 to 15.0 kN/m^3 respectively. The values of swelling potential of laboratory compacted pit samples has been varied from 2.0% to 4.0%. Swelling potential of twenty five sub-soil samples has also been predicted using the expression reported by Chen (1975). The predicted value has been found to vary from 0.5% to 39.0%. Swelling pressure of five undisturbed soil samples have been determined, where one samples is non-swelling type while swelling pressure of the rest four samples varied from 3.4 kPa to 14.5 kPa.

By comparing the laboratory measured values of index and swelling properties of the sub-soil samples with the various recommended criteria outlined, the relative degree of expansion of the subsoil samples has been evaluated. Based on the values of liquid limit and plasticity index as recommended by United States Army Engineers Waterways Experimental Station **(**Johnson and Snethen, 1978)**,** the degree of expansion of samples of the samples, in general, is low to high. Based on the values of linear shrinkage data of Bangladesh soil as recommended by Hossain (1983), the degree of expansion of sub-soil samples is low to high. Based on the values of free swell as proposed by IS: 1948 (1970), the degree of expansion of the samples is low. Based on the values of free swell index proposed by IS: 2911 (1980), the degree of expansion of undisturbed samples is low. Based on the values of swelling pressure as proposed by Chen (1975), the degree of expansion of undisturbed samples is low. Based on the values of swelling potential as recommended by Seed et al. (1962), the degree of expansion of the laboratory compacted samples is medium. Based on the predicted values of swelling potential is recommended by Chen (1975), the degree of expansion of the samples, in general, is low to high. On the basis of the above mentioned findings, it can be concluded that the overall degree of expansion of the samples is low to high. Because of presence of sub-soil of high expansion potential at different locations, modification of the sub-soil is essential to reduce the degree of expansiveness. The upper soil layer up to depth of about 1 m, need to be stabilized before placement of embankment fill. Although soil stabilization may be done to achieve various objectives, the purpose of soil stabilization here is to reduce the shrinkage/expansion potential. Mixing of lime about 4% to 5% by weight of dry in-situ soil may be adopted. Powdered quick lime (CaO) will have to be spread over an area and then mixed with the soil by harrows. However, this will require procurement of huge amount of lime. Alternatively granular material, such as fine sand or dredge sand (50% to 60% of sand by weight of in-situ dry soil) may be mixed with the existing in-situ top soil. After mixing the loosened material has to be leveled and compacted over which embankment fill can be constructed in compacted layers. In order to assess the appropriate proportion of sand to be mixed, a sample with relatively high linear shrinkage value has been mixed with fine sand (% finer No. 200 Sieve=4.9, Fineness Modulus, F.M. =1.17) in proportions of 20%, 40% and 60% of dry weight of in-situ soil and linear shrinkage tests have been conducted on the three sand mixed samples. It has been found that due to mixing of 60% of sand, the linear shrinkage has been reduced from 18% to 12% i.e. a reduction of 33%. Therefore, it has been recommended that top 1 m of sub-soil should be mixed with at least 60% by weight of fine sand (% finer No. 200 sieve $\leq$ 5, F.M. $\geq$ 1).

The values of compression index (C_c) of the samples have been varied between 0.1 and 0.67. Out of the 12 samples the values of C_c of nine samples are around 0.3 and above. The values of swell index (C_s) have been varied between 0.03 and 0.14. Initial void ratio (e_o) of the samples varied between 0.76 and 1.69. Depending on the stress range, the values of coefficient of consolidation for vertical flow C_v of four samples has been varied between 1.3 m^2/year and 30.0 m^2/year while the values of coefficient of consolidation for horizontal flow (C_h) of eight samples has been varied between 1.0 m^2/year and 33.4 m^2/year. Depending on the stress range and void ratio, the values of coefficient of vertical permeability (k_v) of four samples has been varied 5.6×10^{-11} m/s to 8.3×10^{-9} m/s while the values of coefficient of horizontal permeability (k_h) of eight samples has been varied 5.3×10^{-11} m/s to 9.5×10^{-9} m/s.

5. CONSOLIDATION SETTLEMENT

Total 32.365 km railway embankment has been divided into 18 segments according to the variation of the thickness of soft compressible layer. In the first 2.535 km thickness of soft compressible layer is 4.5 m. 60 kPa surcharge pressure has been considered due to axle load. The considered unit weights, initial void ratio (e_o) and compression index (C_c) are 18 kN/m^3, 1.25 and 0.35 respectively. For design of subsoil improvement, average thickness of the soft compressible layer and average height of embankment and estimated settlements (both before and after the PVD using) along different segments have been presented in Table 1.

6. SOIL IMPROVEMENT

The project stretch of Kashiani-Gopalganj new Railway Line passes through mostly paddy fields and the sub soil varies from soft silty Clay to clayey Silt up to 6m depth from OGL and beyond 6m, up to 10m depth there is very loose to loose fine sand with SPT (N) values ranging from 1 to 10. It clearly indicates that the ground cannot bear loads arising from structure or even from embankment formation. Further, the ground is going to experience substantial settlements due to its soft state of condition. The project alignment requires the construction of embankment with an average height of 5 to 8m all along the alignment. Since the soil underlying is found to be soft silty clay, ground improvement by installation of Prefabricated Vertical Drains (PVD) also called as Band Drains/ Wick Drains followed by preloading has been proposed. In the foundation level of the railway embankment, total 4,402,326 number of PVD has been used.

6.1 Design of PVD

Soil improvement works for eighteen segments of embankment have been considered based on the available geological profiles and the results of laboratory tests conducted under additional geotechnical investigations. Design of soil improvement works involved some steps such as, determination of maximum thickness of soft layer from the bore log data. Estimation of undrained shear strength of soft soil and the embankment fill. Values of undrained shear strength of soft soil have been assumed to vary with depth. Stability analysis at different depths of a soft soil layer which involve determination of the values of factor at different depths of the soft soil layer. A soil layer has been assumed to be safe against bearing capacity failure when the calculated factor safety at each depth of the soil layer is at least 1.1. If the stability of the sub-soil layer under the loading of full embankment height and surcharge, if any is adequate, then single stage loading is decided. Otherwise, double or multiple stages loading is proposed.

Settlements resulting from the long term consolidation of cohesive soils often create serious problems in foundation engineering. In many cases, pre-compression of the foundation soils, by applying a surcharge load prior to the placement of the final permanent load, has been used to reduce settlement problems. As the consolidation process is governed by the rate of excess pore pressure dissipation, shortening the length of pore water flow paths greatly reduces the consolidation time. PVD are artificially created drainage paths installed for the purpose of shortening drainage paths.

Table 1 Thickness of soft compressible layer and final height of embankment and the settlements (mm) for different segments of Kashiani-Gopalganj embankment

Segment	**Chainage (km)**	**Thickness of Soft Compressible Layer (m)**	**Final Height of Embankment (m)**	**Height Including Surcharge Load (m)**	**Required Base Width (m)**	**Predicted Settlements, S_c (mm)**	**Required Time (Days) [Year]**	**PVD Spacing in Triangular Pattern (m)**	**Predicted Settlements Using PVD, S_c (mm)**	**Required Time using PVD (Days)**
1.	0+500 to 2+535	4.5	0.90	-	-	-	-	-	-	-
2.	2+535 to 5+000	8	5.20	8.5	31.65	1057	956 [2.62]	1	1009	41
3.	5+000 to 7+000	12	4.84	8.14	30.21	1280	2271 [6.22]	1	1230	48
4.	7+000 to 8+000	5	4.30	7.6	28.05	774	336 [0.92]	1	724	28
5.	8+000 to 9+575	10	5.20	8.5	31.65	1193	1547 [4.23]	1	1145	47
6.	9+575 to 11+000	5	2.7	6.0	17.65	704	323 [0.88]	1.5	655	80
7.	11+000 to 12+000	8	4.0	7.3	22.85	987	936 [2.56]	1.5	938	94
8.	12+000 to 13+500	5	6.0	9.3	34.85	835	345 [0.94]	1.5	785	87
9.	13+500	10	5.7	9	33.65	1219	1556	1.5	1177	123

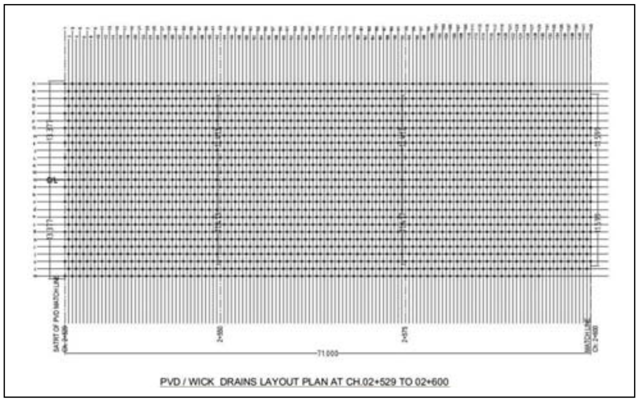
	to 16+500						[4.26]			
10.	16+500 to 18+000	5	5.5	8.8	32.85	818	343 [0.94]	1.5	770	84
11.	18+000 to 20+500	6	6.84	10.14	38.21	968	523 [1.43]	1.5	918	89
12.	20+500 to 22+000	9	6.6	9.9	37.25	1208	125 [0.35]	1.5	1158	116
13.	22+000 to 23+500	5	5.13	8.43	31.37	805	341 [0.93]	1.5	756	84
14.	23+500 to 25+500	10	6.16	9.46	35.49	1254	1568 [4.3]	1.5	1204	121
15.	25+500 to 27+000	7	6.68	9.98	37.57	1046	729 [2]	1.5	998	111
16.	27+000 to 28+500	10	10.0	13.3	54.85	1454	1618 [4.45]	1.0	1406	59
17.	28+500 to 30+500	16	10.74	14.04	57.81	1929	4418 [12.1]	1.0	1881	89
18.	30+500 to 32+365	11	6.56	9.86	37.09	1345	1932 [5.3]	1.5	1296	133

PVD are used to improve the ability of the soil to support construction and accelerate the rate of settlement. Most soil deposits have greater permeability in the horizontal direction than in the vertical direction. Therefore, PVD help in accelerating the rate of consolidation settlement. Because of their ease of installation, flexibility, reliability and lower cost, PVD have almost totally replaced conventional sand drains for a majority of application. The center to center spacing (S) between drains are S=D/1.05 (for triangular spacing) and D/1.13 (for rectangular spacing) respectively. Here D is the diameter of cylinder of influence for the drains. In designing PVD, the value of consolidation co-efficient for horizontal (c_h) flow can be estimated 2 to 3 times the value of consolidation co-efficient for vertical flow (c_v). The values of c_h are sometime considerably larger than c_v, particularly in sedimentary deposits of a continuous nature. For design purposes, it is reasonable to calculate the equivalent diameter ($d=2(a+b)/\pi$), where a is drain width and b is the drain thickness (Hansbo, 1979).

Design of soil improvement works has been carried out for the seventeen soft ground segments of embankment from Kashiani to Gopalganj on the basis of detailed sub-soil investigation. Besides laboratory test results on samples collected from 52 boreholes have been also considered. In segment-I (chainage 0+550 to 2+535 km) sub-soil improvement is not to be considered. A summary of the thickness of soft sub-soil layers at different segments of embankment and height of embankment fill has been presented in Table 1. The values of different soil parameters, embankment and PVD dimensions and criteria and criteria have been adopted for PVD design. Axle load, slide slope, berm width and crest width of embankment are 60 kPa, 2 m, 2 m and 6.85 m respectively. The value of undrained shear strength of embankment fill (C_m), undrained angle of internal friction (ϕ_m), unit weight of fill (γ) and C_T has been considered 0 kN/m^2, 35°, 18 kN/m^3 and 12 kN/m^2 respectively. Again the value of ΔC_T and D_c has been considered 0. The values of initial void ratio of soft sub-soil layer (e_o), compression Index (C_c), coefficient of consolidation for vertical flow (c_v), coefficient of consolidation for horizontal flow (c_h) and well resistance (k_h/q_w =ratio of horizontal permeability of the soft sub-soil and discharge capacity of the PVD) has been adopted 1.25, 0.35, 7 m^2/yr, 14 m^2/yr and 0.01 respectively. The width and thickness of PVD and allowable settlement of embankment after improvement are 100 mm, 3.2 mm and 50 mm respectively. Desire degree of consolidation in various stages has adopted as 80%-90%. The value of angle of friction (ϕ) of sub-soil for calculation of ΔC_u after each stage loading is 15°. Minimum factor of safety (FS) for stability against foundation failure for each stage loading has been considered as 1.1. Embankment height has been varied 4 m to 8 m and 8 m to 12 m for one and two number of berm on each side. In all the analysis, the soil has been assumed to be normally consolidated due to the presence of very soft sub-soil deposits.

Additional surcharge height, equivalent to the design axle load of 60 kPa has been considered in the design to reduce future potential settlements under service conditions. This additional surcharge height is taken as 3.3 m (= 60 kPa/ 18 kN/m^3) of fill height. Fill height in various stages is determined with consideration to ensuring a minimum factor of safety of 1.1 against stability failure. Estimated total consideration settlement at center of embankment under design height and axle load at various segments is found to vary from about 700 mm to 1929 mm. in the analyses it is considered that 50 mm of settlement of the embankment may be allowed to occur in future, and the rest amount of the total consolidation settlement shall have to be completed at the end of the sub-soil improvement and before placement of the railway track. A summary of the analyses containing estimated total settlement and required time before and after PVD has been used; PVD spacing etc. has been presented in Table 1.

In segment-2 to segment-5 (Chainage 2+535 km to 9+575 km) PVD has already been installed at 1 m spacing in a triangular pattern, as such in the analysis for that stretch of the embankment, stage construction and waiting time for 1 m PVD spacing has been assessed as shown in the Figure 5. Figure 4 shows PVD layout plan at chainage 2+529 km to 2+600 km.



It has been found from analysis that three-stage loading with waiting times is necessary to ensure foundation stability. Total waiting times for embankment loading in three stages are found to be in the range of 28 days to 48 days.

For segment-6 to segment-15 (Chainage: 9+575 km to 27+000 km) and segment-18 (Chainage: 30+500 km to 32+365 km), it is found that construction of the embankment shall have to be done in three stages to avoid stability failure. For these segments, minimum waiting times for the three stage of construction have been calculated for PVD spacing of 1.5 m and 2.0 m. It is found that total waiting time for the three stages vary from 80 days to 133 days for PVD spacing of 1.5 m has been presented in Table 1. For PVD spacing of 2.0 m, the total waiting time for the three stages vary from 159 days to 259 days has been presented in Table 1.

In segment-16 (Chainage: 27+000 to 28+500 km) and segment-17 (Chainage: 28+500 to 30+500 km), both embankment height and compressible soft layer thickness is large. Analysis show that for these segments four stage construction is required with appropriate waiting time in each stage to ensure foundation stability. For these segments, minimum waiting times for the four stages of construction have been calculated for PVD spacing of 1.0 m and 1.5 m. It is found that total waiting time for the four stages vary from 59 days to 89 days for PVD spacing of 1.0 m has been presented in Table 1. Whereas for PVD spacing of 1.5 m, the total waiting time for the four stages vary from 155 days to 221 days has been presented in Table 1.

It is to be noted that, in addition to the waiting times for different stages, additional duration is required to attain the fill heights in stages and removal of additional surcharge. While placing the fill, proper compaction has to be ensured up to the design height of the embankment in the respective segment. The rest of the fill height can be placed without compaction. It is also to be noted that, required base widths for placement of fill up to the surcharge height, with a side slope of 1 (V): 2 (H) is larger than the design base width of the embankment sections. The required base widths are shown in Table 1. The fill for surcharge loading and additional material on sides will have to be removed after desired improvement has been occurred. Predicted settlements at the end of each stage load and waiting time have shown in Table 1. However, actual waiting times for the different stages will be governed by field monitoring of settlement using settlement places. In addition to settlement plates, alignment stakes shall have to be placed at specified locations to monitor any unusual lateral displacement of the foundation soil.

6.2 Construction of PVD

Prefabricated Vertical Drain (PVD) shall be installed with approved hydraulic stitcher (shows in Figure 9 a. and b.) which will cause a minimum of disturbance to the soil during installation and maintain the mandrel in a vertical position as Figure 9 c) shows the installed PVD without disturbance to the soil. The PVD's shall be installed using a mandrel or sleeve that will be advanced through the compressible soils to the required depth using constant load, or constant rate of advancement. There are some steps which have been followed for the improvement of sub-soils. The existing ground surface has been prepared by stripping of top vegetation and grubbing and leveling at the desired elevation. After clearing the surface soil including vegetation and vegetation roots upto a depth of 150 mm no separate payment shall for clearing of vegetation and vegetation roots from surface soil, a sand blanket of medium to coarse sand of 500 mm compacted thickness has been laid over the top of compacted formation and should project at least 150 mm above NGL and 5.0 m on all sides as shown in the Figure 9 d). The blanket has been spread over the entire area of treatment. In case any pits are observed, the same shall also be filled with sand. The blanket has been laid in layers of 175 mm (maximum compacted thickness) and compacted to 95% Relative Density by means of vibratory rollers as shown in the Figure 9 e).

In order to remove the water from consolidating system, proper drainage arrangement including pits, channels and pumping arrangement has been provided. 200 mm of thick compacted layer of sand (F.M. $\geq$ 1.0, % Finer No. 200 Sieve $\leq$ 5, Relative Density, $D_r \geq 70\%$) has been placed. First layer of 200 mm thick compacted coarse sand layer (F.M. $\geq$ 2.2, % Finer No. 200 Sieve $\leq$ 3, Relative Density, $D_r \geq 70\%$) has also been placed as shown in Figure 6. PVD have been installed at specified spacing. In areas where wind is prevalent, fabric installation has been started at the upwind side of the project and proceeds downwind. The leading edge of the fabric has been secured at all times with sandbags or other means sufficient to hold it down during high winds. Sandbags or rubber tires have been used as required to hold the fabric in position during installation. Tires shall not have exposed steel cords or other sharp edges may snag or cut the fabric. Materials equipment or other items shall not be dragged across the fabric or be allowed to slide down slopes on the fabric. Should the fabric be damaged during any step of the installation, the damaged section has been repaired by covering it with a piece of fabric. Installed Geo-textile has been covered by preloading fill. Surcharge shall have been used as preloading surcharge. The material shall be earth locally available and fit for earth filling purposes. The earth shall have been spread in layers not more than 250 mm compacted thickness. Earth-fill below designed formation level and up to 500mm above the designed formation level and shall be compacted up to 95% Proctor density/80% relative density as applicable. Remaining height of Earth fill shall has been compacted to 80% Proctor density 60% relative density. Now non-woven needle punched geotextile fabric has been placed over the first coarse sand layer as shown in Figure 7. Second layer of 300 mm thick compacted coarse sand layer (F.M. ≥ 2.2, % Finer No. 200 Sieve ≤ 3, Relative Density, $D_r \geq 70\%$) has also been placed as shown in Figure 6.

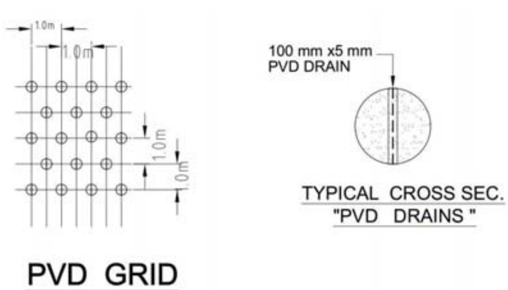


Figure 5 Figure shows the PVD grid and typical cross section of PVD drains.

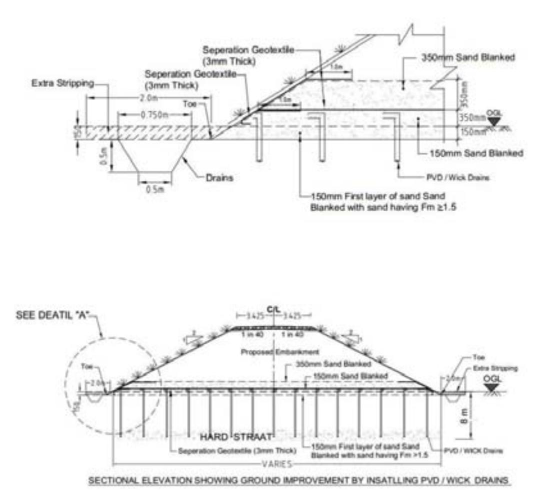


Figure 6: sectional elevation showing ground improvement by installing PVD at chainage-02+529-8+000

The settlement plates has been allocated with their base at the top of the second coarse sand layer to monitor the vertical settlement of sub-soil. Then embankment fill has been positioned. Alignment stakes at and beyond the embankment toes has been inserted to monitor the horizontal movement of ground.

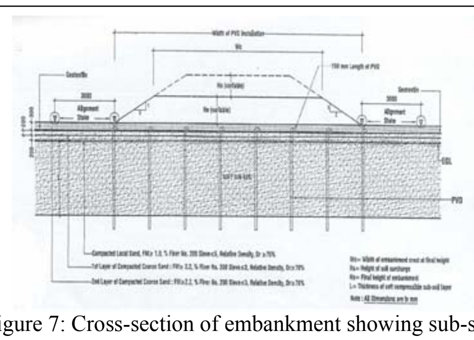


Figure 7: Cross-section of embankment showing sub-soil improvement scheme.

Settlement of the fill has been monitored (record RL) at least twice a week. After the required maintenance period of preloading and surcharging, the surcharge has been removed and construction of the railway track has been started. Figure 7 shows the cross-section of embankment showing the proposed sub-soil improvement scheme while Figure 8 shows plan and section of embankment showing the locations of the settlement plates and alignment stakes.

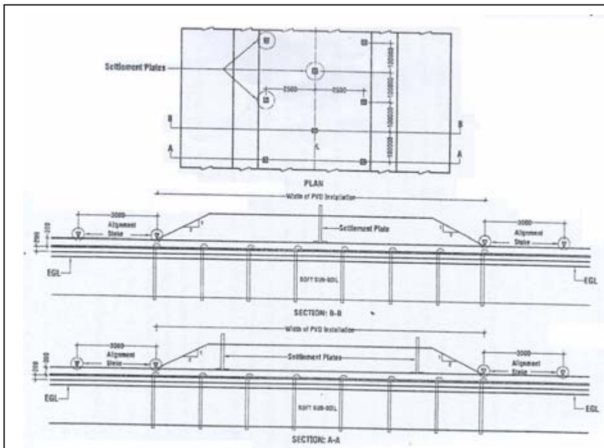


Figure 8: Plan and section of embankment showing the locations of settlement plates and alignment stakes.

Needle-punched geotextile has been used for PVD construction. The specification of non-woven needle-punched geotextile is given here. The values of mass per unit area (ASTM D 5261), thickness (under a pressure of 2 kPa, ASTM D 5199), apparent/ Effective opening size (AOS/EOS, ASTM D 4751) and Vertical permeability at 20°C (UNDER 2 kPa normal stress, DIN) has been estimated as $\geq$ 400 gm/m^2, $\geq$ 3.5 mm, < 75 µm and $\geq 3.0\times10^{-3}$ m/s respectively. The values of horizontal permeability (ASTM D 4716), grab tensile strength (ASTM D 4632), grab tensile elongation (ASTM D 4632), wide width tensile strength (ASTM D 4595), wide width tensile elongation (ASTM D 4595) and CBR puncture resistance (ASTM D 6241) at 20°C has been tested as $\geq 3.0\times10^{-3}$ m/s, $\geq$ 1500 N, $\geq$ 85%, $\geq$ 20 kN/m, $\geq$ 80% and $\geq$ 3500 respectively. Figure 9 f) shows the completed rail way track.

7. MONITORING OF SETTLEMENTS

Ground settlement has been monitored using the settlement plates at seven chainage locations (up to 15 km) during consolidation under embankment load to validate the design assumption and to ensure pre-consolidation before construction of PVD. Practically in the field it is a challenging and tough job to manage the application of surcharge load which has been considered during design phase. During implementation no surcharge (60 kPa) has been placed, only embankment load has been used as preloads. The required time for settlement is much higher than the time estimated in the design phase. Settlement monitoring has been started immediately after placement of the materials to the embankment height and continued until consolidation has been completed.

Figure 9: a) and b) shows the installation of PVD, c) shows the installed PVD, d) shows first layer of sand blanket spread over the top, e) shows sand blanket is compacted with vibratory roller and f) shows the completed railway track.

Settlement versus time curve of these chainage points have been presented at Figure 10. At chainage point 3+800 km, 486 mm settlement in 256 days has been observed at the end of first stage and 657 mm settlement has been observed at 376 days (which has been monitored until 525 days) at the end of second stage. At chainage point 5+050 km, first and second stages have been completed with 490 mm settlement in 220 days and 730 mm settlement in 360 days (which has been monitored until 560 days), respectively.

At chainage point 5+300 km, first and second stages have been completed with 470 mm settlement in 220 days and 731 mm settlement in 340 days (which has been monitored until 490 days), respectively. At chainage point 5+800 km, first and second stages have been completed with 475 mm settlement in 225 days and 644 mm settlement in 360 days (which has been monitored until 500 days), respectively. At chainage point 6+300 km, first and second stages have been completed with 441 mm settlement in 225 days and 638 mm settlement in 365 days (which has been monitored until 550 days), respectively.

At chainage point 8+300 km, first and second stages have been completed with 361 mm settlement in 180 days and 626 mm settlement in 360 days (which has been monitored until 500 days), respectively. At chainage point 11+800 km, first and second stages have been completed with 399 mm settlement in 190 days and 524 mm settlement in 385 days (which has been monitored until 530 days), respectively.

Predicted and observed settlement with percentage of error in prediction for specific seven chainage points have been presented at Table 2.

Table 2 Thickness of soft compressible layer, Predicted and Observed Settlement (mm) for different chainage of Kashiani-Gopalganj embankment

Chainage (km)	s of soft compress ible layer	Surcharg e Load	Settlemen t (mm)	Settlemen t (mm)	in Predictio
3+800	7.5	5.4	629	657	4.5
5+050	4.5	5.9	683	730	6.9
5+300	10.5	5.3	721	731	1.38
5+800	3	5.6	529	644	21.8
6+300	3	5.4	521	638	22.4
8+300	4.5	4.8	621	626	0.81
11+800	3	4	459	524	14.16

At all the seven chainage points, predicted settlement without using surcharge is less than the observed settlement. Currently, construction work of 15 km of railway embankment has been completed and rest 17.365 km railway embankment is under construction stage.

8. CONCLUSIONS

The application of prefabricated vertical drain (PVD) technique, as a soil stabilization method has been presented in this paper. Regarding the time consumption aspects and value of required work, soil strengthening by forming PVD is a more preferable technique. In this project 4,402,326 number of PVD has been installed at 1 m to 1.5 m center to center spacing in triangular pattern up to a depth of 16 m. Initially, 32.365 km railway embankment has been divided into 18 segments. Predicted settlement with using a surcharge load of 60 kPa has varied between 704 mm and 1929 mm. The predicted time required for the above settlement has varied between 0.88 years to 12 years. During implementation of the initial 15 km out of the total 32.365 km of the embankment, surcharge load (60 kPa) has not been placed due to some construction related issue. For this reason, the measured settlement time needed is higher than predicted during the design phase. At seven chainage locations along the 15 km already constructed embankment, settlements have been monitored. The predicted and observed settlements at those points are almost same. The concept of the soil improvement using PVD beneath the railway embankment is not only cost-effective but also safe, reliable and time-saving as shown through the success of the project.

9. ACKNOWLEDGEMENTS

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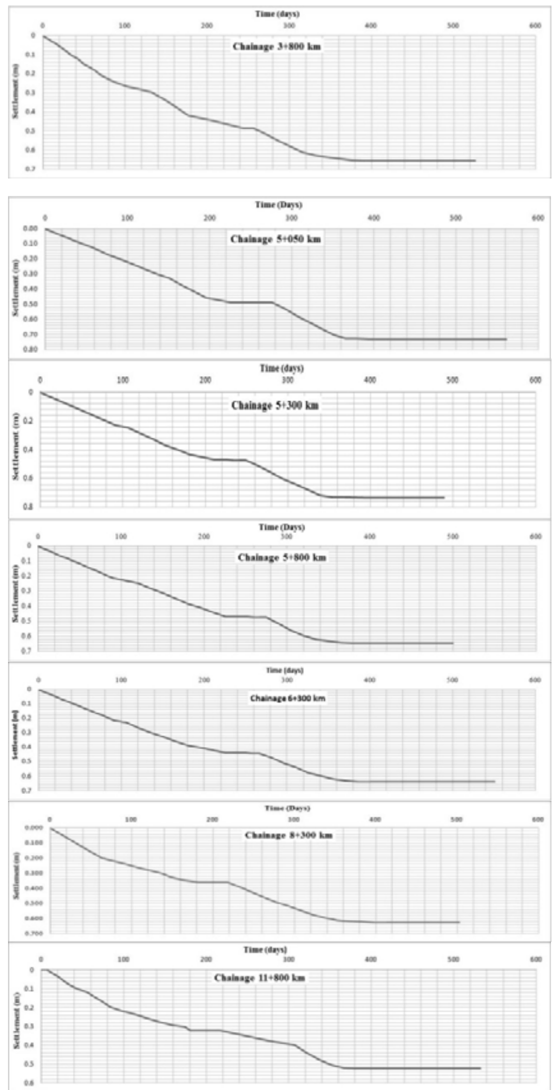

Figure 10 Settlement versus time curve at eight chainage points.

BANGLADESH NETWORK
OFFICE FOR URBAN SAFETY

PART-IV

INTER-ORGANIZATIONAL RESPONSE TO CYCLONE SIDR (2007): A NETWORK BASED APPROACH

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

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1.Introduction

Natural disasters such as cyclone, flood, earthquake etc. cause immense destruction every year around the world. Apart from causalities, such events hamper the lifeline system and cause widespread loss of life and property by damaging social and physical infrastructures [1]. In all cases, a series of actions is required to address such catastrophic consequences and overcome the effects of destruction. While it may be impossible to completely prevent the occurrence of catastrophe, properly planned measures starting from preparedness to response and rehabilitation can minimize the anticipated loss [2].

Bangladesh is one of the most disaster-prone countries in the world due to its geographical location, soil characteristics, diversity of rivers and monsoon climate. It is not surprising that the country has a long history of cyclones, landslides, tornadoes and is under the threat of earthquake [3]. With Bay of Bengal at its southern border, Bangladesh is particularly vulnerable to tropical cyclones and from 1584 to 1991, about 53% of the world deaths from these cyclones have taken place in Bangladesh. Studies regarding climate change argue that global warming can induce the occurrences of cyclone and the situation in Bangladesh is likely to worsen [4].

Cyclone Sidr (a category IV storm on the Saffir-Simpson hurricane scale of I to V) is one of the most devastating cyclones in the history of Bangladesh. Being originated from a depression in Bay of Bengal, the cyclone has swept through the southwestern coast of Bangladesh on 15 November, 2007 with a diameter of nearly 1000 km and sustained winds of up to 240 km per hour. According to official reports, about 27 million people from 30 districts have been affected by the cyclone with a death toll of 3,406 and estimated loss of $1.3 billion. Storm surge with a maximum height of 20 feet in certain areas has caused immense physical destruction, damage of crops, livestock and flooding of low lying areas. Mainly the poverty-prone districts of the country have been affected by the cyclone [1,3,5]. Although the death toll is significantly less compared to previous cyclones that hit Bangladesh, Sidr has caused extensive damage to properties. The scale and devastation of the cyclone have created dynamics that are impossible to be addressed by any single organization or jurisdiction area. In addition to national assistance directed towards the affected people, the cyclone has resulted in a global response with supports from various international donors and development partners [3].

The term “network” is defined as- “group of individuals or organizations who, on a voluntary basis, exchange information and undertake joint activities and organize themselves in such a way that their individual autonomy remains intact”. The term is used to describe the multiple organizations engaged in interactions involving multiple nodes [6]. After catastrophic events the formal structure of operation, including the functioning of existing support networks, communication networks and other infrastructures are often disrupted as seen from previous incidents of South-Asia Tsunami (2004), Hurricane Katrina (2005), the Great Japan Earthquake (2011) etc. [7]. At times of emergencies, a collective action is required among public, private and non-profit organizations towards mitigating the adverse consequences [8,9]. Emergency management organizations, both governmental and non-governmental, look to one another for topical information and practical guidance [10,11]. Inter-organizational networks in emergencies play a vital role in facilitating the flow of information across organizational boundaries [6]. Therefore, network analysis can be conducted to determine the pattern of relationship among different organizations that interacted within a disaster response system. Social network analysis is a well-developed area of organizational sociology which provides tools and concepts for analyzing organizations as networks. The basic idea is to consider the organizations as "nodes" and the relationship between them as "ties", forming a network-like structure [12,13].

In practice, natural disasters result in a number of complexities that may exceed what has been anticipated by national policies and existing planning process. Careful examination of organizational network following a disaster is vital to determine the discrepancies between disaster management plans and actual performance under the stress of a catastrophe. Effective response and recovery require well-coordinated interorganizational networks between government agencies at all levels and between the public and private sectors [6]. Inter-organizational network analysis after extreme events may further assist in exploring ways to ensure the optimum utilization of the capabilities of these networks [14]. Although existing disaster management policies of Bangladesh, including "Standing Order on Disaster" have declared the responsibilities of each organization related to disaster management, the involvement of large number of non-governmental actors after a disaster may create complexities beyond the comprehension of government [15,16]. The governmental report "Super Cyclone Sidr 2007: Impacts and Strategies for Interventions" has revealed a number of lessons stated as learned or observed from the response system of cyclone Sidr. Many of the lessons are somehow related with interorganizational response issues [3].

Considering the vulnerability of Bangladesh to tropical cyclones and the future probability of cyclones in the country, the inter-organizational relationships that emerge in response to cyclones must be thought with great importance. Understanding the formation of response network and the key organizations related to the network is urgent for the policy makers in order to develop a disaster management system that can better respond to the changing environment and leverage the efforts of the organizations to collectively achieve the common goal [9,17].

2.Interorganizational Network Analysis in Catastrophic Events

Recently there has been growing literature on the importance of network analysis and its application in disaster research. Research works have addressed issues of communication networks during disaster [18-21], importance of social networks on disaster relief management [22-23] and inter-organizational coordination in disaster response systems [24-26].

The inter-organizational response to major catastrophic events has been recognized by many researchers. Kapucu (2005) has explored the inter-organizational network in response to *World Trade Center attack (2001)* and found that interactions among the organizations are limited and have primarily occurred between organizations of similar type from the same jurisdiction. FEMA and New York City Government/Mayor have been identified as most influential in response operations [6]. Findings from *Hurricane Katrina (2005)* have revealed a moderate level of interaction among the responding actors. The inter-organizational network of the hurricane involves smaller portion of non-profit organizations while major share of response network belongs to the public organizations [14,27]. An inter-organizational network study on *ChiChi Earthquake (1999) and Typhoon Marakot (2009*) in Taiwan has revealed that, public organizations have possessed the central role in disaster response system whereas non-profit and private organizations have worked with their own close groups instead of connecting with the major response network. According to the study, major proportion of the transactions has been involved in emergency response, damage assessment and fund-raising activities [9]. In case of response to *Haiti earthquake (2010*), there is large number of isolates in the response network that are not connected to any other organizations. Water, Sanitation and Hygiene (WASH) and UNICEF, closely followed by World Food Programme (WFP) are among the top key entities [28]. In *Tohoku-Oki disasters of Japan (2011)* it has been seen that, in contrast to the plans which have designated primary responsibilities in disaster response to the public authorities, private and non-profit organizations have consisted nearly half of the organizations responding to the massive event. The overall as well as separate centralization measures of the networks are very low which indicates a highly-decentralized network of response organizations during first three weeks of the disasters [29,30]. Social network analysis of *Australian floods (2010-2011*) has identified local authorities, political personalities, social media volunteers, media reporters, and people from non-profit, humanitarian, and community associations as effective players during the Queensland flood [31]. Results from a Twitter based emergency management-related organizational analysis of *Colorado Wildfire (2017)* have denoted that the federal agencies like FEMA, Centers for Disease Control and Prevention, Department of Homeland Security, etc. are among the most important players in this network [7]. Although these studies may differ in terms of their methodology and coverage, findings from the studies have signified the fact that networks emerging in response to disasters consist of a large number of organizations varying in their scale, size, extent and scope.

This research discusses the identification of most influential actors in the context of networks of organizations in response to cyclone Sidr (2007). Specifically, this paper examines the interactions among organizations engaged in responding to cyclone Sidr. An important feature of the research is to revise the disaster management system in Bangladesh and determine the degree to which actual condition corresponds to the stated policies while interacting with hazards. By exploring such interactions among organizations, this research would be able to recommend which aspects of the planning process could be changed in order to enable communities to respond effectively to catastrophic events.

3.Initial Condition of Disaster Risk Reduction in Bangladesh

Natural disasters cause great economic loss every year in Bangladesh. About 14% of GDP in Bangladesh is vulnerable to natural disasters, while every year the country faces 1.8% of GDP loss due to natural disasters [32]. Disaster management in Bangladesh has gone through significant reform since independence in 1971. Since the devastating flood in 1988 and cyclone in 1991, the conventional disaster management model involving emergency response has been converted into a more holistic model, which includes hazard identification and mitigation, community preparedness and integrated response efforts [15,33].

Because of the unique geographical condition, cyclonic events are considered as regular catastrophic phenomena along the coastal areas of Bangladesh, affecting at least 15 districts and hundreds of off-shore islands. As seen from Table 1, from 1960 to 1965, five severe cyclones hit the coastal belt of Bangladesh killing approximately 50,000 people [34].

Table 1: Major cyclone events in Bangladesh since 1960 *(Source: GoB, 2013)*

Year	Month	Human death
1960	October	5149
1961	May	11466
1963	May	11520
1965	May	19276
1965	December	-
1966	October	850
1970	November	500000
1985	May	11069

1991	April	138000
1994	May	170
1997	May	126
2007	November	3363
2009	May	190
2013	May	17

Considering the emerging disaster risk in Bangladesh, the country is internationally committed to Hyogo Framework for Action 2005-2015 (HFA) for pursuing an intergraded multi-hazard approach by placing disaster risk at the center of political priorities and policies. Bangladesh is also an active member of South Asian Association for Regional Cooperation (SAARC) which adopted a comprehensive framework on disaster management at the 13th SAARC Summit held in Dhaka (2006-2015) titled as "Disaster Management in South Asia: A Comprehensive Regional Framework for Action". Strategic goals of the framework include mainstreaming of disaster risk reduction, strengthening emergency response system and developing networks of relevant national, regional and international organizations. Bangladesh has also contributed to the formation and adoption of Comprehensive Framework on Early Warning, Disaster Management and Disaster Prevention in 2007 [15,35].

As implementation measure for both HFA and SAARC framework, Bangladesh has developed National Plan for Disaster Management (NPDM) (2010-2015) which provides a simple model to

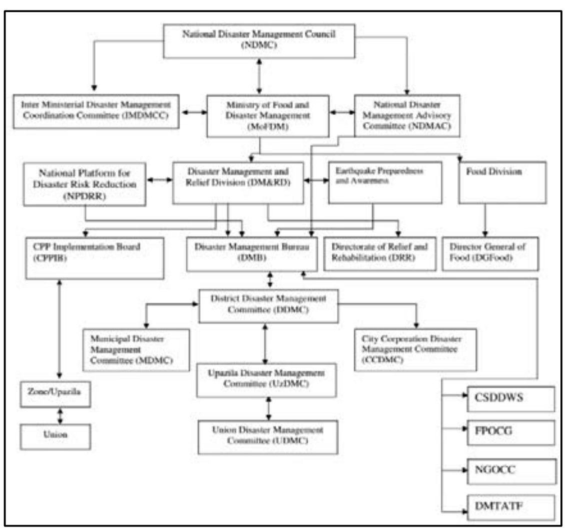

Figure 1: Institutions of disaster management in Bangladesh (Source: GoB, 2010)

guide disaster management and emergency response efforts in Bangladesh. Currently Disaster

Management Act of 2012, SODs and other DRM-related laws and codes constitute the central of Bangladesh national disaster management regulatory framework. Disaster Management Act (2012) provides the legal mandates for government agencies and non-government actors. Standing Order on Disasters (SOD), first published in 1999 and revised in 2010, clearly outlines the responsibilities of public representatives, ministries, agencies and non-governmental organizations related to disaster management [15,35].

4.Institutional Framework and Preparedness for Cyclone in Bangladesh

The consistent occurrences of tropical cyclones in Bangladesh made preparedness for cyclone a necessity for the country. The organizational framework dealing with cyclone hazard in Bangladesh can be divided into two levels- national and local. Government has established an elaborate disaster management committee that ranges from National Disaster Management Council to Union Disaster Management Committee as shown in Figure 1.

National Disaster Management Council (NDMC) is the highest committee to deal with crisis and is responsible for policy making and formulation of strategies for disaster management. Ministry of Food and Disaster Management (MoFDM) is the main national agency for disaster risk reduction. Its focal office for disaster risk management is Department of Disaster Management (DDM). MoFDM works with other ministries that have disaster management related mandates whereas DDM works with local government bodies [15,35]. In April 1993, government has established Disaster Management Bureau (DMB) which coordinates and overviews all activities related to disaster management from national to grass-root level, raise awareness regarding hazards and work in close collaboration with district and upazila level authorities. As continuation of the paradigm shift process in disaster management, Comprehensive Disaster Management Programme (CDMP) has been established in November, 2003 for optimizations of long-term risk and strengthening operational capacities for responding to emergencies [33]. In case of weather forecasting, Bangladesh Meteorological Department (BMD) is responsible for the monitoring of sea condition and provision of weather information to concerned authorities [15]. Armed Forces Division (AFD) plays a vital role in disaster management in Bangladesh. According to SOD, as per the requisition of MoFDM at times of crisis, AFD coordinates the overall rescue and relief operation. Army, Navy and Air Force together ensure early recovery, relief and rehabilitation work as decided by the government at times of disaster [15,36].

At local level, Deputy Commissioner (DC), Upazila Nirbahi Officer (UNO) and Union Parishad (UP) Chairman are responsible for the operation and coordination of relief and recovery activities in cyclone affected districts, upazila and union respectively. The Cyclone Preparedness Porgramme (CPP) established in 1972 is a good example of cyclone preparedness, warning dissemination and response system in Bangladesh. Awareness for cyclone preparedness activities emerged when Bangladesh Red Crescent Society (BDRCS) requested the International Federation (IFRC) to support the establishment of warning system for the people of coastal Bangladesh. In 1966, IFRC and Swiss Red Cross initiated the implementation of a pilot scheme through the provision of warning equipment such as transistors, sirens etc. and training of local personnel. Following the devastating cyclone in 1970, IFRC and BDRCS conducted an extreme evaluation of CPP which lead to a new programme consisting of 20,310 volunteers 24 thanas. In 1973, CPP became a government programme with joint venture of government and BDRCS [33, 37-39].

Currently the Cyclone Preparedness Programme (CPP) is organized in 258 unions of 30 thanas divided into 2733 units of Bangladesh. CPP volunteers are trained in early warning dissemination, evacuation, search and rescue, first aid and relief operations. Their capacity development process also includes basic disaster management and leadership training. In 2007, CPP volunteers have guided almost 1.5 million people to cyclone shelters when cyclone Sidr hit Bangladesh [39].

5. Response Process to Cyclone and Key Participants

In turbulent or complex situations, organizations frequently develop formal or informal relationships in order to work together and respond to the environment [6]. Responders to disasters can generally be classified into four groups: governmental agencies, volunteer organizations, private sector and individual citizens. The central responsibility for planning and performing response operations during extreme events is mainly assigned to governmental agencies (including military) at local, state and federal levels. Volunteer or non-profit organizations, mainly engaged in basic human and medical services, can range from local civic groups to large international organizations. Private sector ranging from small business groups to multi-national corporations can make contributions through donation or provision of professional services in specialized sectors such as information and logistics management [40].

In Bangladesh, SOD includes the responsibilities assigned for governmental agencies including ministries, Armed Forces Division (AFD), cabinet etc. at central level and district administration committee at local level. Responsibilities are described for normal times, alert and warning stage, disaster stage and rehabilitation stage [15]. As soon as a depression is formed in Bay of Bengal, BMD transmits cyclone warning signals in the form of special weather bulletins to CPP office at Dhaka. BDRCS is also responsible for issuing warning notices to CPP and relevant Red Crescent Unit. This information is transmitted to 6 zonal offices and 30 thana level offices over High Frequency (HF) radio, which is in turned passed to the unions through Very High Frequency (VHF) radio. The union team leaders of CPP disseminate cyclone warnings along with volunteers in the villages using megaphones, hand signs and public-address system. The team leaders also keep track of the approaching cyclone by listening to the national radio broadcast. When situation turns serious, government calls for emergency evacuation and the volunteers implement the order by helping people in taking shelter in cyclone shelters or other available safe places [37]. Divisional Commissioner, DC, UNO and Disaster Management Committee (DMC) provide necessary directives and Fire Service and Civil Defense of the affected areas are assigned to contact with local administration for carrying emergency operations. In case of NGOs, SOD assigned them to assist government agencies and work in liaison with DMB, DC, UNO and UP Chairman [15].

The brief review of national policies related to disaster risk reduction in Bangladesh reveal the following important characteristics that may affect the response system of natural disasters-

Firstly, national policies especially the SOD have bestowed primary responsibilities of disaster management to public organizations. Both ministries and governmental agencies are held responsible for disaster preparedness, mitigation, response and recovery. However, personnel in public organizations often lack sufficient capacity to effectively deal with emergency situations. There are many public organizations which lack proper awareness of SOD and their responsibilities during natural disasters. Organizations at local level including CPP volunteers also lack proper resources and training. There is no formal mechanism for non-profit organizations and private sector to assist public organizations. Effective coordination and management of response efforts is hindered by such discrepancy between legal responsibility and actual capacity of public organizations.

Secondly, the expected scenario in case of emergency response is based on a "top-bottom approach". Many of the key organizations including AFD has to work as per requisition of the central government during emergency situations. In case of local administration, the higher order of administration is responsible to guide and coordinate the activities of lower level authorities including NGOs. For example- District Disaster Management Committee (DMMC) is entitled to coordinate the activities of union, pourashava and upazila DMC. Although in the DM Act local disaster management committees have been given the provision of requesting the deputy commissioner to declare emergency for a particular disaster affected area, the order has to come from upper levels of administration. Poor information management among different levels of authorities and lack of decentralization at local levels of governance hinder effective response during emergency situations.

Lastly, the SOD is not prepared for any specific hazard. The stages of disaster management vary distinctly among different disasters. SOD (1999) was prepared based on flood in 1988 and major cyclone in 1991. Later earthquake has been included when SOD was updated in 2010. Tropical cyclones, as regular natural hazards of Bangladesh, require separate sets of guidelines and organizations for the vulnerable coastal regions. Listing the organizations solely responsible for earthquake, cyclone, storm surge and flood may enable them to adapt to changing circumstances more effectively

These structural characteristics of the response system, written into the policy documents, create barriers in emergency response management of Bangladesh. Therefore, cyclone Sidr gave a valuable opportunity to explore the actual organizational response system under the stress of a disaster.

6. Organizational Response to Cyclone Sidr (2007)

The performance of any disaster risk reduction plan can be verified when an actual incident of disaster occurs. Cyclone Sidr provided major test of SOD (1999) and the international commitment of HFA (2005) and SAARC framework (2006).

The organizational response system that emerged following cyclone Sidr has been observed through content analysis. From the news articles reported in *The Daily Star* newspaper, all the organizations that participated in the response system through provision of search and rescue services, medical care, relief distribution, donation, shelter and other types of assistance for the affected persons have been identified. Content analysis has been conducted for a period of three weeks, starting from 15 November, 2007 to 7 December, 2007. Content analysis of news reports has identified 203 organizations that responded to cyclone Sidr and it does not claim to represent the entire response network. Table 2 shows the composition of the response system as found from the analysis. Here city based organizations denote those organizations that are mainly based on capital Dhaka or other major cities. Local based organizations have been identified as organizations that are located at 30 districts that have been directly affected by the cyclone. Organizations that operate worldwide or outside the territory of Bangladesh have been mentioned as international.

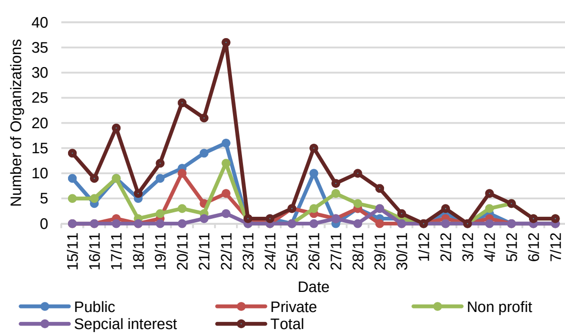

Figure 3: Entry of new organizations into the response system by funding source and date (Source: Data from *The Daily Star)*

Table 2: Frequency Distribution of Organizational Response System by Jurisdiction and Source of Funding, Cyclone Sidr, November 15–December 07, 2007

	Public		Private		Non-profit		Special interest		Total	
	N	%	N	%	N	%	N	%	**N**	**%**
International	43	21.18	11	5.41	38	18.71	0	0	92	45.32
National	33	16.25	15	7.38	6	2.95	7	3.44	61	30.05
City	9	4.43	7	3.44	11	5.41	0	0	27	13.30
Local	12	5.91	1	0.49	10	4.92	0	0	23	11.33
Total	97	47.78	34	16.74	65	32.01	7	3.44	203	100

(Source: Content analysis of news reports regarding cyclone Sidr from *The Daily Star*)

Appendix 1 contains the full list of organizations as found from the content analysis.

Table 2 documents 203 organizations in the response system, with the largest number, 97 organizations (47.78%) are identified as public organizations. The breakdown by jurisdictions shows that the largest number of public organizations are from international level (43, or 21.18% of total organizations). National and international organizations have made up 34.02 % and 44.33% of the public organizations respectively. In case of private sector, national organizations (44.12%) have dominated over international organizations (32.35%). The non-profit organizations have made up the second highest group of organizations (32.01% of total), with more than half (38, or 58.46%) belonging to international organizations. It is noteworthy from the analysis that nearly half of the total organizations (45.32%) are from international level. Local organizations constitute the smallest segment (11.33%) and majority of the local organizations are public (15.38%). The special interest group has been identified as groups having political interest that didn't fit any of the other three categories.

Results from content analysis doesn't fully correspond to the SOD (1999) as only 34.02% of the public organizations are from national level. In contrast to the national policies which have designated major responsibilities towards the public organizations, nearly half of total organizations (48.75%) has been represented by private and non-profit organizations. Undoubtedly national and public organizations required the support from international public, private and non-profit organizations. The significant participation of international aid organizations in the response network denotes the country's dependency on international assistance. The lowest participation made by local organizations signifies the lack of power and resources at the local level despite their importance being mentioned in SOD and other national policies.

The performance of the organizations can be more clearly defined by identifying the time at which organizations from different jurisdiction and sector entered into the response system. Figure 2 and 3 show the date of entry of organizations into the response system by jurisdiction and source of funding respectively.

At the day of landfall (15 November, 2007) the local organizations have responded quickly, followed by international and national organizations. District and upazila administration, law enforcement agencies and local NGOs have quickly entered into the response system as per requisition of upper levels of administration. Among the national organizations, central government and ministries have responded rapidly through an emergency meeting of National Disaster Management Council and directed the district administrations. Significant international assistance came in 17 November, two days after the cyclone made landfall. Seven days after the storm, city based organizations had their peak on 22 November, 2007. The entrance of new organizations into the response system has been increasing for the first week after landfall and decreased after 22 November, 2007.

When the rate of entry is analyzed by source of funding, results show the early and intense response by public and non-profit organizations, which has been continued throughout the first three weeks after landfall. Organizations from private sector have only entered into the response system on 20 November, five days after the cyclone hit. Organizations with special or political interest have entered into the response system at a slower rate and had their peak on the 15th day, 29 November, 2007.

The results obtained from this analysis can be validated from a post-disaster survey report prepared by Japan International Cooperation Agency (JICA). The report includes a survey of 200 households from four Sidr-affected districts. Results from household survey and Focus Group Discussion (FGD) indicate that firstly local organizations (especially upazila and district DMC), secondly government officials from AFD followed by NGOs have extended their cooperation for emergency support and rescue operation [41].

7. Network Analysis

After identification of organizations, a matrix has been prepared depicting the interactions among them for network analysis. The data has been entered into ORA, a network analysis software developed by Center for Computational Analysis of Social and Organizational Systems (CASOS), Carnegie Mellon University. Figure 4 shows the visual representation of interaction among 203 organizations responding to cyclone Sidr as prepared by ORA. Sources of funding are represented by colors of the node and jurisdiction areas are shown by node shapes. The network map depicts the presence of a large cluster located at the center of the response network. Many of the international, national and city based organizations from public, private and non-profit sectors have channeled their assistance through central government which can be seen from the diagram. Organizations with special political interest haven't take part into the central network, rather they have worked alone.

Findings from the network analysis can be validated from the review of news reports. Immediately after the cyclone, the Chief Advisor of contemporary Care Taker government has established emergency relief fund which collected donations from the donor agencies, from both national and

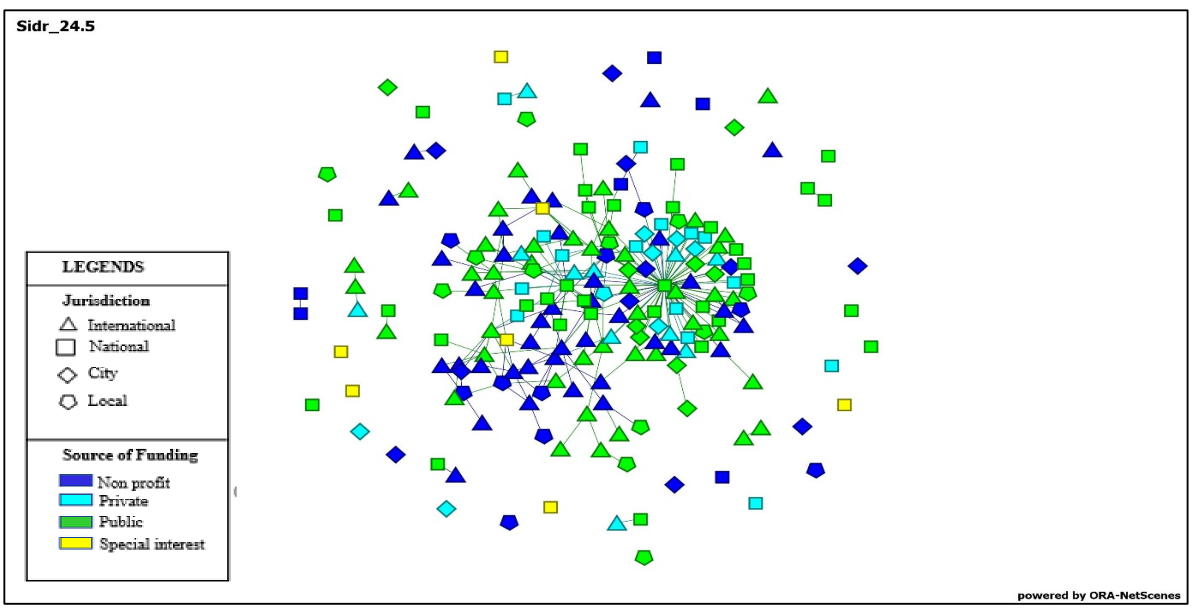

Figure 4: Network diagram of the cyclone Sidr (2007) response system (Source: Data from *The Daily Star* and analysis from ORA)

international level. Therefore, maximum amount of donation has to be channelized through central government in order to reach the affected people. However, some international/ public agencies have disbursed their assistance through international NGOs. For example- German Red Cross in association with CARITAS, an international NGO, distributed the amount granted by German government.

One key information that can be derived from the network map is the large number of isolates. 33 out of 203 organizations (16.26%) don't have any interaction with other organizations, and are isolated from the central network. Major portion of the isolated organizations are national and public (6 or 18.2%) organizations. Isolates are quite common in network structures, but such large number of isolated organizations in response to a major disaster of the country is not typical. An organization that is disconnected from others will find it difficult to manage by itself as the lack of connections will weaken its ability to learn from others' actions [28]. Especially for public organizations who have prime responsibility in emergency management, this lack of interaction denotes a major discrepancy from the stated national policies.

The study has identified ten key organizations in the response system calculated by ORA, as shown in Figure 5. Key entities are those organizations which have the most ability to monitor information flow and reach out to other organizations [30].

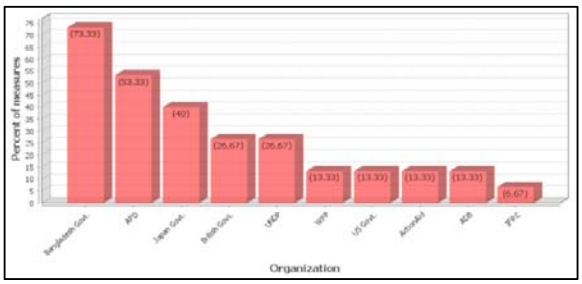

Figure 5: Key agents in the overall disaster response system (Source: Data from *The Daily Star* and analysis from ORA)

Among the ten key organizations, only two of them are national and public. Interestingly, eight out of ten organizations are from international level, with five of them being international NGOs and three from the public sector.

Given the severity of cyclone Sidr, the projected destruction has been expected to be much higher than what has actually occurred. The Care Taker government has taken the following measures to manage the response situation and reduce the amount of destruction-

(1) Government has made investment on an improved Early Warning System that served to alert the population to the impending storm.

(2) Immediately after the cyclone making landfall, the National Disaster Management Council has directed the local government, especially the deputy commissioners of 15 vulnerable districts to take necessary preparations.

(3) In collaboration with international agencies, the Care Taker government has executed the immediate relief effort. Donor funds allocated to the relief efforts have been managed in a judicious manner by the government.

(4) Regular meetings have been held by the Advisory Council with national and international donors to discuss the situation.

(5) Relief provided by donor agencies often require long time to distribute due to the lengthy government bureaucratic processes. To handle this, the government has delineated the

affected districts of coastal area to remove hassles and smooth out the relief distribution process. The assistances provided by international donors have been directly received by a temporary center established at Barisal. The contact numbers of all DC of affected districts have been provided to the donor agencies. Such delineation made it easier and quicker for the local administrations to distribute relief material among the affected people.

AFD has contributed to the response operation by immediately launching search and rescue and relief operations. They have monitored the weather condition in the pre-landfall period, executed search and rescue operations, distributed relief materials and provided medical services to the victims. While executing such functions, AFD has coordinated with central government and international agencies like US Army.

Among the international aid agencies, Japan government has provided relief goods under "Japan Disaster Relief". Alongside coordinating with government of Bangladesh and ministries, government of Japan has interacted with WHO, WFP and UNICEF. Another key organization, government of US has coordinated through organizations like Save the Children, Oxfam, CARE and UN agencies. IFRC has interacted with a number of international/public organizations, including government of Australia, Spain, Canada and later with BRCS for emergency response management.

The active participation of central government and AFD shows the focus and commitment national, public institutions towards emergency disaster risk reduction in Bangladesh. It is also notable that, organizations having prior experiences with disaster situations and/or high disaster preparedness and infrastructure dominate the list of key organizations. In contrast to the "top-to-bottom" disaster management system mentioned in SOD, the contemporary Care Taker government has put an effort to strengthen the local government by delineating the relief channel process along coastal regions. However, the low participation and absence of any local based agencies among the key entities denote that local organizations still require adequate resources and mechanism to fully coordinate with the central government. Despite the activeness of central government and AFD, the absence of enough public organizations among the key organizations indicates the lack of efficiency among public organizations to properly manage the emergency management process.

8. Centrality Measures

In this section, the nodes are analyzed based on their centrality. An analysis of network centrality measures helps to identify the actors that shape the performance of the response network. Centrality scores are assigned to nodes based on the principle that connections to high-score nodes contribute more to the score of the particular node than connections to low-score nodes [30, 31].

Table 3 shows the top 10 organizations in the main component of cyclone Sidr ranked by order of importance on their centrality values named as – degree, betweenness, closeness, and eigenvector centrality.

Table 3: Top ten organizations under different centrality measures in response to Sidr (2007)

Total degree centrality	
1. Bangladesh government	6. German government
2. AFD	7. UNDP
3. Japan government	8. WFP
4. British government	9. IFRC
5. US government	10. MoFDM
Out-degree centrality	
1. Bangladesh government	6. German government
2. Japan government	7. Swiss government
3. British government	8. Denmark government
4. US government	9. UNICEF
5. Australia government	10. WFP
In-degree centrality	
1. Bangladesh government	6. MoFDM
2. AFD	7. CARE
3. IFRC	8. UNO
4. WPB	9. WFP
5. NGO	10. Agriculture secretariat
Betweenness centrality	
1. Bangladesh government	6. MoFDM
2. AFD	7. UNO
3. UNDP	8. Ministry of Education
4. WFP	9. Ministries
5.German government	10. Thai businesswomen
Closeness centrality	
1. British government	6. China government
2. Japan government	7. UNDP

3. US government	8. Amir of Kuwait
4. Australia government	9. India government
5. Denmark government	10. Italy government
Eigenvector centrality	
1. Bangladesh government	6. MoFDM
2. WFP	7. UNDP
3. AFD	8. UNICEF
4. US government	9. ADB
5. Japan government	10. Agricultural secretariat

Degree centrality is the measure that evaluates actors in the network by the number of ties actors possess [12]. An analysis of degree centrality shows the organizations that most frequently interacted with other organizations in the network. Total degree centrality calculated by ORA shows that government of Bangladesh has the highest degree centrality, and can be regarded as the most influential in the response network. A centrality degree analysis can be represented by two types of scores- out degree and in degree.

Out-degree centrality represents the number of links or connections emanating from a node. Organizations with high out degree centrality scores include government of Bangladesh, Japan, Britain, US, and Australia. Bangladesh government has communicated with local administration, MoFDM, local NGOs as well as with multiple international organizations such as UN to coordinate the relief efforts. Other international and public organizations have distributed their donations through a number of international NGOs.

In-degree centrality depicts the number of links directed to a node, or the number of connections the node of interest receives from other nodes. The top organizations in terms of in degree centrality include government of Bangladesh, AFD and IFRC. Government and AFD both have received significant response from national and international donors through the emergency fund. IFRC has received information from BDRCS and coordinated relief from international donors. Local NGOs and local administration (UNO) have ranked fifth and eighth among 203 nodes respectively, which denotes that the local organizations have received substantial assistance from other nodes in the form of order of evacuation, donations, relief materials etc. Therefore, strengthening local government can leverage this effect and have a greater impact on overall emergency management.

Betweenness centrality is another centrality measure which measures the extent to which a particular node lies between the various other nodes of the network [42]. Greater betweenness centrality of an actor also depicts that more actors are dependent on that actor to communicate with other actors [27]. In regards to betweenness centrality, the top organizations are- government of Bangladesh, AFD, UNDP, WFP etc. Many of the donor countries have coordinated with Bangladesh government and disbursed their assistances through international organizations like WFP and UNDP. Being the shortest path between other nodes, these organizations have served as gatekeepers between organizations and controlled the flow of response network.

Closeness centrality measures how close an actor is to other actors of the network [12]. Nodes with high values of closeness centrality are likely to receive information more quickly than others, as there are less numbers of intermediaries to reach them [31]. The top organizations in terms of closeness centrality include government of Britain, US, Japan etc. Government of US has coordinated the efforts of USAID, US State Department, US Army, US Mission, as well as maintained connection with the central government of Bangladesh. Thus, it is considered as the leader in terms of closeness centrality.

Lastly, organizations that are connected to groups that have many connections themselves can be identified using **eigenvector centrality**. Organizations that are connected to isolated nodes will have a lower score compared to those organizations that are connected to well-connected nodes [43]. Government of Bangladesh is the leading organization according to this criterion. This means that it is connected to many other organizations who are well connected and thus is most likely to receive new information.

Effective response operations require collaboration between various government levels and between the government, private sector and non-profit sector [6]. In response to cyclone Sidr (2007), the degree of connectedness among the nodes is calculated as 0.531. A connectedness score of 1 suggests that all actors are reachable to each other and deviation from 1 indicates the fragmentation of network [30]. The overall degree of centralization is 10.3%. The percentage of isolated nodes discussed before and the degree of centralization value indicate that a large number of organizations were not in communication with other organizations.

Another interesting finding from the response network is the identification of cliques. Cliques are subset of organizations, often consisting of three or more organizations, that develops recurring pattern of interaction in conduct of disaster operations [44]. Using ORA, 19 cliques were identified from the larger network as shown in Table 4.

Table 4: Cliques identified within the disaster response network of cyclone Sidr: 15 November- 7 December, 2007

Clique	Members
1	AFD, Bangladesh government, WFP,
2	AFD, Bangladesh government,
3	AFD, Bangladesh government,
4	AFD, Bangladesh government,
5	Bangladesh government, UN,
6	Bangladesh government, MoFDM,
7	Bangladesh government, NGO,
8	Bangladesh government, NGO,
9	Bangladesh government, US
10	Bangladesh government, WFP, US
11	Bangladesh government, Japan
12	Bangladesh government, Denmark,
13	Bangladesh government, Youngone
14	CARITAS, World Vision, Tree Das
15	CARITAS, World Vision,
16	CARITAS, World Vision, Shiblee's
17	CARITAS, German government,
18	British government, CARE, German
19	NGO, Agriculture ministry,

Among the 19 identified cliques, 13 or 68.4% include Bangladesh government. The next largest subset includes 12 or 63.2% of cliques with interactions among national and international organizations. Only 5 or 26.3% of cliques has represented interactions among national and local level organizations, a finding that confirms the gap between disaster management plans and practice. Two cliques have involved only non-profit agencies, working at the international and local level.

Following cyclone Sidr, government of Bangladesh proceeded to formulate early recovery action plan in cooperation with UN agencies and other national and international organizations under the joint leadership of DMB, MoFDM and UNDP Bangladesh. Rapid damage assessment has been conducted in all Sidr affected districts and action plans have been linked to long-term reconstruction activities. Besides, government has taken some additional coordination mechanism to enhance emergency information sharing by establishing a formal link between MoFDM and AFD.

9. Conclusion and Future Work

Three conclusions can be drawn from the study to assist further improvement in the inter-organizational emergency response management following catastrophic events-

Firstly, the political situation at times of cyclone Sidr (2007) has a direct impact on the emerging response network. On January, 2007, the non-party interim Care Taker government took control during the political crisis and continued until new elections were held in 29 December, 2008. All the leaders from leading political parties of Bangladesh have been imprisoned during that time. Therefore, the network analysis of response organizations lacks any proper assistance from the major political parties. Most of the organizations from special interest group have been isolated from the central network. Although there has been lack of extensive response and interactions among other public organizations as seen from the results, the Care Taker government has undertaken strict initiatives and sensibly coordinated response and relief efforts which is prevalent from the list of both key organizations and cliques.

Secondly, findings from the study have documented a higher degree of action at the central or national level, with the central government providing assistance to the local agencies. But effective emergency management must come bottom-up and local agencies should also have responsibilities. Although local agencies are fast and responsive to the cyclone, they have been unable to coordinate their activities as subgroups. According to the post-Sidr survey report of JICA (2008), DMC at central, district and upazila level have played their role effectively but DMC at union level was found inactive in most of the cases. About 80% people from the survey has revealed that they have no perception about the Union Disaster Management Committee and some UP members don’t even know about the existence of such a committee in their union. Reports from various organizations and news articles have also indicated favoritism by UP Chairmen and members in the relief distribution process despite the strict surveillance of government and AFD. Results from the research have showed that although local administration has received information from upper levels, their participation rate has been significantly low (11.33%) and some of them have been isolated from the central network. Creating central as well as local database showing the amount of received relief materials and organizations acting in the specific area is vital to remove such obstacles when a disaster occurs. Ensuring effective communication channels among different levels of government, preparing a comprehensive disaster management plan for coastal areas and initiating proper training at local level including UP members and CPP volunteers are necessary to ensure coherence with the SOD and other DM policies.

Thirdly, international community response constitutes a major part of emergency response to disasters in Bangladesh. Starting from relief to recovery and reconstruction, donor agencies around the world have played a significant role in delivery of humanitarian assistance during cyclone Sidr. The huge number of actors makes practice of coordination extremely challenging. According to SOD, NGO Coordination Committee (NGOCC) is responsible to guide and monitor the activities of NGOs. Broader and inclusive coordination is not fostered as there is no mechanism to incorporate UN agencies and other donors. The Care Taker government has guided the coordination of international assistance during Sidr. But the extent of international contribution highlights the need for a coordination mechanism with international NGOs as well as other international stakeholders.

Lately the country experienced other cyclones including cyclone Aila (2009), cyclone Roanu (2016), cyclone Mora (2017) which have showed a lot of mismanagement in their emergency response activities. For example- findings from cyclone Aila have revealed that there was negligence in the provision of services as well as bribery and misuse of resources in the post-disaster interventions [45]. The inter-organizational connectedness or degree of centralization which have been achieved through the leadership of the Care Taker government in case of cyclone Sidr (2007), may differ significantly for other disaster events due to variation in political situation under the leadership of a typical democratic government. Therefore, further network analysis can be conducted for other disaster events to generate a comparative analysis of inter-organizations network. Due to the increasing frequency of cyclones in the recent years in Bangladesh, effective interorganizational network at all levels of governance should receive due attention from the policy makers. Inability to do so will adversely affect the emergency management process resulting in increased causalities and destruction of properties after disastrous events.

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PART-V

EXPERIMENTAL INVESTIGATION ON BEHAVIOR OF REINFORCED CONCRETE INTERIOR BEAM COLUMN JOINTS RETROFITTED WITH FIBER REINFORCED POLYMERS

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1. Introduction

Reinforced concrete buildings constructed before 70's were designed for gravity loads only and did not show adequate seismic performances (Bai 2003, Sharma et al. 2010). Weaknesses in joints were identified as one of the main causes for poor seismic performance. To overcome this deficiencies first guidelines for reinforced concrete beam-column (BC) joints were published in United States in 1976 (ACI 352R-76) followed by New Zealand in 1982 (NZS 3101:1982). Therefore, buildings constructed before 1976 may have significant deficiencies in the joint regions (Bai 2003, Murat et al. 2005). Due to poor design and detailing of the BC joints of these buildings, they may lead to a total or partial collapse due to an earthquake (Sezen 2012, Zhao et al. 2009, Sezen et al. 2010, Bracci et al. 1992 from Prota et al. 2004). BC joints are subjected to large shear forces during seismic events; therefore many experimental and analytical researches had been carried out in past few decades on the behavior of RC BC joints under seismic condition (Mayfield et al. 1971, Ichinose 1991, Erduran et al. 2003). Various international codes (ACI 318, 318M-08, ACI 352R-02, ACI ASCE, Committee 352, FEMA 273, BNBC 1993) of practices had also been evolved and undergone periodic revisions to incorporate these research findings into practice.

In Bangladesh, many RC buildings had been constructed without seismic detailing in the BC joints before or even after the inception of BNBC (1993). Change in the types of occupancy is very common as residential buildings are frequently converted to commercial and industrial buildings; number of floors is increased without proper design analysis. These buildings are vulnerable to seismic hazard and need to be strengthened. Conventional retrofitting methods are sometimes difficult due to the nature of occupancy, importance of the structure, economic value of the non-operational period and cost of the man and materials. FRPs, which have high strength to weight ratio, are suggested and are used as retrofitting materials in many countries of the world as these materials are easy to place, need minimum relocation of existing occupancy and retrofitting time is very short compared to other methods. Sharma et al. 2011, Sezen 2012, Tara Sen 2010, Pandelties et al. 2000, Mahini and Ronagh 2007 strengthened the joints by FRP wrappings. Mukharjee and Joshi 2005 used FRP plates to increase the shear and flexural strength of the beam. Akguzel and Pampanin 2010, Sezen 2012, Mahini 2007 conducted research on exterior joints where access to the joints was relatively easy and the existence of floor slab was not considered.

Al-Salloum et al. (2007a, 2007b) carried out experimental and analytical studies to see behavior of FRP strengthened joints with or without mechanical anchorage and found that CFRP sheets epoxy bonded to the joint region, and prevented against debonding through mechanical anchorage; prevents joint failure and failure is directed to the beams. He also deducted that, joint shear strength increases with increased quantity of FRP and axial load due to joint confinement. Mukharjee et al. (2002) carried out a study to investigate the behavior of RCC joint with and without adequate shear reinforcement in the joint region. The specimens with adequate shear reinforcement and strengthened with FRPs exhibited higher dissipation of energy and ultimate deformation than controlled specimens. Non-ductile joints strengthened by FRP also exhibited better performance and their performance depends on the number of layers of FRP wrapping. Murshed and Ahmed (2011) carried out seismic analysis on eight soft story structures which were retrofitted with FRP wraps. It was found that seismic performance of the soft story structures can be improved by FRP wraps. Improve in the lateral strength was negligible due to wraps but ductility improvement was quite satisfactory. Almusallam et al. 2007, Shiohara et al. 2010, Osamu et al. and Li et al. 2011 conducted research on the behavior of RC interior beam-column joints. These studies were conducted on interior joints which did not include transverse beams and slabs.

This study attempted to access the interior beam column joints with transverse beams on all four sides and monolithic floor slab. It also attempted to increase the shear strength of the joints by inserting CFRP plate into the beam-column joint, wrapping beam and columns by CFRP fabrics and inclusion of tie bar in the joint region. To investigate the behavior of the RC interior BC joints retrofitted by FRP plates, fabrics and tie bars, incremental cyclic loading were provided with constant axial load on to the test samples. Half scale models with transverse beams and slab had been constructed before strengthening the joints. Following parameters had been considered to investigate the behavior of the joints: (a) Interior joints having different concrete strength, (b) Interior joints strengthened by wrapping beams and columns by CFRP fabrics, (c) Interior joints strengthened by inserting CFRP plates (d) Interior joints strengthened by inserting tie bar in the joint and replacing concrete by micro-concrete. Total eight models had been constructed for the study as follows: (a) Two control models designated as Con 1 and Con 2, (b) Three Models strengthened by CFRP Fabrics designated as Fabrics 1, Fabrics 2 and Fabrics 3, (c) Two models strengthened by CFRP plate designated as Plate 1 and Plate2, (d) One model strengthened by additional tie bar and micro-concrete mixture designated as MCS 1.

The outcome of the study will unveil the behavior of the strengthened RC interior BC joints and compare the behavior with the joints which lack in shear reinforcement. The research will also facilitate in developing methods of determining strength of retrofitted joints and identify suitable procedures to retrofit interior BC joints by CFRPs.

2. Detailing of control and test models

The models had been selected considering a typical full scale six storied RC Frame Structured Building. The building was analyzed as per BNBC (1993). An interior joint at the mid height of the structure had been selected for the experimental program. Considering the existing laboratory set up an half scale model had been finally selected. Total eight models were constructed for the experiment. All the models had identical beams, columns and slab. The columns were 150x150 mm in width and breadth.12 mm Φ and 8 mm Φ bar had been used as longitudinal reinforcement and transverse reinforcement (tie bar) respectively. The dimensions of the longitudinal beam (B1) were 150x225 mm and those of the transverse beam (B2) were 150x150 mm. 12 mm Φ bar had been used as longitudinal reinforcement. 8mm Φ bar was used as stirrups. There was no tie bar (Shear reinforcement) in the BC joints. Neither beams nor the columns had any lap joint. Thickness of the slab was 75 mm having one layer of reinforcement in both X and Y directions. Tie and stirrups had standard 90º hook as per BNBC (1993). Two control specimens had also been constructed. Dimensions and detailing of the as built models are shown in Fig. 1. Concrete strength of the samples are shown in Table 1.

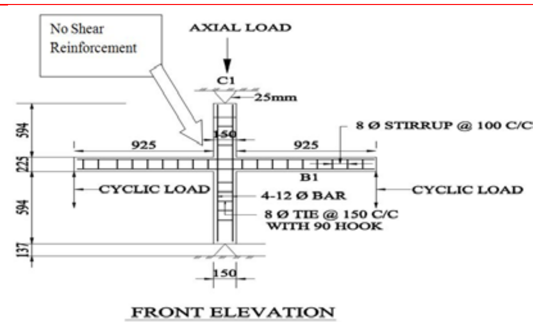


Fig. 1 Dimensions and detailing of models

Table 1 Concrete strength of the samples

Mix No	Average Strength (MPa)	Mix No	Average Strength (MPa)
Con-1	18.31	Fabrics-1	21
Con-2	28.31	Fabrics-2	24.53
Plate-1	15.03	Fabrics-3	33.77
Plate-2	26.8	MCS-1	18.0

3. Strengthening the Joints

The joints were retrofitted in three schemes. In first two schemes, joints were retrofitted by CFRP Plate and Fabric and in the third scheme joint was retrofitted by introducing tie bars around the column and replacing the concrete by micro-concrete.

3.1 First scheme: Strengthening by CFRP fabrics

Top and bottom Columns were wrapped up to 150 mm from the top of the slab and bottom of the deeper beams respectively. Beams were wrapped up to 150 mm length in U shape from the face of the column. CFRP wraps is not recommended to use for inside corners and minimum 12 mm radius should be provided for confinement by FRPs. The models had transverse beams at all four sides with slab on top. The beams and column sides were rounded to provide 12 mm radius curvature. The surface of the beams and columns were smoothened by grinding machine and cleaned thoroughly by brush before applying Primer. Hardener and Base (1:2 ratios) were mixed thoroughly for 3 minutes before applying on the prepared surface. This epoxy primer was applied by using a brush and dried for 24 hours before applying the saturant. The fabrics were cut into 150 mm in width and 300 mm and 450 mm in length. The hardener and the base (1:2 ratios) of the saturant were mixed and applied over the primed surface. CFRP fabric had been pressed on to the saturant applied area by hand first and then was pressed by a surface roller to remove air bubbles. After 30 minutes another coat of saturant was applied over the carbon fabrics.

3.2 Second scheme: Strengthening by CFRP plates

In Second scheme, the joints had been strengthened by introducing FRP plate into the joint. The concrete from beam at column face, up to a distance of 75 mm, were removed to insert the CFRP plates. CFRP plate was cut into pieces of 300 mm in length. Each of the joints was strengthened by four plates as shown in Fig. 4.1.15. Exposed surfaces were prepared by the grinding machine. Hardener and Base (1:2 ratios) of epoxy adhesive had been mixed thoroughly before application. The mixed adhesive was applied on the CFRP plates and pressed over the joint area to squeeze out the mixed adhesive. Additional adhesive had been applied to remove any voids underneath the plate. The joint concrete was replaced by the micro-concrete after three days of placing the plates and another two CFRP plates were placed after seven days of casting by micro-concrete.

3.3 Third scheme: Strengthening by Tie bar and Micro-concrete

Concrete up to 75 mm from the face of the beam was removed from all sides of the corner joint region. 8mm Φ tie bars each of 200 mm in length were welded around the column. Let micro concrete was used for the casting. The details of strengthening the joints are shown through Fig. 4.1.24 to 4.1.27.

4. Experimental setup

The experiment had been carried out in Concrete and Strength of Materials Laboratory of BUET. The models were placed on a steel base plate which had the arrangement of column seat. The base plate was intended to allow column rotation. The base plate was fixed on a steel beam which was fixed with the concrete floor. A hydraulic jack was set to provide axial load on the top of the column. Two sets of steel frame had been designed for this experiment. They were fixed at both side of the column to arrest any horizontal movement of the column. Two manually operated hydraulic jacks were used to provide cyclic loading at the tip of the beams. Total five dial gauges were used to measure the deflection of the beam and columns. First two dial gauges were set near the tip and at the beam-slab joint of the right beam where as one dial gauge was fixed at the beam-slab joint of the left beam. Another two dial gauges were set at below the top of column and at 10 cm distance from the column-slab joint. Video extensometer was used to measure the rotation of the beam and column joint. Video extensometer had been placed much closed to the joint due to space constrain and location of the steel frame.

The strength of BC joints are influenced by the effective confinement. Column axial load increase the confinement. The samples were made from different concrete batches as such there concrete strength had been different. To understand the behavior of all joints under identical condition 10% of the column capacity ($0.1f_c'A_g$) was provided as the axial load. Axial load had been constant throughout the experiment. Axial loads and capacities of the control and strengthened specimens are shown in Table 2.

Table 2 Concrete strength of the samples

Model No	Con1	Con2	Plate1	Plate2	MCS1	Fabrics 1	Fabrics2	Fabrics3
Axial Load (kN)	45	65	35	60	42	50	55	75

The static cyclic loading had been provided by two manually operated hydraulic jacks. The load had been controlled by measuring the column drift of the top column. 0.25%, 0.50%, 1% and 2% of the top column drift had been selected to control the load. 5 kN load had been applied while loading and unloading. However, as the jacks were manually operated, unloading could not be maintained at the same rate.

4. Load deflection response

4.1 Load deflection behavior of beam

Deflections of all the samples were measured by five dial gauges and Video Extensometer had been used to measure the joint and column rotations. The test continued till the left dial gauges reached optimum deflection or the jacks reached their maximum lift capacity. The load deflection behavior of all the beams is similar within the elastics range and exhibits a linear relationship.

Beam of Plate 1 exhibited better ductility than the Con 1. The beam yielded at higher loading than the load corresponding to its plastics yield moment in both forward and reverse loading. Beam of MCS 1 failed much closer to its theoretical yield strength. This may be due to the fact the columns failed earlier than the beams and the test discontinued before determining the beam ultimate strength. Beam of Fabrics 1 deflected less with higher loading in forward loading and showed ductile behavior by deflecting high under the same applied load. Beam failed at higher load than its theoretical strength at the joint.

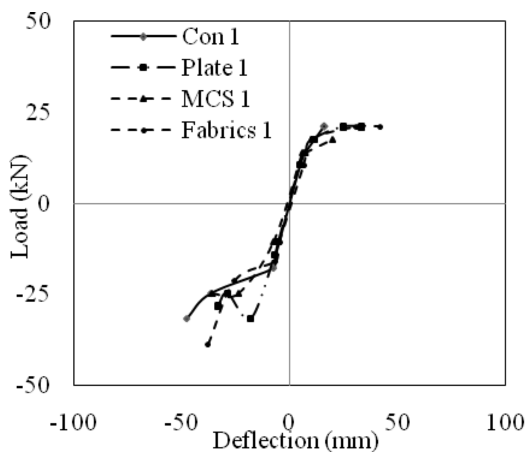


Fig. 2 Load deflection response of beam of Group A

In Group B, beam of Plate 2 deflected 73 % with 86% loading of the Con Beam 2 in forward loading while it deflected 4% higher than the control beam with 80% excess load in reverse cycle. Beam of Fabrics 2 deflected 96% with 25% higher loading of the beam of Con 2 in forward loading and deflected same amount with 40% higher loading in reverse loading. Beam of Fabrics 3 deflected 27% as high as the control beam in forward loading while loading was 29% higher. In all the cases, the beams yielded at higher loading than their theoretical yield strength.

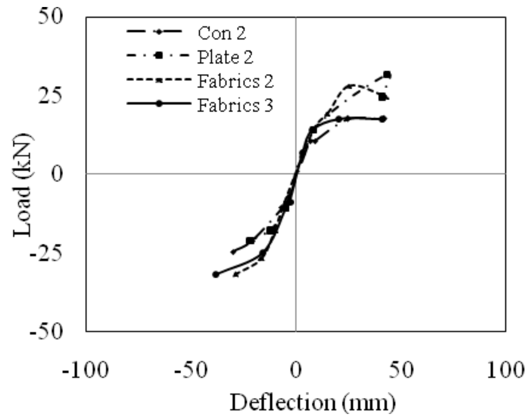
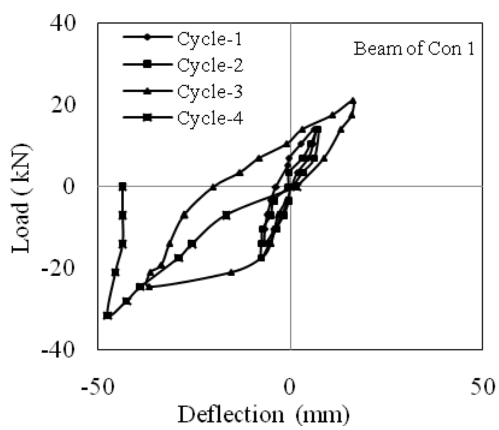
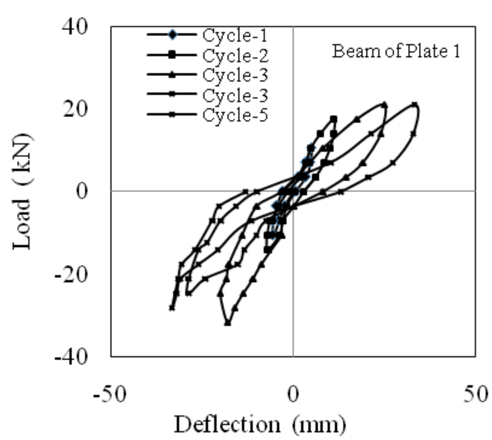


Fig. 3 Load deflection response of beam of Group B

Load-Deflection behavior of beams is illustrated by hysteresis loops through Fig. 4.





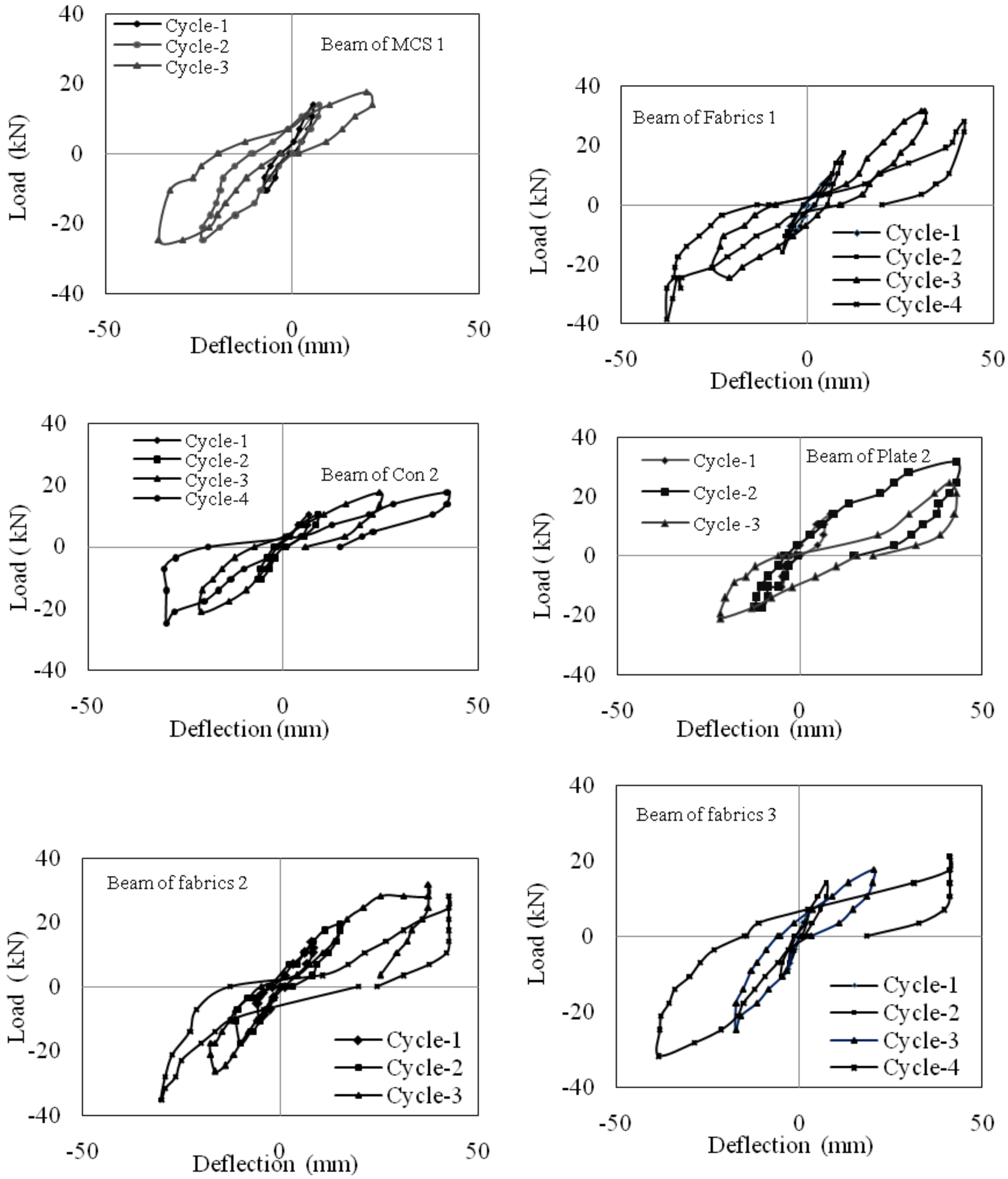


Fig. 4 Load deflection response of beam

By analyzing the hysteresis loops of the load-deflection, it is found that, within the elastic limit, all the models have non-degrading curve. But in subsequent circles, the loops exhibit stiffness degradation. The characteristics of the hysteresis loops can be analyzed by the slopes of the loading cycles. In order to evaluate the stiffness of the beams, slope of the forward loading cycles are measured from the load-deflection curve of each cycle. The slope is determined by drawing tangent on forward loading curve. It is found that, the slope gradually decreases as shown in Fig. 5.

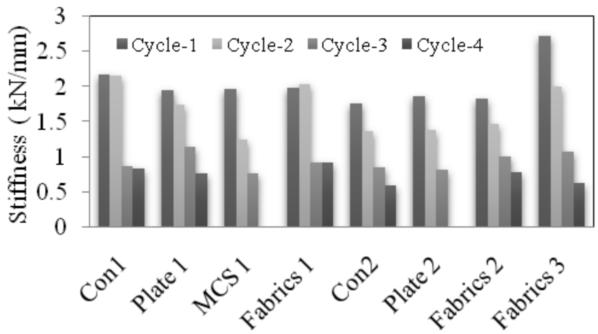


Fig. 5 Forward slope of load deflection cycle of beams.

Secant stiffness is defined as the ratio of the strength to the maximum displacement. Secant stiffness of the beams for each load-deflection cycle is measured by considering the maximum load and deflection of both forward and reverse loading and it is found that beam stiffness decreases in each subsequent cycle as shown in Fig. 6.

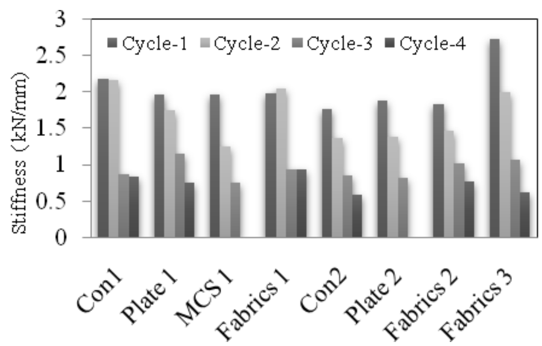


Fig. 6 Stiffness of beams.

4.2 Load deflection behavior of column

Load deflection response of columns of Group A is presented in the following Fig. 7. Column of Plate 1 experienced enhanced column shear capacity. Column of Plate 1 experienced 6.5% excess column shear force while deflecting 13% less in forward loading and 8% high column shear force while deflecting 93% higher in reverse loading than the column of Con 1. Column of MCS 1 displayed similar behavior of the control model in reverse loading while it deflected 32% high against 17.81% excess loading than that of Con 1 in forward loading. Column of Fabrics 1 deflected same amount against 42.2% excess loading in forward cycle. It deflected 16% more than the column of Con 1 against 46% higher loading. Column of Fabrics 1 experienced high column shear against same deflection compared to the column of Con 1. In all the cases, the columns experienced high shear than their theoretical yield strength except MCS 1 where in later case the column failed at its yield limit.

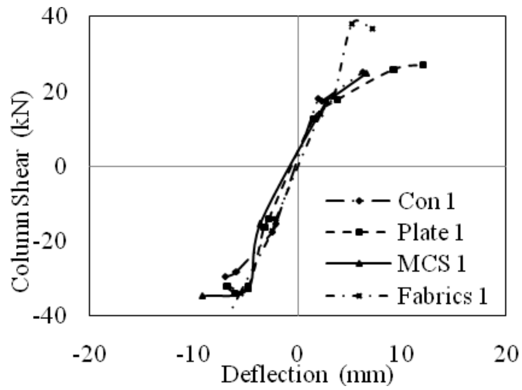


Fig. 7 Load deflection response of column of group A.

The load-deflection response of columns of Group B is shown through Fig. 8. Column of Plate 2 deflected 87% with 84 % loading of the column of Con 2 in forward loading cycle. It experienced 19% higher column shear force than that of Con 2 while deflected only 48.6% of the Column of Con 2 in reverse loading. In forward loading, Column of Fabrics 2 experienced 52% higher shear force than that of Con 2 with the same deflection in forward loading. The column experienced maximum 84% shear force while deflecting 43.4% of the same column of Con 2 in forward loading. The same column experienced column shear 22.7% higher than that of Column of Con 2 while deflecting 9.5% more than the same column. Column of Fabrics 3 deflected 7.5% higher than column of Con 2against 13.3% excess loading in forward cycle but the same column deflected 5.7% higher against 19.1% higher loading in reverse loading cycle. In all the cases, the columns experienced higher shear forces than their theoretical strength.

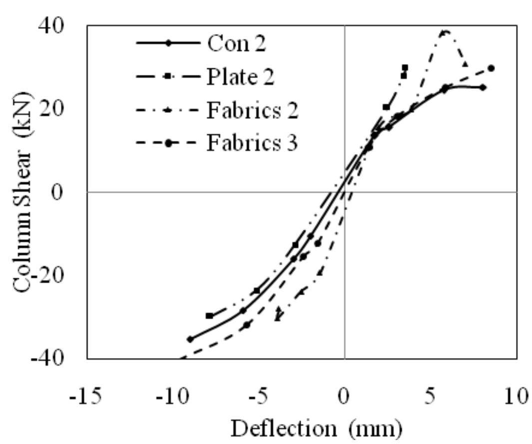
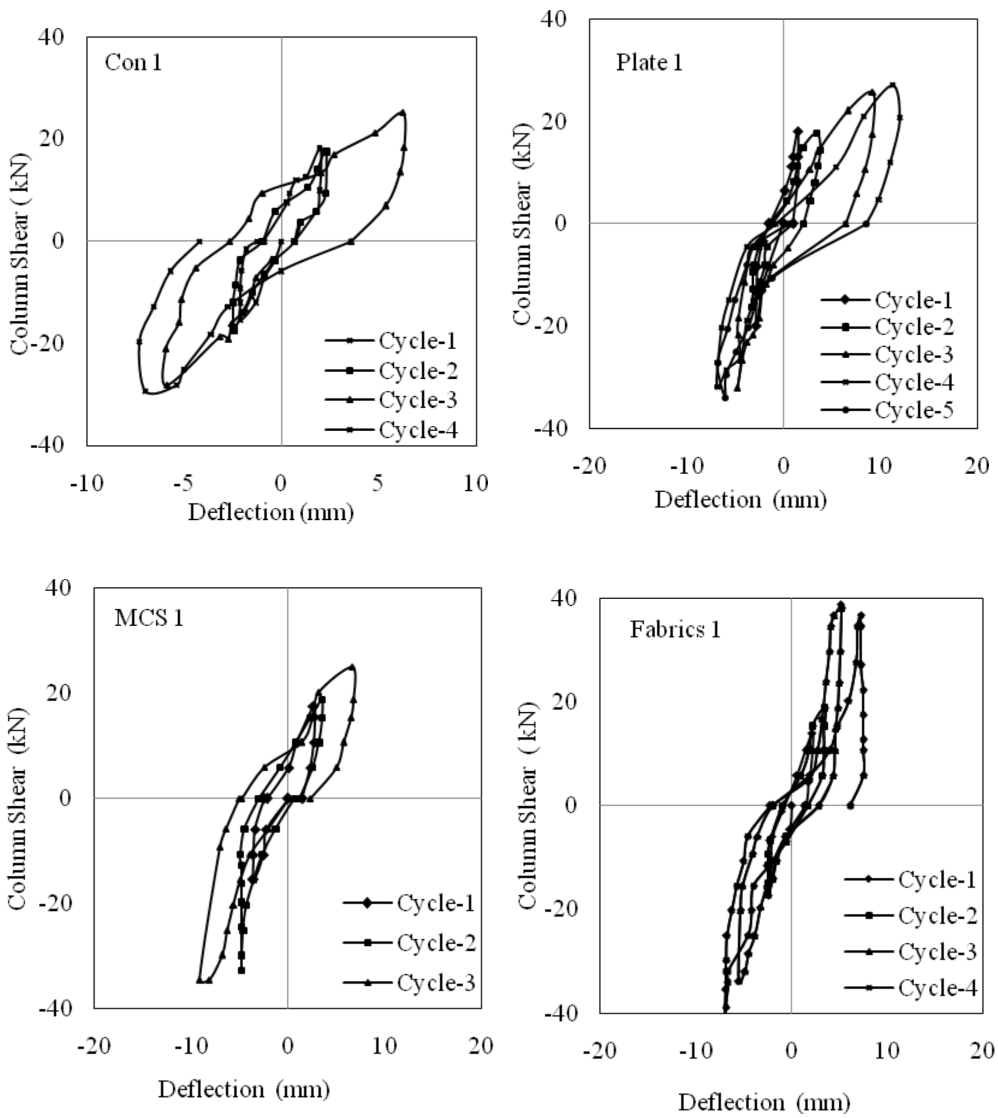


Fig. 8 Load deflection response of column of group B.

The behavior of the columns can be analyzed by the load-deflection hysteresis loops plotted for each cycle. Hysteresis loops for the columns are illustrated in the following Fig. 9.



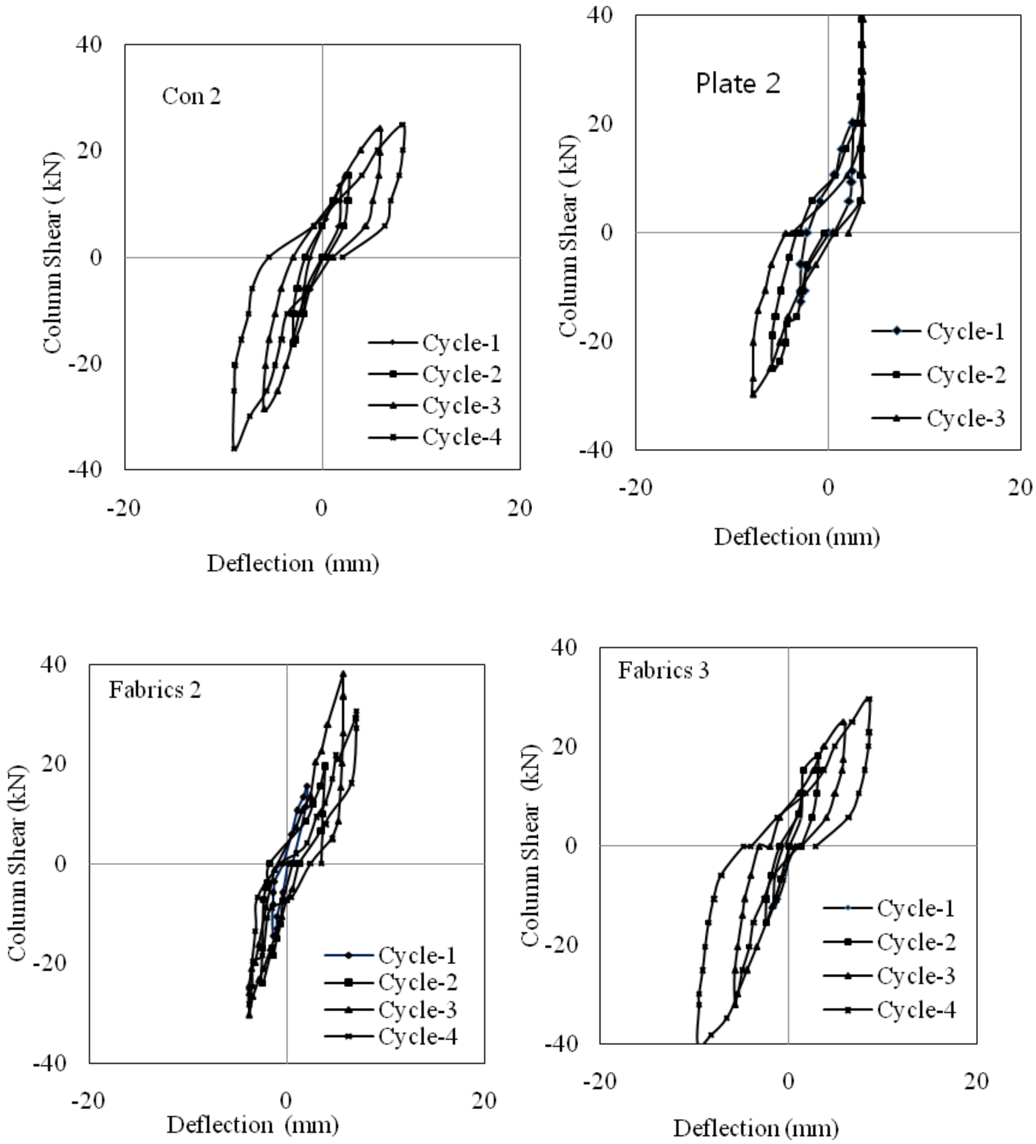


Fig. 9 Load deflection response of column.

Slope of the Load-Deflection cycle is determined to evaluate the magnitude of stiffness degradation of the column. The slope is determined as it was determined for beams. The slopes of the Load-Deflection Cycles of the columns of Group A and B are illustrated by Fig. 10 and 11.

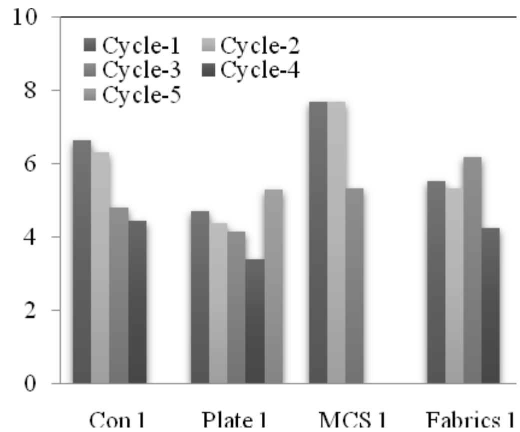


Fig. 10 Slope of load deflection curve o forward loading (Group A)

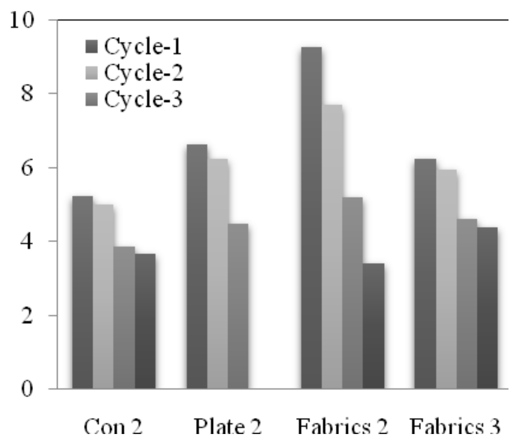


Fig. 11 Slope of load deflection curve o forward loading (Group B)

Column secant stiffness for each cycle is measured by considering maximum applied moment against maximum deflection. The computed stiffnessesare illustrated by Fig. 12 and 13.

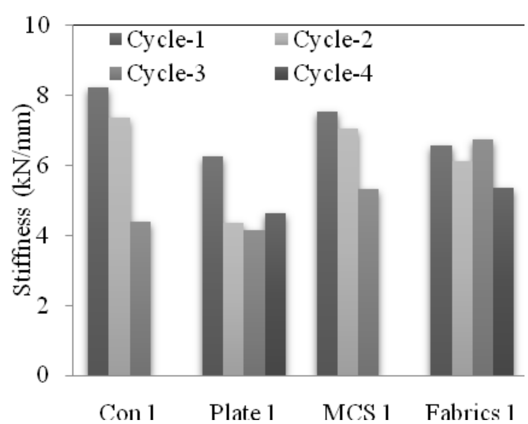


Fig. 12 Column stiffness (Group A)

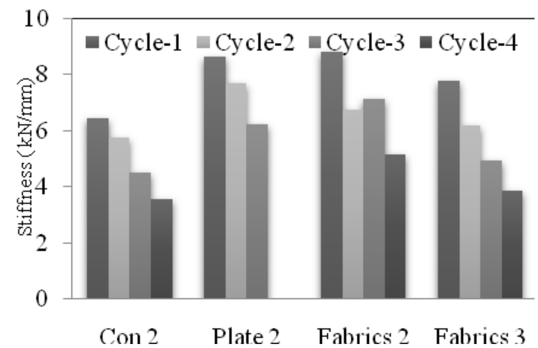


Fig. 13 Column stiffness (Group B)

The slopes and the secant stiffness of the column decreased with the commencement of cycles. The column shear had been measured indirectly from the load applied at the tip of the beam. Upon failure, beams were unable to transfer load on the column. This led to increased column shear without deflection resulting in higher slope and stiffness in subsequent cycles. The rate of loosing stiffness in subsequent cycles indicates the collapse behavior of the member. Percentage of initial stiffness of the column are shown Fig. 14 In Group A, Plate1 kept higher rate of initial stiffness compared to Con 1 at higher stage of loading. Considering the maximum load provided in each cycle, columns of MCS 1 and Fabrics 1 retained high initial stiffness compared to the column of Con 1. In Group B, considering the maximum load provided in each cycle, columns of Plate 2, Fabrics2 and 3 retained high initial stiffness compared to the column of Con 2.

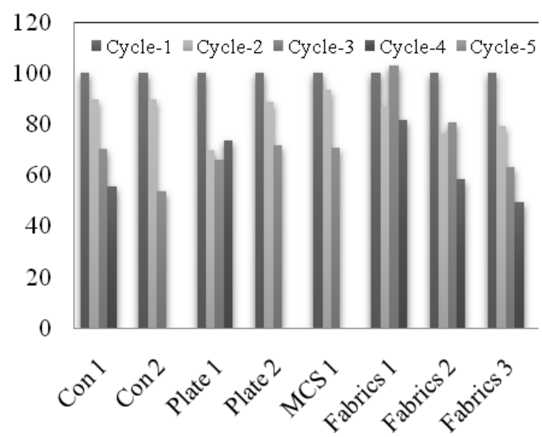


Fig. 14 Percentage of initial column stiffness (Group A and Group B)

4.2 Load deflection behavior of column

Rotation experiences by the joints in each cycle depend on the magnitude of the applied moment. Rotations of the beams and columns at the joint against corresponding loading (applied moment) were measured and evaluated by Video Extensometer. Maximum load and corresponding rotation had been found by analyzing the computer output.

Applied maximum moment and corresponding beam joint rotations of Group A are shown in the following Fig. 15 Beam joint of Con 2 rotated 53.4% more against 22.4% excess loading than that of Con 1 in forward cycle whereas the same beam joint rotated further 75% against the same loading compared to the joint of Con 1. M-Φ curve of both the joint indicates that the ductility increases with the increased concrete strength. Rotational ductility of Con 1 was 3.45 whereas it was 6.45 for Con 2.

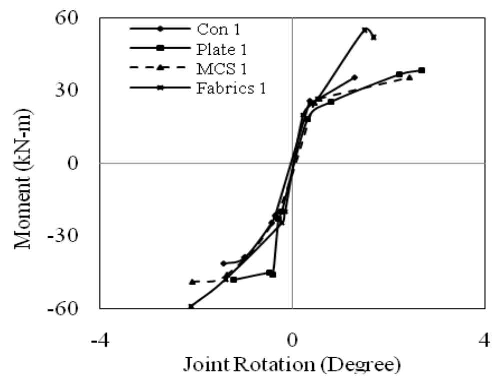


Fig. 15 Applied moment vs rotation of joint (Group A)

Joint of Plate 1 rotated 86% of the Con joint 1 while applied load was 16.1% higher in forward loading. The same joint rotated 109% higher against 8% excess loading compared to the same control joint. Joint of MCS 1 rotated additional 46.5 % when the applied moment was 17.8% higher and it rotated further 89% against the same applied moment in reverse loading compared to the con 1 joint. The joint of Fabrics 2 rotated 32.3 % more against 46 % higher applied moment in forward loading compared to Con 1 joint. The same joint rotated additional 45.5 % against 42.2 % excess loading in comparison to Con joint 1.

Applied maximum moment and the corresponding rotation of the joints in each cycle of Group B are illustrated in the following Fig. 16.

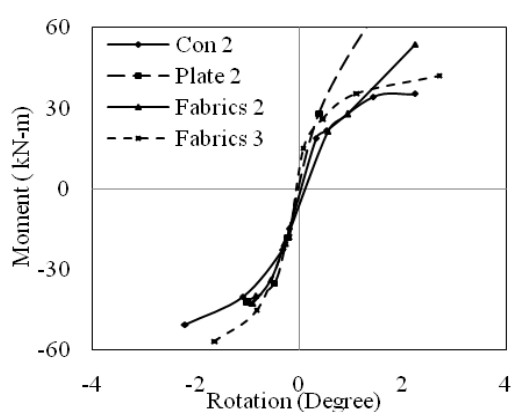


Fig. 16 Applied moment vs rotation of joint (Group B)

Joint of Plate 2 rotated 46% of the joint of Con 2 in forward loading while it is subjected to 83% load of the control joint. It rotated 70% of the control joint in reverse loading against 74% excess load of the control joint 2. Joint of Fabrics 2 rotated the same against 52.5% excess load of the control joint in reverse cycle. The same joint had 38% rotation of the control joint in forward loading while it was subjected to 78% load of the control joint. Fabrics 3 joint rotated 75% of the control joint 2 against 11.78% excess loading in forward loading cycle. The rotation of the same joint was 21.4% higher against 19% excess loading in reverse loading.

Hysteresis loops of Con2, Plate 2, MCS 1, and Fabrics 3 column and beam joints are shown through Fig. 17 to Fig. 32.

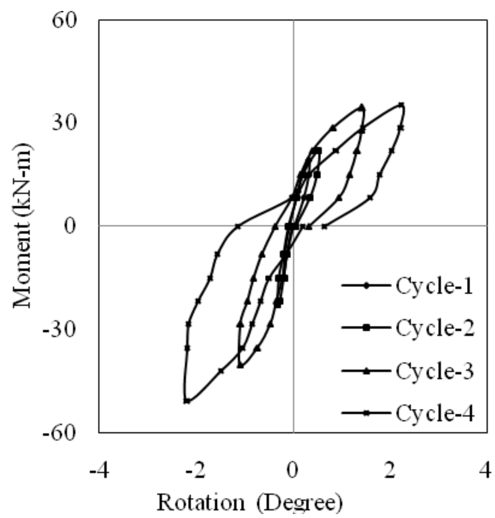


Fig. 17 Rotation of beam joint of con 2

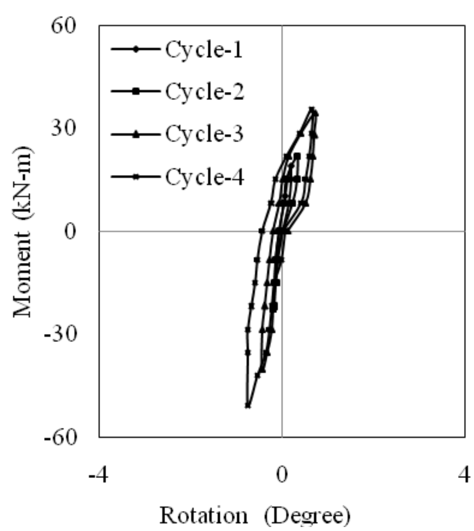


Fig. 18 Rotation of column joint of con 2

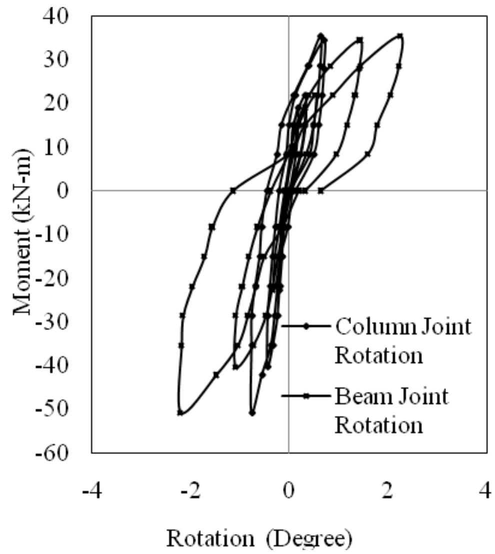


Fig. 19 Relative rotation of beam and column joint of con 2

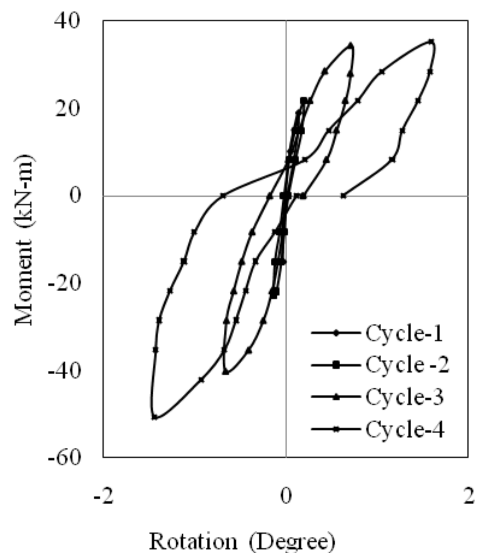


Fig. 20 Difference of beam and column joint rotation of con 2

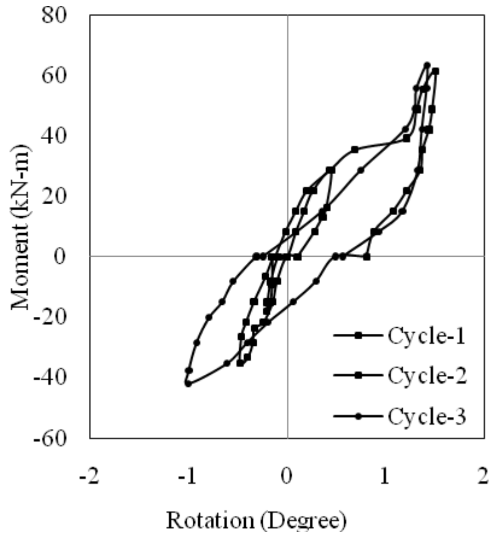


Fig. 21 Rotation of beam joint of plate 2

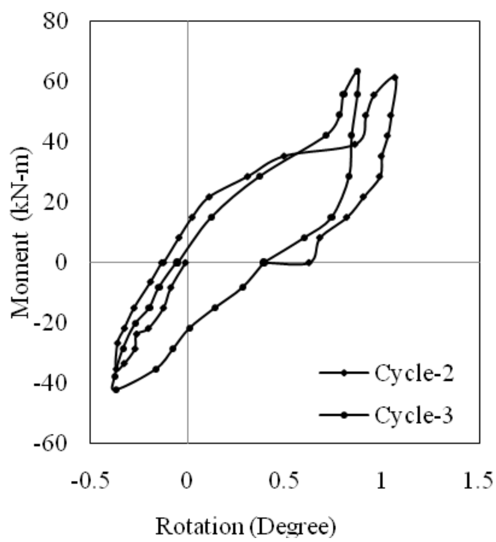


Fig. 22 Rotation of column joint of plate 2

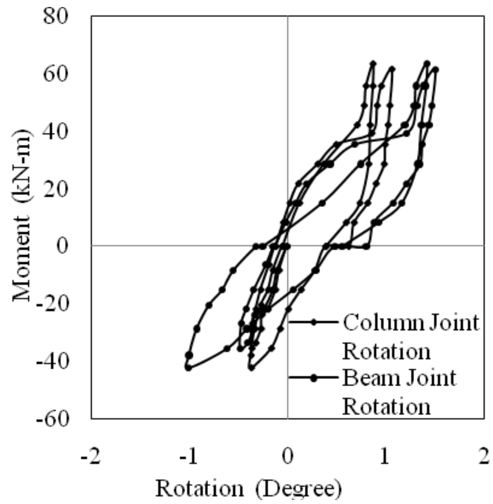


Fig. 23 Relative rotation of column and beam joint of plate 2

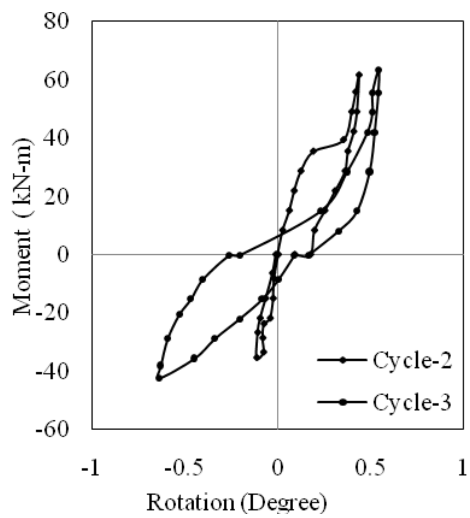


Fig. 24 Difference in beam and column joint rotation of plate 2

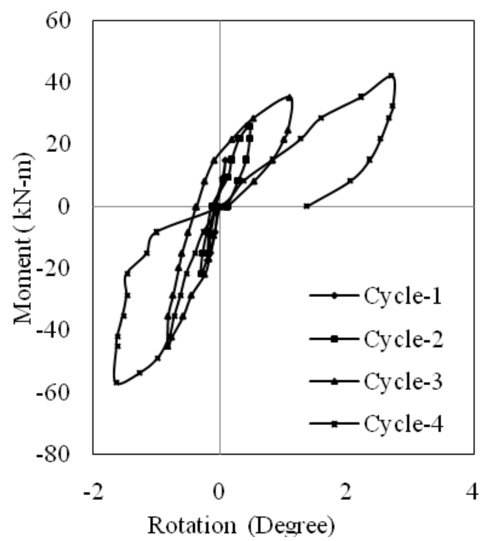


Fig. 25 Rotation of beam joint of fabrics 3

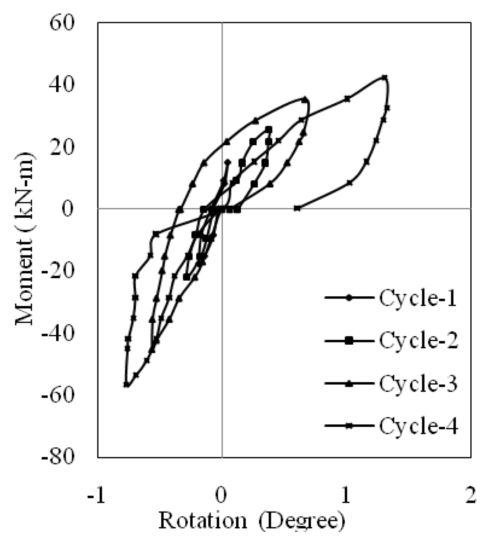


Fig. 26 Rotation of column joint of fabrics 3

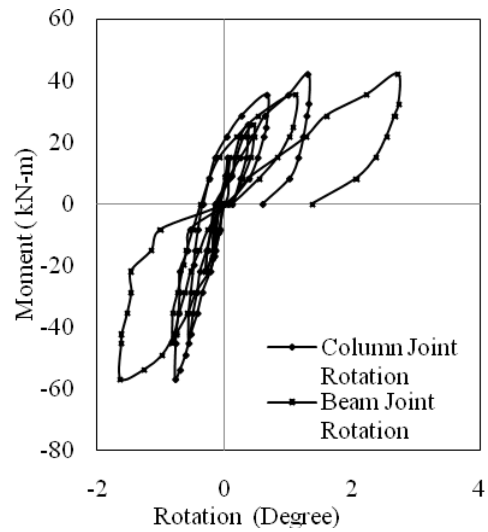


Fig. 27 Rotation of beam and column joint of fabrics 3

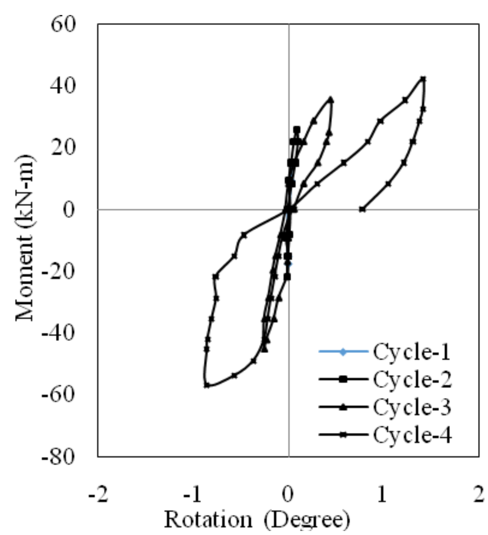


Fig. 28 Difference in beam and column joint rotation of fabrics 3

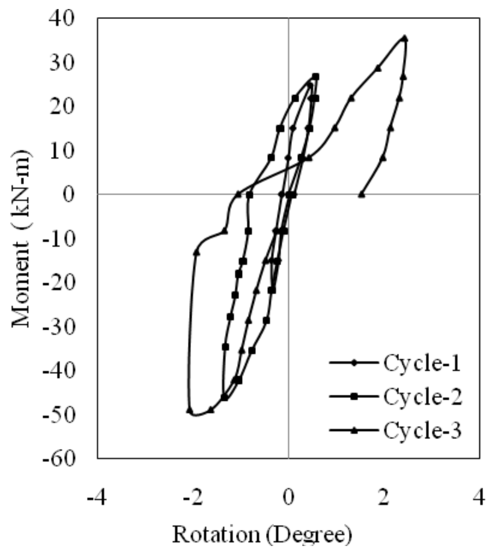


Fig. 29 Rotation of beam joint of MCS 1

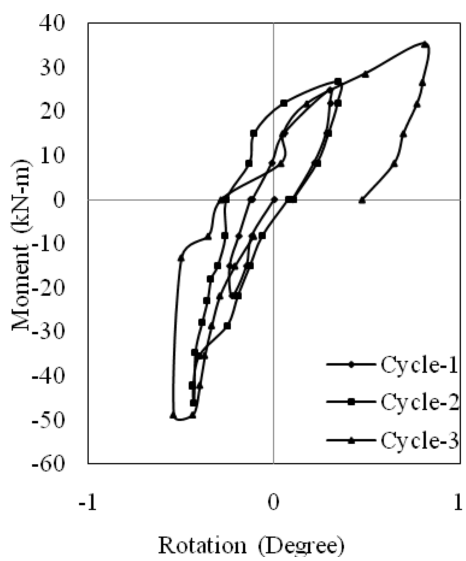


Fig. 30 Rotation of column joint of MCS 1

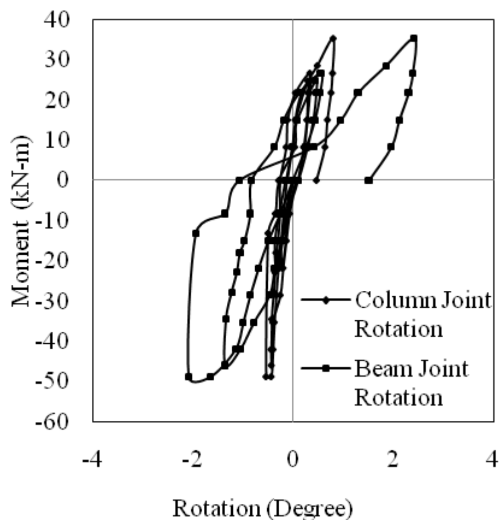


Fig. 31 Relative rotation of beam and column joint of MCS 1

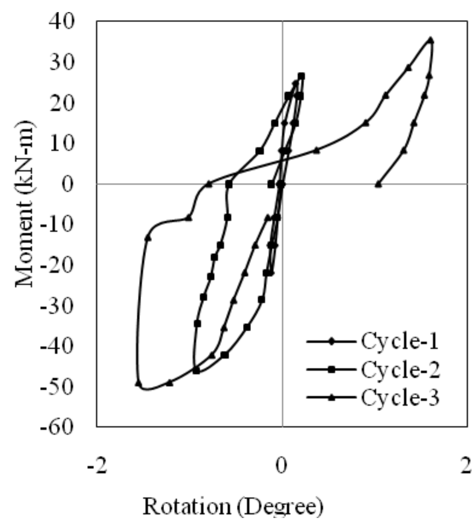


Fig. 32 Difference in beam and column joint rotation of MCS 1

It is found that the column and joint rotate equally for all the models with in the elastic limit but their relative rotations are different in subsequent cycles. The rotation of the column and joints are plotted together to evaluate their relative rotation. The magnitude of maximum rotation experienced by the beam joints in each cycle are illustrated through Fig. 33 and 34.

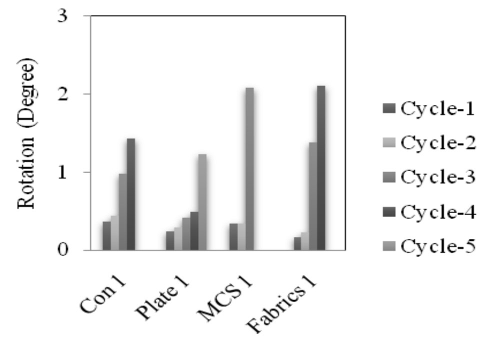


Fig. 33: Rotation of beam joints in forward cycle (Group A)

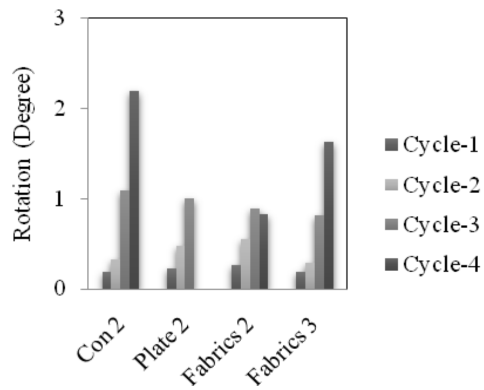


Fig. 34: Rotation of joints in forward cycle (Group B)

Rotational stiffness means the moment required to cause unit rotation. High stiffness means high resistance to deflection. Secant Rotational Stiffness of the joint is computed by averaging the maximum rotation against the applied maximum moment.

Rotational stiffness of Group A and B are illustrated through Fig. 35 and 36. The rotational stiffness joint decreased with the commencement of the cycles for all samples in Group A and B. Plate 1 exhibited high rotational stiffness compared to the joint of Con 1considering the concrete strength. Rotational stiffness of the joint of MCS 1 was less compared to stiffness of the joint of Con 1.

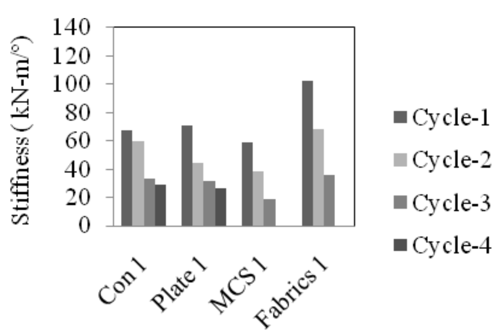


Fig. 35: Joint stiffness of Group A

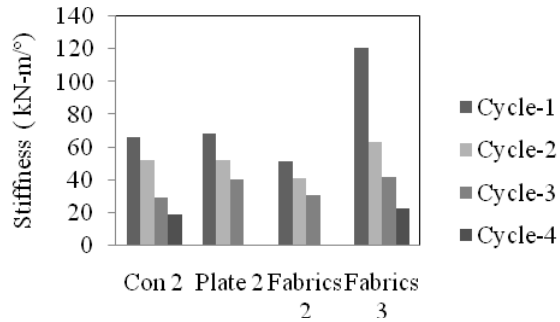


Fig. 36: Joint rotational stiffness of Group B

In Group B, rotational stiffness of the joint of Plate 2 was higher than that of the joint of Con 2 in all cycles of loading. Rotational stiffness of the joint of Fabrics 2 was slightly less compared to the rotational stiffness of the joint of Con 2 considering the concrete strength. Rotational stiffness of the joint of Fabrics 3 is higher than that of the control joint considering the concrete strength for all the cycles.

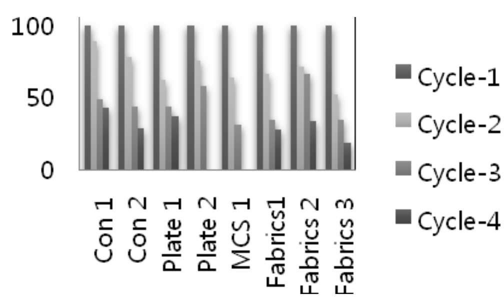


Fig. 37: Percentage of initial rotational stiffness

It is normal for the structural member to lose some stiffness under cyclic loading but excessive loss of stiffness can lead to a collapse. Percentage of initial stiffness of the joints in subsequent cycles is computed to measure the rate of loss of stiffness from the initial value and the values are illustrated in Fig. 37. The joints of Con1 and Con 2 retained 43% and 29% of the initial stiffness. Plate 1 and 2 retain 37% and 59% of the initial stiffness. Fabrics 1, 2 and 3 retain 29%, 60 % and 18.86% of the initial stiffness.

5. Conclusions

Behavior of the interior joints under cyclic loading, both of the control specimens and the retrofitted ones, were investigated based on the performed test result. Following conclusions are drawn based on the experiment and analysis of the results:

a. Diagonal cracks occurred under cyclic loading in interior joints which lack in shear reinforcement. Diagonal cracks of such specimen traveled to transverse beams at higher stage of loading and caused the transverse beam to fail.
b. Ductility of beams, columns and joints increased with increased concrete strength. Rotational ductility of the joints increased 2.5 to 2.75 times by increasing 54% of the concrete strength.
c. Stiffness of the joints decreased gradually under cyclic loading. But, Stiffness of the joint did not degrade at the same rate for all the retrofitted samples.
d. The rotational capacity of the joints can be increased by strengthening the BC joints by CFRP Plates. Rotational stiffness of these joints was higher than that of the control models. Rotational stiffness of these joints also decreased gradually. From M-Φ curve, it is found that BC joints strengthened by CFRP Plates show ductile behavior.
e. CFRP Plate is effective in resisting diagonal crack travelling to transverse beams. Diagonal crack traveled up to the CFRP Plate and changed their direction. Beams from both the models, failed at the Plate-Beam joints. It can be concluded that location of plastic hinge may be altered by altering the length of the plate.
f. Moment capacity of the joints can be enhanced by additional tie bar in the joint and micro-concrete depending on the initial concrete strength. Joint retrofitted by micro-concrete and additional tie bar underwent large deformation before failure exhibiting ductile behavior of the joint.
g. Joints can be strengthened by CFRP Fabrics. Moment capacities of the joints strengthened by CFRP Fabrics were higher against the same rotations compared to the control models.
h. Joints strengthened by CFRP fabrics undergo greater deformation than the control joints. Joints strengthened by CFRP fabrics exhibited better ductile behavior than the control models.
i. The mode of failure may be shifted from column to beam by strengthening joints by CFRP fabrics. Column shear and flexural capacity can be increased by CFRP wrapping.
j. Micro-concrete and concrete have good bonding strength as micro-concrete was used for strengthening joints by CFRP Plates and additional tie bar. Micro-concrete and concrete joints failed at higher stage of loading and associated with plate debonding.

PART-VI

A REVIEW ON FACTORS AFFECTING CYCLONE EVACUATION DECISION AND BEHAVIORAL RESPONSE

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1. Introduction

Coastal areas are mostly threatened by natural disaster like cyclone which leads the resident of the areas towards evacuation to get out of high-risk areas as quickly and safely as possible. The complication or success of evacuation process mostly depends on evacuation decision of the residents and their behavioral response which is again dependent on or influenced by several other factors. To ensure successful cyclone evacuation and to reduce loss of lives it is necessary to influence the residents to evacuate as quickly as possible. To increase efficiency in cyclone evacuation and to influence people to evacuate safely at an event of cyclone, it is necessary to understand their behavior. Over the last few decades, substantial researches have been carried out focusing on cyclone evacuation including interpretation of warning messages and risk by people, and consequent protective actions they take (Dash & Gladwin, 2007). Most of the literatures related to cyclone evacuation decision and behavioral response have concentrated on understanding people on whether they evacuate or not as well as the reason for such decision and response (Hasan et al. 2010). This review of literatures has focused on the most common and primary factors affecting cyclone evacuation decision and behavioral response.

2. Factors Affecting Cyclone Evacuation Decision and Behavioral Response

In different literatures most common factors considered to study cyclone evacuation decision and behavioral response are: household characteristics (location of residence, type of residence and family size, length of residence, family members' education status, social capital), transportation inadequacy, previous experience and risk perception, evacuation characteristics (type of evacuation notice, source of information, place and time of evacuation, sense of place for evacuation shelter). Table 1 summarizes the literatures reviewed in this research including context of the research, research strategy, data collection procedure, factors considered and research limitations. In the following sections, the factors affecting cyclone evacuation decision and behavioral response from the review of literatures are discussed as well as the limitations of those researches.

2.1Household characteristics

2.1.1Location of residence

Location of residence has been considered as an important factor in many researches influencing evacuation decision after cyclone. Concept of residence location varied in different researches. Hasan et al. (2013); Hasan et al. (2010); Sadri et al. (2013); Xu et al. (2016) have found that geographic location (region or state) of residence play important roles in evacuation decision making has significant influence on household's decision to evacuate or stay at home. The researchers have found significant difference in evacuation decision by households living in Alabama, Mississippi, Florida and Louisiana after the passing of Hurricane Ivan through the area of the west of Gulf

Shores, U.S. in September 2004.Several studies have found that evacuation decision after cyclone depends on proximity to hazard location (Dash & Gladwin, 2007; Huang et al., 2012; Lindell et al., 2005). Huang et al. (2012) have found that rate of evacuation lessened as the region's distance from the coast and projected point of landfall increased after Hurricane Lilihit Louisiana parishes of Vermilion and Cameron and the Jefferson and Chambers, Texas counties of Orange, U.S. They have also found strong correlation of evacuation decisions with geographic features, i.e. proximity to lakes, rivers and coast. Dash & Gladwin (2007) have found that in addition to proximity to hazard location, geographic location, such as proximity to highways and exit routes play a significant role in understanding evacuation decision making. Thus, the factors related to location of residence considered in different literatures for understanding cyclone evacuation decision include geographic location (region or state); proximity to hazard location; proximity to lakes, rivers, and the coast; and proximity to highways and exit routes.

2.1.2 Type of residence and family size

In several researches, type of residence and number of family accommodated in the residence have been considered together to understand their cyclone evacuation decision(Xu et al., 2016). Lindell et al. (2005) have considered five types of residence in their research considering family size, structure type and number of storey (i.e. separated single family, multifamily with one or two stories, multifamily with three or more stories, mobile home, and other) to study evacuation decision after Hurricane Lili in the Louisiana parishes of Vermilion and Cameron and the Jefferson and Chambers, Texas counties of Orange, U.S. The researchers have found non-significant correlation between residing in a mobile home and evacuation decision. That means, mobile home residences have neither a direct nor anshared effect on evacuation decisions. Hasan et al. (2013); Hasan et al. (2010) have considered three types of residence in their researchconsidering type and family size (i.e. single family home, multiple family unit and mobile home) to understand evacuation decision by households after the hit of Hurricane Ivan to the region of the west of Gulf Shores, U.S. in September 2004. In contrary to the findings of Lindell et al. (2005), the researchers have found families living in a mobile house had a higher probability to evacuatecompared to the households living in other type of houses. Thus the factors related to type of residence and family size considered in different literatures for understanding cyclone evacuation decision include family size (single family, multi-family), structure type (detached, mobile or manufactured) and number of storey.

2.1.3 Length of residence:

Factors such length of residence appears to be less significant when studied separately; however, understanding how these factors impact other factors such as risk perception or social capital is important. The review suggest that these factors are fortified or weakened in the presence or absence of each other and consideration should be given to such factors when planning communication strategies, and emergency evacuation plans.

2.1.4 Family members' education status

Different literatures have found significant influence of family members' education status on cyclone evacuation decision making process. From the literatures it has been seen that families having members with post graduate or graduate degree have the higher probability of evacuation. It is further noticed that family members' with low in education are more likely to take the risk of not evacuating if the evacuation notice is voluntary. However, in case mandatory evacuation notices the decision of evacuation is quite uniform and has higher percentage of evacuees. Hasan et al. (2010)in their research have showed that family members' with high education status perceive the risk cyclone more seriously, thus, have a higher percentage of evacuees.

2.1.5 Social capital

Social capital has been considered as one of the major factors defining the cyclone evacuation decision making process in different literatures. The fundamental consequences of resilient social interactions are variable and the research proposes that social factors may have both positive and negative influences on evacuation decisions. Patterns of social capital may include religious or ethnic affiliations, community connections such as civic organizations, community involvement, participation in school functions or interactions with friends and family. These social relations may play a substantial role in apprising decisions during evacuation states and should be reflected when designing research to inform future evacuation initiatives.Membership in religious or ethnic groups is one example of social capital and may play animportant role in affecting decisions about evacuation. These memberships may help to inform a decision by providing targeted information in a native language or to provide resources such as information about where, when and how other's within the affiliation are evacuating. They may also provide transportation, financial, or spiritual backing during times of need and smooth communication that allows families or affiliation members to stay in touch during this time of crisis. Specially, these links seem to increasereliance level among members and there is generally acasual communication system by which information and resources flow to pledge that all the members within the community are well taken care of (Litt, 2008). These lines of communication are often critical and very effective in situations of emergency and can greatly influence evacuation decisions (Airriess et al., 2008; Chamlee-Wright & Storr, 2009; Eisenman et al., 2007). Social capital is seen to be influenced by socio economic conditions of the households. Households of a particular society normally have almost same type of socio economic condition. Actually on the merit of socio economic conditions social bindings are normally built.

Hasan et al. (2013); Hasan et al. (2010); Huang et al. (2012); Xu et al. (2016) have considered house holds' income status which eventually contributes to build social capital. Thus, social capital cannot be overlooked when evaluating the level of risk. Information gets fabricated by social settings that influence how individuals perceive the level of risk. As "potential"threats become realized threats, and as abstract, vague ideas of potential damage become real, levels of danger may increase(Dash & Gladwin, 2007). For these reasons, decision making becomes more complex as decisions are in part influenced by "Risk Perception", which itself is affected by fabricated informationrepresenting the threat as real.

2.2Transportation inadequacy

Lack of transportation is one of the major factors that cause failure in evacuation planning. Households residing in the areas lack in transport facilities hardly have the choice of proper evacuation at the time of cyclone. The statement is very much evident in underdeveloped countries (e.g. Bangladesh) where lack of transportation and consequent loss of lives and resources is a common affair. However, transportation inadequacy was strongly associated with failure to evacuate in areas of poverty in New Orleans during hurricane Katrina. This issue included a pure lack of transportation as well as deficiency of financial resources to afford gas for the car (Baker, 1991; Bourque et al., 2006; Brezina, 2008; Eisenman et al., 2007; Elder et al., 2007; Elliott & Pais, 2006; Spence et al., 2007; West & Orr, 2007). It is also noted that in areas of extreme poverty in New Orleans no provisions were made for the poor and thus left many people stranded with no way out during hurricane Katrina and is attributed to higher risk of injury and death (Brezina, 2008; West & Orr, 2007). In the study of Brezina (2008), professional interviewers administered face to face interviews with 394 participants who evacuated after hurricane Katrina made landfall in New Orleans and 247 evacuees who left prior to the storm. This sample was drawn from a pool of greater than 8000 residents who were housed in shelters following the storm. Of the 394 study participants who evacuated after the storm, 298 participated in post storm, government assisted evacuation. Of these 38 stated that they did not have transportation to leave and 45 stated that looking back, they would not have been able to find a way to leave (Brezina, 2008).

2.3Previous experience and Risk Perception

Information about cyclone alone is not adequate to motivate evacuation action rather the information must be interpreted into a definite conception of awaiting danger associated with cyclone hit. Thus, risk perception is one of the primary factors in understanding the evacuation decision making process. The review findings reveal that normally when residents feel unsafe to stay in their homes during the storm, they evacuate and those who feel safe tend to stay. Risk can be seen as a technical notion calculated based on the probability of events and the magnitude of specific consequences

(Kasperson et al., 1988), others express it based on its social sense, characterized by worry, dread, angst, concern, or anxiety (Jaeger, Webler, Rosa, & Renn, 2013) whereas other researchers view it as more of a social notion that takes into account context and culture in the understanding of what is dangerous (Turner, 1979). In his 1987 article, risk perception (Covello et al., 1987) asserts that "whereas technologically sophisticated analysts employ risk assessment to evaluate hazards, the majority of citizens rely on intuitive risk judgments, typically called risk perception. However, this perception may be reformed by many factors including community, racial or religious affiliations and also by the interpretation of media messages or simply a misinterpretation of the possible severity of the storm. Individuals perceive information by their own social lenses created by their specific cultural context, and as a result, different people may well interpret the similar information and messages differently (Dash & Gladwin, 2007).

Adeola (2009a, 2009b)study has revealed that most of the residents underestimated the impact of the storm and never awaited a 15 ft. storm surge and breeches to the levees. In this case, the wrongness of the perception of risk put great numbers of residents at danger needlessly and led to avoidable death. In his study, Hasan et al. (2010) have suggested that perception of risk perception largely depends on the trust worthiness of the source of information. Most of the risk perception problems arise from complications in receiving and processing information. Interestingly, Gender serves as a significant factor in the personalization of risk. Bateman and Edwards (2002) have revealed that the perception of risk for men and women is significantly different. The authors quoted that "...*Women were more likely to evacuate than men, in part, because compared to men, they perceive their residence to be at greater risk, and were more likely to have developed a household evacuation plan*...".

Previous cyclone experience influences the risk perception process significantly. A community or an individual having a bad evacuation experiences result in a lower probability of evacuation for future storms (Dash & Gladwin, 2007). In all studies, previous cyclone experience led to inaccurate risk perception and optimism established on previous experience with riding out the storm and put more residents in danger when they decided not to evacuate (Adeola, 2009a, 2009b; Bourque et al., 2006; Elder et al., 2007). Horney et al. (2010) have explained in post cyclone research following hurricane Isabel in North Carolina in September 2003, that older residents had a lower perception of risk that led to their failure to evacuate because the last major hurricane to affect their region was Hurricane Hazel in 1954. In a brief it can be said risk perception and previous cyclone experience plays a critical role in evacuation decision making. It is thus vital to recognize how people shift from receiving evacuation orders to decision of evacuation grounded on their level of risk perception.

2.4Evacuation characteristics

2.4.1 Type of evacuation notice

Evacuation notice and its type is a very important factor on which households' evacuation decision is significantly dependent. It has been an important focus of many researches research on cyclone evacuation decision (Dash & Gladwin, 2007). To understand evacuation decision by households after the passing of Hurricane Ivan through the province of the west of Gulf Shores, U.S. in September 2004, Hasan et al. (2013); Hasan et al. (2010)have considered whether a cyclone evacuation notice was received, as well as type of the evacuation notice received (mandatory or voluntary). The researchers have found that households receiving evacuation notice are more likely to evacuate than those who do receive any order. Additionally they have found that households receiving mandatory notice are more likely to evacuate than those receiving voluntary evacuation notice.To study evacuation decision in Louisiana, U.S. after Hurricane Ivan in September 2004, Sadri et al. (2013) have considered the time of evacuation notice received by households.The researchers have found that the timing of evacuation notice havesignificant influence on the evacuees' mobilization time, i.e. evacuees getting early evacuation notice get enough time for evacuation process and preparation.Thus the factors related to type of evacuation notice considered in different literatures for understanding cyclone evacuation decision include reception of cyclone evacuation notice, type of evacuation notice (mandatory or voluntary) and timing of evacuation noticereception.

2.4.2 Source of information

Several literatures included a discussion of the importance of households' perception of the source of information. The decision maker dimension emphases on the competency of decision makers to process and understand information (Dash & Gladwin, 2007). This above stated belief is basically psychologically dominated and attempts to measure the cerebral capability of decision makers'. During cyclone households can receive information from various sources (e.g. radio, TV, local government officials, news media, and their community contacts including neighbors, civic organizations, religious affiliations, etc). When households trust the source of the information they are more likely to evacuate and having multiple channels of information may develop evacuation decisions (Spence et al., 2007). Previous bad experience with a particular source of information regarding cyclone evacuation reduces the probability of decision to evacuation. For example, to examine the media credibility in a study conducted by the American Red Cross Disaster Relief Operations Control for Columbia, SC following hurricane Katrina, in which participants who evacuated to Columbia South Carolina were identified. The evacuees reported that they trusted television media reporting of the size and strength of the cyclone because they could see it. Elder et al. (2007) stated "*...It was right there in front of your eyes showing where it is coming and how fast it's coming...*".

Households' may have issues of trust regarding local officials or even the media as a potential source of information. This distrust is mainly based on previous experience and may be augmented when evacuation for previous cyclones are proven superfluous (Baker, 1991). Several factors that contribute for distrust local government officials were identified such as language barriers, socio-economic status, and minority preference for a particular information source (Peguero, 2006; Spence et al., 2007). This distrust may be a barrier to evacuation and lead to higher numbers of casualties and injuries. Baker (1991)have indicated that households who did evacuate, at the warning of public officials, did so because the information provided to them, convinced them of the danger or they wanted to be compliant or obedient.

2.4.3 Place and time of evacuation

After a cyclone, evacuation decision of people greatly depends on the place where they are evacuating and for how long (Baker, 1991). This is also dependent on the time of their evacuation. In September 1988 Hurricane Gilbert struck in Cancun, Mexico. After getting evacuation notice, majority of the local people were not willing to evacuate from their home due to their concern for the safety of their belongings. As a result, many of them were rescued afterwards by the army. Majority of the evacuees found shelter in the homes of friends, neighbors, and relatives in Cancun, Mexico, and very few of them stayed away from their homes for more than seven days (Aguirre, 1991). At the event of hurricane Katrina, vast majority of residents evacuated before the storm that were living in the affected region (Burnside et al., 2007; Eisenman et al., 2007; Elliott & Pais, 2006). This response was more common in the City of New Orleans compared to others due to their perceived risk and prior planning (Brezina, 2008; Burnside et al., 2007; Elliott & Pais, 2006; Jacob et al., 2008; Vu et al., 2009). Most of the evacuees took shelter in an apartment, hotel or temporary shelter or in someone else's home for more than one month after the storm due to late recovery of their home (Adeola, 2009a, 2009b; Elliott & Pais, 2006; Jacob et al., 2008).

Hasan et al. (2013) have studied evacuation decision by households after the passage of Hurricane Ivan through the region of the west of Gulf Shores, U.S. in September 2004. The researchers have found that households waited longer for deciding on evacuation to public shelter than those evacuating to other types of shelters which reflect their preference to take the risk of remaining longer at home than evacuating to the public shelter. Sadri et al. (2013) have studied evacuation decision in Louisiana, U.S. after Hurricane Ivan in September 2004 and have found that households are expected to evacuate early (in an hour or less) as opposed to evacuating later (more than 24 h) once they choose to evacuate due to their perceived risk and prior planning. Among them most of the evacuees who decided to evacuate to a public shelter took least amount time for evacuation compared to those evacuating to someplace safer. Thusit can be said that timing of evacuation of people depends mostly on their perceived risk and prior planning as well as place of evacuation.

2.4.4 Sense of place for evacuation shelter

Sense of place plays a vital role in cyclone evacuation decision making as residents tend to move to places with environmental similarity to their home and community. Vu et al. (2009)in his study has revealed that evacuees seek out refuge in an area with similar ethnic, cultural and religious background where they might find acceptance and resources to help them during this time of displacement. In his research he further found that the during hurricane Katrina 78% of Vietnamese-American community in New Orleans evacuated to Houston during hurricane Katrina with the primary decision based on the fact that Houston has the second largest Vietnamese-American population in the United States. Findings of Chamlee-Wright & Storr (2009) also support the above outcome. The research showed that communities tried to stay in touch and made plans to return to their homes and rebuild their communities as soon as possible following the storm.

3. Limitations in Researches Related to Cyclone Evacuation Decision

Several of the significant potential research limitations noted in this literature review (Table 1) include cognitive biases, social response, sample size or distribution, characteristics of the sample population considered, etc for research that does not accurately represent the population. It is important to understand how these features affect the precision of information that is stated and to think about ways to lessen these issues to improve research outcomes. Social response and cognitive biases may appear when survey respondents have difficulty accurately recalling or articulating responses to survey questions or when they provide answers that are inaccurate because of dissonance (Eisenman et al., 2007; Elder et al., 2007). Dissonance may occur in research such as in a study of African American's evacuated after Katrina to Columbia, in which the respondentsself-reported the event before and after the hurricane (Elder et al., 2007). Bias may also take place when evacuees answer survey questions in a way that they feel will please the surveyor. These biases may be lessened when surveys are conducted immediately after the event, leaving less elapse of time for the evacuees to fabricate their decision or to think about the results of their actions (Spence et al., 2007). In the Spence's (2007) research following hurricane Katrina, the data was collected over an extended period of time allowing some respondents to provide response hours after the event while other information was gathered weeks after the event due to the time consuming nature of finding and interviewing cyclone evacuees. The recall accuracy should be enhanced and bias lessened by collecting data at a single time point as close to the event as possible (Spence et al., 2007).

One of the most significant factor emergency management planning is communication strategies. Furthermore, interpretation of media messages may be more important than the number of messages heard (Aguirre, 1991). It is vital to understand how demographic data coupled with variances in social capital may affect how emergency media messages are interpreted (Aguirre, 1991). It is also critical to understand the population represented in this research. Often post-cyclone survey respondents are not representative of the entire population (Elder et al., 2007). In certain situations, the financially or physically restrained people are unable to evacuate due to issues with lack of transportation, financial resources or physical issues to allow them to travel away from their homes. In other situations, when post disaster surveys are completed immediately following a cyclone, only the people with the financially advanced condition returned to their homes because those with less financial resources may be unable to make repair to their property to allow them a safe place to reside. These disagreements may lead to a small sample size with racial or monetary bias due to a less representation of the poor (Elliott & Pais, 2006).

For example, in the study of Aguirre (1991) on hurricane Gilbert in Cancun, 431 interviews were conducted of residents of Cancun one year following the cyclone to understand experiences of residents during and after the cyclone. The sample was derived by identifying 18 sampling cells and randomly interviewing at least 25 people residing within those cells. The model identified that the most impoverished residents of Cancun were underrepresented in the sample. For this underrepresentation of the sample to be considered the assessed impact of the dangers of the study was conservative (Aguirre, 1991). Thus, it is important to understand and note these potential biases in the research. Also, researchers should adjust analysis to take into consideration the biases that may affect the accurateness of the sample collected by surveys. Surveyors should develop skill to collect a representative sample for proper outcome of the research.

4. Conclusion

As, the decision making process prior to cyclone hit is multifaceted phenomenon, in this paper the most common and primary factors that have been considered by the researchers to assess the cyclone evacuation decision making process are considered. In this context, our major findings suggestthat cyclone evacuation compliance is governed by a number of overlapping factors considered under thethemes of household characteristics (location of residence, type of residence and family size, length of residence, family members' education status, social capital), transportation inadequacy, previous experience and risk perception, evacuation characteristics (type of evacuation notice, source of information, place and time of evacuation, sense of place for evacuation shelter).

From the review it has been found that the factors related to location of residence considered in different literatures for understanding cyclone evacuation decision include geographic location (region or state); proximity to hazard location; proximity to rivers, lakes and coast; and proximity to highways and exit routes. The factors related to type of residence and family size considered in different literatures for understanding cyclone evacuation decision include family size (single family, multi-family), structure type (detached, mobile or manufactured) and number of storey. Families having members with post graduate or graduate degree have the higher probability of evacuation. Households residing in the areas lack in transport facilities hardly have the choice of proper evacuation at the time of cyclone. Social capital plays a significant role in determining the decision of evacuation. Evacuation decision making process largely depends on the risk perception. However, risk perception is affected by different factors. Few researches showed that in case of mandatory evacuation notice the perception of risk is great thus, results in greater probability of evacuation. Risk perception on the other hand is greatly dependent on previous cyclone experience as well as their preparedness planning. Factors related to type of evacuation notice considered in different literatures for understanding cyclone evacuation decision include whether a cyclone evacuation notice was received or not, type of the notice received (mandatory or voluntary) and whether the households received an evacuation notice early enough or not.During cyclone households can receive information from various sources (e.g. radio, TV, local government officials, news media, and their community contacts including neighbors, civic organizations, religious affiliations, etc). When households trust the source of the information they are more likely to evacuate and having multiple channels of information may develop evacuation decisions. Timing of evacuation of people depends mostly on their perceived risk and prior planning as well as place of evacuation.

Among different limitations mentioned in researches related to cyclone evacuation decision and behavioral response most significant is the problem of recall.After a cyclone people face difficulty in recalling their experiences throughout the evacuation process exactly as time elapse. In such cases, researchers have to rely on the altered memories of the evacuees. Todeal with this matter, it is necessary to undertake more systematic pre-event research focusing onevacuation needs. Additionally, a systematic approach should be developed to get in cyclone hit areas for data collection at a moment's notice during an event or afterwards.

In spite of having research limitations the studies regarding the decision making process at the eve of cyclone event give in depth understandingof the factors that determine the evacuation decision making. This review will further guide the researchers studying cyclone evacuation decision and behavioral response regarding consideration of factors for their researches. This will also guide the corresponding authorities to prepare a data log to keep ready for collecting data after a cyclone event for further improvement of cyclone preparedness form lesson learned. This will enable decision makers toward people centric cyclone preparedness considering their context as well as individual's and household's behavioral response.

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PART-VII

EXPERIMENTAL INVESTIGATION OF EMBANKMENT ON SOFT SOIL UNDER CYCLIC LOADING: EFFECT OF INPUT ACCELERATION

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

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INTRODUCTION

The soil-foundation composed of clayey soil has become the focus of earthquake engineering in more cases. However, it is rather scarce to study the characteristic of pore water pressure in such soil-foundations with cohesive or clayey soil under earthquake action due to its clay content is thought of relatively high. Although such soil-foundations of higher clay content are not easily susceptible to liquidity, a rise of excess pore water pressure triggered by earthquakes and a drop of effective stress may lead to the soil softening. Also, soil-foundation softening may cause damage to the embankment. Today, there is no absolute conclusion on whether the softening effect of cohesive or clayey soils under earthquake excitation should be considered and under what shake condition the damage induced by excess pore water pressure may not be considered in analysis. Based on shaking table tests, this paper attempts to investigate the changing characteristics of the amplification, displacement and pore water pressure (due to input acceleration) in soft soil-foundations under harmonic wave. The soil-foundation in the test has been built with soft soils in Dhaka clay. The physical mechanism responsible for variation behavior of the pore water pressure in the repeated process has been studied. The results of experimental investigation have been expected to provide some research basis for softening problems of clayey embankment under earthquake actions.

Methodology

Previous Research

Developments of model testing in earthquake geotechnical engineering, two aspects of model testing have been given importance, namely rigid and laminar box. Design, development, calibration and performance of this equipment are very important (Prasad S. K. et al., 2004). Latha M. G. et al. (2006) has presented Shaking table studies which have been carried out on wrap-faced reinforced soil retaining walls to gain insight into their behaviour under dynamic loads. Soft soil with the larger void ratio, the higher water content and higher the saturation degree, the peak of excess pore water pressure during the repeated loading process will not be significantly higher than that of the previous cycle (Zhang, Z. et al., 2009). Moss, R. et al (2010) has proposed scale soil-structure models to mimic the coupled seismic response of underground structures and surrounding/supporting soil (termed soil-structural-interaction or SSI). Currently the seismic design of subways and other critical underground infrastructure rely on little to no empirical data for calibrating numerical simulations. Srilatha et al. (2014) has also been conducted series of laboratory shaking table tests for observing the performance of without reinforced and reinforced soil slopes through. Frequency of base acceleration has been varied from 1 Hz to 7 Hz in different tests. Acceleration of base shaking has been kept as 0.3 g in all the tests. A recent laboratory test has been conducted by Yazdandoust (2017) to assess the behavior and performance of steel-strip reinforced-soil retaining walls during seismic loading, a series of 1-g shaking table tests have been conducted on 0.9 m high reinforced-soil wall models with different strip lengths.

Current Investigation

Based on the aforementioned necessities the present research targets the seismic design of subway/ road way or railway embankment. A scale model testing platform has been developed for single degree of freedom shaking table tests that mimics the dynamic free-field conditions of Dhaka clayey soil where a sand retaining wall has been erected on clayey soil has been subjected to seismic loading. A total of 90 shaking table test have been carried out on this model embankment. The effect of frequency, amplitude, surcharge, pore water pressure and displacement along the different elevations (effect of input acceleration) has been observed.

Equipment and Materials

Shaking table: A computer-controlled servo-hydraulic single degree of freedom shaking table facility has been used to simulate the horizontal shaking action, associated with seismic and other vibration conditions. The testing platform is a square having 2×2 m^2 dimension and approximate payload capacity of 1000 kg, which has been made from steel plates. Shaking has been provided by a digitally controlled servo-hydraulic actuator with ±200 mm stroke and 30 kN force rating. The shaking table can be operated over an acceleration range of 0.05g to 2g and frequency range 0.05 to 50 Hz with a maximum amplitude of ±200 mm. Maximum velocities are 0.3 m/s.

Laminar box: In this study, embankment with soft clay soil models has been constructed in a laminar box to reduce boundary effects as far as practicable. The laminar shear box developed at BUET has composed of 24 hollow aluminum layers of frames. Each layer consists of an inner frame with inside dimensions of 915 mm × 1220 mm × 1220 mm. Laminar box mounted on the shake table has been presented in Fig. 1(a).

Backfill material & Reinforcement: Dry sand (Specific gravity=2.64) has been used as the backfill material. The sand has been classified as poorly graded sand (SP) according to the Unified Soil Classification System. Maximum dry density of the sand is 18 kN/m^3 and minimum dry density observed in the loosest state is 15 kN/m3. A non woven polypropylene multifilament geotextile has been used for reinforcing the sand in the tests.

Model Construction and testing procedure

Re constitute clay soil sample: In this research work Dhaka soft clay soil has been used. The liquid limit of this soil has been found 40%. The water content of this soil sample has been found 23%. For preparing the soil sample used 50% of water content (1.25 times of liquid limit). From the direct shear test cohesion and friction have been found 14.8 KN/m2 and 10.03 respectively. After loading had been done, the water content of soil sample was 15% and unconfined compression strength (qu) was 20 kPa. The constitute clay layer thickness of the soil sample is 18 inch. Preparation of re constitute sample has been shown as Fig. 1(b). Two pore water pressure sensor: one is base level of sample and another is 18 inch above the base level have been used in this soil sample. Two acceleration sensors have been placed in the soil sample.

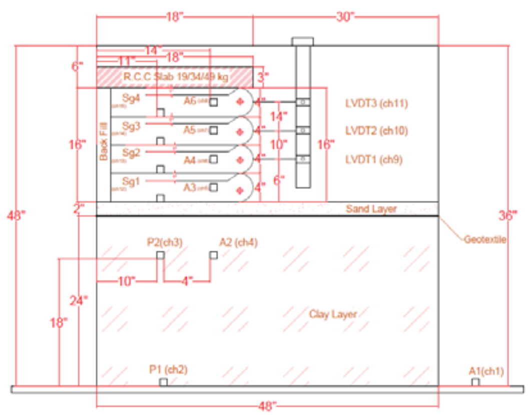
[Fig. 1]. Detail setting of Shake table test. (a) Laminar box mounted on shaking table (b) Placement of reconstitute soil sample

Testing Process: The model embankment has been constructed in a laminar box to a size of 915 mm x1220 mm in plan area and 1220 mm deep. Each geotextile layer has been wrapped at the facing for a length of 150 mm. To achieve uniform density, sand was placed in the laminar box using the pluviation (raining) technique (Hossain and Ansary, 2018). After the completion of all lifts up to full height of the wall (406 mm), surcharge in the form of three type concrete slabs (19/34/49 kg) have been applied to anchor the top wrapped geotextile. The facing formwork was removed carefully in sequential lifts from bottom to top after the backfill layers (2 inch) and surcharge have been completed. Fig. 2 shows the finished embankment for four-layer with 2 ft clay layer. A typical model configuration showing the instrumentation for the test wall with four layers of reinforcement has been shown in Fig. 3. Two pressure sensors; P1 and P2 have been placed inside the wall, in contact with the measure horizontal displacement, three displacement sensors (LVDTs), L1, L2 and L3, have been positioned at elevations 32, 42 and 56 inch, respectively, along the facing for the tests with four-layer configurations.

Results and Discussions

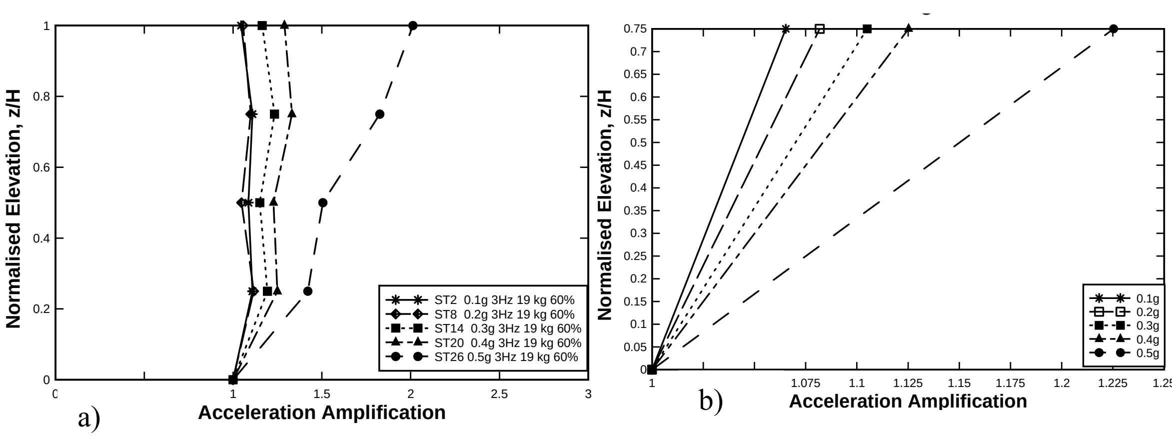
Results obtained from sixteen different shaking table tests from ninety combinations on embankment with soft clay models have been discussed in this paper. The parameters varied in model tests are base acceleration, frequency and surcharge pressure on the crest. The base acceleration has been kept as 0.1g, 0.2g, 0.3g, 0.4 g and 0.5g in different tests. The frequency has been varied from 1 Hz to 15 Hz. The surcharge pressure on the embankment has been kept as 19, 34 and 49 kg. Soft clay layer has been used (24 in) which unconfined compression strength is 20 kPa. Model has been constructed using sand on the clay layer in equal lifts (Sv) of 4 and total wall height (H) is 16 in. The length (L) of the geotextile reinforcement at the interface of the sand layers has been kept the same in all tests as 15 in. Model wall was subjected to 20 cycles of sinusoidal shaking. The average unit weight and relative density achieved were within the ranges 18 kN/m3 and 60% respectively for the same height of fall.

[Fig. 2].Setting of Setting of displacement sensor.



[Fig. 3]. Schematic diagram of typical test wall configuration and instrumentation

Acceleration response: Fig. 4(a) and Fig. 4(b) compare the acceleration amplification profile along the height of the wall for different configurations of wall and base motion after each test of 20 cycles of sinusoidal motion. Here the elevation (z) has been represented in non-dimensional form after normalizing by the full wall height (H). Maximum acceleration amplification has been observed at the top of the wall in all the tests. This observation is in concurrence with the results of physical tests reported by Telekes et al. (1994), El-Emam and Bathurst (2005) and Krishna et al (2007). Fig. 4(a) shows the acceleration amplifications along the height of the wall for different base accelerations of 0.1, 0.2, 0.3, 0.4 and 0.5g from ST2 (0.1g, 3 Hz and 19 kg) , ST8 (0.2g, 3Hz and 19 kg), ST14 (0.3g, 3Hz and 19 kg), ST20 (0.4g, 3 Hz and 19 kg) and ST26 (0.5g, 3Hz and 19 kg) model tests, respectively, which have been conducted at 3 Hz frequency, 19 Kg surcharge. However, within the range of tests conducted, acceleration amplifications at the top of the wall for 0.1,0.2, 0.3, 0.4 and 0.5g base accelerations are 1.06 to 1.22. Fig.4(b) shows the two sensor in clay soil sample layer for different base accelerations of 0.1, 0.2, 0.3, 0.4 and 0.5g from ST2, ST8, ST14, ST20 and ST26 model tests, respectively, which were conducted at 3 Hz frequency, 19 Kg surcharge.



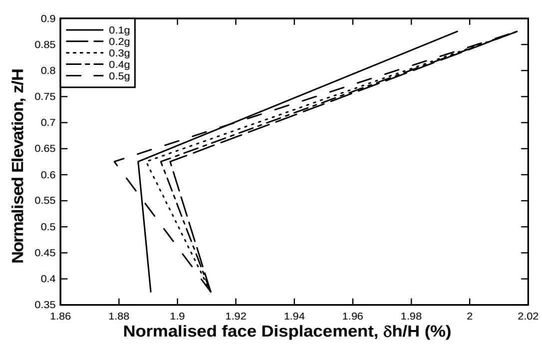
[Fig. 4]: a) Effect of base acceleration on acceleration amplification b) Effect of base acceleration on acceleration amplification (Clay layer)

Face displacement response: Horizontal face displacements along the height of the wall have been monitored using three LVDTs positioned as shown in Fig. 3. Fig. 5 presents the displaced face profiles from various tests after 20 cycles of sinusoidal motion. Here elevation (z) and horizontal displacements (h) have been presented in non-dimensional form after normalizing them by the total height of the wall (H). Fig. 5 shows normalized displacement profiles of the facing after 20 cycles for different base accelerations of 0.1, 0.2, 0.3, 0.4 and 0.5g from tests ST1 (0.1g, 1Hz and 19 kg), ST7 (0.2g, 1Hz and 19 kg), ST13 (0.3g, 1Hz and 19 kg), ST19 (0.4g, 1Hz and 19 kg) and ST25 (0.5g, 1Hz and 19 kg) respectively. The normalized displacements are relatively high at the higher base accelerations. A maximum horizontal displacement of 2.02% of the total wall height, H, for 0.5g have been observed compared with 0.01% for 0.1g base acceleration. The displacements obtained in the present study are in close agreement with the results presented by Sakaguchi et al. (1992) and Krishna et al (2007) corresponding to the accelerations and frequency levels used in the present study.

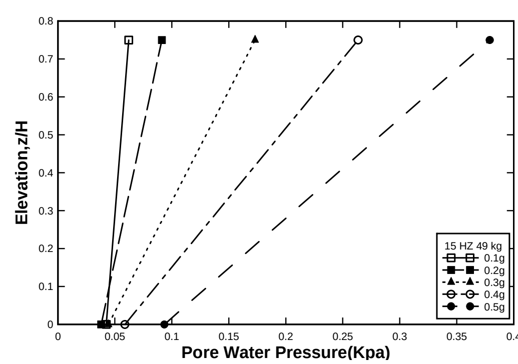
Pore Pressure response: Fig. 6 presents typical pore pressure variations obtained from the model tests. Fig. 6 shows variations of the pore pressure from model tests ST66 (0.1g, 15Hz and 49 kg), ST72 (0.2g, 15Hz and 49 kg), ST78 (0.3g, 15Hz and 49 kg), ST84 (0.4g, 15Hz and 49 kg) and ST90 (0.5g, 15Hz and 49 kg) with of base acceleration 0.1, 0.2, 0.3, 0.4 and 0.5g respectively for 15Hz frequencies and surcharge load 49 kg. It is observed that pore water pressure has been increased with elevation. The highest pore water pressure is 0.38 kPa at base acceleration 0.5g. The highest pore water pressure for model tests ST66, ST72, ST78, ST84 and ST90 is 0.06, 0.09, 0.17, 0.26 and 0.38 kPa respectively.

Conclusions

The seismic response of geotextile-reinforced embankment on soft clayey soil has been investigated by conducting shaking table tests on model test. A model test with variations in acceleration and frequency of base motion, surcharge pressure on the crest and pore water pressure (effect of input acceleration) have been described along with the model preparation, testing methodology and results. It has been observed that the seismic response of the embankment has significantly been affected by the variations of the base motion, surcharge pressure on the crest and pore water pressure. In fact, accelerations have been amplified at higher elevations with low surcharge pressures. The acceleration amplification response with change in base shaking frequency clearly indicates the role of the fundamental frequency on the response of the system. In some case the face deformations are high with high base accelerations. Pore water pressure is high at higher elevations with low surcharge pressures and high base acceleration.



[Fig. 5]: Effect of Acceleration on displacement profile



[Fig. 6]: Variations of pore water pressure with respect to Elevation (Effect of base acceleration)

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PART-VIII

DEVELOPMENT OF ZONATION FOR BANGLADESH BASED ON SOFT CLAY USING GIS

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

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INTRODUCTION

Soft clay soil layer identification is very significant for selecting the different soil improvement techniques. So presenting the subsoil characteristics in one platform is major challenge. Basically soft clay soil is a finely-grained natural rock or soil material that combines one or more clay minerals with possible traces of quartz ($SiO2$), metal oxides ($Al2O3$, MgO etc.) and organic matter. Beside these soft clay deposits are mostly composed of phyllosilicate minerals containing variable amounts of water trapped in the mineral structure. Construction on soft clay soil may cause failure the structure. So before construction, implementation the soil improvement techniques has been necessary.

Methodology

Previous Research

Kamal and Midorikawa (2004) delineated the geomorphology of Dhaka city area, differentiating the ground of the city into seventeen geomorphic units using aerial photographs. These geomorphic units represent the soil conditions. They also classified the fill-sites into four classes based on the thickness of fills. Ansary, M.A. and Rashid,M.A.(2000) has conducted to analysis the mitigation of the disaster due to future shocks is an essential consideration for effective land use and proper town-planning. This is the first study initiated in Bangladesh as part of the micro-zonation investigations. Alam, J. and Islam, S. (2009) has described the understanding the geological setting of Bangladesh is important for foundation design as well as to assess the Earthquake hazards. A brief description of the geology, stratification and subsoil investigation evidences of soil formations of Bangladesh has been presented in this paper. Hossain et. at. (2003) has evaluated sub-soil characteristics and liquefaction potential of Mirpur DOHS area. To characterize soil deposit eight bore holes were drilled at the project site. Moisture content, specific gravity, Atterberg limits, grain size distribution, unconfined compressive strength, density and shear strength parameters of the collected samples have been determined in the laboratory. Rahman (2004) updated the seismic micro-zonation maps for liquefaction as well as site amplification due to earthquake.

Current Investigation

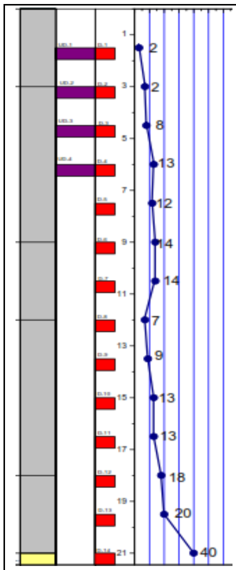
All these research paper described the sub soil characteristic at specific location of Bangladesh. Basically seismic or liquefaction micro zonation map have been produced. In these research papers an attempt has been conducted to produce proposed zonation map base on soft clay soil using GIS Software 2010 which is effectively useful to selecting proper soil improvement techniques.

Geology of Bangladesh:

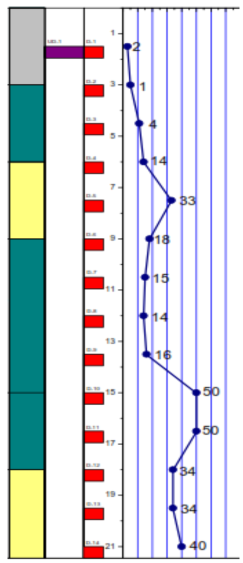
The Geology of Bangladesh has been affected by the country's location, as Bangladesh is mainly a riverine country. It is the eastern two-thirds of the Ganges and Brahmaputra river delta plain stretching to the north from the Bay of Bengal. There are two small areas of slightly higher land in the north-centre and north-west composed of old alluvium called the Madhupur Tract and the Barind Tract, and steep, folded, hill ranges of older (Tertiary) rocks along the eastern border. The down warping of the basement rocks under central and southern Bangladesh result from the pressure of sediments that have been accumulating since the Cretaceous period, mostly a large quantity of carbonate. In the Late Eocene epoch the conditions in the Bay of Bengal changed and these deposits ceased. In the late Cretaceous, the Indian Plate collided with the Eurasian Plate, after the Indian and African Plate split to form the Indian Ocean during the Triassic. The tectonic collision in the Cretaceous separated the Gulf of Assam and the Gulf of Burma, while narrow channels from the ocean fed water into the two gulfs. As ridges formed in the Tethys Ocean on the other side of the Shillong and Dinajpur Shields, small island arcs formed locally. The Tura sandstone, Sylhet limestone and Kopili shale were all deposited during an intermediate shall marine depositional environment in between these tectonic changes. A renewed period of collision and tectonic activity began with the Himalayan orogeny in the Eocene. As tectonic activity slowed somewhat, a river delta environment deposited of the other significant Cenozoic sedimentary units. Renewed tectonism in the Pliocene formed the Dinajpur Shield into a graben, relative to the horst of the Shillong Plateau and Mikir Hills. The Pliocene orogeny led into the Pleistocene ice age, resulting in regional extinction of many large mammals. A final period of uplift raised the red clay table lad 30 to 100 feet, along with St. Martin's Island in the Pleistocene. Surface rocks and stratigraphy in Bangladesh have been formed during the Cenozoic and rock units date to all epochs of the Cenozoic except for the Oligocene, which has been poorly preserved.

Sub Soil Condition

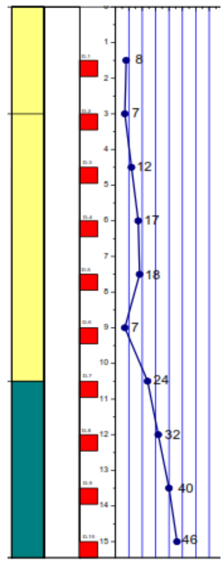
The sub-surface investigation work includes execution of 1000 borings, performance of the required field tests. Boreholes have been drilled vertically using wash boring technique. The density and stiffness characteristics of the subsoil layers in the boreholes have been measured by performing Standard Penetration Test (SPT). The bore log along the alignment has been shown by Fig. 1. The sub soil investigation has been performed by Soil and Foundation Consultants. Thickness of soft clay layers varies from 1 to 20 m. The most common index properties for estimating liquefaction strength is the N-value obtained from the standard penetration test. The SPT consists of driving a thick-walled sampler into the granular soil deposit. The measured SPT N-value (blows per foot) is defined as the penetration resistance of the soil, which equals the sum of the number of bows required to drive the SPT sampler over the depth interval of 15 to 45 cm. Driving the standard split-barrel sampler of dimensions. a distance of 460 mm into the soil at the bottom of the boring and counting the number of blows to drive the sampler the last 305 mm to obtain the N number. Using a 63.5 kg driving mass (or hammer) falling "free" from a height of 760 mm.



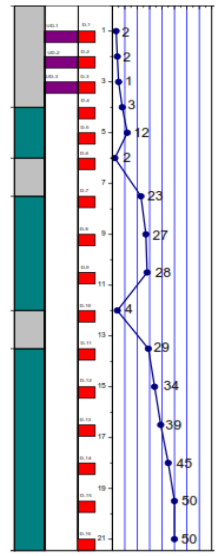
Dhaka Soil



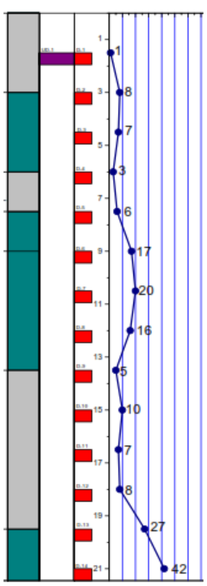
Barisal soil



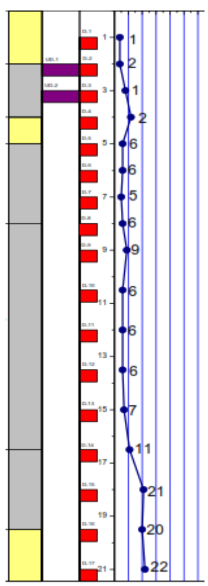
Comilla soil



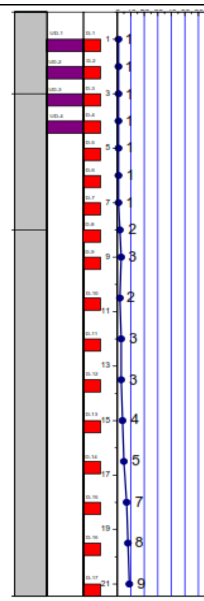
Rangpur Soil



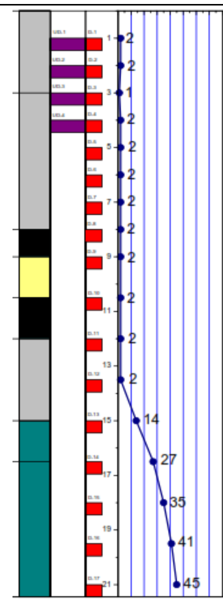
Mymenshing soil



Rajshahi Soil



Khulna soil



Sylhet soil

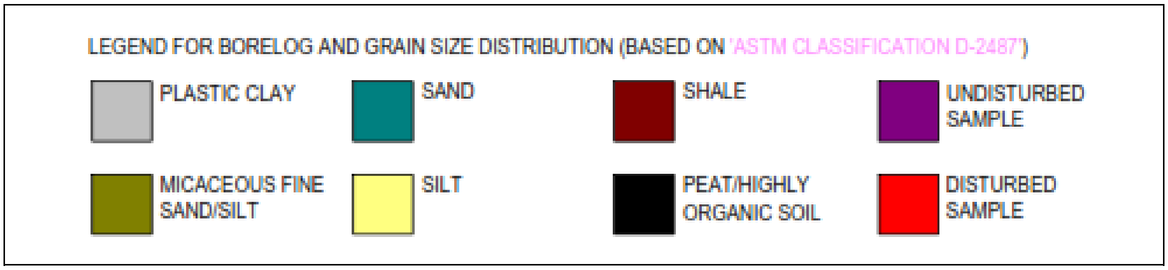


Fig. 1.Sub Soil information

Results and Discussions

Geographical information System (GIS)

GIS application in Geotechnical purpose and the spatial distribution is new dimension for data analysis for proper structural suitability study. First step for the GIS application is data processing for GIS input. Data processing belonging the modification of the location of the lithology and analysis the data. Classify the soft layer at particular interval depending on SPT (SPT value 1 to 5). Two map named SPT distribution and lithological thickness has been shown in Fig 2. After processing the data locations has been input into the GIS interface. Sub soil information has been shown in Table 1. Soft clay soil thickness layer, clay layer thickness, N value rang and soil type have been input in the table. Latitude, Longitude and location have also been shown in the table. This table has been imported to GIS interface.

Table 1: Sample Information of GIS input

LAT.	LONG.	Thickness Layer (m)	Thickness (m)	N value Range	N value (Max.)	N value (Min.)	Soil type	Location
92.00	24.83	0-18	18.00	1-5	5.00	1.00	Clay	Sylhet
92.15	24.89	0-7	7.00	1-4	4.00	1.00	Clay	Sylhet
91.89	24.91	0-4	4.00	1-5	5.00	1.00	Clay	Sylhet
91.98	24.91	2-5	3.00	1-5	5.00	1.00	Clay	Sylhet
92.10	25.16	4-6	2.00	3-5	5.00	3.00	Clay	Sylhet
91.80	24.98	0-6	6.00	3-5	5.00	3.00	Clay	Sylhet
91.93	24.95	2-7	5.00	1-5	5.00	1.00	Clay	Sylhet
91.75	24.85	0-3	3.00	1	1.00	1.00	Clay	Sylhet
91.72	24.88	0-4	4.00	1-4	4.00	1.00	Clay	Sylhet
92.15	24.88	0-4	4.00	1-4	4.00	1.00	Clay	Sylhet
91.85	24.91	2-4	2.00	4	4.00	4.00	Clay	Sylhet

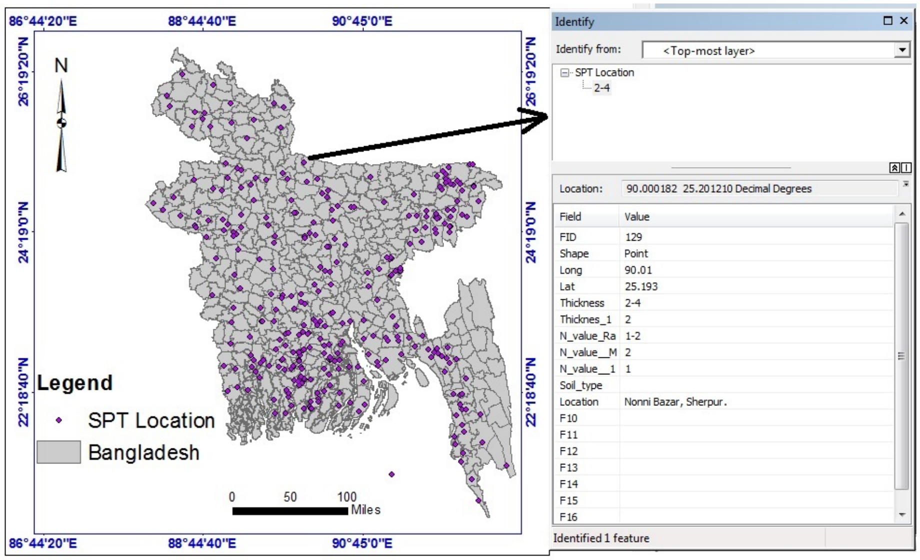


Fig. 2: SPT Location Map

In this research total 1000 boreholes have been conducted for SPT test around Bangladesh. From these boreholes 470 boreholes have been selected for soft clay soil layer formation. Three GIS maps have been created by Arc GIS 2010. One for soil parameters information map and second is zonation map for SPT N value from 1 to 5. Another is zonation map for the soft clay layer thickness. Soil parameters information map has been shown in Fig. 3. From the map different sub soil parameters have been found by clicking the specific location of Bangladesh. Total 470 bore hole (soft clay soil layer) has been presented in the GIS interface map. On the other hand zonation map for SPT N value has been shown in Fig. 3. Soft clay layer thickness has been shown in Fig. 4.

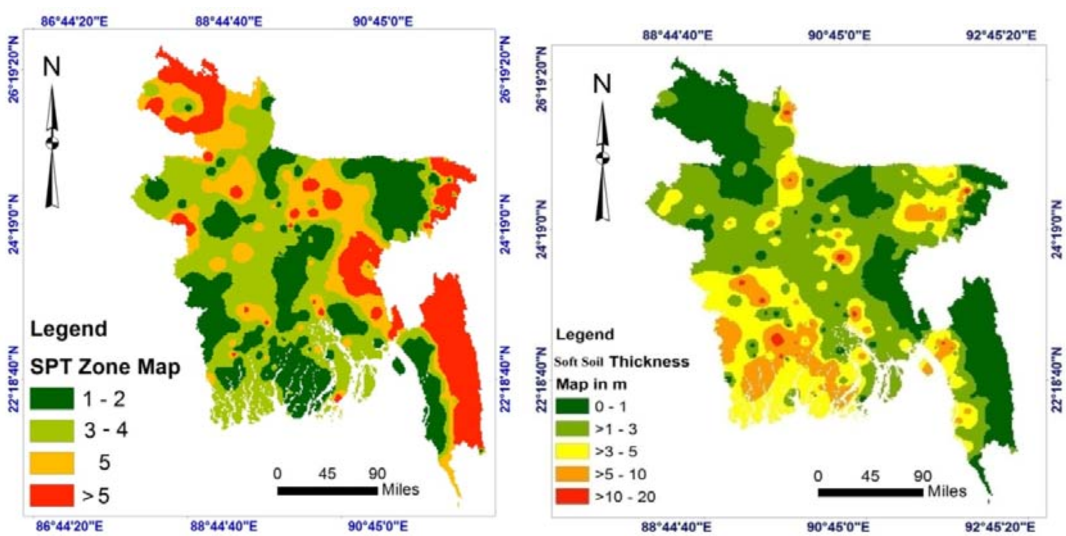


Fig. 3: Zonation map based on SPT value

CONCLUSIONS

Availability of soft clay is high in southern part of the country and in the riverside locations. The soft cay soil thickness is varying from 1 to 20 meters. This paper has proposed three GIS based map which will be useful for selecting soft ground soil improvement techniques in the different regions of the country.

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PART-IX

PREDICTING THE GROUND MOVEMENT ABOVE A TUNNEL IN CHITTAGONG COASTAL AREA OF BANGLADESH UNDER SEISMIC LOADING

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1 INTRODUCTION

Developing of underground space, tunneling is the most important issue in civil engineering. Tunnel is being constructed to densely populated areas as well as for long transportation infrastructures. Construction of tunnel induces ground movements which may affect existing structures. Ground movement is related with damage rate of tunnel. Generally, damage rate of tunnels are lower than surface structures under seismic loading. To prevent damages of tunnels, accurate assessment is necessary to predict tunneling-induced ground movements. Ground movement above a tunnel in sand has been reported by Mair and Taylor (1997), Vorster et al. (2005), Marshall et al. (2012) etc. Tunneling effects on pipelines and buildings have been investigated in sand by several authors (Klar et al., 2007, 2015; Farrell et al., 2014; Giardina et al., 2015; Franza & Marshall, 2017; Ritter et al., 2017). Relative depth of tunnel (A_n/D_n) and diameter of tunnel (D_n) are main factor to handle ground movement above a tunnel in sand with proper construction technique and relative density. The goal of this paper is to predict ground movement above a tunnel in sand in Patenga, Chittagong, Bangladesh. In this paper, circular type tunnel has been considered which moves along a straight line in sand layer. Variable parameters in these paper are relative depth of tunnel, diameter of tunnel and tunnel length with constant relative density and construction method (EPB – TBM). Numerically, ground settlements are observed with the variation of variable parameters under static as well as seismic loading. Linear analysis has been performed to predict ground movement above a tunnel. Finally, appropriate placement of tunnel in sand layer has been performed through numerical analysis.

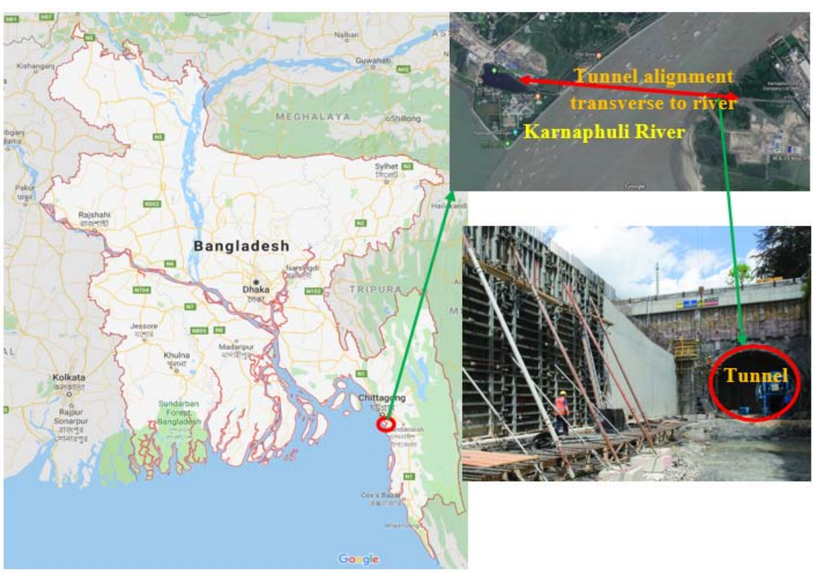


Figure 1: Under construction of tunnel at Potenga, Chittagong, Bangladesh

2 LOCAL GEOLOGY AND GEOTECHNICAL PARAMETERS

According to GSB (1990), the local geology consists of mainly beach and dune sand. This sand contains light to whitish-grey sand which is medium to fine, well sorted, and subrounded; this also contains concretions, shell fragments, heavy minerals, and rare clasts which include small mud-flat deposits. Unconformably overlies Late Tertiary formations. Several bore logs have been carried out at the project site. A typical bore log has been presented in Figure 2. The soil profile mainly consists of softy silty clay up to a depth of 3 to 5 m, which is underlain by fine sand.

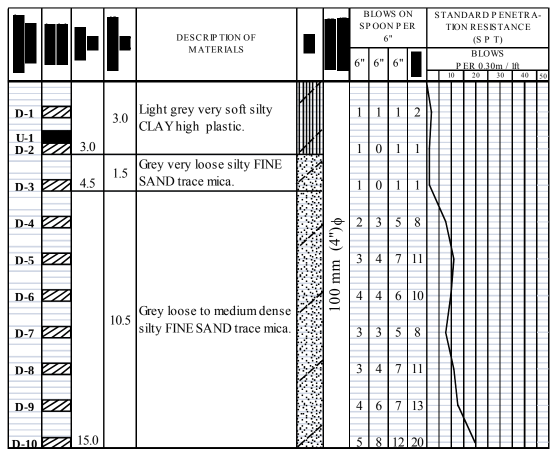


Figure 2: Typical borehole log at Potenga, Chittagong, Bangladesh

3 MODIFIED EMPIRICAL AND ANALYTICAL FORMULAS

Underground space technology such as tunneling has become very popular and demanding. In urban areas, people wants alternative mode of transportation for excellent facilities. Engineer must take note and gain high knowledge about tunneling technology. Protection needs of surface structures as well as underground facilities from ground movements due to construction of tunneling as well as seismic shaking after construction exist.

3.1 Modified Empirical Formula of Vertical Settlement

Vertical ground settlement is the major important issue during tunneling as well as seismic shaking and also long term behavior of tunnel. For practical purpose, important issue is the maximum settlement due to tunneling. The authors have modified Mair’s (1993) maximum ground settlement formula with the consideration of 0.5 percent uniform volume loss (Mair and Taylor, 1997) for sand and 35 percent of *K* factor (Mair and Taylor, 1997) as shown below.

$$V_{(z),max.} = 0.0045 \frac{D^2}{(H-z)} \tag{1}$$

Where, D, H, z, $V_{(z),max.}$ are represented by inner diameter of tunnel (m), vertical distance (m) from free surface to tunnel center line, any vertical distance (m) from free surface and maximum vertical settlement (m). For surface settlement, z is equal to zero.

3.2 Modified Empirical Formula of Lateral Settlement

Lateral ground settlement affects surface structures and underground facilities similar to vertical settlement of ground. Maximum lateral settlement of ground has great role in professional field. O'Reilly and New (1981) gives an empirical formula to predict lateral surface settlement. The authors have modified this formula with the consideration of Atkinson and Potts (1977) equation from the centrifuge tests for tunneling in dry sands which is shown below:

$$U_{(x),max.} = V_{(z),max.} \frac{A+D}{4(H-z)} \tag{2}$$

Maximum lateral ground settlement (m) and distance (m) from free surface to tunnel crown are expressed as $U_{(x),max.}$ and A in equation (2).

3.3 Modified Empirical Formula of Longitudinal Settlement

Most of tunneling analysis (Franza et al., 2018, Pescara et al., 2011, Franza and Marshall 2015) has been carried out based on plain strain consideration which has not included longitudinal settlement profile of tunnel. A few researches have been expressed in longitudinal settlement above a tunnel based on field observations. Attewell and Woodman (1982) gives an empirical relation to predict longitudinal ground settlement above a tunnel. Authors have modified this relation as shown below:

$$U_{(y),max.} = \frac{V_{(z),max.}}{(H-z)} \tag{3}$$

Where $U_{(y),max.}$ is expressed as maximum longitudinal ground settlement (m) and unit length consider along the longitudinal direction of tunnel due to plain strain consideration.

3.4 Modified Empirical Formula of Lateral Settlement Under Seismic Loading (USL)

A lot of seismic analysis has been performed for surface structures. A few data are available to express damage of tunnels after an earthquake before 1970's. Pescara, (2011) gives an empirical relation to predict lateral displacement above a tunnel under seismic shaking by using Eurocode 8. The authors have modified Pescara, (2011) formulae as shown below:

$$\Delta_{(x),max.} = f \frac{a_1 gSCk}{C_s} \left(C_d - (H-z)\right) \tag{4}$$

Where $\Delta_{(x),max.}$, a_1, g, S, C, k, C_d, f and C_s are represented as maximum lateral settlement (mm), seismic coefficient such as 0.15 (Bangladesh National Building Code (BNBC) 2006), gravitational acceleration (9.81m/s^2), soil factor (1.15) based on Eurocode 8 which equivalent to BNBC 2006, factor of ground motion (0.9) (Power et.al 1996), ratio of peak ground velocity to peak ground acceleration (142) (Power et.al 1996), total depth (27.5m) of upper layer and tunnel layer, modified factor (10) based on present author modified analytical formulae and apparent propagation velocity of S-wave: several authors [O'Rourke and Liu, 1999; Power et al., 1996; Paolucci and Pitilakis, 2007] have suggested values between 1 and 5 km/s.

3.5 Modified Analytical Formula of Vertical Settlement

Verruijt and Booker (1996) have showed a closed form general solutions for the calculation of the vertical ground settlement under uniform radial ground loss. Authors have modified these formula for long term as well as seismic loading. Long term ground deformation has been taken as 1mm based on observations by Rankin, (1988) and Loganathan et.al (1998). Maximum ground settlement for long term and seismic loading has been expressed by equations (5) and (6) which have been provided below, respectively.

$$\begin{aligned} V_{(z)max.} = & -0.005R^2\left(\frac{z_1}{r_1^2}+\frac{z_2}{r_2^2}\right)+0.001R^2\left[\frac{z_1(-z_2^2)}{r_1^4}+\frac{z_2(-z_2^2)}{r_2^4}\right] \\ & +\frac{0.01R^2}{m}\left[\frac{(m+1)z_2}{r_2^2}+\frac{mz(-z_2^2)}{r_2^4}\right] \\ & -0.002R^2H\left[\frac{-z_2^2}{r_2^4}+\frac{m}{m+1}\frac{2zz_2(-z_2^2)}{r_2^6}\right] \qquad (5) \end{aligned}$$

$$V_{(z)max.} = -0.005R^2\left(\frac{z_1}{r_1^2}+\frac{z_2}{r_2^2}\right)+\frac{0.01R^2}{m}\left[\frac{(m+1)z_2}{r_2^2}+\frac{mz(-z_2^2)}{r_2^4}\right] \qquad (6)$$

Where, $z_1 = z - H$, $z_2 = z + H$, $r_1^2 = z_1^2$, $r_2^2 = z_2^2$, $R = D/2$, $m = 1/(1 - 2\upsilon)$, $k = \upsilon(1 - \upsilon)$. υ is the Poisson's ratio of soil. Long term ground deformation due to ovalization is equal to zero under seismic loading.

3.6 Modified Analytical Formula of Lateral Settlement

Verruijt and Booker (1996) have also showed a closed form general solutions for the calculation of the lateral ground settlement under uniform radial ground loss. Authors have also modified these formula based on Hunt (2004) and Zhou (2014) considering lateral distance from tunnel axis for long term and seismic loading which is shown below:

$$U_{(x),max.} = 0.00125\mathrm{R}^2\left(\frac{(\mathrm{A}+\mathrm{D})}{\mathrm{r}_1^2}+\frac{(\mathrm{A}+\mathrm{D})}{\mathrm{r}_2^2}\right) - 0.0000625\mathrm{R}^2\left[\frac{\mathrm{z}_1((\mathrm{A}+\mathrm{D})^2-16\mathrm{k}\mathrm{z}_1^2)}{\mathrm{r}_1^4}+\frac{((\mathrm{A}+\mathrm{D})^3-(\mathrm{A}+\mathrm{D})16\mathrm{k}\mathrm{z}_2^2)}{4\mathrm{r}_2^4}\right] + \frac{0.0025(\mathrm{A}+\mathrm{D})\mathrm{R}^2}{\mathrm{m}}\left(\frac{1}{\mathrm{r}_2^2}-\frac{2\mathrm{mzz}_2}{\mathrm{r}_2^4}\right) + \frac{0.001\mathrm{R}^2(\mathrm{A}+\mathrm{D})\mathrm{H}}{(\mathrm{m}+1)}\left[\frac{\mathrm{z}_2}{\mathrm{r}_2^4}+\frac{\mathrm{mz}((\mathrm{A}+\mathrm{D})^2-48\mathrm{z}_2^2)}{16\mathrm{r}_2^6}\right] \quad (7)$$

$$U_{(x),max.} = 0.00125\mathrm{R}^2\left(\frac{(\mathrm{A}+\mathrm{D})}{\mathrm{r}_1^2}+\frac{(\mathrm{A}+\mathrm{D})}{\mathrm{r}_2^2}\right)+\frac{0.0025(\mathrm{A}+\mathrm{D})\mathrm{R}^2}{\mathrm{m}}\left(\frac{1}{\mathrm{r}_2^2}-\frac{2\mathrm{mzz}_2}{\mathrm{r}_2^4}\right) \quad (8)$$

Where, equation (7) represents as the maximum lateral settlement for long term loading and equation (8) represents as the maximum lateral settlement for seismic loading.

4 NUMERICAL ANALYSIS

Numerical analysis is necessary to evaluate behavior of underground structures under seismic loading. Material properties have been determined from two types of tri-axial tests such as consolidated drained and consolidated un-drained. Models have been created for analysis in software PLAXIS 3D based on the Potenga, Chittagong site conditions. Two types of parameters are used in this model such as fixed and variable. Fixed parameters are soil volume, material properties of soil and tunnel lining, borehole location etc. Variable parameters are tunnel length, diameter and relative depth. Mohr-Coulomb material model has been considered for soil and linear elastic model consider for tunnel lining in long and short term behavior. Non-porous drainage type has been considered for lining segment. Bulk unit weight of silty clay, fine sand and lining segments are 16.4 kN/m^3, 18.6 kN/m^3 and 24 kN/m^3 for long term behavior and for short term behavior these values are 17 kN/m^3, 19.03 kN/m^3. Saturated unit weight of short and long term behavior of sands, clays are 20 kN/m^3, 20 kN/m^3, 19 kN/m^3 and 18.90 kN/m^3. Modulus of elasticity of clay, sand and lining segments are 14.4 MPa, 26.1 MPa and 28 GPa for long term behavior and 22.5 MPa, 40.8 MPa for short term loading. Cohesion of clay has 30 kPa for both long as well as short term loading. Internal friction angle of sands and clays are 29^0, 23^0 for short term loading and 36^0, 23^0 for short term behavior. Dilatancy angle of sand is 6^0 for long term behavior only. Poisson's ratio of sands, precast segment and clays are 0.25, 0.20 and 0.31 for both cases. Face pressure, grouting pressure and jacking force of tunnel are 90 kN/m^2 with axial increment 14 kN/m^2/m, 100 kN/m^2 with axial increments of 20 kN/m^2/m and 600 kN/m^2. 0.5% uniform surface contraction has to be taken with axial increment of 0.05%.

In seismic analysis, free field boundary conditions have been taken along lateral direction because of seismic loading has to be applied in this direction. Software automatically considers other values which are necessary to analyze this model. Most of the earthquakes have a frequency range such as 8 to 12 Hz. Material damping has been considered as 5%. Length of Earth Pressure Balance Tunnel Boring Machine (EPB-TBM) considered is 12m. Maximum number of steps and maximum number of iteration are 250 and 60 in analysis for long and short term loading. Initial length of tunnel is 25m and tunnel advancement of 2m along its own axis is considered. Three stage of advancement of tunnel have been considered for analysis. Variable diameters of tunnel are 10.5m, 10.8m and 11.0m. Depths from free surface to top surface of tunnel are 4.5m, 5.5m, 6.5m, 7.5m, 8.5m. Thickness of pre-cast segment considered is 0.5m. The finite element model is shown in Figure 3.

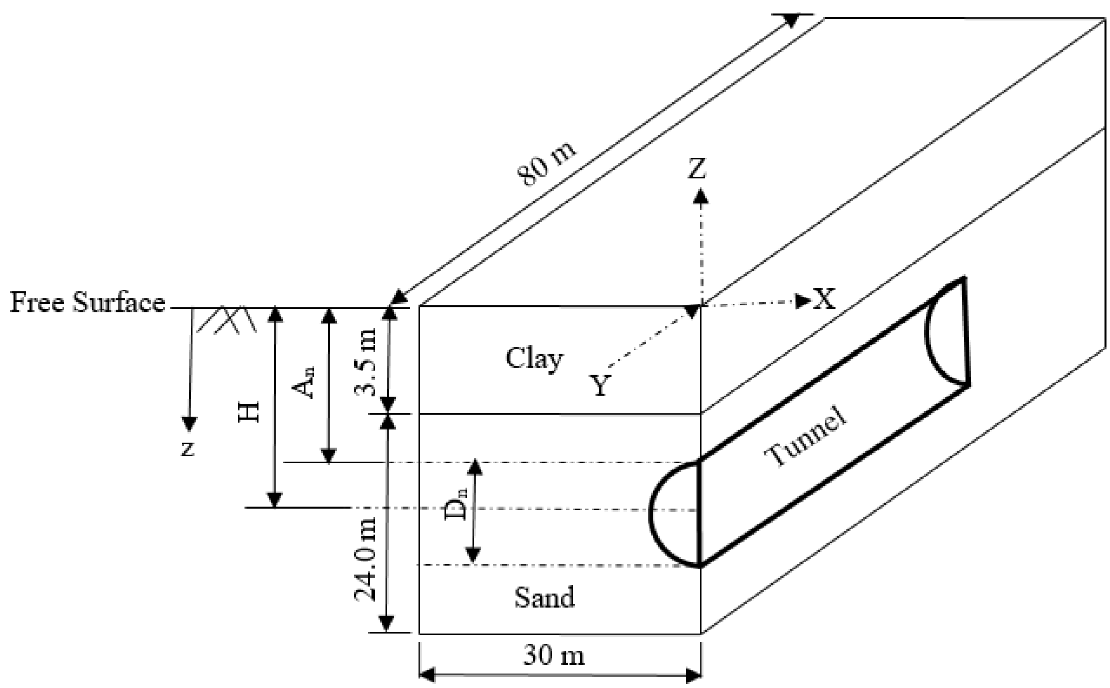


Figure 3: Finite element model based on Potenga soil conditions at Chittagong

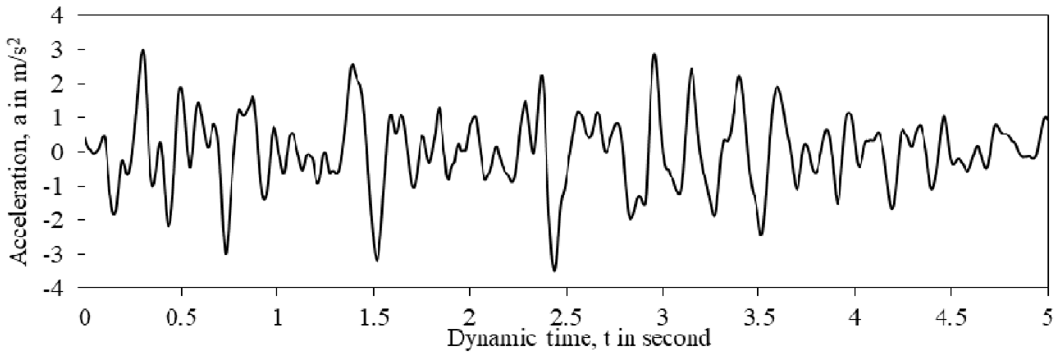


Figure 4: Seismic data at Potenga, Chittagong.

When model geometry, material properties and other relevant data are fully defined then model has to be divided into finite elements in order to perform finite element calculations. This type of composition of finite element method is called mesh. Fine mesh will be used to obtain accurate numerical results. Half portion of the tunnel has been considered because of symmetry. 10-node tetrahedrons soil element have been taken for analysis. Every phase consists of a particular loading or construction stage. Analysis phases are initial, plastic and seismic. In plastic phase of calculation, drained behavior has been taken and un-drained (A) option has been taken for seismic loading. Seismic data has been input in the software based on a real seismic event in Chittagong as shown in Figure 4. Plastic calculation is related with the elastic-plastic deformation analysis. In a normal plastic calculation, the stiffness matrix is based on the original un-deformed geometry. Loading can be defined in various sense during plastic calculation mode such as changing the load combination, stress state, weight, strength or stiffness of elements, activated by the changing the load and geometry configuration or pore pressure distribution by means of staged construction. For meshing, the number of cores is set to 256 for this model. Software performs seismic analysis after the completion of modeling and static analysis. Seismic analysis is the complex type of dynamic analysis which contains non-periodic loading history. The applied seismic load is the product of the input value of the defined seismic load and corresponding seismic load multiplier. Activation of the seismic load or seismic prescribed displacement, free field boundary conditions can be defined for a seismic analysis. Meshing of the model is presented in Figure 5. Meshing effect on model has been shown in Table 1.

Table 1: Meshing effect on model due to tunneling

Tunnel Length, y_1 (m)	Ratio, A_1/D_1	Maximum total vertical settlement, V_{zt} in mm		
		Coarse	Medium	Fine
27	0.4286	44.7	44.5	44.5

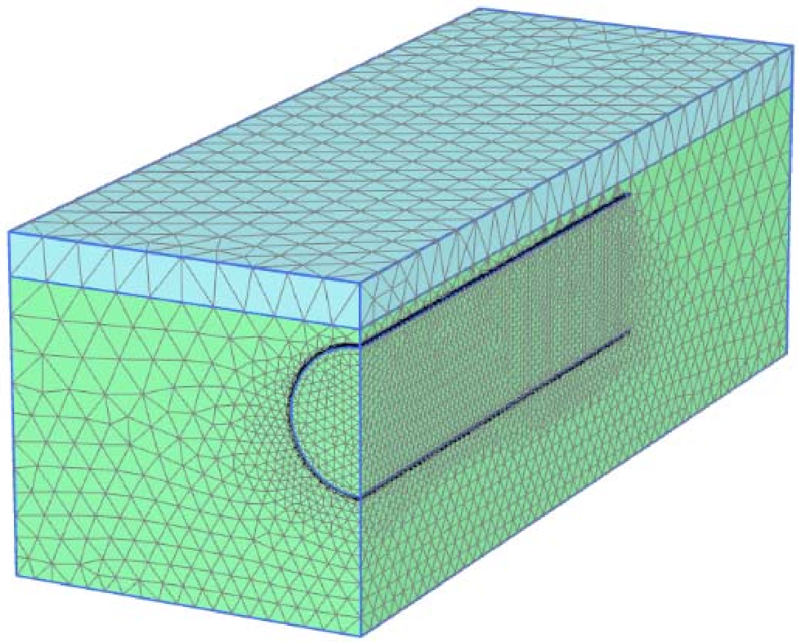


Figure 5: Un-deformed fine meshing of the research model

Seismic loadings are imposed for a short time but its impact upon the structures or soil is high. High frequency of seismic loading can easily pass through the small elements of these model. Fine meshing which yields best analysis is applied under seismic loading.

5 RESULTS AND DISCUSSIONS

Maximum surface settlement in vertical, lateral and longitudinal directions above a tunnel has been discussed here. Variation of surface acceleration in lateral direction is also presented. Seismic loading has been applied in the model for five seconds in lateral direction. Some terms used to express results are MEF-LTL (Modified Empirical Formulae Long Term Loading), MEF-SL (Modified Empirical Formulae Seismic Loading), MAF-LTL (Modified Analytical Formulae Long Term Loading), MAF-SL (Modified Analytical Formulae Seismic Loading) etc. Following parameters are varied: diameter – 10.5m (D_1), 10.8m (D_2), 11.0m (D_3), length – 27m (y_1), 29m (y_2), 31m (y_3) and relative depth – 4.5m (A_1), 5.5m (A_2), 6.5m (A_3), 7.5m (A_4), 8.5m (A_5).

5.1 Vertical Surface Settlement Above a Tunnel

Vertical surface settlement consists of stability of structures which stands on the ground surface. Vertical surface settlement depends on the variation of relative depth, tunnel length and tunnel diameter. These settlements are calculated based on previously mentioned equations and are shown in Figure 6. Three diameters represent almost similar results during seismic and long term loading based on modified formula. Results of modified analytical and empirical formulae are very close for long term loading. Settlement gradually decreases with the increase in relative depth based on author modified formulae. Minimum settlement is 30mm at A_5/D_1 location using MAF-SL formula.

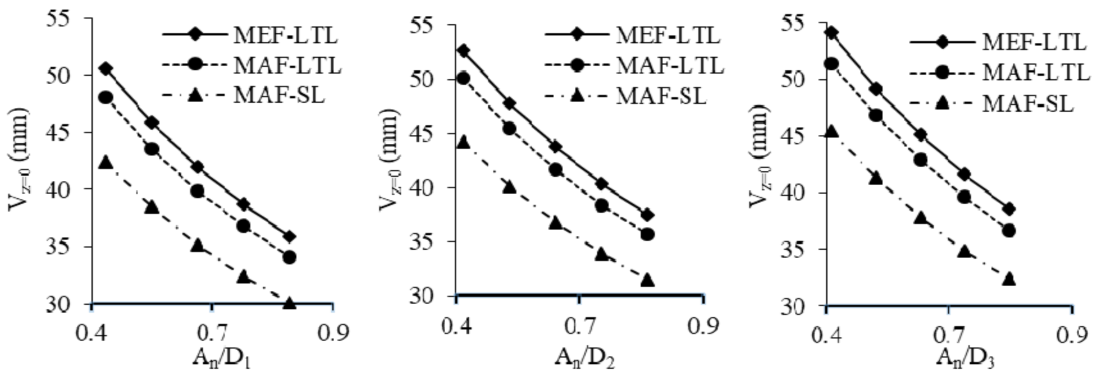


Figure 6: Vertical surface settlement for long term and seismic loading based on modified formulae.

Figure 7 and Figure 8 present the vertical surface settlement for long term and seismic loading based on numerical analysis using PLAXIS 3D. Uplift has been observed for each loading types, longitudinal length and diameter. Three construction stages of tunnel coincide at a point A_5 for long term loading which represents minimum settlement, apparently 7 mm at A_5/D_1 location. Third construction stage of tunnel fully represents uplift under seismic loading for three diameters. Minimum settlement is nearly 2 mm at A_5/D_1 location under seismic loading.

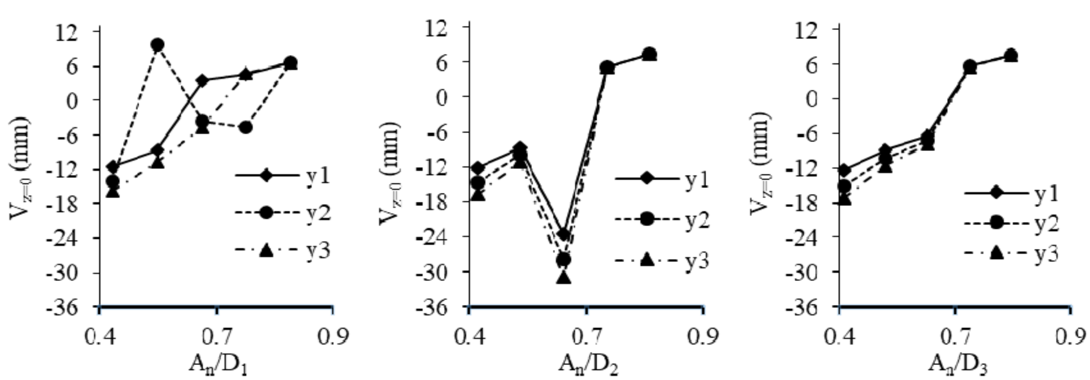


Figure 7: Vertical surface settlement for long term loading based on finite element method.

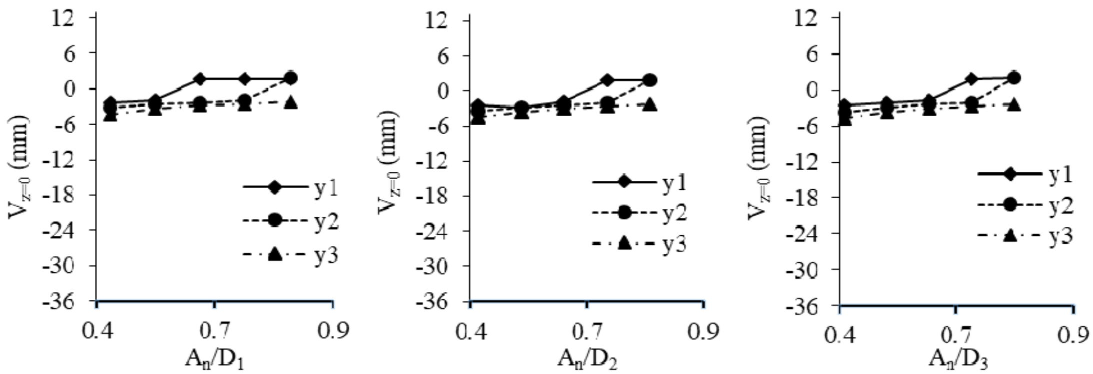


Figure 8: Vertical surface settlement for seismic loading based on finite element method.

5.2 Lateral Surface Displacement Above a Tunnel

Lateral surface settlement consists of lateral stability of super structures under long term (Figure 9) and under seismic (Figure 10) loading effect. Change of these settlements is made based on variation of depth of tunnel crown, length of tunnel and diameter of tunnel. Modified and numerical methods have been used to calculate these settlements. At A_5 location, lateral settlement is nearly 9mm of diameter D_1 for long term loading based on modified formulae in Figure 9.

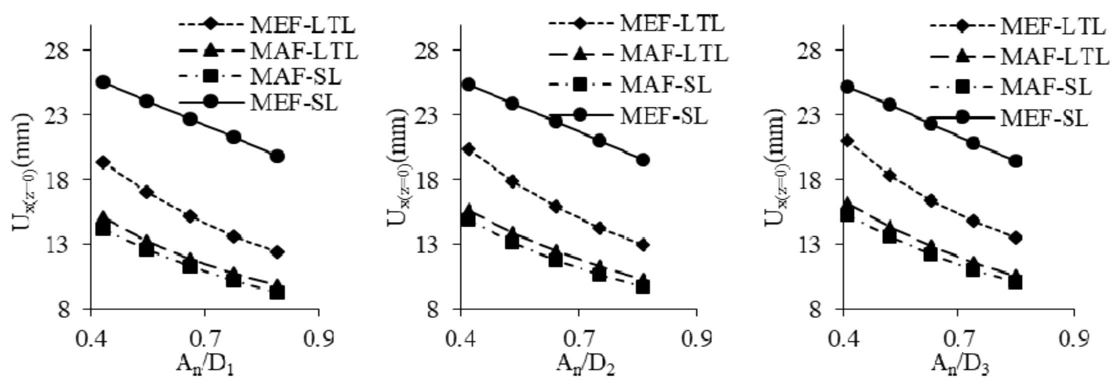


Figure 9: Lateral surface settlement for long term and seismic loading based on modified formulae.

At A_5 location, lateral settlement is nearly 3mm of diameter D_1 for long term loading based on finite element method in Figure 10. According to Figure 11, uplift is observed during seismic loading at A_5 location which indicates the minimum value.

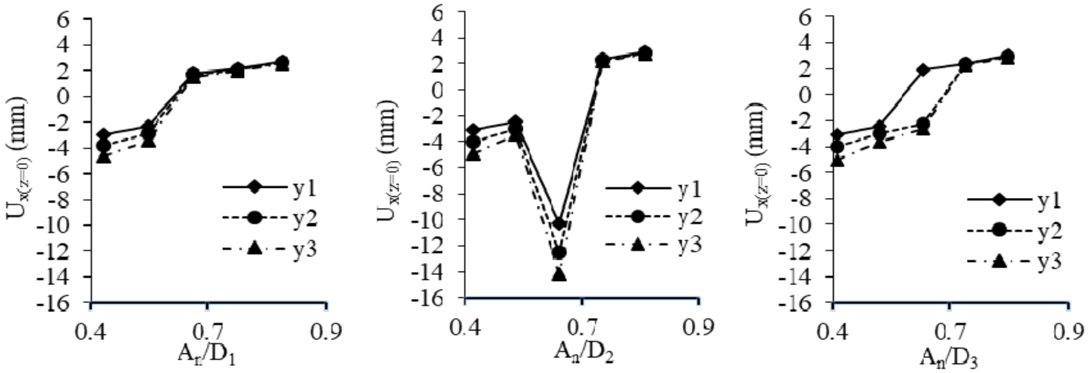


Figure 10: Lateral surface settlement for long term loading based on finite element method.

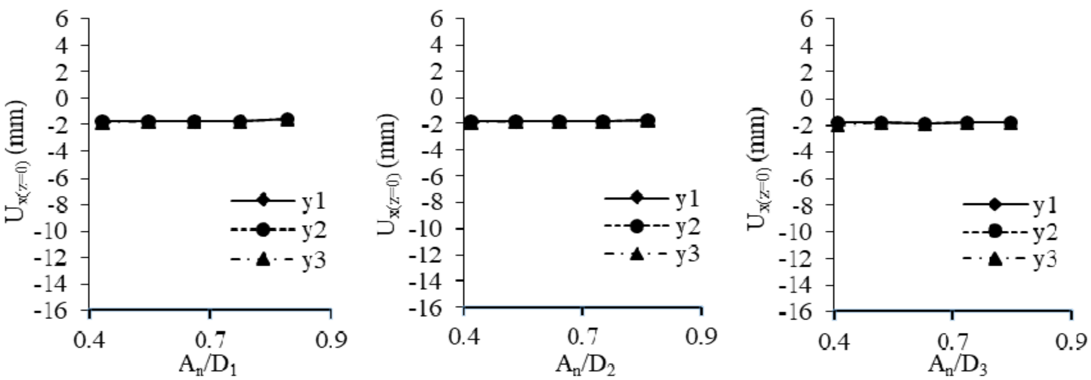


Figure 11: Lateral surface settlement for seismic loading based on finite element method.

5.3 Longitudinal Surface Displacement Above a Tunnel

Longitudinal ground movement along length of the tunnel can be seen in Figure 12. These settlement profile also express that the effect of phased construction of tunnel. Minimum value of settlement is 2.6mm due to extension at A_5/D_1 location based on author modified formulae as can be seen in Figure 12.

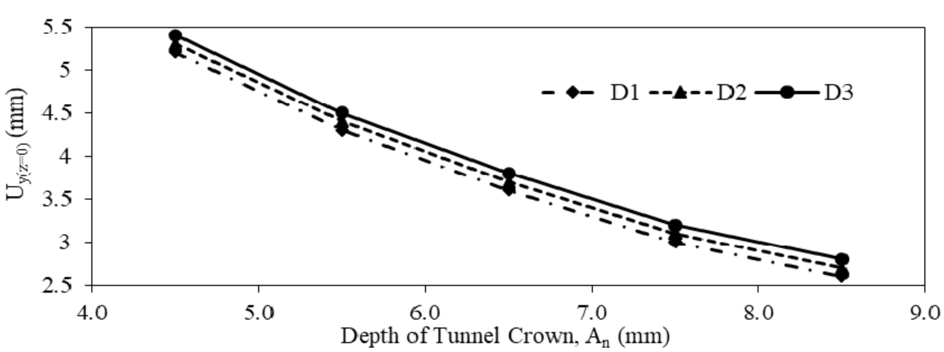


Figure 12: Longitudinal surface settlement for long term loading based on modified formulae.

Figures 13 and Figure 14 show negative value of settlement which indicates the contraction of ground due to tunneling and positive settlement express that the extension of tunnel along its length. Settlement gradually decreases with the increase of depth of tunnel crown for modified and numerical formulae. Minimum settlement is 3mm due to contraction at A_5/D_1 locations for long term loading based on numerical analysis. Longitudinal settlement is very low during seismic analysis which is nearly 0.3mm at A_5/D_1 location. Figure 15 shows longitudinal surface settlement profile based on finite element method PLAXIS 3D.

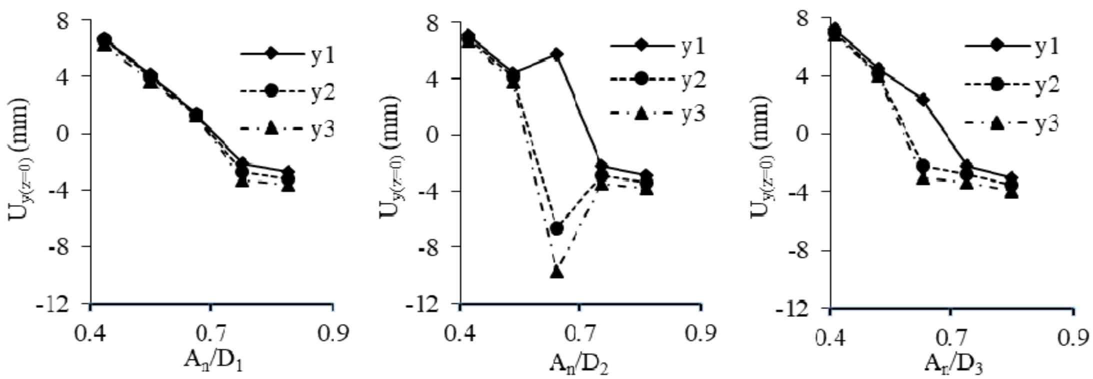


Figure 13: Longitudinal surface settlement for long term loading based on finite element method.

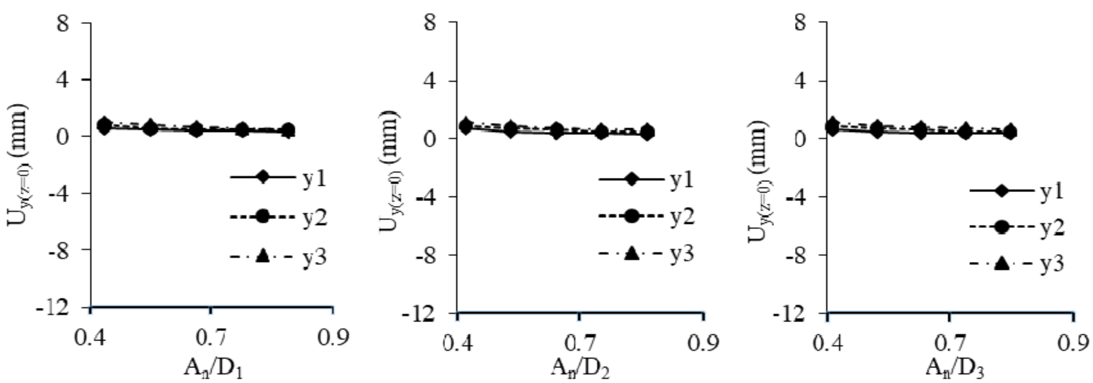
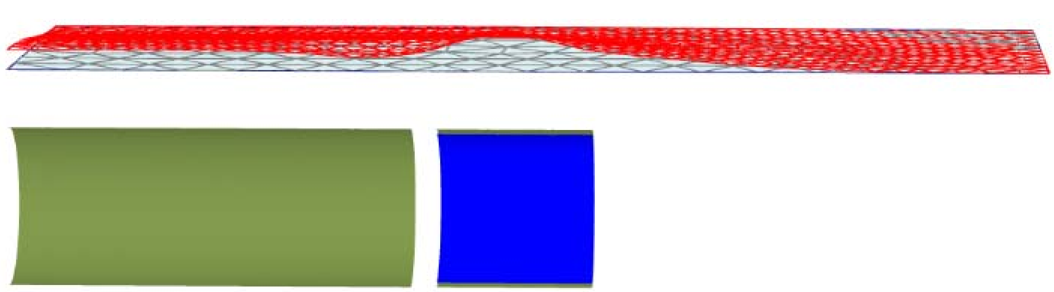
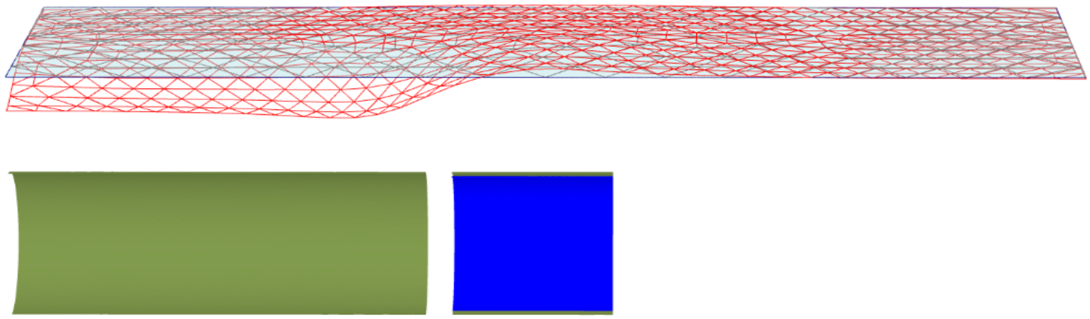


Figure 14: Longitudinal surface settlement for seismic loading based on finite element method.



(a) Upward settlement due to tunneling

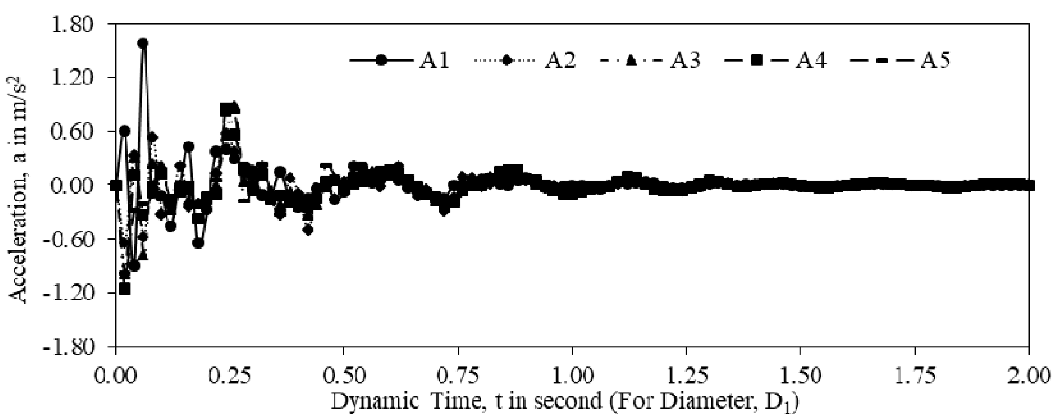


(b) Downward settlement due to tunneling

Figure 15: Longitudinal surface settlement profile based on finite element method.

5.4 Surface Accelerations Above a Tunnel Under Seismic Loading (USL)

Ground movement above a tunnel has been produced by surface acceleration. Lateral acceleration of tunnel is critical than other two directions. A lot of points are present on the surface. One point (-3, 15.5, -0.1) has been used here to express surface acceleration. Surface acceleration gradually decreases with the increase in depth of tunnel crown for diameter, D_1 as shown in Figure 16. Line A_5 shows the minimum acceleration for diameter, D_1 at 0.25s. The acceleration value is nearly 0.24 m/s^2. The value of acceleration for diameter, D_2 and D_3 is higher than diameter, D_1. Acceration values are -0.5 m/s^2 for diameter D_2 and nearly 0.8 m/s^2 for diameter D_3 at 0.25s.



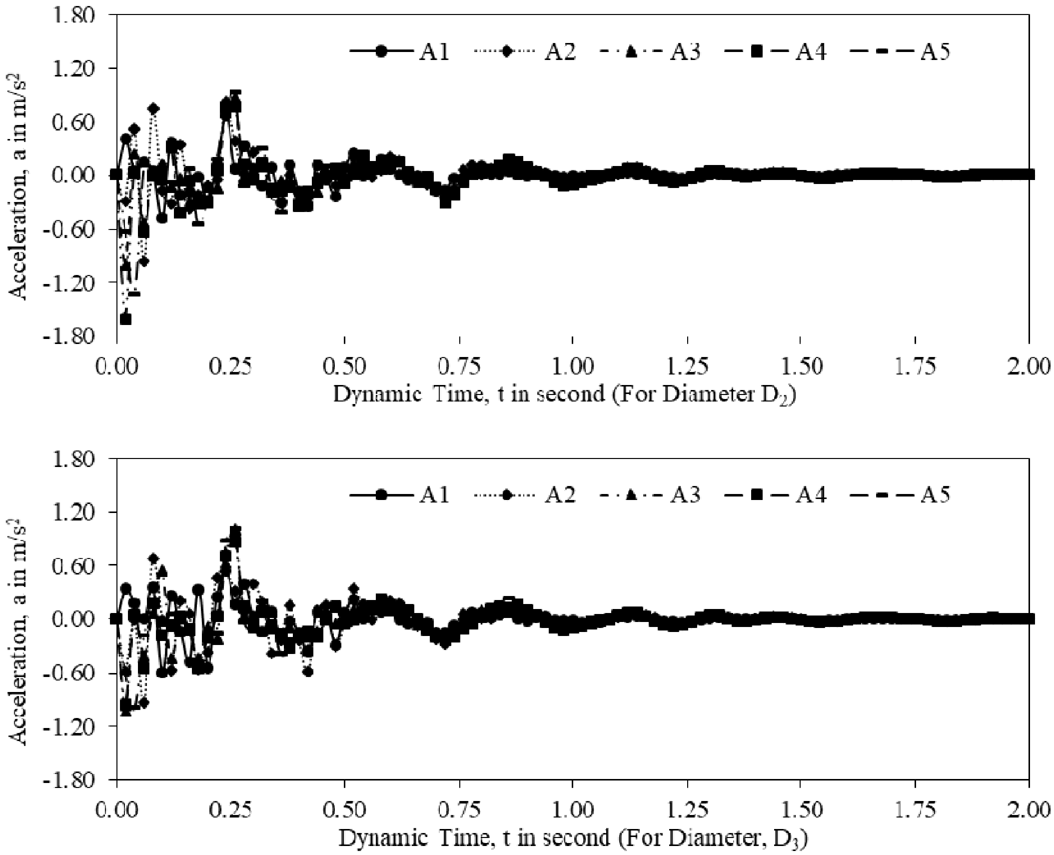


Figure 16: Lateral surface acceleration during seismic loading based on numerical analysis.

6 CONCLUSIONS

Movement of tunnel in homogeneous sand layer has been studied for ground structures in Chittagong coastal area. Upward surface settlement occur because of soft upper clay layer. Another reason of upward settlement is the shallow depth of tunnel placement. The results obtained from author modified empirical and analytical formula apparently match well. Surface settlement is more important than the total settlement for tunneling. Results of these research deals with maximum value. Minimum values of maximum vertical surface settlements are 7 mm for long term loading and 2 mm for seismic loading. Minimum values of maximum lateral surface settlements are 3 mm for long term as well as seismic loading and 9 mm for modified formulae. Similarly, minimum values of maximum longitudinal surface settlements are 3 mm due to contraction for long term loading and 0.3 mm for seismic loading. Settlement obtained from the author modified formula are greater or nearly equal to the finite element methods. Minimum value of acceleration is 0.24 m/s^2 under seismic loading. In these research, value of seismic loading is lower than the long term loading because of seismic source is located far away from the tunneling project. Two major conclusions are:

(1) Author modified formula may be used for practical purpose for all types of underground tunnel which passes through the sand layers.

(2) Suitable depth of the tunnel for this analysis is 8.5 m and suitable diameter is 10.5 m.

Future studies may be conducted such as replacement of homogeneous layer with the heterogeneous layers, considering strong seismic loading, inclination of tunnel, two or more tunnel, tunnel passes through the active seismic fault reason etc.

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PART-X

HUMAN BEHAVIOUR AND WORKPLACE SAFETY OF READY-MADE GARMENT FACTORIES IN DHAKA DURING FIRE: A CURRENT SCENARIO

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

Prepared By: Fahad Hossain

IT Hosain

Mehedi Ahmed Ansary

INTRODUCTION

The Ready-Made Garments (RMG) industry occupies a unique position in the economy of Bangladesh. It is the largest exporting industry, which experienced phenomenal growth during the last 25 years. It attained a high profile in terms of foreign exchange earnings, exports, industrialization and contribution to GDP of Bangladesh within a short span of time. The industry plays a key role in employment generation and in the provision of income to the poor. In this study an attempt has been made to describe the overall scenario of Bangladesh Ready Made Garments industry. Despite the phenomenal success of the RMG industry in remittance earning and employment potential, in the last two decades, this sector has experienced some worst industrial accidents in the history the fire.

All factories including those in the RMG sector in Bangladesh, have to obtain certification from Bangladesh Fire Service and Civil Defense Authority (BFSCDA) for their compliance with fire regulations. Purpose-built factories that constructed after 1993 have to comply with Bangladesh National Building Code of 1993 (BNBC-93) and have to obtain the certification of local authorities assigned from the Ministry of Housing and Public Works, Government of the People's Republic of Bangladesh. Factories operating in old buildings (buildings those were built before the code was formulated but was in practice), have to collect another fitness certificate from the BFSCDA, which allows them to get a second certificate from the Ministry of Housing and Public Works. According to BFSCDA regulations, garment factories have to take an operational certificate at the very beginning of operation from them and this certificate have to be renewed in every month by the respective zone officials. BFSCDA officials check a total of 61 parameters of which 41 parameters are structural or 'hard' in nature. It was defined as 'hard' factors as those whose conditions cannot be changed very quickly. Since the buildings are expected to have been built following the building code, our initial expectation is that the 'hard' parameters would be in a better condition as compared to the 'soft' parameters, the performance in which can change from day-to-day due to management practices.

Two international groups of stakeholders - Alliance for Bangladesh Worker Safety (Alliance) and Accord on Fire and Building Safety in Bangladesh (Accord) - are currently conducting regulatory checks and suggesting remedies for every RMG factory of Bangladesh. Although the focus is wider safety environment, fire safety forms a part of their monitoring process as well.

METHODOLOGY

The survey work was done in two phases. One analysis the human behavior during fire and the other phase analyse the workplace safety for fire hazard. In the first phase team randomly selects four garments factory in Bangladesh for survey work. After that the team randomly selects some workers from the garments and asked them some pre determined questions. Then SPSS (Statistical Package for the Social Sciences) tool is used to analyse the survey data collected from the garments factory. In the second phase the team collected some information from the garments factory relevant to fire safety. The information was about factory structure, emergency exit system arrangements for firefighting and workers training facilities.

Data was collected by questionnaire survey from four factories in Dhaka named Pearl Garments Company Ltd., MBM Garments Ltd., Cutting Edge Garments Factory Ltd. and Cosmopolitan Industries Pvt. Ltd- CIPL-Epic group. Data was collected using real interaction with people in the site from officers to workers without informing them earlier so that company cannot give any training to the worker to manipulate their opinion.

Company name	Collected data (person)
CIPL	701
MBM	364
CUTTING EDGE	414
PGCL	291

ANALYSIS AND RESULT

Evacuation Behavior: Workers were asked about their evacuation plan and they were provided with the options like shelter in place, evacuate. If they fail to make choice, then it was considered the as "undecided". Any other answer was considered in other category.

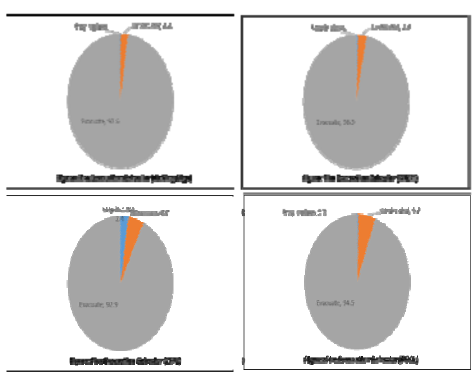

Figure1: Fire evacuation behavior in different factories workers.

These pie charts show us that in the event of fire in the garments factories the workers behavior regarding evacuating that place. In all the factories, more than 95% which is the majority of worker will evacuate that place as early as possible. Other 5% workers have mix opinion about staying in the place, wait for rescue and some have no idea about what they will do in the case of fire hazard in their factory. These indecisions are mostly from newly joined people who did not get any fire training yet and a few are because of age.

Fire Evacuation Timing Based on Gender: Following tables show the cross tabulation between gender and time to stop the work and leave if there is any effect or not.

Table 1: Fire Evacuation Timing on Gender (Cutting Edge)

In case of emergency, how much time would it take to stop your work and leave		what is your gender		Total
		Male	Female	
Less than 5 minuets	Count	196	217	413
	% of Total	47.3%	52.4%	99.8%
More than 5 minutes	Count	1	0	1
	% of Total	0.2%	0.0%	0.2%
Total	Count	197	217	414
	% of Total	47.6%	52.4%	100.0%

Table 2: Fire Evacuation Timing on Gender (MBM)

In case of emergency, how much time would it take to stop your work and leave		what is your gender		Total
		Male	Female	
Less than 5 minutes	Count	191	170	361
	% of Total	52.5%	46.7%	99.2%
More	Count	0	3	3

than 5 minutes	% of Total	0.0%	0.8%	0.8%
Total	Count	191	173	364
	% of Total	52.5%	47.5%	100.0%

Table 3: Fire Evacuation Timing on Gender (CIPL)

In case of emergency, how much time would it take to stop your work and leave		what is your gender		Total
		Male	Female	
Less than 5 minutes	Count	305	384	689
	% of Total	43.5%	54.8%	98.3%
More than 5 minutes	Count	5	7	12
	% of Total	0.7%	1.0%	1.7%
Total	Count	310	391	701
	% of Total	44.2%	55.8%	100.0%

Table 4: Fire Evacuation Timing on Gender (PGCL)

In case of emergency, how much time would it take to stop your work and leave		what is your gender		Total
		Male	Female	
Less than 5 minutes	Count	85	197	282
	% of Total	29.2%	67.7%	96.9%
More than 5 minutes	Count	0	9	9
	% of Total	0.0%	3.1%	3.1%
	Count	85	206	291
	% of Total	29.2%	70.8%	100.0%

From the data chart it is seen that from 1770 workers almost all the workers believe that they can stop what they will be doing and leave the incident place within five minutes. Only 24 workers that they will take more than five minutes where 19 of them are female. This is because they are may be concern about their children staying in day care centre situated inside the factory. But this quantity is very low as most of the female workers are unmarried.

Fire Evacuation Timing Based on Age: Following bar chart summarized the cross tabulation between escape time and age. It was asked that if the people think they will be able to stop the work what they are doing, stop the machine and can leave the compound in less than 5 minutes. The age of the workers is divided into many groups for convenience.

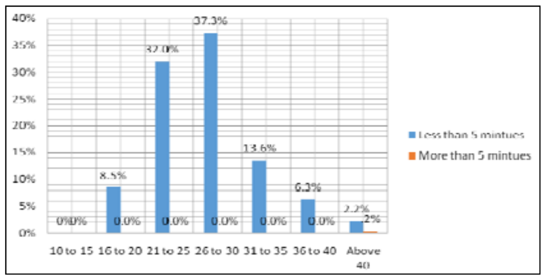

Figure: Cross Tabulation between Escape Time and Age (Cutting Edge)

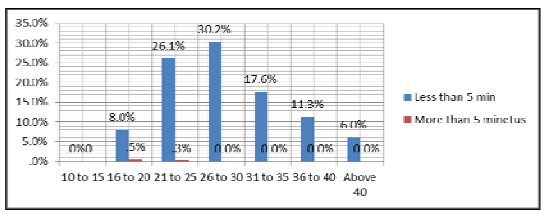

Figure: Cross Tabulation between Escape Time and Age (MBM)

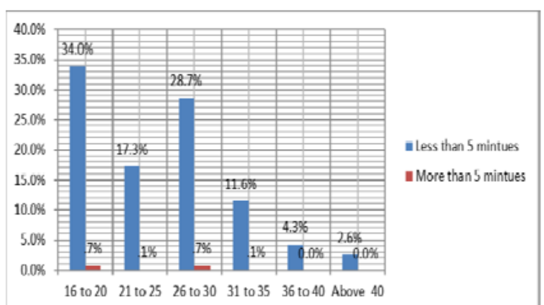

Figure: Cross Tabulation between Escape Time and Age (CIPL)

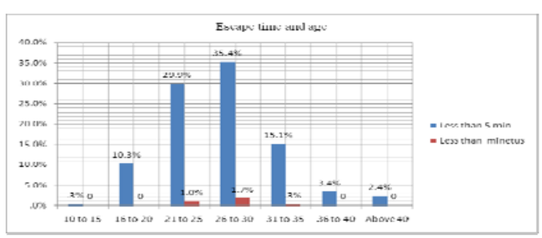

Figure: Cross Tabulation between Escape Time and Age (PGCL)

From the bar chart it is seen that most of the workers are from 21 to 30 years old except one factory named CIPL where they have around 34% workers are 19 to 20 years old. In Cutting Edge factory, among 414 workers 412 of them said that they will be able to move less than 5 minutes. Only 2 out of 414 workers said that they may take more than 5 minutes. This is due to position working place, and age as those people are around or above 40 years old. In other factories, the bar chart illustrates that no matter what the age group is majority of the people think they will be able to stop the work what they are doing, stop the machine and can leave the compound in less than 5 minutes. Only a few workers gave voice that 5 minutes is an inadequate time for leaving. This might be due to their position working place, and some of them are willing to help in stopping fire and in some case the machine on which they are working with is complicated to stop.

Capacity to Protect Against Injury: The following pie charts show the result of the question "Do you have necessary preparation to protect yourself from possible injury?" The answer was limited to yes and no.

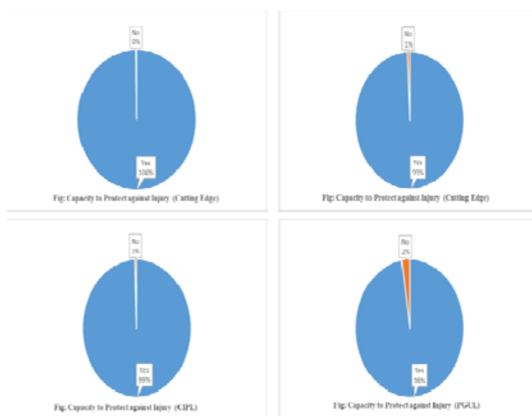

Figure: Capacity to protect against injury in different factories workers.

From the pie charts it is clear that majority of the people think they can protect themselves in the case of injury during fire. This is a great turnover in the mentality of workers as they get regular training from the company authority. In the COSMOPOLITAN INDUSTRY PRIVET LIMITED (CIPL) all the 701 workers are confident about there protection against injury. Only a few workers from other garments do not have the necessary knowledge about how to protect themselves in the event where injury can occur. This is because they are new and yet to receive training from the company.

Regular Fire Drill: Total 1770 people were questioned from four garments factory that if they have regular fire drill in their factory. It is a very positive result that all the workers conduct regular fire drill. Authority also learnt from previous fatal accidents and they are more aware about there workers safety.

Evacuation Plan: The next pie charts below illustrate the opinion of the workers about how they prefer to evacuate in case of fire incident. They have options like evacuate themselves alone or along with their colleagues.

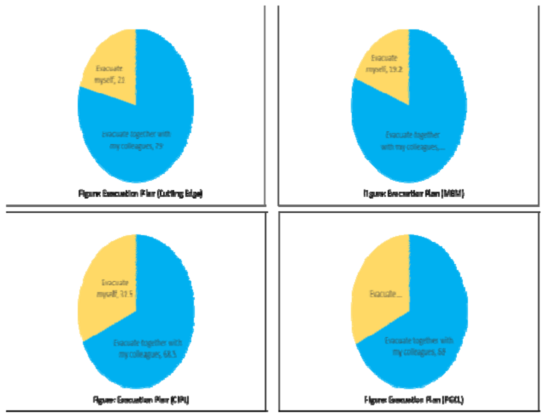

Figure: Evacuation plan in different factories workers.

From the pie charts it is seen that in all of the four garments around 70% of the workers want to evacuate with their colleagues where rest people think they will evacuate themselves alone as early as possible. This is because they are going through regular training and fire drill from company. But still most of the elder people aged above 35 who have family do not want to take risk in case of fire as they have seen some fatal incidents earlier. In total, it is a positive motivation among most of the workers.

Education and Evacuation Plan: The following charts represent changes in evacuation plan with the level of education. Most of the workers have studied from Primary School Certificate to maximum Higher Secondary Certificate. Only manger and top-level employees are graduate. Security guards and other staffs who are not directly related to production who have no educational qualification and they are introduced by None.

These charts show the relation between escape plan and highest level of education. It shows that no matter what the level of education is majority of the people will always try to evacuate with their colleagues.

Help Stopping Fire: The following bar chart shows the outcome of the question “In case of fire, will you help stopping the fire or evacuate?”. Option was ‘I will help stopping fire’ and ‘I will evacuate’.

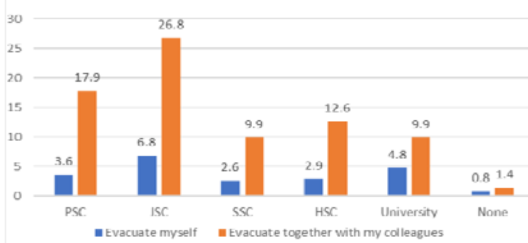

Figure: Education and Evacuation Plan (Cutting Edge)

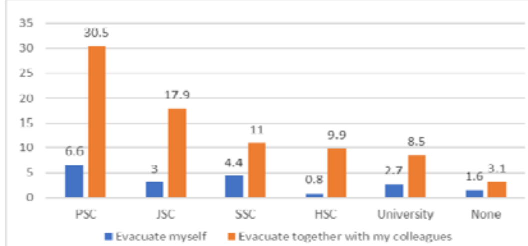

Figure: Education and Evacuation Plan (MBM)

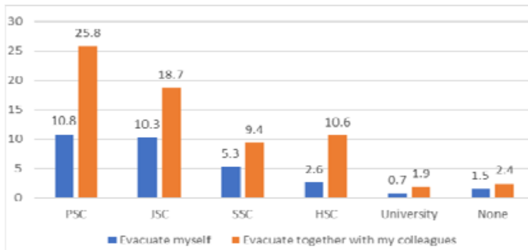

Figure: Education and Evacuation Plan (CIPL)

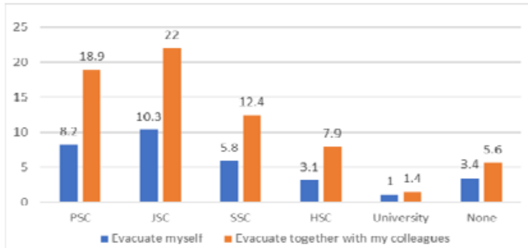

Figure: Education and Evacuation Plan (PGCL)

Figure: Education and Evacuation plan in different factories workers.

The bar charts show that more than half workers from all the garments are willing to help stopping fire during a fire emergency. Among them more than 70% of CIPL workers have positive thinking about it where PGCL have 53.6%. This is because they have less worker and CIPL has 2.5 times more worker than PGCL and most of them are young and energetic. This is a positive scenario in RMG factories. It is happening because authority and workers both are conscious about their safety and rules during an incident. And the dramatic changes in mentality and behavior of workers are the results of regular training and fire drill in working place.

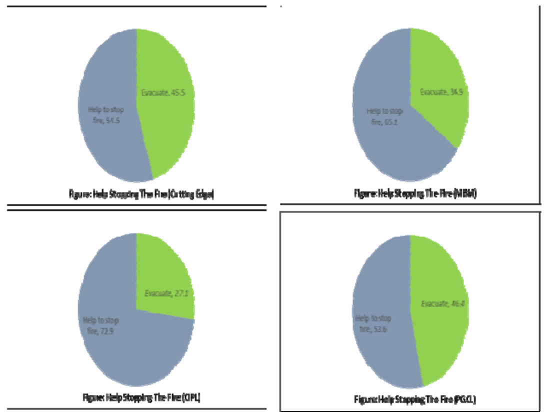

Figure: Willingness to stop fire in case of fire incident in different garments workers.

CONCLUSION

This paper explored the current behavior of workers in different RMG factories from manager to operator during a fire incidence. The response during fire incident is positive especially their willingness to evacuate with colleagues and help stopping fire. These are because of regular training and fire drill arranged from the authority. This positive behavior will not only save lives but also it will save a lot of goods and reduce a lot of property damage. This is a significant movement in RMG sector of Bangladesh for workers as well as authority after some big fatal incident and bad reputation regarding workplace safety. This observation gives an insight to the turnover in workers behavior during fire incident and allow the investors a second thought before leaving this sector.

By conducting this type of behavior analysis will help to avoid accident related injury or death it will also provide perception about strength and weakness of that company to face fire hazard.

Acknowledgments

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PART-XI

ASSESSMENT OF SEISMIC VULNERABILITY INDEX OF RAJUK AREA IN BANGLADESH USING MICROTREMOR MEASUREMENTS

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

Prepared By: A. Khair

Mehedi Ahmed Ansary

1. INTRODUCTION

Bangladesh has not suffered any damaging large earthquakes in recent past; but, in the past few 100 years, several large catastrophic earthquakes have struck this area. So far, all the major recent earthquakes have occurred away from major cities, and have affected relatively sparsely populated areas (Ansary & Raman, 2012). Dhaka city is the most populated city in Bangladesh having population of 19 million. Besides, Bangladesh is located in a region of significant seismic activity, most of the population and policy makers do not perceive seismic risk to be important (Ansary & Rashid, 2016). It is a cause for great concern that it may cause high damage to the infrastructures when the next great earthquake may occur in this region.

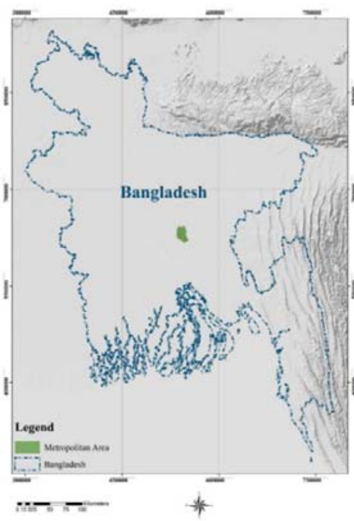
In many past and recent earthquakes, it has been observed that the local soil conditions and topographic effects have a great influence in the damage distribution. Severe damage even at large epicentral distances may occur due to the local site effects and double resonance (double resonance is the resonance of body wave frequency with F_0 of soil and then again resonance with the natural frequency of structure) (Shiuly et. al., 2014). Microtremor observations are easy to perform, inexpensive and can be applied to places with low seismicity. The H/V spectral ratio technique of microtremors has gained popularity in the early nineties, after the publication of several papers (Nakamura 1989; Field and Jacob 1993; Lermo and Chavez-Garcia 1994) claiming the ability of this technique to estimate the site response of soft sedimentary deposits satisfactorily.

2. STUDY AREA AND SITE SELECTION

Dhaka is the capital, cultural, political, and financial center of Bangladesh. It is one of the largest and most densely populated cities in South Asia. Microtremor studies have been conducted inside the Dhaka city by several researches, Ansary and Saidur Rahman (2012) and Ministry of Food and Disaster Management (MoFDM) in 2009. In the current study, the location of stations will be considered for the whole Dhaka city and RAJUK (Capital Development Authority) area. The application of microtremor analysis in this study is to determine the seismic vulnerability index (K_g), by using the H/V ratio Method. The primary distribution of the 500 stations is shown in Figure 2.

3. DESCRIPTION OF SITE EFFECT

The influence of local geologic and soil conditions on the intensity of ground shaking and earthquake damage has been known for many years. Wood (1908) and Reid (1910) showed that the intensity of ground shaking in the 1906 San Francisco earthquake was related to local soil and geologic conditions. Gutenberg (1927) developed site-dependent amplification factors from recordings of microseisms at sites with different subsurface conditions.



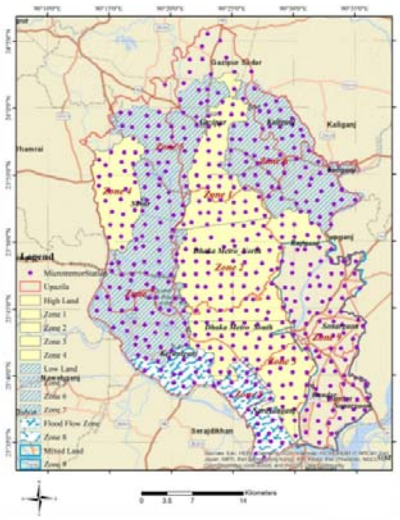


Figure 1: Bangladesh country and metropolitan area within RAJUK area

Figure 2: Distribution of the microtremor record stations in RAJUK area

3.1 Effects of local site conditions on ground motion

Local site conditions can profoundly influence all of the important characteristics of strong ground motion including amplitude, frequency content, and duration. The nature of local site effects can be illustrated in several ways: i) simple, theoretical ground response analyses, ii) measurements of actual surface and subsurface motions at the same site, iii) measurements of ground surface motions from sites with different subsurface conditions. Local site effects can be very significant, particularly when long period structures such as bridges and tall buildings are founded on deposits. In general, the effects of topography and basin are the main factors of site effects phenomenon.

3.1.1 Topography effect

The topographic effects caused by simple irregularities can be estimated from exact solutions to idealized problems (Aki, 1988). For a triangular infinite wedge subjected to vertically propagating SH-waves (with particle motion parallel to its axis), apex displacements are amplified by a factor $2\pi\varphi$ where φ is the vertex angle of the wedge (Figure 3 left). This approach can be used to approximate topographic effects for certain cases of ridge-valley terrain (Figure 3 right).

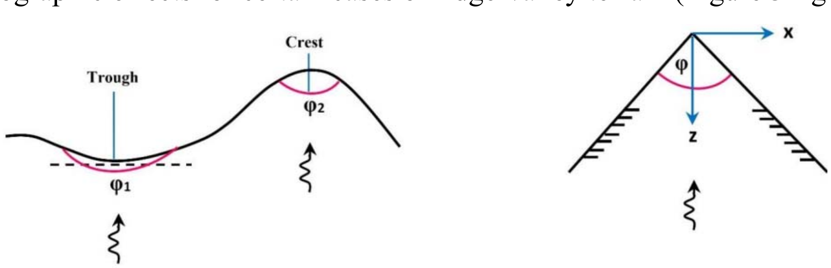


Figure 3: Characterization of simple topographic irregularities: (left) notation for a triangular wedge; (right) approximation of actual ground surface (solid line) at trough and crest by wedges. (After Faccioli, 1991.)

Different geometries and different wave fields have been considered also (e.g., Geli et al., 1988; Sanchez-Sesma, 1990; Faccioli, 1991). A schematic view of topography effect on amplification of horizontal acceleration for a linear elastic slope is presented in Figure 4.

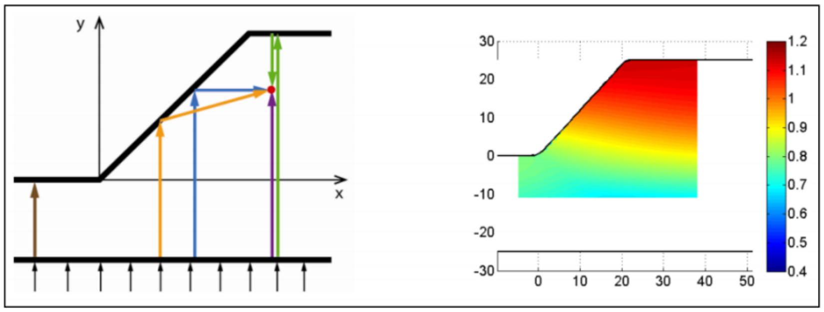


Figure 4: Topography effect on amplification of horizontal acceleration for a linear elastic slope

3.1.2 Basin effect

Since many large cities are located on or near alluvial valleys, the effects of basin geometry on ground motion is of great interest in geotechnical earthquake engineering. The curvature of a basin in which softer alluvial soils have been deposited can trap body waves and cause some incident body waves to propagate through the alluvium as surface waves (Vidale and Helmberger, 1988). These waves can produce stronger shaking and longer durations than would be predicted by one dimensional analysis that consider only vertically propagating S-waves.

3.2 Methodology to evaluate site effect

The most preferred methodology in estimating PGA on bedrock is to use attenuation relations. Though, all the building structures are not situated on the bedrock, they are mostly located on soil surface. Consequently, applying attenuation relations will be accompanied by high uncertainties, while local site effect needs to be assessed. The common approaches for evaluation of local site effects are categorized as follows:

- Level 1: evaluating the local site effects using existing information that is readily available from published reports and other sources.
- Level 2: methods require additional investigations including geotechnical investigations, geophysical testing and soil sampling from boreholes for laboratory tests.
- Level 3: methods of zonation require the conducting of ground response analyses (including the one-dimensional equivalent-linear and nonlinear analyses, and 2D and 3D analyses).

3.2.1 Microtremor survey method

The surface of the earth is always in motion at seismic frequencies, even without earthquakes. These constant vibrations of the earth’s surface are called microseisms or microtremors. The amplitude of these microtremors is, with some extreme exceptions, generally very small. Although they are very weak, they represent a source of noise to researchers of earthquake seismology; if amplifier gain is increased to record earthquake signals from a distance source, the amplitude of microtremors proportionally increases, and the desired earthquake signal is buried in the "noise" of microtremors. Elimination of this background noise is technically extremely difficult or impossible to achieve.

3.2.2 H/V determination based on Nakamura technique

The method use for data analysis is the Horizontal to Vertical Spectral Ratio (HVSR) approach developed by Nakamura (1989). The HVSR approach is applied to ambient noise and generates a Fourier spectral ratio of amplitude versus frequency. The HVSR method divides the horizontal component of noise to the vertical component to remove source effects as shown in Figure 5. The spectral ratio is calculated by taking the Fourier transform (Welch, 1967) of the ambient noise recordings.

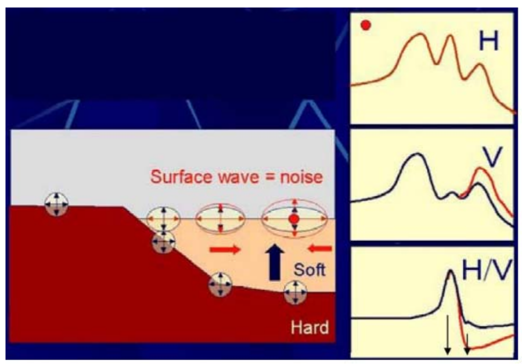


Figure 5: Schematic of H/V method (Nakamura, 2008)

H/V technique has been frequently adopted in seismic microzonation investigation due to its low-cost both for the survey and analysis. The method is especially recommended in areas of low and moderate seismicity, due to the lack of significant earthquake recordings, as compared to high seismicity areas. This technique consists in estimating the ratio between the Fourier amplitude spectra of the horizontal (H) to vertical (V) components of the ambient noise vibrations recorded at one single station. There have been some criteria given by SESAME European research project (2004), in order to obtain a reliable H/V curve and clear H/V peak, which are not mentioned here.

4. MICROTREMOR DATA COLLECTION AND ANALYSIS

The microtremor survey has been carried out in 500 locations in RAJUK area. At first, a regular square network with approximately 1.7 kilometers sides was considered which; one station was implemented in each square. The regularity of the stations then was disoriented based on the nearest sensitive center inside the square (i.e. health facilities, police stations, fire stations and, educational centers) and accessibility through the roads. Then, the stations were omitted from military area and flood plains. A few coordinates of the planned stations are presented in Table 1.

Table 1: Coordinate of a few microtremor stations

No.	Station No.	Longitude	Latitude	No.	Station No.	Longitude	Latitude
1	P307	90.350592	23.854833	4	P373	90.433492	23.89947
2	P308	90.361233	23.857776	5	P390	90.368273	23.916326
3	P309	90.3823	23.854792	6	P391	90.385777	23.914658

4.1 Data Acquisition

Microtremor data were collected on a three component Sensors of GS11D Geospace Technology with an internal 12V rechargeable lead battery with the capability of 5 hours continues recording. More over the data logger having the characteristics are- A/D converter: 24-bit monolithic sigma-delta converter, 1 per channel, Sensitivity: 78 v/m/s (±10%) Natural Frequency: 4.5 Hz (±15%) etc. Data were acquired using Seismowin Software. Surveys were made at 100 samples per second.

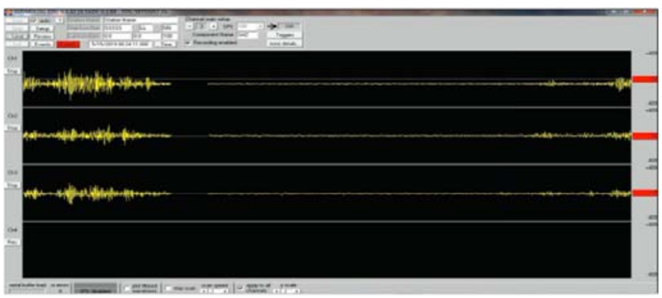


Figure 6: Illustration of a Seismowin Software during data acquisition in the field

4.2 Data Analysis and Obtaining the H/V curve

All 500 recorded data were analyzed by expert seismologists. The H/V method is applied to obtain the natural frequency and amplification factor in the stations. The obtained graph from all the record and after noise removal are shown in Figure 7 and Figure 8. The assessed parameters including natural frequency, amplification factor and natural period in station 5 are presented in Table 2.

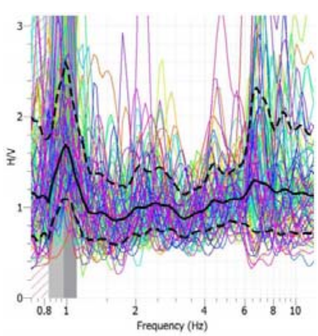


Figure 7: The H/V graph for all length of the record in station 5

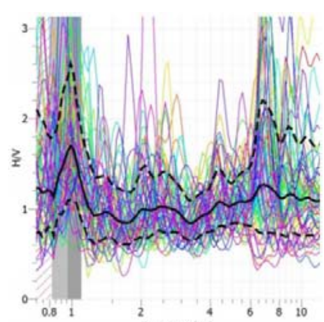


Figure 8: The H/V graph of the station 5 after noise removal

Table 2: The obtained results of H/V graph for station 23

Station No.	**Longitude**	**Latitude**	**Natural Frequency f_0 (Hz)**	**Amplifi-cation Factor(A_0)**	**Natural Period (s)**	**Vulnerability Index ($K=A_0^2/f_0$)**	**Remarks**
5	90.4372	23.6236	0.9606	1.6401	1.041	2.8003	low

5. RESULTS

Seismic vulnerability index (Kg) is an index indicating the level of vulnerability of a layer of soil to deform. Therefore, this seismic vulnerability index is helpful for locating of areas that are weak zone (unconsolidated sediment) during occurrence of earthquakes. Some studies like 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. The seismic vulnerability index has been classified into four major types. These are Low (0–5), Moderate (6–10), High (11–20), and Very High (>20). The highest Kg value has been obtained at station P326 (90.346478, 23.8654). It may be concluded that this location is relatively weaker than other locations. Most of the zones having higher Vulnerability Index (Kg) are situated in reclaimed areas. In the following Figure 9 and Figure 10 the zonation maps of the natural frequency and amplification factor are presented.

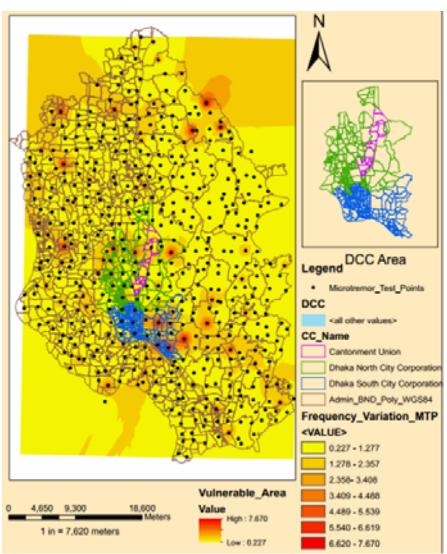


Figure 9: Natural frequency variation in RAJUK area

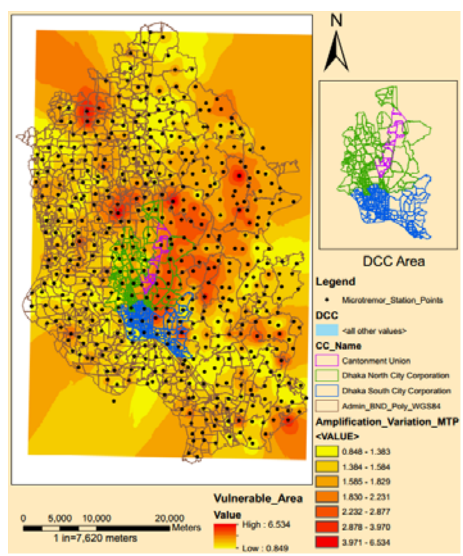


Figure 10: Amplification factor variation in RAJUK area

Figure 11 shows the vulnerable area in GIS map of 500 locations using Nakamura's Vulnerability Index (Kg). The number of low vulnerability type locations, which is 381, is the most common among 500 locations. The second most predominant number of vulnerability type is moderate type, which varies between 6 and 10. The number of very high type vulnerable site is seven.

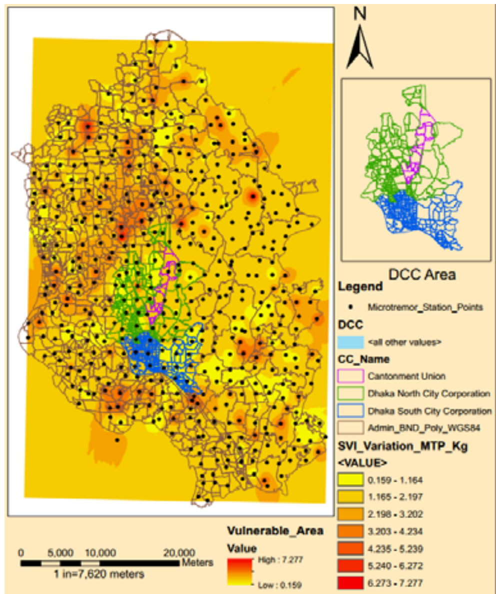


Figure 11: Seismic vulnerability index variation in RAJUK area

6. CONCLUSIONS

The microtremor investigation has been conducted within the RAJUK area. A network of 500 stations has been designed, considering the sensitive centers, roads, restricted areas, and flood plains. The outputs of the study have been presented in the form of natural frequency, amplification factor and seismic vulnerability index distribution. The predominant frequencies of the study area are relatively uniform, ranging from 0.2 to 8.0 Hz. The low frequencies are obtained to soft soil sites in maximum measurements and the high frequencies are obtained to stiff soil sites in a few measurements. The amplification factor (A_0) or peak of H/V spectral ratio is in investigation sites ranging from 0.8 to 6.6. Low values are measured for stiff soil sites and high values for soft soil sites. The seismic Vulnerability Index (Kg) varies between 0.2 and 124. The low seismic vulnerability index indicates that the areas are very stiff as well as thick sediment deposit. Seismic vulnerability index (Kg) in the study area has been found that the high values are scattered in the soft alluvial deposits area having a high seismic vulnerability indication. The results of microtremor investigation can be used as the input of many other studies, such as the site selection of geotechnical boreholes.

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BANGLADESH NETWORK
OFFICE FOR URBAN SAFETY

PART-XII

THREE DIMENSIONAL FINITE ELEMENT MODELING OF CONTIGUOUS PILE WALL AS A SOIL RETAINING STRUCTURE ON THE CONTEXT OF BANGLADESH

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Mehedi Ahmed Ansary

1. INTRODUCTION

Construction projects involving deep excavations are widespread in many urban areas around the world. The commonly used systems for the support of such deep excavations to minimize lateral and vertical ground movements are secant and contiguous pile walls, diaphragm walls, and steel sheet piles. The above soil retention systems are used in combination with horizontal struts, corner struts, and anchors, etc. (Ou, 2006). The behavior of a deep excavation support system is defined and analyzed by using a number of measures, mainly: (a) the displacement of wall elements, (b) the movement of soil masses surrounding the excavation, (c) the movement of existing adjacent structures, and (d) the forces acting on the lateral support elements (Ng et al., 2004). The above measures can be evaluated by the following methods: (1) performance of numerical analyses (Zdravkovic et al., 2005), (2) analyzing physical models of small and medium scale (Laefer et al., 2009) and (3) collecting performance data from instrumented large scale deep excavation projects (Zekkos et al., 2004).

Numerical modeling is an effective way to investigate the performance of deep excavations. A significant amount of numerical analyses have been conducted on deep excavations to approximate real deep excavations in the design process by adopting 2D analyses (Clarke et al., 1984; Hubbard et al., 1984; Finno et al., 1991; Hashash et al., 1996). Most of these analyses rely on simplifying assumptions, and therefore, the information they can provide is limited and sometimes misleading.

In reality, all geotechnical problems involving retaining structures are three dimensional, and ideally, three-dimensional analyses, fully representing the structure's geometry, loading conditions and variations in ground conditions across the site. Three-dimensional analyses have some advantages over two-dimensional analyses. For instance, a 2D analysis is not able to consider the corner effects in deep excavations, which indicate that the wall deformation and ground movement are smaller closes to the wall corner than around the wall center. Besides, 2D plane strain analysis tends to overestimate the wall deflection and ground settlement behind the wall compared to the simplified 3D symmetric square or rectangular analysis (Gouw et al., 2014; Ou et al., 1996).

In Bangladesh, reinforced retaining system, i.e., contiguous pile wall is common and relatively economical to be used in cohesive soil. There is a scarcity of research work regarding the finite element application on contiguous pile wall. Recent work has been done by Vinoth and Ghan(2018) to present a case history on the use of temporary support of excavation using contiguous bored piled wall technique for deep basement excavation in Chennai. They conducted a two-dimensional finite element analysis using PLAXIS 2D and monitored the data with a total station. They concluded by observing the Total station measurements that contiguous pile moved towards retaining side (negative deflection) at the top of the contiguous pile wall due to the development of tension zones behind the contiguous pile.

In this Study, a three-dimensional analysis of Contiguous pile wall based on site investigation report taken in Dhaka the capital city of Bangladesh has been conducted using PLAXIS 3D. The practical demonstration will be demonstrated by validating a case study of Siam Motor building in Bangkok and also validating with field monitoring data of strut force in excavation using vibrating wire strain gauge obtained from the construction of a Pier in 2nd Bridge over Gumti River.

2. MODELING USING PLAXIS 3D

In this study, several three-dimensional finite element model have been analyzed by using PLAXIS 3D. The models include a soil profile, a deep excavation with different basement levels and bracing components, nearby structures, etc.

A summary of engineering properties collecting from the soil investigation report of the site in Dhaka which have been used for both MC model and HS model are given in Table 1. According to the site investigation report, the site is underlain by alluvial deposits. The groundwater table was well below the borehole depth of 39m. The soil profile is divided into 4 sub-layers according to the difference in soil characteristics, physical and mechanical properties. The subsurface consists of a 10m layer of stiff silty clay and 5 m thick layer of medium dense fine sand. Underlying is a 15m thick very dense silty fine sand. Underneath the silty fine sand is a 9.5m thick layer of very dense fine sand.

Table 1: Engineering Properties of the site in Dhaka

Parameter	**Unit**	**Formation**		
		Stiff Silt with little fine sand	**Medium dense fine Sand**	**Very dense fine sand**
Avg SPT N		16	37	>50
Unit weight	kN/m^3	19	18	20
Dry unit weight	kN/m^3	15.8	16	17
Liquid limit	%	50	-	-
Plasticity index	%	22	-	-
Undrained Shear Strength, S_u	kPa	19	-	-

Cohesion, c`	kPa	31	0	0
Angle of friction, φ	Degree	14	31	33
Dilantancy angle, ψ	Degree	0	1	3
Poision's ratio, υ		0.3	0.3	0.3
Co-efficient of Permeability	m/s	$7x10^{-10}$	$5.27x10^{-6}$	$5.78x10^{-6}$
Young Modulus, E	kPa	26500	27000	28000
Secant Modulus, E_{50}	kPa	35000	43000	35000
Oedometer Modulus, E_{oed}	kPa	33000	22000	35000
Unloading reloading Modulus, E_{ur}	kPa	105000	129000	105000

Soils were modeled by 10-noded elements. Undrained Method A was adopted for MC model and Undrained method D was adopted for HS model. Initial groundwater was assumed to be 50 meters below the existing ground surface for the site in Dhaka. Reduced shear resistance was assumed with a standard reduction factor of 0.7 for contiguous pile wall and 0.5 for basement slab. The contiguous pile wall modeled as an embedded beam element. The interaction between the pile and the surrounding soil at the pile shaft is described employing embedded interface elements. There is no need for mesh refinement around piles as the 3D mesh is not distorted by introducing embedded elements which make embedded piles very efficient and time-saving especially when a large group of piles is modeled (Engin and Brinkgreve 2009). The internal strut, walling, king post, and raft foundation was modeled as beam element whereas bored piles were modeled as embedded beam. Piled-raft foundation system was considered as the type of foundation. For advanced HS model, similar assumptions were used so that a direct comparison of performance could be made. Additional geotechnical parameters required for the input were added to those used in the MC model.

A cross section of the excavation zone has been presented in Figure 1. The section is approximately 35 m across between contiguous pile walls and the excavation is 3m, 6m, and 9m respectively for single, double and three basement system deep. The finite element model connectivity plot after the base slab being cast for the contiguous pile is presented in Figure 2.

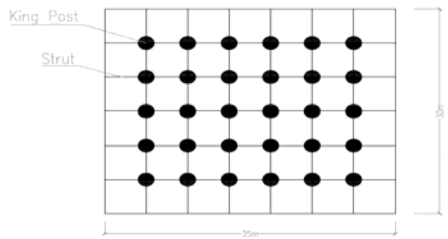

Figure 1: Plan layout of excavation zone

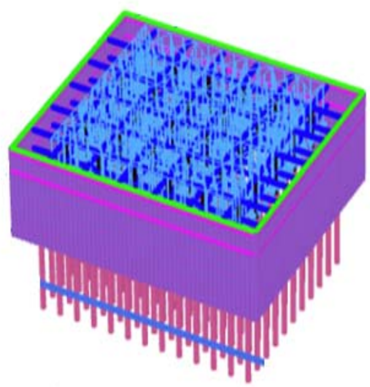

Figure 2: Connectivity plot of finite element model

A summary of structural elements properties are given in the following Table 2.

Table 2: Summary of structural elements properties

Properties	**Unit**	**Steel Strut**	**Steel Walling**	**King Post**	**Cap Beam**	**Contiguous Pile**	**Pile below raft**
Unit Weight, γ	kN/m^3	78.5	78.5	24	24	24	24
Area, A	m^2	0.00736	0.00862	0.4900	0.700		
Thickness, d	m	-		-	-		
Modulus of Elasticity, E	kN/m^2	210 $x10^6$	210 $x10^6$	30 $x10^6$	30 $x10^6$	30 $x10^6$	30 $x10^6$
Diameter	m	-	-	-	-	0.5	0.5
Element Type		Beam	Beam	Beam	Beam	Embedded Beam	Embedded Beam

3. VALIDATION OF MODEL

In this study, validation of the model has been done by taking field instrumentation data of the construction of a pier in the 2nd bridge over the Gumti River. Vibrating wire strain gauge has been used in the investigation of lateral movement of soil supported by sheet pile wall with eight horizontal struts. The struts were installed at the corners of two different levels. The forces in all the eight struts were estimated from frequency reading taken every five seconds over six months.

A model of the bridge pier has been done using PLAXIS 3D. The cross-section of the bridge pier is shown in Figure 3.

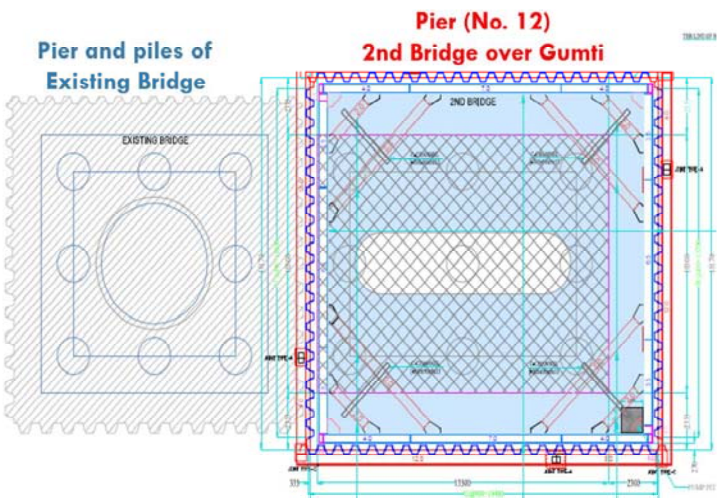

Figure 3: Cross section of bridge pier (No. 12)

The meshing of the model is done by using coarse meshing and coarseness factor as 0.25. Deformed mesh of the model is shown in Figure 4.

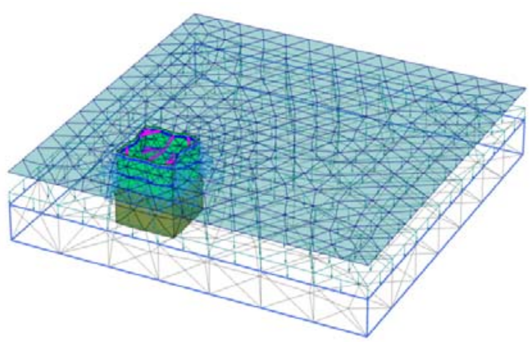

Figure 4: Deformed mesh of the model

It has been observed from the field instrumented data for strut force is that maximum force acting on the strut is approximately 202 kN whereas maximum force obtained for strut force using PLAXIS 3D is 206 kN. The difference between the results is around 2%. In this particular case, it may be concluded that the model is validated.

Another model was validated by following a case study of Siam Motor Machine Building in Bangkok which was conducted by Chhunla Chheng and Suched Likitlersuang (2017). The output result of the displacement of the model is shown in Figure 5.

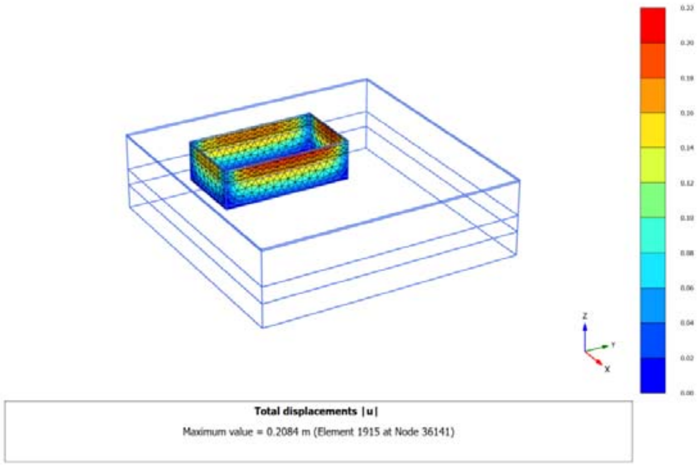

Figure 5: Displacement of the Sheet pile wall

It is observed that maximum displacement occurs in the short side of the sheet pile wall where B1 inclinometer was used to measure the reading of displacement. The data for the displacement of the short side of the sheet pile wall obtained from the study of Chhunla Chheng and Suched Likitlersuang (2017) was 216mm and the same data appeared in the inclinometer was 222mm. In this study, the value obtained for the displacement of the same side of the sheet pile was 208.4mm. The discrepancy between the performed analysis with the review of Chhunla Chheng and Suched Liktlersuang is around 3.5% whereas the difference is about 6% with the inclinometer data. As the differences are within 10%, so it is recommended that the model is validated for this case.

4. RESULT AND DISCUSSION

Performance of deep excavation is related to both stability and deformation. The ratio of wall depth to an excavation depth of 2 was applied to provide a comfortable margin of safety against wall instability and excessive base heave. With the strengthening of retaining structure in place, the aspects of interest in the performance of deep excavation at hand reduced to wall deflection. The results of numerical modeling of the excavation using the Mohr-Coulomb (MC) and Hardening Soil (HS) models for the site in Dhaka using contiguous pile wall retaining system have been obtained and compared with the different conventional method. Note that the while drawing different graphs contiguous pile is set at the origin point of the graph and extends up to pre-defined depth for different cases in the Y-axis of the graph. In this study, the Ux value obtained from the PLAXIS output results of wall displacement depicts the lateral movement for the short side of the retaining wall while the

Uy value renders the lateral displacement value of the long side of the retaining wall. Moreover, the positive value of Ux indicates that the wall may be pushed into the soil retained and negative value of Ux represent the wall may tile away from the soil retained for this particular study. Again, the positive value of Uy shows that the wall moves away from the soil retained and the negative value of Uy indicates the wall may be pushed into the soil retained. The displacement in the X, Y, Z direction, as well as the total displacement, are also depicted in the graph to have a general idea of wall deflections for a particular case.

The contiguous pile wall displacements for Dhaka site for double basement system for both the long side and short side of the contiguous pile wall obtained by applying MC and HS model is shown in Figure 6.

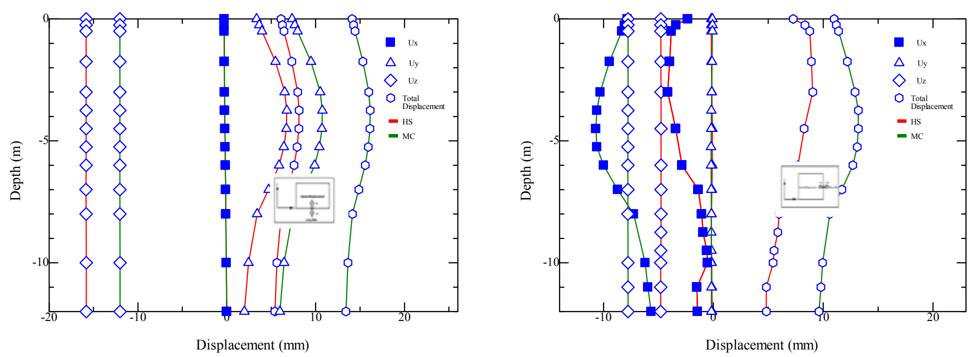

Figure 6: Contiguous pile wall displacement in the short and long side-MC & HS Model

It can be observed from the output result of MC model is that maximum lateral displacement is found out to be around 12mm in the long side of contiguous pile wall and 13mm in the short side of contiguous pile wall whereas in case of HS model the maximum lateral displacement is 5mm in the long side of contiguous pile wall which is noticed at 3m below the ground surface and 4mm in the short side of contiguous pile wall. In case of MC model, the maximum lateral displacement is on the positive side in the long side and on the negative side in the short side of contiguous pile wall which indicates that the contiguous pile wall move away from the retained soil the displacement occurs in such a way that it indicates that the wall move away from the retained soil and the scenario is same as well as for HS model. The maximum total displacement obtained from the MC model is approximately 16mm in the long side of contiguous pile and 18mm in the short side of contiguous pile wall and it is 8mm for both the side in case of HS model. In both the case, the effect of raft slab to restrain wall movements is obvious. It is also observed that movement at the bottom of the wall is almost restrained. Moreover, the bulging of deflection curves above the raft slab is also visible. In addition, the ground settlement of the contiguous pile wall is also obtained.

A comparison of the output result with the available conventional method is shown in Table 3.

Table 3: A comparison of output result with available literature for the displacement of contiguous pile wall for MC and HS model

Researcher/ Research group	**Basis of the comparison**	**Result from the literature**	**Result from HS model**	**Result from MC model**
Clough and O'Rourke (1990)	Lateral Displacement	12mm	5mm	13mm
Clough and O'Rourke (1990)	Lateral Displacement	18mm	5mm	13mm
Yandzio (1998)	Lateral Displacement	Bottom of the wall assumed not to displace	Matched	Not matched
National Engineering Handbook (2007)	Maximum total displacement	25mm-75mm	7mm	18mm
Kung (2007)	Lateral Displacement	12mm	5mm	13mm

In this study, the effect of the adjacent structure on the model has been investigated. It has been considered that in total 8 six-storied buildings are around the excavation area. The surcharge load that has been imposed by each building is assumed as 86 kN/m^2. The displacement of contiguous pile with presence of adjacent structures is shown in Figure 7

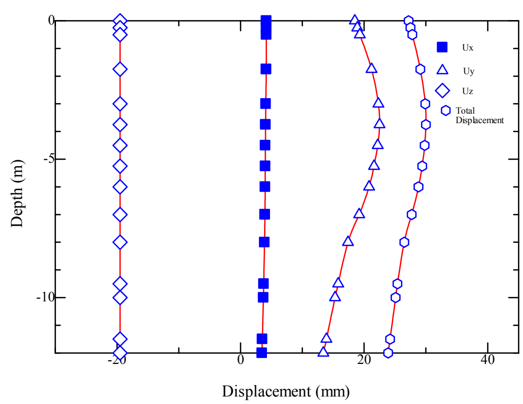

Figure 7: Contiguous pile of displacement with presence of adjacent structure

The effect of the adjacent structure on the model is visible. The maximum lateral displacement is found 12mm in the long side and 13mm in the short side of the contiguous pile wall without the presence of any adjacent structures by applying MC model whereas the value is 21mm and 9mm in the long side and short side respectively in the presence of nearby structures.

In the actual model, six struts are used in the X direction keeping 5m spacing, and five struts are used in the Y direction maintaining the same spacing like X direction. The influence of the number of struts has been investigated by reducing the number of struts in both the direction. The struts are reduced to four struts in the X direction by maintaining 7m spacing and two struts in the Y direction by keeping 10m spacing. The contiguous pile wall displacement reducing the number of struts is shown in Figure 8.

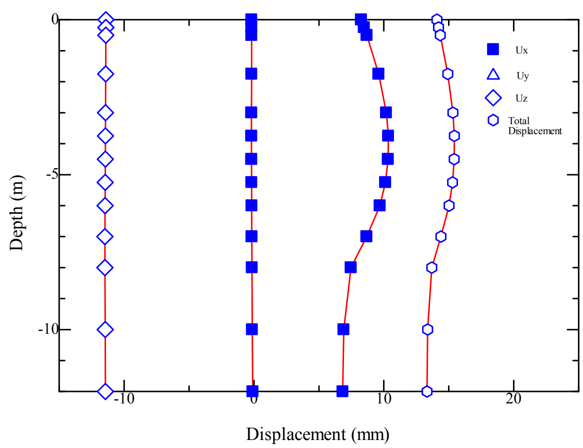

Figure 8: Contiguous pile wall displacement - reducing the number of strut in both side

The effect of the reduction of the number of struts on the model is evident. The maximum lateral displacement is found 12mm in the long side of the contiguous pile wall whereas the value is found 13mm in the long side while reducing the number of the struts

5. CONCLUSIONS

In general, it is noticed that the HS model predicts lower than the MC model both for the Sheet pile wall and contiguous pile wall. The reason behind this is due to the fact that the MC model does not consider the strain-dependent stiffness behavior or the small strain characteristics that involve high stiffness modulus at small strain levels of soil. The MC model only uses a single Young's modulus and does not also distinguish between loading and unloading stiffness. In the HS model, soil stiffness is calculated much more accurately by using three different stiffnesses (triaxial loading secant stiffness, triaxial unloading/reloading stiffness and oedometer loading tangent stiffness). The MC model represents Young's modulus of soil in the in situ stress state. On the other hand, the HS model represents its three moduli at the reference pressure, and these moduli at the in situ stress state are automatically calculated as a function of the current stress state. Moreover, the displacements of contiguous pile wall show good harmony with the available conventional methods. The effect of adjacent structures and reduction of struts on the displacement of contiguous pile wall is also evident from the model.

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PART-XIII

BUILDING CODE IMPLEMENTATION AND ENFORCEMENT STRATEGY FOR RAJUK

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

Prepared By: Mehedi Ahmed Ansary

INTRODUCTION

According to Ansary and Barua (2015), rampant safety issues were discovered at more than a thousand RMG factories in Bangladesh. The country has been under pressure to improve its safety record after the 2013 Rana Plaza building collapse, one of the worst in the industry, killing more than 1100 workers. After the incident an Accord for Fire and Building Safety in Bangladesh was signed. The Accord is an agreement between more than 180 largely European apparel makers including H&M and Adidas. Signatories pledge to increase safety standards at Bangladeshi factories. The agreement required independent inspections and public reporting of the results.

More recently, in March 2019, another major Fire broke in the 24-story F.R. Tower, killing 25 people. In a drive launched after the FR Tower fire incident, RAJUK has found 1,155 buildings that are in violation of fire safety regulations. Meanwhile, at least 431 residential high-rise buildings and 44 government establishments were built violating the building code, the capital city development authority has discovered. According to the RAJUK report, only 539 buildings in the city have sufficient fire safety facilities – i.e. fire extinguishers, fire alarm, hose pipes, and fire hydrants.

The article establishes the absolute need for code enforcement within the area governed by RAJUK by highlighting the poor state of fire safety in Dhaka as well as by comparing the major fire incidents that have taken place in Dhaka in recent years. One common thread that runs through all the man-made (as opposed to natural) disasters is that they are often directly traceable to code and safety violations that are quite often blatant.

GAP ANALYSIS

The following are some of the important findings and suggestions from the extensive stakeholder interviews:

- No Certificate of Occupancy is taken out for 99% of buildings. This makes a mockery of the entire regulatory process.
- Without Certificate of Occupancy, municipal corporations should withhold issuance of holding no.; utility connections are dependent on the holding no.
- Reliable sources have found RAJUK very reluctant to issue Certificate of Occupancy even when it is properly applied for and when there is no code violation.
- Time limit set in BNBC-2017 Part 2, Chapter 3 (15 days from time of application) needs to be enforced for RAJUK to issue Certificate of Occupancy.
- Building approval is obtained for a particular land use zone and use purpose, but then the design is changed, and the building is used for other purposes.

- Along some streets, declared commercial, permission for change in use is routinely granted. Elsewhere, applications are evaluated on a case by case basis and have to be referred to the Ministry. This policy needs to be reexamined to avoid negative public perception.
- A few accredited engineers and architects sign a disproportionate percentage of approved drawings issued by RAJUK. It has been suggested that a limit be put on the number of jobs for which an engineer or architect can sign the drawings in a year.
- Enforcing the requirement to obtain a Certificate of Occupancy appears to be key to solving this problem.
- The key to eradication of corruption and a lack of transparency – perceived or real - in the approval process of RAJUK is Electronic Construction Permitting, electronic record keeping, and so forth.

Every U.S. Building Department is basically divided into two parts: a part that does plan review by certified individuals and the other part that does inspections by qualified individuals certified in areas they inspect. Typically, structural and nonstructural plan checks are done by one group, while MEP plan checks are done by another. Similarly, structural and nonstructural inspections are doe by one group, while MEP inspections are done by another. RAJUK is already divided along the same lines.

RAJUK’s plan review, while reasonably rigorous, is confined to only architectural drawings. Structural drawings, when submitted, are not checked because RAJUK does not have the needed trained manpower. To what extent fire safety requirements are checked is not clear. In the United States, the setback requirements are based solely on fire safety considerations.

Table 1 Plan Review by RAJUK – Current Situation

	Structural Plan Review	**Nonstructural (Architectural and Fire Safety) Plan Review**	**MEP Plan Review**
Low-Rise	RAJUK depends on stamp of professional	Architectural: Done by RAJUK Fire Safety: Not Done	RAJUK depends on stamp(s) of professional(s)
High-Rise	RAJUK depends on stamp of professional	Architectural: Done by RAJUK Fire Safety: Undergoes FSCD Review	RAJUK depends on stamp(s) of professional(s)

Table 2-2: Inspections by RAJUK – Current Situation

	Structural Inspection	Nonstructural (Architectural and Fire Safety) Inspection	MEP Inspection
Low-Rise	RAJUK depends on professional's assurance	Architectural: Done by RAJUK Fire Safety: Not Done	RAJUK depends on professionals' assurances
High-Rise	RAJUK depends on professional's assurance	Architectural: Done by RAJUK Fire Safety: Undergoes FSCD Inspections	RAJUK depends on f professionals' assurances

MODELS OF BUILDING CODE IMPLEMENTATION AND ENFORCEMENT

A number of other building code implementation and enforcement models used in a number of cities and countries around the world are reviewed. While some jurisdictions were selected based on their demographic and cultural similarities with the areas covered by RAJUK, others were selected in the developed and developing parts of the world, considering the seismic hazard.

INCENTIVES

Issuing an Occupancy Certificate to a code-compliant building will be one of the best tools for code enforcement in Bangladesh. A code-compliant building with an Occupancy Certificate will enjoy the following benefits: (i) A holding number from the City Corporation, which is necessary for multiple purposes, (ii) Service or utility connections, (iii) Lower City Corporation taxes, (iv) Low interest rate at banks, and (v) Higher rental in view of better and safer living, especially in the event of fire and earthquake incidents. The government can introduce these incentives to encourage construction of code-compliant buildings. On the other hand, RAJUK's Authorized Officers should also be empowered to impose severe penalties on non-compliant buildings, the provision for which exists in the Building Construction Act of 1952.

In the relatively near future, it would be most desirable to develop and put into use a seismic rating system for the Dhaka metropolitan area. The U.S. Resiliency Council's system as well as the New Zealand system can be consulted to come up with a system that is right for Bangladesh.

BNBC IPLEMENTATION AND ENFORCEMENT STRATEGY

What should be the future role of RAJUK needs to be visualized. Given RAJUK's limitations in terms of shortage of manpower and insufficiency of technical knowledge, it has become almost inevitable for RAJUK to outsource certain activities, especially the vetting of building design. The public's perception of RAJUK was never favorable and has become considerably worse in the wake of recent fire related incidents and the loss of many valuable lives in Dhaka. People want change in the time-worn procedural strategy of RAJUK. Dhaka City dwellers expect RAJUK to be a more transparent, proactive and pro-people organization. The following concepts toward enhancing the legal framework and competent resources of RAJUK should be considered for adoption:

1. RAJUK should focus primarily on strengthening its Development Control and Planning wings. The existing resources and the attention of RAJUK Management should be diverted more towards Development Control activities, so that RAJUK can gradually transform into more of a Regulatory Body. The main purpose for enacting the BC Act of 1952, which eventually resulted in the creation of DIT and subsequently RAJUK, was to stop 'haphazard construction' through activation of the Development Control wing of RAJUK. So this division needs to be mobilized as fully as practicable.
2. Currently over 50% of the approved posts of Authorized Officers (AOs) are lying vacant. This in itself defeats the purpose for which RAJUK was created. The vacant posts of Authorised Officers should be filled up immediately, and AOs provided with logistical and financial resources to facilitate proper inspection of buildings 'during construction. For filling the posts of AOs, if Executive Engineers/Architects/Planners are not available in sufficient numbers, then as a fall-back option, Assistant Engineers/Planners/Architects with 3-5 years of experience should be trained and posted to fill-up the vacant positions.
3. Consideration should be given to vesting all Authorized Officers of RAJUK with full Magisterial Power to implement and enforce the Building Code. To ensure such enforcement, RAJUK should also have its own police force or assured access to police force under the control of another part of Government, to help the AO conduct Mobile Court and impose penalties for code violations on the spot.
4. Considering RAJUK's manpower situation, knowledge base, and public safety and welfare needs, Tables 3 and 4 below are proposed as the concept for pre-construction checking of structural, non-structural and MEP drawings and for inspection during construction, respectively. Plan checking involves RAJUK as well as 3rd-party plan checkers. Similarly, inspections also involve RAJUK as well as 3rd party inspectors. Although it is true that, over time, RAJUK has developed a pool of trained in-house Authorised Officers and Inspectors, they still need to be trained elaborately and rigorously about BNBC-2017 provisions. This is because a fundamental aspect of the concept presented in Tables 3 and 4 is that, as a Regulatory Body, RAJUK will supervise and monitor the activities of 3rd Party plan checkers and inspectors. It is primarily the 3rd-party plan checkers who will ensure that structural, non-structural as well as MEP drawings are in full compliance with BNBC-2017. Similarly, it

will mostly be the 3rd-party plan checkers who will supervise and monitor buildings under construction.

Table 3: Plan Review by RAJUK (Pre-Construction) – Recommendations

	Structural Plan Review	**Nonstructural (Architectural and Fire Safety) Plan Review**	**MEP Plan Review**
Low-Rise	RAJUK depends on stamp of professional Switch to 3rd-party plan checking and replace that with direct plan checking by RAJUK as early as practicable	Architectural: Done by RAJUK Fire Safety: Not Done Architectural: Continue current practice Fire Safety: Switch to plan checking by RAJUK	RAJUK depends on stamp(s) of professional(s) Switch to 3rd-party plan checking
High-Rise	RAJUK depends on stamp of professional Switch to 3rd-party plan checking	Architectural: Done by RAJUK Fire Safety: Undergoes FSCD Review Architectural: Continue current practice Fire Safety: Initiate 3rd-party plan checking in addition to FSCD Review	RAJUK depends on stamp(s) of professional(s) Switch to 3rd-party plan checking

Note: Low-rise buildings are up to 6-stories tall; high-rise buildings are more than 6-stories tall.

Table 4: Inspections by RAJUK (during Construction) – Recommendations

	Structural Inspection	**Nonstructural (Architectural and Fire Safety) Inspection**	**MEP Inspection**
Low-Rise	RAJUK depends on professional's written confirmation Switch to direct inspection by RAJUK	Architectural: Done by RAJUK Fire Safety: Not Done Architectural: Continue current practice Fire Safety: Initiate direct inspection by RAJUK	RAJUK depends on professionals' written confirmation Switch to 3rd-party inspections
High-Rise	RAJUK depends on professional's written confirmation Switch to 3rd-party inspections	Architectural: Done by RAJUK Fire Safety: Undergoes FSCD Inspections Architectural: Continue current practice Fire Safety: Initiate direct inspection by RAJUK in addition to FSCD Inspections	RAJUK depends on professionals' written confirmation Switch to 3rd-party inspections

5. Issuance of the Certificate of Occupancy and post-construction inspections should be as indicated in Table 5.

Table 5: Issuance of Certificate of Occupancy and Post-Construction Inspections

- ***Post Construction but before the building is handed over for use of occupants:***

(1) For all low rise buildings, 'OCCUPANCY CERTIFICATE' will be issued by RAJUK, if their inspections satisfies them that construction is in compliance with applicable code requirements..

(2) For high-rise, special type and KPI buildings, the professional who issues written confirmation that "the construction work has been completed under his/her/their supervision following usual practice" will issue 'COMPLETION CERTIFICATE' and on that basis, RAJUK will issue 'OCCUPANCY CERTIFICATE'.

- ***From the date of handing through the life-time of the building:***

(1) The 'Building Owners Association' in collaboration with 'RAJUK ZONAL OFFICES' will periodically check whether the building is used by the owners/occupiers as per approved building plan.

- Deviation(s) occurring after the building is occupied, will be identified and required to be corrected within a stipulated period, failing which, the deviation will be referred to the RAJUK Zonal Office for imposition of penalty.

6. The 3rd-party Inspectors should have the legal mandate to inspect buildings under construction. If access is denied or other resistance develops, the 3rd-party inspectors being non-government persons, the 3rd Party Inspectors should be entitled to seek and receive help from the concerned Authorised Officers who will be in a position to use the powers vested in him or her, if need be.
7. The best and probably the only way to implement a fast, transparent and pro-people permit-processing procedure is to introduce the 'Electronic Construction Permitting' (ECP) System. Development of ECP is currently underway by the S-7 Component of RAJUK's URP. In addition, Fast Automated Structural Plan Check (FASP) and Fast Remote Control Method (FRCM) should also be in place. They may be used as initial screening and flagging tools, although they will not provide sufficient check for plan approval.
8. The recruitment and accreditation of 3rd-party firms and professionals should be done under strict policy similar to that practiced in the U.S. or other developed countries. RAJUK engineers, architects and planners will be trained to monitor the 3rd parties before renewing their license of accreditation. The license of accreditation of a 3rd party provider can be cancelled (or withheld) and the architects, engineers, planners and Inspectors can be black-listed in case they are found to have been involved in any malpractice. Depending upon the nature of violation, the 3rd-party firm along with the individuals can also be barred from taking part in any future contract under RAJUK.

PART-XIV

CYCLONE BULBUL, 9th NOVEMBER, 2019

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

Prepared By: Maruf Billah

Mehedi Ahmed Ansary

Background

A severe cyclonic storm Bulbul, hit Bangladesh on 9 November, 2019 through Khulna division. Maximum sustained wind speed within 64 km of the severe cyclone center was about 100 kph rising to 120 kph in gusts/squalls according to the Met office. The coastal areas of Bangladesh receiver heavy rainfall prior to the cyclone's arrival which continued as the cyclone passed. The cyclone crossed Khulna coast around 5am on Sunday with a heavy precipitation, flooding low-lying areas in the district. The low-lying areas of the coastal districts including Chattogram, Noakhali, Laxmipur, Feni, Chandpur, Barguna, Bhola, Patuakhali, Barishal, Pirojpur, Jhalakati, Bagherhat, Khulna, Satkhira and their offshore islands and chars are likely to be inundated by storm surge of 5-7 feet height above normal astronomical tide, said Abdul Hamid, a meteorologist of Bangladesh Meteorological Department. Among these 14 districts, Barisal, Sathkhira and Khulna seem to have been affected the most.

Local offices of the Department of Agricultural Extension (DAE) in 12 districts told different newspapers that more than 250,000 hectares of cultivable lands, where farmers were growing paddy, mustard, beetle leaf, vegetables and fruits, have been damaged. In Sathkhira, some 25,000 hectares of paddy was fully or partially damaged, while 2,000 hectares of vegetables, beetle leaf, mustard and plums were damaged as well. In Khulna, 25,000 hectares of Aman paddy land and 1,092 hectares of fruits and vegetable land were partially or fully damaged. In Barisal, Aman and Boro paddy in 100,000 hectares of lands were affected, while 6,000 hectares of mustard and 2, 000 hectares of pulses were partially or fully damaged. Besides, some 100,000 small and large trees were uprooted or felled during the storm. Croplands were fully or partially damaged in Madaripur, Bhola, Jessore, Barguna and Bagerhat as well.

Director of Crops Wing at the DAE, (Abdur Razzak) told Dhaka Tribune that they had yet to receive reports about the state of the damage caused by Bulbul from the affected districts. About 150,150 houses were damaged in Satkhira, Khulna, Barisal, Bagerhat, Madaripur, Chandpur, Barguna, Gopalganj, and Jhalakathi. Besides, 151 schools were partially or fully damaged. Some 5,017 fish farms in Satkhira, 160 fish and shrimp farms in Barguna and 435 fish farms in Barisal were damaged. Besides, 120 km of road in Barisal and 38.5km of embankment in Barguna were damaged as well.

Over 2 million people were evacuated to more than 5,500 cyclone centers in 14 districts according to country's media reports (The Daily Star, 10/11/2019). According to the Department of Disaster Management, government allocated 4300 metric ton of rice, 14,000 dry food packages, children food worth BDT 900,000, animal food worth BDT 900,000 and total cash grant of BDT 18,500,000 in 16 districts heavily affected by the cyclone.

The cyclone damaged households, agricultural lands, destroyed plantation and disrupted communication. According to SOS forms published by the DC, DRRO, the worst hit districts included Satkhira, Khulna, Barguna and Bagerhat. The cyclone also claimed lives of 17 individuals.

Overview of Bulbul Impact

SOS forms reveal that the cyclone hit coastal areas and heavily damaged the district of Shatkhira where water logging become the most prominent and visible damage. Other districts that suffered less severe damage included Potuakhali, Bagerhat, Bhola, Borguna and Khulna. So far the cyclonic destruction resulted in the loss of seventeen lives, out of which eleven people died from tress falling on them. The cyclone also damaged houses, crops, fish enclosures and embankments. (The Daily Star, 11/11/2019).(*Due to discrepancies in data found in NDRCC reports, this note has been prepared primarily using SOS forms signed by DC, DRRO from respective districts, Information is still being updated so it is difficult to comprehend the extent of damage),*

Table 01: Affected people in Different District.

District	Number of people affected
Shatkhira	226,000
Khulna	2,97,500
Bagerhat (Morrelganj and Rampal Upazila)	135,859
Borguna	12,225
Total	671,584

Source: (SOS Forms signed by DC, DRRO from respective districts).

Damages of Shelter

Damage to houses have been most visible in the districts of Shatkhira and Khulna, with Shatkhira facing more damage. SOS forms reveal the extent of damaged houses suffered in these areas:

Figure 01: Pictorial representation of some partial and fully damaged houses.

Table 02: Damages of shelter in respected districts

District	Damage to Shelter	
	Partially damaged houses	Fully damaged houses
Shatkhira	33,630	16,580
Khulna	37,820	9,455
Bagerhat (Morrelganj and Rampal Upazila)	10,764	826
Borguna	2025	Non reported

Source: (SOS Forms signed by DC, DRRO from respective districts).

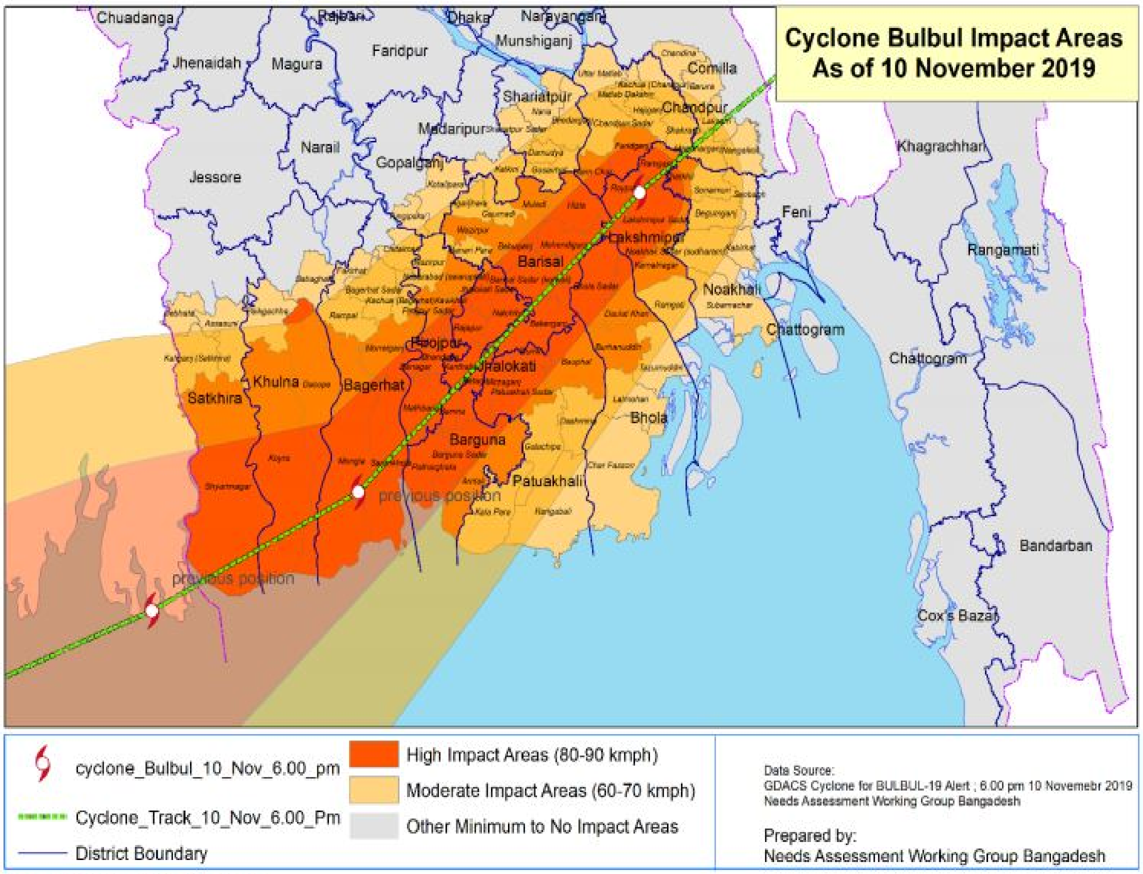
Impacted area of Cyclone Bulbul on coastal regions of Bangladesh

Extent of damages – overview

Human lives and injuries

According to DGHS data, 15 were injured due to the storm. At least 13 people have died due to the impact of cyclonic storm Bulbul in Bangladesh, However, the official estimates of Directorate General of Health Services (DGHS) confirmed 8 people were killed so far and at least 55 others injured

Impact of Cyclone Bulbul on coastal regions of Bangladesh



Source: RCO Flash Update 11/11/2019

Figure 02: Impact of Cyclone Bulbul on coastal regions of Bangladesh.

Table 03: Number of Death in respected districts.

Sl. No	District	Casualty Reported
01	Khulna	02
02	Patuakhali	01
03	Bagerhat	01
04	Bhola	01
05	Barguna	01
06	Gopalganj	02
07	Shariatpur	01
08	Barishal	01
09	Pirojpur	01
10	Satkhira	02
	Total	**13**

Food security and Livelihood

In Sathkhira, 25,000 hectares of Aman paddy, 1,200 hectares of vegetable crops and 6,000 shrimp enclosures have been destroyed. In Bagerhat, the cyclone severely damaged Aman paddy on 5,000 hectares of land along with farmlands of winter vegetables. In Khulna, 750 fish enclosures were washed away (RCO Flash Update 2, 11/11/2019). According to information from DC office of Borguna 9,863 hectares of agricultural land, 550 hectares of vegetation land and approximately 50 hectares of fish enclosures have been damaged. The monetary loss suffered by aquaculture amount to BDT 10,300,000. Damage to agriculture affects income of farmers as well as laborers who work on the agricultural land, especially in Sathkhira and Bagerhat where high rates of engagement in agriculture (HIES 2016) is present. Also if there is salinity intrusion due to tidal surge agriculture might be severely affecting for the next growing season due to decreased soil fertility.

Health

So far seventeen individuals have been reported dead due to the cyclone with falling trees being the major cause (The Daily Star, 11/11/2019). Moreover, inundation of water from heavy rain heavy rain can become a breeding ground for spreading water borne diseases. Salinity intrusion is a major risk since fish enclosures have been washed away. Additionally, as mentioned in the previous section, submerged latrines can also impose health risks, especially on women.

Electricity

Power supply snapped due to uprooting of electricity poles, damage to substations and transmission lines.


Figure 03: Fully and partial damage of electricity poles by cyclone Bulbul.

Governance infrastructures

Special Circuit House Khulna, Office and Residence of SP and Collector have been badly damaged like many other buildings.

Communications

Huge numbers of trees have been uprooted resulting in disruption of road communication. Sathkhira and Khulna city have been severely affected. Telecom towers have been affected resulting in cellular and telephone network down in wide area. All telephone and cell phones are down in 14 district. Telephone and mobile connectivity has also been severely affected in Sathkhira including Barisal city.

Figure 04: Communication hampered by tree blockage.