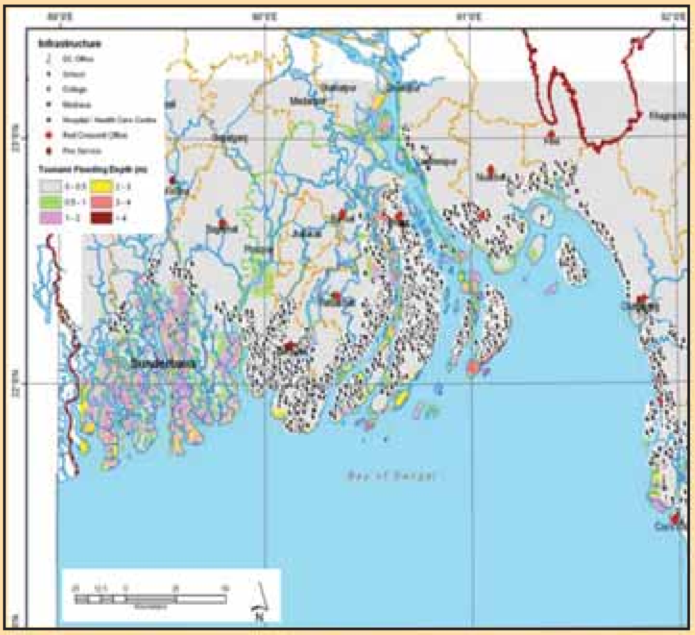
Identify Tusnami-vulnerable School/Hospital/ Emergency Response and Control Buildings in the Coastal Region and Evaluate Adaptation Capacity to Tsunami Events

FINAL REPORT



Spatial Distribution Map of Tsunami Vulnerable Infrastructures

West Bashkhali High School Chapaichari, Chittagong

April 2009

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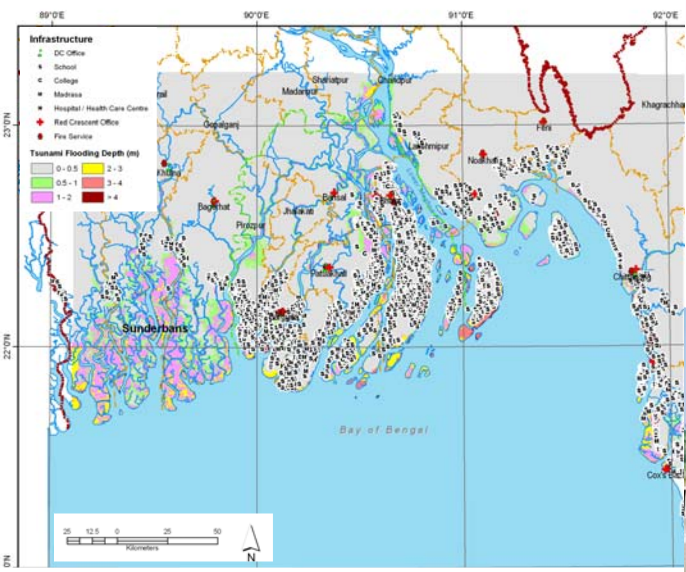

Spatial Distribution Map of Tsunami Vulnerable Infrastructures

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Institute of Water Modelling
In association with
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ACRONYMS AND ABBREVIATIONS

3D	Three Dimensional
ASCE	American Society of Civil Engineers
BMD	Bangladesh Meteorological Department
CCM	Coastal Construction Manual
CDMP	Comprehensive Disaster Management Programme
CPP	Cyclone Preparedness Programme
DEM	Digital Elevation Model
DFID-B	Department for International Development- Bangladesh
EC	European Commission
FEM	Finite Element Method
FEMA	Federal Emergency Management Agency
FWC	Family Welfare Centre
GIS	Geographic Information Systems
GoB	Government of Bangladesh
HRA	High Risk Area
IWM	Institute of Water Modelling
Km	Kilometer
Km/h	Kilometer per hour
KN	Kilo Newton
MHWS	Mean High Water Spring
MCSP	Multipurpose Cyclone Shelter Programme
MoFDM	Ministry of Flood and Disaster Management
m	Meter
m/s	Meter per second
mm	Millimeter
N	Newton
PWD	Public Works Department
RCC	Reinforced Cement Concrete
RFP	Request for Proposal
RZ	Risk Zone
UNDP	United Nations Development Programme

EXECUTIVE SUMMARY

E.1 Introduction

Vulnerability and adaptation capacity of the existing coastal infrastructures mainly school, hospital, emergency response and control buildings to storm surges and tsunami events have been assessed in the present study. The findings of the study have been finalized through a number of interaction meetings with the Technical Advisory Group (TAG) of CDMP. This Final Report contains the spatial distribution maps of infrastructure vulnerable to tsunami and storm surge, the structural strength analysis of the existing infrastructures, the evaluation of the adaptation capacity of the coastal dwellers to take shelters in the infrastructure during Tsunami and surge event and the guideline to improve the adaptation capacity of coastal infrastructure during tsunami and storm surge events.

The study area is the coastal region of Bangladesh. The main objective of this study is to identify the tsunami and storm surge vulnerable school/hospital/emergency response & control buildings in the entire coastal regions. The specific objectives are as follows:

- preparation of spatial distribution maps of the tsunami and storm surge vulnerable infrastructures;
- structural strength analysis of infrastructures in the coastal region of Bangladesh and to determine the adaptation capacity of the vulnerable infrastructures for tsunami and storm surge events;
- evaluation and understanding of the adaptation capacity of the coastal dwellers to take shelters in the infrastructures during Tsunami and Storm surge; and
- preparation of a guideline to improve the adaptation capacity of the infrastructure during tsunami and storm surge events.

E.2 Spatial Distribution Map of Infrastructures

Spatial distribution map of the infrastructures have been prepared based on the field surveyed data. A group of experienced field investigators/enumerators collected relevant data on infrastructures like schools, colleges, madrashas, hospitals, district headquarters, fire services, Cyclone Preparedness Programme (CPP) offices and Red Crescent offices from the coastal region of Bangladesh. The relevant data on infrastructures includes location, type of structure, size, number of story, year of construction, present condition for each category of structure from 245 unions under 46 upazilas of 13 districts located in the High Risk Area (HRA) according to the criteria of Multipurpose Cyclone Shelter Programme (MCSP, 1993). The total numbers of surveyed infrastructure are 4707 nos.. A GIS database has been developed using all the collected data of different type of buildings for the development of spatial distribution map of infrastructures and also for future reference. Figure E.1 shows the distribution of the infrastructures in the coastal region of Bangladesh.

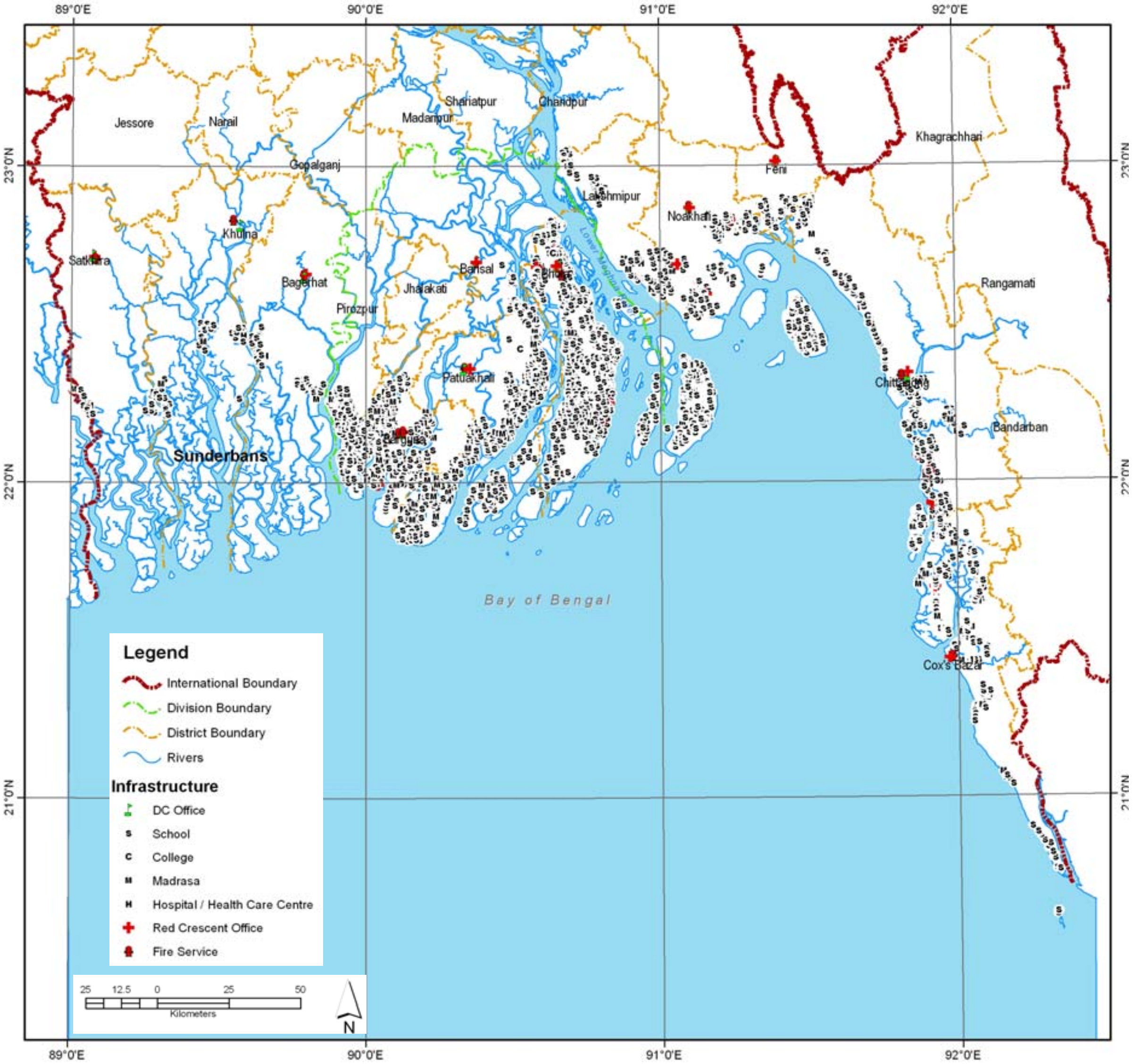


Figure E.1: Spatial distribution map of infrastructures in the coastal region

E.3 Vulnerability Assessment of Infrastructures

Inundation risk maps of tsunami and storm surge for the coastal region of Bangladesh prepared under another CDMP study have been used to generate spatial distribution maps of tsunami and storm surge vulnerable infrastructures using GIS tool. The level of vulnerability of infrastructures during tsunami and storm surge has been assessed based on the inundation depth of the infrastructure. The structures, which are likely to be inundated by more than 1 meter fall under HRA. These structures may be considered vulnerable to tsunami or storm surge. The degree of vulnerability of the infrastructures has been assessed through structural strength analysis. Figure E.2 shows the spatial distribution map of infrastructures vulnerable to storm surge.

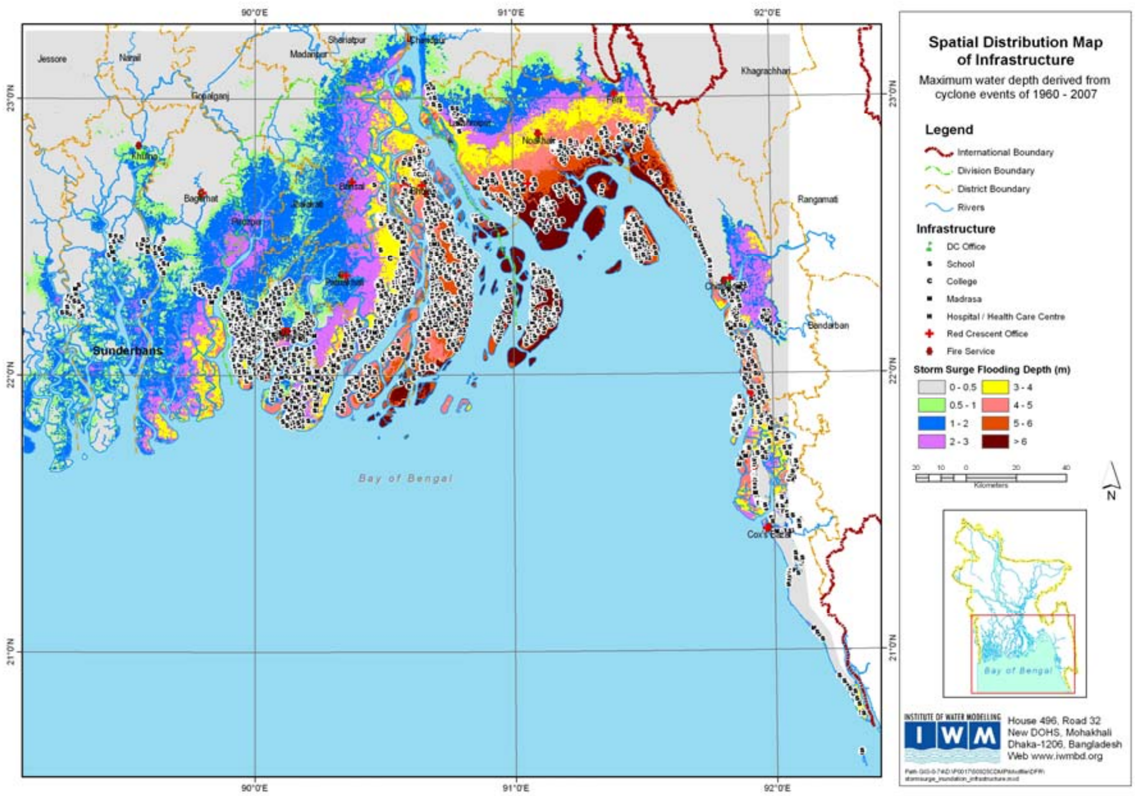


Figure E.2: Spatial distribution map of storm surge vulnerable infrastructures

E.4 Structural Strength Analysis of Infrastructures

In coastal areas the buildings or structures should be designed to resist the effects of coastal floodwaters and tsunami/ storm surge. In the present study, structural members in ground floor of existing buildings have been investigated since the tsunami/ surge forces are greatest at these levels, and these members carry the greatest loads. Failure of any of these members could lead to progressive collapse of significant portion or whole of the building.

E.4.1 Structural Strength Analysis

Design drawings of four typical structures, each one for primary school, high school, college and madrasha have been collected from Facilities Department and upazila offices of Local Government Engineering Department. Assessment of structural strength of a building requires modeling and analysis of the structure of the building to determine the stress and load levels it can sustain for different modes of loading. Three dimensional (3D) FEM models of the selected coastal structures have been generated in the present study using structural design software package ETABS (version 9.0.4). For each of the different 144 conditions each of the four different types of selected structures has been analyzed and the developed stresses have been compared with the allowable stresses.

Capacity of the individual members of an RC structure depends both on the concrete section and the amount and location of the steel reinforcement. In the following paragraphs the results of the analyses and adequacy of each of the selected structure types are explained.

- The Primary School building can sustain the loads due to cyclone with basic wind speed of 260 km/h and surge height of 3 m without any structural members failing. However, a number of columns require more reinforcement than provided for Tsunami load of only 1m surge height.

- The High School building can sustain the loads due to cyclone with basic wind speed of 260 km/h and surge height of 3 m without any structural members failing. However, a number of columns require more reinforcement than provided for Tsunami load of 1 m surge height.

- A number of columns of the College building require more reinforcement than provided even for dead and live loads and thus fail to sustain any Tsunami or Cyclone loading

- The Madrasha building under usual live load condition can sustain a 3m storm surge along with wind load of 260 km/h. A number of columns of the Madrasha building, however, fails to withstand any Tsunami loading.

Flood velocity for Tsunami is much higher compared to that of storm surge. In case of Tsunami, for only 1 m inundation flood velocity becomes about 7 m/s whereas the maximum velocity in case of storm surge is around 2.5 m/s. Due to higher flood velocity, Tsunami exerts greater hydrodynamic and impact forces on a structure. In addition, when Tsunami load is combined with Dead and Live loads unlike Cyclonic loading does not have a reduction factor of 0.75. Thus from the above analyses it is found that all the selected structures are inadequate to resist Tsunami forces even for 1 m inundation even for normal occupancy.

The Primary School building, the High School building and the Madrasa building under normal occupation are adequate against cyclonic load along with storm surge. Only the Primary School building is however adequate against cyclonic load as a shelter. Table E.1 summarizes the capacity of the analyzed buildings to withstand Tsunami and Cyclone.

Table E.1: Allowable surge height in case of Tsunami and Cyclone

Building	Allowable surge height for Tsunami		Allowable surge height for Cyclone	
	Normal Occupancy	As a Shelter	Normal Occupancy	As a Shelter
Primary School Building	< 1m	< 1m	3m	3m
High School Building	< 1m	< 1m	3m	< 1m
College Building	< 1m	< 1m	< 1m	< 1m
Madrasa Building	< 1m	< 1m	3m	< 1m

E.4.2 Foundation Analysis

A good number of logs of bore holes at different locations along the coastal belt have been collected. It has been observed from the collected bore logs that the area is covered with a deposit of fine grained material such as clay and silt on the surface. The deposits extend up-to a considerable depth below the surface. The materials are very fine in grain-size and are cohesive. The standard penetration test results indicate they are very soft to soft or medium stiff in consistency.

The bearing capacities of cohesive soil have been calculated on the basis of the available data. The laboratory test results available are not considered sufficient for the purpose and also they do not correspond to the depths at which the foundations are usually located. As such standard penetration test results have been taken as the basis for calculation of bearing capacities. At all the bore holes the standard penetration tests have been performed at regular as well as close intervals. In calculating the bearing capacities Hansens's formula has been used. The values of cohesion or c have been taken from Tarzaghi's correlation of SPT with unconfined compression test results.

The footing areas thus calculated for the selected structures are compared with those actually provided under the columns of the buildings already constructed. All the selected structures are in the Patuakhali district. Worst condition of the bore log for Emdad Ali hostel of Patuakhali govt. college, Patuakhali is used for determination of bearing capacities. From the calculated bearing capacities of the selected structures it has been observed that foundation provided for all selected structures are inadequate for tsunami and storm surge even for normal occupancy. The reasons for structures being still existing may be that the structures might have undergone good amount of settlement. But since it is uniform settlement no unsightly cracks have developed on the structures.

E.5 Evaluation of the Adaptation Capacity of Vulnerable Infrastructure

Among the selected structures the Primary School building, the High School building and the Madrasha building are one storied and the College building is three storied. In case of cyclone the one storied buildings suited only at places where there is no chance of storm surge. Although the primary school and the high school buildings have capacity to withstand storm surge of 3m, in that case, the people will have to take shelter on the roof. Thus only the multistoried building should be made adaptable to cyclone. In order to make the college building adaptable to withstand cyclones with basic wind speed of 260 km/h and surge height of 3m, seven corner columns and three interior beams of the building are required to be strengthened. Similarly in order to make the structures adaptable against Tsunami load, a large number of beams and columns need to be strengthened.

E.6 Guideline to Improve the Adaptation Capacity of the Infrastructures

In order to pursue the study a participatory method was used to collect opinion of the people about their practices. Their adoption about tsunami and storm surge has been noted from the people living in the main coastline areas of Bangladesh. Indeed, to list down the opinion of the people several large group discussions (LGDs) were conducted in different coastline areas. Most of the cases the LGD were attended by different segment of the society as different occupational and income groups had to adapt differently.

The following suggestions may be considered to improve the adaptation capacity of coastal infrastructures and also coastal dwellers in order to reduce vulnerability as well as awareness raising during tsunami and surge events:

- In areas where there is a plausible risk of tsunami, large number of structures must be strengthened so that they can bear the additional live load if people take refuge during a tsunami;
- All individual structure shall be analyzed with respect to structural strength considering cyclonic wind, tsunami and surge loads, to see the possibility of using shelter;
- Since lead-time for tsunami may be much less compared to cyclones, the concentration of shelters should be increased as much as possible;
- Since storm-surge is also accompanied by strong cyclonic wind, one-storied structures cannot be used as shelters;
- When the inundation depth exceeds 3 m, one story building cannot be used as shelter as it will be completely inundated;
- Masonry structures should be evacuated before a cyclone or tsunami in areas where there is risk of inundation;
- Structural adaptation of all physical interventions and the human adaptation as mentioned in article 12.6.1 may be followed; and
- A detailed guideline consisting of planning, design, construction and maintenance aspects of infrastructures to be build in future in coastal areas need to be prepared separately.

1. INTRODUCTION

A comprehensive study has been carried out to identify the tsunami and storm surge vulnerable school/ hospital/emergency response and control buildings in the coastal region of Bangladesh and evaluate their adaptation capacity to tsunami and storm surge events. The results of the study has been finalised during the course of the study. A number of interaction meetings with the Technical Advisory Group (TAG) of CDMP have been made to finalise the findings of the study. This Final Report contains final versions of all the deliverables, which includes the spatial distribution maps of infrastructure vulnerable to tsunami and storm surge, the guideline to improve the adaptation capacity of coastal infrastructure during tsunami and storm surge events, the evaluation of the adaptation capacity of the coastal dwellers to take shelters in the infrastructure during Tsunami and surge event and the structural strength analysis of the Infrastructures.

1.1 Background

The coastal region of Bangladesh is densely populated and about 28% of the population live in coastal zone (Coastal Zone Policy, 2005). The population is expected to increase from 36.8 million in 2001 to 43.9 million in 2015 and to 60.8 million by 2050 (PDO-ICZM, 2005).

The coastal region of Bangladesh is vulnerable to natural hazards like floods, droughts, cyclones, storm surge and others. The frequency and intensity of natural disasters like floods, cyclones, storm-surges, tidal bores and droughts are very high in Bangladesh. Its flat deltaic topography with very low elevation makes it more vulnerable to tsunami and storm surge. The coastal region is low-lying with 62% of the land have an elevation of up to 3 metres and 86% up to 5 metres from mean sea level.

The Comprehensive Disaster Management Programme (CDMP) of the Government of Bangladesh (GoB) is being implemented by the Ministry of Food and Disaster Management (MoFDM) and is supported by the United Nations Development Programme (UNDP), UK Department for International Development- Bangladesh (DFID-B) and the European Commission (EC). CDMP is designed to strengthen the Bangladesh disaster management system and more specifically to achieve a paradigm shift from reactive response to a proactive risk reduction culture. This programme has adopted a more holistic approach, embracing processes of hazard identification and mitigation, community preparedness and integrated response efforts, where relief and recovery activities are planned within an all-risk management framework. CDMP seeks to raise the capabilities of communities while lowering their vulnerability to specific hazards.

In July 2005 the European Commission Delegation to Bangladesh raised concern about the capacity of vulnerable communities to withstand earthquake, tsunami and other hazards, assessed national disaster management programme and proposed project design to address some of the gaps they identified. In August 2006 the European Commission and UNDP signed a cooperation agreement related to the funding of three new components within the CDMP framework. Component 4a: *Earthquake and Tsunami Preparedness* is one of them.

The component-4a recognizes growing urban vulnerability to earthquake caused by increasing population densities and unplanned development and responds to the tsunami risk which 2004 Indonesian tsunami brought to public attention and it is concerned with the RFP IV: *Tsunami* *inundation and vulnerable mapping.* The activities under RFP IV are differentiated into four smaller areas namely:

RFP IV.1: Prepare tsunami and storm surge inundation risk maps for the entire coastal region;

RFP IV.2: Update available information on cyclone shelter management for tsunami and storm surge preparedness;

RFP IV.3: Identify Tsunami-Vulnerable Schools/Hospitals/Emergency Response and Control Buildings in the Coastal Region and Evaluate their Adaptation Capacity to Tsunami and Storm Surge Event

RFP IV.4: Identify and appraise economic risk to the coastal livelihoods (e.g. fishing/ tourism industry) to tsunami/ storm surge event.

This study has been carried out under RFP IV.3. CDMP commissioned Institute of Water Modelling (IWM) in December 2007 to carry out the study titled "*Identify Tsunami-Vulnerable Schools/Hospitals/Emergency Response and Control Buildings in the Coastal Region and Evaluate their Adaptation Capacity to Tsunami and Storm Surge Event*".

1.2 Study Area

The study area is the coastal region of Bangladesh. The coastal region has about 710 km long coastline and 123 polders. The coastal region is characterized by a complex network of rivers, enormous river water flow heavily laden with sediments, strong tidal and wind actions, waves and tropical cyclones and associated storm surges. Figure 1.1 shows the coastal region of Bangladesh.

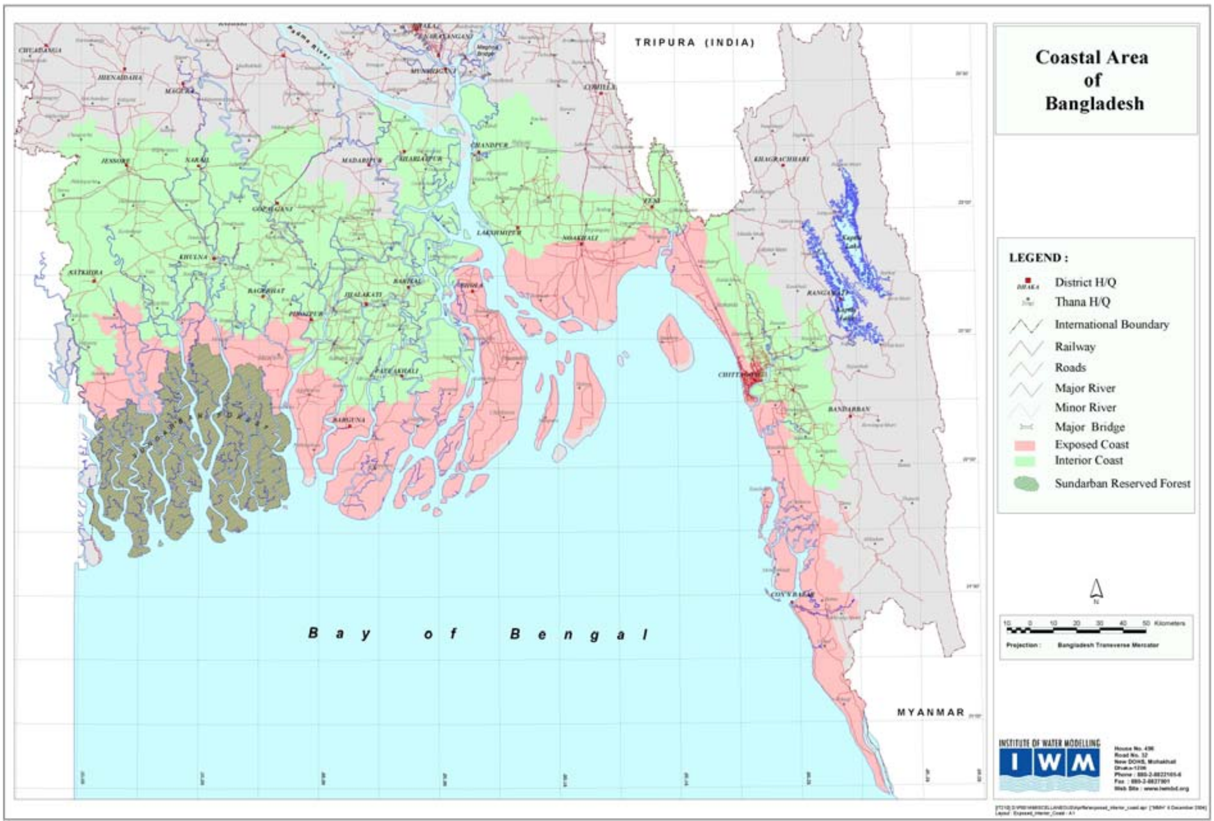


Figure 1.1: Coastal Region of Bangladesh

Coastal zone of Bangladesh consists of 19 districts with an area of 47,201 sq. km which is about one third of the total area of the country. Sixty-two percent of the land of the coastal zone has an elevation of up to three meters and 86 percent up to five meters (MoWR, 2005). Out of 19 districts, 12 districts (i.e. Satkhira, Khulna, Bagerhat, Pirojpur, Barguna, Patuakhali, Bhola, Lakshimpur, Noakhali. Feni, Chittagong and Cox's Bazar) comprising 48 upazilas/ thanas are considered as 'exposed' directly to vulnerabilities from natural disasters (Coastal Zone Policy, 2005).

1.3 Objective

The main objective of this study is to identify the tsunami and storm surge vulnerable school/hospital/emergency response & control buildings in the entire coastal regions.

The specific objectives of this report are as follows:

- preparation of spatial distribution maps of the tsunami and storm surge vulnerable infrastructures, school/hospital/emergency response and control buildings;
- structural strength analysis of infrastructures in the coastal region of Bangladesh and to determine the adaptation capacity of the vulnerable infrastructures for tsunami and storm surge events;
- evaluation and understanding of the adaptation capacity of the coastal dwellers to take shelters in the infrastructures during Tsunami and Storm surge; and
- preparation of a guideline to improve the adaptation capacity of the infrastructure during tsunami and storm surge events.

1.4 Outputs

The following outputs have been delivered based on the study:

- Spatial distribution maps of infrastructures vulnerable to tsunami and storm surge;
- A database containing the detail information of infrastructures;
- Structural stability of infrastructure against Tsunami and Surge load;
- Evaluation of the adaptation capacity of the coastal dwellers to take shelters in the infrastructure during Tsunami and surge event; and
- A guideline to improve the adaptation capacity of the infrastructure and also the coastal dwellers to take shelters in the infrastructures during tsunami and storm surge events.

1.5 Structure of the Report

This report consists of thirteen chapters and six appendices. Each chapter's outlines are given below:

- Chapter-1 is the introduction of this report and it describes the objectives, outputs and study area;
- Chapter-2 describes the approach and methodology of the study;
- Chapter 3 outlines the data used under the study and database developed under this study;
- Chapter 4 includes the spatial distribution map of infrastructures in the coastal region of Bangladesh;
- Chapter 5 determines the level of vulnerability of infrastructures due to the inundation by tsunami and storm surge;

- Chapter 6-10 describe the structural strength analysis of infrastructure vulnerable to tsunami and storm surge;
- Chapter 11 evaluates the adaptation capacity of the coastal dwellers to take shelters in the infrastructures during tsunami and storm surges;
- Chapter 12 includes the guideline to improve the adaptation capacity of the infrastructures; and
- Chapter 13 provides the conclusions and recommendations.

Literature review done in connection with this report, spatial distribution maps of infrastructures in district level, number and type of infrastructure, drawings of typical infrastructure, details of structural strength analysis and public consultation report have been presented in Appendix-A, Appendix-B, Appendix-C, Appendix-D, Appendix-E and Appendix-F respectively.

2. APPROACH AND METHODOLOGY

The study is being carried out by a multi-disciplinary team. In the beginning and during the course of the study relevant past study reports and documents were collected and reviewed. The summary of the review is presented in Appendix-A. Information on infrastructures in the coastal region of Bangladesh has been collected through a field survey campaign. The spatial distribution maps of the tsunami and storm surge vulnerable infrastructures have been prepared based on the field information and the inundation risk maps of tsunami and storm surge generated under another study of CDMP. The following are the approaches and methodology to prepare the deliverables under this study.

Field Data Collection

Information on school, fire services, Cyclone Preparatory Programme (CPP) offices, Red Crescent offices, emergency response and control buildings of relevant departments of Bangladesh Government were collected from the field survey. Apart from the requirement of ToR, infrastructures like College and Madrasha were also included.

In the beginning, the study team prepared an inventory sheet for data collection. The sheet contains all the specification of the required data. Field investigators collected all the relevant data on the infrastructures and field conditions including positions and photographs of the infrastructures.

Development of Spatial Distribution Maps

Spatial distribution maps of tsunami and storm surge vulnerable infrastructures have been generated combining the field data and the inundation risk map of the coastal region using GIS tool. Infrastructures include school, college, madrasha, hospital, district headquarters, fire services, CPP offices, Red Crescent offices and other emergency response and control buildings.

Identification of Vulnerable Infrastructure

The spatial distribution maps of tsunami and storm surge vulnerable infrastructures provide the maximum inundation depth at structure under affected upazilas. The maps also indicate the inundation that the building might experience during its service period. A list of infrastructures with different depth of inundation has been prepared. The structures inundated by more than one (1) meter fall under High Risk Area (HRA) according to the criteria of Multipurpose Cyclone Shelter Programme (MCSP, 1993). These structures may be considered vulnerable to tsunami or storm surge. The degree of vulnerability of the infrastructures is being assessed through structural strength analysis of different type of structures. The result will be included in the following report.

Development of Database

Apart from the spatial distribution maps, a GIS database has been developed using the collected information and the findings in a digital GIS-ready format. It has been developed in order to overlay the data on the inundation risk maps of tsunami and storm surge in GIS environment and also to archive the collected data.

3. DATA

3.1 Field Data of Infrastructure

A considerable number of infrastructures have been developed in the coastal region of Bangladesh over the last decade to meet the social needs with the increasing population. There are different types of structures for different purposes. In this study mainly those infrastructure have been selected which can be used as shelter during cyclonic storm surge and tsunami in addition to existing cyclone shelter. Information on school, fire services, CPP offices, Red Crescent offices, emergency response and control buildings of relevant departments of Bangladesh Government were collected from the field survey. Apart from the requirement of ToR, infrastructures like College and Madrasha were also included.

In the beginning of the study, an inventory sheet was prepared for data collection. The sheet contains all the specification of the required data. A group of experienced field investigators/ enumerators were recruited and trained on the data collection methods and formats. They were equipped enough to collect all the relevant data on different type of buildings and its surrounding field condition, geographical position and photograph. They collected the infrastructure data like schools, colleges, madrashas, hospitals, district headquarters, fire services, CPP offices and Red Crescent offices from the coastal region of Bangladesh. The data collection areas were selected based on the Risk Zone (RZ) and the High Risk Area (HRA) defined by the Multipurpose Cyclone Shelter Programme (MCSP, 1993) and the cyclone SIDR affected area in the coastal region of Bangladesh. During the course of the study the numbers of upazilas/ thanas were updated based on the coverage of the inundation risk maps of tsunami and storm surge.

The list of different types of surveyed buildings under the present study is presented in Table 3.1. The field investigators covered 13 districts namely Pirojpur, Barisal, Patuakhali, Barguna, Bagerhat, Khulna, Satkhira, Bhola, Feni, Noakhali, Lakshmipur, Chittagong, and Cox's Bazar. They also collected cyclone shelter and school-cum-cyclone shelter data. But, these data were not used in this study to avoid the duplication with the other CDMP project.

Table 3.1: List of buildings surveyed under the present study

District	*Upazila*	*Number of Biulding*									
		Cyclone Shelter	*School-cum-Cyclone Shelter*	*School*	*College*	*Madrasha*	*Hospital/ FWC*	*D.C. Office*	*Fire Service*	*Red Crescent*	*Total*
Cox's Bazar	Teknaf	5	19	18		2	2				46
	Ukia	1	11	6		3					21
	Ramu		9	12		2	2				25
	Cox's Bazar	6	22	33	3	10	2	1	1	1	79
	Maheskhali	13	27	59	8	19	7				133
	Chakaria	4	28	51	3	16	4				106
	Kutubdia	17	43	32	2	12	2				108
	Pekua	2	28	15	1	11	1				58
Chittagong	Banshkhali	18	80	147	7	22	4			1	279
	Anwara	1	29	48	4	10	3				95
	Patiya		7	81	9	5	1				103
	BandarThana		7	20	1	1					29
	Sitakunda	1	37	101	7	3					149
	Sandwip		100	183	11	17	9				320
	Mirsharai	4	16	50		10					80
	Chittagong Port							1	2	1	4
	Chandanaish		3	65	3	8	3				82
Feni	Feni Sadar							1	1	1	3
	Sonagazi		32	50		12	3				97
Noakhali	Companiganj	1	8	49	1	10	2				71
	Noakhali	1	28	62	2	9	1	1	1	1	106
	Hatiya	6	36	161	4	18	3				228
Lashimpur	Ramgati		30	85	1	11	4				131
	Lashimpur	1	8	51		4	3				67
	Raipur		2	20		2	1				25
	Kamalnagar		22	55		11	2				90
Bhola	Bhola	3		107	2	5		1	2	1	121
	Daulatkhan	2		98		2	1				103
	Borhanuddin	2		96		4	1				103
	Tazumuddin	1		59		1					61
	Manpura	1		33		2					36
	Lalmohon	5		131		4					140
	Charfession	3		130		7			1		141
Barisal	Barisal			8		2	1				11
	Bakerganj			12		4	1				17
Patuakhali	Bauphal	1		69	3	26	4				103
	Dashmina	5		93	1	15	5				119
	Patuakhali							1			1
	Galachipa	20		134	5	26	4				189
	Kalapara	34		109	4	27	1				175
Barguna	Amtali	4		68	1	16	3				92
	Barguna	7		136	3	22	2	1	1	1	173
	Betagi	1		26	1	6	2				36
	Patharghata	14		133	3	17	2				169
	Bamna	3		42	3	9	2				59
Pirojpur	Mathbaria	1	11	72	4	12	3				103
Bagerhat	Sarankhola	4	20	41	3	5		1	1		75
	Mongla	2	7	21		1	2				33
Khulna	Dacope	2	14	26		1	3				46
	Khulna Sadar							1	1		2
	Koyra	1	11	13		3	1				29
Satkhira	Shymnagar	2	8	19		4	2				35
	Total:	199	703	3130	100	449	99	9	11	7	4707

3.2 Development of Database

A GIS database has been developed using all the collected data of different type of buildings for development of spatial distribution map of infrastructures and also future reference. Initially data entry software was developed to enter error free and quality data fast into the system. This software handled a huge number of images and stored in database. Image based search option has also been added in this system.

Technical Background

It is developed in visual basic 6.0 as front end development environment and SQL Server 2000 has been used as back-end database server. SQL Server can handle quite a large volume of data. For systems scalability, security and robustness SQL Server is suitable for this system.

Main Features

The system has been designed in such a way so that the users can enter all data using keyboard. The database is user friendly and user can add new information in the database easily. The database is useful to make chart, table and comparison plots. The key features of this system are listed below:

1. In-built image based search system;
2. Structure wise image data are stored as attribute info in database;
3. Data can be edited through the interface;
4. Extensive search option is available, even image which was stored in database can be checked; and
5. Data can be exported to Excel format.

A sample plot of data entry menu is presented in Figure 3.1.

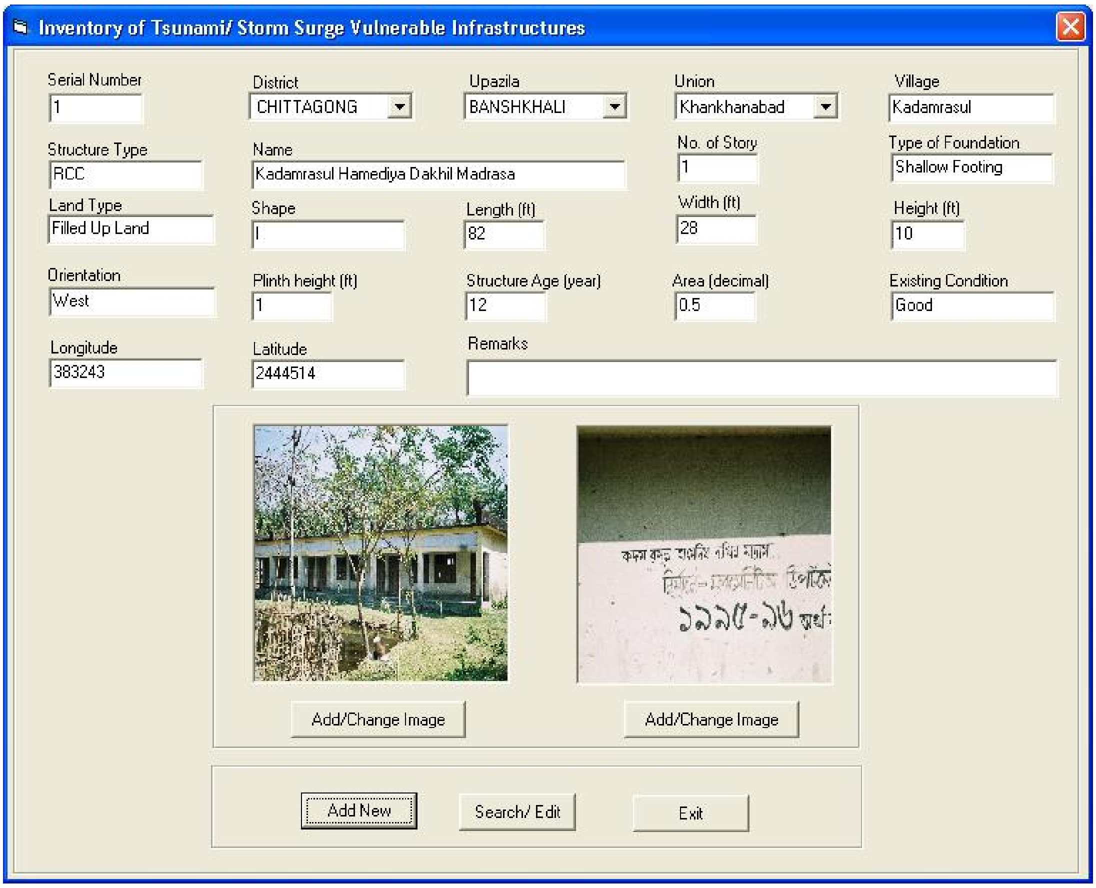


Figure 3.1: Data Entry Interface

3.3 Inundation Risk Map

Inundation risk maps for tsunami and storm surge for the coastal region of Bangladesh have been prepared under another study of CDMP titled "*Use existing data on available digital elevation models to prepare useable tsunami and storm surge inundation risk maps for the entire coastal region*". These maps have been used in this study to generate spatial distribution maps of tsunami and storm surge vulnerable infrastructures using GIS tool. Inundation risk maps for tsunami and storm surge have been presented in Figure 3.2 and Figure 3.3 respectively. These maps were prepared considering the land level based on digital elevation model and the existing polders in the coastal region of Bangladesh.

Inundation risk map for tsunami was prepared based on the four scenarios of tsunami originated from four potential sources of earthquake in the Bay of Bengal. All the scenarios of tsunamis were simulated under Mean High Water Spring (MHWS) tide condition using MIKE 21 modelling system of $\text{DHI}_{\text{Water.Environment.Health}}$. The tsunami model resolved the coastal region of Bangladesh in 600m grid resolution. The inundation risk map for storm surge was prepared based on the 18 major cyclones of the period 1960 to 2007.

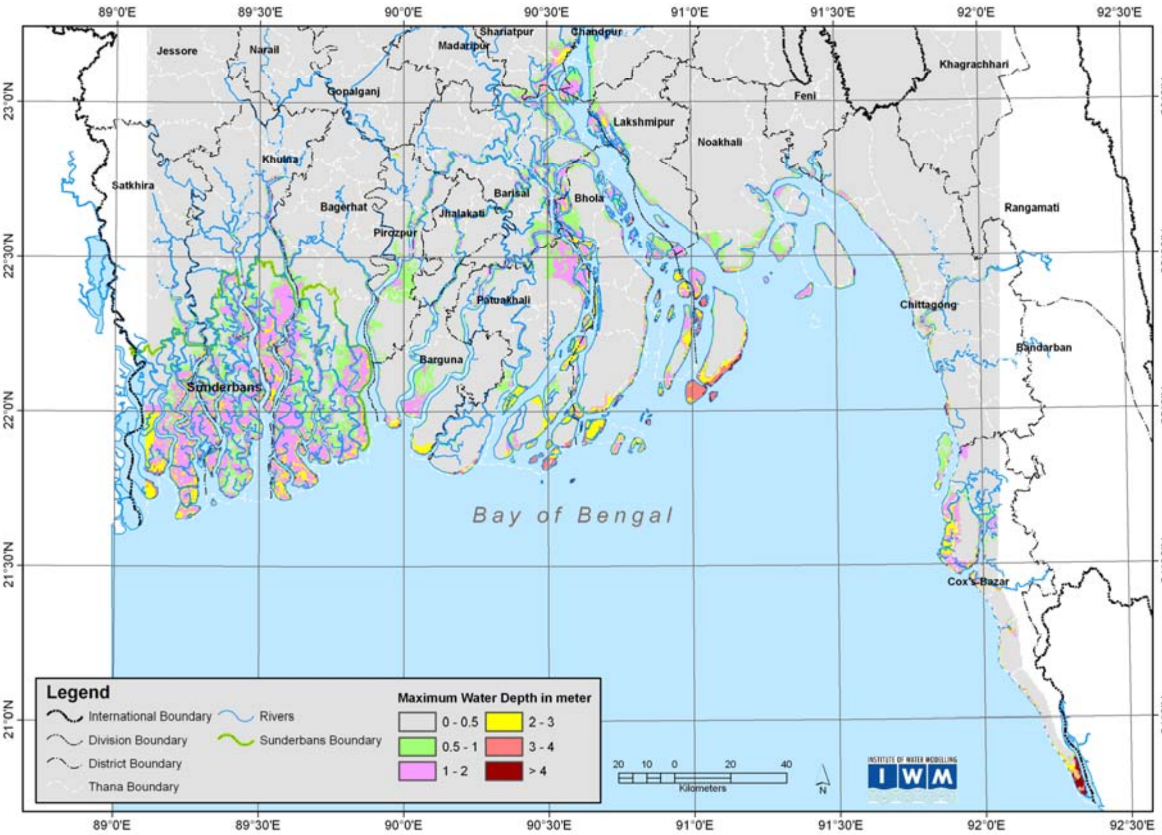


Figure 3.2: Inundation risk map for tsunami

The Figure 3.2, the inundation risk map of tsunami, shows that Sundarban area, Nijhum Dwip, south of Hatia (outside polder) and Cox's Bazaar coast are likely to be inundated during tsunami. Maximum inundation is seen at Nijhum Dwip in the range of 3-4 m, and at Sundarban area and Cox's Bazar coast in the range of 1-3 m. Small islands and part of the Manpura island in the Meghna Estuary may experience inundation of 1-3 m. Bauphal upazila of Patuakhali district is low lying area which may experience inundation of 1-2 m mainly due to MHWS tide. In this area the influence of tsunami wave is insignificant.

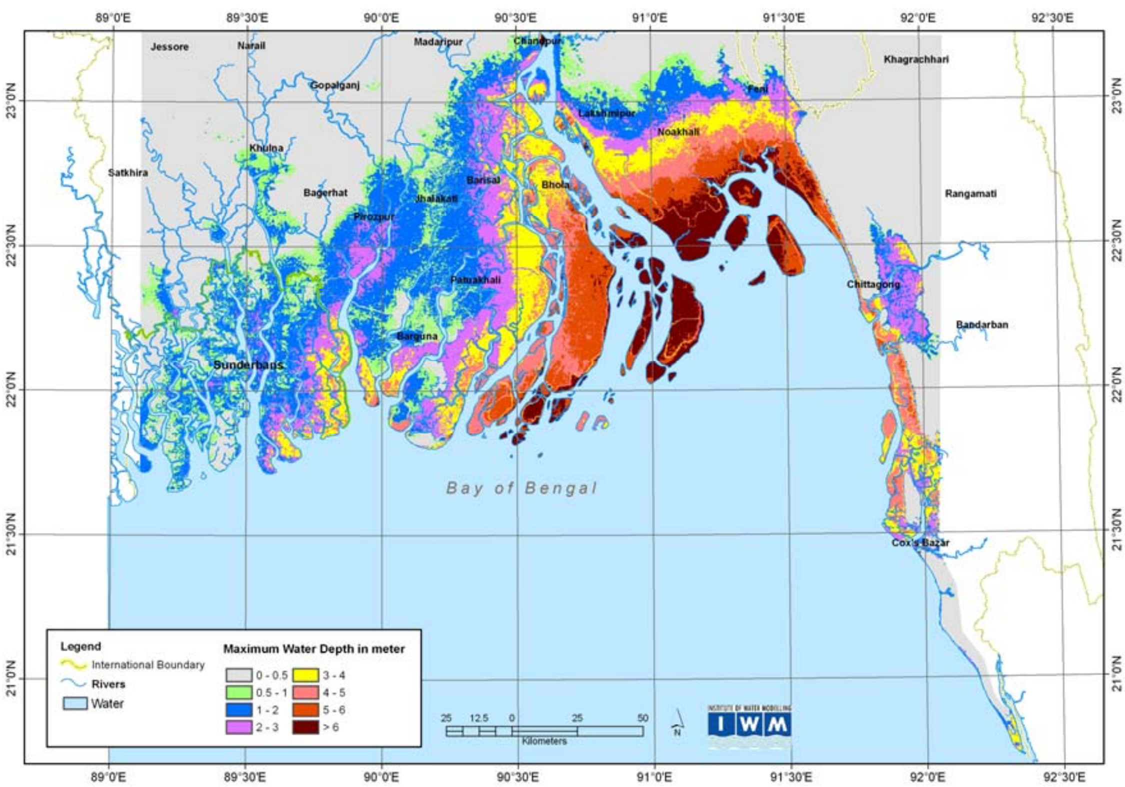


Figure 3.3: Inundation risk map for storm surge

The Figure 3.3, the inundation risk map of storm surge, shows that the highest inundation depth having range between 5 m and 7 m lies within the Meghna Estuary area. The eastern coast experiences maximum inundation between 4 m and 6 m and the western coast experiences inundation within the range of 3-5 m. Upazilas under inundation risk due to storm surge have been presented in Table 3.2.

Table 3.2: Upazilas under inundation risk due to storm surge

SL No.	Name of Upzilla	Area, ha (excluding river)	Innundation							
			d*<=1m		1m>d*<=3m		3m>d*<=6m		d*>6m	
			Area, ha	%	Area, ha	%	Area, ha	%	Area, ha	%
1	Agailjhara	16176	15916	98	260	2	0	0	0	0
2	Amtali	50972	15916	31	27696	54	7296	14	64	0
3	Anowara	14404	1212	8	6208	43	6884	48	100	1
4	Assasuni	33132	32464	98	628	2	24	0	16	0
5	Babuganj	14584	1560	11	12672	87	248	2	104	1
6	Bagerhat Sadar	26436	26436	100	0	0	0	0	0	0
7	Bakerganj	36772	848	2	27488	75	8304	23	132	0
8	Bamna	8696	7972	92	688	8	36	0	0	0
9	Banari Para	12572	11924	95	616	5	8	0	24	0
10	Banshkhali	34976	13580	39	2900	8	18376	53	120	0
11	Barguna Sadar	31792	7288	23	16980	53	7428	23	96	0
12	Barisal Sadar (kotwali)	27352	236	1	20832	76	6128	22	156	1
13	Batiaghata	21744	17160	79	4404	20	140	1	40	0
14	Bauphal	41204	4	0	9308	23	31392	76	500	1
15	Betagi	15068	6360	42	8672	58	36	0	0	0
16	Bhandaria	14708	424	3	14084	96	184	1	16	0
17	Bhola Sadar	33844	488	1	2820	8	30348	90	188	1
18	Burhanuddin	23020	0	0	96	0	22456	98	468	2
19	Chakaria	38168	7220	19	8980	24	21964	58	4	0
20	Chandanaish	9400	4680	50	4704	50	16	0	0	0
21	Char Fasson	55360	0	0	652	1	48872	88	5836	11
22	Chitalmari	19304	19296	100	8	0	0	0	0	0
23	Chittagong Port	3532	456	13	356	10	2632	75	88	2
24	Companiganj	28564	0	0	216	1	16384	57	11964	42
25	Cox's Bazar Sadar	11564	4260	37	5284	46	1988	17	32	0
26	Dacope	73556	46428	63	26268	36	732	1	128	0
27	Dashmina	21948	0	0	1380	6	20468	93	100	0
28	Daulatkhan	15616	12	0	360	2	14264	91	980	6
29	Fakirhat	16056	15820	99	236	1	0	0	0	0
30	Galachipa	79580	264	0	17588	22	53044	67	8684	11

Table 3.2 (continued): Upazilas under inundation risk due to storm surge

SL No.	Name of Upzilla	Area, ha (excluding river)	Innundation							
			d*<=1m		1m>d*<=3m		3m>d*<=6m		d*>6m	
			Area, ha	%	Area, ha	%	Area, ha	%	Area, ha	%
31	Gaurnadi	14112	8536	60	5576	40	0	0	0	0
32	Gopalganj Sadar	36572	36548	100	24	0	0	0	0	0
33	Gosairhat	16072	556	3	13356	83	2056	13	104	1
34	Haim Char	9184	1976	22	5228	57	1980	22	0	0
35	Hatiya	51136	4	0	452	1	5144	10	45536	89
36	Hizla	21088	0	0	5796	27	14800	70	492	2
37	Jhalokati Sadar	18396	8084	44	10296	56	16	0	0	0
38	Kachua	12596	10080	80	2516	20	0	0	0	0
39	Kala Para	42672	10292	24	16316	38	15928	37	136	0
40	Kanthalia	15048	3868	26	11164	74	16	0	0	0
41	Kawkhali	6956	120	2	6740	97	84	1	12	0
42	Kotali Para	36284	36276	100	8	0	0	0	0	0
43	Koyra	121452	87248	72	32888	27	1116	1	200	0
44	Kutubdia	6712	0	0	304	5	6348	95	60	1
45	Lakshmipur Sadar	46072	5888	13	34636	75	5192	11	356	1
46	Lalmohan	27188	0	0	448	2	25056	92	1684	6
47	Maheshkhali	25460.03	9728	38	6272	25	9288	36	172	1
48	Manpura	12704	0	0	0	0	2760	22	9944	78
49	Mathbaria	32252	7368	23	24468	76	416	1	0	0
50	Mehendiganj	31344	68	0	9268	30	21716	69	292	1
51	Mirsharai	49004	16928	35	2984	6	19072	39	10020	20
52	Mirzaganj	15436	4944	32	10392	67	28	0	72	0
53	Mollahat	20308	20308	100	0	0	0	0	0	0
54	Mongla	125776	33492	27	81064	64	11008	9	212	0
55	Morrelganj	41720	12904	31	28780	69	32	0	4	0
56	Muladi	20196	188	1	18280	91	1668	8	60	0
57	Nalchity	22180	2592	12	19544	88	32	0	12	0
58	Nazirpur	21604	16068	74	5536	26	0	0	0	0
59	Nesarabad (swarupkati)	17228	6484	38	10724	62	20	0	0	0
60	Noakhali Sadar (sudharam)	91800	4	0	4080	4	63980	70	23736	26

Table 3.2 (continued): Upazilas under inundation risk due to storm surge

SL No.	Name of Upzilla	Area, ha (excluding river)	Innundation							
			d*<=1m		1m>d*<=3m		3m>d*<=6m		d*>6m	
			Area, ha	%	Area, ha	%	Area, ha	%	Area, ha	%
61	Paikgachha	35264	33008	94	2180	6	64	0	12	0
62	Patharghata	22708	6304	28	10488	46	5852	26	64	0
63	Patiya	26580	9600	36	14748	55	2180	8	52	0
64	Patuakhali Sadar	40496	9156	23	31132	77	180	0	28	0
65	Pirojpur Sadar	23592	2488	11	20776	88	264	1	64	0
66	Rajapur	15416	3976	26	11368	74	72	0	0	0
67	Ramgati	40208	0	0	1484	4	36140	90	2584	6
68	Rampal	31012	26908	87	4092	13	12	0	0	0
69	Ramu	100	0	0	56	56	44	44	0	0
70	Roypur	19968	7576	38	9024	45	3136	16	232	1
71	Rupsa	9016	7940	88	1076	12	0	0	0	0
72	Sandwip	23676	0	0	12	0	11772	50	11892	50
73	Sarankhola	63796	1184	2	33560	53	28768	45	284	0
74	Shyamnagar	120388	82856	69	36576	30	844	1	112	0
75	Sitakunda	24652	12040	49	2040	8	9396	38	1176	5
76	Sonagazi	19952	0	0	48	0	16616	83	3288	16
77	Tazumuddin	17888	0	0	40	0	9236	52	8612	48
78	Tungi Para	12248	12248	100	0	0	0	0	0	0
79	Wazirpur	24140	19076	79	5052	21	0	0	12	0

*d is the depth of innundation

4. SPATIAL DISTRIBUTION MAP OF INFRASTRUCTURES

Spatial distribution map of infrastructures like schools, colleges, madrassas, hospitals, district headquarters, fire services, CPP offices and Red Crescent offices have been prepared based on the surveyed data. Figure 4.1 shows the distribution of the infrastructures in the coastal region of Bangladesh. Few sample plots of the spatial distribution map have been shown in district and upazila level in Figure 4.2 and Figure 4.3 respectively.

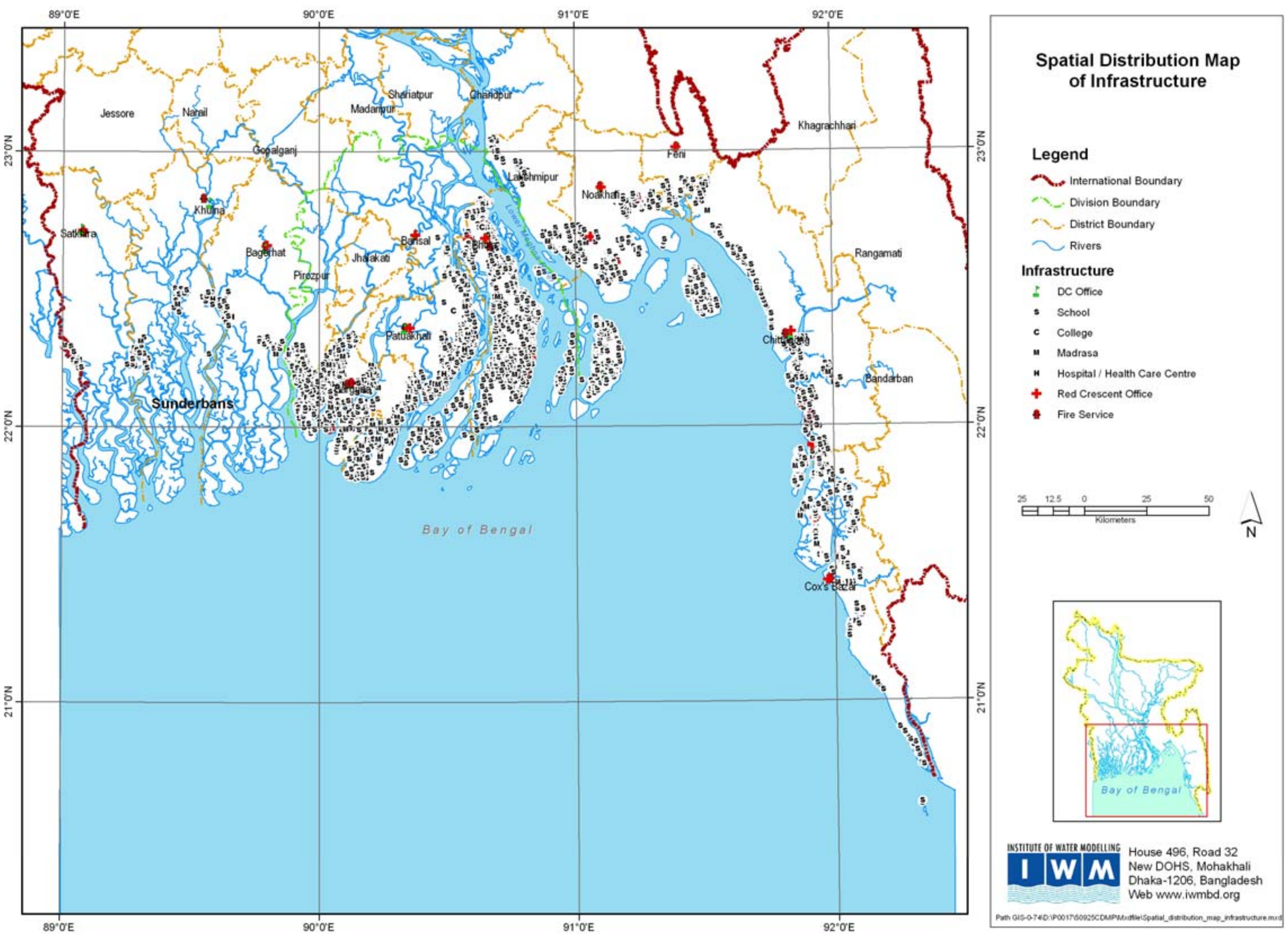


Figure 4.1: Spatial distribution map of infrastructures in the coastal region

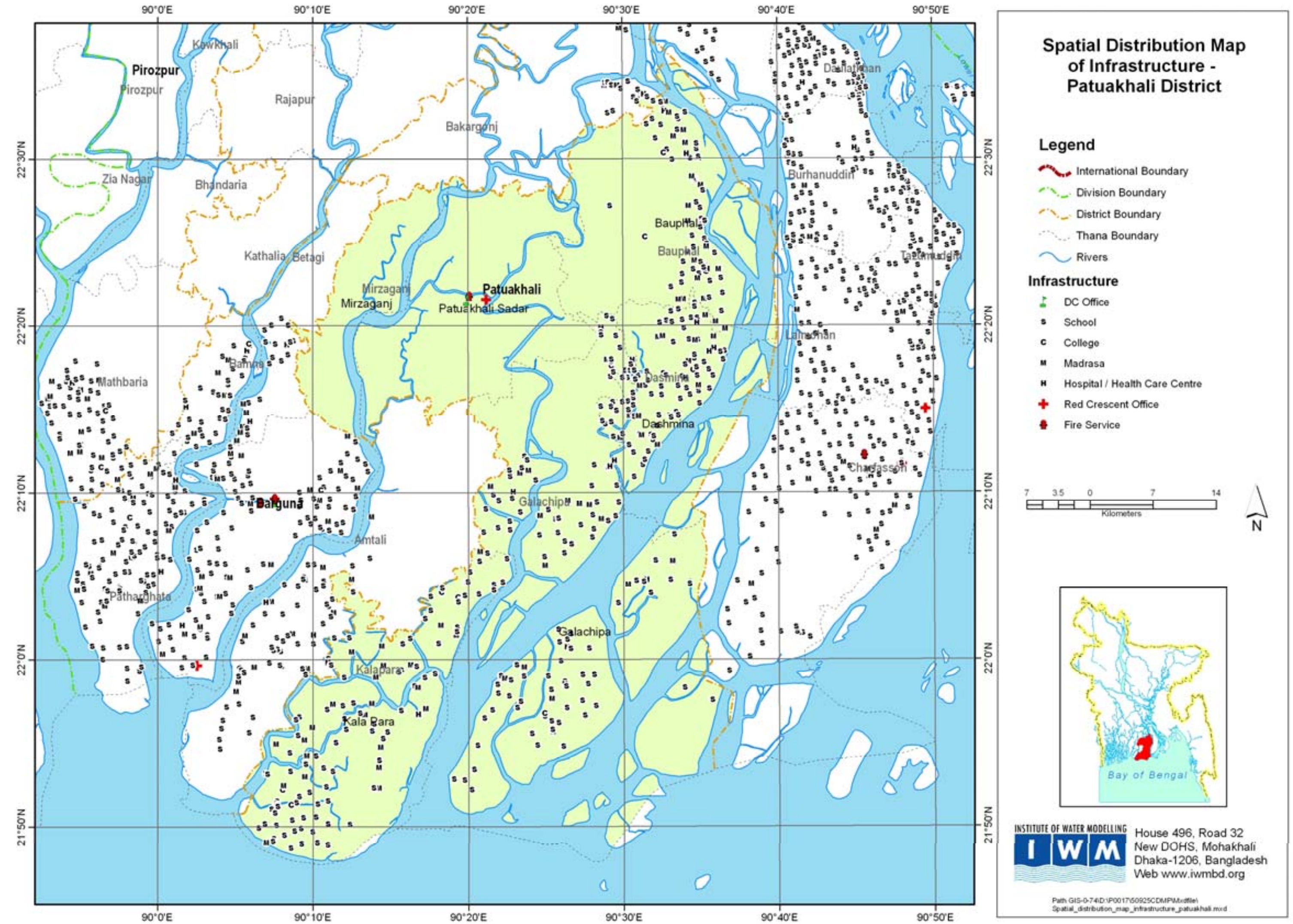


Figure 4.2: Spatial distribution of infrastructures in Patuakhali district

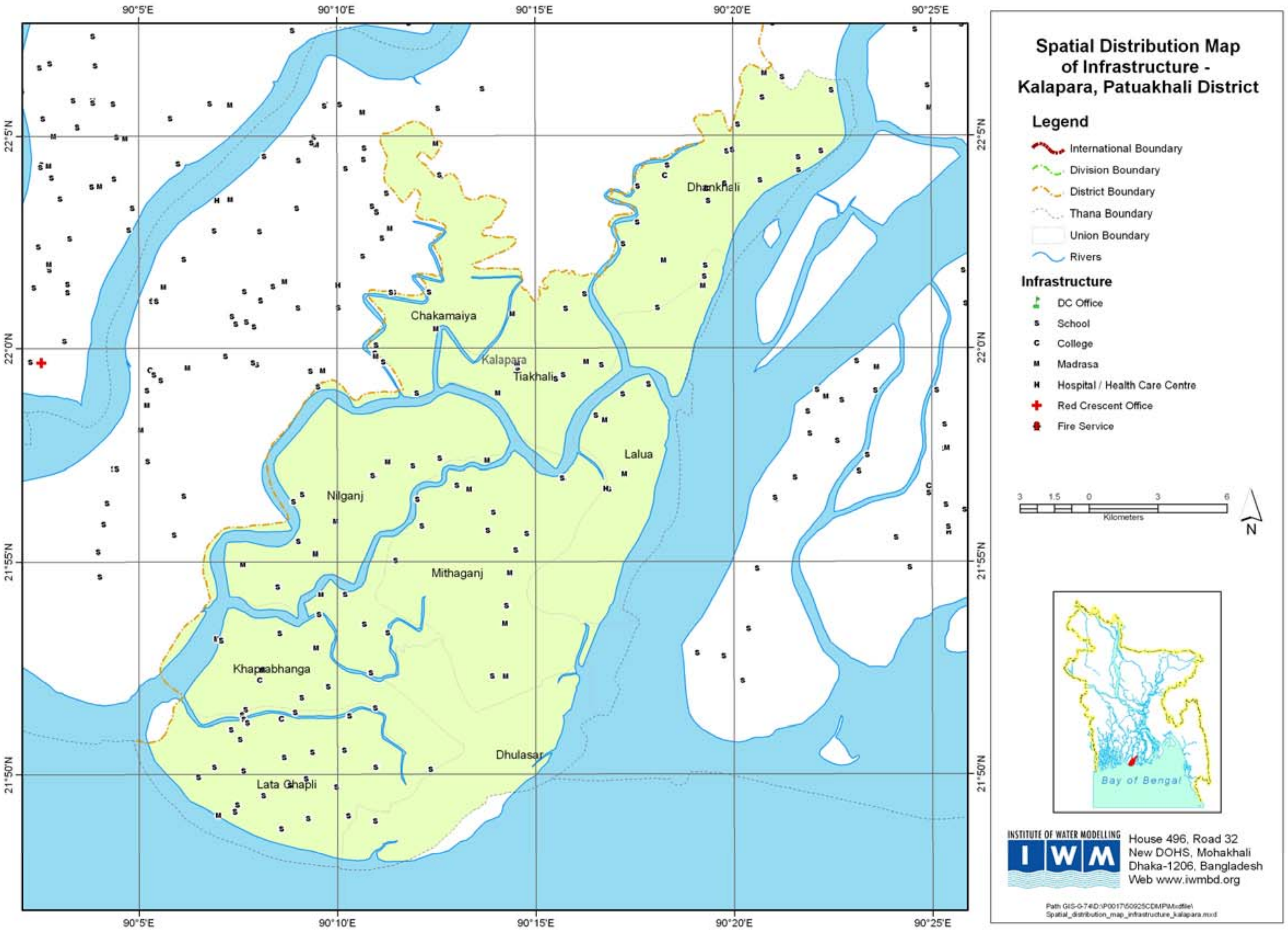


Figure 4.3: Spatial distribution of infrastructures in Kalapara upazila under Patuakhali district

5. LEVEL OF VULNERABILITY OF INFRASTRUCTURES

Inundation risk maps for tsunami and storm surge for the coastal region of Bangladesh prepared under another study of CDMP have been used in this study to generate spatial distribution maps of tsunami and storm surge vulnerable infrastructures using GIS tool.

In this study the level of vulnerability of infrastructures during tsunami and storm surge has been assessed based on the inundation depth of the infrastructure. The structures inundated by more than 1 meter fall under High Risk Area (HRA) according to the criteria of Multipurpose Cyclone Shelter Programme (MCSP, 1993). These structures may be considered vulnerable to tsunami or storm surge. The degree of vulnerability of the infrastructures has been assessed through structural strength analysis of different type of structures and described in the following chapters.

5.1 Tsunami Vulnerable Infrastructure

Spatial distribution map of tsunami vulnerable infrastructures have been prepared by superimposing all the locations of the infrastructures collected under the present study on the inundation risk map for tsunami. The special distribution map provides the maximum inundation depth, the building might experience during occurrence of tsunami.

Figure 5.1 shows the spatial distribution map of tsunami vulnerable infrastructures like schools, colleges, madrassas, hospitals, district headquarters, fire services, CPP offices and Red Crescent offices respectively. The spatial distribution maps of tsunami vulnerable infrastructures for all the affected districts are presented in **Appendix- B**. Figure 5.2 shows a sample plot of spatial distribution map of tsunami vulnerable infrastructures for Kalapara upazila under Patuakhali district. It shows that the impact of tsunami lies along the coast of Kalapara upazila. The infrastructures inside the polder of Kalapara upazila remain free from inundation.

A list of infrastructures with inundation information has been generated from the spatial distribution map of tsunami vulnerable infrastructures and presented in tables under **Appendix-C**. The list of infrastructures has been organized according to different inundation ranges.

The area of tsunami-vulnerable infrastructure has been identified and presented in Table 5.1. It shows that the maximum inundation depth greater than 3 m takes place in minor part of the Kutubdia island of Cox's Bazar district. The area inundated by more than 1 meter of water depth may be considered as High Risk Area (HRA) according to the criteria of Multipurpose Cyclone Shelter Programme (MCSP, 1993).

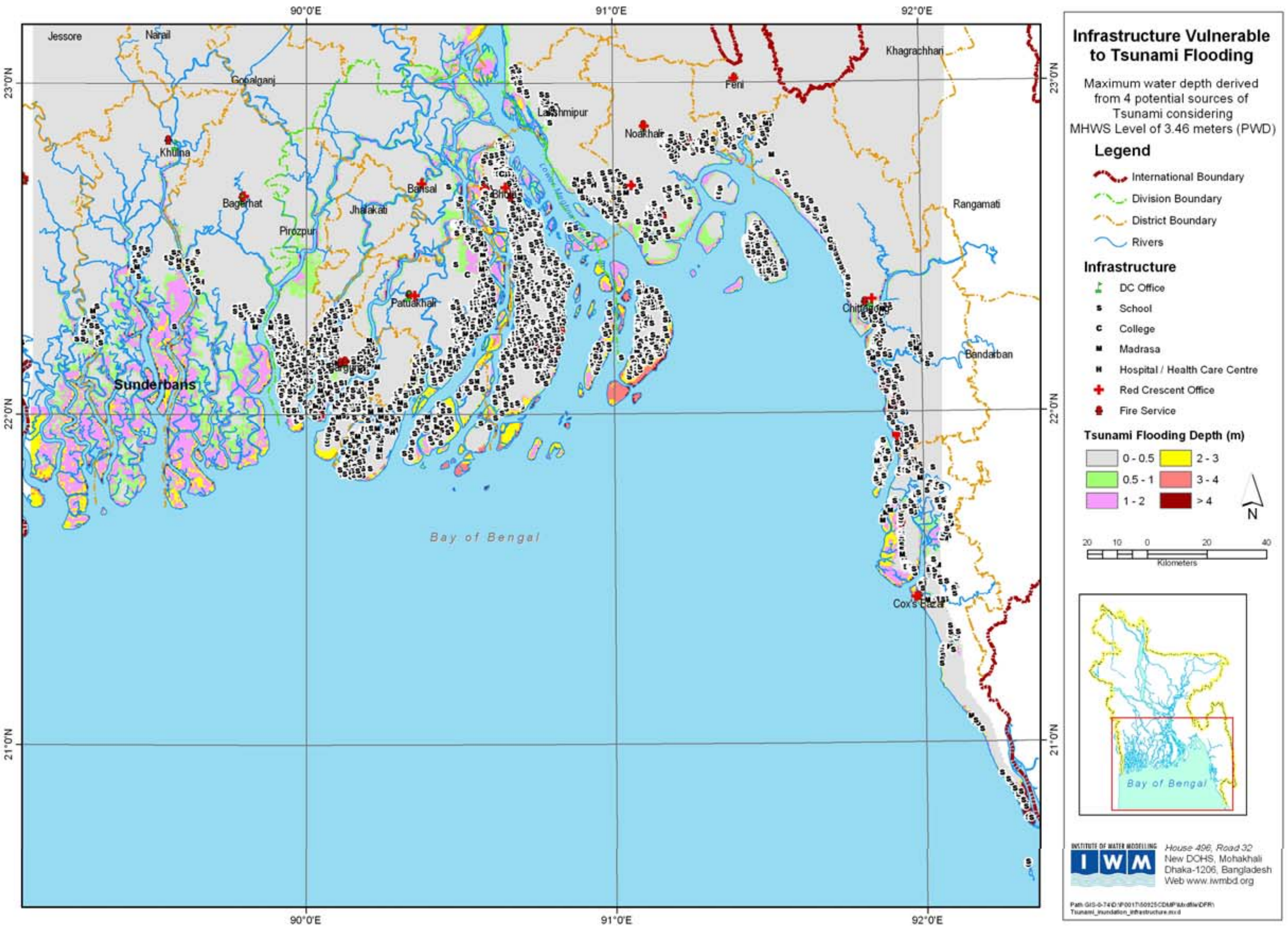


Figure 5.1: Spatial distribution map of tsunami vulnerable infrastructures

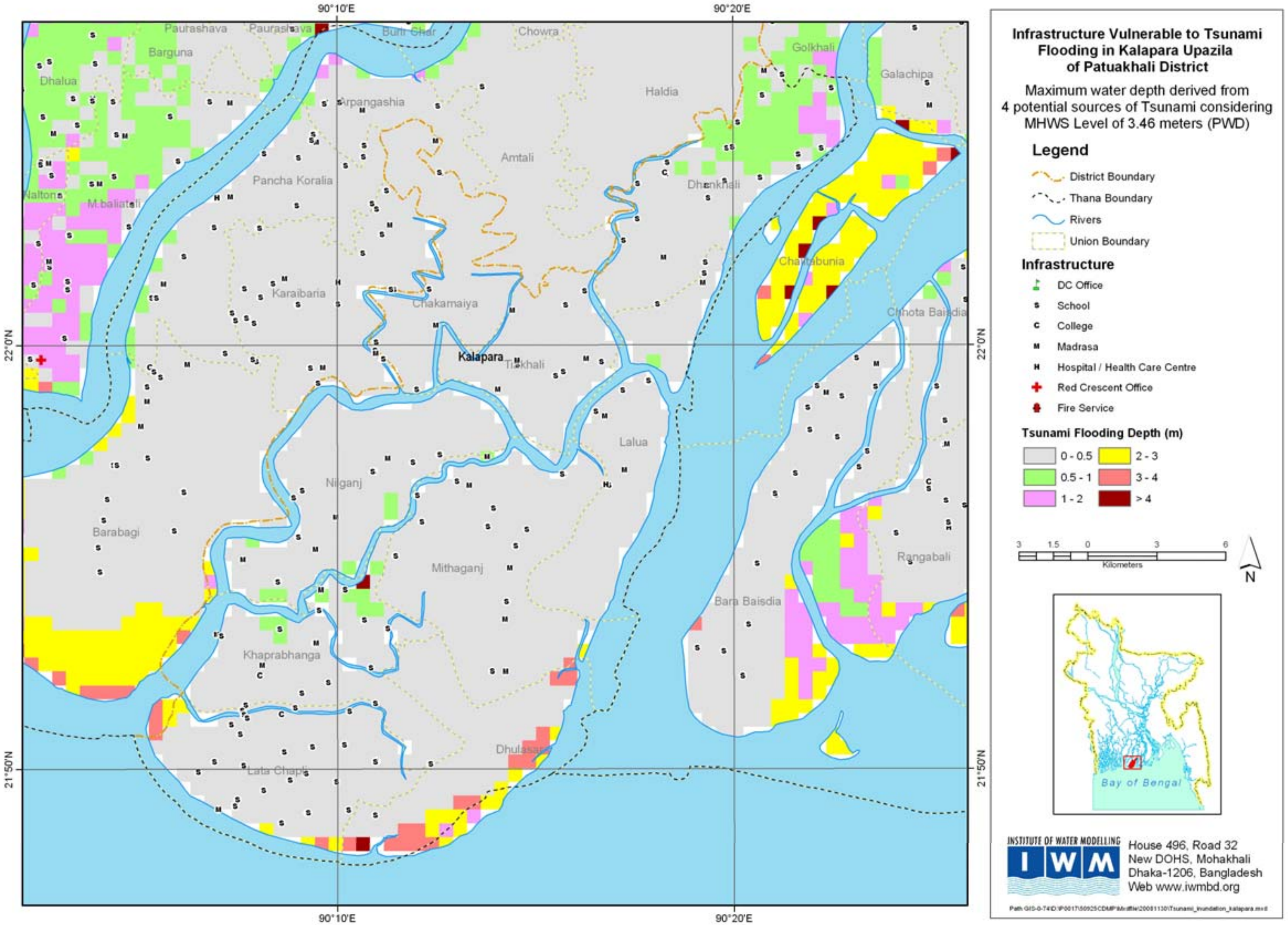


Figure 5.2: Spatial distribution map of tsunami vulnerable infrastructures for Kalapara upazila under Patuakhali district

Table 5.1: Area of Tsunami-vulnerable Infrastructure

Range of Inundation Depth (d)	***District***	***Upazila***
d < 1 m	Bagerhat	Sarankhola
	Baguna	Amtali, Bamna, Barguna Sadar (major part), Patharghata, Betagi
	Barisal	Bakerganj (part), Barisal Sadar (major part)
	Bhola	Bhola sadar (major part), Burhanuddin, Charfassion (major part), Daulatkhan (major part), Lalmohon, Manpura (part), Tazumuddin (part)
	Chittagong	Anwara, Bashkhali, Chittagong Port, Mirsharai, Patiya (major part), Sandwip (major part), Sitakunda (major part)
	Cox's Bazar	Chakaria (part), Cox's Bazar Sadar (major part), Kutubdia (major part), Moheskhali (major part)
	Lakshimpur	Lakshimpur Sadar , Ramgati (major part), Raipur
	Noakhali	Companiganj, Hatiya (major part), Noakhali Sadar (major part),
	Patuakhali	Bauphal (minor part), Dashmina (major part), Galachipa, Kalapara
	Pirojpur	Mathbaria (major part)
	Satkhira	Shyamnagar
1 m <d ≤ 3 m	Bagerhat	Mongla (part)
	Barguna	Barguna Sadar (minor part)
	Bhola	Charfassion (minor part), Monpura (partially),
	Chittagong	Bashkhali (minor part), Chandanaish, Patiya (minor part), Sandwip (minor part), Sitakunda (minor part)
	Cox's Bazar	Chakaria (part), Cox's Bazar Sadar (minor part), Kutubdia (minor part), Moheshkhali (minor part)
	Lakshimpur	Ramgati (minor part)
	Noakhali	Hatiya (minor part)
	Patuakhali	Bauphal (major part), Dashmina (minor part)
3 m < d ≤ 6 m	Cox's Bazar	Kutubdia (very minor part)

5.2 Storm Surge Vulnerable Infrastructure

Figure 5.3 shows the spatial distribution map of storm surge vulnerable infrastructures like schools, colleges, madrashas, hospitals, district headquarters, fire services, CPP offices and Red Crescent offices respectively. It has been prepared by superimposing all the building related data collected under the present study on the inundation risk map of the storm surge. The spatial distribution map provides the maximum inundation depth due to storm surge, the building might experience during the occurrence of storm surge. The spatial distribution maps of surge vulnerable infrastructures for all the affected districts are presented in **Appendix- B**. Figure 5.4 and Figure 5.5 show sample plots of spatial distribution map of storm surge vulnerable infrastructures for Patuakhali district and Kalapara upazila. It shows that the impact of storm surge is less at the Kalapara upazila.

A list of infrastructures with inundation information has been generated from the spatial distribution map of storm surge vulnerable infrastructures and presented in tables under **Appendix-C**. The list of infrastructures has been organized according to different inundation ranges.

The area of cyclonic surge-vulnerable infrastructure has been identified and presented in Table 5.2. It shows that maximum inundation depth greater than 6 m takes place partially in Bhola, Chittagong, Feni, Lakshmipur and Noakhali districts.

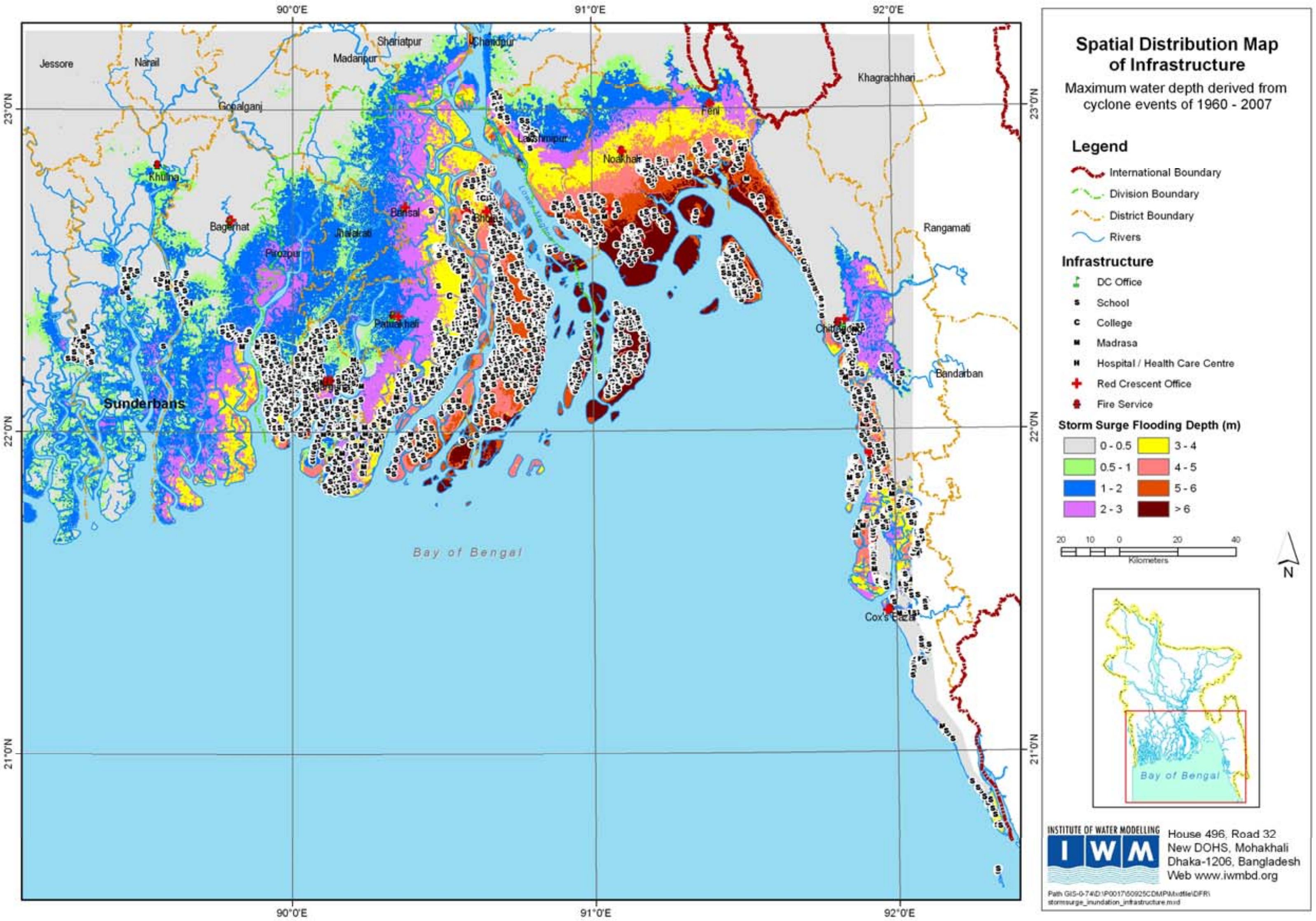


Figure 5.3: Spatial distribution map of storm surge vulnerable infrastructures for the coastal region.

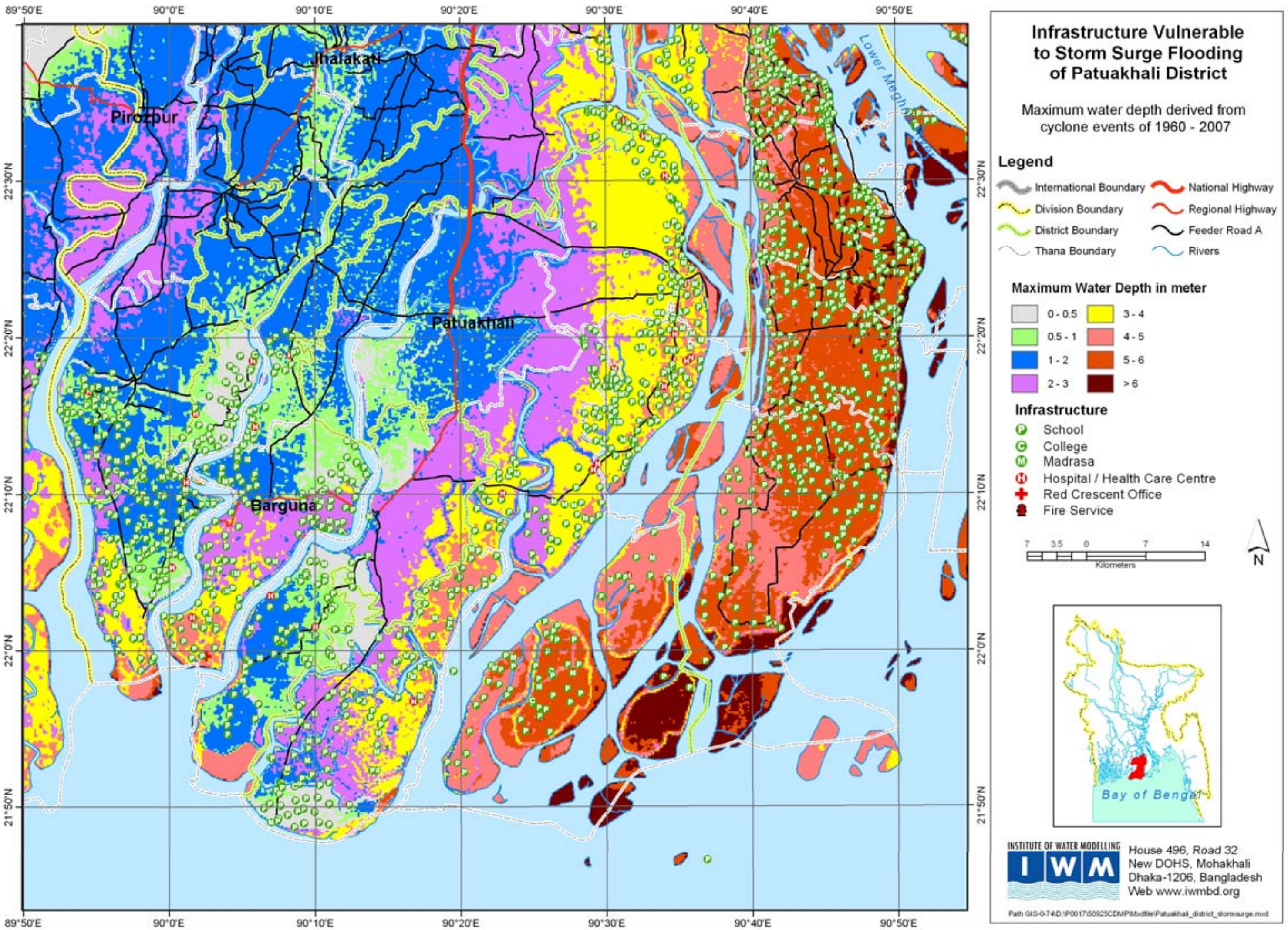


Figure 5.4: Spatial distribution map of storm surge vulnerable infrastructures for Patuakhali District.

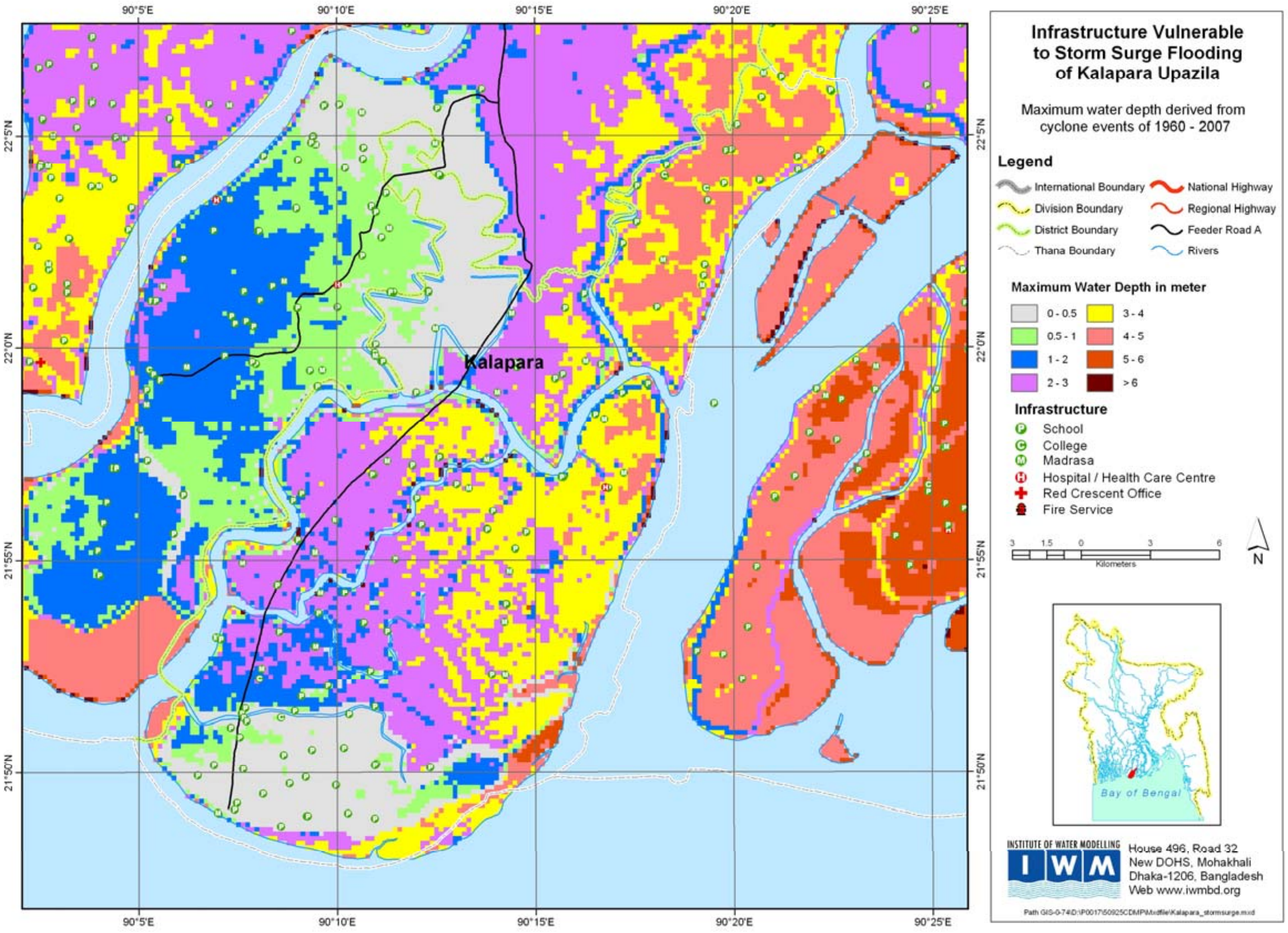


Figure 5.5: Spatial distribution map of storm surge vulnerable infrastructures for Kalapara upazila under Patuakhali District.

Table 5.2: Area of Cyclonic Surge-vulnerable Infrastructure

Range of Inundation Depth (d)	***District***	***Upazila***
d < 1 m	Bagerhat	Mongla (part) , Sarankhola (part)
	Barguna	Amtali (part), Bamna, Barguna Sadar, Patharghata, Betagi
	Chittagong	Anwara, Chandanaish, Chittagong Port, Sitakunda
	Cox's Bazar	Chakaria (minor part), Cox's Bazar (major part), Moheskhali (part)
	Khulna	Dacope, Koyra
	Lakshimpur	Raiipur
	Patuakhali	Kalapara
	Pirojpur	Mathbaria
	Satkhira	Shyamnagar
1 m<d ≤ 3 m	Bagerhat	Mongla (part), Sarankhola (part)
	Barguna	Amtali, Barguna Sadar , Patharghata, Betagi
	Barisal	Bakerganj, Barisal Sadar (part)
	Bhola	Bhola Sadar (minor part)
	Chittagong	Bashkhali (part), Chandanaish, Patia (part), Sitakunda , Chakaria (part)
	Cox's Bazar	Cox's Bazar, Kutubdia (part), Moheshkhali (part)
	Lashimpur	Lashimpur Sadar, Roypur
	Patuakhali	Galachipa (part), Kalapara (part)
	Pirojpur	Mathbaria (part)
3m <d ≤ 6m	Barguna	Barguna Sadar (part), Patharghata (minor part)
	Barisal	Bakerganj, Barisal Sadar (part)
	Bhola	Bhola Sadar (major part), Burhanuddin, Charfassion, Daulatkhan, Lalmohon, Tazumuddin (major part)
	Chittagong	Anwara, Bashkhali (major part), Mirsharai, Patiya (minor part), Sandwip (part), Sitakunda
	Cox',s Bazar	Chakoria, Kutubdia, (major part), Moheskhali (minor part)
	Feni	Feni Sadar (part), Sonagazi (major part)
	Lakshimpur	Ramgati (major part)
	Noakhali	Companyganj, Noakhali Sadar (major part)
	Patuakhali	Bauphal, Dashmina (major part), Galachipa (part) , Kalapara (part)
d > 6 m	Bhola	Daulatkhan (minor part), Lalmohon (minor part), Manpura, Tazumuddin (minor part)
	Chittagong	Sandwip (major part)
	Feni	Sonagazi (minor part)
	Lakshimpur	Ramgati (minor part)
	Noakhali	Hatiya (major part), Noakhali Sadar (minor part)

6. VULNERABLE INFRASTRUCTURE

The categories of infrastructure considering various occupancies are: Educational institution buildings (such as college, school, madrasha), hospital, fire service, CPP office, Red crescent office and emergency response buildings.

The detail information concerning location, type of structure, size, number of story, year of construction , present condition etc. for each category of structure have been collected by field survey from 245 unions under 46 upazilas of 13 districts located in high risk area (depth of inundation > 1.0m) in coastal region. The total numbers of surveyed infrastructure are 4707 nos. (i.e. college-100 nos, school-3130 nos, madrasha-449 nos, hospital/ FWC-99 nos, DC office-9 nos, fire service-11 nos and red crescent office-7 nos).

It can be mentioned that there are many schools now located in the cyclone shelters which have been constructed over tilts considering various surge height. This cyclone shelter-cum-school has not been considered under this study. Moreover, it can be further mentioned that there are many college, school and madrasha in which more than one building exists.

The details of survey for all infrastructures can be seen in data base. The Upazila wise number of each category of structure have been furnished in **Appendix-C**. The district wise category of total structure is given in Table 6.1 below.

Table 6.1: District wise number of infrastructure

District	Number of Infrastructure						
	College	School	Madrasha	Hospital/ FWC	DC Office	Fire service	Red crescent office
Cox's Bazar	17	226	75	20	1	1	1
Chittagong	42	695	76	20	1	2	3
Feni	42	695	76	20	1	1	1
Noakhali	7	272	37	6	1	1	1
Lakshimpur	1	211	28	10			
Bhola	2	654	25	3	1	3	1
Barisal		20	6	2			
Patuakhali	13	405	94	14	1		
Barguna	11	405	70	11	1	1	1
Pirojpur	4	72	12	3			
Bagherhat	3	62	6	2	1	1	
Khulna		39	4	4	1	1	
Satkhira		19	4	2			
Total	**100**	**3130**	**449**	**99**	**9**	**11**	**7**

The surveyed infrastructures include pucca (898 nos), semi pucca (387 nos), RCC frame (2661 nos), brick wall (99 nos) and tin shed (622 nos) type construction. The number of one story, two story and three story structures are 2726, 1522 and 419 nos respectively. Most of the structures are one story building. The details are given in Table 6.2.

Table 6.2: Details of surveyed infrastructures

District	Upazila	Type of structure						No of story		
		No of infrastructure	Pucca	Semi-pucca	RCC frame	Brick wall	Tin shed/ others	One	Two	Three
Cox's Bazar	Chakaria	162	11	16	124	1	10	87	44	31
	Sadar	85	3	18	61	1	2	47	19	19
	Kutubdia	106		4	98	1	3	23	69	14
	Maheskhali	131	1	21	99	2	8	67	50	14
	Ramu	23	2	5	16			11	9	3
	Teknaf	62	2	6	47	6	1	31	16	15
	Ukhia	22		4	18			9	9	4
Chittagong	Anowara	96	3	1	72	13	7	35	33	28
	Banshkhali	371	4		306	26	35	159	119	93
	Chandanaish	60	2	4	45	6	3	48	9	3
	Chittagong Port	4	2		2				3	1
	Mirsharai	80		1	72	4	3	42	22	16
	Patiya	102			71	20	11	74	24	4
	Sandwip	271		2	229	6	34	96	150	25
	Sitakunda	149		12	125	1	11	55	67	27
Feni	Sadar	3	1	1	1			1	1	1
	Sonagazi	81	7	11	52	1	10	49	30	2
Noakhali	Companiganj	70	1	16	46		7	44	22	4
	Hatiya	221	4	14	156		47	163	34	24
	Sadar	158	16	23	99		20	110	45	3
Laxmipur	Sadar	43	1	1	33		8	34	8	1
	Ramati	138	4	23	99		12	71	63	4
	Roypur	47	1	5	41		0	34	11	2
Bhola	Sadar	121	63	9	30	1	18	83	34	4
	Burhanuddin	105	60	5	31	1	8	69	35	1
	Charfasson	157	71	18	65		3	81	70	6
	Daulatkhan	103	45	10	38		10	56	45	2
	Lalmohan	133	51	7	72		3	57	66	10
	Manpura	37	24		8		5	25	11	1
	Tazumuddin	62	25	4	33		0	27	34	1
Barisal	Bakerganj	18	1	3	6		8	17	1	
	Sadar	15	1	7	4		3	10	3	2
Patuakhali	Bauphal	101	21	14	21		45	82	17	2
	Dashmina	125	50	6	8		61	89	28	8
	Galachipa	185	96	18			71	132	40	13
	Kala Para	171	17	9	100		45	112	50	9
	Sadar	3	1	1	1			1		2
Burguna	Amtali	90	12	20	48		10	66	23	1
	Bamna	56	8	7	32		9	41	14	1
	Sadar	169	57	15	53	1	43	141	22	6
	Betagi	36	13	5	8		10	31	4	1
	Patharghata	165	30	15	96	4	20	114	48	3
Pirojpur	Mathbaria	100	57	12	22		9	79	19	2
Bagerhat	Sadar	3	1		2				2	1
	Mongla	34	22	1	11			22	11	1
	Sarankhola	43	22	4	16		1	26	17	
Khulna	Dacope	46	23	2	17		4	31	15	
	Sadar	2	2						1	1
	Koyra	29	14	1	12		2	13	15	1
Satkhira	Sadar	3	2		1			1	1	1
	Shyam Nagar	70	44	6	14	4	2	30	39	1
Total		**4667**	**898**	**387**	**2661**	**99**	**622**	**2726**	**1522**	**419**

7. METHODS OF STRUCTURAL STRENGTH ANALYSIS

7.1 General Requirements

In coastal areas the buildings or structures should be designed to resist the effects of coastal floodwaters and tsunami/surge. The following factors must be considered for design of buildings to be used as tsunami/surge shelter:

- The shelter must be able to withstand seismic ground shaking that often precedes the tsunami attack: seismic ground shaking and tsunami attack are seldom concurrent;
- Tsunami shelters located near the shore must be evaluated both for resistance to structural and foundation failure;
- Shelter must provide sufficient floor space for evacuees above the base flood elevation. No matter how strong the shelter is, evacuees may drown if the shelter is submerged by the inundation;
- The shelter must withstand tsunami induced forces, including impact of water-borne missile;
- Tsunami often trigger fires, hence the shelter must be fire resistant; and
- Careful attention must be paid to evaluation of tsunami induced scour around the shelter's foundation.

In the present study, structural members in ground floor of existing buildings are required to be investigated because the tsunami/ surge forces are greatest at these levels, and these members carry the greatest loads. Failure of any of these members could lead to progressive collapse of significant portion or whole of the building.

7.2 Methods and Steps of Analysis

The following ten steps procedure have been followed for structural strength and foundation analysis and evaluation of capacity of existing vulnerable infrastructure/building for tsunami/surge force/loads.

Step -1: Select building type representative to a particular category and collect information related to type of structure, type of foundation, adopted design criteria, construction drawing etc.

Step -2: Select design inundation depth and flow velocity relevant to the structure which are the two important parameters considering external force imparted to structures by tsunami /surge waves.

Step -3: Compute various types of tsunami/surge loads/forces using various available empirical formulae and prepare various force/load combinations.

Step -4: Calculate base shear for the entire structure.

Step -5: Calculate forces on the structural members such as column, wall and beam for each combination of surge/tsunami force/load.

Step - 6: Compute the maximum bending moment and shear for structural member for each load combination and select the maximum one out of several combinations.

Step -7: Calculate the actual strength of the members from structural section properties and reinforcing steel layout using the as-built drawings of concerned structure.

Step - 8: Compare the resisting capacity of members with the computed moment and shear and comment on the structural safety.

Step – 9: Compute the tsunami/surge induced scour around the foundation of building;

Step -10: Evaluate the foundation stability of structure considering the type of foundation used and computed scour.

8. STRUCTURAL STRENGTH REQUIREMENTS

8.1 Design Codes

In general, Bangladesh National Building Code, 1993 has been followed for selection/computation of loads and analysis of structural members.

The Washington Division of Geology and Earth Resources has prepared Open File Report 2005-4, November 2005, titled "*Development of Design Guidelines for Structures that Serve as Tsunami Vertical Evacuation Site*" (52-AB-NR-200051) by Harry Yah - Oregon State University, Ian Robertson - University of Hawaii and Jane Preuss - Plant West Partners.

The following design codes as mentioned in aforementioned design guideline with respect to computation of tsunami loads have been used for this study:

1. The City and Country of Honolulu Building Code (CHH)
2. The Federal Emergency Management Agency Coastal Construction Manual (FEMA CCM)
3. The ASCE 7-98 (ASCE 7) authored by the American Society of Civil Engineers Committee 7 (ASCE 7).

8.2 Design Loads

Load on buildings include, dead load, live load, wind load, hydraulic (storm surge/tsunami) load, earthquake loads etc. and their various combinations. The dead load, live load and wind loads as specified in the Bangladesh National Building Code, 1993 are presented below.

8.2.1 Dead Load

Dead load is the vertical load due to the weight of permanent structural and nonstructural components of a building, such as walls, floor, ceilings, permanent partitions and fixed service equipments. In estimating dead load the following (Table 8.1) unit weight of materials and constructions shall be used.

Table 8.1: Unit Weight of Different Materials

Material	Unit Weight
Brick	18.9 kN/m^3
Cement	14.7 kN/m^3
Concrete - stone aggregate (unreinforced)	22.8 kN/m^3
- brick aggregate (unreinforced)	20.4 kN/m^3
(For reinforced concrete, 0.63 kN/ m^3 for each 1% by volume of main reinforcement to be added)	
Iron - cast	70.7 kN/m^3
- wrought	75.4 kN/m^3
Steel	77.0 kN/m^3
Sand - dry	15.7 kN/m^3
Soil - dry	15.7 kN/m^3
- moist	17.3 kN/m^3
- saturated	18.9 kN/m^3
Concrete slab - 100 mm thick	2.36 kN/m^2

- 150 mm thick	3.54 kN/m^2
Corrugated galvanized steel sheet - 1.0 mm thick	0.120 kN/m^2
- 0.8 mm thick	0.096 kN/m^2
- 0.6 mm thick	0.077 kN/m^2
Cement plaster - 10 mm thick	0.191 kN/m^2
Timber	5.9 – 11.0 kN/m^3
Water - fresh	9.80 kN/m^3
- sea	10.10 kN/m^3

1 kN = 0.2248 kips = 102 kg.

8.2.2 Live Load

As a general requirement uniformly distributed live load shall not be less than as shown Table 8.2 below.

Table 8.2: Uniformly Distributed Live Loads

Occupancy	Category	Use of floor	*w*, kN/m^2
Residential	a) One or two family dwelling	1. Room, internal corridor, private stair.	2.0
		2. External stair corridor	3.0
	b) Hotels, hostels, boarding houses, flat apartments, bungalows	1. Bed room, living room, bathroom, toilet, dressing room.	2.0
		2. Office room	2.5
		3. Cafeteria, restaurant, kitchen, laundry, lobby, lounge, game room, dining hall, balcony.	3.0
		4. Corridor, retail store, staircase.	4.0
		5. Store room.	5.0
		6. Garage, car parking floor, ramp.	2.5
Institutional, Educational, Health-Care	School, college, university, penal institutions, hospitals, clinics.	1. Bed room, toilet, dressing room, wards and cabins, cell blocks of jail.	2.0
		2. Office room, staff room.	2.5
		3. Operating room, utility room, reading room.	2.5
		4. Class room, lecture room, cafeteria, lounge, restaurant.	3.0
		5. Laboratory, kitchen, laundry.	3.0
		6. Balcony, corridor, lobby, reading room with book storage, stair case.	4.0
		7. Assembly area, fire escape, store room, projection room.	5.0
		8. Stack room for books.	6.5
Business, Mercantile	a) Office, bank, laboratory.	1. General office room, banking hall	3.0
		2. Laboratory, kitchen.	3.0
		3. Computer, business machine room.	3.5
		4. File room, filing and storage space.	6.0
			5.0

Occupancy	Category	Use of floor	w, kN/m^2
		5. Vaults in office and bank. 6. Telephone exchange.	6.0
	b) Shops, markets, departmental stores.	1. Retail room 2. Whole sale store. 3. Light storage 4. Heavy storage	4.0 6.0 6.0 12.0

However, for cyclone shelters the final report of Multipurpose Cyclone Shelter Programme, 1993 proposes that live load on floors and roof shall be 4.8 kN/m^2 minimum and no live load reduction shall be made.

Provision for Partition Walls: When partitions, not shown in the plan, are anticipated to be placed on the floor, then if the total weight per meter run is not greater than 5.5 kN, a uniformly distributed live load per square meter shall be 33% of the weight per meter run of the partition wall, subject to a minimum of 1.2 kN/m^2.

Minimum Roof Live Loads : The minimum live load on roof shall not be less than a) Flat roof (slope = 0) 1.5 kN/m^2, b) Green house and agricultural building 0.5 kN/m^2.

Roofs Used for Special Purposes : For special purpose roofs, live load shall be estimated based on the actual weight depending on the type of use, but shall not be less than the following values:

a) Roofs used for promenade purposes - 3.0 kN/m^2
b) Roofs used for assembly purposes - 5.0 kN/m^2
c) Roofs used for gardens - 3.0 kN/m^2
d) Roofs used for other special purposes - loads resulting from probable use.

8.2.3 Wind Load

The minimum wind load on buildings and components thereof, shall be determined based on the velocity of wind, shape and size if the building and the terrain exposure condition.

Terrain Exposures: The terrain exposure in which the building or structure to be sited shall be assessed as being one of the following categories:

a) Exposure A : Urban and sub urban areas, industrial areas, wooded areas, hilly or other terrain covering at least 20% of the area with obstructions of 6 meter or more in height and extending from the site at least 500 meters or 10 times the height of the structure, whichever is greater.

b) Exposure B : Open terrain with scattered obstructions having heights generally less than 10 meters extending 800 meters or more from the site in any full quadrant. This category include air fields, open park lands, sparsely built up out skirts of town, flat open country and grasslands.

c) Exposure C : Flat and unobstructed open terrain, coastal areas and river side facing large bodies of water, over 1.5 km or more in width. Exposure C extends inlands from the shoreline 400 meters or 10 times the height of structure, whichever is greater.

Basic Wind Load: The minimum design wind load on buildings, structures and components thereof shall be calculated taking the following effects:

i) Equivalent static pressure or suction on building surface arising due to sustained or mean wind velocity,

ii) Variation of the mean wind velocity, and hence the pressure, along the height above the ground.

iii) Terrain exposure of the building site.

iv) Configuration and dynamic response characteristics of the building or structure.

v) Occupancy importance of the building.

vi) Magnification of the mean wind pressure due to the effects of the fluctuating component of wind speed.

vii) Additional load amplification resulting from the dynamic wind-structure interaction effects due to gusts on slender buildings and structures.

Sustained Wind Pressure: The sustained wind pressure, q_z on a building surface at any height z above the ground shall be calculated from the following relation:

$$q_z = C_c\, C_I\, C_z\, V_b^2$$

Where,
q_z = Sustained wind pressure at height z, kN/m^2
C_c = Velocity to pressure conversion coefficient = 47.2 x 10^{-6}
C_I = Structure importance coefficient (0.80 – 1.25 depending on structure category)
C_z = Combined height and exposure coefficient (for height above the ground, z = 0 - 300 meters, C_z = 0.386 – 2.362 for exposure A, 0.801 – 2.647 for exposure B and 1.196 – 2.762 for exposure C)
V_b = Basic wind speed in km/h (from basic wind speed map for 50 year return period).

Design Wind Pressure: The design wind pressure, p_z for a structure or an element of a structure at any height z above the ground shall be determined from the following relation:

$$p_z = C_G\, C_p\, q_z$$

Where,
p_z = Design wind pressure at height z, kN/m^2
C_G = Gust coefficient which shall be G_z, G_h or $\bar{G}$

where, G_h = Gust response factor for non-slender buildings and structures at height h above mean ground level. The height h shall be defined as the mean roof level or the top of the parapet, which ever is greater.

G_z = Gust response factor for buildings and components and claddings evaluated at height z above the ground at which the component or cladding under consideration is located on the structure.

$\bar{G}$ = Gust response factor for the primary framing system of slender buildings and structures.

C_p = Pressure coefficient for structures or components. The values of C_p shall be used as:

a) C_{pe} = External pressure coefficient for walls and roof.

b) C'_{pi} = Internal peak pressure coefficient for the external surface of individual components and claddings on walls and roof.

c) C'_{pe} = External peak pressure coefficient for the external surface of individual components and claddings on walls and roof.

d) $\overline{G}_p$ = Overall pressure coefficient for various cross sectional shape of the building

q_z = Sustained wind pressure at height z, kN/m^2

Design Wind Load for Buildings and Structures: Design wind load on the main wind force resisting systems of buildings and structures shall be determined by using one of the following two methods.

a) Method 1 (Surface Area Method): The surface area method shall be used for gabled rigid frames and single storey rigid frames and may be used for other framing systems. In this method the design wind pressure shall be assumed to act simultaneously normal to all exterior surfaces including roof of building or structure. The force F_1, acting normal to the building surfaces or roof, shall be calculated as follows:

i) For all framing systems:

$$F_1 = \square p A_z$$

Where,

F_1 = Wind force on primary framing system acting normal to a building surfaces or roof or a part thereof.

p = Design wind pressure on building surface, kN/m^2
= p_z for wind ward surface (obtained above in Design Wind Pressure)
= p_h for non-wind ward surface (obtained above in Design Wind Pressure)

A_z = Area of the building surface or roof tributary to the framing system at height z upon which the design pressure p operates, in m^2.

ii) For gabled frames and single storey rigid frames:

$$F_1 = \square p - p_i)\ A_z$$

Where,

p_i = Internal pressure = $C'_{pi}\, q_h$.
C'_{pi} = Internal peak pressure coefficient
q_h = Sustained wind pressure evaluated at mean roof height.

Design Wind Load for Components and Claddings: Design wind load on individual structural component such as roofs, walls, and individual cladding units and their immediate supporting members and fixings of enclosed buildings and structures shall be determined in accordance with the following relation:

$$F' = \square\ (\, C'_{pe}\, q - C'_{pi}\, q\,)\ A_z$$

Where,

F' = Total wind force on building component perpendicular to the surface.
C'_{pe} = External peak pressure coefficient for components
C'_{pi} = Internal peak pressure coefficient

q = Sustained wind pressure acting on external surface of the building.
q_i = Wind pressure developed at the interior of the building.
A_z = Area of the building surface or roof tributary at height z upon which F' acts.

The pressures q and q_i shall be determined as follows:

For $h \leq 18$ m: $q = q_h$ and $q_i = q_h$.

For $h > 18$ m: $q = q_z$ for +ve values of C'_{pe}
$q = q_h$ for -ve values of C'_{pe}
$q_i = q_z$ for all values of C_{pe}.

If the peak pressure coefficient C'_{pe} and C'_{pi} are not provided, the following equation may be used for determining the wind forces on structural components:

$$F' = \pm 1.25 \; p_z \bar{A}_z$$

Where, p_z = Design wind pressure on components, kN/m^2.
$\bar{A}_z$ = Projected area of the component normal to wind at level, z, in m^2.

8.2.4 Storm Surge/Tsunami Load

There are significant differences in physical conditions between tsunami and other floods. For a typical tsunami, the water surface fluctuates near the shore with amplitude of several meters during a period of a few to tens of minutes. This timescale is intermediate between the hours to days typical of riverine floods, and the tens of seconds or less associated with cyclic loading of storm waves. In short, these may be categorized as:

Tsunami : amplitude of several meters during a period of a few to tens of minutes;
Riverine floods : timescale is intermediate between the hours to days and
Storm surge : timescale is tens of seconds or less associated with cyclic loading.

The associated forces to be considered in the structural design considering tsunami wave are:

Hydrostatic Forces : Hydrostatic forces occur when standing or slowly moving water encounters a building or building component. Hydrostatic loads can act laterally on an object. This load always acts perpendicular to the surface to which it is applied. It is caused by an imbalance of pressure due to a differential water depth on opposite sides of a structure or structural member.

Buoyant Forces : The buoyant or vertical hydrostatic forces on a structure or structural member subject to partial or total submergence will act vertically through the center of mass of the displaced volume. Buoyant forces are a concern for basements, empty above-ground and belowground tanks, and for swimming pools. Any buoyant force on an object must be resisted by the weight of the object and any opposing force resisting flotation.

Hydrodynamic Forces : When water flows around a building (or structural element or other object) hydrodynamic loads are applied to the building. These loads are a function of flow velocity and structure geometry, and include frontal impact on the upstream face, drag along the sides, and suction on the downstream side. These loads are induced by the flow of water moving at moderate to high velocity. They are usually called the drag forces, which are combination of the lateral loads caused by the impact of the moving mass of water and the friction forces as the water flows around the obstruction.

Surge Forces : Surge forces are caused by the leading edge of a surge of water impinging on a structure. The surge force is computed as a force per unit width on a vertical wall subjected to a surge from the leading edge of a tsunami.

Impact Forces : Impact loads are those that result from debris such as driftwood, small boats, portions of houses, etc., or any object transported by floodwaters, striking against buildings and structures or parts thereof. The magnitude of these loads is very difficult to predict, yet some reasonable allowance must be made for them. The velocity of water borne objects are assumed to be the same as the flood velocity. The object is assumed to be at or near the water surface level when it strikes the building. Therefore, the object is assumed to strike the building at the water level. Uncertainty about the duration of the impact time is the most likely cause of error in the calculation of debris impact loads. According to Chopra (1995), the duration of impact is influenced primarily by the natural frequency of the building, which is a function of the building's "stiffness." This stiffness is determined by the properties of the material being struck by the object, the number of supporting members (columns or piles), the height of the building above the ground, and the height at which the building is struck.

Breaking Wave Forces : Two breaking wave load conditions are of interest in construction; waves breaking on small-diameter vertical elements (e.g., piles, columns in the foundation of a building in V zones) and waves breaking against walls (e.g., breakaway walls in V zones). Breaking wave forces are modified in instances where the walls or surfaces upon which the breaking waves act are non-vertical. Breaking waves that are obliquely incident and not perpendicular to the wall result in a lower force. The net force resulting from breaking wave acting on a rigid vertical pile or column is assumed to act at the still water elevation. A wave breaking against a vertical wall causes a reflected or standing wave to form against the seaward side of the wall. The crest of the wave is some height above the still water elevation. Two cases are considered: (1) where a wave breaks against a vertical wall of an enclosed dry space, and (2) where the still water level on both sides of the wall is equal. Case 1 is equivalent to a wave breaking against an enclosure in which there is no floodwater below the still water level. Case 2 is equivalent to a wave breaking against a wall with openings that allow floodwaters to equalize on both sides of the wall.

8.3 Tsunami and Storm Surge Inundation Depth Data

District and Upazila wise inundation depth maps have been furnished in **Appendix-B** of this report. The numbers of infrastructures under each category of inundation depth have been identified and shown in Table 8.3 and Table 8.4 for Tsunami and surge vulnerability respectively.

Table 8.3: Infrastructures vulnerable to Tsunami

Inundation Depth (number of structure)	**District** (number of structure)	**Upazila** (number of structure)
d < 1 m (1130)	Bagerhat (28)	Sarankhola (9), Mongla (19)
	Barguna (188)	Amtali (19), Bamna (16), Barguna Sadar (97), Patharghata (33), Betagi (23)
	Barisal (28)	Bakerganj (16), Barisal Sadar (12)
	Bhola (204)	Bhola sadar (59), Burhanuddin (17), Char Fasson (18), Daulatkhan (53), Lalmohon (25), Manpura (8), Tazumuddin (24)
	Chittagong (133)	Anwara (15), Banshkhali (28), Chittagong Port (1), Mirsharai (2), Patiya (21), Sandwip (44), Sitakunda (22)
	Cox's Bazar (180)	Chakaria (23), Cox's Bazar Sadar (15), Kutubdia (66), Moheskhali (76)
	Feni (1)	Sonagazi (1)
	Khulna (13)	Dacope (7), Koyra (6)
	Lakshimpur (66)	Lakshmipur Sadar (3), Ramgati (36), Raipur (27)
	Noakhali (74)	Companiganj (3), Hatiya (63), Noakhali Sadar (8)
	Patuakhali (142)	Bauphal (31), Dashmina (12), Galachipa (55), Kalapara (44)
	Pirojpur (69)	Mathbaria (69)
	Satkhira (4)	Shyamnagar (4)
1 m <d ≤ 3 m (153)	Barguna (20)	Barguna Sadar (20)
	Bhola (19)	Bhola sadar (8), Monpura (11)
	Chittagong (7)	Bashkhali (2), Chandanaish (1), Sitakunda (4)
	Cox's Bazar (32)	Chakaria (9), Cox's Bazar Sadar (3), Kutubdia (11), Moheshkhali (9)
	Khulna (4)	Dacope (3), Koyra (1)
	Lakshimpur (10)	Ramgati (10)
	Noakhali (5)	Hatiya (5)
	Patuakhali (50)	Bauphal (44), Dashmina (6)
3 m < d ≤ 6 m (14)	Chittagong (1)	Banshkhali (1)
	Cox's Bazar (6)	Kutubdia (6)
	Feni (2)	Sonagazi (2)
	Noakhali (3)	Noakhali Sadar (3)
	Patuakhali (2)	Bauphal (2)

Table 8.4: Infrastructures vulnerable to Storm Surge

Inundation Depth (number of structure)	**District** (number of structure)	**Upazila** (number of structure)
d < 1 m (430)	Bagerhat (19)	Bagarhat Sadar (2), Mongla (12), Sarankhola (5)
	Barguna (208)	Amtali (47), Bamna (44), Barguna Sadar (26), Patharghata (65), Betagi (26)
	Barisal (1)	Barisal Sadar (1)
	Bhola (1)	Bhola Sadar (1)
	Chittagong (29)	Anwara (7), Chandanaish (10), Chittagong Port (4), Sitakunda (6), Patitya (1), Sandwip (1)
	Cox's Bazar (34)	Chakaria (4), Cox's Bazar (24), Moheskhali (6)
	Khulna (38)	Dacope (23), Khulna Sadar (2) , Koyra (13)
	Lakshmipur (8)	Raipur (8)
	Patuakhali (35)	Kalapara (34), Patuakhali Sadar (1)
	Pirojpur (47)	Mathbaria (47)
	Satkhira (10)	Shyamnagar (10)
1 m<d ≤ 3 m (699)	Bagerhat (38)	Mongla (11), Sarankhola (27)
	Barguna (185)	Amtali (31), Bamna (1) , Barguna Sadar (87) , Patharghata (61), Betagi (5)
	Barisal (7)	Bakerganj (1), Barisal Sadar (6)
	Bhola (36)	Bhola Sadar (31),Char Fasson (1), Daulatkhan (3), Tazumuddin (1)
	Chittagong (123)	Anowara (1), Bashkhali (13), Chandanaish (26), Patia (31), Chakaria (28), Sandwip (1), Sitakunda (23)
	Cox's Bazar (82)	Cox's Bazar (29), Kutubdia (15), Moheshkhali (38)

	Feni (2)	Feni Sadar (1), Sonagazi (1)
	Khulna (1)	Dacope (1)
	Lakshmipur (74)	Lakshmipur Sadar (39), Ramgati (2), Raipur (33)
	Noakhali (1)	Noakhali Sadar (1)
	Patuakhali (102)	Bauphal (3), Galachipa (45), Kalapara (50), Dasmina (4)
	Pirojpur (48)	Mathbaria (48)
3m <d ≤ 6m (1837)	Barguna (45)	Barguna Sadar (34), Patharghata (11)
	Barisal (22)	Bakerganj (15), Barisal Sadar (7)
	Bhola (587)	Bhola Sadar (79), Burhanuddin (94), Charfassion (144), Daulatkhan (92), Lalmohon (123), Manpura (3), Tazumuddin (52)
	Chittagong (269)	Anwara (27), Bashkhali (74), Mirsharai (47), Patiya (10), Sandwip (79), Sitakunda (32)
	Cox's Bazar (206)	Cox's Bazar (2), Chakoria (68), Kutubdia, (68), Moheskhali (68)
	Feni (61)	Feni Sadar (1), Sonagazi (60)
	Lakshimpur (100)	Ramgati (100)
	Noakhali (215)	Companyganj (62), Hatiya (46) , Noakhali Sadar (107)
	Patuakhali (332)	Bauphal (88), Dashmina (95), Galachipa (113), Kalapara (36)
d > 6 m (338)	Bhola (39)	Daulatkhan (4), Lalmohon (2), Manpura (27), Tazumuddin (6)
	Chittagong (92)	Sandwip (90), Mirshari (2)
	Feni (3)	Sonagazi (3)
	Lakshmipur (9)	Ramgati (9)
	Noakhali (192)	Hatiya (157), Noakhali Sadar (35)
	Patuakhali (3)	Bauphal (2), Dasmina (1)

8.4 Tsunami/ Surge Design Code Equations

Hydrostatic Force: The CCH and FEMA CCM provide similar expressions for lateral hydrostatic force. The CCH equation includes a velocity head while the FEMA CCM does not include the velocity head. The CCH equation was selected because it is somewhat more conservative.

It has been noted (Dames and Moore, 1980) that hydrostatic forces are normally relatively small compared to surge and drag forces for the case of bore-like tsunamis, however for tsunamis that act as a rapidly rising tide, the hydrostatic forces generally become increasingly important. This equation does not include the direct drag at the top of a wall when the wall is less than *h* in height.

$$F_h = \frac{1}{2}\rho g\left(h + \frac{u_p^{\,2}}{2g}\right)^2$$

where,

F_h = hydrostatic force on a wall, per unit width of wall,
ρ. = water density,
g = gravitational acceleration,
h = water depth, and
u_p = velocity component normal to the wall.

The resultant force will act horizontally at a distance of h_R above the base of the wall where: $h_R = \frac{1}{3}\left(h + \frac{u_p^{\,2}}{2g}\right)^2$

Buoyant Force

All codes provided the same expression for buoyant force, F_b:

$$F_b = \rho g V$$

where V is the volume of water displaced by the building.

Design Flood Velocity

FEMA CCM and CCH provide the following estimate of the flood velocity u in the surge depth ds, based on Dames and Moore (1980):

$$u = 2\sqrt{g d_s}$$

Hydrodynamic Force

Both CCH and FEMA CCM provide the following expression for hydrodynamic force (drag force) Fd:

$$F_d = \frac{1}{2} \rho C_d A u_p^{\ 2}$$

Where:

C_d = drag coefficient, and
A = projected area of the body on the plane normal to the flow direction.

The CCH recommends:

C_d = 1.0 for circular piles, 2.0 for square piles and 1.5 for wall sections.

The FEMA CCM recommends:

C_d = 2.0 for square or rectangular piles and 1.2 for round piles.

In addition, Table 8.5 is given for the drag coefficients for larger obstructions.

Table 8.5: The drag coefficient recommended by FEMA CCM

Width to Depth Ratio (w/d_s or w/h)	Drag Coefficient, Cd
1-12	1.25
13-20	1.3
21-32	1.4
33-40	1.5
41-80	1.75
81-120	1.8
>120	2

Surge Force

The CCH adopted the following equation (Dames & Moore, 1980) for surge force F_s.

$$F_s = 4.5 \rho g h^2$$

where, h = surge height. The resultant force acts at a distance approximately h above the base of the wall. This equation is applicable for walls with heights equal to or greater than $3h$. Walls whose heights are less than $3h$ require surge forces to be calculated using appropriate combination of hydrostatic and hydrodynamic force equations for the given situation.

Impact Force

The CCH, FEMA CCM and ASCE 7 contained similar equations that resulted in the following generalized expression for impact force F_I *acting* at the still water level:

$$F_I = m\frac{du_b}{dt} = m\frac{u_I}{\Delta t}$$

where,

u_b = velocity of the impacting body,
u_I = approach velocity of the impacting body that is assumed equal to the flow velocity,
m = mass of the body,
Δt = impact duration that is equal to the time between the initial contact of the body with the building and the maximum impact force.

The CCH recommends Δt values for wood construction as 1.0 second, steel construction as 0.5 second, and reinforced concrete as 0.1 second. The FEMA CCM provides the Δt values shown in Table 8.6.

Table 8.6: The impact duration Δt recommended by FEMA CCM

Type of construction	Duration (t) of Impact (sec)	
	Wall	**Pile**
Wood	0.7 - 1.1	0.5 - 1.0
Steel	NA	0.2 - 0.4
Reinforced Concrete	0.2 - 0.4	0.3 - 0.6
Concrete Masonry	0.3 - 0.6	0.3 - 0.6

Breaking Wave Forces

Breaking Wave Loads on Vertical Piling and Columns

The ASCE 7 and FEMA CCM provide the following expression for the breaking-wave force F_{brkp}:

$$F_{brkp} = \frac{1}{2}\rho g C_{db} D H_b^2$$

where,

C_{db} = shape coefficient (ASCE 7 and FEMA CCM recommended Cdb values of 2.25 for square or rectangular piles and 1.75 for round piles),
D = pile diameter, and
H_b = breaking wave height (FEMA CCM recommends that $Hb = 0.78\ ds$ in which ds is the design still-water flood depth).

Breaking Wave Loads on Vertical Walls

Equations from both FEMA CCM and ASCE 7 are given because their equations differ slightly so no generalized equation was determined. The following equations are from FEMA CCM, which incorporates the lateral hydrostatic force. If this formula is used then the hydrostatic force should not be added.

Case 1 (enclosed dry space behind wall):

$$\int_{brkw} = 1.1 C_p \gamma d_s^2 + 2.41 \gamma d_s^2$$

Case 2 (equal still water level on both sides of wall):

$$\int_{brkw} = 1.1 C_p \gamma d_s^2 + 1.91 \gamma d_s^2$$

where,

f_{brkw} = total breaking wave load per unit length of wall acting at the still water level (ds),
C_p = dynamic pressure coefficient from Table 8.7.
γ . = specific weight of water.

Table 8.7: The dynamic pressure coefficient Cp, recommended by FEMA CCM

C_p	Building type	Probability of exceedance
1.6	Accessory structure, low hazard to human life or property in the event of failure	0.5
2.8	Coastal residential building	0.01
3.2	High-occupancy or critical facility	0.001

The following equations are provided by ASCE 7:

$$P_{max} =_{.} C_p \gamma d_s \; 1.2 \; \gamma d_s,$$

$$F_t = 1.1 C_p \gamma d_s^2 .4 \; \gamma d_s^2,$$

where P_{max} is the maximum combined dynamic ($C_p \gamma \, d_s$) and static ($1.2 \; \gamma \, d_s$) wave pressure, also referred to as shock pressure, and Ft is the total breaking wave force per unit length of the structure, also referred to as shock, impulse or wave impact force acting near the still water elevation (d_s). C_p is the dynamic pressure coefficient ($1.6 < C_p < 3.5$: see Table 8.8), and ds is the still water depth at base of building where the wave breaks.

If free water exists behind the wall, the hydrostatic component of the wave pressure and force disappears and the dynamic wave pressure and the net force are computed by:

$$P_{max} = C_p \gamma \, d_s$$

$$F_t = 1.1 \; C_p \gamma \, d_s$$

Table 8.8: The dynamic pressure coefficient recommended by ASCE 7

Building Category	C_p
I = low hazard	1.6
II = standard	2.8
III = substantial hazard	3.2
IV = essential facilities	3.5

Occupancies with respect to different building categories have been furnished in Table 8.9.

Table 8.9: (from ASCE 7)

Name of Occupancy	Category
Structures that represent a low hazard to human life in the event of failure including, but not limited to: • agricultural facilities • certain temporary facilities • minor storage facilities	I
All structures except those listed in Categories I, III and IV	II
Structures that represent a substantial hazard to human life in the event of failure including, but not limited to: • Structures where more than 300 people congregate in one area • Structures with elementary school, secondary school, or day-care facilities with capacity greater than 250 • Structures with a capacity greater than 500 for colleges or adult education facilities • Healthcare facilities with a capacity of 50 or more resident patients but not having surgery or emergency treatment facilities • Jails and detention facilities • Power generating stations and other public utility facilities not included in Category IV • Structures containing sufficient quantities of toxic or explosive substances to be dangerous to public if released	III
Structures designated as essential facilities including but not limited to: • Hospitals and other health-care facilities having surgery or emergency treatment facilities • Fire, rescue, and police stations and emergency vehicle garages • Designated earthquake, hurricane, or other emergency shelters • Communications centers and other facilities required for emergency response • Power generating stations and other public utility facilities required in an emergency • Structures having critical national defense functions	IV

8.5 Loading Combinations

Individual loading conditions must be applied to standard elements in appropriate load combinations. The following load combinations are by FEMA CCM, based on Dames & Moore, 1980. The structural members considered in these references are piles or open foundations, columns, walls and basements. Outer edge beams at second floor level are not mentioned because the reference codes are intended for smaller scale residential structures.

Type 1 - Columns in tsunami prone areas (Required):
The following combinations are used to calculate the force on a column from a tsunami with the additional impact force from debris.

F_{brkp} (on column) + F_i (on column), or F_d (on column) + F_i (on column).

Type 2 - Solid walls facing the shoreline in tsunami prone areas:
Construction of non-breakaway walls or solid walls parallel to the shorelines is not recommended in structural designs. The combinations provided below are for walls, which are perpendicular to the flow of the tsunami. Tsunami effects on structural walls with additional impact force of debris.

F_{brkw} (on walls facing shoreline) + F_i (on one corner) or
F_s (on walls facing shoreline) + F_i (on one corner) or
F_d (on walls facing shoreline) + F_i (on one corner).

Type 3 - Vertical (Buoyant) Forces on Structure:

This loading combination is used when there is a sudden increase in the water level. The buoyant force on the structure must also be considered with other lateral forces, F_b (for basements, swimming pools, empty above-ground and below ground tanks).

8.6 Breakaway walls

The design codes specify that all non-structural walls below the anticipated flow depth be designed as breakaway walls. These walls and their connections are required to be designed for a lateral pressure not less than 10 psf and not more than 20 psf.

8.7 Scour

The codes indicate that the potential for scour around structural foundations must be considered, but provide no guidance on how this scour can be estimated or how footings can be designed to withstand the effects of scour.

8.8 Allowable Stresses

The allowable stresses in concrete and reinforcement according to Bangladesh National Building Code, 1993 are given in the following sub-articles.

8.8.1 Allowable Stresses in Concrete

The allowable stress in concrete, f_c shall not exceed the following:

a) Flexure fiber stress in compression — $0.45 f'_c$

b) Shear : Beams, one way slab and footing

Shear stress carried by concrete, v_c — $0.091\sqrt{f'_c}$

Maximum shear stress carried by concrete plus shear reinforcement — $0.457\sqrt{f'_c}$

Ribs : Shear stress carried by concrete, v_c — $0.10\sqrt{f'_c}$

Two way slabs and footings:

Shear stress carried by concrete, v_c — $(0.083 + 0.17/\beta_c)\sqrt{f'_c} \le 0.17\sqrt{f'_c}$

Where, $\square_c$ = Ratio of long side to short side concreted load or reaction area.

c) Bearing stress on loaded area :

When the loaded area (area of column, pier and base plate) and the supporting area (area of the top of footing) are equal — $0.30\sqrt{f'_c}$

When the supporting area is larger than the loaded area on all sides — $0.30\sqrt{\left(\frac{A_1}{A_2}\right)} f'_c \le 0.60 f'_c$

Where,

A_1 = Area of the lower base of the largest frustum of a pyramid, cone, or tapered wedge contained wholly within the footing and having for its upper base, the area actually loaded, and having side slopes of 1V : 2H and
A_2 = Loaded area of the column base.

8.8.2 Allowable Stresses in Reinforcement

The allowable stress in reinforcement, f_s shall be as specified below

a) Except as specified in (b) below, f_s shall be determined as follows:

i) For 250 N/mm^2 $\leq f_y <$ 275 N/mm^2	:	f_s = 125 N/mm^2
ii) For 275 N/mm^2 $\leq f_y <$ 410 N/mm^2	:	f_s = 138 N/mm^2
iii) For $f_y \geq$ 410 N/mm^2	:	f_s = 165 N/mm^2

b) For flexural reinforcement, 100 mm or less in diameter in one way slabs of not more than 3.5 m span. : f_s = 165 N/mm^2 but not more than 200N/mm^2.

9. STRUCTURAL STRENGTH ANALYSIS

9.1 Selected Structures for Analysis

Design drawings of four typical structures, each one for primary school, high school, college and madrasha have been collected from Facilities Department and upazila offices of Local Government Engineering Department as shown in Table 9.1 below.

Table 9.1: Information on collected structures

Srl.	Type of structure	Type of construction	No. of story	Source of collection
1	Primary school	RCC frame	One story building with provision of 2 story	Patuakhali Sadar Upazila Office
2	High school	-do-	One story	Facilities Department, Patuakhali
3	College	-do-	Three story	-do-
4	Madrasha	-do-	One story	-do-

The plan of each structure with size and reinforcement of column and beam have been furnished in **Appendix-D**.

9.2 Analysis of Structures

Assessment of structural strength of a building requires modeling and analysis of the structure to determine the stress and load levels it can sustain for different modes of loading. The most convenient method of modeling a building structure is to develop numerical model in Finite Element Method (FEM). Three dimensional (3D) FEM models of the selected coastal structures have been generated in the present study using structural design software package ETABS (version 9.0.4).

9.2.1 Software Selection Criteria

Linear 3D FEM analyses of the selected buildings have been conducted in order to assess the capacity of the structures to withstand loading caused by tsunami and cyclone along with storm surge. A wide spectrum of FEM software and tools are available for such analyses. In the present study, ETABS (Version 9.0.4) has been used for this purpose. ETABS has been chosen for its user friendly features in analyzing building structures (Computers and Structures, Inc., 2005). The special features of ETABS are mentioned below:

- User friendly graphical user interface for generating story-wise building models
- Availability of necessary elements for developing FEM model of a building
- Provision for changing orientation of frame elements
- Automatic consideration of rigid end zones of frame elements
- Automatic calculation of member self-weight
- Automatic calculation of member sectional properties
- Integrated design features
- Consideration of moment magnification for slender columns

9.2.2 Finite Element Models of the Buildings

Frame elements have been used to model the columns and plate/shell elements have been used to model the slabs. The frame elements are typical two-noded elements in space having six degrees of freedom per node – three translations and three rotations in three mutually perpendicular axes system. The plate/shell elements are of rectangular (or quadrilateral) and triangular shape. The quadrilateral element has four nodes at its four corners. Each node has six degrees of freedom – three translations and three rotations in a 3D space configuration. Each regular slab has been meshed with 4 by 4 grid of plate elements. For irregular shapes triangular elements have been used when necessary. At the base level, the columns are assumed to be held fixed. 3D views of the Finite Element Models of the selected structures are shown in **Figures 5.1** to **5.4**.

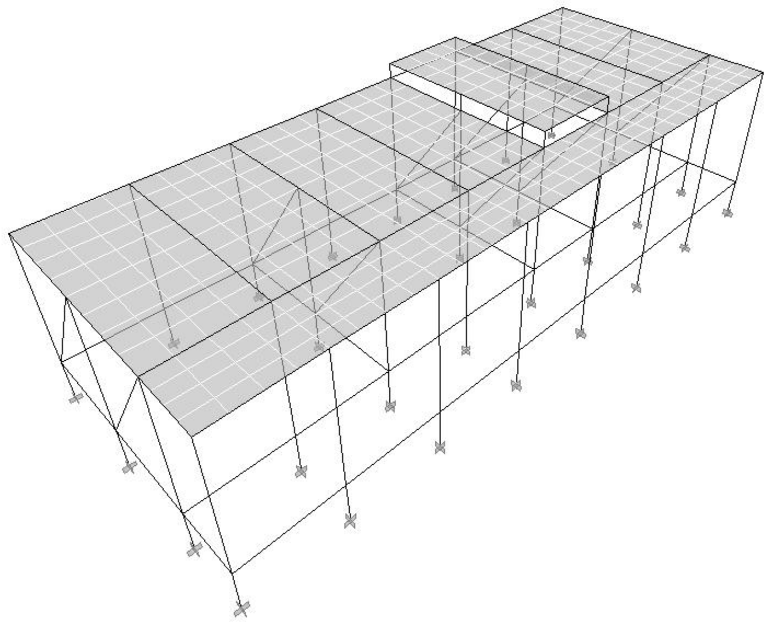


Figure 9.1: 3D view of the Finite Element Model the Primary School building

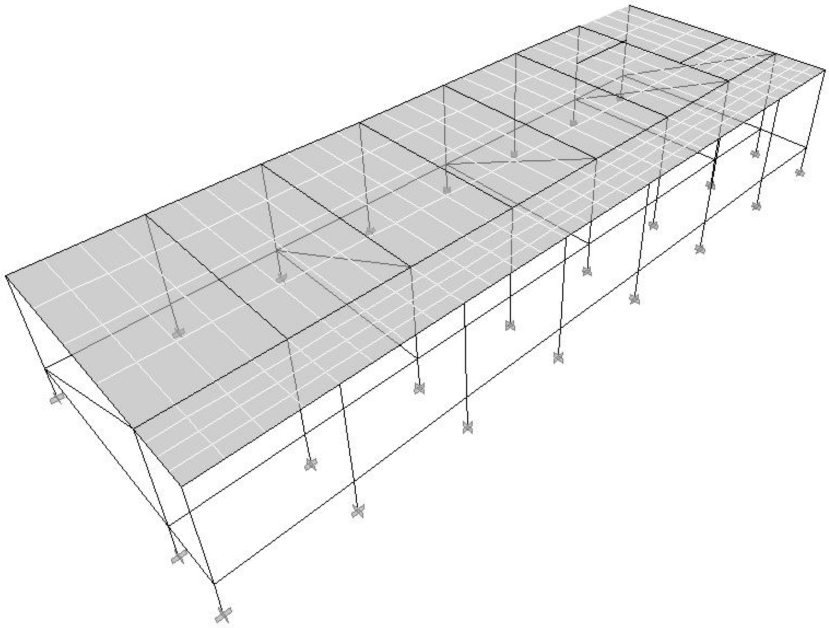


Figure 9.2: 3D view of the Finite Element Model of the High School building

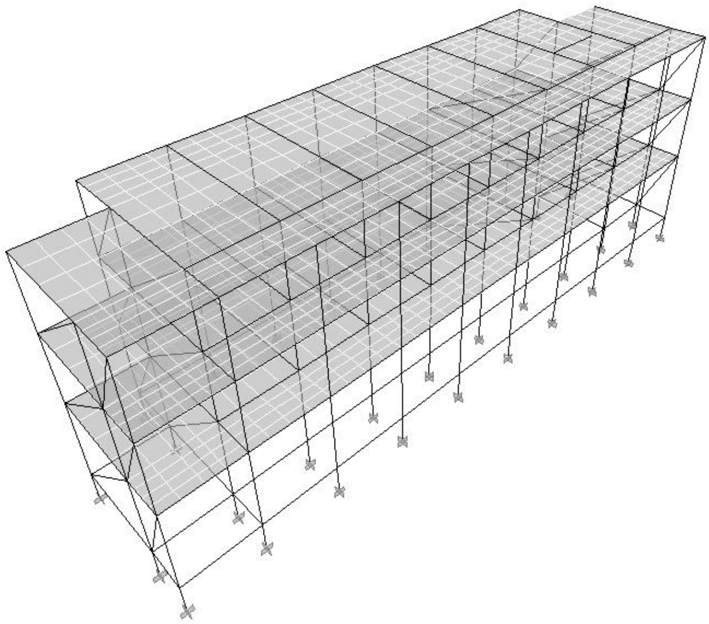


Figure 9.3: 3D view of the Finite Element Model of the College building

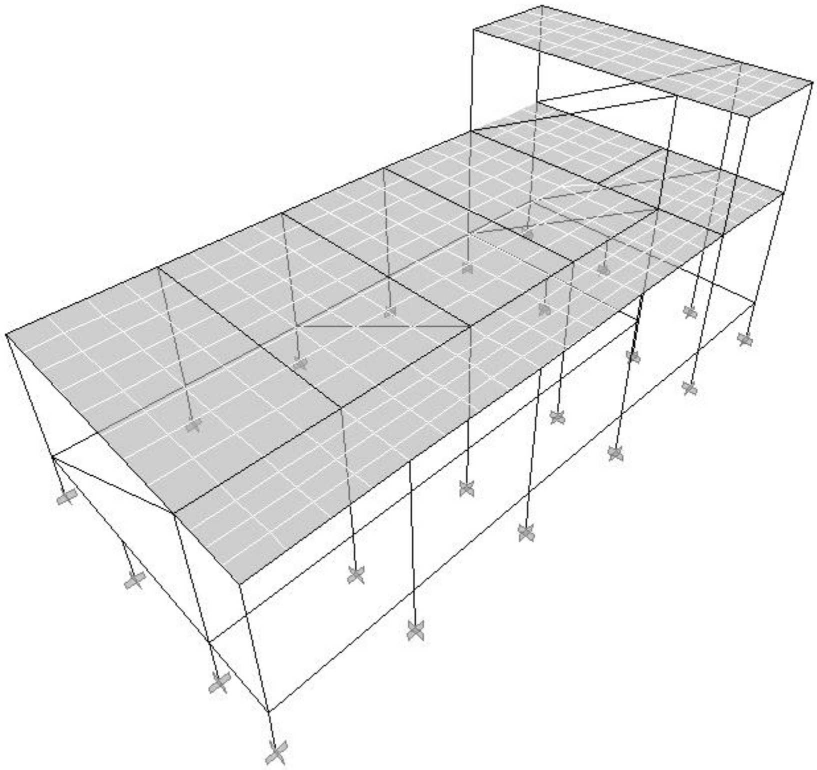


Figure 9.4: 3D view of the Finite Element Model of the Madrasa building

Masonry Infill Model: Equivalent strut model has been used to consider the effect of infill masonry walls. The masonry infill panel has been represented by an equivalent diagonal strut of width, *a* and thickness, *t*. The equivalent strut width, *a* depends on the relative flexural stiffness of the infill to that of the columns of the confining frame. The relative infill-to-frame stiffness is evaluated using equation (Stafford-Smith and Carter, 1969):

$$\lambda_1 H = H[(E_m t \sin\theta)/(4E_c I_{col} h_w)]^{1/4}$$

Where, H is the height of the story, E_m is modulus of elasticity of the masonry work, t is the thickness of the masonry wall, θ is the angle of the diagonal with the horizontal, E_c is modulus of elasticity of concrete, I_{col} is the moment of inertia of the column section and h_w is the height of the masonry work. The equivalent strut width is given by,

$$a = 0.175D(\lambda_1 H)^{-0.4}$$

Where, D is the diagonal length of the wall. In the FEM model strut is modeled using frame elements. A sample calculation of struture width is provided in **Appendix- E1.**

Geometric Configuration and Material Properties: Detail geometric configuration and material properties of the structures are required to develop their finite element models. Information regarding their geometric configuration have been collected from secondary sources as produced in **Appendix- D**. Information regarding the existing concrete properties have been gathered through field testing like Rebound Hammer test and Windsor Pin test; the results of which are provided in **Appendix- E2**. It was found that in general concrete property was satisfactory in the tested structures. For the developed models the 28 day cylinder strength of concrete was assumed to be 20 N/mm^2 (3000 psi). It was difficult to collect adequate samples of reinforcement for testing their tensile strength. Hence it is conservatively assumed that 40 grade steel was used as reinforcement in the selected structures.

9.2.3 Special Considerations for Loading

All the selected structures have been analyzed separately for tsunami loading and loading due to cyclone along with storm surge. In both the cases Dead Load and Live Load were considered as described in previous chapter. For live load, two cases has been assumed. First, live load for normal occupancy of the structures is considered. Secondly, since these schools and colleges may be used as shelters during cyclone or tsunami, according to the guideline of Multipurpose Cyclone Shelter Programme, 1993, live load on the floors and roof is assumed to be 4.8 kN/m^2 (100 psf). **Figures 5.5** and **5.6** show live loads considered for the Madrasa building for these two cases.

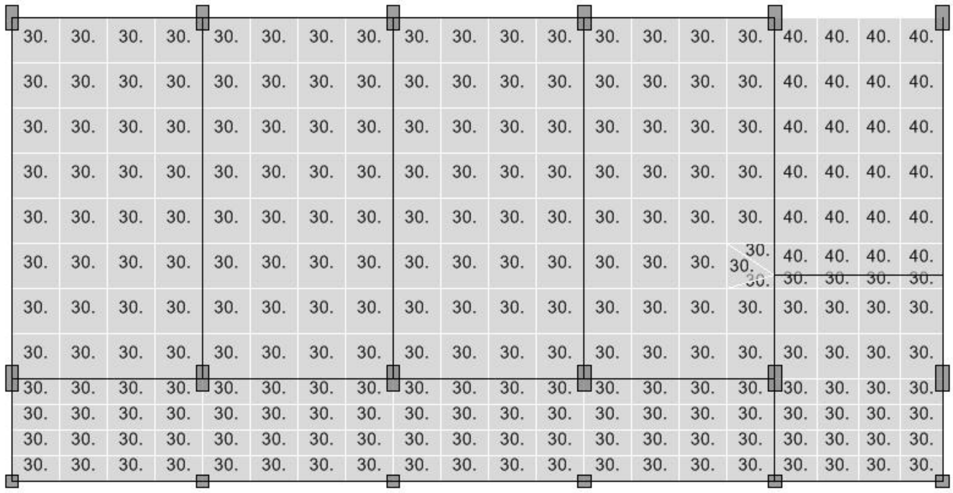


Figure 9.5: Live load at the roof of the Madrasa building for normal occupancy

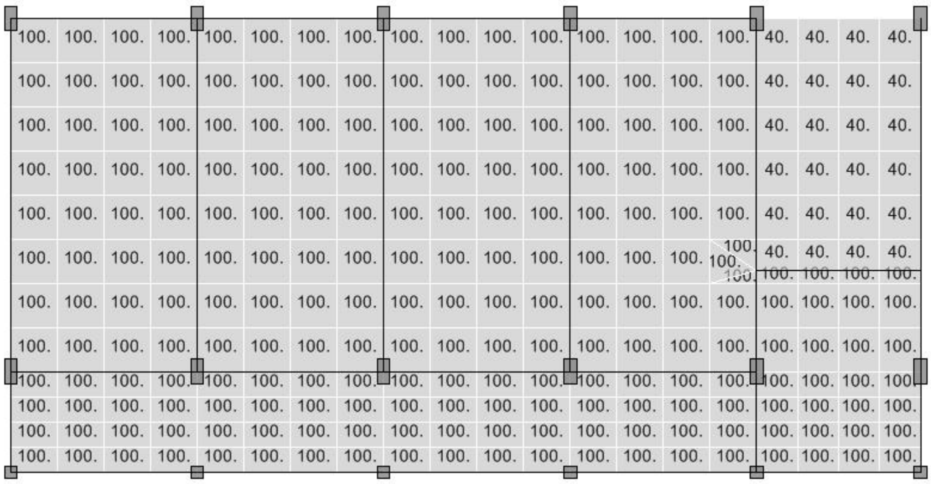


Figure 9.6**:** Live load at the roof of the Madrasa building for shelter

For both tsunami and storm surge, three cases of inundation have been considered in this study: a surge height of 1m, 2m and 3m. Among the selected structures the primary school, the high school and the madrasa are one storied. So there is no scope of considering surge height of more than 3m. It is later shown in the present report that the college building is inadequate against a surge height of 3m both in the case of Tsunami and Cyclone. Since for such inundation no floor is submerged, buoyant forces do not act on the structures.

The lateral loads have been applied along the shorter direction of the buildings which is more critical. For tsunami loading hydrodynamic and impact forces on the columns of a structure have been estimated as explained in previous chapter. Flood flow velocity has been estimated by the relation of tsunami flow velocity with inundation depth as provided by Dames and Moore (1980). A sample calculation of tsunami load is given in **Appendix- E3**. **Figures 5.7 and 5.8**, respectively, show hydrodynamic and impact forces due to tsunami on the Primary School building.

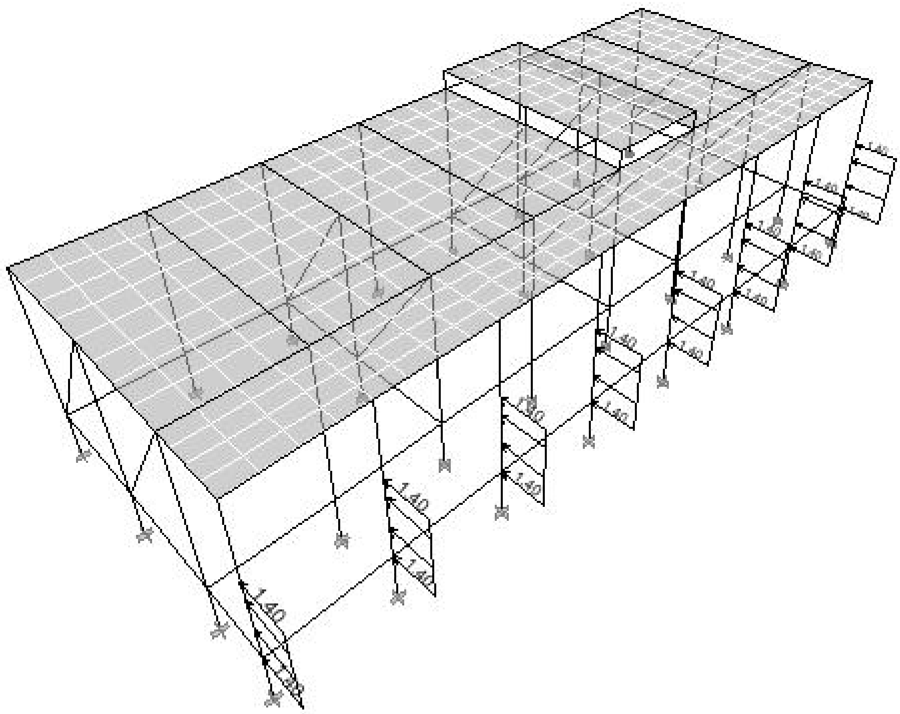


Figure 9.7**:** Hydrodynamic forces on the Primary School building for 2 m Tsunami Height

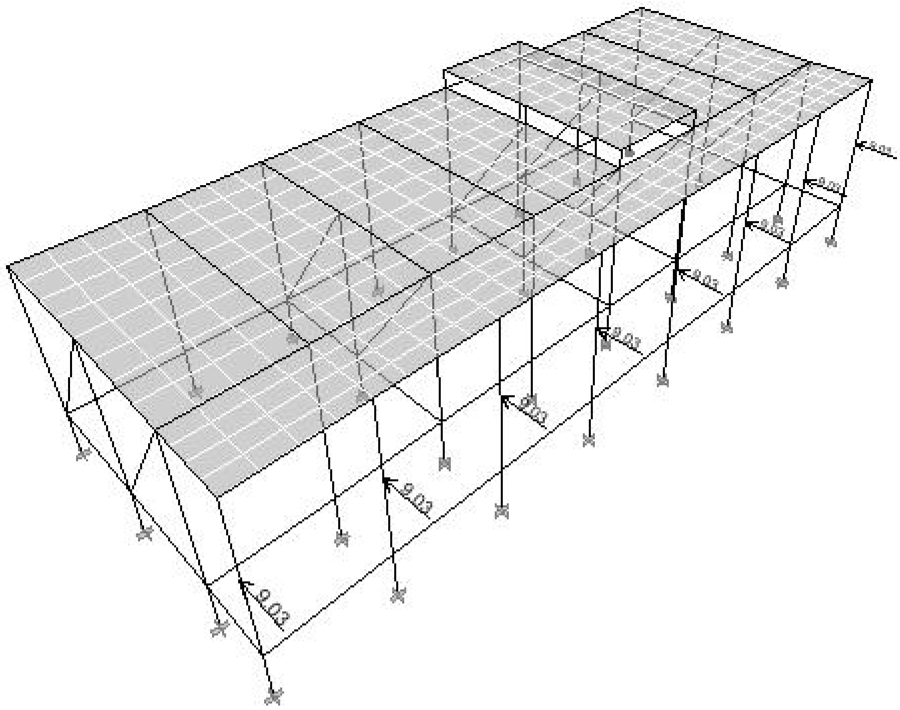


Figure 9.8**:** Impact forces on the Primary School building for 2 m Tsunami Height

Relationship between Maximum Wind Speed and Storm Surge Height during Cyclone: An attempt has been made to develop a relationship between the maximum wind speed and the surge height based on the simulation results of past 15 cyclones. All the simulations have been carried out using existing Bay of Bengal Model maintained by the IWM. Observed cyclone data of Bangladesh Meteorological Department (BMD) have been used, which includes cyclone track, cyclone intensity, pressure drop, maximum wind speed and radius to maximum wind. Maximum storm surge height experienced during cyclone near the coast of Bangladesh has been considered. The simulated surge heights at different locations with corresponding cyclone information and wind speeds are presented in Table 9.2.

Table 9.2: Simulated surges height with cyclone information

Sl. No.	*Cyclone*	*Maximum Wind Speed*		*Tide Level, m PWD (Without Cyclone)*	*Surge Level, m PWD (with Cyclone)*	*Surge Height (m)*	*Surge Height Location*
		m/s	*km/hr*				
1	1960	58	208	-0.5	**7.5**	**8.0**	Chitagong Coast
2	1961	39	142	2.0	6.0	4.0	Noakhali Coast
3	1963	49	175	2.3	5.0	2.8	Chitagong Coast
4	1965 May	45	161	-0.2	4.0	4.2	Patuakhali Coast
5	1965 Dec	49	175	0.8	2.8	2.0	Near Moheskhali
6	1966	40	145	2.3	5.7	3.5	Chitagong Coast
7	1970	62	222	3.2	**10.0**	**6.8**	Noakhali Coast
8	1974	45	161	1.3	3.7	2.4	Patuakhali Coast
9	1985	40	145	-0.2	2.0	2.2	Near Moheskhali
10	1986	32	116	0.6	1.1	0.5	Sundarban Coast
11	1988	42	150	-0.2	2.5	2.7	Near Hiron Point
12	1991	62	224	2.0	6.7	4.7	Near Anwara
13	1997 May	56	200	1.0	4.1	3.1	Near Kutubdia
14	1998	46	165	1.8	2.7	0.9	Along Karnafully
15	2007	67	240	0.0	**6.1**	**6.1**	Near Patharghata

The table shows that maximum surge height of 8 m occurred in 1960 cyclone. At that time tide level and surge level at Chittagong coast were -0.5 m PWD and 7.5 m PWD (Fig. 9.8). Difference between the two levels gives the surge level, which is 8 m.

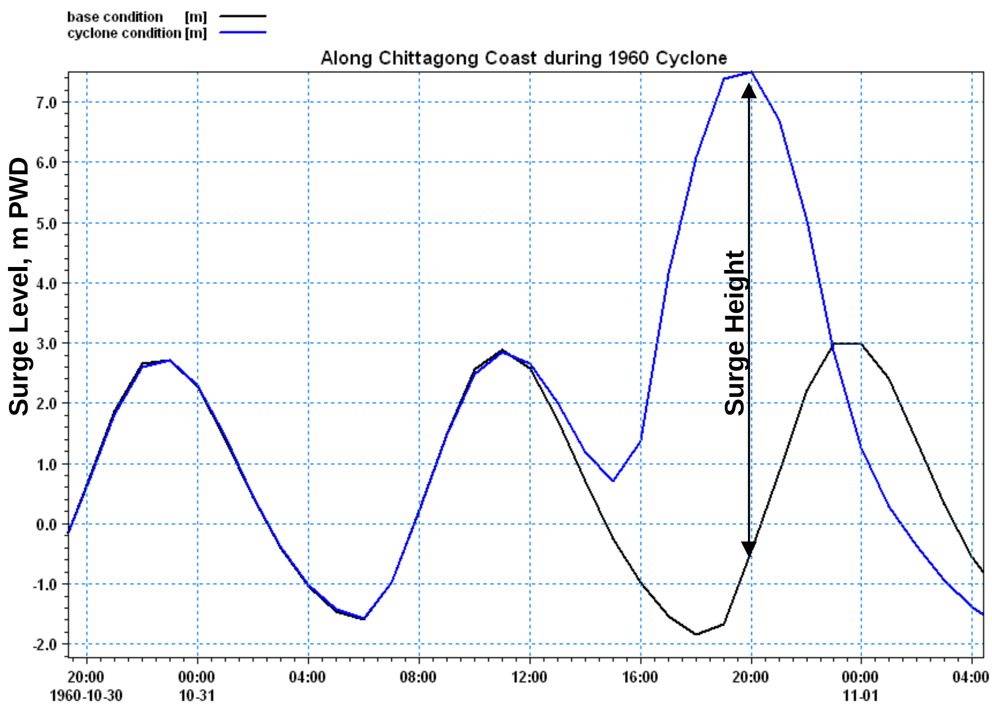


Figure 9.9: Tide and surge levels during 1960 cyclone at the coast of Chittagong

A relationship between the maximum wind speed and the surge level has been developed based on the information of the Table 9.2. The graph in Figure 9.10 shows that the surge height can roughly be said that increases with increased wind speed. The relationship can be expressed as:

Surge Height (m) = 0.16 x Wind Speed (m/s) - 3.98

There can be an error of ±2m.

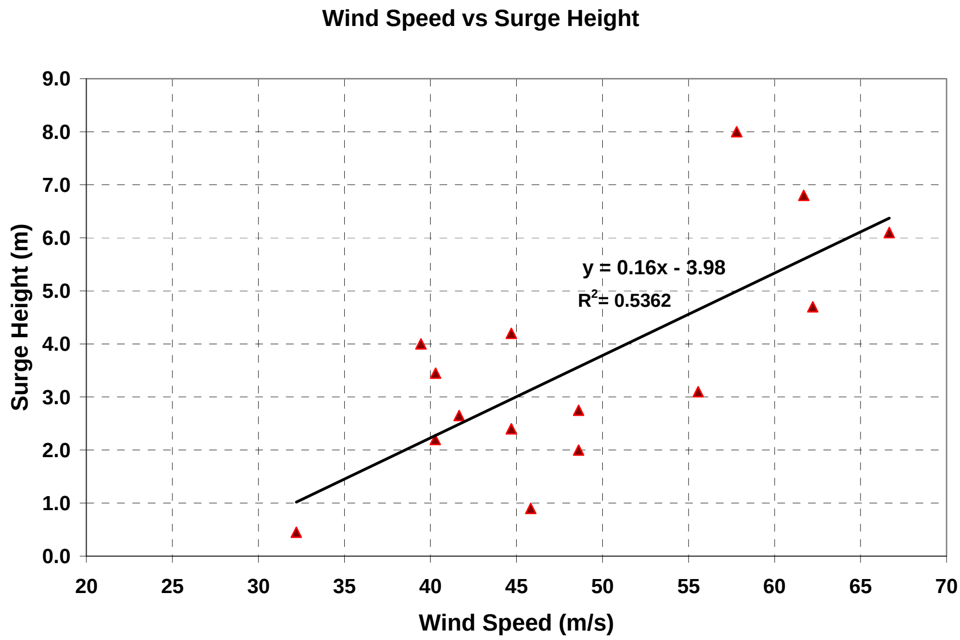


Figure 9.10: Relationship between wind speed and surge height

In these simulations real situation has been considered (i.e. observed cyclone track, wind speed, radius to maximum wind speed and atmospheric pressure fall data, bathymetry and topography of land). There are some uncertainties may be involved in the result as the surge height modifies with the other parameters like bathymetry, air pressure fall, cyclone track and land topography.

Table 9.3 shows the relationship between the parameters as used by BMD. A relationship between the pressure drop and the maximum wind speed has been presented in Table 9.3, which is based on the work of Choudhury *et al.* (1974) and used by BMD.

Table 9.3**:** The Relationship between the Involved Parameters

Classification	**Pressure Drop (mB)**	**Max. wind speed (km/hour)**	**Radius to max. wind speed (km)**
D	2-4	40-51	44
DD	4-6	52-61	48
CS	6-12	62-88	54
SCS	12-21	89-117	64
SCSH	≥21	≥118	≥74

Note:
D: *Depression*
DD: *Deep Depression*
CS: *Cyclonic Storm*
SCS: *Severe Cyclonic Storm*
SCSH: *Severe Cyclonic Storm with a core of Hurricane winds*

Storm Surge Loading during Cyclone**:** For cyclonic storm surge it is extremely difficult to estimate flood flow velocity. There is no reliable method available in literature for estimating flood flow velocity from inundation depth. However, Multipurpose Cyclone Shelter Programme (1993) suggests that the flow velocity during inundation by storm surge is unlikely to be greater than 2.5 m/s. Hence for the present study the flow velocity for storm surge has been assumed to be 2.5 m/s. A sample calculation of storm surge load is given in **Appendix- E4**. As it has already been mentioned that it is difficult to relate flow velocity with the cyclonic wind speed. Since Bangladesh National Building Code (1993) prescribes that the basic wind speed for the design of coastal structures should be taken as 260 km/h, for the present analyses loads due to wind have been calculated for a basic wind speed of 260 km/h. However, in order to examine the performance of the structures against different categories of cyclones analyses have also been carried out for 210 km/h and 178 km/h which corresponds to Cyclones of Category 4 and 3 respectively in the Saffir-Simpson Hurricane Scale.

Lateral loading on the Masonry Walls at the Ground Story**:** Bangladesh National Building Code (1993) prescribes that non-structural walls located below the maximum surge elevation are required to break away under wave action; such non-structural elements shall be designed to sustain a maximum uniformly distributed load of 1.0 kN/m^2 (20 psf) but not less than 0.5 kN/m^2 (10 psf). The ground story masonry walls are hence not explicitly modeled in the FEM building models. However, it is necessary to find actually what amount pressure the traditional brick masonry can sustain and the amount of load coming on to the wall from tsunami or surge to the adjacent columns.

Hydrostatic forces come into play when ground story infill walls are present. Since the walls are less that three times the inundation depth surge force as explained in previous chapter, surge force does not occur. **Appendix- E5** shows through a sample calculation that if a 3 m by 3 m (10 ft x10 ft) wall could transfer all the load coming from hydrodynamic and impact forces it would have to transfer about 220 kN/m (15 k/ft) load to the column. However, the walls are connected to the columns only by cement mortar and **Appendix- E6** shows that the amount of shear that the mortar joint between the wall and the column can take without any pre-compression is only about 35 kN/m (2.4 k/ft) equivalent to 10 kN/m^2 (200 psf) lateral pressure on a 3 m by 3 m wall. Again **Appendix E4** shows that a 3 m by 3 m wall with a thickness of 125 mm (5 in.) would break away under much smaller load due to flexure. The load that the particular wall can transfer to the column before breaking away due to flexure is about 0.4 kN/m^2 (8 psf) as shown in **Appendix- E7**.

Now comparing these values, it is clear that the traditional brick masonry would fail in flexure when subjected to much smaller load than actually imposed load. For analyses, as a conservative estimate 0.5 kN/m^2 (10 psf) load, which is the minimum limit by codal provision, has been assumed to act on the ground story masonry walls. However once the walls get break away in the ground story, columns on both sides of the building are subjected to flood loads. **Figures 5.11 and 5.12** show loading cases for the High School building when masonry walls transfers the load to the column and when after masonry walls break away.

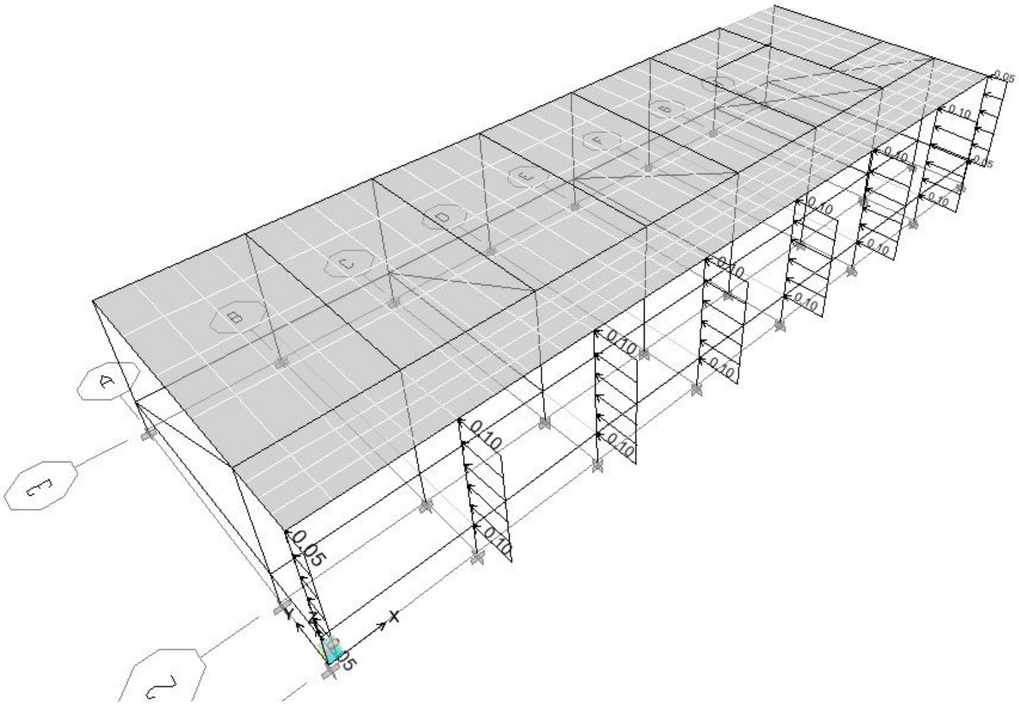


Figure 9.11: Wall load transferred to columns of the High School building for 3 m storm surge height

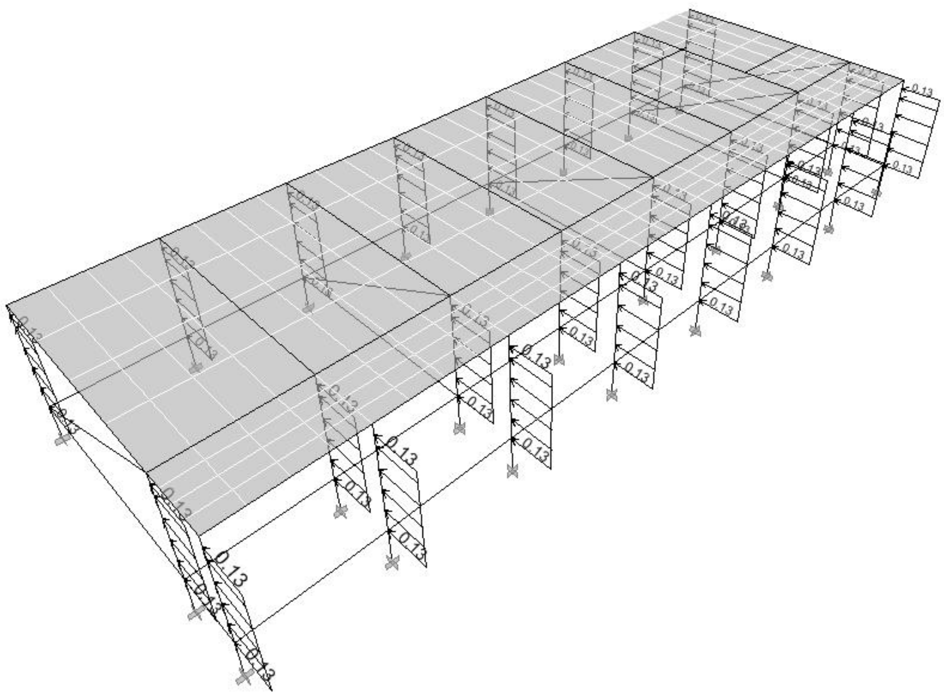


Figure 9.12: Hydrodynamic forces on all the columns of the High School building for 3 m storm surge height after breaking away of the walls

9.2.4 Analyzed Cases

All the four types of structures have been analyzed for each of the following loading conditions and checked for their adequacy:

1. a) 1.4DL + 1.7LL + 1.7T for d_s = 1m.
   b) 1.4DL + 1.7LL - 1.7T for d_s = 1m.
2. a) 1.4DL + 1.7LL + 1.7T for d_s = 2m.
   b) 1.4DL + 1.7LL - 1.7T for d_s = 2m.
3. a) 1.4DL + 1.7LL + 1.7T for d_s = 3m.
   b) 1.4DL + 1.7LL - 1.7T for d_s = 3m.
4. a) 0.75(1.4DL + 1.7LL + 1.7WL + 1.7S) for d_s = 1m and V_b = 260 km/h.
   b) 0.75(1.4DL + 1.7LL - 1.7WL - 1.7S) for d_s = 1m and V_b = 260 km/h.
5. a) 0.75(1.4DL + 1.7LL + 1.7WL + 1.7S) for d_s = 2m and V_b = 260 km/h.
   b) 0.75(1.4DL + 1.7LL - 1.7WL - 1.7S) for d_s = 2m and V_b = 260 km/h.
6. a) 0.75(1.4DL + 1.7LL + 1.7WL + 1.7S) for d_s = 3m and V_b = 260 km/h.
   b) 0.75(1.4DL + 1.7LL - 1.7WL - 1.7S) for d_s = 3m and V_b = 260 km/h.
7. a) 0.75(1.4DL + 1.7LL + 1.7WL + 1.7S) for d_s = 1m and V_b = 210 km/h.
   b) 0.75(1.4DL + 1.7LL - 1.7WL - 1.7S) for d_s = 1m and V_b = 210 km/h.
8. a) 0.75(1.4DL + 1.7LL + 1.7WL + 1.7S) for d_s = 2m and V_b = 210 km/h.
   b) 0.75(1.4DL + 1.7LL - 1.7WL - 1.7S) for d_s = 2m and V_b = 210 km/h.
9. a) 0.75(1.4DL + 1.7LL + 1.7WL + 1.7S) for d_s = 3m and V_b = 210 km/h.
   b) 0.75(1.4DL + 1.7LL - 1.7WL - 1.7S) for d_s = 3m and V_b = 210 km/h.
10. a) 0.75(1.4DL + 1.7LL + 1.7WL + 1.7S) for d_s = 1m and V_b = 178 km/h.
   b) 0.75(1.4DL + 1.7LL - 1.7WL - 1.7S) for d_s = 1m and V_b = 178 km/h.
11. a) 0.75(1.4DL + 1.7LL + 1.7WL + 1.7S) for d_s = 2m and V_b = 178 km/h.
   b) 0.75(1.4DL + 1.7LL - 1.7WL - 1.7S) for d_s = 2m and V_b = 178 km/h.
12. a) 0.75(1.4DL + 1.7LL + 1.7WL + 1.7S) for d_s = 3m and V_b = 178 km/h.
   b) 0.75(1.4DL + 1.7LL - 1.7WL - 1.7S) for d_s = 3m and V_b = 178 km/h.

Where,
DL: Dead Load (both self-weight and super-imposed)
LL: Live Load
T: Tsunami Load (hydrodynamic and impact forces are combined as per **Sec. 8.4**)
WL: Wind Load (calculated as per **Sec. 8.2.3**)
S: Surge Load (hydrodynamic and impact forces are combined as per **Sec. 8.4**)
d_s: Depth of Submergence
V_b: Basic Wind Speed

Here +/- implies two opposite directions. All these above cases have further been analyzed for two different conditions: One before breaking of the ground story infill walls and the other after breaking of the ground story infill walls. Again all these cases have been analyzed for two live load cases: one for normal occupancy and the other for shelter purposes. Thus, in total, 48 different cases for each building have been analyzed and checked with the design.

9.3 Results of Analysis

For each of the 48 different conditions mentioned in the previous section each of the four different types of selected structures has been analyzed and the developed stresses have been compared with the allowable stresses, as explained in **Sec. 8.6**. **Figures 5.13** and **5.14** show respectively the axial column force diagrams and beam bending moment diagrams of a frame of the College building due to live load.

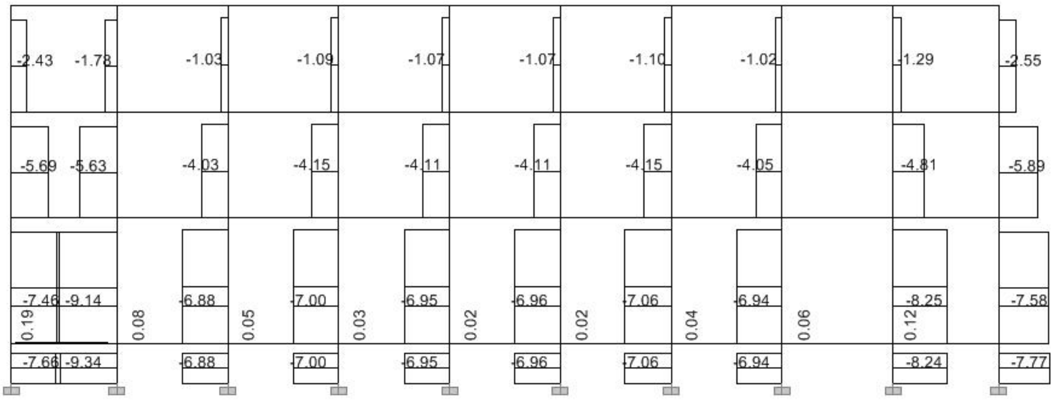


Figure 9.13: Axial force diagrams of the columns of the front frame of the College building due to live load

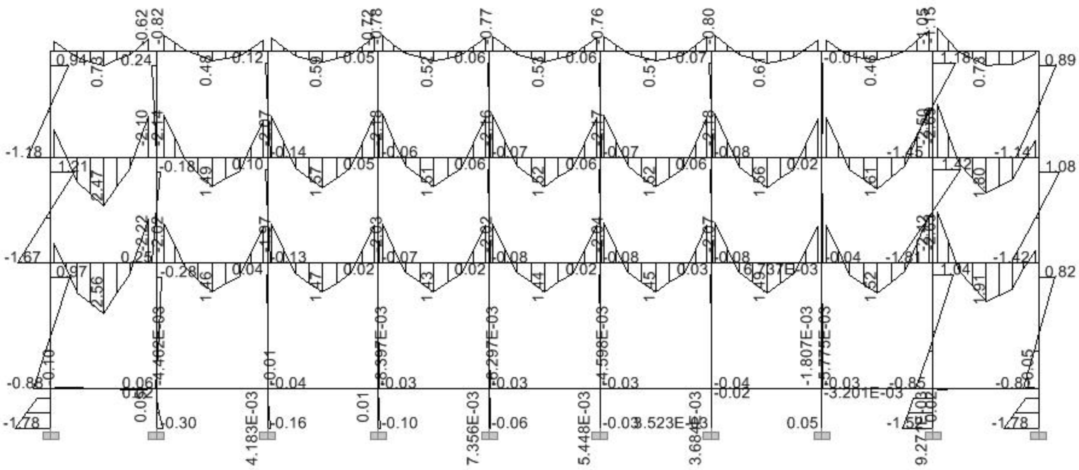


Figure 9.14: Axial force diagrams of the beams of the front frame of the College building due to live load

Capacity of the individual members of an RC structure depends both on the concrete section and the amount and location of the steel reinforcement. **Fig. 5.15** shows the required reinforcement of the members of a frame of the Madrasa building. Slabs in all the cases have been found adequate. Since it is not possible to gather information regarding the soil condition at different places in the coastal region for these typical structures adequacy of foundation could not be checked. In the following sections results of the analyses and adequacy of each of the selected structure types are explained. Between the cases of before and after breaking of ground story masonry walls, only the governing results have been reported.

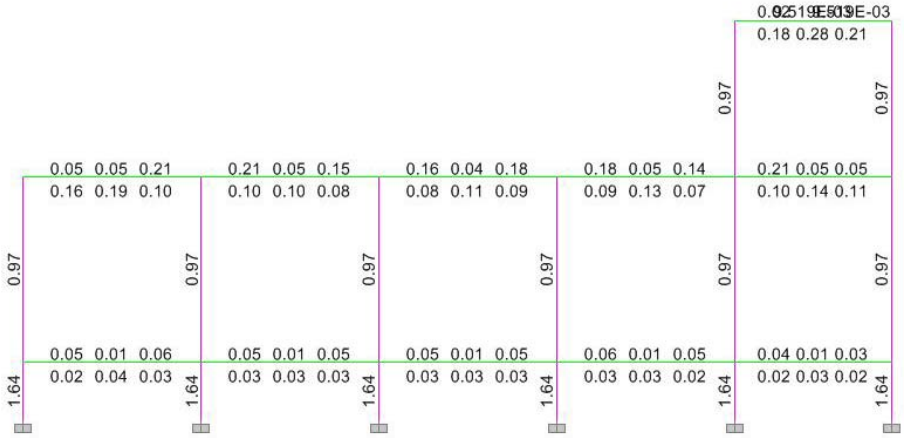


Figure 9.15: Required longitudinal reinforcement of the members of the front frame of the Madrasa building for the case of 3 m storm surge

9.3.1 Structural Adequacy of the Primary School Building

Fig. 5.16 shows the plan of the one storied Primary School Building. The Primary School building can sustain the loads due to cyclone with basic wind speed of 260 km/h and surge height of 3m without any structural members failing even when additional live load is considered for shelter purposes. However, as is shown in Tables 9.4 and 9.5, a number of columns require more reinforcement than provided for Tsunami load of only 1m surge height both for normal occupancy and shelter purposes. For greater surge height a number of beams also become inadequate.

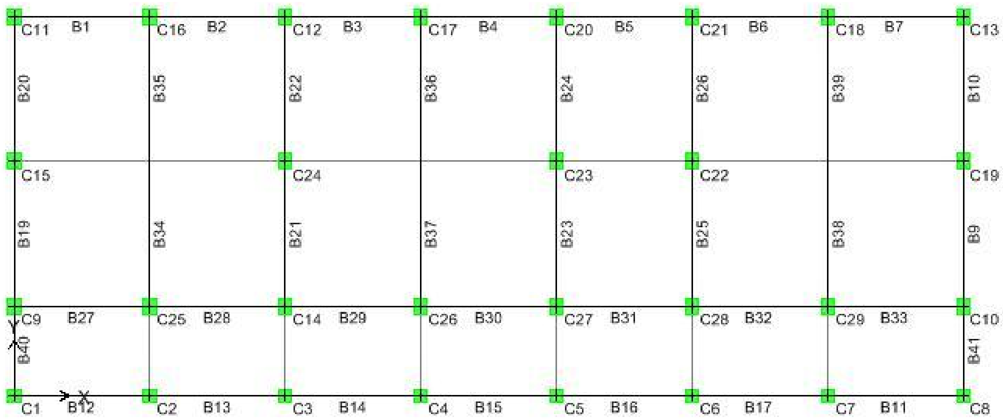


Figure 9.16: Plan of the Primary School building

Table 9.4: Inadequate members of the Primary School building under Tsunami load for normal occupancy

Structure Type	Height of Tsunami	Inadequate Beams	Beam Failure Condition	Inadequate Columns	Maximum Required Reinforcement in Column	Maximum Provided Reinforcement in Column
Primary School Building	1m	-	-	C1-C8	2.92%	1.24%
	2m	B40-B41	Flexure	C1-C8	>6%	
		B11-B17	Shear & Torsion			
	3m	B40-B41	Flexure	C1-C8	>6%	
		B11-B17	Shear & Torsion			

Table 9.5: Inadequate members of the Primary School building under Tsunami load for shelter purposes

Structure Type	Height of Tsunami	Inadequate Beams	Beam Failure Condition	Inadequate Columns	Maximum Required Reinforcement in Column	Maximum Provided Reinforcement in Column
Primary School Building	1m	-	-	C1-C8	2.95%	1.24%
	2m	B40-B41	Flexure	C1-C8	>6%	
		B11-B17, B6,B28-B30,B32	Shear & Torsion			
	3m	B40-B41	Flexure	C1- C8	>6%	
		B11-B17, B27-B33, B4,B6	Shear & Torsion	C16-C18	1.63%	1.55%

9.3.2 Structural Adequacy of the High School Building

Fig. 5.17 shows the plan of the one storied High School Building. The High School building can sustain the loads due to cyclone with basic wind speed of 260 km/h and surge height of 3 m without any structural members failing for the case of normal occupancy. However, a number of columns of the building fail to sustain the additional live load for sheltering people even for a wind speed of 178 km/h as shown in Table 9.6. The building fails to withstand a Tsunami load of 1 m surge height even for normal occupancy. Tables 9.7 and 9.8 show the inadequate members of the building for Tsunami load in case of normal occupancy and shelter respectively.

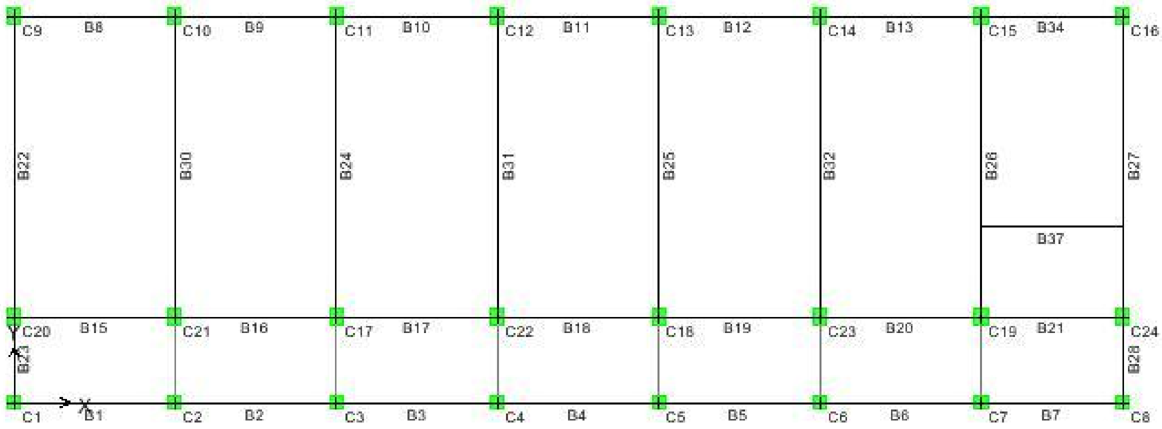


Figure 9.17: Plan of the High School building

Table 9.6: Inadequate members of the High School building for shelter purposes under Storm Surge load with basic wind speed of 178 km/h

Structure Type	Height of Surge	Inadequate Beams	Beam Failure Condition	Inadequate Columns	Maximum Required Reinforcement in Column	Maximum Provided Reinforcement in Column
High School Building	1m	-	-	C10-C14	1.43%	1.33
	2m	-	-	C10-C14	1.43%	
	3m	-	-	C10-C14	1.45%	

Table 9.7: Inadequate members of the High School building under Tsunami load for normal occupancy

Structure Type	Height of Tsunami	Inadequate Beams	Beam Failure Condition	Inadequate Columns	Maximum Required Reinforcement in Column	Maximum Provided Reinforcement in Column
High School Building	1m	-	-	C1,C3-C6,C8	1.5%	1.33%
	2m	B1, B7	Shear & Torsion	C1-C8	3.10%	
		B28	Flexure			
	3m	B23,B28	Flexure	C1-C8	3.92%	
		B1-B7	Shear & Torsion	C10-C15	1.50%	

Table 9.8: Inadequate members of the High School building under Tsunami load for shelter

Structure Type	Height of Tsunami	Inadequate Beams	Beam Failure Condition	Inadequate Columns	Maximum Required Reinforcement in Column	Maximum Provided Reinforcement in Column
High School Building	1m	B22,B30-B32	Flexure	C10-C14 C1,C8	1.83% 1.51%	1.33%
		B8	Shear & Torsion	C21-C23	1.47%	
	2m	B22-B25,B28,B30–B32	Flexure	C1-C8 C21,C23	3.10% 1.54%	
		B1-B8	Shear & Torsion	C10-C15	2.01%	
	3m	B22-B25,B28,B30–B32	Flexure	C1-C8, C21-C23	3.92% 1.73%	
		B1-B8	Shear & Torsion	C9-C15	2.33%	

9.3.3 Structural Adequacy of the College Building

Figure 9.17 shows the plan of the three storied College Building. A number of beams and columns of the College building do not satisfy the requirements for Cyclonic loading with basic wind speed of 260 km/h and Tsunami loading as shown in Tables 9.9 and 9.10 for both cases of occupancy. However for reduced wind speed of 210 km/h all the columns are adequate and only one beam fails in flexure as shown in Table 9.11.

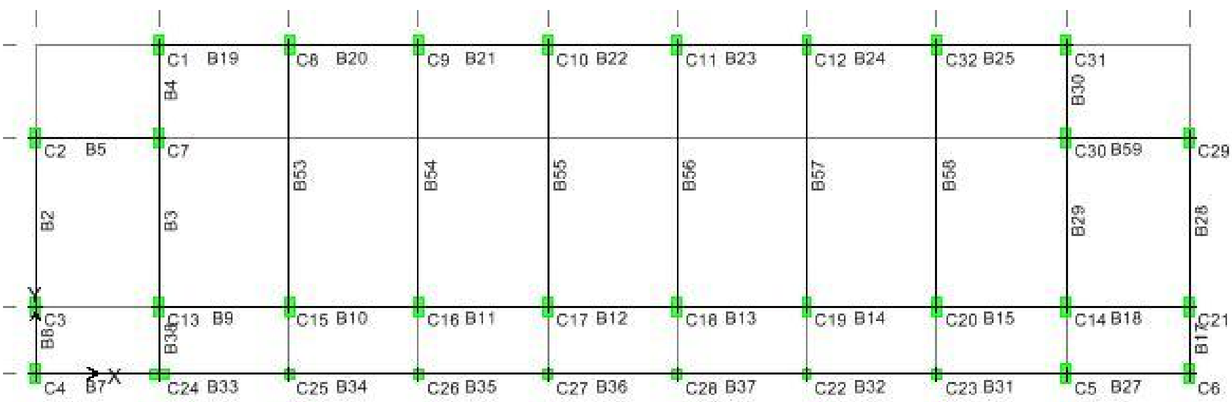


Figure 9.18: Plan of the College building

Table 9.9: Inadequate members of the College building under Tsunami load

Structure Type	Height of Tsunami	Inadequate Beams	Beam Failure Condition	Inadequate Columns	Maximum Required Reinforcement in Column	Maximum Provided Reinforcement in Column
College Building	1m	B54,B55,B57	Flexure	C22-C23, C25-C28	3.84%	1.28%
	2m	B55-B57	Flexure	C24	3.24%	
		B31,B33	Shear & Torsion	C22,C23, C25-C28	>6%	
	3m	B53-B58	Flexure	C22,C23, C25-C28	>6%	
		B31-B37	Shear & Torsion	C24	4.06%	

Table 9.10: Inadequate members of the College building under Storm Surge load for a basic wind speed of 260 km/h

Structure Type	Height of Surge	Inadequate Beams	Beam Failure Condition	Inadequate Columns	Maximum Required Reinforcement in Column	Maximum Provided Reinforcement in Column
College Building	1m	B54,B55,B57	Flexure	C4-C6	1.45%	1%
	2m	B54,B55,B57	Flexure	C4-C6	1.49%	
	3m	B54,B55,B57	Flexure	C4-C6	1.47%	

Table 9.11: Inadequate members of the College building under Storm Surge load for a basic wind speed of 210 km/h

Structure Type	Height of Surge	Inadequate Beams	Beam Failure Condition	Inadequate Columns	Maximum Required Reinforcement in Column
College Building	1m	B57	Flexure	-	-
	2m	-do-	-do-	-	-
	3m	-do-	-do-	-	-

9.3.4 Structural Adequacy of the Madrasa Building

Fig. 5.19 shows the plan of the one storied Madrasa Building. The building is safe for Cyclonic loading under normal occupancy. However for the increased live load as a shelter a number of columns become inadequate as shown in Table 9.12. The building also fails to withstand Tsunami loading both for normal occupancy and as a shelter as shown in Tables 9.13 and 9.14.

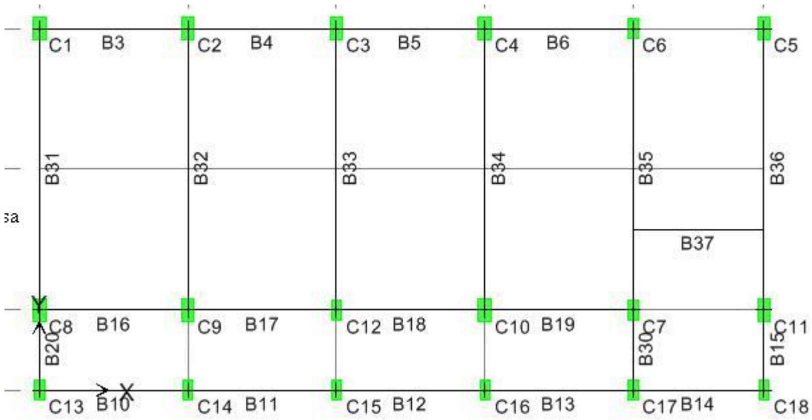


Figure 9.19: Plan of the Madrasa building

Table 9.12: Inadequate members of the Madrasa building for live load of a shelter under Cyclonic load of 260 km/h

Structure Type	Height of Surge	Inadequate Beams	Beam Failure Condition	Inadequate Columns	Maximum Required Reinforcement in Column	Maximum Provided Reinforcement in Column
Madrasa Building	1m	-	-	C1-C5, C8-C11	1.70% 1.49%	1%
	2m	-	-	C1-C5, C8-C11	1.71% 1.49%	
	3m	-	-	C1-C5, C8-C11	1.72% 1.51%	

Table 9.13: Inadequate members of the Madrasa building under Tsunami load for normal occupation

Structure Type	Height of Tsunami	Inadequate Beams	Beam Failure Condition	Inadequate Columns	Maximum Required Reinforcement in Column	Maximum Provided Reinforcement in Column
Madrasa Building	1m	-	-	C2-C4	1.18%	1%
				C13-C18	2.84%	1.28%
	2m	B10- B13	Shear & Torsion	C2-C4	1.34%	1%
		B20,B30	Flexure	C13-C18	>6%	1.28%
	3m	B10- B13	Shear & Torsion	C2-C4	1.55%	1%
		B20,B15,B30	Flexure	C13- C18	>6%	1.28%

Table 9.14: Inadequate members of the Madrasa building under Tsunami load for shelter condition

Structure Type	Height of Tsunami	Inadequate Beams	Beam Failure Condition	Inadequate Columns	Maximum Required Reinforcement in Column	Maximum Provided Reinforcement in Column
Madrasa Building	1m	B4,B6,B31	Shear & Torsion	C1-C5, C8-C11	2.25% 1.77%	1%
				C13-C18	2.83%	1.28%
	2m	B10- B14, B3,B6,B31	Shear & Torsion	C1-C5, C8-C11	2.45% 1.8%	1%
		B20, B30	Flexure	C13-C18	>6%	1.28%
	3m	B10- B13 B3,B6,B31	Shear & Torsion	C1-C5, C8-C11	2.74% 2%	1%
		B20,B15,B30	Flexure	C13-C18	>6%	1.28%

9.4 Remarks on the Results of Analysis

Flood velocity for Tsunami is much higher compared to that of storm surge. In case of Tsunami, for only 1 m inundation flood velocity becomes about 7 m/s whereas the maximum velocity in case of storm surge is around 2.5 m/s. Due to higher flood velocity, Tsunami exerts greater hydrodynamic and impact forces on a structure. In addition, when Tsunami load is combined with Dead and Live loads unlike Cyclonic loading does not have a reduction factor of 0.75 (**Sec. 9.2.4**). Thus from the above analyses it is found that all the selected structures are inadequate to resist Tsunami forces even for 1 m inundation even for normal occupancy.

The Primary School building, the High School building and the Madrasa building under normal occupation are adequate against cyclonic load along with storm surge. Only the Primary School building is however adequate against cyclonic load as a shelter. Table 9.15 summarizes the capacity of the analyzed buildings to withstand Tsunami and Cyclone.

Table 9.15: Allowable surge height in case of Tsunami and Cyclone

Building	Allowable surge height for Tsunami		Allowable surge height for Cyclone	
	Normal Occupancy	As a Shelter	Normal Occupancy	As a Shelter
Primary School Building	< 1m	< 1m	3m	3m
High School Building	< 1m	< 1m	3m	< 1m
College Building	< 1m	< 1m	< 1m	< 1m
Madrasa Building	< 1m	< 1m	3m	< 1m

10. FOUNDATION ANALYSIS

10.1 Selected Structures

Four typical structures, each one for primary school, high school, college and madrasha have been collected from Facilities Department and Upazila Office as shown in Table 10.1 below.

Table 10.1: Information on collected structures

Srl.	Type of structure	Type of construction	No. of story	Source of collection
1	Primary school	RCC frame	Single storied building with provision of two story	Patuakhali Sadar Upazila Office
2	High school	-do-	Single storied building with provision of three story	Facilities Department, Patuakhali
3	College	-do-	Three storied building with provision of three story	-do-
4	Madrasa	-do-	Single storied building with provision of single story	-do-

10.2 Soil Condition

A good number of logs of bore holes at different locations along the coastal belt have been collected. It has been observed from the collected bore logs that the area is covered with a deposit of fine grained material such as clay and silt on the surface. The deposits extend up-to a considerable depth below the surface. The materials are very fine in grain-size and are cohesive. The standard penetration test results indicate they are very soft to soft or medium stiff in consistency.

10.3 Available Data

The bearing capacities of cohesive soil have been calculated on the basis of the available data. The laboratory test results available are not considered sufficient for the purpose and also they do not correspond to the depths at which the foundations are usually located. As such standard penetration test results have been taken as the basis for calculation of bearing capacities. At all the bore holes the standard penetration tests have been performed at regular as well as close intervals. In calculating the bearing capacities Hansens's formula has been used. The values of cohesion or c have been taken from Tarzaghi's correlation of SPT with unconfined compression test results.

10.4 Analysis of foundation of selected structures

Calculation of Loads on Footings

The plan of each structure with size have been furnished in **Appendix-D**. From the drawings total load at the foundation level on the columns have been found out for normal occupancy and for the Tsunami/Cyclone shelter. Maximum loads on the foundation are taken for foundation analysis and given in the Table 10.3.

Calculation of Bearing Capacities

The bearing capacities have been calculated by using the formula suggested by Hansen. A simplified form of the formula for cohesive soil is given in the Standard Design Manual of BWDB. When □□0 and $N_q = 1$ then the bearing capacity of soil according to Hansen's formula becomes:

$$q_{ult} = cN_c s_c d_c$$

From the above Hansen's formula a generalized form for determination of bearing capacities at different SPT values are given in the Table 10.2. Bearing capacities of the selected structures are given in the Table 10.3.

Table 10.2: Generalised form for determination of Bearing Capacity

Srl.	SPT N	q_u (tsf)	c (tsf)	D/B ratio Assumed	$N_c s_c d_c$ (BWDB Design Manual table 5.7)	$q_{ult} = cN_c s_c d_c$ (tsf)	$q_{all} = q_{ult}/3$ (tsf)
1	0-2	0-0.25	0-0.125	0.6	7.04	0-0.88	0-0.29
2	2-4	0.25-0.5	0.125-0.25	0.6	7.04	0.88-1.76	0.29-0.59
3	4-8	0.5-1.0	0.25-0.5	0.6	7.04	1.76-3.52	0.59-1.17
4	8-15	1.0-2.0	0.5-1.0	0.6	7.04	3.52-7.04	1.17-2.35

Determination of Footing Size

The required area of footings under critical columns has been calculated dividing the load on the footing by the bearing capacity of soil. As the bearing capacity of soil at the location of the building is not known the S P T values of the nearest bore log (Emdad Ali Hostel of Patuakhali Govt. College**)** have been used for calculating the same and thus the areas of different footings have been determined and shown in Table 10.3.

10.5 Adequacy of the Footings Provided

The footing areas thus calculated for the selected structures are compared with those actually provided under the columns of the buildings already constructed. All the selected structures are in the Patuakhali district. Worst condition of the bore log for Emdad Ali hostel of Patuakhali govt. college, Patuakhali is used for determination of bearing capacities. From the calculated bearing capacities of the selected structures it has been observed that foundation provided for all selected structures are inadequate for Tsunami/Cyclone shelter even for normal occupancy. The reasons for structures being still existing may be that the structures might have undergone good amount of settlement. But since it is uniform settlement no unsightly cracks have developed on the structures.

Table 10.3 summarizes bearing capacities, existing footing size and required footing size of the selected structures for normal occupancy and for theTsunami/Cyclone shelter.

Table 10.3: Foundation Analysis for Selected Structures

Category of Building	No of story	Max^m load on footing (kN)		Allowable Bearing Capacity kN/m^2	Required Footing Size (mxm)	Existing Footing Size (mxm)	Remarks
		LL=3kN/m^2 (Normal)	LL=4.8kN/m^2 (Tsunami/Cyclone)				
Primary School	Existing single storied	80	90	15.88	2.250x2.250 (Nomal) 2.380x2.380 (Tsunami/Cyclone)	1.828x1.828	Inadequate
	Propose two storied	152	172	15.88	3.10x3.10 (Nomal) 3.290x2.290 (Tsunami/Cyclone)	1.828x1.828	Inadequate
High School	Existing single storied	162	188	14.82	3.30x3.30 (Nomal) 3.560x3.560 (Tsunami/Cyclone)	2.625x2.725	Inadequate
	Propose three storied	452	530	14.82	5.520x5.520 (Nomal) 5.980x5.980 (Tsunami/Cyclone)	2.625x2.725	Inadequate
College	Existing three storied	431	493	16.98	5.000x5.000 (Nomal) 5.390x5.390 (Tsunami/Cyclone)	2.588x2.600	Inadequate
	Propose three storied	431	493	16.98	5.000x5.000 (Nomal) 5.390x5.390 (Tsunami/Cyclone)	2.588x2.600	Inadequate
Madrasa	Existing single storied	189	210	15.88	5.000x5.000 (Nomal) 5.390x5.390 (Tsunami/Cyclone)	2.325x2.575	Inadequate
	Propose single storied	189	210	15.88	5.000x5.000 (Nomal) 5.390x5.390 (Tsunami/Cyclone)	2.325x2.575	Inadequate

11. EVALUATION OF THE ADAPTATION CAPACITY

11.1 Adaptation Capacity of Vulnerable Infrastructure

Among the selected structures the Primary School building, the High School building and the Madrasha building are one storied and the College building is three storied. In case of cyclone the one storied buildings suited only at places where there is no chance of storm surge. Although the primary school and the high school buildings have capacity to withstand storm surge of 3m, in that case, the people will have to take shelter on the roof. Thus only the multistoried building should be made adaptable to cyclone. In order to make the college building adaptable to withstand cyclones with basic wind speed of 260 km/h and surge height of 3m, seven corner columns and three interior beams of the building are required to be strengthened as can be seen from Table 8.8. Similarly in order to make the structures adaptable against Tsunami load, a large number of beams and columns need to be strengthened as shown in Tables 8.4, 8.5, 8.6 and 8.8.

11.2 Field Findings

The present study covered adaptation in case of both tsunami and storm surge but since coastal dwellers in Bangladesh have not experienced tsunami they could not mention much about that. There is no doubt that tsunami and storm surge are not identical although both have some common features as well, gravity of the two also not the same. However, since there was at least one signal for tsunami in 2008, people could refer to their preparation for the same. At the outset of the description of field findings that has been mentioned.

11.2.1 Source of weather information

Tsunami

The participants in the public consultation at Ramgoti mentioned that they heard of Tsunami from different sources such as radio, television, Cyclone Preparedness Program (CPP) and publicity of the ensuing Tsunami through miking by local volunteers of Red Crescent Society. Several other sources of information were also reported in other public consultations. For example, the people were informed about Tsunami from local educated people reported in Dakkhin Char Nurul Amin public consultation, through miking from mosque by the local conscious person in Musapur, through miking from Union Parishad in Guchakati and from their own experience of watching the sea water level in Khankhanabad. However, the most common source of warning of Tsunami was radio.

In public consultation at Ramgoti, one participant from Red Crescent mentioned that he had a meeting after receiving news about possible hit of tsunami. The purpose was to fix the role for each volunteer. Accordingly, some of the volunteers disseminate information through megaphone and some of them evacuate the people to safer places.

Storm surge

In all the places coastal dwellers mentioned that they learned through radio, TV, miking, publicity by red crescent, etc. about cyclone and storm surge. Participants in Hatia mentioned that when signal number is 8-10, the volunteers of Red Crescent informs people through siren. In Khankabad, Bashkhali, they also mentioned about Red Crescent and role of NGOs. Both the organizations play very crucial role in case of tsunami and storm surge. Thus, they understand that there will be severe cyclone. The participants in Ramgoti public consultation mentioned that except two out of 26 participants, all of them have radio sets and through that they could learn. The volunteers of Red Crescent had some preparatory activities before disseminating the warning signal of the cyclone.

11.2.2 Anticipation of Storm Surge

The coastal people from their own can not anticipate the possible storm surge that in most cases emanates from the cyclone. A group of people claimed to be able to anticipate while others can not predict it. Among the people who can predict usually use both scientific knowledge to anticipate storm surge along with the local traditional knowledge.

Some of the participants at Ramgoti public consultation mentioned that every signal does not indicate to possibility of occurrence of storm surge rather if the signal number is normally high storm surge likely to occur. Some could not identify the exact level of high number of signal which may lead to probable storm surge, but one person worked in CPP responded that they categorized the level of signal 1-3, 4-7 and 8-10. The last numbers of signal generates storm surge and based on that they decide to evacuate the people to safer places. In Hatia too, the people sense cold from which they can anticipate cyclone when there is high number of signal. Some people also mentioned that when severe wind comes they anticipate the storm surge. But the people in Dakkhin Char Nurul Amin were likely to anticipate storm surge by their own indigenous knowledge. For example, some of the older people mentioned that if the cyclone occurs at the night of the full moon, they anticipate storm surge. Similar to Dakkhin Char Nurul Amin, people in other places such as Guchakati, Nishan Baria and Khankhanabad anticipated the storm surge through their TAK (Traditional Indigenous Knowledge). For example, if the cyclone occurs during the ebb tide they anticipate storm surge (Guchakati), if the cyclone comes from south-east angle the people anticipate storm surge, or else they do not anticipate storm surge (Nishan baria) and sometimes they anticipate storm surge especially when the wind force is very severe (Khankhanabad). However, some of the participants in the pubic consultation at Guchakati mentioned that cyclone and storm surge are different, so they do not anticipate storm surge from each cyclone.

11.2.3 Preparatory Activities

The coastal dwellers preparatory activities include taking shelter in cyclone shelter, strong houses, embankment, on trees, etc. Besides, some people reported that they open the chain of the domestic animal in order to give them a chance to survive. The participants at Ramgoti public consultation mentioned that if the water level rises to a danger level they usually go to the cyclone shelters, schools, strongly built houses and high places. But if the water level does not rise to a significant level, the people usually pack the household items and take the domestic animals to a safer place. When the water level went up to a significant level as it happened in 1991, they took shelter in building, schools, and mosques. Besides, some of them took domestic animals with them to a safer place. However, sometimes they could not take any preparation. Recalling the cyclone of 1991, some of the participants mentioned that when they heard of the cyclone they tried to take shelter. But when they were moving to a safer place they confronted storm surge. The reason is that if they could get the news earlier they could prepare for the cyclone.

Some of them recalled devastating cyclone occurred in 1970 and mentioned that they had no prior idea about that cyclone. There was no signal and no one could predict that cyclone. As a result, they could not take any preparation for that devastating cyclone. Another person reported about the experience of cyclone in 1970. He took his grandmother to the roof for shelter where she spent the whole night. In the morning, they could see the water on their yard which was about 7/8 ft.

Some differences in regard to the preparatory activities were also found in different areas. The participants in Dakkhin Char Nurul Amin mentioned that the house was tied to a pillar on ground and they released the chain of domestic animals. In Musapur, the participants mentioned that if there were branches of tree over the house, they cut them off so that they could not fall upon and break the house due to cyclone. Besides, people listen to radio in order to be aware of the latest news of the cyclone. Food preparation was mentioned in Guchakati, i.e., they put rice and daal under ground had they any reserve of such items in their houses. In Nishan Baria, the participants reported that they did not let their children to go outside the home and their husband to go far after hearing the signal while in Kakchira, the people transferred the valuable things to another strong house if the house structure was weak. In Hatia, people sometimes do not go to shelter because the shelters are too far from the houses, the people near to the shelter take the shelter first and they may lose their property had they left for shelter. As a result, around 25% of people do not go to cyclone shelter even if the signal number is 10.

11.2.4 Actions taken during cyclone

On the basis of the preparatory activities, the coastal people take different actions in order to save their lives - the lives of their near and dear ones as well as the lives of domestic animals. In this regard, the variation was also recorded among different areas of coastal region. The participants in the public consultation at Ramgoti mentioned that they took people and domestic animals to safer places when they heard about the cyclone. Besides they prepared raft of banana trees to save them. The **box-1** presents the story of cyclone, 1970.

Box-1 : Story of Cyclone 1970

In 1970, there was a catastrophic cyclone in the costal region of Bangladesh. Many people died and many injured along with the loss of domestic animals, houses, crops, etc. One person recalled his memory of that cyclone at Daulat Khan, Bhola, who is now resident of Ramgoati. He gave a vivid account of that night. Storm surge was engulfing the entire region. People ran to and fro to escape from the death trap. He along with the other members of his aunt's family tried to save their lives. The entire family members were inside the house as the house structure was very strong. But the then little boy of 7 years old were sitting capturing a wood post of the house structure facing the cyclone direction inside the house. He believed that if the house structure is taken away by wind or water he would be able to see it and leave the structure to save him. He noticed that suddenly the house felt down due to severe water force as well as the storm. Five of that family member was washed out with the house structure. He also floated in water with flow in favor of the stream and thus he could manage to hold a nearby tree. But due to the severe wind and rain, he was slipping from the tree. Instantly, he used his lungi to tie himself with the stem of the tree which ultimately saved his life. During the time of storm and water surge, he saw many people were calling the name of relatives when they were sweeping out by the surge water.

In Dakkhin Char Nurul Amin, it was reported that there was no pucca house or shelter, so people could not go anywhere but when the water level went high they left for raised place at nearby place to take shelter. People in Musapur mentioned different strategies based on the number of signal. For example, the participants mentioned that when they get the signal of cyclone they take shelter at pucca house but when they get the signal of storm surge they take shelter at shelter houses, especially when they get the signal number 9-10. Tree based activities was mentioned by the participants in Guchakati, especially when they can not get shelter. They mentioned that if they can not take shelter at shelter house usually they ride up to the tree and hold the branches of tree. In this regard, one upholds a child towards the person already in tree and that person lift the child. Other strategies were also mentioned by participants in Nishan baria, Kakchira and Khankhanabad. For example, people who have the greed on property among the middle class usually do not take shelter anywhere except their own house lest they lose their property (Nishan baria) and people usually go to cyclone shelter when they hear the signal on emphatically (Khankhanabad). However, participants in Kakchira mentioned that due to the lack of shelter houses, no one could take shelter at cyclone shelter rather had people anticipate the severity they would not stay at home during the cyclone. The **box-2** presents the story of natural disaster in Kakchira, Borguna. Also in Hatia, participants mentioned that some people take shelter in cyclone shelter, some take shelter in strongly built houses, some at higher places, some on the roofs, some stay in their own houses and some do not take shelter even. However, the most of the women mentioned that they usually take shelter on embankment.

Box-2: Story of Natural Disaster in Kakchira, Borguna

(This story is a recalled one by husband of a couple who suffered a catastrophic cyclone)

At first we could not understand after getting warning signal, we in total 19 people took shelter at our three storied building. The velocity of the wind was gradually increasing. Suddenly my daughter came and told us that water engulfed our first floor. Then we (husband and wife) went down to the first floor and saw that there was hip level of water. As there was no electricity, we came with lantern but the wind turned it off. I tried to find the door but could not, but my wife found it and called me. Then we together tried to open the door and we opened it. Immediately the water force floated us away. At a certain point of time I became unconscious. When I regained my consciousness, I discovered myself on a branch of tree. Some moments later I heard that my wife was crying by calling my name. I discovered her at another branch of another tree. We then came down and saw that freedom fighter Abdur Razzaq Zihadi was crying. Out of 19 people who took shelter in our house 13 died including 7 from our family. Four people came to take shelter at my house, but all of them died due to the deadly cyclone.

11.2.5 Shelter taken

Although there is a record of disastrous cyclones in the coastal region in Bangladesh, there is insufficient shelter in those regions. To some specific regions, there is no shelter at all. The participants in Ramgoti mentioned that there is lack of enough shelter places. The existing shelter houses can not provide accommodation to all the people in the locality rather many of the affected people stay outside the shelter. All the people want to go to the cyclone shelter but due to the shortage of shelter, some people can move there especially those who are aware of the catastrophe and live near to the cyclone shelters. The rest of the people usually go to another place for shelter. Women to some extent go to shelter if possible; however, many women and children can not go to shelter rather they stay in their own houses or other nearby places to take shelter. The participants in Kakchira public consultation also mentioned that there is shortage of cyclone shelter. However, participants in Dakkhin Char Nurul Amin mentioned that there is no cyclone shelter near that place. The **Box-3** gives a picture of 1991.

Box-3: Story of Natural Disaster, 1991
The cyclone that affected in 1991 had severe consequences on human lives, domestic animals, crops and many others. It was one of the deadliest cyclones in the history of Bangladesh. One couple recalled their experiences in that cyclone. The water level was around 2 ft high in cyclone shelter even. People tried to save their lives moving to safer places. Some could take shelter in cyclone shelter, house built in high areas, or strong houses and some to embankment and many other places; however, many could not take any shelter at all. That couple went to embankment to take the shelter but due to severe storm, they could not take the shelter there. At that time they saw two ships anchored to a nearby place of the coast. At first they decided to take shelter in those ships. But suddenly they felt that the ships may get capsized due to the strong cyclone. Instantly they moved to another place of the embankment and took shelter. After passing certain time of the cyclone, they were coming back to their house. On the way they saw that two ships were capsized and people staying in the ships died. They also experienced hundreds of people washed out by surge water in front of their eyes.

A woman participated in Ramgoti public consultation recalled an event during the cyclone Sidr. She mentioned that she got the signal and took shelter into a nearby house. But everyone could not get shelter as there was limited arrangement compare to the number of people looking for the same. Among the people who took shelter, older people, children and women got priority. However, it was not possible all the time especially when the time is very much limited for taking shelter. The B**ox 4** provides another story of natural disaster of 1991.

Box-4:Natural Disaster in 1991
A person aged 40 recalled the experience of cyclone in 1991. He reported that at that time he was around 23 years old. He got the signal in the morning at the day of cyclone. All the day there was rain with moderate level of wind. With the increasing hour of hot day since morning, the rain and wind were becoming severe. In the evening the rain and severe wind gradually were turning into storm. Around 7/8 pm, the sever cyclone struck the headquarters area of Hatia Upazila. He shut down the shops and sat down inside the shop. After an hour a slice of wood struck him and he

fell down and after a few minutes he found that the shop has disappeared but he was still there. He came out to an open field where he observed the deadliest events. He took shelter at the corner of the field and under a tree taking the tree as a protector from CI sheets flying away due to the cyclone. During that devastating time he further observed that the storm took away two-three children. They cried but he could do nothing as there were still some CI sheets passing that place sporadically. Spending three to 4 hours there, he came back to a school when the storm turned to be less severe. In the next morning he found several dead bodies along the road, the most of whom were children.

11.2.6 Training received

Training is considered as highly essential in order to save the coastal people from the catastrophic cyclones because training will help them to prepare to tackle cyclone. However, insufficient training is given to the people living in the coastal regions. Although training is provided by a few organizations like Red Crescent, and NGOs, the coverage is very limited i.e., only a few number of people as well as a few areas are covered.

Among the participants at Ramgoti, except 4/5 people all got training provided by Red Crescent. One of the trained volunteers said that trained volunteers can do something in order to manage the disaster ranging from preparation to rehabilitation. However, due to lack of logistics like megaphone, raincoat and lack of other logistic supports they could not utilized their full capacity. Some of the participants said that through first aid, they cold save some people after the attack of Sidr. They further mentioned that such training gives benefits both in case of cyclone as well as in non-cyclone period. For example, how to save life when one drowns. The problem arises not only during cyclone but even in normal time also.

From public consultation in Khankhanabad it was found that some women got training on disaster. The training provided the following instructions:

- to be prepared as soon as they got the signal
- to motivate the children not to go far after hearing the danger signal
- to put valuable things under ground
- it is necessary to prepare dry food earlier
- it is necessary to take dry food to the cyclone center
- it is necessary to release the shackle of domestic animals and if possible to take them to the higher place immediately hearing the danger signal
- if possible one should help other people with providing shelter to their children
- to plant tree as much as possible.

However, participants in Dakkhin Char Nurul Amin and Nishan Baria mentioned that there was no such training. In Musapur, participants reported that although there was no institutional training system, but people from Red Crescent sometime advise some people. Among the participants in Hatia, 4 participants mentioned that they got training. Among the trained people there was only one woman. They further mentioned that only Red Crescent provides such training. The participants also reported that there was no usefulness of training as there was no cyclone after 1991. However, in regard to first aid and to save the life from the water, the training is still useful.

11.2.7 Changes in coping strategy or adaptation

It is necessary to change the coping strategies in order to be better able to protect the lives of the coastal people, domestic animals as well as valuable household items from the devastating cyclone. However, in some places there was almost no change while in other places there were some changes in coping strategies. Some of the participants in Ramgoti public consultation mentioned that there was no change in the Baazar, road, and embankment. However, they had taken several measures in order to cope with the cyclone such as:

Changes in Homestead Ground Level:

The coastal people learned from the previous cyclones that water may engulf their house if it is built on low land. As a result, they raised their low-lying homestead level keeping pace with the possible inundation level of surge water. However, as it requires huge fund so it was not possible for all the people rather only some solvent people raised their homestead ground.

Making Strong Pillar/Post for House

The coastal people experienced from the past cyclones that the normal pillar can be broken down easily due to the wind pressure during cyclone along with the storm surge. In order to combat that, they now build strong pillar which they think can protect the houses, human lives, domestic animals as well other household valuables. However, this practice is also limited as most of the coastal people are poor who do not have enough fund to bring about a change in the pillars of their houses. As a result, a vast majority of the people can not change their coping strategy in this regard.

Planting Trees

Trees are the filters of winds, i.e., it reduces the intensity of the force of the cyclone and at the same time generates less severe impact of the cyclone upon the people. Besides, the coconut trees provide the water immediately after the cyclone when water scarcity is more severe for the people who are the cyclone survivors. The local people now take interest to plant trees as much as possible in order to get the most benefit out of the trees during cyclone as well as post cyclone period. The participants in Hatia, mentioned that many trees were planted along the roadside after the devastating cyclone of 1991.

Paving the Floor

Some of the participants in Ramgoti mentioned that storm surge destabilize the katcha floor ultimately leading the entire house to collapse. This is because due to velocity of water, the katcha floor can not hold it together. As a result, with flow of the storm surge the floor gets washed out where pillars also fall down. In order to protect the houses some rich people converted their katcha floor to Pucca.

Converting Semi Pucca Building into Full Building

Semi-pucca building can not stand the high force of the cyclone. The coastal people experienced that many of the semi–pucca building collapsed during the cyclone causing severe damage to the people as well as household items. In order to cope better with the cyclone, they now built full scale building especially those who have financial ability. Some of the participants in Ramgoti mentioned that it has another advantage. More people can take shelter in building because of the concrete roof and domestic animals can also be protected on roof to save from deadly cyclone with storm surge.

Paving the Road

The participants in Dakkhin Char Nurul Amin mentioned that the road became pucca earlier which was katcha. The benefits of such pucca road are that it is easy to move to a safer place very quickly, many people also can take shelter on road especially those who can not take shelter during the cyclone and immediately after the cyclone people whose houses are damaged may use the road for temporary living. The similar change was also found in Nishan Baria where Caritas NGO paved road for the people

Avoiding Risk

The participants in Musapur mentioned that in the past they used to go for fishing even after hearing the signal; however, nowadays, they come home as soon as they learn about the signal. The coastal dwellers recalled that most of the people who came later even hearing the signal died due to the cyclone. As a result, they learnt to avoid the risk by coming back earlier to the house and manage safer places for themselves, their near and dear ones and help other people to have a shelter.

Avoiding Earthen Houses

Some of the participants in Guchakati mentioned that they do not build earthen houses anymore because the storm surge destroys earthen houses. As a result, some people changed their house structure especially those who have ability they made pucca house.

Besides, some of the women in Guchakati mentioned that they made their children aware of the cyclone and some fishermen mentioned that they always keep radio with them to learn about the latest weather information and save their lives from cyclone hazard. Despite above trend that they mentioned in different locations, such changes are not taking place rapidly as most of the people are unable to bear the cost for any changes. The changes were not found in all the localities. Some of the participants in Dakkhin Char Nurul Amin mentioned that there was no change in schools, madrasha, mosque, and embankment structures. The participants in Guchakati mentioned that there was no scope to bring about changes by the poor people rather they completely depend on divine support. Since last disaster they could only repair their damaged houses. Besides, there is almost no change in Kakchira except repairing the damaged shops.

In Hatia also the participants mentioned that there was almost no change in bazaar, mosque, etc. As the embankments were built after 1991, so there was no change in the embankment. However, in 2008, there was a change in embankment to some extent. However, some of the participants mentioned that a building was made after 1991 by a person in the locality for his own need. People took shelter in that house after getting the signal of Sidr. Such kind of private initiative can be a good alternative of the government endeavour for constructing shelter houses.

The above-mentioned findings and observations reveal an important change in adaptation approach which has been presented in **Box -5:**

Box -5: Important Changes in Adaptation Approach

- A shift from no-preparation to some preparations
- A shift from indifference to structural adaptation/adjustment approach
- A shift from public initiatives to private initiatives
- A shift from structural approach to non-structural approach
- A shift from individual approach to community approach
- A shift from fatalist approach to pragmatic approach
- A shift from single approach to holistic approach
- A shift from indigenous approach to scientific approach
- A shift from mitigation approach to adaptation approach

11.2.8 Approaches if there is no shelter

When there is no shelter at nearest places or in the locality, it is, indeed, a big challenge for the local people. In order to save themselves, the people undertake different measures which include taking shelter to nearby building, road, strong houses, etc. In this regard, location specific policies and adaptation strategies were reported.

The participants in Ramgoti mentioned that if there is no shelter, they usually take shelter in a higher place where they consider storm surge may not reach. They try to take the older people and children to a safer place first. But sometimes older people do not like to go to another place rather they prefer to stay in their own place even if they die. As a result, it was not always possible to take the older people to a safer place. Most of the people stayed in their own house due to lack of shelter. The participants further mentioned that if the shelter is in nearby place older people and women may be taken to the shelter very easily.

The participants in Dakkhin Char Nurul Amin reported that there was no place to take shelter except embankment. But in Musapur, the participants mentioned that there was a two-storied building in which they take shelter as there was no scope to take shelter in cyclone shelter. Some of the participants of Nishan Baria reported that they depended on divine support while people in Kakchira were likely to take shelter in other places as there is no shelter house or embankment. The participants in Khankhanabad mentioned that people took shelter at the roof, tree and other higher places. The participants in Hatia mentioned that only around 12% of the local people can take shelter in the existing cyclone shelters. Recalling the experience of 1991 cyclone, they mentioned that people made their floor higher to some extent. However, most of the participants mentioned that due to the lack of money most of them could not take such initiative.

11.2.9 Improvement of the Existing Capacity

The casualties were more severe in 1970 and 1991, mainly due to lack of warning system, easy-to-collapse house structures and late response to the cyclone affected people. Due to the demand of time and changing weather, it is now necessary to improve the existing capacity to tackle the cyclone affect to save human lives and reduce property damages. The participants in different public consultations mentioned that in the following manner:

- **NGOs:** It is common to see that coastal dwellers are marginal producer and most of them live hands to mouth, so it is not possible to store dry food for the post cyclone management. Besides, due to continuous wet condition for a longer period of time cyclone survivors' cloth gets wetted and to save the survivors from the injuries immediately they need proper medication. Considering all those factors, the participant in Ramgoti mentioned that NGOs can play a vital role in this regard. The participants in Musapur and Nishan Baria mentioned that NGOs can play crucial role through distributing shot-term loan to the cyclone victims.
- **Private Company:** Some of the participants in Ramgoti mentioned that as there is huge number of people live in the coastal area so they need food for survivals after disaster. NGO alone may not be able to provide the necessary food to needy survivors. In this regard, different companies may come forward and provide food to the cyclone affected people.
- The poor people are not in a position to change the physical structure like houses, roads, etc. Some of the participants in Ramgoti and Nishan Baria mentioned that the rich people may help in building houses for the poor people, metalling roads, distributing clothes, etc. among the poor.
- People with small family size has comparatively lower burden to take shelter. Pointing to it, some of the participants in Musapur mentioned that people from such family can help others in taking them to shelter houses after providing shelter of their own family members. A collaborative effort was, indeed, suggested by them.
- The participants in Guchakati and Kakchira mentioned that it is urgent to increase the number of cyclone shelters to increase the holding capacity. The participants in Guchakati also mentioned the necessity of converting the schools into two storied building and of increasing the number of tube wells in the locality in order to ensure the availability of the drinking water immediately after any devastating cyclone.
- The participants in Khankhanabad mentioned the need of tree plantation, building houses at higher places, building pucca mosque and Madrasha. They rationalized it by saying that it will better equip the people to cope with the cyclone.

Table 11.1: Similarities and dissimilarities among the studied areas in regard to adaptation during cyclone

S. No	Areas	Similarities in Action taken during Cyclone	Dissimilarities in Action taken during Cyclone
1	Ramgoti	Taking shelter in own house	Taking shelter in • cyclone shelter • mosque • school • strong houses • higher places • helping other people to take shelter • taking domestic animals in safer places
2	Bhola	Taking shelter in own house	Taking shelter on • Embankment

3	Bashkhali	Taking shelter in own house	Taking shelter in • cyclone shelter • trees • roof of the house • strong built/pucca house
4	Borguna	Taking shelter in own house	Taking shelter in • strong built houses • cyclone shelter • strong built/pucca house • trees • roof of the house
5	Nishanbaria, Patuakhali	Taking shelter in own house	Taking shelter in • cyclone shelter • pucca house
6	Guchakati, Potuakhali	Taking shelter in own house	Taking shelter in • trees • cyclone shelter
7	Sondip	Taking shelter in own house	Taking shelter in • cyclone shelter • strong built houses
8	Hatia	Taking shelter in own house	Taking shelter in • cyclone shelter • embankments • roads • strong built houses • roof of house • floor of strong built houses

Analyses of above data show that there are similarities and dissimilarities in case of adaptation during cyclone.

Table 11.2: Similarities and dissimilarities in case of structural adaptation in study areas

S. No	Areas	Similarities in Adaptation Approaches	Dissimilarities in Adaptation Approaches
1	Ramgoti	• planted more trees	• made floor of houses high • made floor of shops high • made polls of house stronger • paved the floor • paved floor of the tin shed school
2	Bhola	• planted trees at home	• Paved the road • made shops stronger • made floor of shops high • made houses stronger • made houses high

3	Bashkhali	• planted trees at home	• repaired road by local Government • repaired shops • made the floor high • made madrasha strong
4	Borguna	• planted trees	• repaired houses • repaired shops • made tinshed building by financial support from Arab Government
5	Nishanbaria, Potuakhali	• planted trees alongside the embankment	• made new road • repaired affected shops • built affected houses anew
6	Guchakati, Potuakhali	• planted trees on road side and homes	• raised the floor level • made road higher • made house stronger
7	Sondip	• planted trees along the road	• repaired road • made floor of houses high
8	Hatia	• planted trees alongside the road and home	• made shelter newly • improvement in embankment • made a new house by private initiative

The above data show a kind of similarities and dissimilarities in case of structural adaptation in the study area. It reveals the nature and extent of adaptive approach used in different conditions by different set of coastal dwellers.

11.2.10 Principles of adaptation

During field level consultation attempt was made to evolve the principles of adaptation of the coastal dwellers. The followings are the major principles of adaptation that they follow in relation to tsunami and storm surges:

Box-6: Principles of adaptation

- People with higher ability live in low risk zone and vice versa
- The higher is the risk of asset loss, the lower is the tendency to take shelter
- The higher is the economic ability, the better is the preparation
- The higher is the awareness, the better is the preparation
- The higher is the fatalist group, the lower is the risk aversion attitude
- The better is the preparation the more attention women and children get
- Disaster does not come unless people forget the last one and people become serious mainly after each disaster.
- People with land based livelihood are more concerned than the water based livelihood and thereby go for better preparation
- The higher is the secured area the lower is the investment requirement for each

household (Alternatively security benefits to the people can be provided more with low cost if there is natural or man-made safety system like embankment or hill near to coastline).

- The higher is the security cost the lower is the tendency to go for safety measures by the agencies and the persons. At one stage even may give up the idea of ensuring security measures for insecured people.

11.3 Methods for Improvement of Adaptation Capacity

Some methods have been formulated for improvement of adaptation capacity of the coastal dwellers based on the participant's suggestions and field survey data and presented below:

a. ***Private multi-storied house:*** To go for building private multistoried houses which may be used as shelter during catastrophe. This is a new practice in some areas observed during field survey.

b. ***To make all structures as multipurpose:*** All office buildings, NGO offices, UP buildings, health service centres, private commercial and residential building, etc. should be made multi-purpose in the costal areas.

c. ***Raising ground:*** All kinds of school/madrasaha ground, all office grounds, Eidgah ground, burial ground, market ground, embankment, road, etc. may be raised instead of raising each household ground. It would be cheaper and environment friendly.

d. ***Shelter house construction on embankment:*** Keeping bottom side open for traffic the shelter house may be constructed on the embankment without affecting cultivable land from the area. It would be easier to reach there.

e. ***Maximum Security at minimum cost:*** There is a big gap between potential adaptation versus practiced adaptation measures. This gap may be reduced by continuous monitoring measures from the local level disaster management committees.

f. ***Pruning tree for protection:*** During the cyclone people take shelter on the trees which have to be protected from cyclone. In order to protect people, cutting the branches of the tree may be a good approach since it reduces the wind pressure.

g. ***Rich bias shelter house construction:*** Shelter house construction near to rich people's house need to be avoided as that normally remains far from the required location of most of the people who need to take shelter. Approach road is also important to shelter house as during crisis people cannot move rapidly to that structure in absence of approach road.

h. ***Observe 12 November as coastal day:*** The day 12 November may be observed as coastal day to remind people about the possible risks. On that day they may be asked to recall their family members or near and dear one who lost life during previous cyclones or storm surge. There may be some safety rehearsal for Tsunami and storm surge. It will inspire them to prepare further for adaptation.

12. GUIDELINE TO IMPROVE THE ADAPTATION CAPACITY

In order to pursue the study a participatory method was used to collect opinion of the people about their practices. Their adoption about tsunami and storm surge has been noted from the people living in the main coastline areas of Bangladesh. Indeed, to list down the opinion of the people several large group discussions (LGDs) were conducted in different coastline areas. Most of the cases the LGD were attended by different segment of the society as different occupational and income groups had to adapt differently[1].

12.1 Group Discussion Areas

The group discussion was carried out in 8 different areas of coastal zone shown in Table 12.1 covering both main land and island area. Attempt was made to collect data more from coastline areas exposed to sea areas.

Table 12.1: Group Discussion Areas

Sl. No.	Village	Upazila	District
01.	Khankabad	Bashkhali	Chittagong
02.	Musapur	Sondip	Chittagong
03.	Balu Char	Ramgoti	Laksmipur
04.	South Char Nurul Amin	Charfession	Bhola
05.	Nishanbaria	Kalapara	Patuakhali
06.	Guchakati	Baopaul	Patuakhali
07.	Kakchira	Pathargata	Borguna
08.	Shunner Char	Hatia	Noakhali

12.2 Data Collection Procedure

For this study data were collected through 8 separate public consultations organized in eight places. In this regard, a good number of people in the respective locality was requested to assemble to a place where they were interviewed about the different issues related to the study objectives. The participants were representative as the consultations were carried out with the people of diversified occupations, age, and sex. The occupations were agro-farming, fishing, teaching, students, religious leaders, housewives, day laboring and sharecropping, etc. Their age varied from 20 years to almost 70 years. Some children were present in different places who were asked about their preparation and adaptation. But children were found much dependent on their adult family members.

[1] For example, in case of Rakhain group in Cox's Bazar under Khurushkhol area a part of their homestead were inundated by the tidal surge originated from Bay of Bengal in 1991. At least 6 feet water was there. Since they are from an ethnic minority usually they do not like to go to Muslim paras. A group has also taken shelter in their Temple. There are 130 households of that Rakhain para who need shelter during any storm surge or tsunami. One NGO is currently constructing one shelter house next to their para. They do not have there own initiative.

12.3 Differentiate the Vulnerable Buildings based on Adaptation Capacity

Types of Infrastructures

Infrastructures developed in the costal regions are basically of three types where one type is primarily meant for shelter during natural calamities like cyclone and storm surge, another is of multipurpose type in nature where during non-disaster period the infrastructure is basically used for other socio-economic activities. The third type is basically meant for every day affairs of human life. Among all those types the first two although limited in number but gets much attention from the planners and policy makers including local people. Since those have been done under the initiative of the government mostly backed by the donors and development partners, it is obviously limited in number compare to the increased requirement of the people living in those vulnerable areas. With increased scarcity of means of livelihood, having no much space to live inside the country, people from the marginal section are shifting to and settling in the coast even along the coast line or newly accredited char land of the country where even 1 meter rise of high tide brings a large area under water. The density of people living in the coast line in many areas is identical compare to the people living in core part of the country. Thus, the number of people deserving shelter during the disaster in the coast is increasing tremendously every year. Without reversing the present trend it would be impossible for this country to create opportunity for everyone to arrange shelter for them. Redistribution of population may be one way of solving the problem of shelter for them.

Differentiate the Vulnerable Building Based on Adaptation Capacity

Buildings in the coastal area are to be classified based on the vulnerability against storm surge and tsunami. Classification may be as follows (Table 12.1):

Table 12.2: Classification of Vulnerable Buildings based on Adaptation Capacity

Types of Building	Assessment of types	Ranking	Remarks
Shelter house, multipurpose building, private house, hotel, motel, restaurant, residential and functional buildings of the government and non-government agencies	Which has capacity to stand at maximum wind speed and maximum surge and tsunami level at particular location.	**A Grade**	Not Vulnerable
Do	Which has capacity to stand at maximum wind speed of 260 km/hour and maximum surge/tsunami level of 1 meter	**B Grade**	Fairly Vulnerable
Do	Which has capacity to stand at maximum wind speed of 260 km/hour but surge/tsunami level more than 1.0m meter	**C Grade**	Highly Vulnerable
Do	Which has risk of natural	**D Grade**	Totally

	collapse at any time due to any wind speed, surge/tsunami level or flooding/ inundation.		unsafe/ should be declared as high risk building/ abandoned. Tin shed and masonry wall buildings may be under this category.

12.4 Increase Adaptation Capacity of Each Vulnerable Infrastructure

The general techniques to increase adaptation capacity are furnished in Table 12.3 below. .

Table 12.3: General Techniques to Increase Adaptation Capacity

Types of Building	Techniques to increase adaptation capacity	Responsibility
Shelter house and multipurpose buildings	• Doing earth work under the Social Safety Net Program of PRSP-II for strengthening the foundation and maintaining slope for crossing surge water • Identify measures to prevent hydraulic jump if there is such risk • Making easy access to shelter house for rapidly taking shelter • Testing the strength of all buildings and to come up with redesigning where necessary to resign it at minimum cost • Activate all shelter houses located in the interior side although accretion of land to the sea side already occurred. • Redesign the structures to meet the needs of aged, women and children and pregnant mothers • Bringing the embankment upto design level and resectioning regularly using Embankment Maintenance Group (EMG) under the Social Safety Net Program of PRSP-II.	GoB, Local Government
Private house, hotel, motel, and restaurant	• Encourage private sector like to take initiative to help in designing the private houses at free of cost to construct for working as shelter house during cyclone and storm surge. • Give design support to the private sector	Private sector; Public sector; Community members

	while setting up such hotel, motel and restaurant • Instruct financial institutions such as Bank, leasing companies, Micro Finance Institutions (MFIs) to give support to the private sector for building their infrastructure keeping provision of protection from cyclone and storm surge.	
Residential and functional buildings of the government and non-government agencies	• Setting the management for such type of emergency use • Making provision for access to those building for rapidly taking shelter • Doing earth work under the Social Safety Net Program of PRSP-II for strengthening the foundation and maintaining slope for crossing surge water • Identify measures to prevent hydraulic jump if there is such risk • Testing the strength of all buildings and to come up with redesigning where necessary • Giving financial support to such type of organizations under the disaster management programs to reduce the cost of disaster management and shifting the responsibility to the community • Preparing the community before shifting such responsibility	GoB; NGOs; CBOs; Local Government; Club; Market Management Committee;
Embankment	• Resectioning of embankment should be a continuous process using Embankment Maintenance Group (EMG); • Reviewing the needs and strength of the embankment from time to time • Declaring embankment abandoned which is no longer used for protection of the area. Maintenance of that embankment should go to other departments, not to remain with water management organization; • Bringing the new accredited area under the coverage of embankment to increase the safe zone for the coastal dwellers	GoB; NGOs

12.5 Basic Policies for Increasing Adaptation Capacity

The coastal infrastructures of our country are particularly vulnerable to cyclonic wind, storm surge and tsunami. A number of coastal structures have been analyzed in the present project to evaluate their adaptation capacity to these hazards as reported in the Structural Strength Analysis Report (IWM, 2009). Four typical structures were analyzed - a primary school building, a high school building, a college building and a madrasa building. The vulnerability of these structures against cyclonic storm surge and tsunami was studied both under normal occupancy and under occupancy when they are used as shelters. Following observations can be made from the study:

- From field measurement, concrete quality was in general found satisfactory.
- All these structures are unable to resist loads due to tsunami.
- All these structures except the college building can resist loads due to cyclone and storm-surge under normal occupancy.
- Only the primary school building can sustain cyclone and storm-surge even under the increased live load if it is used as a shelter.
- It was found that masonry structures have much less flexural capacity compared to the loads imposed either by storm-surge or by tsunami.

Photo 12.1: A masonry structure completely collapsed due to storm-surge during Cyclone Sidr in 2007

Photo 12.2: A school building which withstood storm-surge during Cyclone Sidr in 2007

From these observations, the following guidelines can be proposed:

- In areas where there is a plausible risk of tsunami, all these structures must be strengthened. Since lead-time for tsunami may be much less compared to cyclones, the concentration of shelters should be increased as much as possible. Thus, a large number of these RC structures should be strengthened so that they can bear the additional live load if people take refuge during a tsunami.
- Since storm-surge is also accompanied by strong cyclonic wind, one-storied structures cannot be used as shelters. The three-storied college building needs to be strengthened so that it can be used as a shelter during cyclone.
- Masonry structures should be evacuated before a cyclone or tsunami in areas where there is risk of inundation.

12.6 Strengthening of Reinforced Concrete Structures

The vulnerability analysis of RC structures showed that they have inadequate beams and columns. Figures 5.1 to 5.4 show that the beams and columns of different structures that need to be strengthened if the structures act as shelters for tsunami. In most of the structures it was found that the exterior columns are most vulnerable except for the Madrasa building where all the columns were found inadequate. For the High School and the College buildings longer beams running in the shorter direction were found inadequate. Details about the inadequacy of different members for other loading conditions are provided in the report on the Structural Strength Analysis (IWM, 2009).

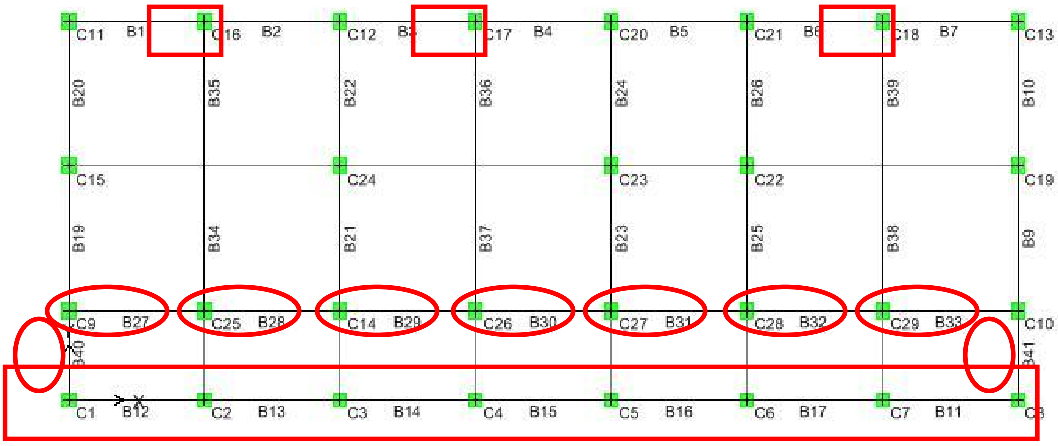


Figure 12.1**:** Inadequate beams and columns of the Primary School building

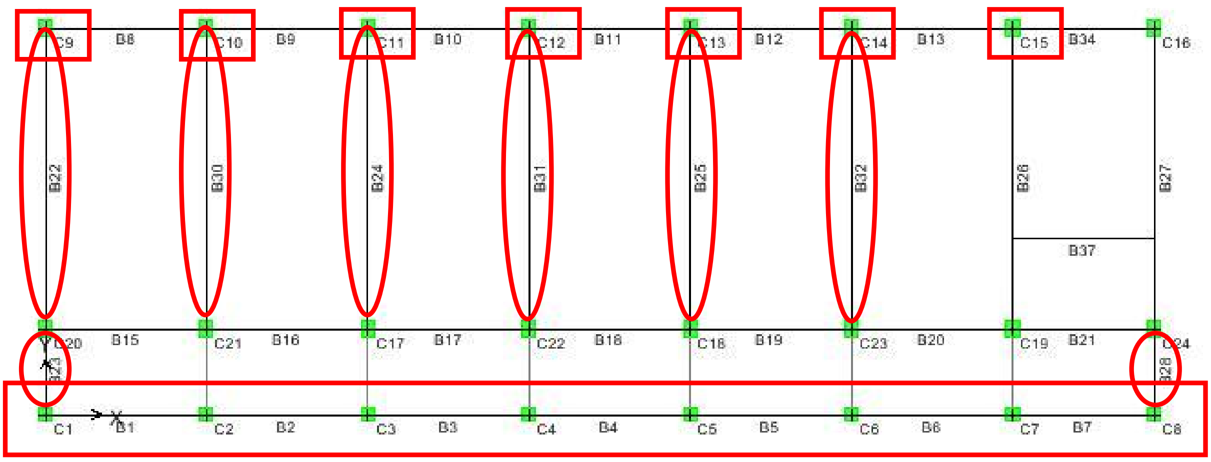


Figure 12.2**:** Inadequate beams and columns of the High School building

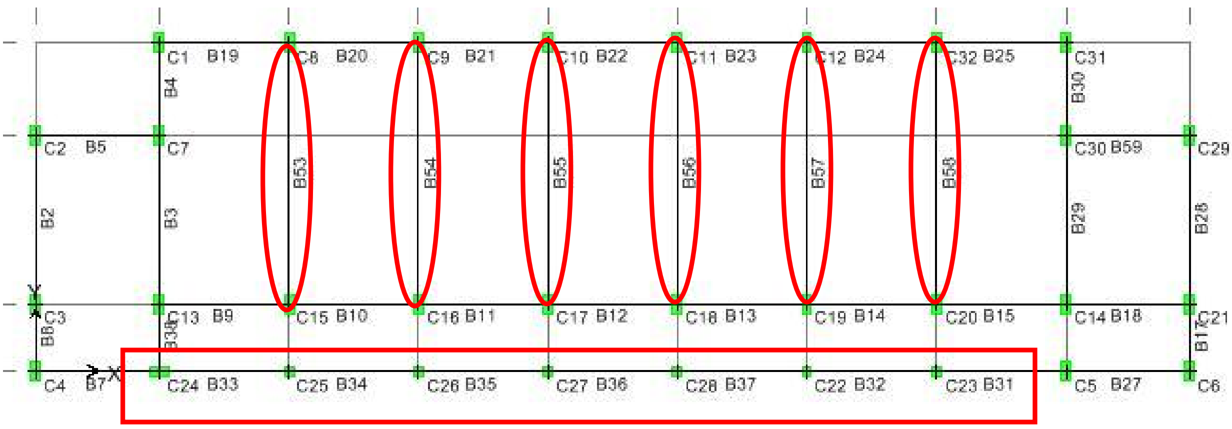


Figure 12.3**:** Inadequate beams and columns of the College building

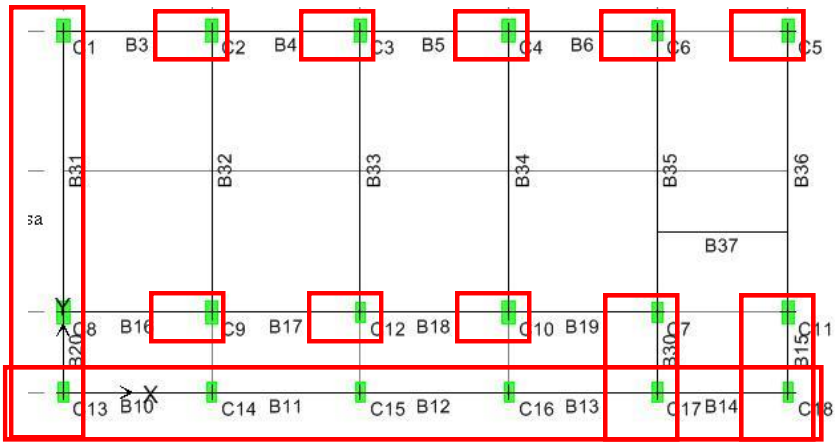


Figure 12.4**:** Inadequate beams and columns of the Madrasa building

The inadequate members of a structure can be strengthened by using different materials:

- Reinforced Concrete
- Steel
- Ferrocement
- Fibre Reinforced Polymer

Reinforced concrete is the most preferred material for structural strengthening because of its availability and familiarity to the masons. For coastal structures, steel would be the least preferred material for its corrosion potential. Ferrocement is appropriate for strengthening of masonry structures or walls. Fibre reinforced polymer (FRP) is a newer material particularly useful for strengthening structures. The greatest disadvantages of FRP are its unavailability in our country and cost. Thus for strengthening of beams and columns of the coastal structures concrete jacketing may be the most suitable solution. For masonry structures, ferrocement may be used as strengthening material. However, before deciding any strengthening scheme each individual structure should first be thoroughly assessed.

Concrete Jacketing of Beams and Columns:

Concrete is added to increase the flexural strength or stiffness of a beam. Providing additional stirrups increases the shear capacity. Several options are available for adding concrete (Fig 5.5). The addition of concrete is relatively cheap. Based on the condition of the existing beam, drilling should be minimized. To ensure good bond, the existing concrete surface has to be roughened by a grinder.

Concrete jacketing of columns involves addition of a thick layer of RC in the form of a jacket, using longitudinal reinforcement and ties with proper detailing (Fig.5.6). The method is comparative straightforward and increases both strength and ductility. The composite deformation of the existing and the new concrete requires adequate dowelling to the existing column. The additional longitudinal bars need to be anchored to the foundation and should be continuous through the slab.

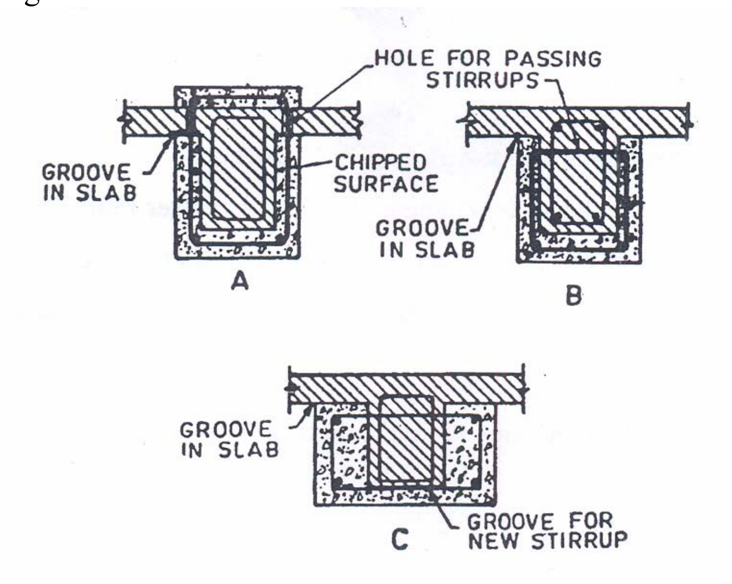


Figure 12.5: Concrete jacketing of beams

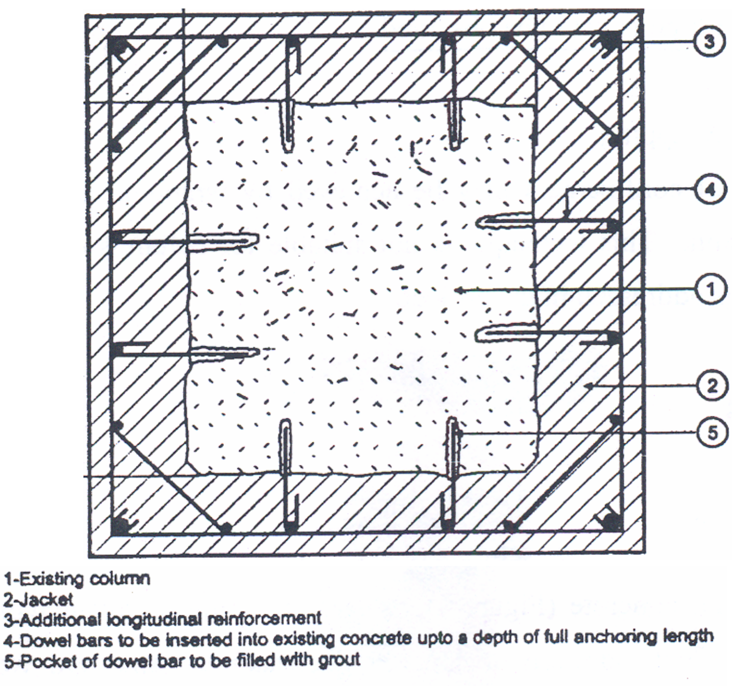


Figure 12.6: Concrete jacketing of columns

Strengthening of Masonry Walls with Ferrocement:

Ferrocement may be used to strengthen masonry walls of both load bearing and infill types. Ferrocement can increase capacity for both out-of-plane bending and in-plane membrane actions. Then steps of strengthening masonry walls with ferrocement are shown in Fig. 5.7.

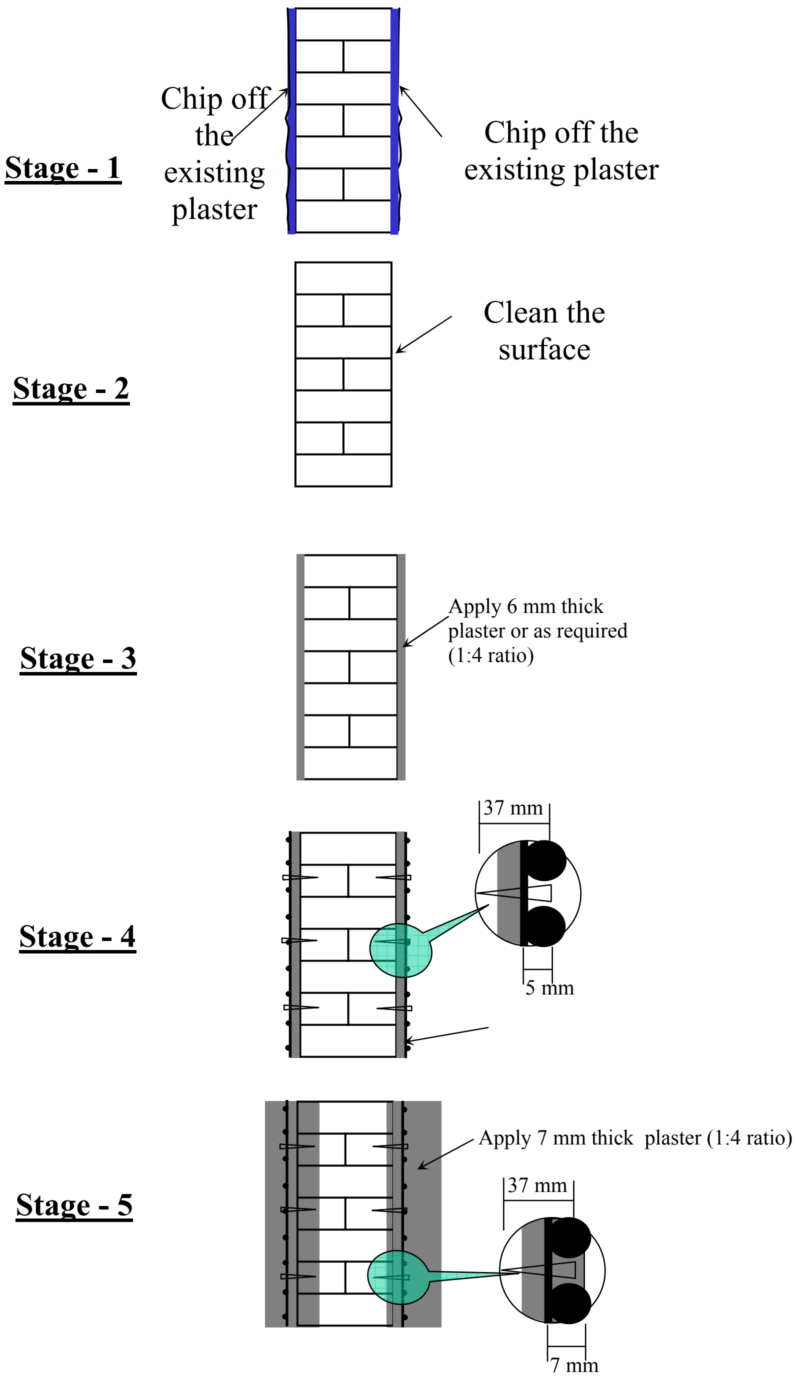


Figure 12.7: Steps of strengthening masonry walls with ferrocement

Specification of Materials used for Strengthening:

Specification of materials to be used for strengthening will in fact be job specific. After assessment of each structure the detail scheme for strengthening should be determined. According to each scheme of strengthening the specifications of materials, dimensions and detailing have to be decided. For a general guidance following specification may be consulted.

Concrete for strengthening work:

Minimum design strength: 21 MPa (3000 psi)

1: 1½ : 3 [Cement : Sand : Stone Chips]

Cement : Good quality OPC conforming to ASTM C109

Sand : Sylhet sand with F.M. not less than 2.0 in SSD condition

Stone chips : 12 mm downgrade for columns in SSD condition

20 mm downgrade for footings in SSD condition

w/c Ratio : 0.4 to 0.45

Recommended slump: 25 to 50mm

Steel for strengthening work:

60 Grade deformed bar

Tie rod and steel anchoring system:

A36 steel

Wire Mesh for ferrocement:

18 gauge woven/welded mesh with 12 mm x 12 mm square openings

Shear Key for ferrocement:

37 mm long screw

Plaster for ferrocement:

1:3 Ratio of Cement and Sand by volume

Cement : Good quality OPC complying with ASTM C150-85, ASTM C595-85 or equivalent standards

Sand : Fine sand with maximum size not greater than 1.18mm (#16 sieve) complying with ASTM C33-86 or equivalent standard

12.7 Issues in Developing Adaptation Capacity of Coastal Dwellers

Coast is the host of the people who have no place to live as do slums in the urban areas. The coastal dwellers are often marginal group of people of the country who maintain a separate pattern of livelihood. Coastal people often encounter many natural devastating disasters. As a result, every year many people embrace untimely death in coastal areas of Bangladesh.

Growth of Coastal Population:

Population growth in coastal areas is a major concern not only for economic reason but also for safety reasons from natural disasters. The world population is expected to grow at an exponential rate from 5.8 billion1995 to 8.5 billion in 2025. More than 50 percent of the world population is already concentrated within 60 kilometers of the coast. In developing countries, the coastal people may be reached to around 3.7 billion. A very significant portion of people live near to its coastal areas in Bangladesh. A vast population is living along the coast line who are always under different natural threats or facing challenges emanating from ecological degradation.

The negative impact of such increased human settlement will intensify further in regard to their livelihood and security. Many of the coastal people earn their livelihood through sea based economic activities like fishing as well as farming in coastal areas. The present trend of insecurity will increase further. Demand for increased security for the coastal dwellers due to concentration of population in that area requires careful intervention. If that can not be pursued properly, people of the entire coastal areas likely to suffer more. Moreover, government, private sector and donor agencies would also require to expand more to stand with the people before, during and after cyclone along with other natural disasters.

Geography of Bangladesh:

Bangladesh, a country of South Asia, situated on the tropic of cancers. Its total area is about 1, 47,570 sq km with about one-fifth in nineteen coastal districts, in zones of multiple vulnerabilities and fragile ecosystems with distinctive development opportunities and challenges. A large population (about 140 million) makes it one of the most densely populated countries in the world. Geographically, this country, a land between the mighty Himalayan chain and the open ocean (Bay of Bengal), is surrounded by India from three sides. Besides, Bangladesh is an exceedingly flat, low-lying, alluvial plain traversed by five major and more than 230 rivers and rivulets (with a total length of 24140 km). It has a coastline of about 580 km along the Bay of Bengal. The coastal zones of Bangladesh cover 19 districts (PDO-OCZMP, 2003).

The geographical location and topographical features of Bangladesh expose the country to almost all kinds of natural and human-induced disasters. Over the past three decades, Bangladesh experienced more than 170 large-scale natural disasters that killed half a million people and affected more than 400 million. Seven of the 10 deadliest cyclones of the twentieth century hit Bangladesh in the past 40 years. Natural hazards increase the vulnerability of the coastal dwellers and hinder social and economic development processes. The government of Bangladesh has already identified the zone as “vulnerable to adverse ecological progress” (ERD, 2003) and as one of the three neglected regions.

Threats to coastal population and infrastructure:

Over the last century, confirmed historical reports of cyclones along various coasts indicate that a single event can produce wind speeds exceeding 250 km/h, and the associated storm surges can attain a height of 12 meters. Hydrometeorological phenomena result in considerable destruction of life and property and, more particularly, lead to extensive and persistent inundations of low-lying coastal plains. The worst impact of a storm surge is when waters get trapped due to the blockage of traditional drainage channels by human activity. A low coast, based on its morphology, is by itself susceptible to invasion by high water. Consequently, flooding often lasts for days resulting in impacts on ports, harbors and associated infrastructure, isolation of villages, and disruption in the movement of people that are marooned. Damage and loss from Cyclone Sidr was concentrated on the southwest coast of Bangladesh.

A New Challenge:

Storm surges caused by cyclones, are familiar natural phenomena that sometimes inundate the coastal region in Bangladesh. Some of the examples are cyclone in 1970, 1991 and the latest one cyclone Sidr. Recently the international scientific community has recognized as real the concern over human induced global warming of the atmosphere, leading to climate changes and sea level rise. The later will particularly affect the low lying areas especially coastal areas of different countries including Bangladesh.

Environmentally sound responses to reduce the vulnerability of coastal dwellers to global climate change and natural disaster like cyclone in Bangladesh requires long lasting solution. Therefore, although effects of some of these changes are of long past, now it is time to consider develop adaptation capacity of coastal dwellers in Bangladesh.

12.8 Development of the Adaptation Capacity of Coastal Dwellers

Natural hazards increase the vulnerability of the coastal dwellers and hinder social and economic development processes. As a result, the government of Bangladesh has already identified the zone as “vulnerable to adverse ecological progress” (ERD, 2003). However, still coastal people suffer much from the cyclone and storm surge. Therefore, it is necessary to save human lives as well as properties so that individual along with community and nation can progress on its due course.

Adaptations are of two types which include structural adaptation and human adaptation. Under the structural adaptation all physical interventions are made while under the human adaptation people take initiatives using their skill and wisdom to adapt with the situation. Here both the approaches have been mentioned.

12.8.1 Structural adaptations by people

Promoting private multi-stored houses:

Although government pursuing developing cyclone shelter in coastal areas but that is not enough to provide the shelter and safety of all the people living in the coastal areas. That is mainly because the aspirant number of people for safety is higher compare to the space available in all the cyclone shelters in any locality. Lack of proper access road to shelters and distance of the shelter are often identified as hindrance. As a result, people constructing their own houses may be encouraged to construct private multi-storied building which may play a role of shelter house during disaster. If the number of private multi-storied houses is higher, the more people will be able to take shelter during cyclone. It will also reduce the government's cost of saving coastal lives and properties.

Although the majority of the coastal people are not financially well off, the construction of multi-storied houses in such areas seem almost imposable. However, still it is possible by involving the rich people in the coastal areas. Rich people in specific locality can build multi-storied houses. Government and non-government organizations may also help in this regard. Private companies can provide necessary financial support for building such houses under its corporate social responsibility budget. The ultimate result will provide safe spaces for everybody. The private company as part of their promotional activities may also pursue that.

To make all structures as multipurpose:

All office buildings, NGO offices, UP buildings, health service centers, private commercial and residential building, etc. should be made multi-purpose in the coastal areas. Although these structures are mainly used as office, they can be used as shelter if such structures are built on by proper design.

Offices can be built as two storied and wide corroder can also be built in offices so that during cyclone people can take shelter in corridor even. Government health service centers can be converted into more spacious place where more people can accommodate during the cyclone. Besides, private health services centers are mostly tin shed building. If possible such structures should be made two storied in the case of construction of new center while in terms of existing centers, floor of the centers should be made higher and if possible the building should be made stronger so that it can tolerate cyclone and storm surge. The same consideration should be given in case of commercial and residential buildings.

Raising ground:

All kinds of ground like school/madrasah ground, all office grounds, Eidgah ground, burial ground, market ground, embankment, road, etc. may be raised instead of raising each household ground. It would be cheaper and environment friendly also.

The people in the coastal areas are mostly depended on agriculture and fishing in order to earn the bread. Such earning sources reflect the poor economic condition of the coastal dwellers. As a result, it may not be possible to build strong houses and make the home ground high for the common people in the coastal areas. Besides, government alone also may not bear the whole burden of the cost of ensuring security of the coastal people raising home ground for every family. In this regard, the authority of Madrasah/school, Eidgah, burial ground and market can undertake initiatives to make ground higher under their self-help program or using fund from social safety net program of the government. Government should take initiatives to raise the embankment and road in order to provide space for the coastal people to take shelter during cyclone. Moreover, the alternative measures should be taken that include motivating the capable people to make the house strong and home ground high which not only help the capable people to be safer but also help other poor people to take shelter there. If it is implemented people will be able to reach to the safer place within a very short period of time.

Shelter house construction on embankment:

At present shelter houses are constructed on agricultural land causing loss to the agriculture in the coastal areas. Moreover, due to the construction of shelter houses in agricultural land, it becomes difficult for the local people to reach to the shelter when needed as road leading to shelter from main road or houses is often inundated by water or tidal water.

In order to solve such problem and increase the adaptation of the coastal people construction of cyclone shelter should be in different places. Shelter house may be constructed on the embankment keeping bottom side open for traffic. It would be easier to reach there. Such initiatives should be taken where the need is high. For example, people living in the areas near to the sea are more prone to disaster. Moreover, it will not affect the cultivable land of the area and will remove rich bias construction of cyclone shelter in coastal regions also.

Maximum Security at minimum cost:

There is a big gap between potential adaptation and practiced adaptation measures. Coastal people usually undertake different measures like taking shelter in trees, strong houses, embankments, cyclone shelter, local market buildings, Bazar buildings, mosques, schools, Madrasha, etc.

In order to protect the lives and property from cyclone, alternative means should be developed by studying the coastal adaptation capacity of the coastal people in Bangladesh. For examples, there may be an approach called public-private partnership, where people will donate land and give labour (voluntary or pay for that) for constructing such shelter. Thus a concept of PPP needs to be tested and considered in different locations using different approaches and in different sectors. Attempt needs to be made to make the protection work as cost effective.

Tree plantation:

To protect people and property from cyclone and surge affect in coastal region of Bangladesh, measures should be taken to plant trees as much as possible in the coastal areas. More specifically trees should be planted both sides of the embankment, roads and homestead in the coastal region. Such tree plantation may be undertaken by local government in public places and at home by the households. In this regard, plantation support may be provided to the households in the coastal region by the government which may be undertaken from the disaster management fund or climate change affect reduction fund.

Proning tree for protection:

Trees are the real helping means for the coastal people during cyclone and storm surge. During the catastrophe people take shelter on the trees which protect them. Moreover, trees reduce the wind force and as a result cyclone that strikes the houses causes less affect. If the trees are not pronoed before disaster during high wind speed there is a risk of falling trees and as a result shelter on the trees becomes ineffective and sometimes even deadly. Those who have used that technique, they got good benefit during cyclones.

Construction of shelter house at unbias location:

Usually shelter houses are constructed near to the home of rich people in the coastal region. This is because rich people provide the necessary land for the construction of shelter. Such construction contradicts the motto of saving coastal vulnerable people from the natural disaster. Its negative consequences are: (i) poor people who need to use cyclone shelter to protect themselves can not easily and quickly reach to shelter, (ii) even if poor people go to take shelter they can not take shelter due to the shortage of available space; and (iii) due to the distance women, children and older people can not take shelter.

In order to solve such problem and increase adaptation of the coastal people, cyclone shelter house construction near to rich people's house need to be avoided and construction should be taken place on the embankment near to the coast line (but not excluding the interior area as well) where most people are at risk. Besides approach road is also important leading to shelter house as during crisis people cannot move rapidly to that structure in absence of suitable approach road.

Floor should be made pucca:

If the floor of the house is pucca that ground does not get eroded due to leaching or flushing of water during cyclone. As a result, it can stand during cyclone which serves the purpose of protecting the household. If there is no severe surge that can stand which in turn protect an important property of the people. Most of the people do not know about that who otherwise could go for such improvement.

Construction of Killa:

A serious attempt needs to be made to construct Killa in the coastal areas to protect most valuable property such as cattle and other useful assets of the households. Indeed, it does not cost the department much if the available land of schools, college, Madrasha, Bazar, mosque, play ground, etc are raised. That can serve the twin purposes and for those there is no need to spend any extra money as for those purposes fund is allocated from different sources of the government and other agencies; even people can volunteer for that.

Redistribution of coast population:

In order to reduce the protection burden an attempt should be there to redistribute the coast population so that concentration of people at the coast can be reduced over the period. With creation of alternative sources of livelihood that trend may be created. More people can be attracted to live outside the coast. Otherwise, it may be treated as Malthusian approach of taking revenge against overpopulation. Thus, the process of constant increasing of population burden can be reduced which has almost no alternative to survive. There is no need of presence of so many people to continue the economic activities in that area rather a good number of them virtually having no alternative but to live there. Any attempt to redistribute the population rather will contribute to economic growth of the country. It is the high time to take that into consideration.

12.8.2 Measures for Awareness Development

Observe 12 November as coastal day:

Naturally people are likely to forget the past. In the coastal region, it was observed that people who did not experience cyclone or storm surge in their own life can not think of the impact of that with degree. On the other hand, natural calamity like devastating cyclone does not occur every year. As a result, it is expected that people may not take immediate necessary steps to protect them from hearing the signal from the radio or other sources due to lack of exact perception regarding the consequences of the predicted disasters.

The day 12 November may be observed as coastal day to remind people about the possible risks that likely to come up. On that day they may be asked to recall their family members or near and dear ones who lost life during previous cyclones or storm surge including 12 November of 1970. There may be some safety rehearsal for Tsunami and storm surge that may inspire them to prepare further for adaptation. More importantly, media such as television may telecast the vivid pictures of previous cyclones and the consequences upon the people and the property. Such initiatives will help the coastal people to take necessary steps in taking shelter on due times and take special care for any sudden attack of cyclone or surge in the coastal region of Bangladesh.

Other on going actions should continue:

Some other actions which have been undergoing under the Red Crescent and disaster management such as imparting training, preparing people for combating disaster should be pursued. Those attempts although considered as very much insufficient should be pursued giving more emphasis and making those more effective. Review of those activities should be carried out from time to time and adjust accordingly, for example, there is always new technology which can help in disseminating information and making more accurate forecasting on the possible risks. Community radio is one such important means which needs to be introduced in the coastal areas for disseminating information and taking timely protection in the coastal belt.

12.9 Suggestions to Improve Adaptation Capacity

The following suggestions may be considered to improve the adaptation capacity of coastal infrastructures and also coastal dwellers in order to reduce vulnerability as well as awareness raising during tsunami and surge events:

- In areas where there is a plausible risk of tsunami, large number of structures must be strengthened so that they can bear the additional live load if people take refuge during a tsunami;
- All individual structure shall be analyzed with respect to structural strength considering cyclonic wind, tsunami and surge loads, to see the possibility of using shelter;
- Since lead-time for tsunami may be much less compared to cyclones, the concentration of shelters should be increased as much as possible;
- Since storm-surge is also accompanied by strong cyclonic wind, one-storied structures cannot be used as shelters;

- When the inundation depth exceeds 3 m, one story building cannot be used as shelter as it will be completely inundated;
- Masonry structures should be evacuated before a cyclone or tsunami in areas where there is risk of inundation;
- Structural adaptation of all physical interventions and the human adaptation as mentioned in article 12.6.1 may be followed; and
- A guideline consisting of planning, design, construction and maintenance aspects of infrastructures to be build in future in coastal areas need to be prepared separately.

13. CONCLUSIONS

A comprehensive study has been carried out to identify the tsunami and storm surge vulnerable school/ hospital/emergency response and control buildings in the coastal region and evaluate their adaptation capacity to tsunami and storm surge events. The findings of the study have been finalized through a number of interaction meetings with the Technical Advisory Group (TAG) of CDMP. The study involves huge data collection of infrastructures in the coastal region of Bangladesh. The present study focuses on spatial distribution map of infrastructures, vulnerability assessment, structural strength analysis and evaluation of the adaptation capacity of vulnerable infrastructures and guideline to improve their adaptation capacity. The conclusions of the study on these areas are given below:

Spatial Distribution Map of Infrastructures

Spatial distribution map of the infrastructures have been prepared based on the surveyed data. A group of experienced field investigators/enumerators collected relevant data on infrastructures like schools, colleges, madrashas, hospitals, district headquarters, fire services, CPP offices and Red Crescent offices from the coastal region of Bangladesh. They covered the detail information concerning location, type of structure, size, number of story, year of construction, present condition etc. for each category of structure from 245 unions under 46 upazilas of 13 districts. The total numbers of surveyed infrastructure are 4707 nos. A GIS database has been developed using all the collected data of different type of buildings for the development of spatial distribution map of infrastructures and also for future reference.

Vulnerability Assessment of Infrastructures

Spatial distribution maps of tsunami and storm surge vulnerable infrastructures have been prepared by superimposing all the locations of the infrastructures on the inundation risk map of tsunami and storm surge respectively. The spatial distribution maps provide the maximum inundation depth, the building might experience during the occurrence of tsunami and storm surge. The spatial distribution map of tsunami shows that the maximum inundation depth greater than 3 m takes place in minor part of the Kutubdia island of Cox's Bazar district. It also shows that six registered primary school buildings are affected by this inundation. The spatial distribution map of storm surge shows that maximum inundation depth greater than 6 m takes place partially in Bhola, Chittagong, Feni, Lakshmipur and Noakhali districts. The structures inundated by more than 1 meter may be considered as vulnerable to tsunami or storm surge.

Structural Strength Analysis of Infrastructures

Design drawings of four typical structures, each one for primary school, high school, college and madrasha have been collected from Facilities Department and upazila offices of Local Government Engineering Department. Three dimensional (3D) FEM models of the selected coastal structures have been generated in the present study using structural design software package ETABS (version 9.0.4). For each of the different 144 conditions each of the four different types of selected structures has been analyzed and the developed stresses have been compared with the allowable stresses.

Model results show that the Primary School building, the High School building and the Madrasa building under normal occupation are adequate against cyclonic load along with storm surge. Only the Primary School building is however adequate against cyclonic load as a shelter.

The foundation analysis shows that the foundation provided for all the typical structures are inadequate for Tsunami/Cyclone shelter even for normal occupancy. The reasons for structures being still existing may be that the structures might have undergone good amount of settlement. But since it is uniform settlement no unsightly cracks have developed on the structures.

Evaluation of the Adaptation Capacity of Vulnerable Infrastructure

Among the selected structures the Primary School building, the High School building and the Madrasha building are one storied and the College building is three storied. In case of cyclone the one storied buildings suited only at places where there is no chance of storm surge. Although the primary school and the high school buildings have capacity to withstand storm surge of 3m, in that case, the people will have to take shelter on the roof. Thus only the multistoried building should be made adaptable to cyclone. In order to make the college building adaptable to withstand cyclones with basic wind speed of 260 km/h and surge height of 3m, seven corner columns and three interior beams of the building are required to be strengthened. Similarly in order to make the structures adaptable against Tsunami load, a large number of beams and columns need to be strengthened.

Guideline to Improve the Adaptation Capacity of the Infrastructures

In order to pursue the study a participatory method was used to collect opinion of the people about their practices. Several large group discussions (LGDs) were conducted in different coastal areas. Most of the cases the LGD were attended by different segment of the society as different occupational and income groups had to adapt differently. The following suggestions may be considered to improve the adaptation capacity of coastal infrastructures and also coastal dwellers in order to reduce vulnerability as well as awareness raising during tsunami and surge events:

- In areas where there is a plausible risk of tsunami, large number of structures must be strengthened so that they can bear the additional live load if people take refuge during a tsunami;
- All individual structure shall be analyzed with respect to structural strength considering cyclonic wind, tsunami and surge loads, to see the possibility of using shelter;
- Since lead-time for tsunami may be much less compared to cyclones, the concentration of shelters should be increased as much as possible;
- Since storm-surge is also accompanied by strong cyclonic wind, one-storied structures cannot be used as shelters;
- When the inundation depth exceeds 3 m, one story building cannot be used as shelter as it will be completely inundated;

- Masonry structures should be evacuated before a cyclone or tsunami in areas where there is risk of inundation;
- Structural adaptation of all physical interventions and the human adaptation as mentioned in article 12.6.1 may be followed; and
- A guideline consisting of planning, design, construction and maintenance aspects of infrastructures to be build in future in coastal areas need to be prepared separately.

REFERENCES

2nd CERP, 2001: Second Coastal Embankment Rehabilitation Project. Hydraulic Modelling Study, carried out by IWM (erstwhile SWMC) in association with $DHI_{Water.Environment.Health}$.

CSPS, 1998: Cyclone Shelter Preparatory Study. Mathematical Modelling of Cyclone-surge and Related Flooding, Stage-I, Feasibility Phase, carried out by Sener Ingenieria Y Sistemas SA, Spain in association with Mott Mac Donald Ltd., Danish Hydraulic Institute and others, May.

MCSP, 1993: Multipurpose Cyclone Shelter Programme. Planning and Implementation issues, Part 4 Volume IV, prepared for Planning Commission, Government of Bangladesh and United Nations Development Programme/ World Bank, July.

Coastal Zone Policy, 2005: Ministry of Water Resources, Government of the People's Republic of Bangladesh.

Coastal Development Strategy, 2006: Water Resources Planning Organization, Ministry of Water Resources, Government of the People's Republic of Bangladesh, February.

WP005, 2003: Working Paper. Delineation of the Coastal Zone, Dhaka, December.

MoFDM, 2000: Ministry of Food and Disaster Management. Draft National Plan for Disaster Management, 2007-2015, Government of the People's Republic of Bangladesh, May.

CDMP, 2008: Comprehensive Disaster Management Programme. Preparation of Inundation Map Considering the Decay Factors for Landuse, Geomorphology and Slope, Draft Report, November.

“Bangladesh National Building Code," Housing and Building Research Institute & Bangladesh Standards and Testing Institution, 1993

Computers and Structures, Inc., "CSI Analysis Reference Manual for SAP2000, ETABS and SAFE", CSI, Berkeley, USA, October, 2005

Dames and Moore, "Design and Construction Standards for Residential Construction in Tsunami-Prone Areas in Hawaii," prepared for the Federal Emergency Management Agency, 1980

Yeh, H, Robertson, I. and Preuss, J., "Development of Design Guidelines for Structures that Serve as Tsunami Vertical Evacuation Sites," Washington Division of Geology and Earth Resources Open File Report 2005-4, Washington State Department of Natural Resources, November, 2005

Hendry, A. W., "Structural Brickwork," The Macmillan Press Ltd, Hong Kong, 1981

IWM, “Prepare Spatial Distribution Maps of the Tsunami and Storm Surge Vulnerable School/Hospital/Emergency Response and Control Buildings” Draft Report, December 2008

"Multipurpose Cyclone Shelter Programme, Final Report," UNDP/World Bank/GOB Project BGD/91/025, Bangladesh University of Engineering and Technology & Bangladesh Institute of Development Studies, July, 1993

Stafford-smith, B. and Carter, “A Method of Analysis for Infilled Frames”, Proceedings of the Institution of Civil Engineers, Vol. 44, 1969

Suguru Mizutani and Fumihiko Imamura, “Dynamic Wave Force of Tsunamis acting on a Structure” Disaster Control Research Center, Tohoka University, Aoba, Sendai, Japan, ITS 2001 proceedings, section 7, Number 7-28

Tsuneo Okada et al., “Tsunami Loads and Structural Design of Tsunami Refuse Buildings”, Building Technology Research Institute, The Building Centre of Japan, University of Tokyo

Ali, A. and Chowdhury, J.U., 1997. Tropical cyclone risk assessment with special reference to Bangladesh. Mausam, 48:305-322.

Chowdhury, A.M. 1991. Cyclones in Bangladesh. Institute of Space and Atmospheric Research. Dhaka.

Dolan, R, Hayden, B. and Heywood, J., 1978. Analysis of coastal erosion and storm surge hazards. Coast. Eng., 2:41-54.

ERD, 2003. Bangladesh - A National Strategy for Economic Growth, Poverty Reduction and Social Development, Ministry of Finance, March 2003.

GoB. 2005. Costal Zone Policy, Ministry of Disaster Management and Rehabilitation, Government of Bangladesh.

Hassan S. 1998. Indigenous disaster management culture: a comparative study between the cyclone affected people of Bangladesh and Japan.

Jones, R.W., Palmer and Stuart Rutherford, 1992. The cyclone of April, 1991. Dhaka;PACT Bangadesh.

PDO-ICZMP, 2003. Coastal livelihoods: Situation and Context (WP 015). Program Development Office for Integrated Coastal Zone Management Plan, September, 2002.

Rahman, M.S. 2001. Tropical Cyclone in Bangladesh. Quarterly Nirapad Newsletter, 4th issue. Dhaka, September, 2001.

Wadud, A., ed. 2002, CPP at a glance. Dhaka: BDRCS.

Alam, Dr. Khurshed. 2008. Socio-economic Aspects of Water Management Engineering in Bangladesh, Paper Presented at Water Club Seminar, 27 November 2008. (Under process of publication as paper).

Alam, Dr. Khurshed. 2009. A report on adaptability of coastal dwellers, BISR, January 2009.
Chen, M., 1991: Coping with Seasonality and Drought. Sage Publications, New Delhi, India, 254 pp.

Cynthia, Bantilan (2002). Vulnerability and adaptation in semi-arid tropical agriculture: a village level case study, Paper presented in the South Asia Expert Workshop on ‘Adaptation to Climate Change for Agricultural Productivity’ organised by the Government of India, United Nations Environment Programmes, and CGIAR during 1- 3 May, 2002, Vigyan Bhavan, New Delhi.

ERD, 2003. Bangladesh - A National Strategy for Economic Growth, Poverty Reduction and Social Development, Ministry of Finance, March 2003.

Jodha, N.S. and Mascarenhas (1989). Adjustment in Self-provisioning Societies. In: Climate Impact Assessment [Kates, R. W., Ausubel, J., and Berberian, M. (eds.)]. Chichester, U.K., John Wiley and Sons.

PDO-OCZMP, 2003. Coastal livelihoods: Situation and Context (WP 015). Program Development Office for Integrated Coastal Zone Management Plan, September, 2002.
Rahman, M.S. 2001. Tropical Cyclone in Bangladesh. Quarterly Nirapad Newsletter, 4th issue. Dhaka, September, 2001.

Wadud, A., ed. 2002, CPP at a glance. Dhaka: BDRCS.

Appendix-A:

Literature Review

Review of the relevant past studies and literatures is a continuous process during the course of the study. At the inception phase following past studies and literatures have been reviewed.

Second Coastal Embankment Rehabilitation Project (2nd CERP)*, Hydraulic Modelling Study, 2001, IWM (erstwhile SWMC) in association with DHI*$_{Water.Environment.Health}$

The main objective of the hydraulic modelling study was to assess the performance of the existing coastal polders to provide a basis for determining design parameters for the embankments. Following outputs of the study have been found relevant to present study:

- Impact mapping of the baseline condition of coastal polders against worst condition of storm surge in the bay and estuaries in terms of depth area duration of flooding, concentration area duration of salinity intrusion;
- Design conditions of water level and wave properties in front of embankments within the study area. The design condition corresponds to return period of 10, 20, 50 and 100 years; and
- Hydraulic variables like extent of wave run-up, velocity, angle of wave attack etc.;

The core of the study was based on two dimensional Bay of Bengal Model developed under Cyclone Shelter Preparatory Study during 1996 and 1998 as well as one dimensional south west region model.

The updated models were simulated for seventeen cyclones during the period of 1960-2000. Baseline flooding condition was assessed based on the results of a range of cyclones. Based on the results of these simulations statistical analysis was carried out for determining the surge levels of the area corresponding to different return period.

The maximum surge elevation map for the period of 40 years shows that maximum part of the surge elevation was the result of 1970 cyclone. The most sensitive region is the northern corner of the bay that covers the region around the Sandwip island and the Meghna River mouth. The surge level exceeds 10 m level (PWD) against 100 year return period at the north of Sandwip island. The surge depth map for November 1970 cyclone just after landfall time shows that Urirchar, Sandwip, north of Hatia, Nijhumswip, Kutubdia has been flooded by 7-9 m, 3-5 m, 3-5m and 1-3m of surge water respectively.

Cyclone Shelter Preparatory Study (CSPS), *May 1998, Stage I: Feasibility Phase, Final Report, Supporting Volume-1, Mathematical Modelling of Cyclone-surge and Related Flooding, Sener Ingenieria Y Sistemas SA, Spain in association with Mott Mac Donald Ltd., Danish Hydraulic Institute and others;*

One of the tasks of the CSPS is to reassess the delineation of High Risk Area derived in the 'Multipurpose Cyclone Shelter Programme (MCSP)' study. The objectives of the modelling study is to provide the CSPS with hydraulic calculation of cyclone induced surge heights for a number of scenarios. The results of these calculation then form the basis for the reassessment of the delineation of High Risk Area.

The results of this study confirms the results of previous studies with respect to the relationship between cyclone wind speed and the surge generated in the Bay. Following table shows the comparison of surge heights between CSPS and MCSP:

Return Period	*20*		*50*		*100*	
Region	*Surge Height (m)*					
	CSPS	*MCSP*	*CSPS*	*MCSP*	*CSPS*	*MCSP*
Cox's Bazar-Chittagong	*4.1*	*4.3*	*5.1*	*5.8*	*5.4*	*7.0*
Chittagong-Bhola	*4.8*	*4.8*	*6.7*	*6.5*	*7*	*7.8*
Bhola-Barguna	*3.8*	*3.8*	*5.3*	*5.1*	*5.5*	*6.2*
Barguna-Khulna	*2.4*	*3.1*	*4.4*	*4.3*	*4.8*	*5.2*

The height and extent of flooding resulting from the wind set-up in the Bay have been assessed considering different scenarios.

Multipurpose Cyclone Shelter Programme (MCSP), *Final Report, July 1993, UNDP/World Bank/GOB Project BGD/91/025, Bangladesh University of Engineering & Technology and Bangladesh Institute of Development Studies;*

The major objective of the study was to formulate a master plan to serve as a framework for the establishment of a cyclone shelter network in the coastal areas which would define the basic concept, strategy and location pattern to be followed in all future construction.

The study area covers the coastal zone prone to the risk of storm surge inundation due to tropical cyclones.

The Risk Zone (RZ) was delineated on consideration of the extent up to which the storm surge might travel inland. The area within the RZ where there is a possibility of loss of lives due to appreciable inundation by storm surges (depth of inundation greater than 1 meter) has been defined as High Risk Area (HRA). The demarcation of RZ and HRA has been based on records of past storm surges, results from mathematical model studies and information from field survey. Figure A.1 shows the boundaries of Risk Zone and High Risk Area in the coastal region. The RZ comprises 49 upazilas/ thanas, where 46 upazilas/ thanas fall under HRA. Table A.1 shows the list of 46 upazilas/ thanas of the High Risk Area.

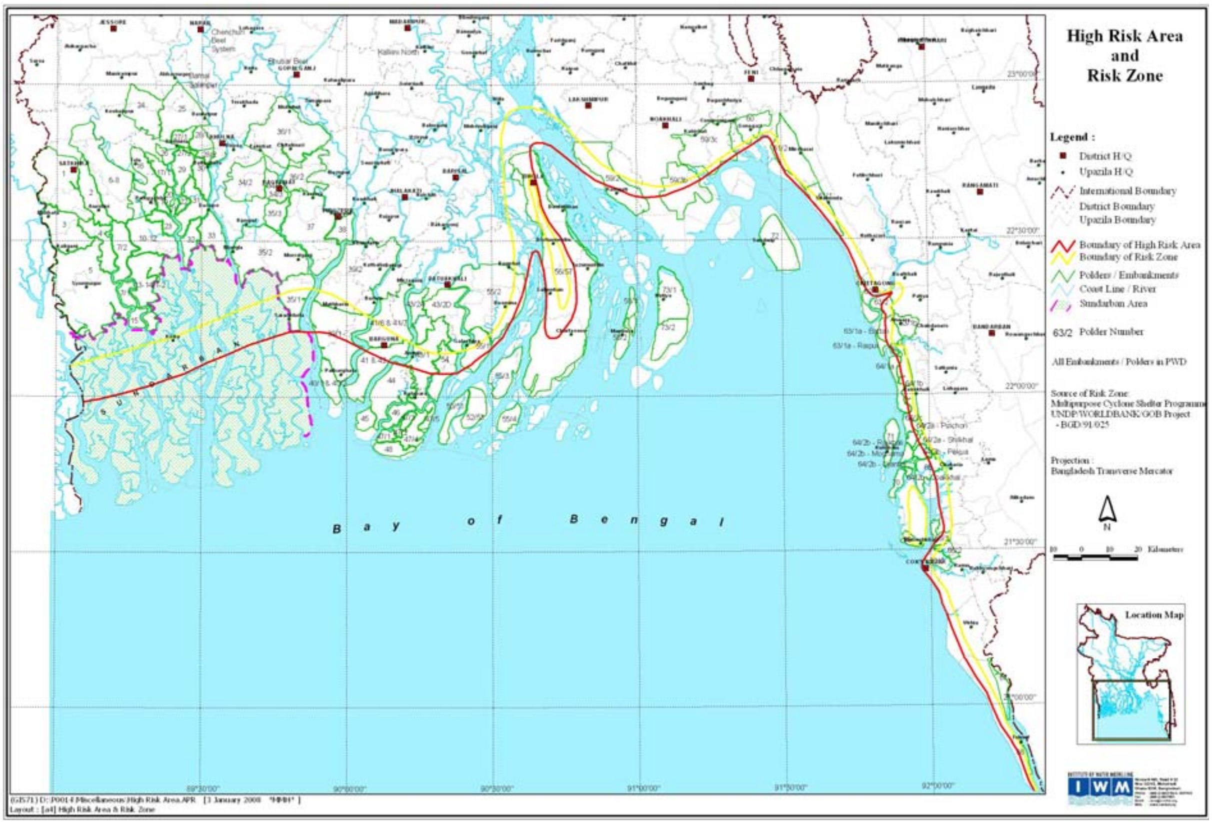


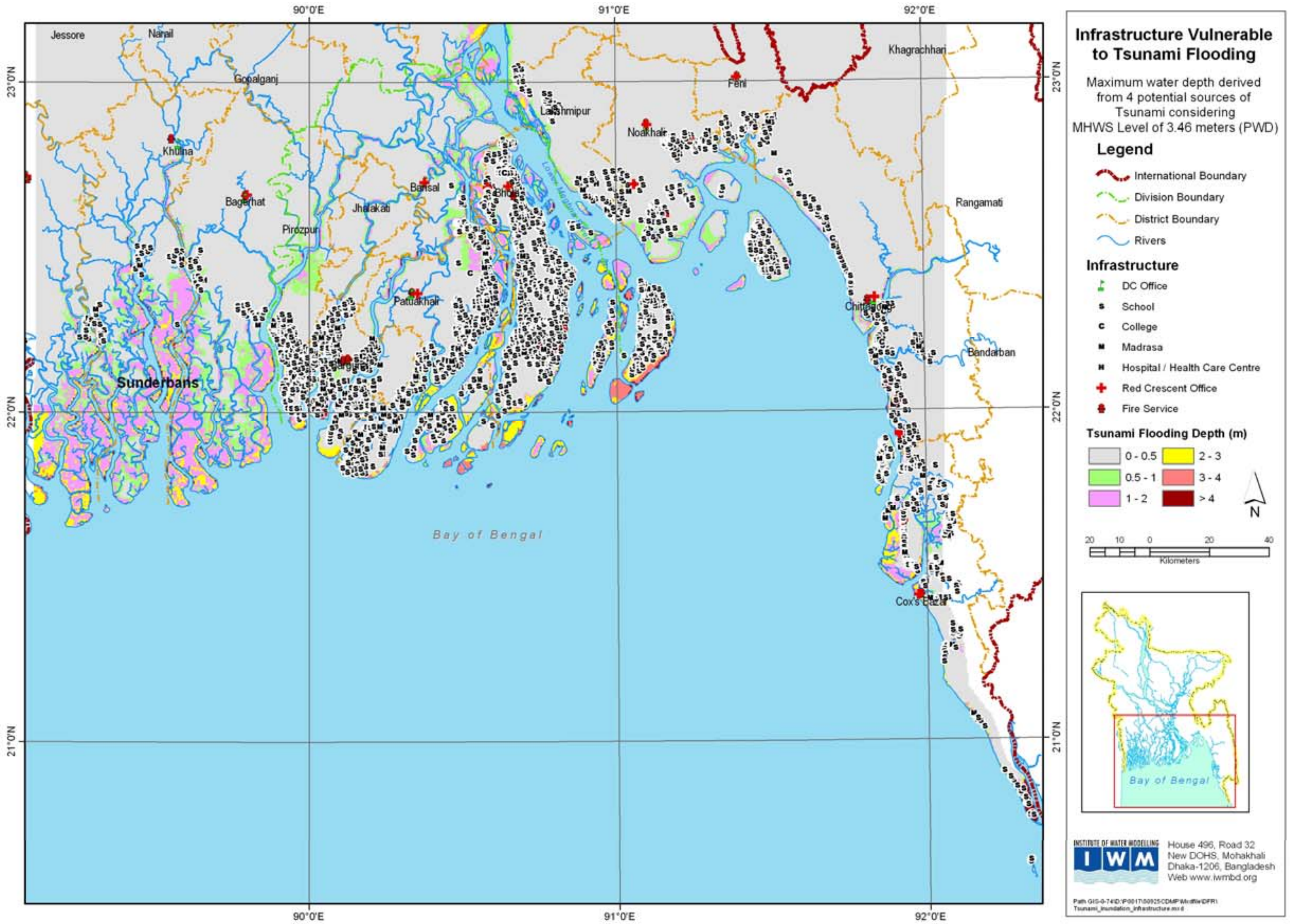
Figure A.1: Boundaries of Risk Zone and High Risk Area

Table A.1: Districts and upazilas in High Risk Area (source: Multipurpose Cyclone Shelter Programme, Final Report, July 1993)

Sl. No.	*Name of Thana/ Upazila*	*District*	*Sl. No.*	*Name of Thana/ Upazila*	*District*
1	Teknaf		24	Daulatkhan	
2	Ukhia		25	Burhanuddin	
3	Ramu		26	Tazumuddin	Bhola
4	Cox's Bazar	Cox's Bazar	27	Manpura	
5	Maheskhali		28	Lalmohan	
6	Chakaria		29	Char Fasson	
7	Kutubdia		30	Barishal Sadar	Barisal
8	Banshkhali		31	Bakerganj	
9	Anowara		32	Bauphal	
10	Patiya		33	Dashmina	Patuakhali
11	Bandar Thana	Chittagong	34	Galachipa	
12	Sitakunda		35	Kalapara	
13	Sandwip		36	Amtali	
14	Mirsharai		37	Barguna Sadar	
15	Chandanaish		38	Betagi	Barguna
16	Sonagazi	Feni	39	Patharghata	
17	Companiganj		40	Bamna	
18	Naokhali sadar (Shudharam)	Noakhali	41	Mathbaria	Pirojpur
19	Hatiya		42	Sarankhola	Bagerhat
20	Ramgati		43	Monglaport	
21	Lakshmipur (Sadar)	Lashimpur	44	Dacope	Khulna
22	Raipur		45	Koyra	
23	Bhola Sadar	Bhola	46	Shymnagar	Satkhira

Appendix-B:

Spatial Distribution Maps of Tsunami & Storm Surge Vulnerable Infrastructure (in District Level)


Infrastructure Vulnerable to Tsunami Flooding
Maximum water depth derived from 4 potential sources of Tsunami considering MHWS Level of 3.46 meters (PWD)
Legend
International Boundary
Division Boundary
District Boundary
Rivers
Infrastructure
DC Office
School
College
Madrasa
Hospital / Health Care Centre
Red Crescent Office
Fire Service
Tsunami Flooding Depth (m)
0 - 0.5
0.5 - 1
1 - 2
2 - 3
3 - 4
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Kilometers
Bay of Bengal
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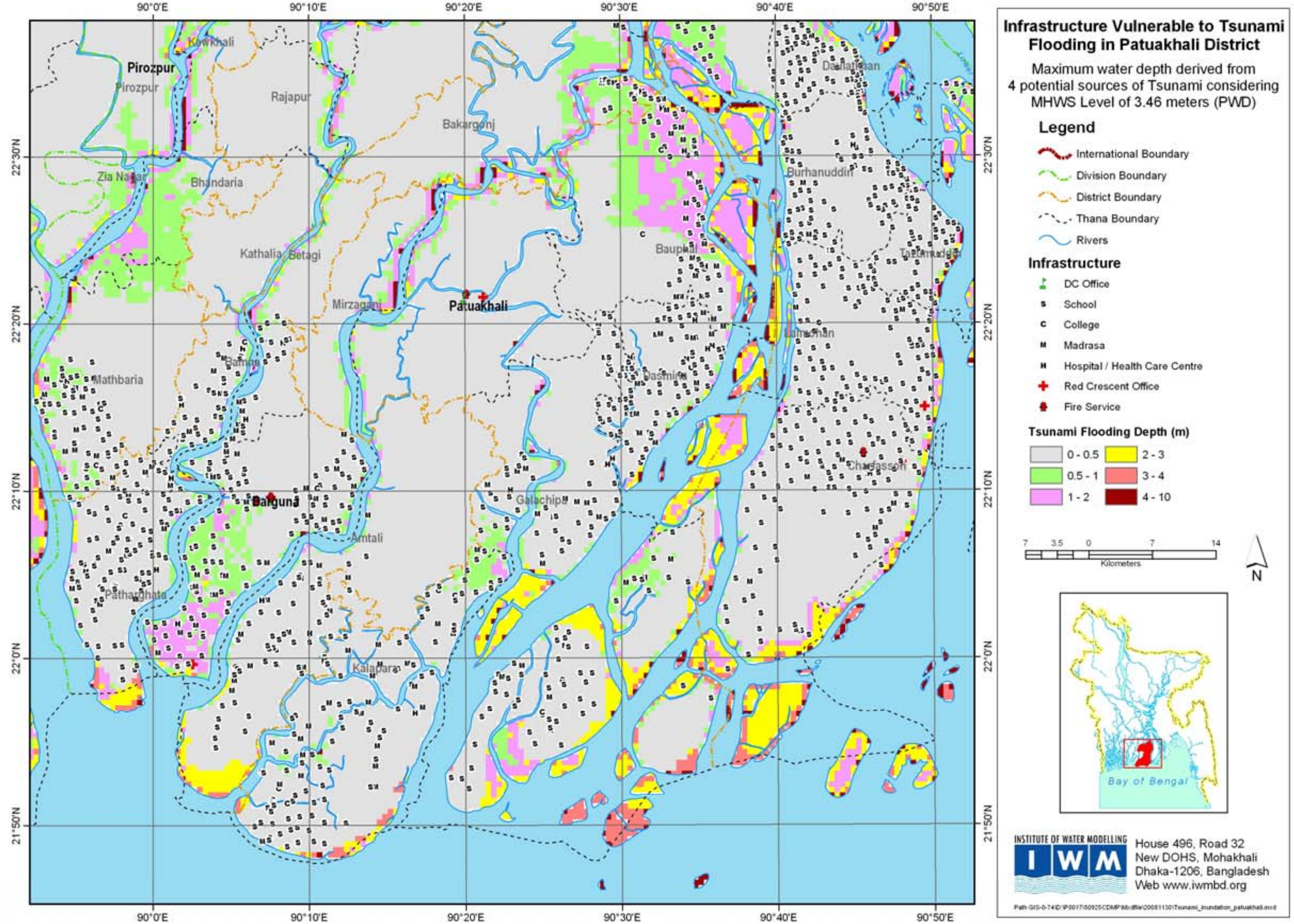
IWM
House 496, Road 32
New DOHS, Mohakhali
Dhaka-1206, Bangladesh
Web www.iwmbd.org
90°0'E
91°0'E
92°0'E
23°0'N
22°0'N
21°0'N
Jessore
Narail
Gopalganj
Khulna
Bagerhat
Pirozpur
Jhalakati
Barisal
Bhola
Patuakhali
Lakshmipur
Noakhali
Feni
Khagrachhari
Rangamati
Chittagong
Bandarban
Cox's Bazar
Sunderbans
Bay of Bengal


Infrastructure Vulnerable to Tsunami Flooding in Patuakhali District
Maximum water depth derived from 4 potential sources of Tsunami considering MHWS Level of 3.46 meters (PWD)
Legend
International Boundary
Division Boundary
District Boundary
Thana Boundary
Rivers
Infrastructure
DC Office
School
College
Madrasa
Hospital / Health Care Centre
Red Crescent Office
Fire Service
Tsunami Flooding Depth (m)
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22°10'N
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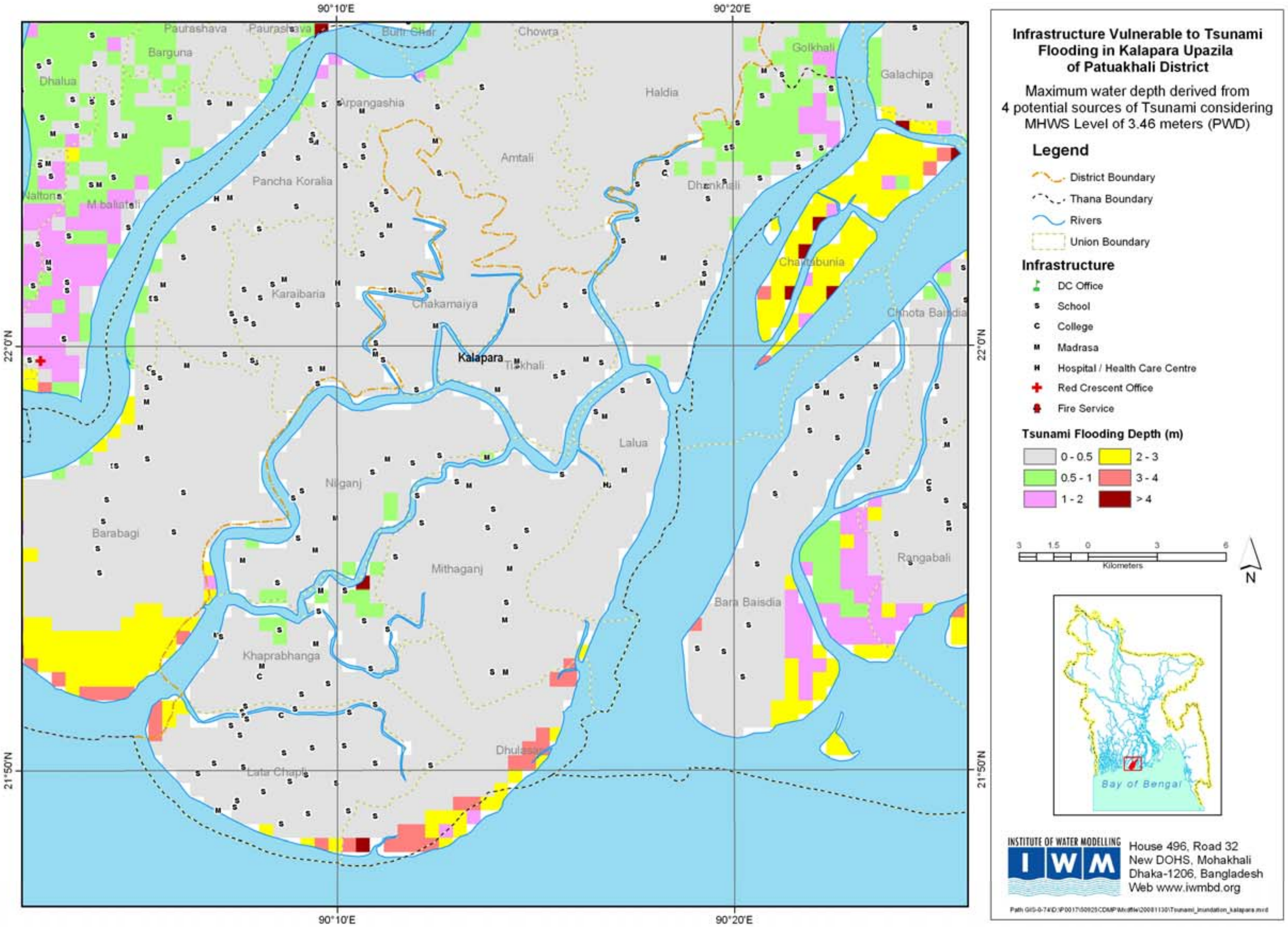
21°50'N
Pirozpur
Kawkhali
Rajapur
Bakarganj
Zia Nagar
Bhandaria
Kathalia
Betagi
Mirzaganj
Patuakhali
Burhanuddin
Bauphal
Tazumuddin
Lalmohan
Dasmina
Mathbaria
Barguna
Amtali
Galachipa
Charfasson
Patharghata
Kalapara


Infrastructure Vulnerable to Tsunami Flooding in Kalapara Upazila of Patuakhali District
Maximum water depth derived from 4 potential sources of Tsunami considering MHWS Level of 3.46 meters (PWD)
Legend
District Boundary
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Infrastructure
DC Office
School
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Madrasa
Hospital / Health Care Centre
Red Crescent Office
Fire Service
Tsunami Flooding Depth (m)
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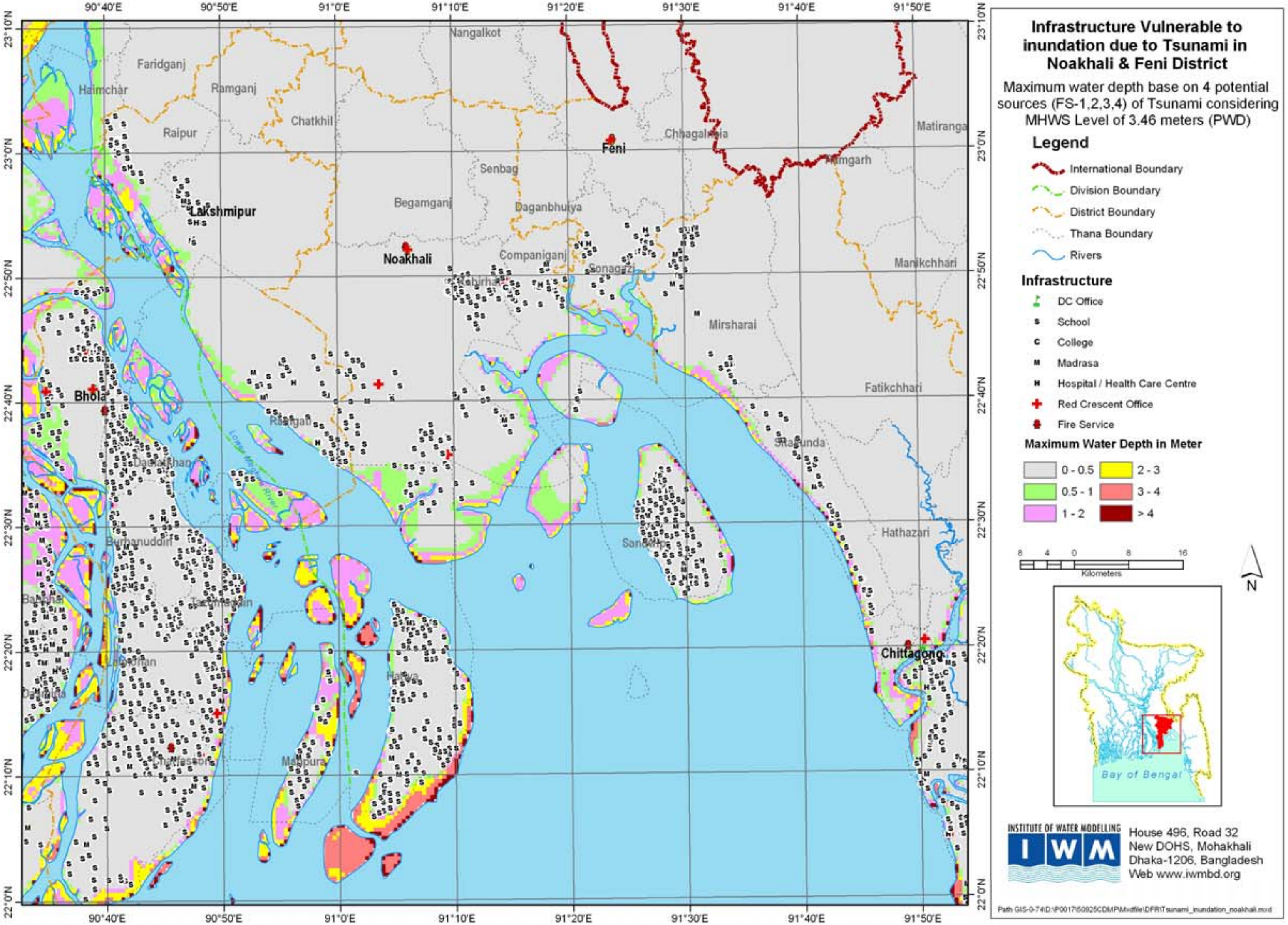
Barguna
Dhalua
Burir Char
Chowra
Haldia
Golkhali
Galachipa
Arpangashia
Amtali
Pancha Koralia
Karaibaria
Chakamaiya
Kalapara
Lalua
Nilganj
Barabagi
Mithaganj
Bara Baisdia
Rangabali
Chhota Baisdia
Charlabunia
Khaprabhanga
Lata Chapli
Dhulasar
Dhankhali


Infrastructure Vulnerable to inundation due to Tsunami in Noakhali & Feni District
Maximum water depth base on 4 potential sources (FS-1,2,3,4) of Tsunami considering MHWS Level of 3.46 meters (PWD)
Legend
International Boundary
Division Boundary
District Boundary
Thana Boundary
Rivers
Infrastructure
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School
College
Madrasa
Hospital / Health Care Centre
Red Crescent Office
Fire Service
Maximum Water Depth in Meter
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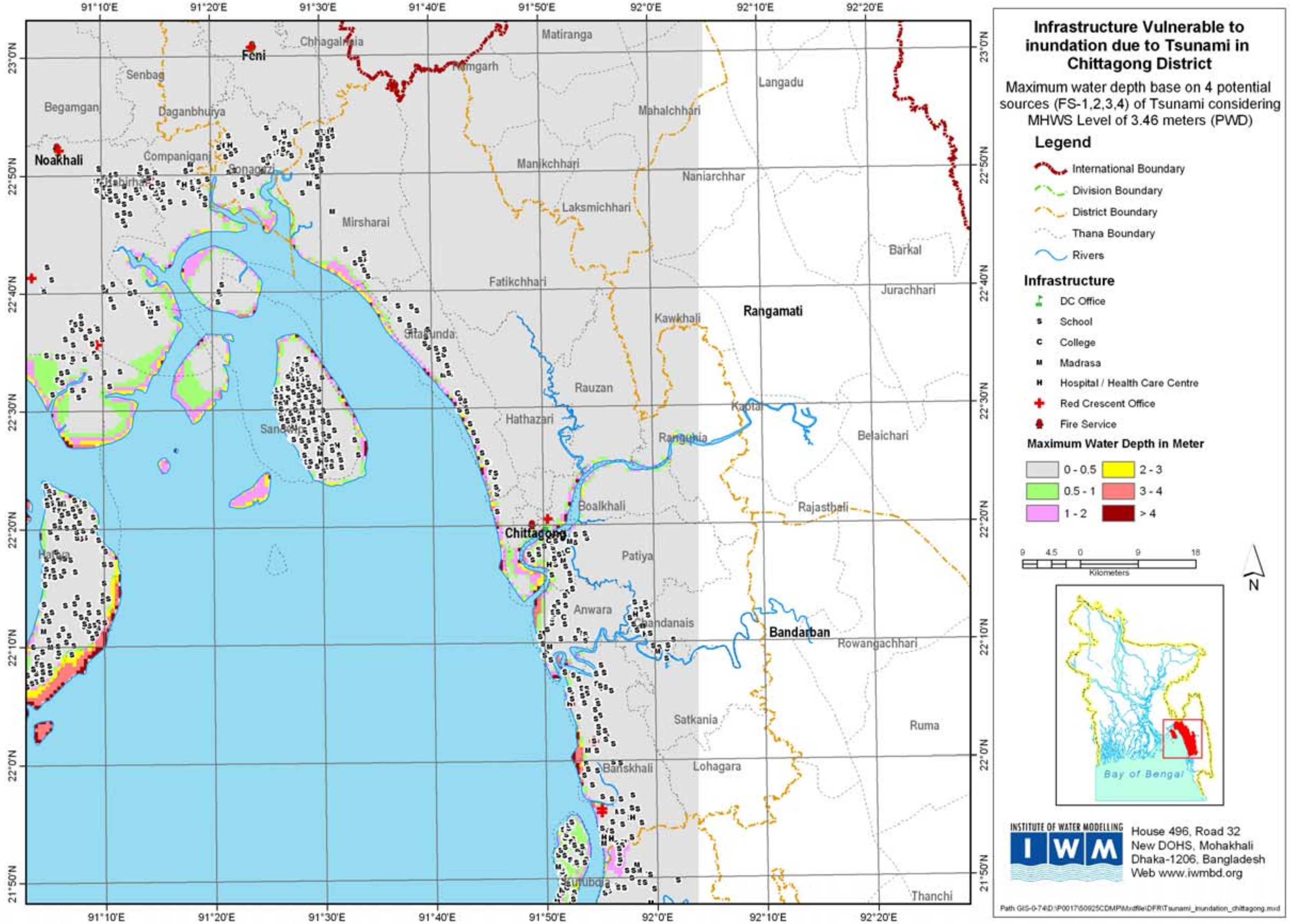
22°50'N
22°40'N
22°30'N
22°20'N
22°10'N
22°0'N
Nangalkot
Faridganj
Haimchar
Ramganj
Raipur
Chatkhil
Feni
Chhagalnaia
Matiranga
Senbag
Begamganj
Daganbhuiya
Lakshmipur
Noakhali
Companiganj
Sonagazi
Manikchhari
Mirsharai
Bhola
Fatikchhari
Sitakunda
Hathazari
Sandwip
Burhanuddin
Hatiya
Chittagong
Manpura


Infrastructure Vulnerable to inundation due to Tsunami in Chittagong District
Maximum water depth base on 4 potential sources (FS-1,2,3,4) of Tsunami considering MHWS Level of 3.46 meters (PWD)
Legend
International Boundary
Division Boundary
District Boundary
Thana Boundary
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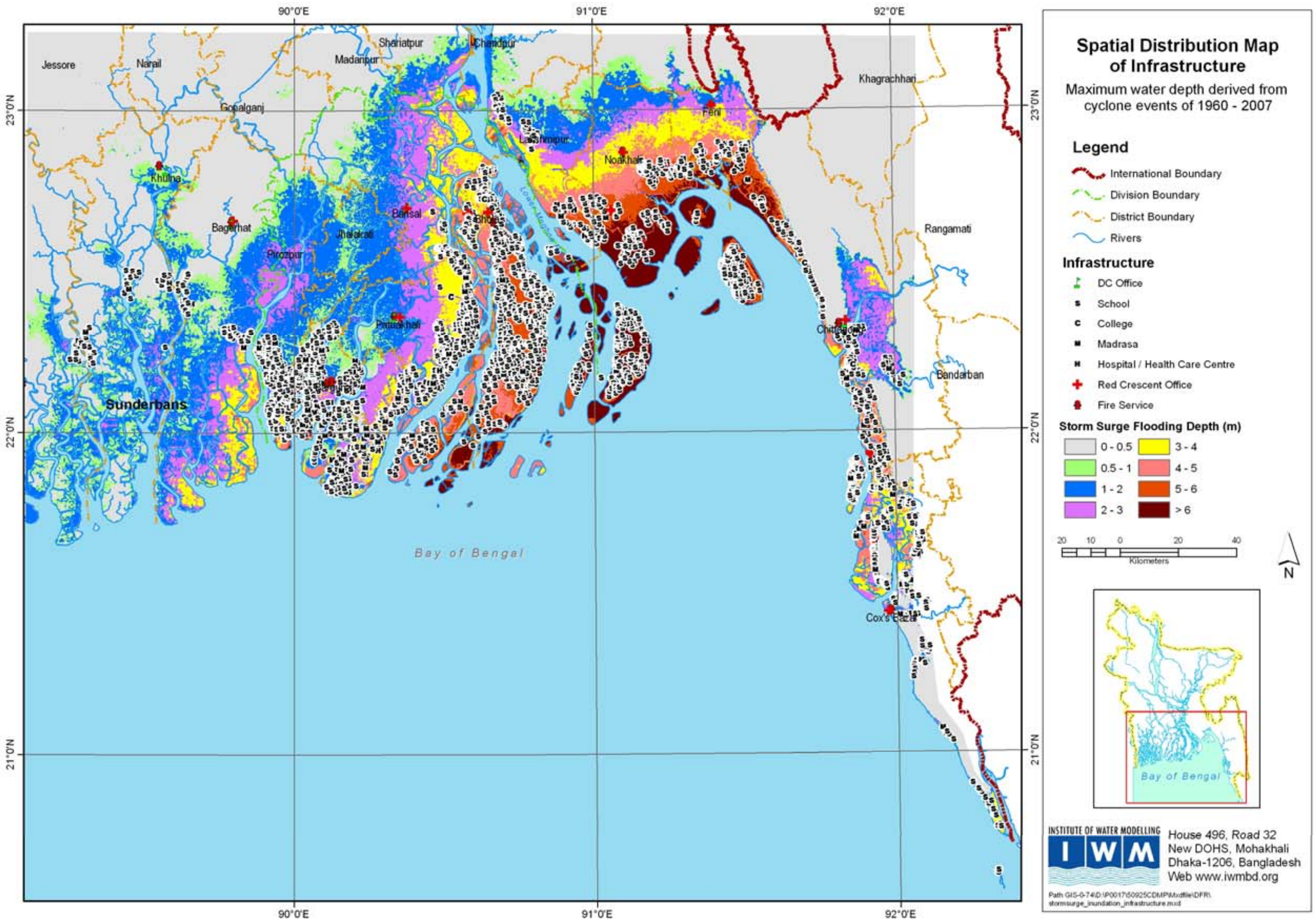
22°20'N
22°10'N
22°0'N
21°50'N
Feni
Chhagalnaia
Matiranga
Senbag
Begamgan
Daganbhuiya
Langadu
Mahalchhari
Noakhali
Companiganj
Manikchhari
Naniarchhar
Laksmichhari
Mirsharai
Barkal
Fatikchhari
Jurachhari
Kawkhali
Rangamati
Rauzan
Hathazari
Belaichari
Rangunia
Boalkhali
Rajasthali
Chittagong
Patiya
Anwara
Bandarban
Rowangachhari
Satkania
Ruma
Banskhali
Lohagara
Thanchi


Spatial Distribution Map of Infrastructure
Maximum water depth derived from cyclone events of 1960 - 2007
Legend
International Boundary
Division Boundary
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Madrasa
Hospital / Health Care Centre
Red Crescent Office
Fire Service
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Kilometers
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Narail
Madaripur
Shariatpur
Chandpur
Gopalganj
Khulna
Bagerhat
Pirozpur
Jhalakati
Barisal
Patuakhali
Lakshmipur
Noakhali
Feni
Khagrachhari
Rangamati
Chittagong
Bandarban
Cox's Bazar
Sunderbans
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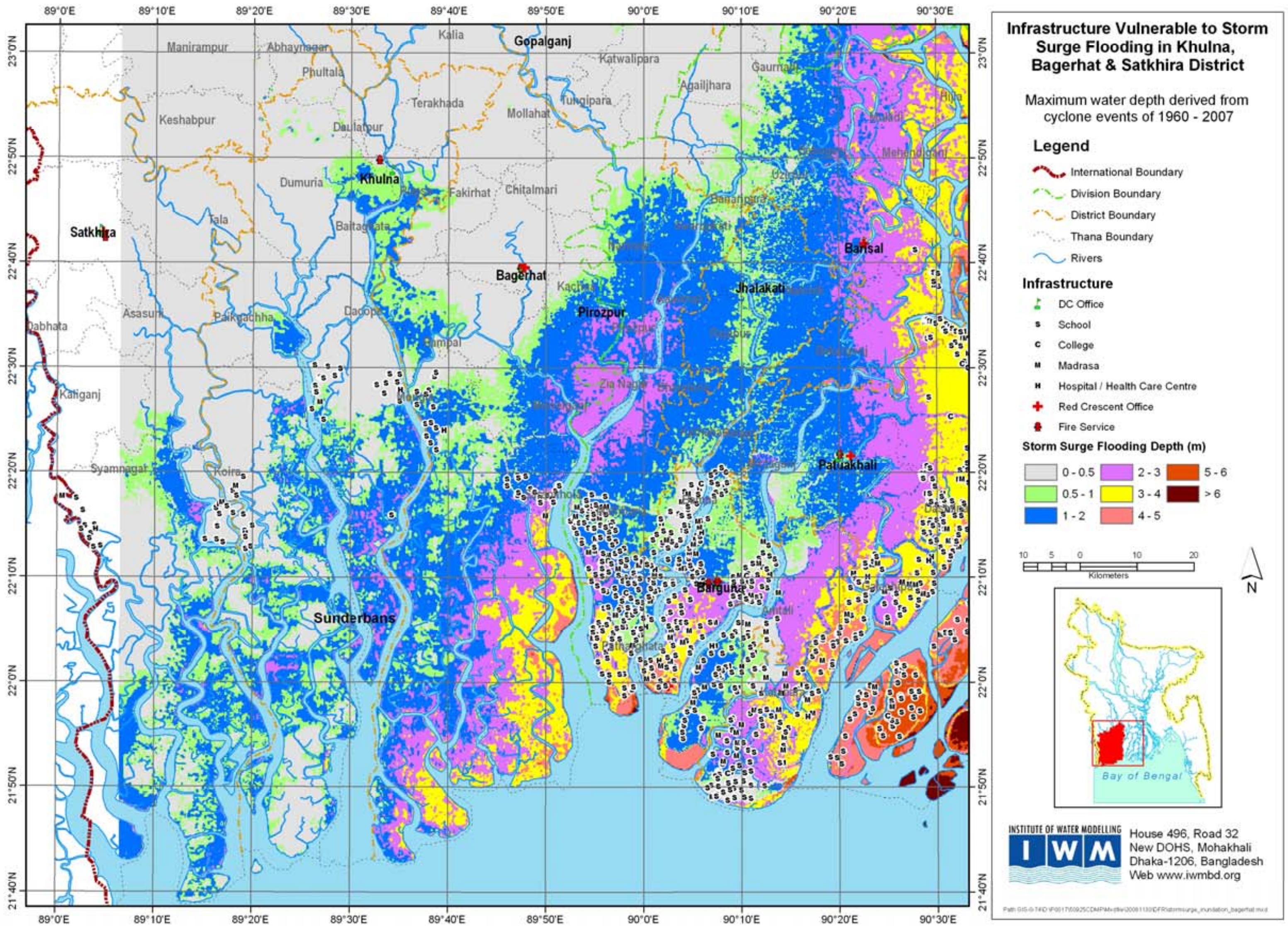

Infrastructure Vulnerable to Storm Surge Flooding in Khulna, Bagerhat & Satkhira District
Maximum water depth derived from cyclone events of 1960 - 2007
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International Boundary
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District Boundary
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College
Madrasa
Hospital / Health Care Centre
Red Crescent Office
Fire Service
Storm Surge Flooding Depth (m)
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Web www.iwmbd.org
Khulna
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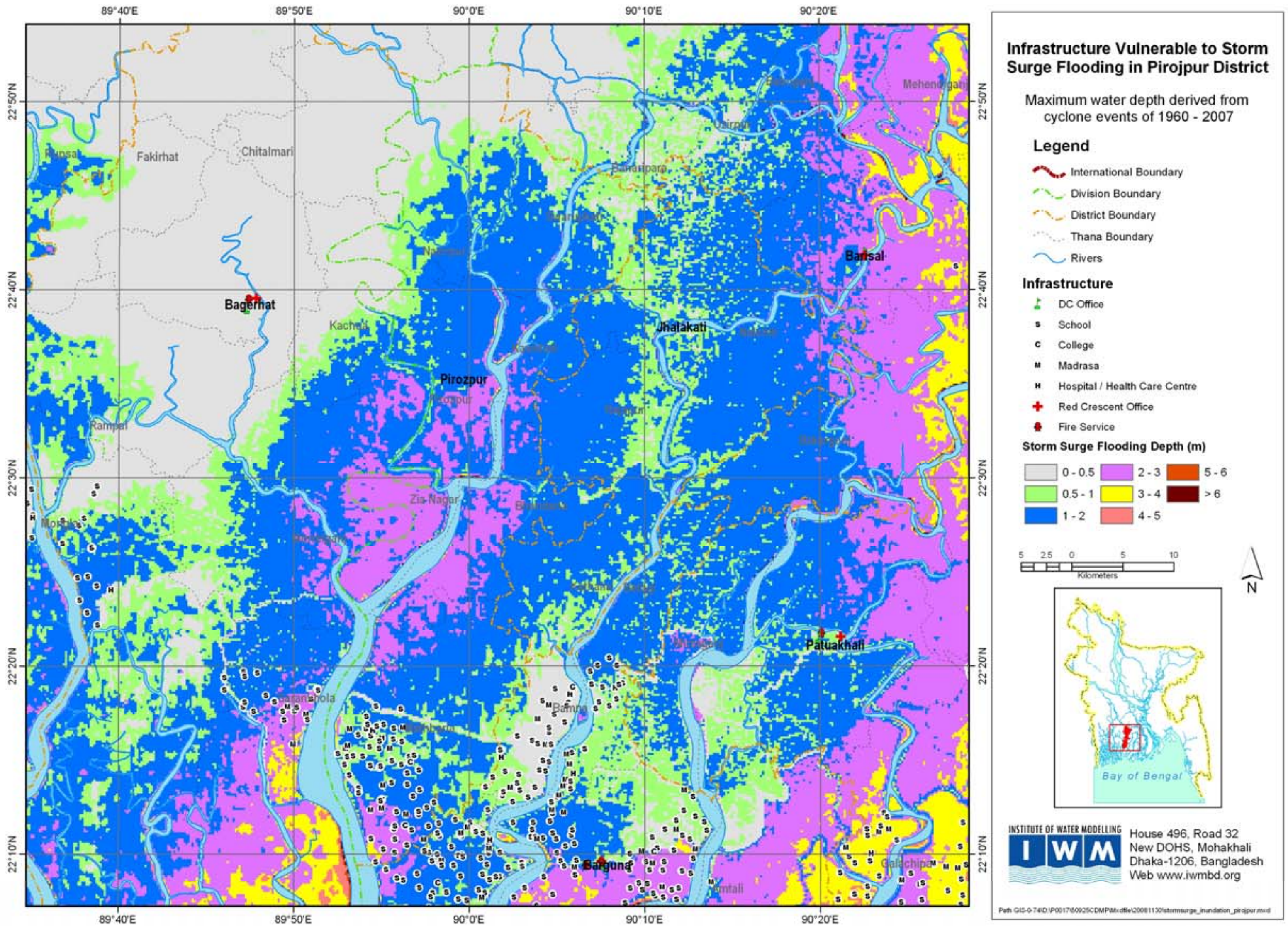
Gopalganj
Pirozpur
Jhalakati
Barisal
Patuakhali
Barguna
Sunderbans


Infrastructure Vulnerable to Storm Surge Flooding in Pirojpur District
Maximum water depth derived from cyclone events of 1960 - 2007
Legend
International Boundary
Division Boundary
District Boundary
Thana Boundary
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Red Crescent Office
Fire Service
Storm Surge Flooding Depth (m)
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INSTITUTE OF WATER MODELLING
House 496, Road 32
New DOHS, Mohakhali
Dhaka-1206, Bangladesh
Web www.iwmbd.org
89°40'E
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Bagerhat
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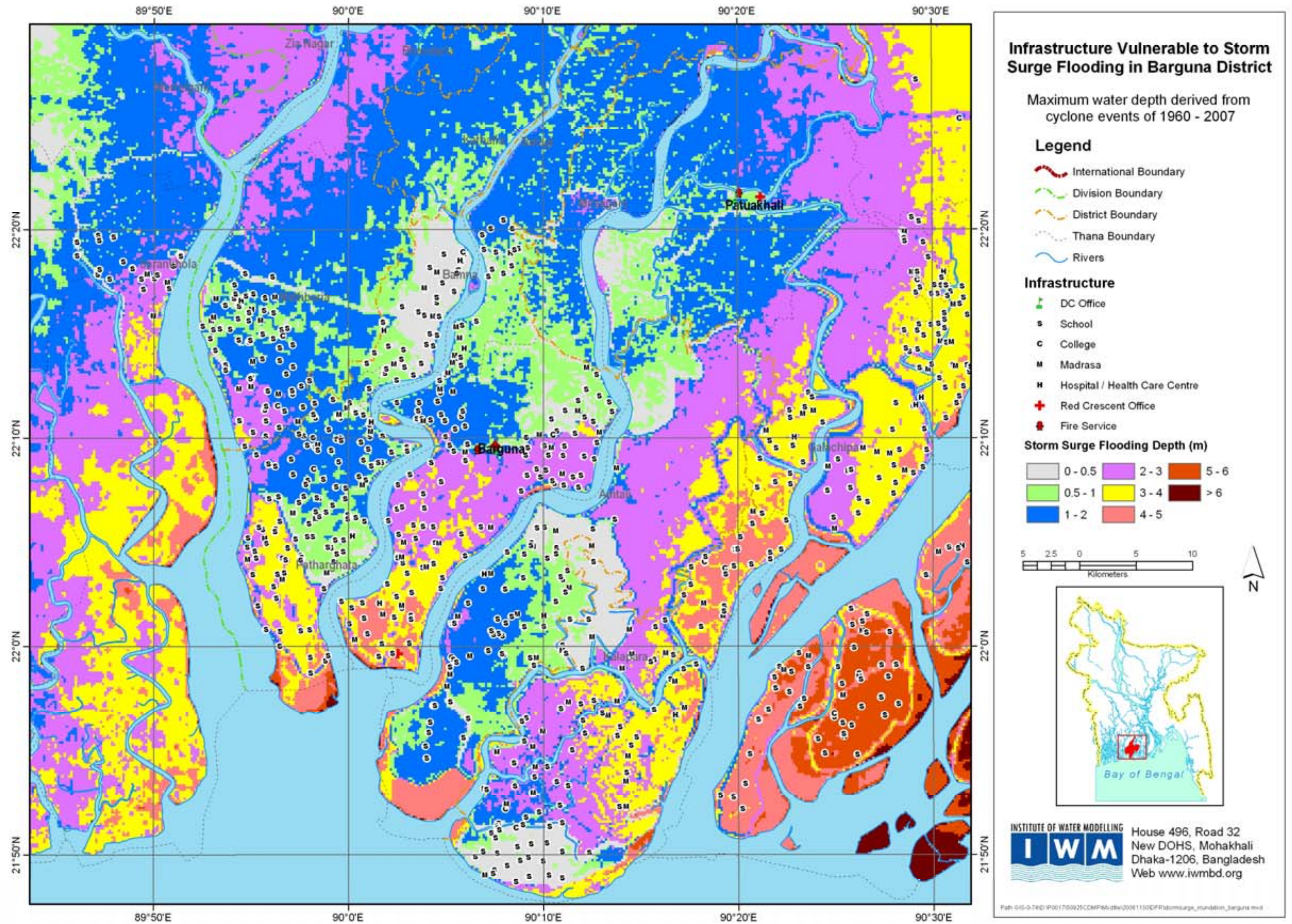
Patuakhali
Barguna
Rampal
Zia Nagar
Mehendiganj
Galachipa
Amtali


Infrastructure Vulnerable to Storm Surge Flooding in Barguna District
Maximum water depth derived from cyclone events of 1960 - 2007
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International Boundary
Division Boundary
District Boundary
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Hospital / Health Care Centre
Red Crescent Office
Fire Service
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INSTITUTE OF WATER MODELLING
House 496, Road 32
New DOHS, Mohakhali
Dhaka-1206, Bangladesh
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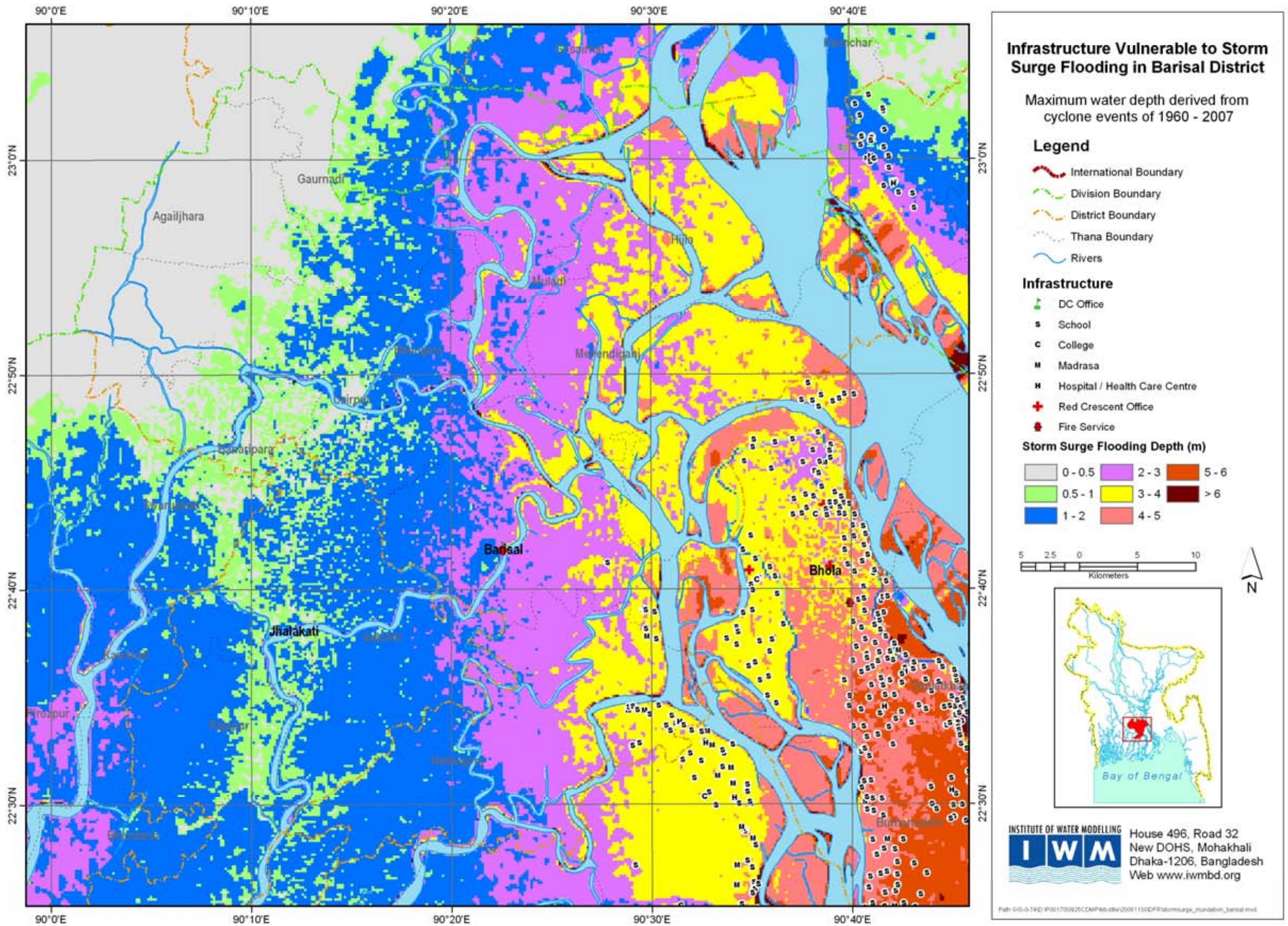
Infrastructure Vulnerable to Storm Surge Flooding in Barisal District
Maximum water depth derived from cyclone events of 1960 - 2007
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International Boundary
Division Boundary
District Boundary
Thana Boundary
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School
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Madrasa
Hospital / Health Care Centre
Red Crescent Office
Fire Service
Storm Surge Flooding Depth (m)
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New DOHS, Mohakhali
Dhaka-1206, Bangladesh
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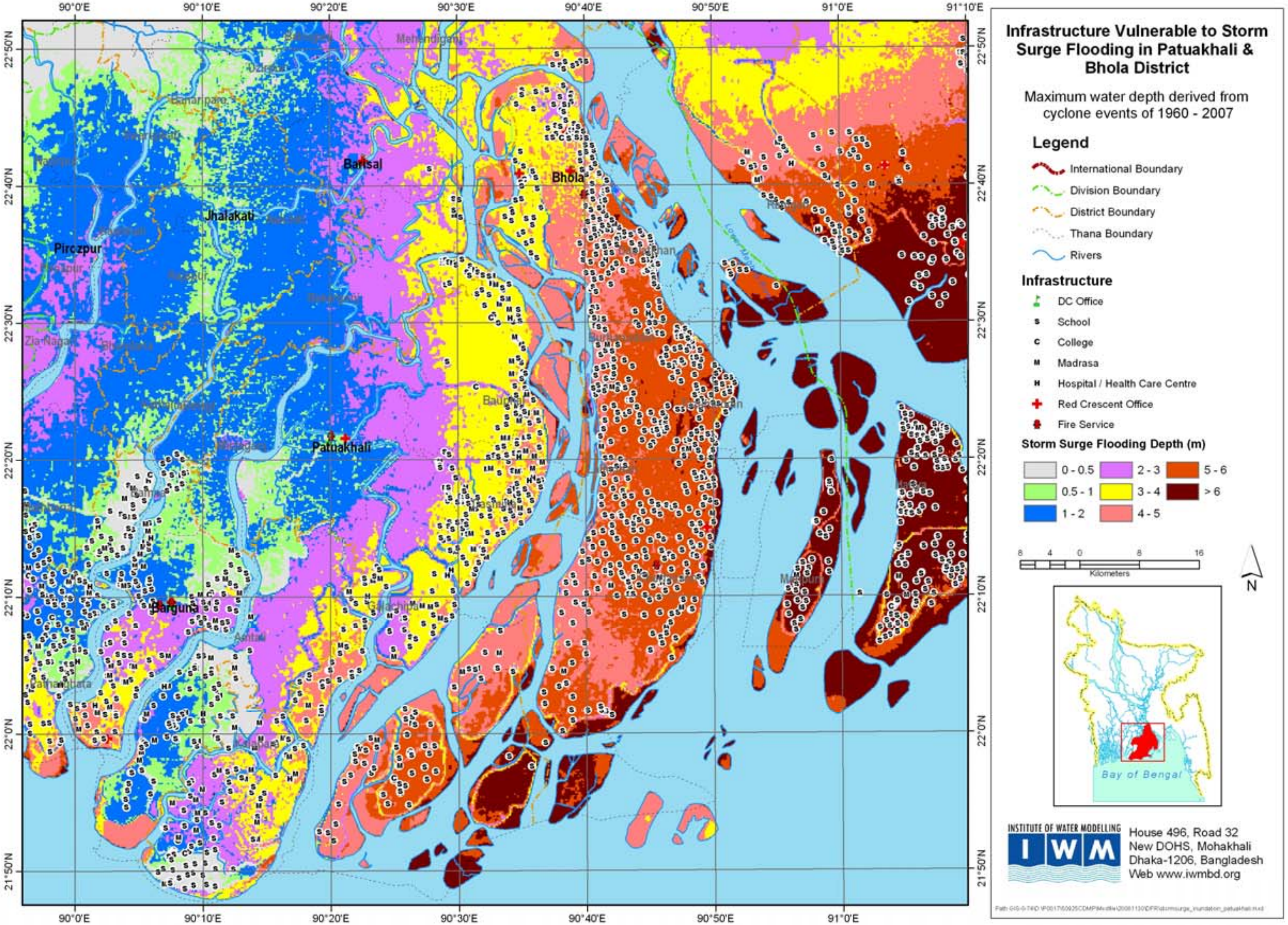
Agailjhara
Muladi
Barisal
Bhola
Jhalakati


Infrastructure Vulnerable to Storm Surge Flooding in Patuakhali & Bhola District
Maximum water depth derived from cyclone events of 1960 - 2007
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International Boundary
Division Boundary
District Boundary
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Fire Service
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House 496, Road 32
New DOHS, Mohakhali
Dhaka-1206, Bangladesh
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Pirozpur
Patuakhali
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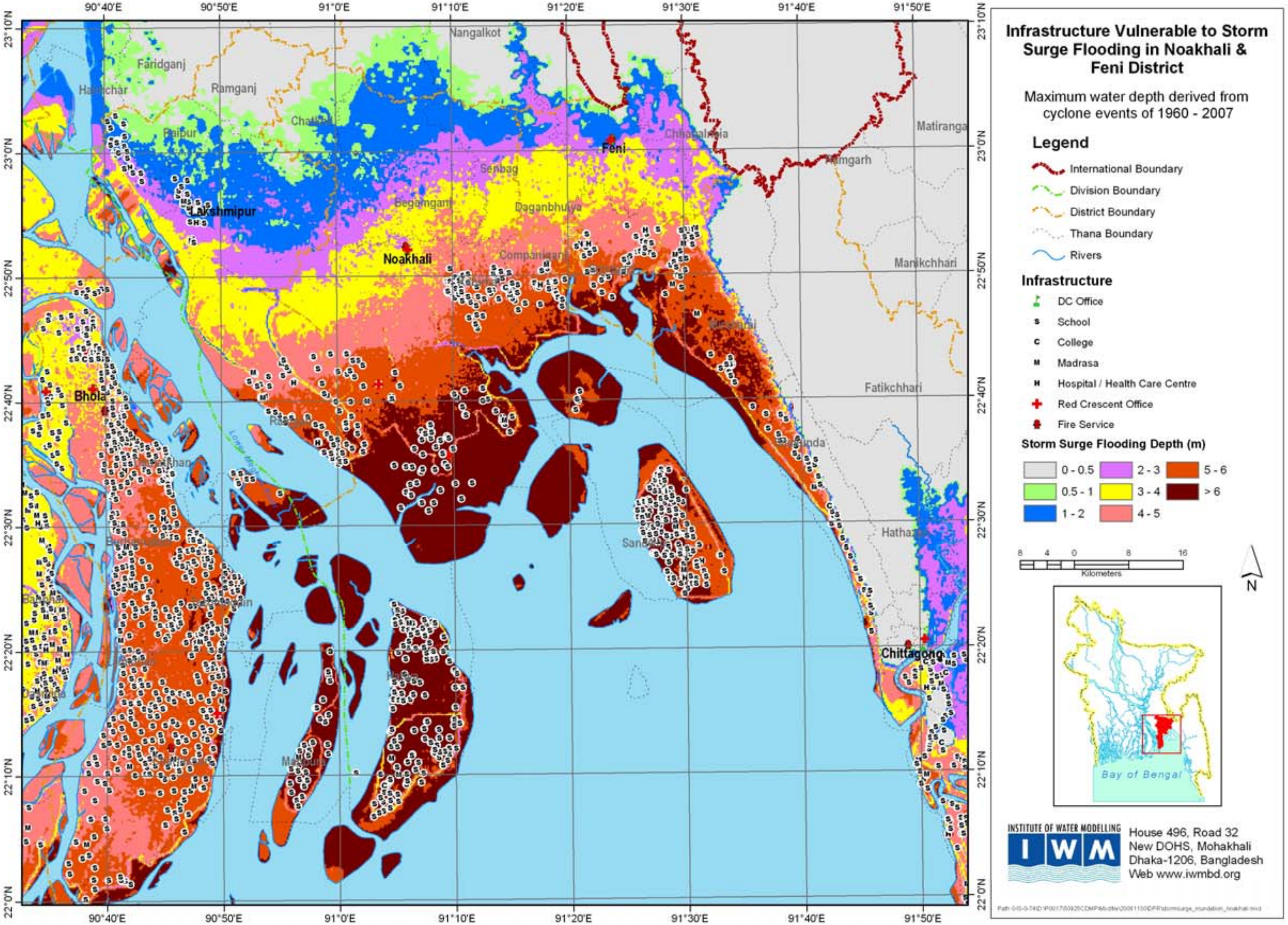

Infrastructure Vulnerable to Storm Surge Flooding in Noakhali & Feni District
Maximum water depth derived from cyclone events of 1960 - 2007
Legend
International Boundary
Division Boundary
District Boundary
Thana Boundary
Rivers
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School
College
Madrasa
Hospital / Health Care Centre
Red Crescent Office
Fire Service
Storm Surge Flooding Depth (m)
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Kilometers
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Bay of Bengal
INSTITUTE OF WATER MODELLING
House 496, Road 32
New DOHS, Mohakhali
Dhaka-1206, Bangladesh
Web www.iwmbd.org
Noakhali
Feni
Lakshmipur
Bhola
Chittagong
Faridganj
Ramganj
Nangalkot
Matiranga
Manikchhari
Fatikchhari
Begamganj
Daganbhuiya
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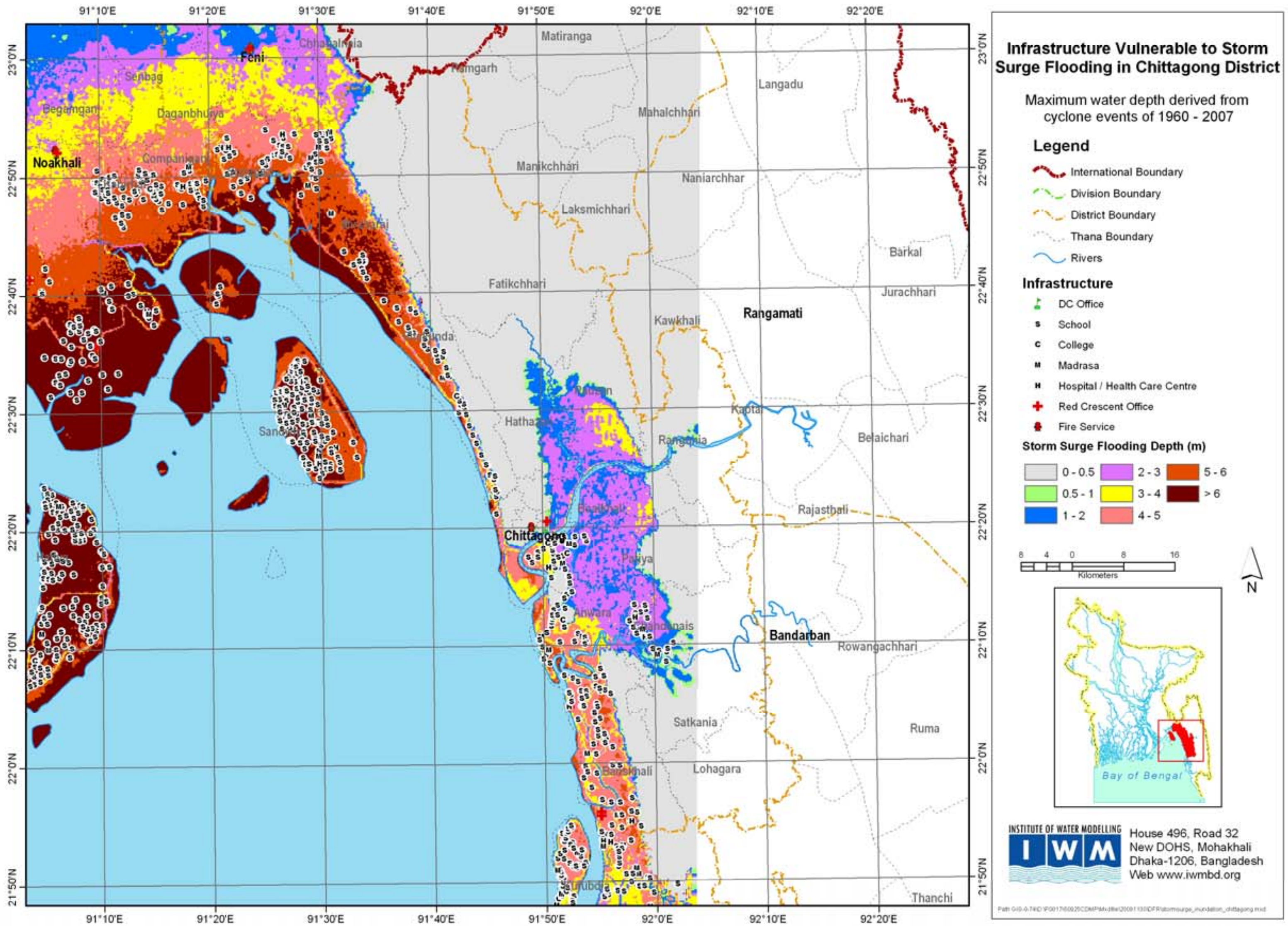
Infrastructure Vulnerable to Storm Surge Flooding in Chittagong District
Maximum water depth derived from cyclone events of 1960 - 2007
Legend
International Boundary
Division Boundary
District Boundary
Thana Boundary
Rivers
Infrastructure
DC Office
School
College
Madrasa
Hospital / Health Care Centre
Red Crescent Office
Fire Service
Storm Surge Flooding Depth (m)
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Bay of Bengal
INSTITUTE OF WATER MODELLING
IWM
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New DOHS, Mohakhali
Dhaka-1206, Bangladesh
Web www.iwmbd.org
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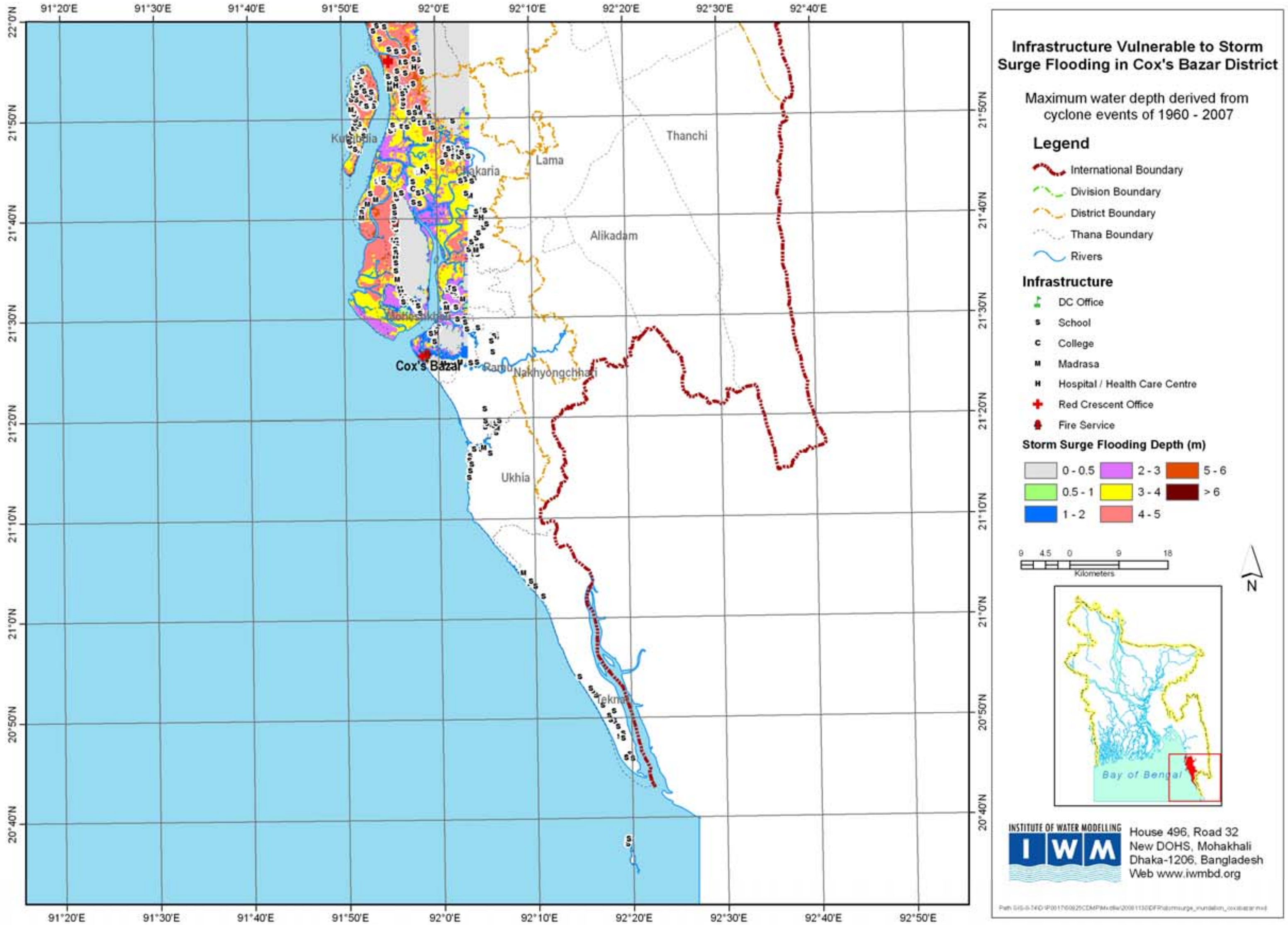
Begamganj
Daganbhuiya
Noakhali
Companiganj
Matiranga
Langadu
Mahalchhari
Manikchhari
Naniarchhar
Laksmichhari
Barkal
Fatikchhari
Jurachhari
Kawkhali
Rangamati
Hathazari
Kaptai
Belaichari
Sandwip
Rajasthali
Chittagong
Bandarban
Rowangachhari
Satkania
Ruma
Lohagara
Thanchi


Infrastructure Vulnerable to Storm Surge Flooding in Cox's Bazar District
Maximum water depth derived from cyclone events of 1960 - 2007
Legend
International Boundary
Division Boundary
District Boundary
Thana Boundary
Rivers
Infrastructure
DC Office
School
College
Madrasa
Hospital / Health Care Centre
Red Crescent Office
Fire Service
Storm Surge Flooding Depth (m)
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Thanchi
Lama
Alikadam
Cox's Bazar
Nakhyongchhari
Ukhia
INSTITUTE OF WATER MODELLING
IWM
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New DOHS, Mohakhali
Dhaka-1206, Bangladesh
Web www.iwmbd.org

Appendix-C:

Inundation Depth at Infrastructure

Appendix-D:

Drawings of Typical Infrastructure

Appendix-E:

Details of Structural Strength Analysis

APPENDIX-E1

Sample Calculation of Strut Width, "a"

According to Stafford-Smith and Carter (1969),

$\lambda_1 H = H[(E_m t \sin 2\Theta)/(4 E_c I_{col} h_w)]^{1/4}$

$a = 0.175 D(\lambda_1 H)^{0.4}$

a =	Equivalent Strut width
t =	Thickness of the masonry infill
E_m =	Modulus of Elasticity of the masonry unit
E_c =	Modulus of Elasticity of concrete
h_w =	Clear ht of Column member
I_{col} =	Moment of Inertia of the Column
Θ =	Angle Produced by the strut with the horizontal
D =	Diagonal

Here,

t =	5 in		
E_m =	1200 ksi	I =	$b*h^3/12$
E_c =	3586.6 ksi	=	1621.68 in^4
h_w =	102.36 in	Where, b=	11.811 in
		h =	11.811 in
I_{col} =	1621.68 in^4		
Θ =	36.87 degree		
D =	196.85 inch		

$\lambda_1 H$ = 4.65 in

a = 18.62 in

APPENDIX-E2

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA
BUREAU OF RESEARCH, TESTING AND CONSULTATION
DEPARTMENT OF CIVIL ENGINEERING

TEST OF COMPRESSIVE STRENGTH OF CONCRETE BY REBOUND HAMMER

BRTC No : 1604/17-18/CE — Date: 28.05.2008
Reference : IWM/51081/570 — Date: 27.05.2008
Client : Deputy Executive Director (Operation), Institute of Water Modelling
Project : Identify Tsunami-Vulnerable Schools/Hospitals/Emergency Response and Control Buildings in the Coastal Region and Evaluate Their Adaptation Capacity to Tsunami and Storm Surge Event
Site : Khuruskul Dhiren Govt. Primary School, Khuruskul, Cox's Bazar.
Date of testing : 30.05.2008

TEST RESULTS

Sl. No	Location	Spot ID	Angle of Hammer position, α (Degree)	Average Rebound Value, R	*Cube Compressive Strength (psi)	
					Mean value	Mean Error, (± Δ)
1	Column	C1	0	28.7	3130	± 874
2	Column	C2	0	25.8	2440	± 781
3	Column	C3	0	30.0	3500	± 885

Note: The cylinder strength is about 80% of the above reported cube strength

Countersigned by :

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Professor
Department of Civil Engineering
BUET, Dhaka-1000, Bangladesh

Dr. Md. Delwar Hossain
Professor
Department of Civil Engineering
BUET, Dhaka-1000, Bangladesh

Test Performed by :

01/06/08

Sheikh Mokhlesur Rahman
Lecturer
Department of Civil Engineering
BUET, Dhaka-1000, Bangladesh

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA
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TEST OF COMPRESSIVE STRENGTH OF CONCRETE BY REBOUND HAMMER

BRTC No : 1604/17-18/CE Date: 28.05.2008
Reference : IWM/51081/570 Date: 27.05.2008
Client : Deputy Executive Director (Operation), Institute of Water Modelling
Project : Identify Tsunami-Vulnerable Schools/Hospitals/Emergency Response and Control Buildings in the Coastal Region and Evaluate Their Adaptation Capacity to Tsunami and Storm Surge Event
Site : Tinshed Building, Khuruskul High School, Khuruskul, Cox's Bazar.
Date of testing : 30.05.2008

TEST RESULTS

Sl. No	Location	Spot ID	Angle of Hammer position, α (Degree)	Average Rebound Value, R	*Cube Compressive Strength (psi)	
					Mean value	Mean Error, (± Δ)
1	Column	C1	0	32.9	4070	± 904
2	Column	C2	0	34.2	4410	± 924

Note: The cylinder strength is about 80% of the above reported cube strength

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Test Performed by :

01/06/08

Sheikh Mokhlesur Rahman
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BUREAU OF RESEARCH, TESTING AND CONSULTATION
DEPARTMENT OF CIVIL ENGINEERING

TEST OF COMPRESSIVE STRENGTH OF CONCRETE BY REBOUND HAMMER

BRTC No : 1604/17-18/CE Date: 28.05.2008
Reference : IWM/51081/570 Date: 27.05.2008
Client : Deputy Executive Director (Operation), Institute of Water Modelling
Project : Identify Tsunami-Vulnerable Schools/Hospitals/Emergency Response and Control Buildings in the Coastal Region and Evaluate Their Adaptation Capacity to Tsunami and Storm Surge Event
Site : Facilities Department Building, Khuruskul High School, Khuruskul, Cox's Bazar.
Date of testing : 30.05.2008

TEST RESULTS

Sl. No	Location	Spot ID	Angle of Hammer position, α (Degree)	Average Rebound Value, R	*Cube Compressive Strength (psi)	
					Mean value	Mean Error, (± Δ)
1	Column	C1	0	32.8	4030	± 902
2	Column	C2	0	31.1	3640	± 889
3	Slab	S1	-90	26.4	3350	± 881
4	Slab	S2	-90	20.6	2100	± 726
5	Slab	S3	-90	18.9	----	----

Note: The cylinder strength is about 80% of the above reported cube strength

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Professor
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Test Performed by :

01/06/08

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BUET, Dhaka-1000, Bangladesh

APPENDIX-E3

Sample Calculation for Tsunami Load :

Tsunami Load is calculated from Hydrodynamic Load and Impact Load according to Yeh *et al*. (2005).

1. Hydrodynamic Force, $F_d = (\rho C_d A u_p^2)/2$

Where C_d is the drag coefficient, ρ is the water density, A is the projected area and u_p is the design flood velocity.

Flow depth, d_s(m)			
=	3	m	
=	9.84	ft	
ρ =	1.99	$ld*sec^2/ft^4$	
Cd =	2		
Column width, d =	0.984	ft	
A =	9.686	sft	$v = 2\sqrt{(g*d_s)}$
g =	32.2	ft/sec^2	
v =	35.600	ft/sec	
F_d =	24427.927	ld	
=	24.428	kip	
W_d =	F_d/d_s		
W_d =	2.483	kip/ft	
=	2482.513	lb/ft	

2. Impact Force, $F_I = (WV)/(g\Delta t)$

Where W is the weight of debris, V is the design flood velocity, g is the gravitational constant and Δt = 0.1 sec Code assumed impact duration in seconds

V =	35.60	ft/sec
Δt =	0.1	sec
W =	1000	lb
F_t =	11056.04	lb
F_t =	11.056	kip

APPENDIX-E4

Sample Calculation for Surge Load :

Surge Load is also calculated from Hydrodynamic Load and Impact Load like Tsunami Load.

1. Hydrodynamic Force, $F_d = (\rho C_d A u_p^2)/2$

Where C_d is the drag coefficient, ρ is the water density, A is the projected area and u_p is the design flood velocity.

Flow depth, d_s(m) =	3	m
=	9.84	ft
ρ =	1.99	ld*sec2/ft4
C_d =	2	
Column width, d =	0.984	ft
A =	9.686	sft
g =	32.2	ft/sec2
v =	2.5	m/sec
=	8.2	ft/sec
F_d =	1295.995	ld
=	1.296	kip
W_d =	F_d/d_s	
W_d =	0.132	kip/ft
=	131.707	lb/ft

2. Impact Force, $F_I = (WV)/(g\Delta t)$

Where W is the weight of debris, V is the design flood velocity, g is the gravitational constant and Δt = 0.1 sec Code assumed impact duration in seconds

V =	8.2	ft/sec
Δt =	0.1	sec
W =	1000	lb
F_t =	2546.584	lb
F_t =	2.547	kip

APPENDIX-E5

Sample Calculation for Load on wall from Surge:

The force per unit height at the base of flood water (Yeh *et al*.),

F_s = $9\rho d_s w$

Here,

Weight density of sea water,	ρ =	64.00	lb/cft
Flow depth,	d_s =	9.84	ft
Width of wall,	w =	12.30	ft
Heifht of wall,	h =	10.83	ft
So,	F_s =	69714.4	lb/ft
	=	69.71	kip/ft
Total Load on wall,	F =	$F_s X d_s/2$	
	=	342.995	Kip

Load transferred to columns on both side of wall = F/(2h)

= 15.84 kip/ft

APPENDIX-E6

Failure of wall due to shear

Summarizing the results of a series of tests on storey-height shear walls, reported by Hendry and Sinha (1969, 1971), the shear strength of brickwork was found to be (Hendry, 1981):

$\tau = 0.3 + 0.5\sigma_c$ N/mm^2

where σ_c is the precompression
So, without precompression,

$\tau = 0.3$ N/mm^2 = 40 psi

For a 5 in. wall the uniformly distributed load transferred to the column,

p_{wall} = 40 x 5 x 12 = 2400 plf.

APPENDIX-E7

Failure of wall due to flexure

According to Hendry (1981),

Allowable lateral pressure, $P_c = (бt + w/2) X\ 2\delta\ X\ 4/Ht$

Here,

б = 0 (Recompression)
H = 120 inch (Height of wall)
t = 5 inch (Thickness of wall)
w = weight per unit length of wall
= 500 lb/ft

$2\delta = 2\{\sqrt{[(H/2)^2 + t^2]} - H/2\} - \Delta$

Here, Δ = sway

Now,

$2\delta = 2\ \{\sqrt{[(120/2)^2 + 5^2]} - 120/2\} - 0$
= 0.416

Pc = (бt + w/2)X 2δ X 4/Ht
= [0+ 500/(2X12)] X 0.416 X 4/(120X5)
= 0.0578 psi
= 8.32 psf

Let wall width = 10 ft

Now Load transferred from wall to column per linear foot = (8.32 x 10)/2 lb/ft
≈ 40 lb/ft

Load transferred to column is taken 100 lb/ft.

APPENDX-E8

Sample Calculation for Bearing Capacity of Cohesive soil

A simplification of Hansen's equation:

$q_{ult} = cN_c s_c d_c + qN_q s_q d_q - q$

which is often written (and dropping $s_{q,} d_q$) as,

$q_{ult} = cN_c s_c d_c + q(N_q - 1)$

When [illegible] and N_q =1.0, we have

$q_{ult} = cN_c s_c d_c$

Here,

SPT N = 1.0 (from bore log of Emdad Ali Hostel of Patuakhali Govt. College)

Unconfined Compressive Strength q_u = 0.125 tons/sft (from N- q_u relationship)

Cohesion c = $q_u/2$ = 0.0625

D/B ratio for primary school building footing = 3/6 = 0.5

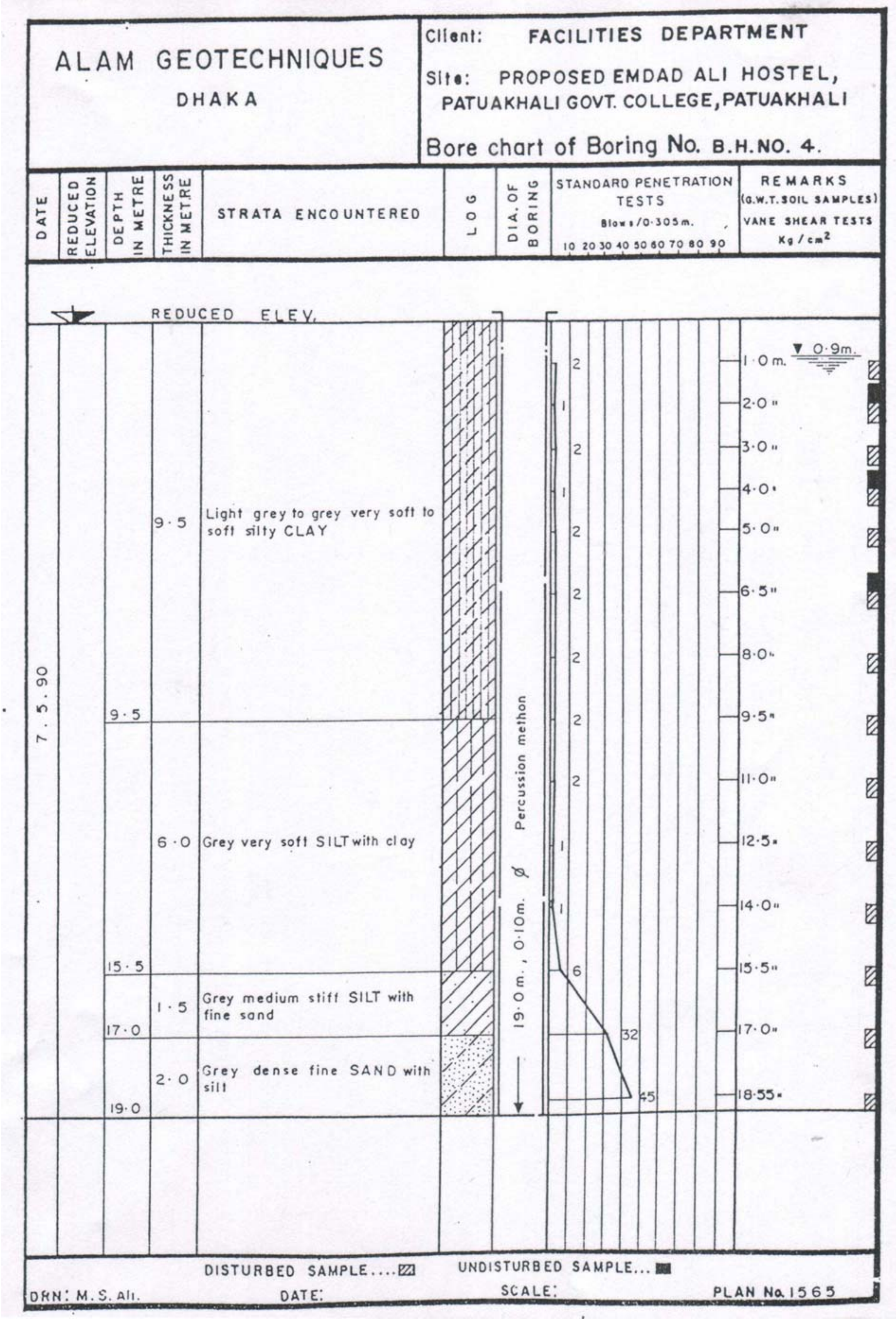
$N_c s_c d_c$ = 6.9 (from D/B ratio - $N_c s_c d_c$ relationship, table 5.7of BWDB Manual)

$q_{ult} = cN_c s_c d_c$ = 0.44 tsf

$q_{all} = q_{ult}/3$=0.15 tsf = 15.88 kN/m^2

$q_{ult} = cN_c s_c d_c$

= 0.0625X6.9 = 0.43 tsf


ALAM GEOTECHNIQUES
DHAKA
Client: FACILITIES DEPARTMENT
Site: PROPOSED EMDAD ALI HOSTEL, PATUAKHALI GOVT. COLLEGE, PATUAKHALI
Bore chart of Boring No. B.H.NO. 4.
DATE
REDUCED ELEVATION
DEPTH IN METRE
THICKNESS IN METRE
STRATA ENCOUNTERED
LOG
DIA. OF BORING
STANDARD PENETRATION TESTS Blows/0·305m.
10 20 30 40 50 60 70 80 90
REMARKS (G.W.T. SOIL SAMPLES) VANE SHEAR TESTS Kg/cm²
REDUCED ELEV.
7.5.90
9·5
Light grey to grey very soft to soft silty CLAY
9·5
6·0
Grey very soft SILT with clay
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Grey dense fine SAND with silt
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UNDISTURBED SAMPLE...
DRN: M.S. Ali.
DATE:
SCALE:
PLAN No. 1565

Appendix-F:

Public Consultation Report

Public Consultation Organized at Sandip
Place: Alam's Shop, Musapur, Mogdara, Sandip, Chitagong
Date: 16-10-2008
Facilitator: Mr. Abul Kalam Azad and Md. Abdul Malek

Information about cyclone or tsunami

1. Usually they get information about cyclone through television. Besides, the volunteers of Red Crescent disseminate information of cyclone through flagging and miking while local aware people inform through miking from mosque.

Anticipation about storm surge

2. Local social activists mentioned that they anticipate storm surge during cyclone. Before cyclone they tighten the house structure with pillar fixing a point deep into earth. If there is any branch of tree on the roof they remove those branches so that those can not cause any damage to the house. They always keep radio to listen to the latest news about cyclone. They suggest children and parents not to go far from the house.

Preparation before surge

3. They move to cyclone shelter with children and parents after being informed about the cyclone, loose the chain of domestic animals like cow, goat, etc. The dwellers tighten the clothes with pillar of the house after making bundle of clothes, store dry foods under earth. Besides, they take necessary medicines and some foods with them to cyclone shelter. The participants also mentioned that when they get the information about the storm surge normally they take similar preparation.

4. Dwellers stay in the cyclone shelter together. In case of cyclone signal they take shelter into pucca houses while in case of storm surge they take shelter in cyclone shelter. Even if they get cyclone signal number 9 to 10, they take shelter in cyclone shelter. All the local people except the fisher who catch fish in the sea go to cyclone shelter.

Training received

5. The participants mentioned that they did not get any institutional training, but the volunteers of Red Crescent sometimes go to that area and provide suggestion to some of the people of that locality. They work during cyclone as per the suggestions of the volunteers.

Changes in strategy

6. They brought important change in case of tree plantation. Besides, they repaired home, road and changed structure of the mosque. Awareness increased through discussion with each other. They combat storm surge along with cyclone through their united effort.

Coping with cyclone

7. Female participants mentioned that they convince their children and male member of the family about the cyclone. Male always keeps radio with them especially when they go to sea. When they get normal signal usually they stop work

and take preparation to come back to the sea shore. In case of children there is almost no change in their coping strategies.

Infrastructural Change:

Road:They repair the road by their our own initiatives.
Bazar: There is no visible change in the market arrangement such as raising ground level of the market.
Embankment: There is almost no visible change, but trees were planted in a large scale.
School: No new school was built. As a result, there was no change in school structure.
Hospital: The local hospital was repaired. As a result, some people can take shelter there.
House: Those who built house they build it stronger.
Home: Almost all of them made the home higher and planted trees.
Mosque: There is no mentionable changes in the mosque structure.
Madrasha: No new Madrasha has been built nor even undertaken repair of Madrasah
Club: There no club in that locality

8. When they make home make it at higher level to some extent and plants trees. They plant trees having more branches.
9. There is cyclone shelter, high embankment and two storied schools to take shelter during cyclone. If there is no place to take shelter in cyclone shelter, they take shelter on embankment.
10. They provide scope for one another. Some families have many members while others have two members. In this regard, family with small size helps the family with larger size in taking shelter in order to increase the adaptive capacity.
11. They think that there is no difference among them as they work together to take shelter.
12. Almost all the people of that locality prepare themselves during cyclone but some older people stay at their own home.
13. Those people who take shelter timely suffer less while those people who hesitate to take shelter suffer more.

Suggestions

14. The participants suggested that in order to cope with the cyclone the following issues should be taken into consideration: to make road beautiful and high, embankment repairement, not to cut trees, raise home and house structure, to provide roof of the mosque, to make madrasah pucca. Besides, it is necessary to inform the people about surviving strategies during cyclone.

Figure F.1: Public Consultation in Sandwip

Public Consultation at South Char Nurul Amin, Nil Komol, Charfashion, Bhola Date: 19-10-2008 Facilitator: Mr. Abul Kalam Azad and Md. Abdul Malek

Information about cyclone or tsunami

1. Participants mentioned that usually they get information about cyclone through radio, television and people of the locality. NGO workers and volunteers of Red Crescent disseminate information of cyclone through miking. Besides, the local educated people inform them.

Anticipation about surge or tsunami

2. The oldest participants mentioned that if the cyclone occurs during the full moon, they anticipate storm surge. Before cyclone they tighten the house with pillar by putting it under earth. Women participants mentioned that they usually take shelter along with the husband and children. Dwellers loose the chain of domestic animals like cow, goat, etc.

Preparation before cyclone

3. They move to strong built house and cyclone shelter after being informed about the cyclone. Wherever their children stay their mothers try to bring them closer. They also mentioned that they usually do not take shelter under the trees. They complained with anger that there was no cyclone shelter in this locality. As a result, they could not take shelter even if they want to do so. Besides, they take necessary medicine and some foods with them during cyclone.
4. The participants mentioned that without remembering the Allah there is almost nothing to do during cyclone. Most of the participants mentioned that as there was no cyclone in that locality, they can not say anything. We get signal and miking but due to lack of shelter we do not go anywhere. When we see high level of water we take shelter on embankment near to that locality.

Training received

5. The participants mentioned that they did not get any institutional training.

Change in strategy

6. They brought change in regard to tree plantation especially rain tree. Besides, raised their homestead level higher and stronger. All the people of that locality planted rain tree on embankment. When they see surge usually take shelter on the tree.

Coping with surge

Women: There is almost no change in case of women taking shelter.
Men: In the past they used to continue fishing in river and sea even after getting the information about cyclone but at present they come back to home as soon as get the information.
Children: There is almost no change in their coping strategies.

Infrastructural Change:

Road: They made the road pucca .
Bazar: Some shops are made high
Embankment: There is no visible change in case of embankment.
School: There is no change in case of school structure.
Hospital: The condition is worse than before.
House structure: Those who build new houses they build it higher and stronger.
Homestead: Almost all of them raised their homestead level.
Mosque: There is no change in the mosque structure.
Madrasah: There is no change in the madrasah structure.
Club: There no change in the club.

7. When they build homes make it at higher place to some extent and plant trees.
8. There is also cyclone shelter except high embankment. As embankment is their place of shelter, so there is no problem in taking shelter.
9. They provide scope for one another. Participants mentioned that NGO is not playing any key role there. Sometimes volunteers of Red Crescent come to suggest about the way of combating cyclone.
10. They do no see there much difference.
11. In the past they did not prepare themselves to combat cyclone. But at present, almost all the people of that locality prepare themselves during cyclone but some older people stay in their home. Even older people also take shelter if requested by others.
12. Those people who take shelter timely suffer less while those people who hesitate to take shelter suffer more. Participants believe that taking shelter brings good result to them.

Suggestions

13. The participants suggested that in order to cope with the cyclone the following issues should be taken in consideration: to plant trees as much as possible, raise road level, repair embankment, and raise homestead level. Besides, it is necessary to train people about the surviving strategies from the cyclone.

Figure F.2: Public Consultation in Bhola

Figure F.3: Public Consultation in Bhola

Public Consultation at
Azizia Hafizia Madrasah, Khankhanabad, Bashkhali, Chittagong
Date: 15-10-2008
Facilitator: Dr. Khurshed Alam, Mr. Abul Kalam Azad and Md. Abdul Malek

Information about surge or tsunami

1. Participants mentioned that usually they get information about cyclone through radio, television, flagging, miking and observing the sea water. Besides, volunteers of Red Crescent also disseminate information.

Preparation before surge

2. Sometimes they anticipate the storm surge. When the wind speed is high they anticipate it, otherwise they cannot anticipate. Before cyclone they store valuable things under soil. They fix their house structure with pillar, loose chain of their domestic animals like cow, goat, etc.
3. The participants mentioned that they bring the older people to the cyclone shelter as those people can not go to cyclone shelter quickly. But most of the times old people prefer to stay home even after getting the signal.
4. They did not anticipate the last cyclone that generated severe storm surge. Most of them took shelter at home, but when they saw the high water level they went to cyclone shelter. Some of them took shelter in trees and roofs. Due to high level of water the roofs of the houses floating on water. Although the death toll was less for men, but it was higher for domestic animals. When they get signal number 9-10, they take shelter at cyclone shelter. Women whose husband and children are in sea for fishing, they do not like to go to shelter.

Training received

5. The participants mentioned that some women got training from Red Crescent. They discourage their children, male partners and others if they want to go to sea after signal. Besides, they brought about a change in tree plantation. If there is any time left after taking shelter of one's own family members the same person helps others to take shelter.

Changes in their strategy

6. They repaired the road with the help of local administration. Besides, they planted trees at a larger quantity, made home higher and stronger, build a madrasah and trying to make the mosques of that locality pucca.

Coping strategy

Women: Some women got training and motivate others to take shelter.
Men: The male participants mentioned that they do not take any risk for fishing as they did in the past, rather they come back home as soon as they get the information. Besides, they plant trees wherever possible.
Children: There is almost no change in their coping strategies.

Infrastructural Change:

Road: They repaired road with the help of local administration.
Bazar: Some shops were repaired.
Embankment: There was no visible positive change, rather it became worse day by day.
School: No change in case of school.
Hospital: No change in case of hospital.
House: They raised the level of their homestead
Home: Planted trees in the homestead areas.
Mosque: No change in the case mosque.
Madrasah: There is no change in the case of madrasah except walls
Club: There is no club in the area to address the issue.

7. Rich people made their house pucca. But most of the poor people raised their homestead land to some extent and planted trees.
8. A two storied cyclone shelter is there. Due to lack of place at shelter, people usually take shelter in trees, roofs and house of relatives. Some people also stay at their own house taking the risk of their lives.
9. It is possible to increase the adaptive capacity by repairing roads, raising homestead level high, making mosque and madrasah pucca and converting the schools into cyclone shelter. The participants opined that government institutions, private organizations, NGOs and local rich people can help in this regard. They also mentioned that NGO played some role to protect the people from storm surge. Only Red Crescent plays role in protecting them from storm surge.
10. They do not see much difference in case of their preparation.
11. Trained women do respond to the cyclone most and they bring the people to shelter. But older people stay at their own home.
12. Those people who take shelter timely suffer less while those people who hesitate to take shelter suffer more.

Suggestions

13. The participants suggested that in order to cope with the cyclone the following issues should be taken into consideration: to increase cyclone shelter, to make hospital, to provide tube well, to build embankment block wise, plant trees as much as possible, make road high and raise homestead and house. Besides, land level of bazar should be raised and made pucca.

Figure F.4: Public Consultation in Chittagong

Figure F.5: Public Consultation in Chittagong

Figure F.6: Public Consultation in Chittagong

Public Consultation at Kakchira, Pathorghata, Borguna Date: 25-10-2008 Facilitator: Mr. Abul Kalam Azad and Md. Abdul Malek

Source of weather information

1. People get information about cyclone through television and radio. Besides, the volunteers of Red Crescent disseminate information of cyclone through flagging and miking.

Anticipation about surge or tsunami

2. If the cyclone occurs at full moon and ebb tide they anticipate storm surge. Local social activists mentioned that they do anticipate storm surge during cyclone.

Preparation before cyclone

3. Before cyclone they fix the house with pillar and give extra support to that. They forbid people to take shelter in dilapidated house.
4. Dwellers move to cyclone shelter after being informed about the cyclone. They loose the chain of domestic animals like cow, goat, etc. When they get signal number 9-10, usually they go to 2/3 storied safe houses. As there is no cyclone shelter there people can not think of taking shelter in cyclone shelter. Some of the participants mentioned that they even provide land for cyclone shelter but still there is no cyclone shelter constructed in that area.
5. As there is no cyclone shelter they suffered much during a cyclone. See one person's story main report.

Training received

6. The participants mentioned that they did not get any training.
7. There is no change in the locality due to lack of money. The participants mentioned that without depending on Allah there is nothing they can do to save their lives.

Coping with cyclone

Women: they could not bring any change.

Men: Although they want to bring change, but due to lack of money they could not bring about a change.

Children-There is almost no change in their coping strategies.

Infrastructural Change

Road: There is no change.
Bazar: No visible change is there in market except repairing of the damaged shops
Embankment: No change
Schools: There is no change
Hospital: There is no change.
House: Some weak houses were made.
Homestead: There is no major change
Mosque: There is almost no mentionable changes in the case of mosque.
Madrasah: There is no change

Club: There is no club in that locality

8. The participants mentioned that they have plans to raise the homestead level and making it stronger.
9. There is no cyclone shelter except embankment. Unfortunately, the embankment was also damaged and hence presently there is no place to take shelter.
10. It is necessary to build cyclone shelter, train local people, etc. to protect people from cyclone.
11. They do not see much difference.
12. Almost all people of that locality prepared themselves and responded to cyclone.
13. Those people who take shelter timely suffer less while who hesitates to take shelter suffer more.

Suggestions

14. The participants suggested that in order to cope with the cyclone the following issues should be taken into consideration: to build cyclone shelter, to set up tube well, to build road, embankment, to make school cum shelter house, to plant trees at home, mosques, roads and to train the local people.

Figure F.7: Public Consultation in Borguna

Public Consultation at
Gusakati, Dhulia, Baofal, Patuakhali
Date: 21-10-2008
Facilitator: Mr. Abul Kalam Azad and Md. Abdul Malek

Source of weather information

1. Coastal dwellers get information about cyclone through radio and television. Besides, they get information through miking from mosque and local union parishad.

Anticipation about surge or tsunami

2. Some of the participants mentioned that cyclone and storm surge is different from each other. As a result, they do not anticipate storm surge with cyclone. However, some of them mentioned that if cyclone occurs during ebb tide, they anticipate storm surge. Before cyclone they fix their house. They always keep radio to listen to the latest news about cyclone. They loose the chain of their domestic animals like cow, goat, etc.

Actions during cyclone

3. They move to union parishad with their children as soon as cyclone comes. Some of the participants mentioned that they do take shelter in the nearby strong houses. When they hear about storm surge they take the children and older people to the union parishad and some of them take shelter on embankment as there is no sufficient place in the union parishad.
4. They also take shelter on trees if there is no other place to take shelter. At first a person climb the tree and then he hold a child to take on the tree. In this way they also provide shelter for the children in the tree during cyclone. There is no pucca house in that area. As a result, if possible they take shelter into the single cyclone shelter in that locality. Besides, old and women are reluctant to go to the cyclone shelter as there is not a single one situated near to their locality.

Training received

5. The participants mentioned that they did not get any training.
6. They brought most changes in the case of tree plantation. Besides, they repaired house structures. There is nothing to do except depending on Allah.

Coping with cyclone

Women: There is no visible change
Men: There is no visible change
Children: There is no visible change.

Infrastructural Change

Road: They repaired the road under a project called 100 days program.
Bazar: Although there is no visible change in market, but recently government allocated money to make pucca shops in the market.
Embankment: There is almost no visible change, but trees were planted in a large scale.
School: There is no visible change.

Hospital: There is no hospital in that locality except one community center. But there is no change in the community center.
House structure: There is no visible change except repairing of some houses.
Home: Some changes are visible in regard to making homestead level high and planting trees.
Mosque: There is no mentionable change in the case of mosque.
Madrasah: There is no madrasah in that locality.
Club: No club in that locality

7. Although there is no visible change in house structure, but when they make house they try to make it stronger. At present they do not make earthen house, but as per the capacity they make tin shed house. Besides, they go for planting trees as much as possible.
8. There is no cyclone shelter except union parishad. As a result, taking the risk of lives they take shelter on embankment.
9. It is necessary to build shelter house, make the mosque of that locality pucca in order to protect the people from cyclone. NGOs are not playing any important role in this regard.
10. People think that there is no difference among them as they work together to take shelter.
11. Almost all the people of that locality prepare themselves during cyclone.
12. As all of them respond so it brings good result for them all.

Suggestions

13. The participants suggested that in order to cope with the cyclone the following issues should be taken into consideration: to build cyclone shelter, to set up tube wells, to convert schools into shelter, to raise level of bazar, to plant trees on embankment as much as possible, to provide necessary transportation facilities to take people to shelter and train people about the surviving strategies during cyclone.

Figure F.8: Public Consultation at Baofal, Patuakhali

Figure F.9: Public Consultation at Baofal, Patuakhali

Public Consultation at Nishanbaria, Chakamoyea, Kalapara, Patuakhali Date: 22-10-2008 Facilitator: Mr. Abul Kalam Azad and Md. Abdul Malek

Source of weather information

1. People get information about cyclone through radio and television. Besides, the volunteers of Red Crescent and workers of Caritas disseminate information of cyclone through miking.

Anticipation about surge or tsunami

2. When cyclone comes from south-east corner they anticipate storm surge, otherwise not. As soon as they get information they cut the trees above the roof of the house as they can fall upon the house and damage it. Before cyclone they fix the house to protect from cyclone. Moreover, they do not permit their children to go to school/college after hearing about the signal. Female participants mentioned that they forbid husband not to go outside.

Action taken before surge

3. When they get signal number 7 they prepare the house and put clothes under earth in a bundle. But when people get signal number 10, they move to cyclone shelter with dry food and water. People put other valuables under the soil so that thieves can not steal. They free their domestic animals like cow, goat, etc. in the name of Allah.
4. One participant mentioned that they could think of the recent catastrophic cyclone. As a result, they stayed at home. But sudden water surge enter into the house, although there was no damage to the family. Some of the participants mentioned that they should take shelter in cyclone shelter after getting the signal number 9-10. Some of the participants also mentioned that as there is greed among the middle class people they are scared to go to cyclone shelter lest they lose their assets.

Training received

5. The participants mentioned that they did not get any training.
6. They brought most changes only in tree plantation.

Coping with cyclone

Women: Female participants mentioned that after hearing the news they take preparation to go to cyclone shelter and forbid their children and other family members not to go outside and to take shelter in cyclone shelter.

Men: After getting the news they try to work near home and at the same time they forbid other people not to go far.

Children: There is almost no change in their coping strategies.

Infrastructural Change

Road: Caritas made a road in this locality.

Bazar: There is no visible change in market except repairing the damaged shops.

Embankment: There is almost no visible change, except tree plantation and removing the fallen trees.

School: No new school was built.

Hospital: There is no positive change in the hospital rather it is negative.
House: Damaged houses are rebuilt with increased strength.
Home: Almost all of them planted trees.
Mosque: They managed to make the mosque pucca with the help of local administration.
Madrasah: There is no change
Club: There no club in that locality

7. When they build home they make it at higher level.
8. There is a cyclone shelter, but it is far away from there. As a result, embankment is the only hope. Allah is considered as their last resort.
9. They provide scope for one another as they live near to the sea shore.
10. People think that there is no difference among them as they work together to take shelter.
11. Poor people respond to the cyclone more than that of rich. Middle class people respond less lest they lose their assets.
12. Those people who take shelter timely suffer less while those who hesitate to take shelter suffer more.

Suggestions

13. The participants suggested that in order to cope with the cyclone the following issues should be taken in consideration: to increase the number of cyclone shelter, to make road to go to cyclone shelter, to provide necessary transportation and hospital for the affected people and to set up tube well and sanitary latrines.

Figure F.9: Public Consultation at Kalapara, Patuakhali

Public Consultations at Ramgoti
Location: Red Crescent Cyclone Center, Balu Char, Ramgoti
Date: 25-10-08
Facilitator: Dr. Khurshed Alam and Mr. Abu Mohammed Sayem

1. Source of weather information

The participants in the public consultation mentioned that they heard of Tsunami from different sources such as radio, television, CPP and publicity of the ensuing Tsnami through miking by local volunteers. However, the most frequent source of warning of Tsunami was the radio. Participants mentioned that except two all of them have radio sets. In this regard the volunteers had a meeting after receiving news about possible hit of tsunami. They fixed the role for each volunteer, all the volunteers worked together to disseminate information to the people as well as to evacuate them to safer places.

2. Anticipation of Storm Surge

Some of the participants mentioned that every signal does not indicate to possibility of storm surge rather if the signal number is normally high storm surge may occur. Some could not identify the exact level of high signal number of which may lead to probable storm surge, but one person worked in CPP responded that they categorized the level of signal 1-3, 4-7 and 8-10. The last number of signal generates storm surge and based on that they decide to evacuate the people to safer places.

3. Preparatory Activities

If the water level rises to a dangerous level they usually go to the cyclone shelters, schools, strongly built houses and high places. But if the water level does not rise to a significant level, the people usually pack the household items and take the domestic animals to a safer place. When the water level went up to a significant level in 1991, they took shelter in building, schools, and mosques. Besides, some of them took domestic animals with them to a safer place. However, sometimes they could not take any preparation. Recalling the cyclone of 1991, some of the participants mentioned that when they heard of the cyclone they tried to take shelter. But when they were moving to a safer place they confronted storm surge. The reason is that if they could get the news earlier they could prepare for the cyclone.

Some of them recalled cyclone occurred in 1970 and mentioned that they had no prior idea about that cyclone. There was no signal and no one could predict that cyclone. As a result, they could not take any preparation for that devastating cyclone. Another person reported about the experience of cyclone in 1970. He took his grandmother to the roof for shelter where she spent the whole night. In the morning, they could see the water on their yard which was about 7/8 ft.

4. Actions taken during cyclone

The participants in the public consultation mentioned that they took people and domestic animals to safer places when they heard about the cyclone. Besides they prepared raft of banana trees to save them.

Box-1 : Story of Cyclone 1970

In 1970, there was a catastrophic cyclone in the costal region of Bangladesh. Many people died and many injured along with the loss of domestic animals, houses, crops, etc.. One person recalled his memory of that cyclone at Daulat Khan, Bhola who is now resident of Ramgoati. He gave a vivid account of that night. Storm surge was engulfing the entire region. People ran to and fro to escape from the death trap. He along with the other members of his aunt's family tried to save their lives. The entire family members were inside the house as the house structure was very strong. But the then little boy of 7 years old were sitting capturing a wood post of the house structure facing the cyclone direction inside the house. He believed that if the house structure is taken away by wind or water he would be able to see it and leave the structure to save him. He noticed that suddenly the house felt down due to severe water force as well as the storm. Five of that family members were washed out with the house structure. He also floated in water with flow in favour of the stream and thus he could manage to hold a nearby tree. But due to the severe wind and rain, he was slipping from the tree. Instantly, he used his lungi to tie himself with the stem of the tree which ultimately saved his life. During the time of storm and water surge, he saw many people were calling the name of relatives when they were sweeping out by the surge water.

5. Shelter

There is lack of enough shelter places. The existing shelters can not provide accommodation to all the people in the locality rather many of the affected people stay outside the shelter. All the people do want to go to the shelter. Those people who are aware of the catastrophe they want to go another place for shelter. Women and children do not go to other place to take shelter. A woman recalled an event during the cyclone Sidr. She mentioned that she got the signal and took shelter into a nearby house. But everyone can not take shelter as there is limited arrangement compare to the number of people. Among the people who took shelter, older people, children and women got priority. However, it was not possible all the time especially when the time is very limited for taking shelter.

Story of Natural Disaster, 1991

The cyclone that affected in 1991 had severe consequences on human lives, domestic animals, crops and many others. It was one of the deadliest cyclones in the history in Bangladesh. One couple recalled their experiences in that cyclone. The water level was around 2 ft high in cyclone shelter even. People tried to save their lives moving to safer places. Some could take shelter in cyclone shelter, house built in high areas, or strong houses and some to embankment and many other places; however, many could not take any shelter at all. That couple went to embankment to take the shelter but due to severe storm, they could not take the shelter there. At that time they saw two ships anchored to a nearby place of the coast. At first they decided to take shelter in those ships. But suddenly they felt that the ships may get capsized due to the strong cyclone. Instantly they moved to another place of the embankment and took shelter. After passing certain time of the cyclone, they were coming back to their house. On the way they saw that two ships were capsized and people in the ships died. They also experienced hundreds of people washed out by surge water in front of their eyes.

5. Training

Among the participants, except 4/5 people all got training provided by Red Crescent. One of the trained volunteers said that trained volunteers can do something in order to manage the disaster ranging from preparation to rehabilitation. However, due to lack of machinery like megaphone, raincoat and lack of logistic supports they could not utilized their full capacity. Some of the participants said that through first aid, they cold save some people after the attack of Sidr. They further mentioned that the benefit of training is that it is useful for cyclone as well as for non-cyclone period.

6. Changes in coping strategy or adaptation

Some of the participants mentioned that they had taken several measures in order to cope up with the cyclone such as:

1. they rose their homestead ground level
2. they made strong pillar/post for their house
3. they planted tree to a greater extent in minimize the wind force of the cyclone
4. some of them also made their floor paved
5. they turned the tin-shed school into building

However, there was no change in the baazar, road, and embankment.

7. Approaches if there is no shelter

If there is no shelter, they usually take shelter in a higher place where they think storm surge may not reach. In this regard, they try to take the older people and children to a safer place first. But sometimes older people do not like to go to another place rather they prefer to stay in their own place even if they die. As a result, it is not always possible to take the older people to a safe place. Most of the people stay in their own house due to lack of shelter. The participants further mentioned that if the shelter is in nearby place older people and women can be taken to the shelter very easily.

8. Improvement of the Existing Capacity

The participants mentioned that in order to improve the existing capacity, the NGO, company and individual person can help in many ways:

NGOs can help in many ways such as providing dry food, clothes, medicines, etc.
Private company can provide food for the affected people.
Individuals can help in building the house structure stronger.

9. Suggestions/opinions

The participants suggested the following issues in order to cope with the cyclone better:

1. the government can build more cyclone shelters in the coastal areas
2. financial assistance to the older people may be given in the cyclone affected areas.
3. Red Crescent or other organizations can come forward to help the affected people financially
4. It is necessary to help the volunteers because due to the exhaustive long day work they sometimes get tired and disinterested in doing their work
5. to build strong houses in the areas
6. to build the house at higher places and to raise the plinth level of the houses.
7. The CPP does not assess the loss of the cyclone. When the relief work or rehabilitation is carried out by the UP-member or union chairman, they prefer their party men for such rehabilitation. As a result, the poor and worse sufferers can not get any relief. For this reason, some of the participants suggested that it is necessary to assess the loss accurately and distribute relief accordingly. They mentioned that due to corruption, the government withdrawn BDT two crores from that area. During joint forces field visits they found that the non-affected people got the tin for building their own houses and some party men only got those tin.

Public Consultation at Hatia
Location: Suryeamukhi Children Welfare Center, Shunneyer Char, Hatia
Date-1-10-2008
Facilitator: Dr. Khurshed Alam and Mr. Abu Mohammed Sayem

1. Source of weather information

The participants mentioned that they were mainly informed about cyclone through radio and television. Although radio was available at home and market, men mostly possessed the radio. Besides, when the signal number is 8-10, Red Crescent alarms the local people through siren. As a result, local people can perceive that the ensuing cyclone would be severe.

2. Anticipation of Storm Surge

Most of the participants reported that they can not anticipate whether the cyclone will bring storm surge or not; however, due to the higher number of signal they can anticipate that storm surge will follow the cyclone. Some of them also mentioned that storm surge might come with server wind force.

3. Preparatory Activities and Action

Although there is cyclone shelter, the participants mentioned that they can not take shelter there as people near to the cyclone shelter take shelter there quickly. As a result, they take shelter on road, strong built houses, etc. Some of the participants mentioned that many of the local people even stay at their own home.

A gender based difference in taking preparation is also there. The participants mentioned that women were likely to convince their husband and children not to go far when there was high number of signal. Most of the women usually took shelter in their own house while men went to embankment. Children normally remain with mother but sometimes even neighbour also help them in taking shelter.

4. Training

The participants made it clear that 4 (6.66) out 60 participants were trained. However, the trained personnel mentioned that as there was no cyclone after 1991, so there was almost no use of such training except first aid and rescuing other from drowning.

5. Changes to Cope

The participants reported that shelter was built in that locality after 1991. In 2008, the embankment was repaired. Besides, under personal ownership a house was built considering the shelter of the local people. People of that locality also undertook some changes such as planting trees at home and roads. Most of the participants mentioned that due to the lack of sufficient money they could change their own houses.

6. Shelter

Some of the participants mentioned that around 1200 people of that locality have the opportunity to take shelter in the cyclone shelter. Female participants mentioned that most of the women were likely to take shelter on embankment. They further mentioned that no women went to cyclone shelter during the last cyclone.

7. Suggestions

The participants provided the following suggestions in order to protect them from cyclone attack:

- To build shelter near to their locality. As a result more people will be able to take shelter
- To build shelter near to or above the embankment so that it can serve as shelter as well as reduce the loss of cultivable land.
- To build ring belt that may reduce velocity of wind.
- The concerned authority should be trained up thoroughly so that they can take effective measures.