CNCRP

Project for Capacity Development on Natural Disaster Resistant Techniques of Construction and Retrofitting for Public Buildings

MANUAL FOR

VULNERABILITY ASSESSMENT AND DAMAGE PREDICTION

OF REINFORCED CONCRETE BUILDINGS AGAINST NON-SEISMIC HAZARDS

Public Works Department

MANUAL FOR VULNERABILITY ASSESSMENT AND DAMAGE PREDICTION OF REINFORCED CONCRETE BUILDINGS AGAINST NON-SEISMIC HAZARDS

(In SI and FPS units)

PUBLIC WORKS DEPARTMENT

PREPARED UNDER

PROJECT FOR CAPACITY DEVELOPMENT ON NATURAL DISASTER RESISTANT TECHNIQUES OF CONSTRUCTION AND RETROFITTING FOR PUBLIC BUILDINGS (CNCRP)

A TECHNICAL COOPERATION PROJECT BETWEEN PWD AND JICA

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Foreword

Bangladesh, as a country, is vulnerable to both seismic and non-seismic hazards. On one hand, it is close to one of the most tectonically active regions in the world. It lies in the region where three tectonic plates meet: the Indian plate, the Eurasian plate, and the Burmese plate. On the other hand, it is situated in the interface of two quite different settings: to the north of the country lie the Himalayas and Khashia - Jaintia hills and to the south, the Bay of Bengal and the Indian Ocean. In northern Bay of Bengal, a unique combination of high tides, a funneling coastline configuration, the low flat coastal terrain and high population density have produced some of the highest mortality figures associated with cyclone, storm surge and coastal flooding. The very geological and geomorphic conditions have made the country easily vulnerable to natural disaster and one of the most disaster prone areas in the world. Be it tornado or flood or cyclone or tidal surge, Bangladesh is one of the worst sufferer from natural calamities.

Fortunately, Bangladesh has not faced any major earthquake for a long time, but at least 23 major cyclones accompanied by tidal surge have struck Bangladesh during the last forty five years, worst of which was the cyclone of November 1970. People fear earthquake, because it is so sudden and devastating that it can destroy a city within seconds. On the other hand, people of Bangladesh are enduring non-seismic hazards like flood, cyclone, and tornado because it is so common and regular. City dwellers are more concerned with earthquake, whereas people affected by non-seismic hazards like cyclone, tidal surge, coastal flooding are demographically weaker section of the population living in the coastal and Char (Island) areas of Bangladesh. With the emergence of Bangladesh, during late seventies, PWD was the first organization to start constructing RC Cyclone Shelter – cum- Primary School in the coastal areas of Bangladesh. Subsequently, many government and non-government organizations constructed thousands of cyclone shelters, schools, community centres, mosques etc. Moreover, many government buildings have been constructed in the coastal areas prior to formulation of BNBC 1993 without any definite knowledge about wind velocity, depth of inundation, debris impact or breaking wave force. Lack of engineering knowledge, inappropriate technique and utilization of low resistance materials have made many of these structures vulnerable to non-seismic hazards.

The project CNCRP (Project for Capacity Development on Natural Disaster Resistant Technique of Construction and Retrofitting for Public Buildings in the People's Republic of Bangladesh) was initially envisaged to develop capacity of engineers of PWD for seismic assessment, retrofitting design and construction of existing RC public buildings. Subsequently, it was decided that as Bangladesh faces many types of non- seismic hazards, a manual should also be prepared for assessment of existing buildings for non-seismic hazards. Out of six manuals prepared under this project, this is the only manual which deals with non-seismic natural hazards. The manual shall help professional engineers in both assessing and designing RC buildings against non- seismic hazards. The manual has been prepared on the basis of requirements of BNBC (Final draft, July 2015) as well as other recognized engineering principles and international standards.

With the publication of the set of six manuals, this shall be the first comprehensive document in the country to assess and address the inadequacies and shortcomings the existing buildings have in their capabilities to withstand all types of natural hazards.

I understand, the scope of the project was limited to only RC buildings. As Bangladesh has huge number of masonry buildings- both public and private- effort should be made in future to develop procedure to assess vulnerability of masonry structures as well.

For four years of hard work, I heartily acknowledge the contributions of all who were associated with the project-JICA, PWD, Bangladeshi and Japanese experts and also the honorable members of Editorial Advisory Board who provided valuable suggestion for the improvement of the manuals. Finally I want to thank the Government of Japan and JICA for their whole hearted support and cooperation to the project CNCRP.

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Preface

This manual is intended to guide, assist and instruct structural engineers engaged in concrete construction to evaluate the strength of an existing reinforced concrete building and it's envelope against non-seismic natural hazards.

The manual is one of the six manuals published under the project "Capacity Building on Natural Disaster Resistant Technique of Construction and Retrofitting for Public Buildings (CNCRP)" implemented by Public Works Department with technical support from Japan International Cooperation Agency (JICA).

Though the importance of seismic evaluation of existing buildings is great, but in Bangladesh, till now, the extent of damage to lives and properties due to non-seismic hazards is much higher compared to seismic hazard. The frequency of non-seismic hazards is also very high due to geographical position, funneling coastline and low flat coastal terrain of Bangladesh. As such, the need to prepare a manual for non-seismic evaluation of existing reinforced concrete building cannot be over emphasized.

The material presented in this document is based on recognized engineering principles and standard set forth in local and international codes and standards and intended for the use of individuals who are competent to evaluate the significance and limitations of the contents and recommendations and who will accept responsibility for the application of the materials it contains.

This manual is based on information from many sources. Published references are listed at the end of the manual. Reference of code and standards used in the manual has also been listed separately.

I gratefully acknowledge the help and assistance given to me by the Japanese experts and Public Works Department Engineers involved in the project in the preparation of the manual.

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Codes and Standards used in this Manual

HBRI / BSTI Housing and Building Research Institute / Bangladesh Standard and Testing Institution: *Bangladesh National Building Code 2015.*

ASCE/SEI 7 American Society of Civil Engineers: *Minimum Design Loads for Buildings and other Structures 2005/2010.*

IBC International Code Council: *International Building Code 2006/2009.*

ACI 318 American Concrete Institute: *Building Code Requirements for Structural Concrete, 2008/2011.*

FEMA 259 Federal Emergency Management Agency:: *Engineering Principles and Practices of Retrofitting Flood Prone Structures.*

FEMA 320: Federal Emergency Management Agency: *Taking Shelter from the Storm: Building a Safe Room*

Greek Alphabets

A number of symbols traditionally used in this type of manuals are taken from the Greek alphabets. This is produced below for reference purpose.

Capital	Small	Name	Capital	Small	Name
Α	α	Alpha	Ν	ν	nu
Β	β	beta	Ξ	ξ	xi
Γ	γ	gamma	Ο	ο	omicron
Δ	δ	delta	Π	π	pi
Ε	ε	epsilon	Ρ	ρ	rho
Ζ	ζ	zeta	Σ	σ	sigma
Η	η	eta	Τ	τ	tau
Θ	θ	theta	Υ	υ	upsilon
Ι	ι	iota	Φ	φ	phi
Κ	κ	kappa	Χ	χ	chi
Λ	λ	lambda	Ψ	ψ	psi
Μ	μ	mu	Ω	ω	omega

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CHAPTER 13

Building Damage Assessment due to Flood, Tidal Surge and Tsunami

CHAPTER 14

Mitigation Measures against Non-Seismic Natural Hazard

Nomenclature

Unless defined otherwise in the text, the following symbols are used in this manual:

Symbols	Terms	Units	
		SI	fps
λ	height and exposure adjustment coefficient	-	-
$\overline{V}_{\bar{z}}$	mean hourly wind speed at height $\bar{z}$ determined from Equation10.23	m/s	mph
$\bar{z}$	equivalent height of structure	m	ft
α	3 second gust speed power law exponent	-	-
γ_w	specific weight of water	kN/m^3	lb/ft^3
GC_{pf}	external pressure coefficient	-	-
$\bar{b}$, $\bar{\alpha}$	constants listed in Table 10.8	-	-
Δ	story drift	m	ft.
Δ_t	impact duration (time to reduce object velocity to zero)	s	s
A	submerged area of the upstream face of the structure as per Equation 13.9	m^2	ft.^{2}
A	projected area of the debris accumulation into the flow, approximated by depth of accumulation times width of accumulation perpendicular to flow as per Equation 13.16	m^2	ft^2
A_g	the gross area of that wall in which $A_o$is identified	m^2	ft^2
A_{gi}	the sum of the gross surface areas of the building envelope (walls & roof) not including A_g	m^2	ft^2
A_o	total area of opening in a wall that receives positive external pressure	m^2	ft^2
A_{oi}	the sum of the areas of openings in the building envelope (walls and roof) not including A_o	m^2	ft^2
B	Beaufort Scale	-	-
B	horizontal dimension of building measured normal to wind direction in Equation 10.15	m	ft
BDD_i	individual building damage degree at wind intensity i	%	%
BFE	base flood elevation	m	ft
BV	replacing value of the building	-	-
c	turbulence intensity factor from Equation 10.14 and Table 10.8	-	-
C_B	blockage coefficient as per Table 13.8	-	-
CCF_i	component cost factor	-	-

C_d	drag coefficient or shape factor from Table13.3	-	-
C_D	depth coefficient as per Table 13.7	-	-
C_f	force coefficients to be used in determining wind loads for other structures	-	-
C_I	importance coefficient (See Table 13.6)	-	-
C_O	orientation coefficient	-	-
C_p	external pressure co-efficient of walls and roof for enclosed, partially enclosed buildings to be used in determining wind loads of buildings as per Table10.10	-	-
C_p	dynamic pressure co-efficient as per Table 13.10	-	-
C_{str}	building structure coefficient	-	-
C_t	coefficient as per Table 10.6	-	-
d	depth of flooding	m	ft
D	depth of saturated soil from adjacent grade to the top of the footer as per Equation 13.5	m	ft
D	pile or column diameter in Equation 13.19	m	ft
$DD(\ell)$	damage degree at hazard level (ℓ)	%	%
DD_i^L and DD_i^u	degree of damage furnished by the lower and upper damage functions of the damage band for the building class under consideration at wind intensity respectively	%	%
DFE	design flood elevation	m	ft
d_h	equivalent head due to low velocity flood flow	m	ft
D_i	flood damage for flood intensity i	%	%
d_s	local still water depth	m	ft
EF	enhanced Fujita Scale	-	-
EFD	expected flood damage	%	%
f	factor of safety (freeboard), typically a minimum of 0.3m(1.0ft)	m	ft
F	impact force in Equation 13.13	N	lb.
F	drag force due to debris accumulation in Equation 13.16	N	lb.
F_{buoy}	vertical hydrostatic force resulting from the displacement of a given volume of flood water	kg	lb
F_d	total force against the structure in Equation 13.9	kN	lb.
F_D	net wave force in Equation 13.19	kN	lb.
f_{dif}	differential soil/water force acting at a distance D/3 from the point under consideration	kN/m	lb/ft
FE	flood elevation for specific flood frequency	m	ft

F_i	lateral force applied at level *i*, *i*= 1 to *n* as per Equation 8.3	kN	kips
F_i	impact force acting at the Base Flood Elevation (BFE) as per Equation 13.15	kN	lb.
f_{n1}	frequency as per Equation 10.10	H_z	H_z
f_{sta}	hydrostatic force from standing water or water moving at a velocity less than 3m/s (10 ft/s) acting at a distance *H*/3 above ground	kN/lm	lb/lft
F_t	net breaking wave force per unit length of structure in Equation 13.21	kN/m	lb./ft
G	gust effect factor in Equation 10.13 for rigid building	-	-
g	acceleration due to gravity	m/s/s	ft/s/s
G	ground elevation in Equation 13.18	m	ft
GC_p	product of gust effect factor and external pressure co-efficient to be used in determination of wind loads for buildings	-	-
GC_{pf}	product of gust effect factor and external pressure coefficient to be used in determination of wind loads for MWFRS of low rise building	-	-
GC_{pi}	product of gust effect factor and internal pressure coefficient to be used in determining wind loads for buildings as per Table 10.9	-	-
GC_{pn}	combined net pressure coefficient for a parapet	-	-
G_f	gust effect factor for MWFRSs for flexible building	-	-
g_Q g_R	peak factor for background response in Equation 10.13 , 10.17 peak factor for resonant response in Equation 10.17	- -	- -
GS	lowest ground surface elevation (grade) adjacent to a structure	m	ft
g_v	peak factor for wind response in Equation 10.13 and 10.17	-	-
h	story height from floor to floor in Equation 8.1 and 8.2	m	ft
H	height of the building as per Equation 10.6	m	ft
h	mean roof height of a building, except that eave height shall be used for roof angle θ of less than or equal to 10^0 in Equation 10.15	m	ft
H	flood proofing design depth over which flood forces are considered in Equation13.3	m	ft
h	flood water depth in Equations 13.10,13.11,13.12	m	ft
H_b	breaking wave height in Equation 13.17	m	ft
h_i	height of the building above the grade of level *i*	m	ft
h_i, h_x, h_n	heights at level *i, x, n* respectively	m	ft
h_n	height above the base to the highest level of the structure	m	ft
I	importance factor as per Table 10.3 based on Table 10.2	-	-

$I_{\bar{z}}$	intensity of turbulence at height $\bar{z}$, which is the equivalent height of the structure defined as 0.6h but not less than z_{min} for all building height h.	-	-
K_1, K_2, K_3	multipliers in Fig 6.2.4 Part6 of BNBC15 to obtain K_{zt}	-	-
K_d	wind directionality factor in Table 10.5	-	-
K_h	velocity pressure exposure coefficient evaluated at height $z = h$	-	-
K_z	velocity pressure exposure coefficient evaluated at height z	-	-
K_{zt}	topographic factor as defined in Section 10.2.5.2 evaluated at mean roof height h	-	-
L	horizontal dimension of a building measured parallel to the wind direction for subscript ℓ of Equation10.22	m	ft
ℓ	integral length scale factor from Table10.8	m	ft
$L_{\bar{z}}$	integral length scale of turbulence at the equivalent height given by Equation 10.16	m	ft
L_{eff}	effecting length in the direction under consideration in Equation 10.3	m	ft
L_i	building length at level i parallel to the wind action	m	ft
n	number of components used in the building damage model/ number of performance parameters in Equation 7.1	no.	no.
n	natural frequency	H_z	H_z
n_1	lower bound estimates of frequency in Equation 10.6	H_z	H_z
N_1	reduced frequency from Equation 10.21	-	-
p	design pressure to be used in determination of wind load for buildings	N/m^2	lb/ ft^2
p_p	combined net pressure on the parapet from the front and backside of the parapet as per Equation10.28	N/m^2	lb/ ft^2
P_d	hydrodynamic pressure in Equation 13.8	kN/m^2	lb/ft^2
P_{fi}	components fragility in Equation 7.1	-	-
P_h	hydrostatic pressure due to standing water or water moving at a velocity less than 3.0m/s (10 ft/s) at a depth of H	kN/m^2	lb/ft^2
P_i	quality point associated with each building wind performance parameter in Equation 7.3	no.	no.
P_{max}	maximum combined dynamic and static wave pressure in Equation 13.20	kN/m^2	lb/ft^2
p_s	combination of the windward and leeward net pressure	N/m^2	lb/ft^2
$p_{s9.1(30)}$	simplified design wind pressure for Exposure A, at h 9.1m (30.0 ft) and for I = 1.0 Importance factor for the building shall be determined on the basis Table 10.3.	N/m^2	lb/ft^2
Q	background response factor from Equation 10.15	-	-
q	velocity pressure	N/m^2	lb/ ft^2

q_h	velocity pressure determined at height z = *h* from ground	N/m^2	lb/ ft^2
q_i	velocity pressure for internal pressure determination	N/m^2	lb/ ft^2
q_p	velocity pressure evaluated at the top of the parapet	N/m^2	lb/ ft^2
q_z	velocity pressure determined at height *z* from ground	N/m^2	lb/ ft^2
R	resonant response factor from Equation 10.19		
R_B, R_h, R_L	values from Equation 10.19	-	-
R_{max}	maximum response ratio for impulsive load as per Table13.9	-	-
R_n	value from Equation 10.20	-	-
RRI	relative resistivity index in Equation 7.3	-	-
S	equivalent fluid weight of submerged soil and water as shown in Table 13.2	kN/ m^3	lb/ft^3
T	TORRO Scale	-	-
T	fundamental period	seconds	seconds
t	*t* is defined as 1 sec.	-	-
T_a	approximate fundamental period in Equation 10.4	sec.	sec.
v	wind velocity as per Equation 3.3	m/s	m/hr
V	basic wind speed corresponds to a 3-second gust speed at 10m (33 ft) above ground in exposure Category B	m/s	mph
V	average velocity of flood water in Equation 13.7	m/s	ft/s
V_b	velocity of object in Equation 13.13	m/s	ft/s
V_l	lower bound velocity of water in Equation 13.10	m/s	ft/s
Vol	volume of flood water replaced by a submerged object in Equation13.6	m^3	ft^3
V_u	upper bound velocity of water in Equation13.11	m/s	ft/s
W	debris weight in Equation13.13	N	lb.
W_i	weight associated with each performance parameter in Equation 7.3	value	value
x	coefficient as per Table 10.6	-	-
z	height above ground level	m	ft
z_g	nominal height of the atmospheric boundary layer as per Table10.8	m	ft
z_{min}	Exposure constant from Table10.8	-	-
α_i	component location parameter as per equation 7.1	-	--
ρ	mass density of fluid	kg/m^3	slugs/ft^3
ϵ	Ratio of solid area to gross area for solid free standing wall, solid sign, open sign, face of a trussed tower, or lattice structure	-	-

DEFINITIONS

ALLOWABLE STRESS DESIGN: A method of proportioning structural members such that elastically computed stresses produced in the members by nominal loads do not exceed specified allowable stresses (also known as working stress design).

BASE FLOOD ELEVATION (BFE): The elevation of flooding, including wave height, having a one percent chance of being equaled or exceeded in any given year.

BASE FLOOD: The flood having one percent chance of being equaled or exceeded in any given year.

BASIC WIND SPEED, V: Three-second gust speed at 10m (33ft.) above the ground in Exposure B (see Section10.1.8) as determined in accordance with Section 10.1.4.

BREAKAWAY WALL: Any type of wall subjected to flooding that is not required to provide structural support to a building or other structure, and that is designed and constructed such that, under base flood or lesser flood condition, it will collapse in such a way that (1) it allows the free passage of flood waters, and (2) it does not damage the structure or supporting foundation system.

BUILDING AND OTHER STRUCTURES, FLEXIBLE: Slender building and other structures that have a fundamental natural frequency less than 1 Hz.

BUILDING ENVELOPE: Cladding, roofing, exterior walls, door assemblies, window assemblies, skylight assemblies, and other components enclosing the building.

BUILDING OR OTHER STRUCTURES, REGULAR SHAPED: A building or other structure having no unusual geometrical irregularity in spatial form.

BUILDING OR OTHER STRUCTURES, RIGID: A building or other structure whose fundamental frequency is greater than or equal to 1 Hz.

BUILDING, ENCLOSED: A building that does not comply with the requirements for open or partially enclosed building.

BUILDING, OPEN: A building having each wall 80% open. The condition is expressed for each wall in Section 10.1.2 (3) (a).

BUILDING, PARTIALLY ENCLOSED: A building that complies with both the conditions as expressed in Section 10.1.2 (3) (b).

BUILDING, SIMPLE DIAPHRAGM: A building in which both windward and leeward wind loads are transmitted through floor and roof diaphragm to the same vertical MWFRS (e.g., no structural separation).

BUILDINGS: Structures usually enclosed by wall and a roof, constructed to provide support or shelter for an intended occupancy.

COASTAL, A-ZONE: An area within a flood hazard area, landward of a V-Zone or landward of an open coast. To be classified as a Coastal A-Zone the principal source of flooding must be astronomical tides, storm surges, seiches, or tsunami, not riverine flooding, and the potential for breaking wave heights greater than or equal to 0.46m (1.5 ft.) must exist during base flood.

COASTAL, HIGH HAZARD AREA (V-ZONE): An area within a Special Flood Hazard Area extending from the offshore to the inland limit of a primary frontal dune along an open coast, and any other area that is subjected to high velocity wave action from storm or seismic sources.

COMPONENTS AND CLADDING: Elements of building envelope that do not qualify as part of the MWFRS.

CYCLONE PRONE REGION: Areas vulnerable to cyclone in Bangladesh and its territories.

DESIGN FLOOD ELEVATION: The elevation of the design flood, including wave height, relative to the datum.

DESIGN PRESSURE, *p*: Equivalent static pressure to be used in the determination of wind loads for buildings.

DESIGN STRENGTH: The product of the nominal strength and resistance factor.

EAVE HEIGHT, *h*: The distance from the ground surface adjacent to the building to the roof eave line at a particular wall. If the height of the eave varies along the wall, the average height shall be used.

EFFECTIVE WIND AREA: The area to determine GC_p.

ESSENTIAL FACILITIES: Building and other structures that are to remain operational in the event of extreme environmental loading from wind, flood or earthquake.

FACTORED LOAD: The product of the nominal load and a load factor.

FORCE DESIGN, *F*: Equivalent static force to be used in the determination of wind loads for open buildings and other structures.

IMPORTANCE FACTOR *I*: A factor that accounts for the degree of hazard to human life and damage to properties.

LIMIT STATE: A condition beyond which a structure or member become unfit for service and is judged either to be no longer useful for its intended function (serviceability limit state) or to be unsafe (strength limit state).

LIVE LOAD: A load produced by the use and occupancy of the building or other structures that does not include construction or environmental loads, such as wind load, earthquake load, flood load or dead load.

LOAD FACTOR: A factor that accounts for deviations of the actual load from the nominal load, for uncertainties in the analysis that transforms the load into a load effect and for the probability that more than one extreme load will occur simultaneously.

LOADS: Forces or other actions that results from the weight of all building materials, occupants and their possessions, environmental effects, differential movements, and restrained dimensional changes. Permanent loads are those loads in which variations over time are rare or of small magnitude. All other loads are variables loads.

LOW RISE BUILDING: Enclosed or partially enclosed buildings that comply with the following conditions:

1. Mean roof height *h* less than or equal to 18m (60 ft.)

2. Mean roof height *h* does not exceed least horizontal dimension.

MAIN WIND FORCE RESISTING SYSTEM: An assemblage of structural elements assign to provide support and stability for the overall structure. The system generally receives wind loadings from more than one surface.

MEAN ROOF HEIGHT: The average of the roof eave height and the height to the highest point on the roof surface, except that, for roof angles of less than or equal to 10^0, the roof height shall be the roof heave height.

NOMINAL LOADS: The magnitude of the loads specified in this standard for dead, live, soil, flood and earthquake.

OPENINGS: Apertures or holes in the building envelope that allow air to flow through building envelope and that are designed as "open" during design winds as defined by these provisions.

STRENGTH DESIGN: A method of proportioning structural members such that the computed forces produced in the members by the factored loads do not exceed the member strength (also called "load and resistance factor design").

WIND- BORNE DEBRIS REGION: Areas within cyclone prone regions located:

1. Within 1.61km (1 mile) of the coastal mean high water line where the basic wind speed is equal to or greater than 177 km/h (110 mph).

2. In areas where the basic wind speed is equal to or greater than 193 km/h (120 mph).

CHAPTER 1

GENERAL

1.1 INTRODUCTION

Total area of Bangladesh is 144000 sq.km. (55500 sq. miles) and located between $20^0 34^/$ to $26^0 39^/$ North Latitude and between $88^0 01^/$ to $92^0 41^/$ East Longitude.

It is also situated at the interface of two quite different settings. To the north of the country lie the Himalayas and Khashia-Jaintia hills and to the south are the Bay of Bengal and the Indian Ocean. Both settings control, modify and regulate the climate of the country and the region. The geographic location of Bangladesh and its geomorphic conditions have made the country easily vulnerable to natural disaster such as tropical cyclone and accompanying storm surge, floods, tornados, nor'westers, draught, river bank and coastal erosion [Ref 1.5]. Bangladesh National Building Code (BNBC93) for the first time introduced the provision of seismic design requirements as well as criteria of building design against other non-seismic natural forces like cyclone, flood, storm surge etc. Prior to introduction of BNBC93 Bangladesh did not have any building code of its own to follow. Engineers followed code of their choice, without following the Basic Wind Speed Map and Seismic Zoning Map of Bangladesh as available in BNBC93. Lack of uniformity in design procedure among engineers and arbitrary choice of Code and Standards necessitate assessment of buildings constructed prior to introduction of BNBC93 as per safety requirements prescribed in BNBC93 against vertical loads, wind, earthquake and other natural loads and their combination. Even after introduction of BNBC 93, it was not mandatory to follow it till 2006, when BNBC93 was enacted as a law through parliament. So, even after introduction of BNBC93, many Engineers might not have followed the code properly. As such vulnerability assessment of existing R.C.C buildings (both building envelope and structural system) shall help in assessing retrofitting measures needed for existing buildings against natural hazards. Necessary mitigation measures can also be suggested for future buildings based on the information available from existing buildings. Moreover, a joint team comprising JICA experts and engineers of Public Works Department are preparing manuals on design, construction, quality control, inspection, strength evaluation and retrofitting measures of existing R.C. buildings against seismic forces. As Bangladesh is frequently facing other natural hazards like cyclone, flood, storm surge and tornado and also is in some danger of being affected by tsunami, it is imperative that a procedure for assessing vulnerability of buildings against these hazards should be taken into consideration.

1.2 PURPOSE

The purpose of this manual is to establish a method of vulnerability assessment of RCC Building against non-seismic natural hazard like cyclone, flood, cyclone /tsunami induced storm/tidal surge etc. so that an appropriate cost effective scheme of retrofitting may be designed for improved resistance to non-seismic natural disaster.

The procedure described in this manual may be applied to any building constructed by both public and private sector within Bangladesh. The expressed intent of the manual is to ensure public safety against non-seismic natural hazards.

1.3 SCOPE

The provision of this manual shall be applied to evaluate whether the structural system of an existing reinforced concrete public building or a portion thereof satisfies the safety requirements as prescribed in BNBC15, (Ref. 1.1) supplemented by ASCE/SEI 7-05(Ref. 1.2), ASCE/SEI7-10 (Ref.1.6), ACI 318-11 (Ref. 1.3) and IBC 06 (Ref 1.4) against non-seismic disaster like cyclone, flood, cyclone induced storm surge, tsunami etc.

The provision of this manual shall also be applied to assess the vulnerability of building envelope against cyclone and possible extend of damage due to flood to building components that are within the reach of flood water due to tidal surge generated by cyclone and tsunami. In addition, any other method, which is based on same concept and has been verified through experimental data or detailed analysis, may also be used for evaluation of reinforced concrete building against non-seismic natural hazards. Vulnerability assessment of buildings other than RCC frame structure with in- filled walls is not within the scope of this manual and is limited to only non-seismic natural hazards.

1.4 ORGANIZATION OF THE MANUAL

The manual has fourteen main Chapters and six Annexure.

Chapter 1: Introduction

This chapter mainly covers the background, purpose and scope of the manual.

Chapter 2: Vulnerability Assessment

This chapter defines what vulnerability assessment is and how to assess the vulnerability of building envelope and main wind- force resisting system of low and mid-rise reinforced concrete building in a logical sequence for non-seismic natural hazards.

Chapter 3: Non-seismic Natural Hazards

This chapter discusses the basics of non- seismic natural hazards like cyclone, flood, storm surge, tsunami, tornado etc., their characteristics, generation mechanism, intensity, behavior and probable effects on buildings.

Chapter 4: Building Elements

This chapter discusses different building elements which are affected by natural hazards.

Chapter 5: Potential Damages due to Non-Seismic Natural Forces

This chapter deals with expected damages, causes of damage and their effect on different building elements due to non-seismic natural forces.

Chapter 6: Vulnerability Assessment Guidelines (Cyclone)

This chapter provides guidelines for the survey of the existing building in a questionnaire form along with Proforma to assess vulnerability of building envelope and main wind-force resisting system due to cyclone.

Chapter 7: Vulnerability and Damage Prediction of Building Envelope by *'Wind Damage Band'* Model

This chapter describes in detail along with example a procedure to calculate the predicted damage of building envelope by cyclone as percentage of the total building cost. The procedure is called "Wind damage band" model.

Chapter 8: Strength Evaluation of Main Wind–Force Resisting System

This chapter mainly deals with theoretical aspects of structural strength analysis of building against wind load along with the procedure to calculate the rigidity and flexibility of the structure.

Chapter 9: Load Combination

This chapter deals with load combination applicable as per BNBC15 as well as ASCE 7-05 and ASCE 7-10 to evaluate the structural elements of building. Load combination for both stress design(WSD) and strength design (USD) have been discussed.

Chapter 10: Wind Load Analysis

This chapter discusses the procedure to be applied for evaluating the strength of main wind-force resisting system for both low rise buildings and buildings of any height.

Chapter 11: Illustrative Example of a Hypothetical Building

In this chapter a 10-story hypothetical building's main wind force resisting system has been analyzed for wind load in axes, rigid structure in one direction and flexible structure in the other direction.

Chapter 12 Inundation Depth due to Storm Surge and Tsunami

In this chapter, based on study by Institute of Water Modeling (IWM), inundation depths in 50 coastal districts along with comparative statements have been shown in tabular form along with maps for storm surge and tsunami.

Chapter 13: Building Damage Assessment due to Flood, Tidal Surge and Tsunami

In this chapter discussions have been made regarding forces exerted by flood, tidal surge and tsunami on buildings. Procedure, equations and examples have been given how to calculate these forces for assessing the aggregated damages due to these forces.

Chapter 14: Mitigation Measures against Non- Seismic Natural Hazards

In this chapter detail discussion has been made regarding mitigation measures that can be undertaken to reduce the damages of a building due to non-seismic natural hazards.

Annexure 1: Extent of Damage due to Different Categories of Hurricane as per Safir-Simpson Hurricane Scale

Annexure 2: Extend of Damage as per TORRO Wind Intensity Scale

Annexure 3: Cyclone Classification in Different Countries

Annexure 4: Storm Surge Inundation Depths in the Coastal Areas of Bangladesh

Annexure 5: List of Tsunami Vulnerable Infrastructure

Annexure 6: Chronology of Major Cyclonic Storms in Bangladesh

References, Index of Tables, Index of Figures

1.5 FINAL REPORT

After non-seismic evaluation has been performed a final report shall be prepared. As a minimum the report shall include the following items:

1. Scope and Intent: The purpose for the evaluation and level of investigation conducted.
2. Site and Building Data
   - General building description (frame, lateral force resisting system, floor and roof diaphragm, foundation system)
   - Non-structural system description(all non-structural elements that affect non-seismic performance)
   - Building occupancy type
   - Availability of original design and construction document
3. List of assumptions, material properties and soil conditions.
4. Findings: A priorities list of deficiencies.
5. Recommendations: Mitigation measures.

The final report serves to communicate the results to the owner and records process and assumptions used to complete the evaluation. Each section should be carefully written in a manner that is understandable to the intended audience.

CHAPTER 2

VULNERABILITY ASSESSMENT

2.1 WHAT IS VULNERIBILITY ASSESSMENT?

Vulnerability analysis, also known as vulnerability assessment is a systematic examination of a building or structure through which crucial components of the structure or building are defined, identified and assessed that may be at risk against natural disaster like earthquake, cyclone, flood, tsunami, cyclone/tsunami induced storm/ tidal surge etc. It also determines appropriate procedure or countermeasures and evaluates their actual effectiveness in reducing or removing the risk after they are put into use.

2.2 STEPS OF VULNERIBILITY ASSESSMENT

Vulnerability assessment follows a logical sequence. These are:

1. Define Building/Structure
2. Form planning group
3. Identify and describe probable hazards
4. Define and classify major components of the structure/building
5. Assign relative level of important to the components
6. Identify potential risk to each component
7. Describe effects
8. Set a strategy to deal with most serious potential problem first followed by natural sequence
9. Define ways to minimize consequence in case of natural disaster
10. Recommend action
11. Implement Action

The entire process begins by identifying objective and scope of vulnerability assessment and the identification of intending task and needed resources. The formation of a planning group facilitates co-ordination between activities. Once the ground work is done, hazards facing the facility can be identified and evaluated with regard to possible effects on the facility.

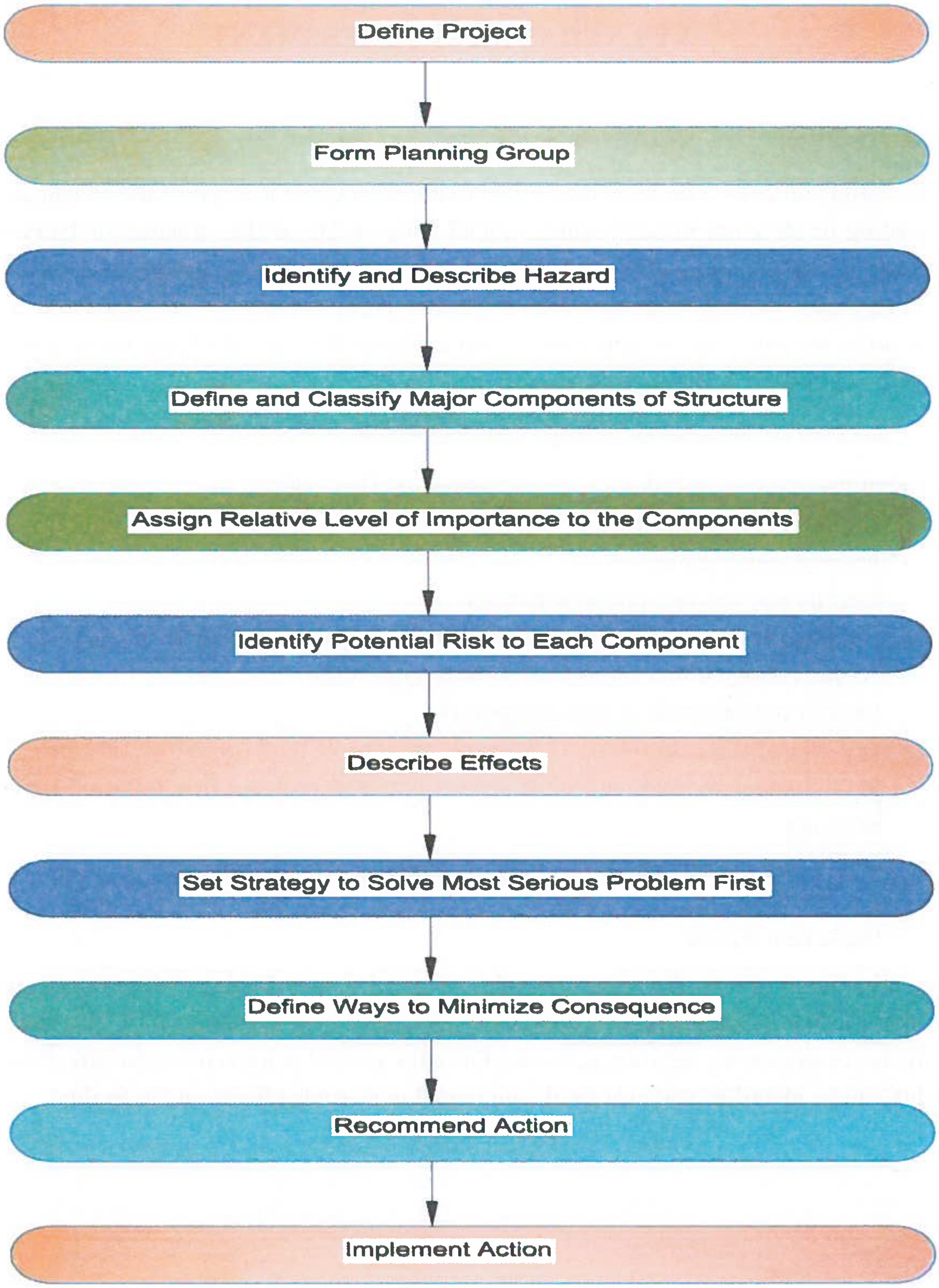


Figure 2.1 Arrow Diagram for Vulnerability Assessment

CHAPTER 3

NON-SEISMIC NATURAL HAZARDS

3.0 NON-SEISMIC NATURAL HAZARDS

There are five major and two minor types of non-seismic hazards that may affect Bangladesh. These are:

MAJOR:

- Cyclone
- Flood
- Cyclone induced storm surge
- Tornado
- Tsunami

MINOR:

- Lighting and Thunderstorm
- Landslide

3.1 CYCLONE

The terms *"hurricane, tropical cyclone and typhoon''* are synonymous for the same type of storm. In the Atlantic Ocean and Eastern Pacific tropical cyclones are known as *hurricanes*. In the Western Pacific Ocean tropical cyclones are known as *typhoons*. In the Indian Ocean tropical cyclones are known as *cyclones*.

A tropical cyclone needs warm ocean temperature in order to form. Temperature in the ocean needs to be at least 28^0 Celsius (82 degrees Fahrenheit) in order to form a cyclone. Heat is drawn up from the oceans creating what is popularly known as *heat engine*. Tall convective towers of clouds are formed within the storm as warm ocean water evaporates. As the air rises higher it cools and condenses releasing latent heat which causes even more clouds to form and feed the storm. Most storms are accompanied by a lot of rain and storm surge near the shore. Often, once the storm makes the landfall, the tropical cyclones can cause *tornadoes*.

Cyclones are normally straight line wind event. The wind is considered, in general, to blow in a straight line. Wind speeds range from very low to very high. High winds associated within tense low pressure can last for days at a given location. Of all the storm types, cyclone has the greatest potential for devastating a very large geographical area and hence affects great number of people.

Bay of Bengal is a breeding ground for cyclone and strikes Bangladesh almost every other year.

Most severe cyclones that struck Bangladesh in previous years normally occurred either during April-May or October-November.

A list of major cyclones that struck Bangladesh since 1584 has been listed in Annexure 6.

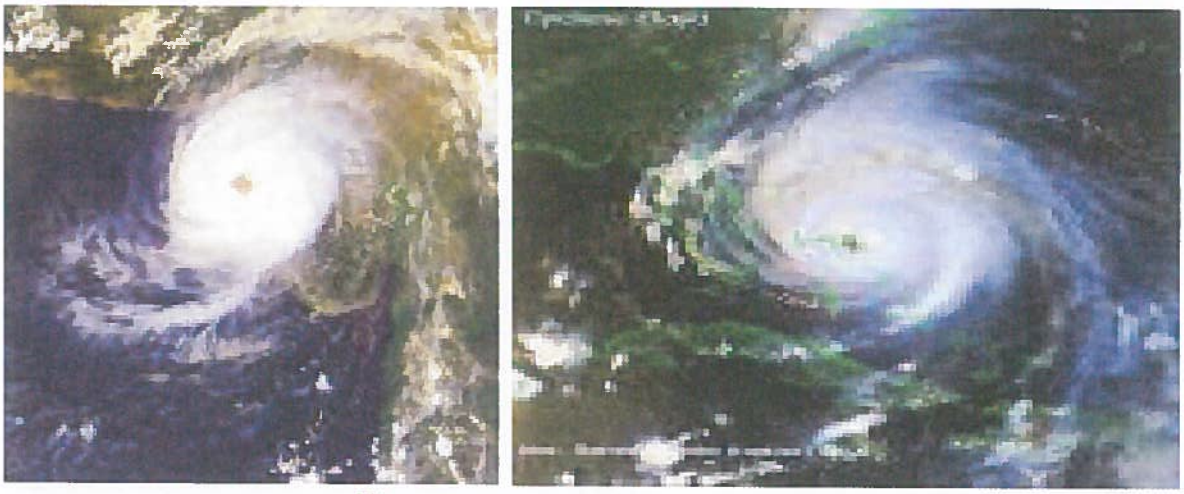


Figure. 3.1 Photographs of Wind Storm (Cyclone)

Figure 3.1A Visible Satellite Image of Cyclone on April 29, 1991(Category 4 cyclone) in Bangladesh.

3-minute sustained wind speed: 240 km/h (150 mph) 1-minute sustained wind speed:260 km/h (160 mph)

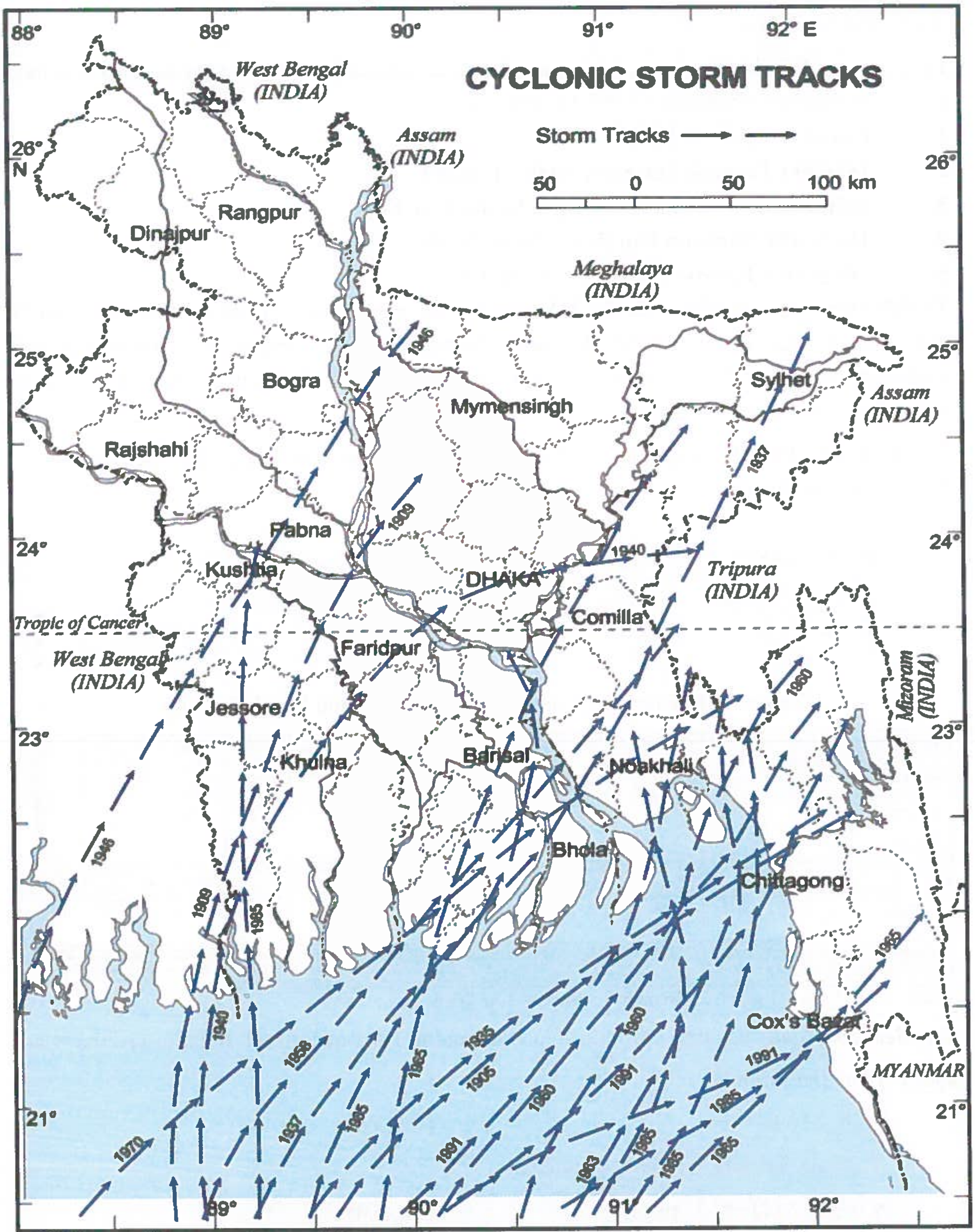


Figure 3.2. Cyclonic Storm Tracks of Bangladesh (Source: Banglapedia)

3.1.1 Wind Intensity Scales

Five types of Wind Intensity Scales are available, developed by different organizations, wind engineers and meteorologists (Ref.3.1). These are:

1. **Beaufort Scale (B-Scale)**
2. **TORRO Tornado Intensity Scale (T-scale)**
3. **Fujita Scale or Enhanced Fujita Scale (F or EF)**
4. **The Saffir-Simpson Hurricane Wind Scale**
5. **Integrated Kinetic Energy Scale (IKE)**

TORRO tornado intensity scale (or T-Scale) is scale measuring tornado intensity between T0 and T11. It was developed by Terence Meaden of the Tornado and Storm Research Organization (TORRO), a meteorological organization in the United Kingdom, as an extension of the *Beaufort scale*.

The Scale sets T0 as the equivalent of 8 on the *Beaufort scale* and is related to the *Beaufort Scale (B)*by the formula

$$B = 2\,(T+4) \qquad \text{(Eq.3.1)}$$

And conversely,

$$T = (B/2 - 4) \qquad \text{(Eq.3.2)}$$

Table 3.1 Relation between B-Scale, T-Scale and Wind Velocity

Beaufort Scale	B	8	10	12	14	16	18	20	22	24	26	28	30
TORRO Scale	T	0	1	2	3	4	5	6	7	8	9	10	11
v m/s	-	19.00	26.50	34.80	43.80	53.60	64.00	75.00	86.40	98.40	111.00	124.00	137.50
v mph	-	42.40	59.40	78.00	98.00	120.00	143.40	168.00	193.21	220.14	248.22	277.39	307.65
v km/h	-	68.43	95.63	125.34	157.80	192.93	230.23	269.61	311.50	354.43	399.63	446.59	495.32

1 mph = 0.447 m/s 1 m/s = 2.236 mph 1mph = 1.61 km/h

The ***Beaufort scale*** was first introduced in 1805 and in 1921 quantified. It expressed the wind speed (v) by the formula:

$$v = 0.837\, B^{3/2}\ \text{m/s} \qquad \text{(Eq. 3.3)}$$

T- Scale formula may be expressed as:

$$v = 0.837\,(2T+8)^{3/2}\ \text{m/s} \qquad \text{(Eq. 3.4)}$$

Or $v = .837\,(2)^{3/2}\,(T+4)^{3/2}$ m/s (Eq. 3.5)

TORRO claims, it differs from the *Fujita Scale* in that, it is purely a wind speed scale. This scale is primarily used in United Kingdom whereas *Fujita scale* is primarily used in NorthAmerica, Europe & rest of the world.

The ***Enhanced Fujita Scale (EF Scale)*** rates the strength of tornadoes in the United States based on the damage they cause.

Implemented in place of the *Fujita Scale* introduced in 1971, by Ted Fujita, it began operational use on February 1, 2007.
The scale has the same basic design as the original *Fujita Scale*: six categories from zero to five are representing increasing degree of damage. It was revised to reflect better examination of tornado damage survey, so as to align wind speeds more closely with associated storm damage.
As with *Fujita Scale*, the *Enhance Fujita Scale* remains a damage scale and only a proxy for actual wind speed.

Table 3.2 Wind Intensities of Enhanced Fujita Scale

Scale		EF0	EFI	EF2	EF3	EF4	EF5
Wind speed (estimated)	mph	65-85	86-110	111-135	136-165	165-200	>200
	km/h	105-137	138-178	179-218	219-266	267-322	>322
	m/s	29.2-38.00	38.33-49.44	49.72-60.56	60.83-73.89	74.17-89.44	>89.44

1 m/s = 3.6 km/h = 2.236 mph

The wind speeds on the original scale were deemed by meteorologists and engineers as being too high and engineering studies indicated that slower winds than initially estimated cause the respective degree of damage. The old scale lists an F5 tornado as wind speeds of 419-512 km/h, (261-318 mph) while the new scale lists an EF5 as a tornado with winds above 322 km/h (200 mph) found to be sufficient to cause the damage previously ascribed to the F5 range of wind speed.

The ***Saffir-Simpson Hurricane Wind Scale*** is a 1 to 5 categorization based on the hurricane's intensity at the indicated time, barometric pressure at the center of the storm, and estimated storm surge and damage potential. The scale originally developed by Wind Engineer Herb Saffir and Meteorologist Bob Simpson-has been an excellent tool for alerting the public about the possible impacts of various intensity hurricanes. The scale provides example of the types of damage and impacts in the United States, associated with the wind of the indicated intensity. In general damage rises by about a factor of four for every category increase.

Table 3.3 Saffir-Simson Hurricane Scale

Hurricane Category	Sustained Wind Speed [a]		Central Barometric Pressure		Storm Surge		Damage Potential
	mph	m/s	Inches of mercury	millibars	ft.	m	
1	74 -95	33.1 -42.5	> 28.9	> 979	4 to 5	0.8 to 1.2	Minimal
2	96 -110	42.6 -49.2	28.50 -28.91	965-979	6 to 8	1.3 to 1.8	Moderate
3	111 -130	49.3 -58.1	27.91-28.47	945-964	9 to12	1.9 to 2.7	Extensive
4	131-155	58.2 -69.3	27.17 -27.88	920-944	13 to 18	2.8 to 3.7	Extreme
5	> 155	> 69.3	< 27.17	< 920	> 18	> 3.7	Catastrophic

1000millibars = 100 kPa [(a)] 1-minute average wind speed at10m (33 ft) above open water

Table 3.4 Approximate Relation between Wind Speed in ASCE7 and Saffir -Simson Hurricane Scale

Saffir/Simson Hurricane Scale	Sustained Wind Speed Over Water [a]		Gust Wind Speed Over Water [b]		Gust Wind Speed Over Land [c]	
	mph	m/s	mph	m/s	mph	m/s
1	74 -95	33.1 -42.5	91 -116	40.7 -51.9	82-108	36.7-48.3
2	96 -110	42.6 -49.2	117 -140	52.0-62.6	109-130	48.4-58.1
3	111 -130	49.3 -58.1	141 -165	62.7-73.8	131-156	58.2-69.7
4	131-155	58.2 -69.3	166 -195	73.9-87.2	157-191	69.8-85.4
5	> 155	> 69.3	> 195	>87.2	>191	>85.4

[a] 1-minute average wind speed at 10m (33 ft) above open water

[b] 3-second gust wind speed at10m (33 ft) above water

[c] 3-second gust wind speed at 10m (33 ft) above ground in Exposure C of ASCE7 (BNBC Exposure B)

Saffir-Simpson Hurricane Scale is a disaster potential scale, assigning storms to five categories which can be used to give an estimate of the potential property damage and flooding expected along the coast with a hurricane.

Expected damage descriptions of *Saffir-Simpson Hurricane Scale* and *TORRO Scale* have been shown in Annexure1 and Annexure 2.

Integrated Kinetic Energy (IKE) scale patented by US government in 2007 is a new scale designated to better convey the destructive power from both hurricane wind and storm surge. It is a measure of the wind speed integrated over how wide an area the winds are blowing. The Saffir-Simpson scale, used by the National Weather Service of USA only takes estimated maximum wind speed in categorizing a hurricane but IKE also integrates over which the hurricane spreads as well as storm surge. Surge is the most devastating element of a hurricane, killing more people than all other hurricane related threats.

The surge potential can be different from wind potential. The IKE scale has the ability to more accurately predict how big the hurricane is, how strong it is and what the storm surge may be, so that the emergency management officials can make an informed decision on whether to evacuate people before the hurricane gets close to landfall. Hurricane Sandy was rather weak storm (wind speed 129kph)(80 mph) as far as wind speed is concerned but its impact was huge due to its massive wind field. Full moon made high tides 20% higher than normal and amplified Sandy's storm surge (Ref.3.7).

The IKE scale measures in a continuous scale from 0 – 5.99 instead of 1- 5 of Saffir-Simpson Scale. So a hurricane potential to wind damage can be 3.4, but its surge potential can rate a 4.5. Cyclones in the South Asian Sub-Continent are presently classified according to their intensity and the following nomenclature is in use by **Bangladesh Meteorological Department.**

Table 3.5 Nomenclature of Cyclone in Bangladesh

Nomenclature	Wind speed km/h	Winds speed mph	Wind speed m/s
Depression	Up to 51	Up to 31.7	Up to 14.17
Deep Depression	52-61	32.3-37.90	14.44 – 16.94
Cyclonic storm	62-88	38.5-54.65	17.22-24.44
Severe cyclonic storm	89-117	55.28-72.67	24.72-32.50
Severe cyclonic storm of hurricane intensity	> 117	> 72.67	>32.50

1 m/s = 3.6 km/h = 2.236 mph

Bangladesh also uses a 1 to 10 scale to classify tropical cyclones with 10 being the most severe.

Alert Stage: Signal No. I, II, and III

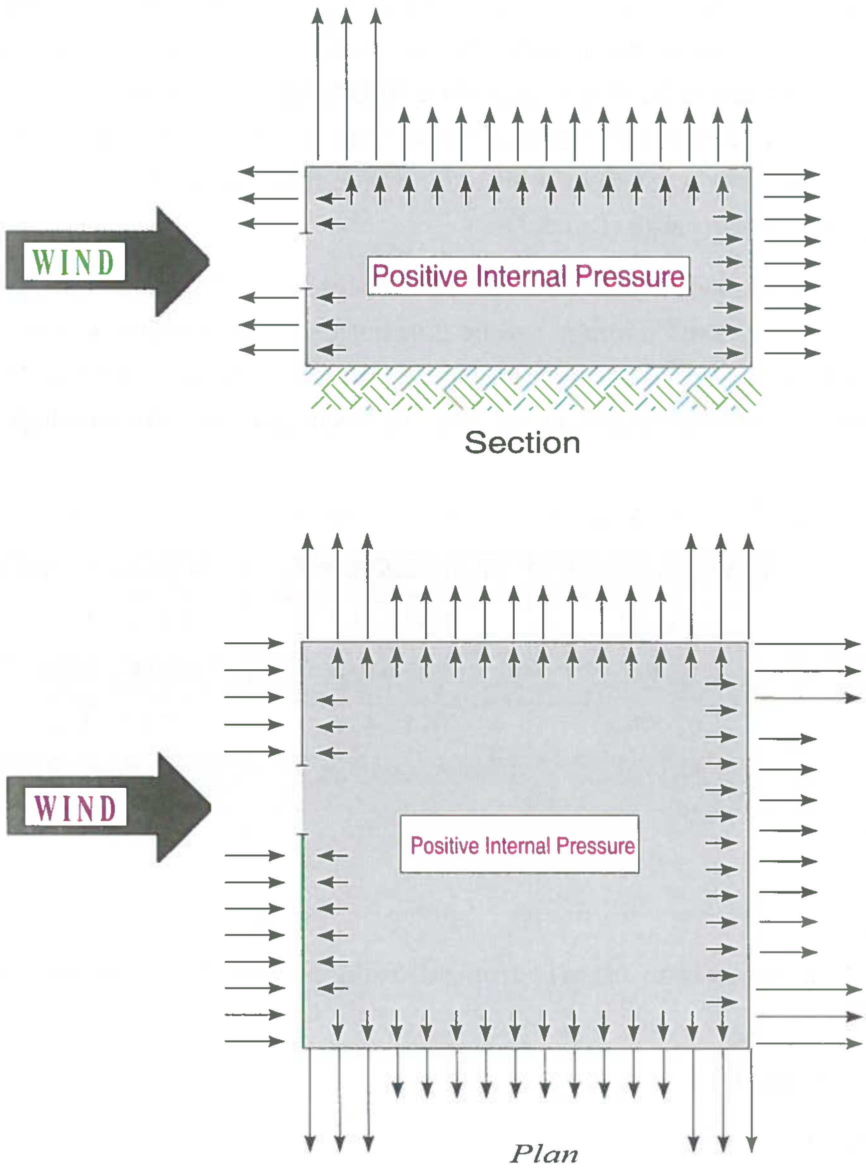
Warning Stage: Signal No. IV

Disaster Stage: Signal No. V, VI, VII and VIII, IX, and X

The most severe cyclones of recent memory since 1970 are November '70 [Wind speed 222 km/h (137.9 mph), lives lost 300000] and April '91 [Wind speed 235 km/h (146mph), lives lost- 145000] cyclones.

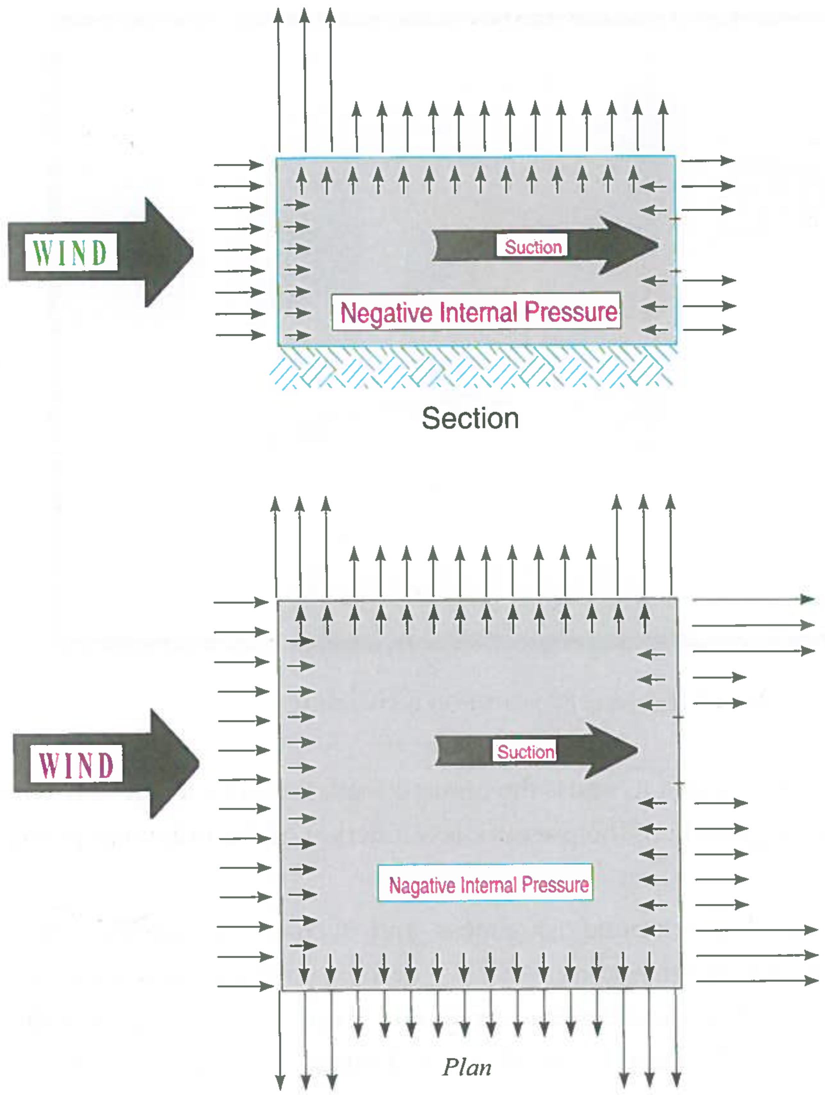
3.1.2 Wind / Building Interaction

When wind interacts with a building both positive and negative (i.e. suction) pressures occur simultaneously.



Note: Arrows indicate direction and magnitude of applied force

Fig. 3.3 Internal Pressure Condition when the Dominant Opening is in the Windward Wall



Note: Arrows indicate direction and magnitude of applied force

Fig. 3.4 Internal Pressure Condition when the Dominant Opening is in the Leeward Wall

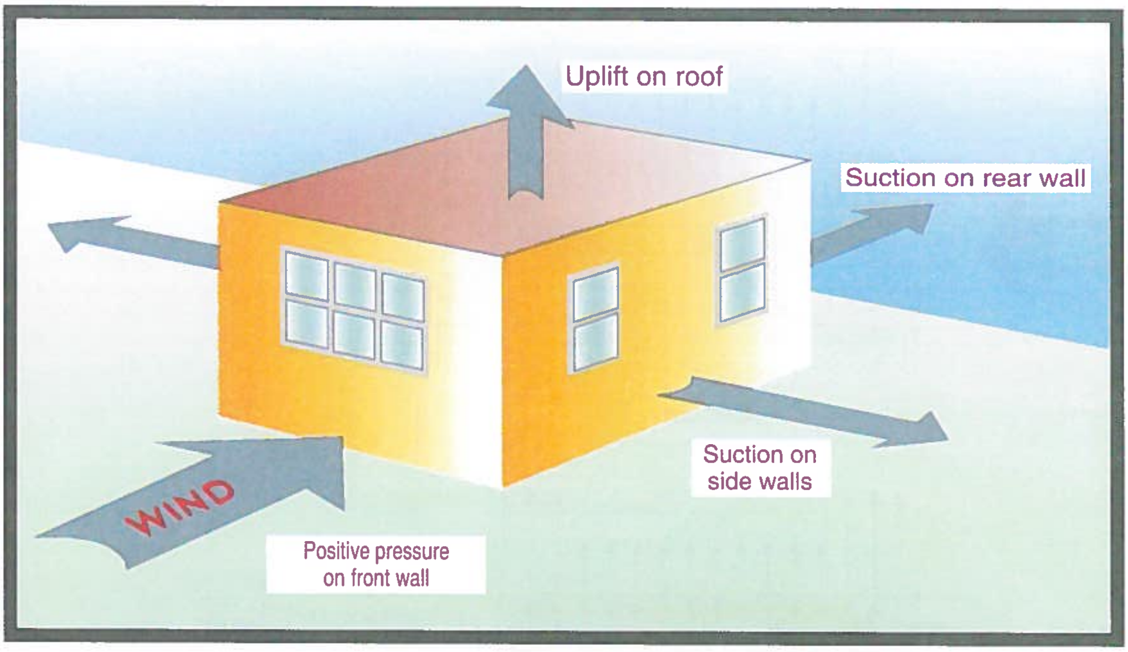


Fig. 3.5 Wind-Induced Pressure on a Building

A building must have sufficient strength to resist the applied loads in order to prevent wind-induced building failure. The magnitude of the pressure is a function of the following primary factors:

Exposure: The characteristic of the ground roughness and surface irregularities in the vicinity of a building influence the wind loading. ASCE 7 defines three exposure categories, Exposure B, C and D. Exposure B is the roughest terrain and Exposure D is the smoothest. Exposure B includes urban, suburban and wooded areas. Exposure C includes flat open terrain with scattered abstractions and areas adjacent to oceans in cyclone prone region.Exposure D includes areas adjacent to large water surfaces outside cyclone prone regions. Because of the wave condition generated by cyclone, areas adjacent to oceans in cyclone-(Exposure B, C, D of ASCE 7 is equivalent to Exposure A, B, C of BNBC) prone regions are considered to be Exposure C rather than smoother exposure D.The smoother the terrain, the greater the wind load. Therefore, buildings (with same basic wind speed) located in exposure D of ASCE7 (Exposure C of BNBC) would receive higher wind loads than those located in Exposure C.

Basic Wind Speed: ASCE 7 defined the basic wind speed as 3-second gust speed with a 50-year mean recurring interval (2 percent annual probability) measured at 10m (33ft) above grade in Exposure C (flat open terrain). If the building is located in Exposure B or D, rather than C, an adjustment for the actual exposure is made in the ASCE 7 calculation procedure. BNBC defined basic wind speed as 3-second gust speed at 10m (33 ft.) above ground in Exposure B having a return period of 50 years. Exposure B of BNBC is identical to Exposure C of ASCE7.

In determining wind pressure, the basic wind speed is doubled, therefore, as the velocity is increased, the pressures are exponentially increased. (Ref. Equation 10.25)

Topography: Abrupt change in topography, such as isolated hills, ridges & escarpments, cause wind speed up; therefore, a building located near a ridge would receive higher wind loads than a building located on a flat land. ASCE 7 provides procedure to account for topographic influence

BNBC adopted same topographic effects as that of ASCE7.

Building Height: Wind speed increases with height above the ground. Therefore, taller the building, the greater the speed and, hence, the greater the wind loads. ASCE 7 provided procedure to account for building height.

BNBC adopted same procedure as ASCE7.

Internal Pressure (i.e. building pressurization/depressurization): Wind striking a building can cause either an increase in pressure within the building (i.e. positive pressure) or it can cause a decrease in the pressure (i.e. negative pressure). Internal pressure changes occur because of the porosity of the building envelope. Porosity is caused by openings around doors and window frames, and by air infiltration through walls, that are not absolutely air tight. A door or window left in the open position also contributes to porosity.

Wind striking on external wall, exerts a positive pressure on the wall which forces air through openings and into the interior of the buildings (this is analogous to blowing up a balloon). At the same time the windward wall is receiving positive pressure, the side and rear walls are receiving negative (suction) pressure; therefore, air within the building is being pulled out at openings in these other walls. As a result, if the porosity of the windward wall is greater than the combined porosity of the side and rear walls, the interior of the building is pressurized. But, if the porosity of the windward wall is less than the combined porosity of the side and rear wall, the interior of the building is depressurized (this is analogous to letting air out of a balloon).

ASCE 7 provides a design procedure to assess the influence of internal pressure and it provides positive and negative internal pressure co-efficient for use in load calculations. Buildings that can be fully pressurized are referred to as partially enclosed buildings. Buildings that have limited internal pressurization capability are referred to as enclosed buildings. BNBC adopted same procedure as that of ASCE7.

3.1.3 Probability of Occurrence

Most buildings are designed for a 50-year mean recurrence interval wind event (2 percent annual probability). A 50-year storm would be expected to happen in about one every 50 years; however, a 50- year storm could occur more or less frequently. A 50- year storm might not occur within any 50-years interval but two 50 years storms could occur within 1-year.ASCE 7 as well as BNBC 15 requires buildings under Occupancy Category III and IV are to be designed for a 100 year mean recurrence interval wind event (1 percent annual probability). [Ref. Table 10.2 of this document.]

Other buildings that must be designed for a 100 year mean recurrence interval wind event include: 1) buildings that will be used for cyclone or other energy shelters, 2) office buildings designated for emergency preparedness, communication or emergency operation center, 3) buildings housing critical national defense functions, 4) buildings containing sufficient hazardous materials.

The importance factor is used to adjust the mean recurrence internal as well as level of structural integrity of the building to be consistent with building classification. For a 50-year interval, the importance factor is 1. For a 100-year interval, the importance factor is 1.15. Hence for a 100-year interval, the design loads are increased by 15%.

BNBC also suggested a 15 percent increase in design load for III, IV class of buildings for both cyclone and non-cyclone prone regions (Table 6.2.9 Part6 of BNBC 15).

3.2 FLOOD

Bangladesh is in the low-laying Ganges-Brahmaputra river delta, with many tributaries flowing into the Bay of Bengal. About 75% of Bangladesh is less than 10 m (33 feet) above sea level and 80% is flood plain. It is believed that about 10% of the land shall be under water, if the sea levels were to rise 1m (3.3feet).

3.2.1 Types of Flood in Bangladesh

In Bangladesh, the following types of flood normally occur; [Ref.3.1]

(1)Monsoon Flood from the major rivers generally rises slowly and the period of rise and fall may extend from 10 to 20 days or more. Spilling through distributaries and over the banks of the major rivers causes the most extensive damage, particularly when the three major rivers [Ganges, local name Padma or Podda, Brahmaputra (Jamuna also known as Yamuna) and Meghna] rise simultaneously.

(2)Flash Flood in the eastern and northern rivers is characterized by a sharp rise followed by a relatively rapid recession, often causing high flow velocities that damage crops and property.

(3)Local floods due to high localized rainfall of long duration in the monsoon season often generate water volume in excess of the local drainage capacity, causing localized floods.

(4)Floods due to storm surges in the coastal areas of Bangladesh generated by tropical cyclone, cause extensive damage to life and property. These cyclones predominate during the post monsoon (October-November) and pre-monsoon (April-June) period. Some of the major floods that devastated Bangladesh during recent years are floods of 1987, 1988, 1998, 2004.

The catastrophic flood of 1987 occurred throughout July and August. It affected 57300 sq.km. (22100sq.miles) of land which is about 40% of the total area of the country. The flood was estimated as a once in 30-70 year event. The flood of 1988, which was also of catastrophic consequences continued throughout August and September. The water inundated about 82000 sq.km (31635 sq. miles) of land. It is about 60% of the total area and its return period was estimated at 50-100.

In 1998, over 75% of the total area of the country was flooded. It was similar to the catastrophic flood of 1988 in terms of the extent of flooding.

The 2004 flood was very similar to the 1988 and 1998 floods with two third of the country under water.

3.3 CYCLONE INDUCED STORM SURGE

A tidal surge is the bulge of water that washes onto shore during a storm, measured as a difference between the height of storm tide and the predicted astronomical tide. It is driven by wind and inverse barometric effect of low atmospheric pressure and is influenced by waves, tides and uneven bathymetric and topographic surface. The coastal flooding triggered by cyclone is as destructive as wind but can be even more deadly and is by far the greatest threat to life and property along the coastline. Storm surge, wave and tides are the greatest contributors to coastal flooding.

The combination of storm surge and normal (astronomical) tide is known as storm tide.

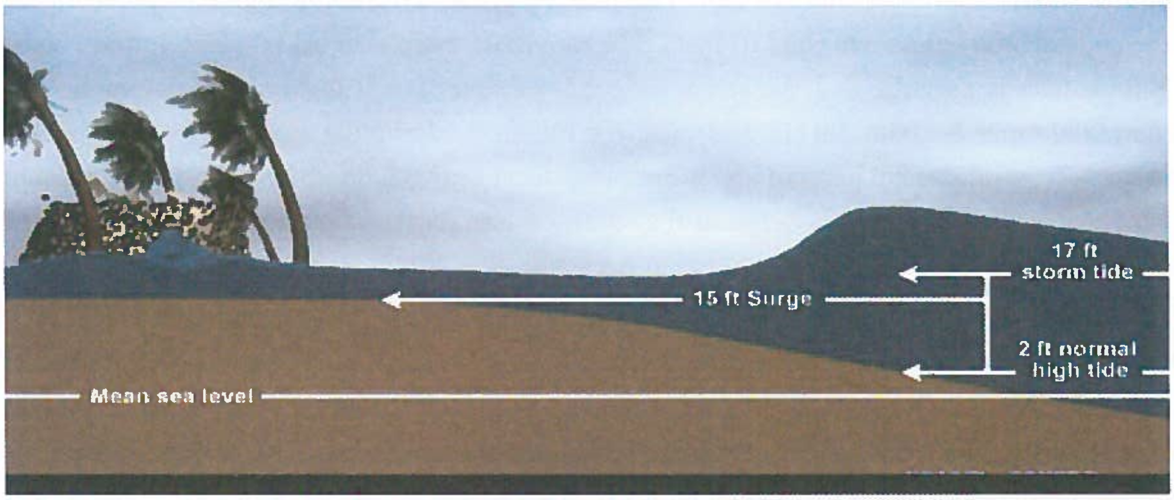


Figure 3.6 Storm Tide and Storm Surge (Ref. 3.8)

The rise in water level can cause extreme flooding in coastal areas particularly when storm surge coincides with normal high tide, resulting in storm tide as high as 6m or more in some cases.

Storm surge and coastline flooding have both vertical and horizontal dimensions. Storm surge can reach height of 12m near the center of Category5 hurricane and fan out across several hundred miles of coast line, gradually diminishing away from the hurricanes center. Coastal flooding can reach several kilometers from the coastline.

3.3.1 Factors Affecting Storm Surge

The maximum potential storm surge for a particular location depends on a number of different factors. Storm surge is a complex phenomenon because it is sensitive to the slightest change in storm intensity, forward speed, size (radius of maximum winds RMW), angle of approach to the coast and the shape and characteristics of coastal features such as bays and estuaries.

Other factors which can impact storm surge are the width and slope of the continental shelf. A shallow slope will potentially produce a greater tidal surge. A stiff continental shelf will cause the storm surge to be less intense. In addition, low lying coastal areas are often at risk of increased flood damage.

Some areas also act as a sort of funnel through which water can surge even higher. The Bay of Bengal is one location where water is literally funneled into the coast. In 1970, a storm surge killed at least 500000 people in the coastal area of Bangladesh.

The rainfall effect is experienced predominantly in estuaries. Cyclone may dump as much as 300 mm (12 inch) of rainfall in 24 hours over large areas, and higher rainfall densities in localized areas. As a result, watersheds can quickly surge water in the rivers that drain them. This can increase the water level near the head of tidal estuaries as storm driven water surging in from the ocean meet rainfall flowing from the estuary.

Cyclone induced storm surge is predominantly a concern of coastal area. The coastal area and offshore islands of Bangladesh are low lying and very flat. The height above mean sea level of the coastal area is less that 3m (10 feet). The range of astronomical tide along the coast of Bangladesh is so large that the storm induced sea level is apt to become very high. The normal tidal range is about 3m (10 feet) near the Indian border in the west and become higher in the east (central coastal part) to about 5m (16.5 feet) near the Sandwip Island at the mouth of Meghna Estuary. The storm surge in the south-eastern part is about 3.5 m to 4m (11.5-13 feet). If storm surges are superimposed on high tide, the situation becomes disastrous. The funneling coastline reduces the width of the storm induced waves and increases the height. (Ref. 3.4).

In northern Bay of Bengal, a unique combination of high tides, a funneling coastline configuration, the low flat coastal terrain and high population density have produced some of the highest mortality figures associated with storm surge.

3.3.2 Storm Surge Inundation Characteristics of Coastal Areas

Multipurpose Cyclone Shelter Programme (MCSP) [Ref.3.4] has identified surge inundation characteristics for cyclones of varying strength in the coastal areas of Bangladesh which has been shown in Table3.6.

Table 3.6 Relation between Wind Velocity, Storm Surge and Limit of Inundation

Wind velocity (km/h)	Storm surge height (m)	Wind velocity (mph)	Storm surge height (ft).	Limit of inundation from coastline (km)	Limit of inundation from coastline (miles)
85	1.5	52.80	4.92	1.0	0.62
115	2.5	71.43	8.2	1.0	0.62
135	3.0	83.90	9.84	1.5	0.93
165	3.5	102.50	11.48	2.0	1.24
195	4.8	121.12	5.74	4.0	2.48
225	6.0	140.00	19.68	4.5	2.8
235	6.5	146.00	21.32	5.0	3.11
260	7.8	161.50	25.58	5.5	3.42

Limit of inundation from the coast line depends on the slope and roughness of the terrain. Naturally for a flat coastline with plane surfaces the extent of inundation shall be more than a coastline having an upward slope with rough surface and obstructions with bushes, trees and other manmade objects.

Expected inundation depths in 13 coastal districts and 50 Upazilas (sub-districts) due to storm surge and tsunami have been shown in Table 12.1 to Table 12.26 of Chapter 12.

3.4 Tornado

The word '*tornado*' comes from Latin word '*tonare*' meaning "*to thunder*". It most likely reached its present form through a combination of Spanish words *tornado* and *tornar* (to turn or twist).

A tornado is a powerful column of winds spiraling around a centre of low atmospheric pressure. It looks like a large black funnel hanging down from a storm cloud. The narrow end will move over the earth, often encircled by a cloud of debris and dust, whipping back and forth like a tail (see Fig.3.7).

Most tornados have wind speeds less than 177 km/h (110 mph), are approximately 80 m across (250 feet), travel several km, lasts less than twenty minutes before dissipating. The most extreme tornados can attain wind speed of more than 480 km/h (300 mph), stretch more than 3 km across and stay on the ground for more than 100 km. Because of the earth's unique weather system, tornados rotate counterclockwise in the Northern Hemisphere and move eastward. They rotate clockwise in the Southern Hemisphere. Tornados also often come with hailstorm.

There are several different scales for rating the strength of tornados. The *Fujita scale* rates tornado by damage caused and has been replaced in some countries by the updated *Enhanced* Fujita *Scale*. The six step scale ranges from F0 (light damage) to F5 (incredible damage). An

F0 or EF0 tornado, the weakest category damages trees but not substantial structure. An F5 or EF5 tornado, the strongest category, rips buildings off their foundation and can deform large sky scrapper. Tornado paths are typically less than 300 meters (1000 ft.). However widths of approximately 1.6 km (1 mile) have been reported.

Tornados are more frequent in United States, but occasionally occur in other countries. Bangladesh about the size of the US state of Wisconsin with a population of about 160 million is the only other country of the world that is prone to strong and violent tornado on an annual basis.

The deadliest tornado in world history was the Doulatpur-Saturia tornado in Bangladesh on 26th April 1989, which killed approximately 1200 people. It was a mile wide and cut a swath of destruction 80km (50 miles) long. The injuries were estimated to be around 12000. The tornado completely destroyed virtually every structure it touched.

Out of the 10 deadliest tornados in the world history, 6 struck Bangladesh. The highest wind speed ever measured in a tornado, which is also the highest wind speed ever recorded on the planet is 484 ± 32 km/h (301 ± 20 mph) in the F5 Bridge Creek- Moore Oklahoma tornado which killed 36 people. Though the reading was taken about 30m (100ft) above ground, this is the testament of the power of the strongest tornado. (Ref. 3.1).

3.4.1 Tornado as "Extraordinary Event"

Tornado falls under the category of 'Extraordinary events' like fire, explosion of volatile liquids or natural gas, sabotage, vehicular impact, subsidence (not settlement) of soil etc. Extraordinary events like tornado arise from extraordinary environmental conditions that traditionally are not considered explicitly in design of ordinary buildings or structures. Such events are characterized by a low probability of occurrence and usually of a short duration. Few buildings are even exposed to such events and statistical data to describe their magnitude and structural effects are rarely available.

Figure 3.7 Photographs of Tornado (Ref. 3.1)

ASCE7 considered probability of occurrence of extraordinary events as 10^{-6} through 10^{-4} per year or greater. (Section C2.5 of ASCE7). It also suggested identifying these events to take measures so that performance of key load bearing structural systems and components are sufficient to withstand these events.

Nothing has been discussed in BNBC15 about tornado.

3.5 TSUNAMI (Soo-NAH-mee)

The term ***tsunami*** comes from the Japanese 津波, composed of the two kanji 津 (*tsu*) meaning "harbour" and 波 (*nami*), meaning "wave". (Ref.3.1)

Tsunami is sometimes referred to as tidal waves. In recent years, this term has fallen out of favour, especially in the scientific community, because tsunami actually has nothing to do with tide. The once popular term derives from their most common appearance, which is that of an extraordinary high tidal bore.

Figure 3.8 Photograph of Tsunami

Figure 3.9 Photograph of Tsunami (Samoan Island)

3.5.1 Generation Mechanism of Tsunami

The principle generation mechanism (cause) of a tsunami is the displacement of a substantial volume of water or perturbation of sea. This displacement of water is usually attributed to earthquakes, landslides, volcanic eruptions, and glacier caving or more rarely by meteorites and nuclear test. The waves formed in this way are then sustained by gravity. Tides do not play any part in the generation of tsunami.

3.5.1.1 Tsunami Generated by Seismicity

Tsunami can be generated when the sea floor abruptly deforms and vertically displaces overlying water. Tectonic earthquakes are a particular kind of earthquake that are associated with earth's crystal deformation; when these earthquakes occur beneath the sea, the water above the deformed area is displaced from its equilibrium position. More specifically, a tsunami can be generated when thrust faults associated with convergent or destructive plate boundaries move abruptly, resulting in water displacement, owing to the vertical component of movement involved.

Tsunami has small amplitude (wave height) offshore and a very long wave length (often hundreds of kilometers long, whereas normal ocean waves have a wave length of 30 or 40 meters), which is why they generally pass unnoticed at sea, forming only a slight swell, usually about 300 mm (12inch) above the normal sea surface. They grow in height when they reach the shallow water.

A tsunami can occur in any tidal state and even at low tide can still inundate coastal areas.

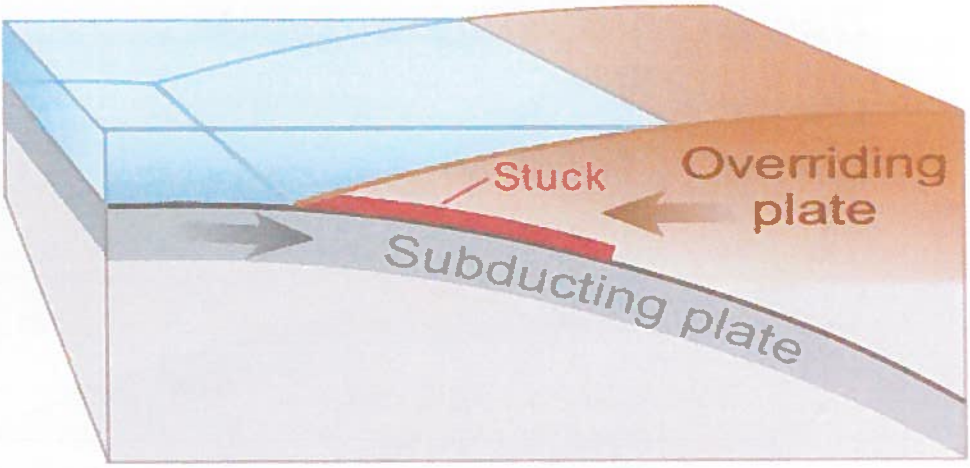


Figure 3.10 Tectonic Plate Boundary before Earthquake (Ref. 3.1)

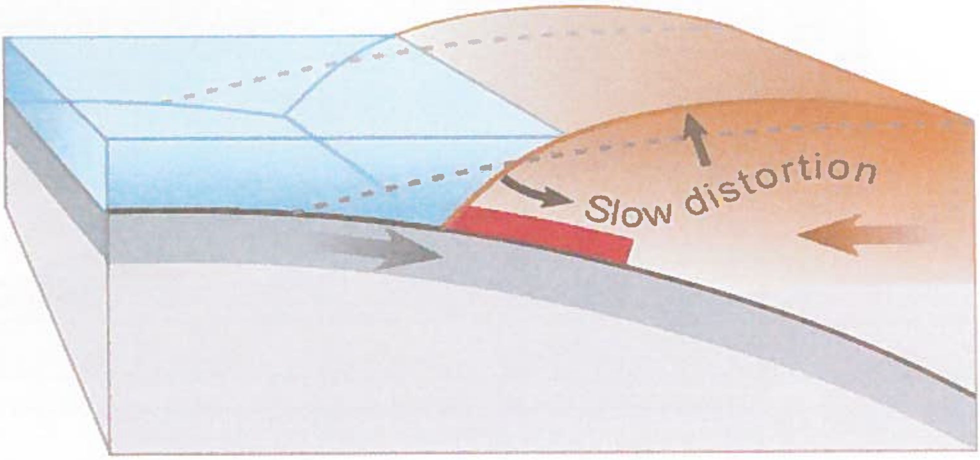


Figure 3.11 Overriding Plate Bulges under Strain, Causing Tectonic Uplift (Ref. 3.1)

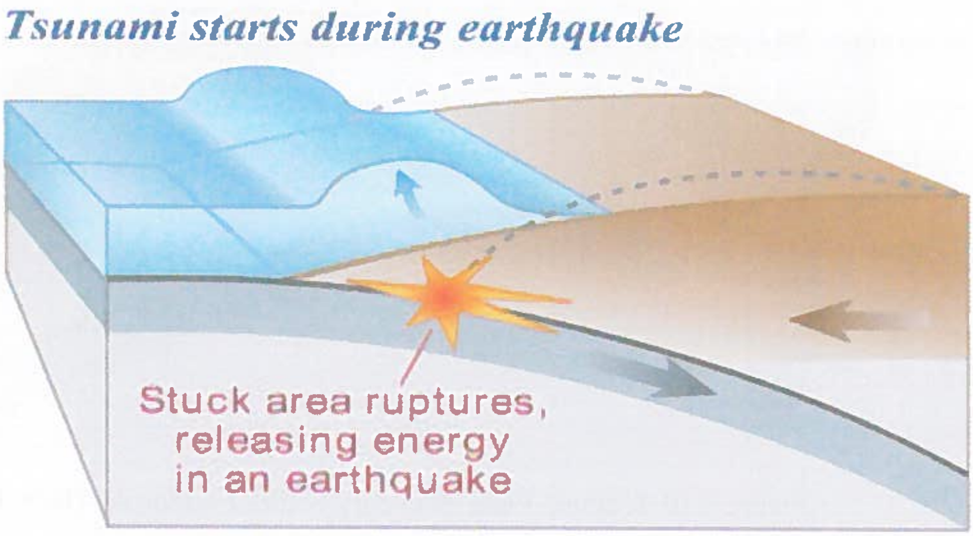


Figure 3.12 Plate Slips, Causing Subsidence and Releasing Energy into Water (Ref. 3.1)

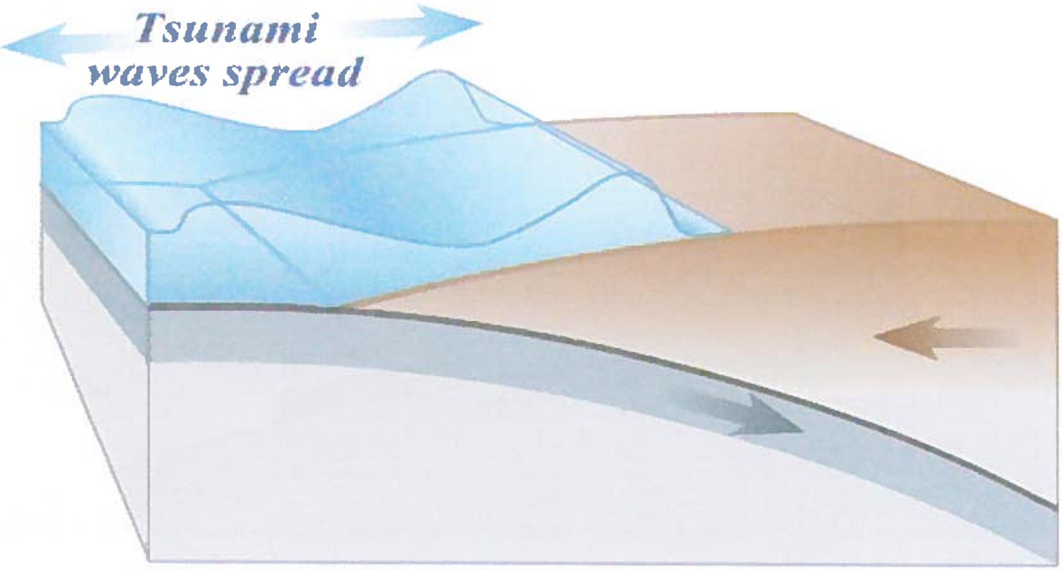


Figure3.13 Energy Released Produces Tsunami Waves (Ref. 3.1)

3.5.1.2 Tsunami Generated by Landslide

In the 1950s, it was discovered that larger tsunamis than previously believed possible could be caused by giant landslides. Underwater landslides that generate tsunamis are called sciorrucks. These phenomena rapidly displace large water volumes, as energy from falling debris or expansion transfers at a rate faster than the water can absorb. Their existence was confirmed in 1958 when a giant landslide in Lituya Bay, Alaska caused the highest wave ever recorded which had a height of 524m (over 1700 ft.). The wave did not travel far as it struck land almost immediately. Two people fishing in the bay killed but another boat amazingly managed to ride the wave. Scientists discovered that extremely large landslides from volcanic island collapse can generate mega tsunamis that can cross oceans.

3.5.2 Characteristics of Tsunami

Tsunamis cause damage by two mechanisms: the smashing force of a wall of water, traveling at high speed and the devastative power of a large volume of water draining off the land and carrying all with it.

While everyday wind waves have a wave length (from crest to crest) of about 100m(330ft) and a height of roughly 2m (6.6 ft.), tsunami in the deep ocean has a wave length of about 200km (120miles). Such a wave travels at well over 800km/hr. (500mph) but owing to the enormous wave length the wave oscillation at any given point takes 20 to 30 minutes to complete a cycle and has amplitude of only about 300mm (12 inch) to 1m (3.3ft). This makes tsunamis difficult to detect over deep water. Ships rarely notice their passage.

As the tsunami approaches the coast and waters become shallow, wave shoaling compresses wave and its velocity slows below 80km/hr. (50mph). Its wave length diminishes to less than 20km (12miles) and its amplitude grows enormously. Since the wave still has the same long period, the tsunami may take minutes to reach full height. Except for the very largest tsunami the approaching wave does not break, but rather looks like a fast- moving tidal bore.

When the tsunami wave peak reaches the shore, the resulting temporary rise in sea level is termed *run up*. A large tsunami may feature multiple waves arriving over a period of hours with significant time between the wave crest.

About 80% of tsunamis occur in Pacific Ocean but they are possible wherever there are large bodies of waters including lakes.
Possibility of damage by tsunami in Bangladesh is less compared to other parts of the world

Before the arrival of the wave crest, the water along the coast line recedes dramatically, exposing normally submerged areas. This is called **drawback**. The *drawback* occurs because the water propagates outward with the trough of the wave at its front. *Drawback* occurs before the wave arrives at an interval equal to half of the wave's period. *Drawback* can exceed hundreds of meters and people unaware of the danger sometimes remains near the shore to satisfy curiosity or to collect fish from the exposed sea bed.

3.5.3 Magnitude and Intensity Scales of Tsunami (Ref. 3.1)

As with earthquake several attempts have been made to setup scales of tsunami intensity or magnitude to allow comparison between different events.

Intensity Scale: The first scales used routinely to measure the intensity were the *Sieberg-Ambraseys Scale used in the Mediterranean Sea and* the *Imamura-Iida Intensity Scale* used in the Pacific Ocean. The later scale was modified by Soloviev who calculated Tsunami Intensity I according to the equation:

$$I = 1/2 + \log_2 H_{av} \qquad \text{(Eq.3.6)}$$

where:

H_{av} is the average wave height along the nearest coast.

This scale known as the *Soloviev- Imamura Tsunami Intensity Scale* is used in the global tsunami catalogues.

Magnitude Scale: The first scale that genuinely calculated magnitude for a tsunami, rather than intensity at a particular location was the ML scale proposed by Murti and Loomis based on the potential energy. Difficulty in calculating potential energy of the tsunami means that the scale is seldom used. Prof. Abe introduced the *tsunami magnitude scale* M_t calculated from the equation:

$$M_t = a \log h + b \log R + D \qquad \text{(Eq. 3.7)}$$

Where h is the maximum tsunami-wave amplitude (in m) measured by a tide gauge at a distance R from the epicenter, a, b and D are constants used to make the M_t scale as closely as possible with the moment magnitude scale. Prof Abe suggested $a = 1$, $b = 1$ and D = 5.8.

3.5.4 Warning and Prediction of Tsunami: Drawbacks can serve as a brief warning. People who observed drawbacks (Many survivors report an accompanying sucking sound), can survive only if they immediately run for high ground or seek the upper floors of a nearby buildings. A tsunami cannot be precisely predicted, even if the magnitude and location of the earthquake is known. Geologists, oceanographers, and seismologists analyze each earthquake and based on many factors may or may not issue a tsunami warning. However there are some warning signs of impending tsunami and automated systems can provide immediate warnings after an earthquake in time to save lives. Regions with high tsunami risks typically use tsunami warning system to warn the population before the wave reaches the land.

The Pacific Tsunami Warning System is based in Honolulu, Hawaii. A sufficiently large earthquake magnitude and other information trigger a tsunami warning. Computers assist in analyzing the tsunami risk of every earthquake that occurs in Pacific Ocean and the adjoining land masses.

Computer models can predict tsunami arrivals usually within minutes of arrival time. Bottom pressure sensors relay information in real time. Based on these pressure readings and other seismic information and the seafloor's shape (bathymetry) and coastal topography, the model estimates the amplitude and surge height of the approaching tsunami.

Some zoologists hypothesize that some animal species have the ability to sense subsonic Rayleigh waves from an earthquake or tsunami etc. If correct, monitoring their behavior could provide advance warning of earthquakes, tsunamis etc. The phenomenon was also noted by media sources in Sri Lanka in 2004 Indian Ocean earthquake. It is possible that certain animals (e.g. elephant) may have heard the sounds of the tsunami as it approached the coast. The elephant's reaction was to move away from approaching noise. By contrast, some humans went to the shore to investigate and many drowned as a result.

Though Bangladesh keeps on facing almost all the calamities of nature, fortunately the country is yet to face the devastation of tsunami and possible effect of tsunami is less compared to tidal surge.

3.6 LIGHTNING AND THUNDERSTROM

Apart from the natural hazards discussed earlier there are two other natural hazards that can damage a building structure. Lightning and thunderstorms are comparatively less hazardous than the ones discussed in Section 3.1

Lightning is a massive *electrostatic* discharge between electrically charged regions within clouds, or between a cloud and the Earth's surface. The charged regions within the atmosphere temporarily equalize themselves through a lightning **flash**, commonly referred to as a *strike* if it hits an object on the ground. There are three primary types; from a cloud to itself (intra-cloud or IC); from one cloud to another cloud (CC) and finally between a cloud and the ground (CG). Although lightning is always accompanied by the sound of thunder, distant lightning may be seen but be too far away for the thunder to be heard.

Lightning occurs approximately 40–50 times a second worldwide, resulting in nearly 1.4 billion flashes per year.

Many factors affect the frequency, distribution, strength, and physical properties of a "typical" lightning flash to a particular region of the world. These factors include ground elevation, latitude, prevailing wind currents, relative humidity, proximity to warm and cold bodies of water, etc. To a certain degree, the ratio between IC, CC and CG lightning may also vary by season in middle latitudes.

Because human beings are terrestrial and most of their possessions are on the Earth, where lightning can damage or destroy them, CG lightning is the most studied and best understood of the three types, even though IC and CC are more common. Lightning's relative unpredictability limits a complete explanation of how or why it occurs, even after hundreds of years of scientific investigation. A typical cloud to ground lightning flash culminates in the formation of an electrically conducting plasma channel through the air in excess of 5 km (3 mi) tall, from within the cloud to the ground's surface. The actual **discharge** is the final stage of a very complex process. A typical thunderstorm has three or more *strikes* to the Earth per minute at its peak.

Lightning primarily occurs when warm air is mixed with colder air masses resulting in atmospheric disturbances necessary for polarizing the atmosphere. However, it can also occur during dust storms, forest fires, tornadoes, volcanic eruptions, and even in the cold of winter, where the lightning is known as thunder snow. Hurricanes typically generate some lightning, mainly in the rain bands as much as 160 km (100 mi) from the center.

The science of lightning is called fulminology. The fear of lightning is called astraphobia.

Objects struck by lightning experience heat and magnetic forces of great magnitude. The heat created by lightning currents traveling through a tree may vaporize its sap, causing a steam explosion that bursts the trunk. As lightning travels through sandy soil, the soil surrounding the plasma channel may melt, forming tubular structures called fulgurites. Humans or animals struck by lightning may suffer severe injury or even death due to internal organ and nervous system damage. Buildings or tall structures hit by lightning may be damaged as the lightning seeks uninterrupted paths to ground. By safely conducting a lightning strike to ground, a lightning protection system can greatly reduce the probability of severe property damage.

Figure 3.14 Cloud- to-ground lightning bolts

Figure 3.15 Brilliant White-Blue flash of Lightning

A **thunderstorm**, also known as an **electrical storm**, a **lightning storm**, **thundershower** or simply a **storm**, is a form of turbulent weather characterized by the presence of lightning and its acoustic effect on the Earth's atmosphere known as thunder. The meteorologically assigned cloud type associated with the thunderstorm is the cumulonimbus. Thunderstorms are usually accompanied by strong winds, heavy rain and sometimes hail, or no precipitation at all. Those that cause hail to fall are called **hailstorms**. Thunderstorms may line up in a series of rain bands, known as a squall line. Strong or severe thunderstorms may rotate, known as super cells. While most thunderstorms move with the mean wind flow through the layer of the troposphere that they occupy, vertical wind shear causes a deviation in their course at a right angle to the wind shear direction.

Figure 3.16 Photograph of Thunderstorm

Thunderstorms result from the rapid upward movement of warm, moist air. They can occur inside warm, moist air masses and at fronts. As the warm, moist air moves upward, it cools, condenses, and forms cumulonimbus clouds that can reach heights of over 20 km (12.45 miles). As the rising air reaches its dew point, water droplets and ice form and begin falling the long distance through the clouds towards the Earth's surface. As the droplets fall, they collide with other droplets and become larger. The falling droplets create a downdraft of air that spreads out at the Earth's surface and causes strong winds associated commonly with thunderstorms.

Thunderstorms can generally form and develop in any particular geographic location, perhaps most frequently within areas located at mid-latitude when warm moist air collides with cooler air. Thunderstorms are responsible for the development and formation of many severe weather phenomena. Thunderstorms, and the phenomena that occur along with them, pose great hazards to populations and landscapes. Damage that results from thunderstorms is mainly inflicted by downburst winds, large hailstones, and flash flooding caused by heavy precipitation.

Stronger thunderstorm cells are capable producing tornadoes and waterspouts.

The effect of thunderstorm on RC building is insignificant. Further discussion on the topic has not been made in this manual.

Figure 3.17 Cloud-to-ground lightning strikes during a thunderstorm

Cloud-to-ground lightning frequently occurs within the phenomena of thunderstorms and have numerous hazards towards landscapes and populations infrastructure including tall buildings. One of the more significant hazards lightning can pose is the wildfires they are capable of igniting. Under a regime of low precipitation (LP) thunderstorms, where little precipitation is present, rainfall cannot prevent fires from starting when vegetation is dry as lightning produces a concentrated amount of extreme heat. Wildfires can devastate vegetation and the biodiversity of an ecosystem. Wildfires that occur close to urban environments can inflict damages upon infrastructures, buildings, crops, and provide risks to explosions, should the flames come in contact with gas pipes or tanks. Direct damage caused by lightning strikes occurs on occasion.

Mitigation measures for lightning has been discussed in Chapter14

3.7 LANDSLIDE

The term landslide describes downhill earth movements that can move slowly and cause damage gradually, or move rapidly, destroying property and taking lives suddenly and unexpectedly. Most landslides are caused by natural forces or events, such as heavy rain and snowmelt, shaking due to earthquakes, volcanic eruptions and gravity. Landslides are typically associated wet periods of heavy rainfall or rapid snowmelt and tend to worsen the effects of flooding. Landslides can also be referred to as mudslides, debris flows, mudflows or debris avalanches.

In Bangladesh many homeless people live at the foot of the hills in the south-eastern hilly districts of the country, despite warning from the authorities about the danger of landslides. During past few years many people were buried alive due to huge waves of mud and debris during incessant monsoon rain. Further discussion on this topic has not been made in this document as this hazard is not directly related to reinforced concrete buildings.

CHAPTER 4

BUILDING ELEMENTS

4.0 BUILDING ELEMENTS

An existing building contains three major elements:

- Structural elements
- Non-structural elements (Building envelope)
- Building contents

4.1 STRUCTURAL ELEMENTS

Structural elements are the part of the building that is designed to carry the weight of the building (dead load), its contents and people (live load) and the impact of any force of nature like earthquake, wind, wind induced storm surge etc. (dynamic load).

Basic structural elements of a RCC building are foundation, through which total load of the building is transferred to ground, column which carries the load of the building from beam/slab and transfers it to foundation, beam which receives the slab load, transfers to column, slab which carries its own weight and weight of partitions & other loads and transfers it to beam and shear walls which is meant to resist horizontal forces of nature.

4.2 NON-STRUCTURAL ELEMENTS

The non-structural building elements include stairways, doors, windows, partitions, glass, cornices, false ceiling, facades, pipes, wall claddings, lighting fixture etc.

4.3 BUILDING CONTENTS

Building contents include all those items that users bring into a building; furniture, appliances, electronics, equipments, air-conditioners, stored items and so forth.

Vulnerability assessment of non-structural elements should be carried out after the assessment of structural vulnerability has been done, since the results of structural elements are very valuable for judging the susceptibility to damage of non-structural elements including building contents.

CHAPTER 5

POTENTIAL DAMAGES DUE TO NON-SEISMIC FORCES

5.1 WIND (CYCLONE)

Buildings that experience design level events and events that are somewhat in excess of design level should experience little, if any damage; however, design level storms frequently cause extensive damage to building envelope, structural damages occur also, but less often. Damage experienced with design level events is typically associated with inadequate design, application or material deteriorations. The exceptions are wind driven water infiltration and windborne debris (missile) damage.

The following are some of the major causes of damage due to wind:

- Low quality of construction
- Inappropriate techniques and utilization of low resistance materials
- Failure of doors and windows due to wind pressure
- Excessive openings in the building envelope which may produce wind pressure twice as great as those that would result if the building remains enclosed
- Location of the building
- General roughness of the surrounding terrain
- Height of the building above ground
- Height of the building more than surrounding structures and vegetation
- Configuration of the building
- Surrounding topography

In cyclone prone region, significant building damage is expected even during design level cyclone events.

Structural damage including collapse of structural elements or collapse of the entire building or major portion thereof, along with damage to the building envelope is the number one type of damage during strong and violent cyclone.

Even modest wind speed can drive rain water into the building exterior wall as well as inside the building. Unless adequate provisions are taken to account for water infiltration, water may damage the wall as well as contents of the building.

When heavy rains accompany high winds (thunderstorm, tropical cyclones), it can cause wind driven water infiltration problems (the magnitude of the problem increases with the wind speed). Leakage can occur between the door and the frame and frame and wall and water can be driven between the threshold and the door. Leakage can also occur at the glazing/frame interface, at the frame itself or between frame & wall.

5.2 FLOOD

A building may face the following hazards due to flood: (Ref.5.2)

- Lateral hydrostatic and buoyant forces caused by standing or slow moving water above the surface of the ground
- Hydrodynamic forces from the moderate-velocity flow or high-velocity flow of water as well as wave action
- Impact load caused by floating debris
- Erosion and scour caused by the removal of soil and loose materials by moving water as it flow over land
- Site specific soil or geotechnical considerations such as soil pressure, bearing capacity, scour potential
- Contamination caused by dissolved chemicals, silt, suspended solids and other contaminants contained in flood-waters
- In coastal areas, breaking waves with floating debris can cause extensive physical damage of the building.

Due to above flood related hazards the building shall face the following problems:

1. **Settlement of Foundation**: Foundation is not able to support the superstructure load because of reduction in load bearing capacity of foundation soil due to rise in water table. This may cause severe crack in both structural and non-structural elements and in some cases, part of the building settles down.
2. **Scouring of wall base**: Fast moving water erodes the foundation of the wall or column. This weakens the structures, resulting in settlement, crack of structure or non-structural element and may cause collapse of part of the building.
3. **Debris Impact**: Impact of water borne debris may damage walls, other structural members.
4. **Impact of storm surge wave**: If the ground floor of the building is not constructed on stilt, sudden impact of fast moving water induced by storm surge may either damage part of the wall or even the complete building may collapse. Unlike flood water which rises slowly, impact of cyclone induced storm surge may be devastating.

5.3 CYCLONE INDUCED STORM SURGE

The combination of storm surge, battering waves and high winds can be deadly. Bangladesh coastline including islands are densely populated and many regions lie less than 3m (10 ft) above mean sea level.

Adding to the destructive power of surge, battering waves may increase damage to building directly along the coast. Water weights extended by pounding waves, can demolish any structure not specifically designed to withstand such forces. The two elements work together to increase impact on land because the surge makes it possible for waves to extend inland. Additionally, currents created by tides combine with the waves to severely erode beaches and coastal highways. Buildings that survive cyclone winds can be damaged if their foundations are undermined and weakened by erosions. In estuaries and bayous, salt water intrusions endangers the public health, kills plants & vegetation & make the agricultural fields unsuitable for further cultivation.

Impact of water borne debris and logs may seriously damage a building or structure in their path.

Influx of sea animals like deadly snakes, alligators in the main land is another potential danger of storm surge.

5.4 TSUNAMI

Potential damage due to tsunami is somewhat identical to that of storm surge. Cyclone normally builds up over a period of time and may take 2-3 days to reach the peak wind velocity and may continue another few hours. As such flood water inundates flood plains slowly and gradually with the increase in wind velocity. As such hydrostatic force is more prominent than hydrodynamic force in case of storm surge. People affected by storm surge get certain period of time to prepare themselves against the onslaught of storm surge induced by cyclone. Of course they need to face the onslaught of cyclone as well.

Difficulty with tsunami is that it cannot be precisely predicted, even if the magnitude and location of an earthquake is known (Ref.3.1). Smashing force of a wall of water travelling at high speed (with the same depth of water the velocity of water of tsunami is much higher than the velocity of storm surge) destroys everything in its path. A series of *wave trains* with periods ranging from minutes to hours arrive when tsunami strikes. Wave heights as high as 10 meters (33ft.) can be generated by a large event. A wave of only 0.9m (3 ft.) high, 3.2 km. (2 miles) long and 1600km. (1000 miles) wide contains 10 billion tons of water. A 3.0 meter (10.0 ft.) wave shall produce water velocity of approximately 20m/s (65ft/s). Unlike tidal surge, the destructive power of large volume of water draining within short period of time may also be substantial.

5.5 TORNADO

Because of extreme high pressure and missile loads that tornados can induce, specially building envelope may face serious damage due to tornado. Except for window brakeage, well designed, constructed and maintained building should experience little, if any damage from weak tornados (F0 and F1). Most buildings experience significant building envelope damage and damage to interior partitions and ceilings if they are in the path of a strong or violent tornado (F4 and F5).

As wind speed rapidly decreases with increase distance from the centre of tornado, a building on the periphery of a strong or violent tornado could be subjected to moderate to high wind speed depending upon the distance from the centre of the tornado.

CHAPTER 6

VULNERABILITY ASSESSMENT GUIDELINES (CYCLONE)

6.1 SCOPE

This part of the document covers the guidelines for survey and inspection of the building for assessment of degree of vulnerability against cyclone.

6.2 BASIC PRINCIPLE

Standard proforma prepared for survey and inspection shall establish building typology, configuration, along with the weaknesses in the structural system and elements, inadequacy in the material strength and method of construction, so that an appropriate cost effective scheme of retrofitting may be designed for improved cyclone resistance and thus decreasing vulnerability to any future non-seismic natural disaster like cyclone.

6.3 GUIDELINES FOR FILLING STANDARD PROFORMA FOR FIELD SURVEYOF BUILDING

The proforma has been prepared on the basis of a questionnaire presented in checklist form through which detailed information can be gathered regarding building configuration, structural system, member sizes, architectural details, construction material and building environment.

The proforma contains basically two types of questions. In the first case, multiple options are given and the surveyors have to provide a tick (√) on the respective box.

In the other set of questions, the answer is to be provided in definite quantitative terms on the basis of actual measurement or information at site like member size and location of critical sections etc. in the box provided.

The surveyor shall use extra sheet of paper if the space in the proforma is not enough.

6.4 EDUCATIONAL BACKGROUND OF PERSON FILLING PROFORMA

As vulnerability assessment shall be done based on the information of the filled-up proforma, it is very important that the person filling the proforma shall have sound engineering knowledge. The following educational background is suggested for the persons filling the proforma.

PROFORMA A:Graduate Engineer/Diploma Engineer with 5 years' experience
PROFORMA B:Graduate Engineer with 3 years' experience
PROFORMA C:Structural Engineer having experience in Wind Load analysis of a building.

6.5 STANDARD PROFORMA FOR VERNERABILITY ASSESSMENT OF BUILDING

Proforma A covers the statistical information of the building for the purpose of characterization of the building typology. It also covers information about structural system, member sizes, connection details for examining the cyclone resistance of the existing building and to retrofit them, if needed for improved performance against cyclone.

Proforma B covers summary of information about building envelope collected from Proforma A for examining the cyclone resistance of building envelope as per procedure depicted in Chapter 7.

Proforma C provides information collected from Proforma A about structural system and its components for performing structural strength analysis as per requirements of Chapter 8 and Chapter 10.

6.5.1 PROFORMA A: Field Survey of proposed Building

1.0 General Information

1.1 Name of the building: [ ]

1.2 GIS location, if any: [ ]

1.3 ID number, if any: [ ]

1.4 Geographic location: [ ]

1.5 Type of use: [ ]

1.6 Year of construction: [ ]

1.7 Surveyor's name with designation:

[ ]

1.8 Surveyor's comments (Add additional sheets, if necessary)

1.9 Survey date: [ ]

2.0 Building Configuration

2.1 Plan shape (Please tick √ one)

Square	Rectangle	L	Tee	Other

2.2 Width of the building (m / ft): [ ]

2.3 Length of the building (m / ft): [ ]

2.4 Minimum width of the building (m / ft):

2.5 Height of building including parapet (m / ft):

2.6 Number of floors:

2.7 Height of each floor (m / ft):

GF	1st	2nd	3rd	4th	5th	6th	7th	8th	9th

2.8 Area in each floor (m^2 / ft^2):

GF	1st	2nd	3rd	4th	5th	6th	7th	8th	9th

2.9 Height of plinth above GL (m /ft):

2.10 Ground slope around the building (please tick √ one):

Flat	Gentle slope	Steep

2.11 Have verandahs? (please tick √ one):

Yes	No

If Yes,

2.12 Size of front verandah (m/ft):

L	B

2.13 Size of back verandah (m / ft):

L	B

2.14 Size of side verandah (m / ft):

L	B

2.15 Is the shape of the building geometrically regular or irregular? (please tick √ one)

Regular	Irregular

2.16 Whether ground floor is open, partially open or closed? (Please tick √ one)

100% Open	100% Closed	% Open

3.0 Building Envelope

3.1 Roof type (please tick √ one)

RCC flat roof with parapet	RCC flat roof without parapet	Any other type (Pl. mention)

3.2 Type of roof covering (please tick √ one)

Lime terracing	Ferro cement layer	Roof tiles	Precast concrete tiles	Any other type

3.3 External walls (please tick √ one)

250mm solid brick masonry wall	Hollow concrete block	Solid concrete block	Any other

3.4 Opening in the front wall (m^2 / ft^2): [ ]

3.5 Percentage opening of the total front wall area %: [ ]

3.6 Opening in the rear wall (m^2 / ft^2): [ ]

3.7 Percentage opening of the total rear wall area %: [ ]

3.8 Opening in the side1 wall (m^2 / ft^2):

3.9 Percentage opening of the total side1 wall area %:

3.10 Opening in the side 2 wall (m^2 / ft^2):

3.11 Percentage opening of the total side 2 wall area %:

3.12 Type of glazing with thickness: mm / in.:

3.13 Window assembling (please tick √ one)

Steel	Alluminium	Timber	Any other

3.14 External door frame (please tick √ one):

Wood	Steel	Alluminium	PVC	Any other

3.15 External door leaf (please tick √ one):

Solid Wood	Metal panels	PVC	Hollow core flush door

3.16 Internal partitions (please tick √ one):

125 mm brick masonry	Aluminum frame with glass	Any other

4.0 Structural details

4.1 Building code used for design (please tick √ one):

BNBC	ASCE Standard/ UBC/IBC/ ACI	British Standard	No Code/Unknown

4.2 Type of Main Wind Force Resisting System (MWFRS) (please tick √ one):

RCC Column-Beam	

RCC column-beam with shear wall	
RCC column-flat plate with/without edge beam	
RCC column-flat plate with/without edge beam & shear wall	
RCC column-flat slab with column capital	
RCC column-flat slab with column capital & shear wall	
Any other type (please mention the type)	

4.3 Simple diaphragm building [(1)] (please tick √ one) Yes

No.	

4.4 Construction materials used for RCC work (please tick √ one):

a) Coarse aggregate: (please tick √ one)

Picked jhama brick chips	Stone chips	Shingles

b) Fine Aggregate [(2)]: (please tick √ one)

Sylhet sand	Local sand	Mixture of Sylhet& local sand

[(1)]Whether there is any structural separation or not?[(2)] Please mention FM ,if possible

4.5 Dimensions of Main Wind Force Resisting System (mm)

(a) Column size: (mm / in.)

1	2	3	4	5

(b) Beam size (mm / in..):

1	2	3	4	5

c) Slab thickness (mm / in.):

d) Shear wall thickness (mm / in.):

4.6 Type of Foundation

a) Shallow foundation (please tick √ one):

Isolated footing	Combined footing	Raft foundation	Any other type

b) Deep Foundation: (Please √ one)

Pre-cast pile size :	Cost in-situ pile size:

4.7 Type of cement used:

4.8 Type and grade of steel used (please tick √ one)

Plain bar 40/60 grade	Deformed bar 40 grade	Deformed bar 60 grade	Deformed bar 500W

4.9 Whether any test result of concrete available or not? (please tick √ one):

Yes	No

If yes, attach the report, if no, go for in-situ test.

4.10 Whether any test result of reinforcing steel is available or not? (please tick √ one) If yes, attach the report

Yes	No

4.11 Whether Architectural drawing is available or not? (please tick √ one) :

Yes	No

If yes, compare with field survey data

4.12 Whether structural drawing is available or not (please tick √ one)

Yes	No

If yes, compare with field survey data.
If no, go for non-destructive test.

5.0 Additional Information for Coastal Are:

5.1 Distance from the Sea/Estuary/Major river [1] (km / m): ☐

5.2 Available maximum flood height from G.L. (m / ft): ☐

5.3 Available maximum storm surge height from GL (m / ft) ☐

5.4 Clear cover of reinforcement [2]:

a) Column (mm / in.): ☐

b) Beam (mm / in.): ☐

c) Slab (mm / in.): ☐

d) ☐

[1] Minimum Width of river 1.5 km. [2]If data not available please write in sl.no. d.

5.5 Any spalling of concrete in any structural member (please tick √ one):

Beam	Column	Slab

6.0 Environment

6.1 Topography (please tick √ one)

Flat or gently undulated	Hilly Areas/Ridges/Valley

6.2 Surface Roughness (please tick √ one)

Urban or Sub-urban Area with closely spaced obstruction	
Open Terrain with scattered obstruction	
Flat unobstructed terrain like coastal area, open field	

7. Damage Report

7.1 Year of previous cyclone:

7.2 Whether any damage report available or not (please tick √ one)

Yes	Not

If yes, describe extent of damage

6.5.2 PROFORMA B: Data to Assess Vulnerability of Building Envelope

Building Parameters	Probable parameter types				Parameter type of Example Building
Roof covering	Clay tiles	Flat concrete tiles	Lime terrace	*	
Roof geometry	Flat with parapet	Flat without parapet	*	*	
Roof span	0-6.1m(0-20 ft.)	6.4-12.2m (21-40 ft.)	12.5-21.3m (41-70 ft.)	>21.3m (70 ft.)	
Roof sheathing	Reinforced concrete	Precast concrete panels	*	*	
Roof structure	Concrete	Steel truss or joist	Steel beam	*	
Exterior wall system	Solid brick wall	Concrete block wall	Reinforced brick or block wall		
Exterior door	Solid core door	Flush (hollow core) door	Aluminium/metal door	*	
Percent wall occupied by exterior doors and windows	0-25 percent	26-50 percent	>50 percent	*	
Partition walls	Masonry	Wood frame	Metal studs	*	
Beam column system	Concrete	Steel	*	*	
Floor structure	Concrete	Wood frame	Metal frame	*	
Building Code	BNBC	ASCE(ACI)	No code /unknown	*	
Building age	1-5 years	6-10 years	10-20 years	20-30 years or above	
Building envelope Maintenance	1/year	1/5 years	1/10 years	1/20 years or greater	
Window glasses	Annealed	Fully tempered	Heat strength	Laminated glass	Unknown glass type
Roof overhang	Yes	No			
Opening in the roof	Yes	No			

Based on the above information vulnerability of building envelope shall be done as per procedure described in Chapter 7.

*Any other type may be shown in blank blocks

6.5.3 PROFORMA C: Data for Structural Strength Analysis

1. Type of Main Wind-Force Resisting System as per Sl.4.2 of Section 4.0

2. Cross sectional dimension of Main Wind-Force Resisting System as per Sl.4.5 of Section 4.0 of PROFORMA A:

   2.1 Column:

   2.2 Beam:

   2.3 Slab:

   2.4 Shear walls:

3. Type of foundation as per SL.4.6 of Sec 4.0 PROFORMA A:

4. Compressive strength of concrete as per SL.4.9 of Sec 4.0 PROFORMA A:

5. Yield strength of steel as per SL.4.8 of Sec 4.0 PROFORMA A:

6. Visible defect conditions(crack, spalling of concrete) in MWFRS with location:

7. Enclosure classification as per Section 10.1.2:

8. Exposure Category as per Section 10.1.8 and Sl.6.2 of Section 6.0 PROFORMA A:

9. Basic wind speed as per Table 10.1:

10. Importance factor as per Table 10.2 and 10.3:

11. Building Code used as per Sl. 4.1 of Section 4.0 of PROFORMA A:

12. Any other information

Based on the above information structural strength analysis of the building shall be done as per procedure prescribed in Chapter 11

CHAPTER 7

VULNERABILITY AND DAMAGE PREDICTION OF BUILDING ENVELOPE BY '*WIND DAMAGE BAND*' MODEL

7.1 INTRODUCTION

Using previously derived building wind vulnerability relationships based on upper and lower damage probabilities of building components and connections, called ***"damage bands"*** and building relative wind resistivity indices based on expert experience, Chapter7 presents detail procedure (Ref. 7.1) for predicting wind damages to individual building envelope.

Wind damage to building principally manifests in breach of roof envelope, if the roof is constructed by materials other than R.C.C and have a slope steeper than approximately 1:3, the wall envelope and consequent damage to the building contents. Hence, the vulnerability of building in windstorm is a function of the strength of the building envelope components and their connections. Also, for a given building impacted by winds of a given intensity, the resulting damage is largely dependent upon the nature of its immediate environment and the architectural design of the building. Prediction of the degree of wind damage suffered by a building has several applications such as damage mitigation and/or reduction, emergency management planning etc.

The amount (or degree) of damage as used in this chapter is defined as the ratio of replacement cost of damaged building components (due to wind pressure and wind borne missiles) to the replacement cost of the building. It is necessary that a wind damage prediction model satisfies the following criteria:

- The model should be capable of predicting the actual amount (or degree) of damage to a building.
- There should have some proportionality relationship between the model predictions of damage degrees to individual buildings based upon their relative wind performance characteristic.

The first criterion is the desired output, upon which several decisions are ultimately based, for example, recommendation for wind resistant construction, selection of building for wind upgrade purposes through retrofitting measures etc.

The second criterion enables a check to be made on the precision of the model prediction and, in a way, serves as the single most important check on the predicted values of damage degrees. The procedure for wind damage prediction to individual buildings is based on a concept of wind damage bands and a buildings relative wind resistivity. (Ref.7.2 and 7.3).

The purpose of the model is twofold:

- To provided a detail procedure complemented by use of example, for implementation of the proposed expression for wind damage prediction to individual building.
- To demonstrate the application of the wind damage models to wind damage mitigation.

7.2 OVERVIEW OF WIND DAMAGE PREDICTION MODEL

The procedure for wind damage prediction of individual building is based on the concept of ***wind damage bands*** for building occupancy classes. ***Wind damage bands*** define the damage degree ranges bounded by a lower and upper damage threshold for given intensities of the wind hazard and are obtained using the formula (Ref 7.3)

$$DD(\ell) = \sum_{i=1}^{n} P_{fi}\ (CCF_i)\ a_i \qquad \text{(Eq.7.1)}$$

where;

$DD(\ell)$ = damage degree at hazard level ℓ

P_{fi} = components conditional probability of failure (or component fragility)

CCF_i = component cost factor

a_i = component location parameter

n = number of components used in the building damage model

The upper boundary of a damage band for a class of building represents the wind damage function of the least wind resistant building in the building class, while the lower boundary represents the damage function of the most wind resistant building in the building class. This implies that the wind damage functions for all other buildings in that occupancy class lie within the damage band. This information presents a powerful tool for determining the damage degree to individual building impacted by high wind.

For individual buildings the damage degree due to wind pressure and wind-borne missile is given by (Ref. 7.2):

$$BDD_i = DD_i^L + RRI\,(DD_i^U - DD_i^L) \qquad \text{(Eq.7.2)}$$

where;

BDD_i = individual building damage degree at wind intensity i

DD_i^L and DD_i^U = degree of damage furnished by the lower and upper damage functions of the damage band for the building class under consideration at wind intensity i respectively

$RRI = i$, which is defined as

$$RRI = \frac{\sum_{i=1}^{n} P_i W_i}{\sum_{i=1}^{n} W_i} \qquad \text{(Eq.7.3)}$$

where;

P_i = quality point associated with each building wind performance parameter

W_i = weight associated with each performance parameter.

n = number of performance parameters.

Table 7.1 Building Performance Parameters

Parameter P_i	Description	Parameter types P_i (.)
P1	Roof covering	(1) Asphalt shingles; (2) Wood shingles; (3) Asbestos shingles; (4) Slate roof; (5) Clay tiles; (6) Architectural metal roof; (7) Flat concrete tiles; (8) Build-up roofs; (9) Ballasted single membrane roof; (10) Mechanically attached single membrane roofs
P2	Roof geometry	(1) Flat without parapet; (2) Flat with parapet; (3) Gable; (4) Hip; (5) Shed; (6) Mansard; (7) Gambrel; (8) Multilevel roof; (9) Complex.
P3	Roof span	(1) 0-20 ft. (0-6.1m); (2) 21- 40ft. (6.4-12.20m); (3) 41-70 ft. (12.5-21.34m); (4) >70 ft (> 21.34m)
P4	Roof sheathing	(1) Reinforced concrete; (2) Precast concrete panels; (3) Plywood;(4) Metal Panels; (5) Oriented strand board
P5	Roof structure	(1) Concrete; (2) Steel trusses or joists; (3) Steel beams; (4) Wood trusses, beams or joists
P6	Exterior wall system	(1) Wood siding- wood frame; (2) Brick veneer-wood frame; (3) Stucco on wood frame; (4) Concrete block (reinforced); (5) Stone veneer-wood frame; (6) Solid brick; (7) Solid stone; (8) Precast concrete panels
P7	Exterior door	(1) Solid core wood; (2) Sliding glass door; (3) Aluminum/metal door (4) Flush (hollow core) door
P8	Percent wall occupied by exterior doors and windows	(1) 0-25%; (2) 26-50%; (3) > 50%
P9	Partition wall	(1) Masonry; (2) Wood frame; (3) Metal Studs
P10	Beam/column system	(1) Concrete; (2) Steel; (3) Laminated wood; (4) None
P11	Floor structure	(1) Concrete; (2) Wood frame; (3) Metal frame
P12	Building code	(1) ANSI/ASCE standard; (2) Model building code; (3) Customized building code; (4) No code/unknown
P13	Building age	(1) 1-5 years; (2) 6-10 years; (3) 11-20 years; (4) 20-30 years; (5) >30 years
P14	Building envelope maintenance	(1) 1/ year; (2)1/5 years; (3) 1/10 years; (4) 1/20 years or greater

P15	Window glass	(1) Annealed (AN); (2) Fully tempered (FT); (3) Heat strengthened (HS); (4) Monolithic insulating (IG-AN/AN); (5) Monolithic insulating (IG-FT/FT); (6) Monolithic insulating (IG-HS/HS); (7) Laminated glass (LG-AN/AN); (8) Laminated glass (LG-HS/HS); (9) Laminated glass (LG-FT/FT); (10) Unknown glass type
P16	Roof overhang	(1) Yes (2) No.
P17	Skylight	(1) Yes (2) No.
P18	Canopy	(1) Yes (2) No.
P19	Overhead doors	(1) Yes (2) No.
P20	Gravel or roof mounted equipment on nearby buildings	(1) Yes (2) No.
P21	Shutters on exterior doors and windows	(1) Yes (2) No.

* Within the parameters P1 and P21 there are as many as 92 parameter types of different components and features of building.

7.3 IMPLEMENTATION OF WIND DAMAGE PREDICTION MODEL

The relative resistivity index *RRI* of a building is a measure of the building's wind damage resistance relative to other buildings. *RRI* is determined for a specific building based upon the relative wind damage susceptibilities of the building's components, features, and nature of the buildings immediate built environment, called building wind performance characteristics or parameters. The building wind performance characteristics employed for the present purpose are listed in Table 7.1. These parameters are based on prevalent U.S. east coast building construction materials, technology and design but can also be used for coastal belts of Bangladesh.

Before the relative resistivity index of a specific building can be determined by this procedure, it is necessary to have a knowledge base of the relative wind damage performance of the various forms of each building wind performance parameter P_i (.). This information forms the basis upon which the components and features of the specific building can be evaluated to obtain the building's relative resistivity index. An expert-supplied knowledge base on quality points for building performance parameters P_i (.) and their relative weight W_i were obtained via a two-stage Delphi method (Ref. C7-4). The aggregated results of the expert ratings of P_i (.) and W_i are shown in Table 7. 2.

Table 7.2 Quality Points for Building Performance Parameters

Performance parameter P_i (1)	Relative weight W_i (2)	Quality Points									
		$P_i(1)$ (3)	$P_i(2)$ (4)	$P_i(3)$ (5)	$P_i(3)$ (6)	$P_i(5)$ (7)	$P_i(6)$ (8)	$P_i(7)$ (9)	$P_i(8)$ (10)	$P_i(9)$ (11)	$P_i(10)$ (12)
P1	14	0.98	0.74	0.64	0.51	0.50	0.65	0.07	0.70	0.35	0.34
P2	6	0.70	0.50	0.70	0.40	0.60	0.50	0.40	0.60	1.00	
P3	12	0.40	0.60	0.75	0.98						
P4	11	0.00	0.15	0.80	0.60	1.00					
P5	12	0.00	0.37	0.14	0.50						
P6	9	1.00	0.49	0.60	0.05	0.20	0.10				
P7	7	0.10	0.97	0.35	0.68						
P8	11	0.60	0.80	1.00							
P9	4	0.05	0.46	0.43							
P10	4	0.00	0.09	0.37	1.00						
P11	4	0.00	0.33	0.16							
P12	5	0.04	0.35	0.05	0.70						
P13	5	0.01	0.12	0.37	0.50	0.90					
P14	5	0.00	0.22	0.62	1.00						
P15	14	1.00	0.00	0.50	0.50	0.00	0.00	1.00	0.50	0.00	1.00
P16	12	0.50	0.00								
P17	11	0.75	0.00								
P18	4	0.75	0.00								
P19	11	1.00	0.00								
P20	11	0.75	0.00								
P21	*	*	*								

* Effect of quality points and weights for two options (i.e. yes or no) of this performance parameter is to default to use of related parameters P7, P8, P15 & P20, in a manner consistent with lower (if yes) or upper (if no) bound damage contribution.

In addition to incorporating interaction effect of building components' failure in developing building wind damage bands (Ref.C7-3), interaction effects of the performance factors in Table 7.2 were taken into consideration in the expert-supplied values of P_i's and W_i's of Table 7.2.

It is also to be noted that the effect of selecting either the "yes" or "no" option of performance parameter P21 is to default to use of the related parameters, P7, P8, P15, P20, in a manner that is consistent with the lower (if yes) or upper (if no) bound damage contributions.

Once the type of a wind performance parameter for a building is selected from Table 7.1, the quality point corresponding to that option is readily obtained from Table7.2. For example, if the partition wall of a certain building is made of wood frame i.e. option # 2 of parameter P9 [or P9 (2)] of Table 7.1, the corresponding quality point P_i (.) is obtained from Table7.2 as follows:

a) Enter Table 7.2 at the row starting with the number P9;

b) Move horizontally along the P9 row until you reach the quality points column indicated as $P_i(2)$;

c) The number at this intersection of the P9 row and $P_i(2)$ column is the required quality point. In this example, the quality point P9 (2) = 0.46.

The *RRI* for any building is obtained from Equation 7.3 once the characteristics of the building $P_i(.)$ are specified. A *RRI* very close to 1 would indicate a building whose features and components offer very little resistance to wind damage, while a *RRI* value close to zero represents a building whose features and components offer very high resistance to wind damage.

To illustrate the implementation methodology described above for an individual building, let us determine the degree of damage to a low rise apartment building impacted by a hurricane with a sustained one minute wind intensity of 58.1 m/s (130 mph) (210 km/hr.).

We assume the wind performance characteristics $P_i(.)$ of the apartment as shown in Table 7.3.

Table 7.3 Determination of Relative Resistivity Index (RRI) of a Sample building

Parameter P_i (1)	Nomenclature (2)	Parameter types $P_i(.)$ (3)	P_i values (Quality points) (4)	Relative Weight W_i (5)	P_iW_i (6)
P1	Roof covering	Asphalt shingles (1)*	0.98	14	13.72
P2	Roof geometry	Gable (3)	0.70	6	4.20
P3	Roof span	25'-0" (7.62m) (2)	0.60	12	7.20
P4	Roof sheathing	Plywood (3)	0.80	11	8.80
P5	Roof structure	Wood trusses (4)	0.50	12	6.00
P6	Exterior wall system	Brick veneer-wood frame (2)	0.49	9	4.41
P7	Exterior door	Flush (Hollow core) Door (4)	0.68	7	4.47
P8	Percent wall occupied by exterior doors and windows	15% (1)	0.60	11	6.60
P9	Partition wall	Wood frame (2)	0.46	4	1.84
P10	Beam/Column system	None (4)	1.00	4	4.00
P11	Floor structure	Wood frame (2)	0.33	4	1.32
P12	Building code	Model Building Code (2)	0.35	5	1.75
P13	Building age	12 years (3)	0.37	5	1.85
P14	Building envelope maintenance	Once in 10 years (3)	0.62	5	3.12
P15	Window glass	Regular (annealed)	1.00	14	14.00
P16	Roof overhang	Yes	0.50	12	6.00
P17	Skylight	No	0.00	11	0.00
P18	Canopy	No	0.00	4	0.00
P19	Overhead doors	Yes	1.00	11	11.00
P20	Gravel or roof mounted equipment on nearby buildings	Yes	0.75	11	8.25
P21	Shutters on exterior doors and windows	No	-	*	
				172	108.8

*Values in parenthesis indicate building parameter types from Table 7.1

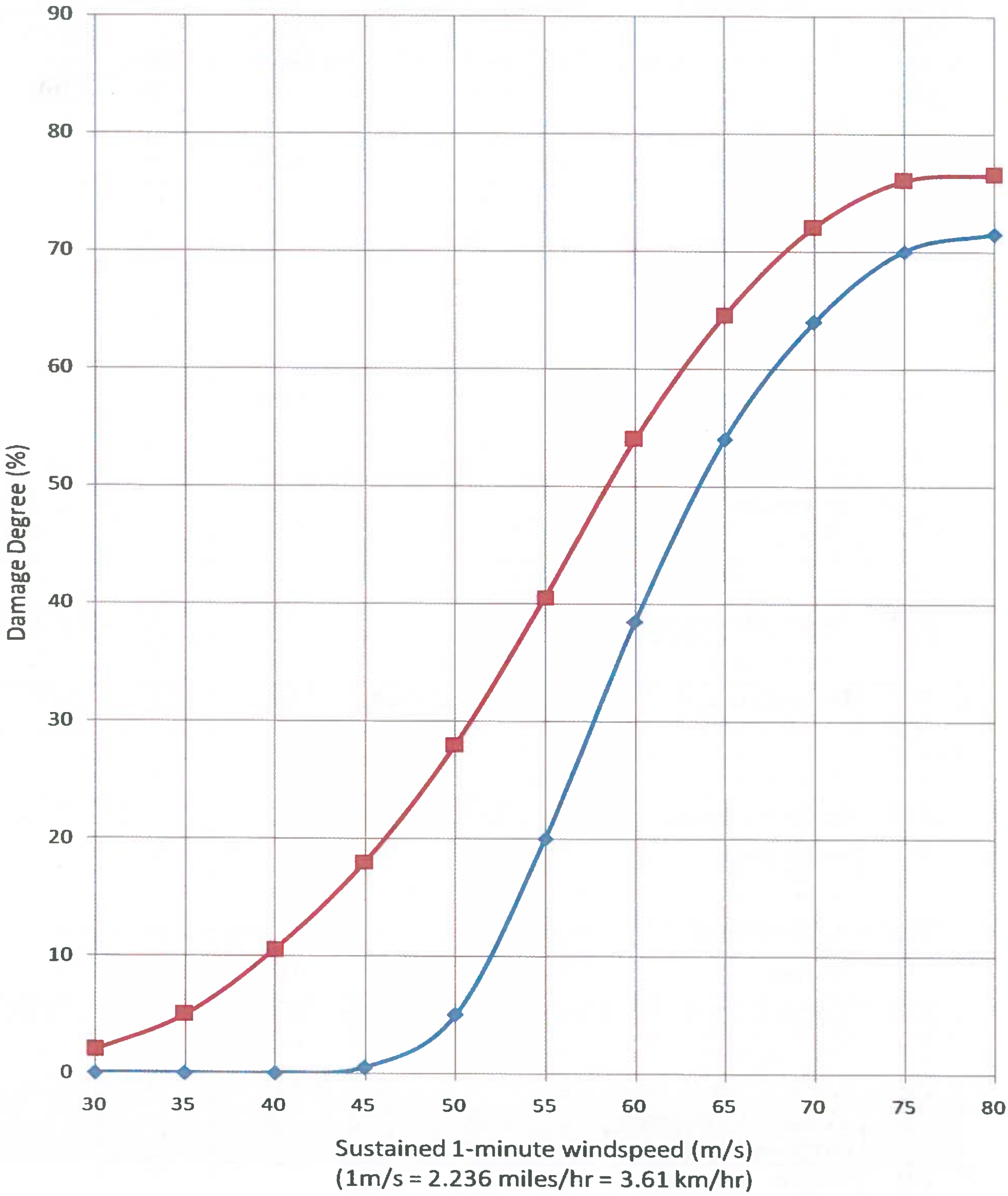


FIG 7.1 Wind Damage Band for 1-3 Story Residential Building

1. Using the above building information and data from Tables 7.1 and 7.2, values of the performance parameters for the building characterized in Table 7.3 are given by the Column 4, 5, 6 of Table 7.3.

2. Employing Column 4, 5, 6 of Table 7.3 the Relative Resistivity Index for the building is obtained from Equation 7. 3,

$$RRI = \frac{\sum_{i=1}^{n} P_i W_i}{\sum_{i=1}^{n} W_i}$$

$RRI = 108.8/172 = 0.633$

3. From the damage band data for residential buildings Fig 7.1, the threshold damage percentages for the 58.1 m/s (130 mph/210kpm) wind speeds are $DD_i^L = 32$ and $DD_i^U = 50$

4. Using Equation 7. 2, the building damage degree *BDD* is obtained as,
$BDD_{58.1} = 32 + 0.633\ (50 - 32) = 43.4\%$.

The result implies that 43.4% of the replacement value of the apartment building will be damaged by the cyclone.

The results of the above procedure for individual building have also been verified against the actual damage suffered by three different buildings in Hurricane Fran in USA and the actual damage degree were found to be within 95% of the model prediction intervals.

7.5 EXAMPLE OF MID-RISE (4-10 STORET) RCC BUILDING DAMAGE DEGREE DETERMINATION

The following example of a mid-rise RCC building has been examined for a wind speed of 69.4 m/s (250 km/hr. / 155 m/hr.) to assess the degree of damage incurred by the building.

The building has a RCC flat roof and floor with external masonry walls and masonry internal partition walls with a life span between 11-20 years. 26-50% of the external walls are occupied by doors and windows. The main wind resisting frame of the building is RCC column and beam. Detail building parameters with their P_i and W_i values are shown in Table 7.4.

Table 7.4 Determination of Relative Resistivity Index (*RRI*) of Mid-Rise R.C.C Building

Parameter P_i (1)	**Nomenclature** (2)	**Parameter types** P_i **(.)** (3)	**Quality points** P_i (4)	**Relative Weight** W_i (5)	P_iW_i (6)
P1	Roof covering	Flat concrete tiles (7)*	0.07	14	0.98
P2	Roof geometry	Flat with parapet (1)	0.70	6	4.20
P3	Roof span	21-40ft (6.1-12.2m)(2)	0.60	12	7.20
P4	Roof sheathing	Reinforced concrete (1)	0.00	11	0.00
P5	Roof structure	Concrete (1)	0.00	12	0.00
P6	Exterior wall system	Solid brick (6)	0.10	9	0.90
P7	Exterior door	Solid core door (1)	0.10	7	0.70
P8	Percent wall occupied by exterior door and windows	26-50% (2)	0.80	11	8.80
P9	Partition wall	Masonry (1)	0.05	4	0.20
P10	Beam/Column system	Concrete (1)	0.00	4	0.00
P11	Floor structure	Concrete (1)	0.00	4	0.00
P12	Building Code	ASCE (1)	0.04	5	0.20
P13	Building age	11-20 years (3)	0.37	5	1.85
P14	Building envelop maintenance	1/5 years (2)	0.22	5	1.10
P15	Window glass	Annealed (1)	1.00	14	14.00
P16	Roof overhang	No (2)	0.00	12	0.00
P17	Skylight	No (2)	0.00	11	0.00
P18	Canopy	No (2)	0.00	4	0.00
P19	Overhead doors	No (2)	0.00	11	0.00
P20	Grovel or roof mounted equipment on nearby building	No (2)	0.00	11	0.00
P21	Shutters on exterior doors and windows	Yes (1)	0.00	*	
			Total:	172	40.13

*Values in parenthesis indicate building parameter types from Table 7.1

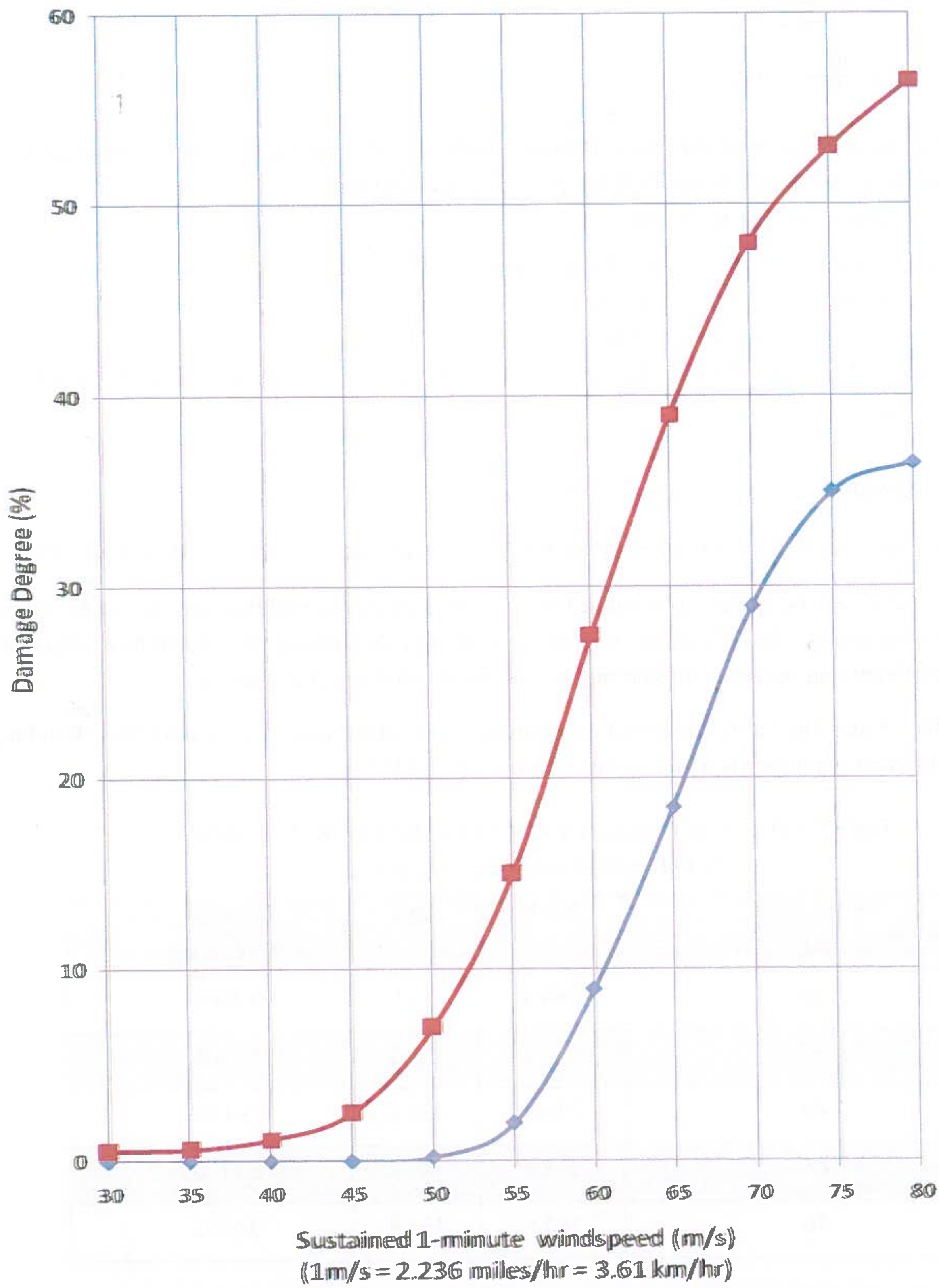


FIG 7.2 Wind Damage Band for 4-10 Story Mid-Rise Building

$$RRI = \frac{\sum_{i=1}^{n} P_i W_i}{\sum_{i=1}^{n} W_i}$$

$$= \frac{40.13}{172} = 0.23$$

From the damage band data for 4-10 storey mid-rise buildings Fig 7.2, the threshold damage percentage for the 69.44 m/s (250 km/hr./155 mph) wind speed is

$DD_i^L = 28$ and $DD_i^U = 48$

Using Equation 7.2, the building damage degree BDD is obtained as,

$BDD_{69.44} = 28 + 0.23\ (48-28)$

$= 28 + 4.66 = 32.66\%$

If the wind speed is 55m/s (123.2 mph/198.4km/hr) the threshold damage percentages are,

$DD_i^L = 2$, $DD_i^U = 16$

So,

$BDD_{55} = 2 + 0.23\ (16-2) = 2 + 3.26 = 5.26\%$

7.6 RELATION BETWEEN PERCENTAGE WIND DAMAGE TO WIND SPEED

The model can be applied to examine the extent of damage the building may sustain at different wind speeds. This shall help in identifying the type of building that should be constructed in different reas in future considering the maximum wind speed of that area.

Table7.5 and Fig.7.2 has indicated the tendency of wind damage to 4-10 story RCC building at different wind speeds with parameters shown in Table 7.4.

Table 7.5 Degree of Damage for 4-10 Story Mid-Rise RCC Building for Different Wind Speeds (Approx).

Wind speed m/s	km/h	mph	Damage Percentage
50	180.3	112	1.84%
55	198.4	123.2	5.26%
60	216.4	134.4	13.14%
65	234.4	145.6	24.6%
70	252.5	156.8	32.6%

It is interesting to note here that up to a wind speed of 55m/s or 200 km/hr. the wind damage to a RCC building with wind parameters shown in Tables 7.4 (which is common is Bangladesh) will be only about 5% of replacement cost of the building. Damage suddenly increases with increase in wind speed and reaches as high as 30% when the sustained wind speed reaches 70 m/s(250 km/hr./155mph)

7.7 APPLICATION OF THE MODEL TO WIND DAMAGE MITIGATION

The procedure for predicting the degree of wind damage to individual buildings can also be applied to determine the relative significance or effect of each of the building performance parameters shown in Table 7.1 on building damage degree. For this purpose, a reference (or basic) building configuration is defined so as to approximate the characteristic of building.

The characteristics of basic building are listed in Table 7.6. The damage function of the basic building *BDDi (basic)* is then determined as previously outlined for an individual building. From Table7.6 and Equation 7.2 for wind speed 58.1m/s (130mph /210km/h)

$$BDD_i\,(basic) = DD_i^L + RRI\,(DD_i^U - DD_i^L)$$

$$= 30.7 + .64\,(50.3 - 30.7)$$

$$= 43.244\%.$$

The effect of each form of a wind performance parameter P_i (.) in Table 7.1 can be investigated by successively substituting each P_i (.) of Table 7.1 for the corresponding basic building parameter while leaving the other parameters of the basic building unchanged and then determining the damage degree for the resulting configuration.

For example, to investigate the effect of flat concrete tiles for roof covering, the only change to be made to the characteristics of basic building in Table 7.6 is simply to replace asphalt shingles with flat concrete tiles. The basic building has 21configurations out of total 92 configurations. As such out of total 92 configurations this process results in 9 building configurations for the Pl(.) alternatives, 8 for P2(.), 3 for P3(.) and so on for a total of (92-21)= 71 configurations. Comparison of the percent damage for each of the resulting configuration BDD_i *(configuration)* with that furnished by the basic building BDD_i (basic) enables the most significant wind performance parameters that affect building damage degree to be identified.

The results are expressed in terms of maximum percent decrease/ increase in damage degree over the basic building maximum damage degree for cyclone intensity *i* .

Percent reduction in damage degree

$$= \frac{BDDi(basic) - BDDi(configuration)}{BDDi(basic)} x100 \qquad \text{(Eq. 7.4)}$$

Table 7.6 Characteristics of Basic Building

Para-meter Pi	Nomenclature	Parameter types P_i (.)	P_i values	Rela-tive weight W_i	$P_i W_i$	*RRI*
P1	Roof covering	Asphalt shingles (1)*	0.98	14	13.72	
P2	Roof geometry	Gable (3)	0.70	6	4.20	
P3	Roof span	21-0 ft (2)	0.60	12	7.20	
P4	Roof sheathing	Plywood (3)	0.80	11	8.80	
P5	Roof structure	Wood trusses (4)	0.50	12	6.00	
P6	Exterior wall system	Wood sliding/ wood frame (1)	1.00	9	4.00	
P7	Exterior door	Flush (hollow core) door (4)	0.68	7	4.76	
P8	Percent wall occu-pied by exterior door and windows	0-25% (1)	0.00	11	6.60	
P9	Partition wall	Wood fame (2)	0.46	4	1.84	
P10	Beam/Column system	None 4)	1.00	4	4.00	
P11	Floor structure	Wood frame (2)	0.33	4	1.32	
P12	Building Code	Model Bldg. Code (2)	0.35	5	1.75	
P13	Building age	6-10 years (2)	0.12	5	0.60	
P14	Building envelop maintenance	Once in 6 yrs (2)	0.22	5	1.10	
P15	Window glass	Regular (Annealed glass (1)	1.00	14	14.00	
P16	Roof overhang	Yes (1)	0.50	12	6.00	
P17	Skylight	No (2)	0.00	11	0.00	
P18	Canopy	No (2)	0.00	4	0.00	
P19	Overhead doors	Yes (1)	1.00	11	11.00	
P20	Grovel or roof mounted equipment on nearby building	Yes (1)	0.75	11	8.25	
P21	Shutters on exterior doors and windows	No (2)	*	*		
				172	110.14	0.64

*Values in parenthesis indicate building parameter types from table7.1

$BDD_i\ (basic) = 32 + 0.64\ (50\text{-}32) = 43.52\%$

Case 1: Roof covering changed from Asphalt singles to flat concrete tiles.

$P_iW_i\ (basic) = 110.14$

P_iW_i *(Configuration)* = (110.14-13.72) + 14x.07= 97.40

RRI (Configuration) = 97.40/172= 0.566

BDD_i *(basic)* = 43.52%

BDD_i *(configuration)* = 32+.566 (50 -32) = 42.19

% decrease = (43.52-42.19)/43.52 = 3.06%

As test cases, few parameters most prevalent in Bangladesh have been changed to examine the degree of reduction due to a single performance parameter over the basic building as shown in Table 7.7.

Parameters P17 to P21 shall in most cases have alternative 'No', as such has no consequence on RRI & parameter P21 shall always be 'yes' for Bangladesh.

Table 7.7 Significant Building Wind Performance Parameters

Parameter type P_i (.)	Maximum percentage reduction in damage degree
P1-Roof covering Flat concrete tiles instead of Asphalt Shingles	3.06%
P4- Roof sheathing Reinforced concrete instead of plywood	2.3%
P5-Roof structure Concrete instead of wood trusses	1.54%
P6-Exterior wall Solid brick instead of wood sliding-wood frame	2.1%
P8-Percent wall occupied by doors & windows > 50% instead of 0-25%	-1.2%

The most significant wind performance parameters are summarized as follows: *roof covering, roof sheathing, roof structure, exterior wall system and exterior door, percent of exterior wall occupied by doors and windows, window glass type*. It is to be noted that parameter P8 (percent of exterior wall occupied by doors and windows), P17 (skylight) contributes significantly in an increase in wind damage. For these parameters, wind damage reduction is affected by having no more than 50% of the wall envelope occupied by exterior doors and windows unless the doors and windows are adequately shuttered and by not providing skylight in the roof envelope of the building.

A major advantage of the damage band concept is its ease of applicability to wind damage prediction or vulnerability of the building against cyclone.

While being useful in itself for selection of building for retrofitting, the individual building damage prediction is rather a method of vulnerability assessment and also very important for wind damage mitigation and also provides useful information for building design. The prediction procedure is also quite robust, as it can be used to predict damage to any given building provided ***damage band*** for that type of building exists.

CHAPTER 8
STRENGTH EVALUATION OF MAIN WIND-FORCE RESISTING SYSTEM

8.1 INTRODUCTION

The designer of a building must be prepared to take into consideration all possible hazards that a structure could be subjected to. When designing for multiple hazards, one must ensure that the design for one hazard does not negatively impact on a building's ability to resists damage from other hazards.

Multiple hazards may occur under two hazard scenarios, as shown below:

- Hazards that have low risk of occurring simultaneously. As an example, there is little risk of cyclone occurring simultaneously with an earthquake. Most designer would consider it unreasonable to design for this combined hazard scenario.
- Hazards that have high risk of occurring simultaneously. As an example cyclone induces both high wind and flooding. In coastal areas, most designers would consider it reasonable to design for this combined hazard scenario.

As such while considering load combination, the designer should use his experience and judgment so that combine effect of one or more natural hazards gives the most unfavorable effects on the structural members, components, claddings and utility services.

8.2 BASIC REQUIREMENTS

Building and other structures and all parts thereof shall be designed and constructed to support safely the factored loads in load combination defined in Chapter 9 without exceeding the appropriate strength limit states for the materials of construction.

Alternatively, buildings and other structures and all parts thereof, shall be designed and constructed to support safely the nominal loads in load combinations defined in Chapter 9 of this document without exceeding the appropriate specified allowable stresses for the materials in construction.

Structural systems, and members thereof, shall be designed to have adequate stiffness to limit deflections, lateral drifts, vibration or any other deformation that adversely affect the intended use and performance of buildings and other structures.

Provision shall be made for anticipated self restraining forces arising from differential settlements of foundations and from restrained dimensional changes due to temperature, moisture, shrinkage, creep and similar effects.

Load effects on individual structural members shall be determined by methods of structural analysis that take into account equilibrium, general stability, geometric compatibility and both short and long term material properties. Members that tend to accumulate residual deformation under repeated service load shall have included in their analysis the added eccentricities expected to occur during their service life.

All structural members and systems and all components and claddings in a building or other structures, shall be designed to resist forces due to earthquake and wind, with considerations of overturning, sliding, and uplift and continuous load path shall be provided for transmitting these forces to the foundation. Where all or a portion of the resistance to these forces is provided by dead load, the dead load shall be taken as minimum dead load likely to be in place during the event causing the considered forces. Consideration shall be given to the effects of vertical and horizontal deflection resulting from such forces.

Design of structural members for wind force is based on linear behavior; the structure is assumed to remain elastic under the design wind force. For coastal areas, where cyclone is normally accompanied by cyclone induced storm surge and coastal flood , while considering load combinations, the maximum effect of appropriate load combination shall be considered in design.

8.2.1 Special Requirements for Coastal Saline Areas

For buildings specially constructed as emergency shelters during natural calamity like cyclone and buildings designated as emergency preparedness, communication and operation centers and other facilities required for emergency response shall be designed for a minimum live load of 4.8 kN/m^2 (100 lb/ft^2) including roof and no reduction in live load shall be considered in design as during cyclone maximum wind load shall act simultaneously with maximum live load to produce the most unfavorable effects.

For buildings in coastal areas special attention shall be given regarding denseness of concrete, clear cover to reinforcement and the effect of chloride on concrete.

For buildings in coastal areas, minimum strength of concrete shall be 24 MPa (3500 psi) with minimum cement content of 400kg/cum (22.5 bags/ 100cft) and no artificial coarse aggregate shall be used in concrete. Fine aggregate shall be 100% coarse or Sylhet Sand with minimum FM 2.2. Water shall be potable water. Saline water is strictly prohibited.

Maximum water soluble chloride ion concentration for corrosion protection in hardened concrete at ages from 28 to 42 days contributed from the ingredients including water, aggregate, cement and admixture shall not exceed 0.15 percent by weight of cement for an exposure where concrete is exposed to moisture and an external source of chloride from deicing chemicals, salt, brackish water, sea water and spray from these sources (Ref. 1.1 and 1.3). Water soluble chloride ion shall be determined by ASTM 1218 (Ref. 1.3).

The limit applies to the sum of the chloride ions from all sources- cement, admixture, aggregate and water- used in making concrete. The purpose of the recommendation is to minimize the amount of electrochemical corrosion of reinforcing bars.

There is a threshold value for chloride content in concrete which must be reached before corrosion of embedded steel can begin

Table 8.1 Limit for Chloride ion in Concrete Prior to Exposure in Service

Type of Member	Maximum water soluble chloride ion (Cl^-)in concrete, percent by weight of concrete
Reinforced concrete exposed to chloride in service	0.15
Reinforced concrete that will be dry or protected from moisture in service	1.00
Other reinforced concrete construction	0.30

For corrosion protection of reinforcement against brackish water, sea water, or spray from these sources, the water-cement ratio shall not exceed 0.4. If minimum concrete cover as required by Section 8.1.7 of BNBC15 is increased by 12mm (½ in) the water-cement ratio may be increased to 0.45.

8.2.2 Concrete Clear Cover of Reinforcement in Coastal Areas

Table 8.2 Clear Cover of Reinforcement for Coastal Areas

Member	Location/Condition	Clear cover	Clear cover
Pile cap	Side	75mm	3 in.
	Bottom	50mm [(1)]	2 in.
Column	Above GL/PL	*50mm	2 in.
	Below GL/PL	*75mm	3 in.
Wall	Above GL	50mm	2 in.
	Below GL	75mm	3 in.
Beam	Top/Side	50mm	2 in.
	Bottom	50mm	2 in.
Grade beam	Top/Side	62.5mm	2½ in.
	Bottom	62.5mm	2½ in.
Slab and stair	Top	40mm	1½ in.
	Bottom	40mm	1½ in.
Retaining wall	Exterior	75mm	3 in.
	Interior	50mm	2 in.
Water tank	Water faces	50mm	2 in.
	Other faces	50mm	2 in.

*from tie or spiral [(1)] from pile cut-off level

For any non-structural member like drop wall, railing, fins etc. the minimum thickness shall be 100mm (4 in.) if one layer of reinforcement is used to maintain a clear cover of 40 mm(1½ in) on each side of reinforcement. 12mm (½ in) downgraded stone chips may be used as coarse aggregate.

If 2-layers of reinforcement are used, minimum thickness shall be 150mm (6 in.).

8.3 STRUCTURAL SYSTEM

Before evaluation of main wind-frame resisting system, the designer shall identify the structural system of the building. Based on the structural system, fundamental period or simply period of the building (or fundamental frequency/frequency) shall be determined using Equation 10.4 and Table 10.6 of Chapter10, to ascertain whether the building is rigid or flexible. It may be noted here that a building may be rigid in one direction and flexible in other direction depending on the structural system (Refer Table 10.7). Gust effect factor G or G_f, as applicable, for wind load analysis shall depend on the rigidity or flexibility of the building.

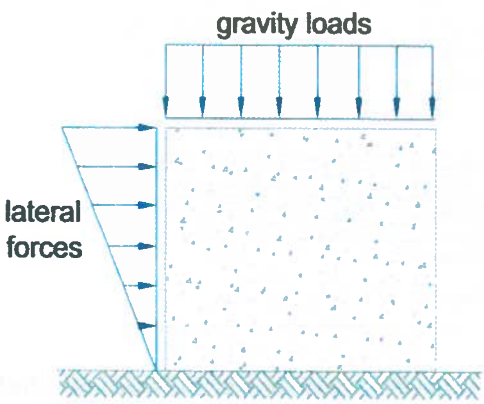
ASCE7 recognizes as many as seven major types of structural systems capable of resisting lateral forces. BNBC 15 restricted the systems into four major types A, B, C and D as shown in the following paragraphs. The reason may be, in Bangladesh Types E and F and G are seldom used as a structural system.

A. BEARING WALL SYSTEM

A *bearing wall system* shown in Fig.8.1 is a structural system that relies on the same elements to resists both gravity and lateral loads. By itself the word "wall" is ambiguous, because there are two main types of structural walls. A *bearing wall* is designed and constructed to resist vertical (i.e., gravity) load. A *shear wall* is designed and constructed to resist lateral loads. A wall can be used to resist both lateral and vertical loads. A bearing wall system does not have a complete vertical load- carrying space frame. Bearing walls or bracing systems support all of the vertical loads. Lateral loads are resisted by shear walls.

It is common to refer to this type design as a *box system.*

A bearing wall system lacks redundancy and has an inadequate inelastic response capability. Such systems do not possess a complete vertical load-carrying frame and rely on walls or braced frames to carry the vertical (gravity) and lateral (seismic and wind) loads.



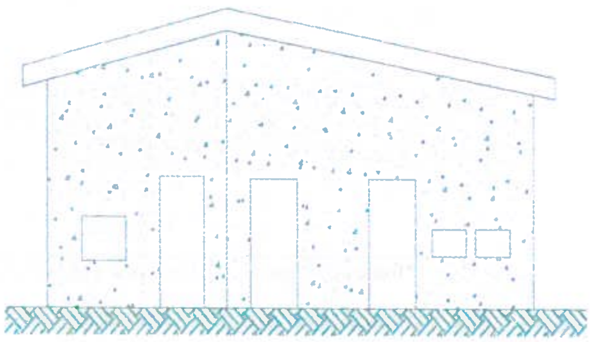


Figure 8.1 Bearing Wall Systems (Ref. 10.1)

B. BUILDING FRAME SYSTEM

A *building frame* (*vertical load carrying frame*) is a complete, self- contained, three-dimensional unit composed of interconnected members as shown in Fig.8.2 *Building frame system* uses a complete space frame to carry the vertical (gravity) loads and a separate system of non-bearing shear walls or braced frames to resist the lateral loads. Unlike the bearing wall system, failure of the primary lateral support system does not compromise the ability of the structure to support gravity loads.

A frame may or may not have bracing. If it does, it is known as a *braced frame*. A braced frame is a vertical truss system of interconnected members designed to resist lateral loads through the development of axial loads in the members.

Figure 8.2 Building Frame Systems (Ref. 10.1)

C. MOMENT RESISTING FRAME

Moment resisting frames resist forces in members and joints primarily by flexure and rely on frame to carry both vertical and lateral forces as shown in Fig.8.3. Lateral loads are carried primarily by flexure in the members and joints. Theoretically, joints are completely rigid. Moment-resisting frames can be constructed of concrete, masonry and steel.

There are three types of concrete moment frames: Special Moment Frames (SMF), Intermediate Moment Frames (IMF) and Ordinary Moment Frames (OMF). These systems provide sufficient degree of redundancy and have excellent inelastic response capability.

Special moment frames are specially detailed to ensure ductile behavior and comply with ACI 318 and BNBC 15 for earthquake loading.

In some cases the maximum expected lateral wind loading will result in larger drift or larger lateral forces than an earthquake. However even in that instance, the design must include seismic detailing. The reason for this requirement is that the structure must be able to resist seismic loads in a ductile manner even when it can resist a large design load elastically. Simply, the intent is to avoid catastrophic failure and to provide the necessary structural integrity to resist actual seismic force, which is potentially much higher than the design seismic force. The code also permits to provide detailing of SMF in IMF and the detailing of SMF and IMF in OMF.

Intermediate moment frames have less stringent detailing requirements and designed in accordance with ACI 318 and BNBC 15 and cannot be used in seismic zones where use of SMF is mandatory depending on site dependent soil factor and occupancy category.

Ordinary moment frames do not meet the special detailing requirements for ductile behavior and restricted in use for seismic zone 1 of BNBC 15.

Figure 8.3 Moment Resisting Frame Systems (Ref. 10.1)

D. DUAL SYSTEM

Dual system has essentially complete space frames that provide support for all vertical (gravity) loads and combine two of the previously mentioned systems (i.e., moment resisting frame and shear wall braced frame) to resist lateral loads. Moment frames (SMF, IMF and OMF) must be able to resist at least 25% of the design base shear independently. Two systems are designed to resist total base shear and lateral loads from wind loads in proportion to their relative rigidity.

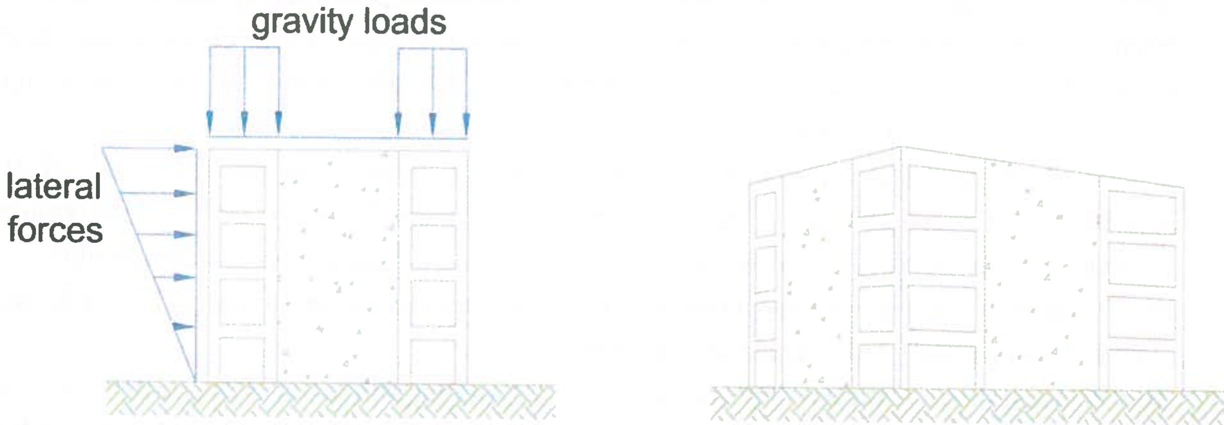


Figure 8.4 Dual Systems (Ref. 10.1)

There are other structural systems like Inverted Pendulum Building System and Shear Wall-Frame Interaction System.

E. INVERTED PENDULUM BUILDING SYSTEM

Inverted pendulum building systems have single cantilevered column elements supporting beams and frames at the top as shown in Fig.8.5. The cantilevered- columns in this building system provide both lateral load resistance and gravity load resistance. These column elements have low redundancy and limited inelastic response capacity (energy dissipation).

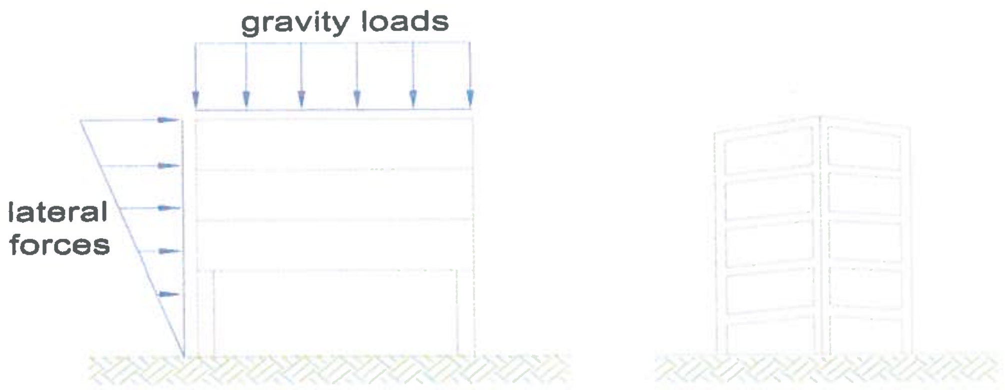


Figure 8.5 Cantilevered- Column Building System (Ref 10.1)

F. SHEAR WALL-FRAME INTERACTION SYSTEM

To resist lateral forces, *shear wall- frame interaction systems* primarily use a combination of shear walls and moment frames. Building frames that are part of the lateral force resisting are required to be concrete frames. These systems are restricted to locations of low seismicity.

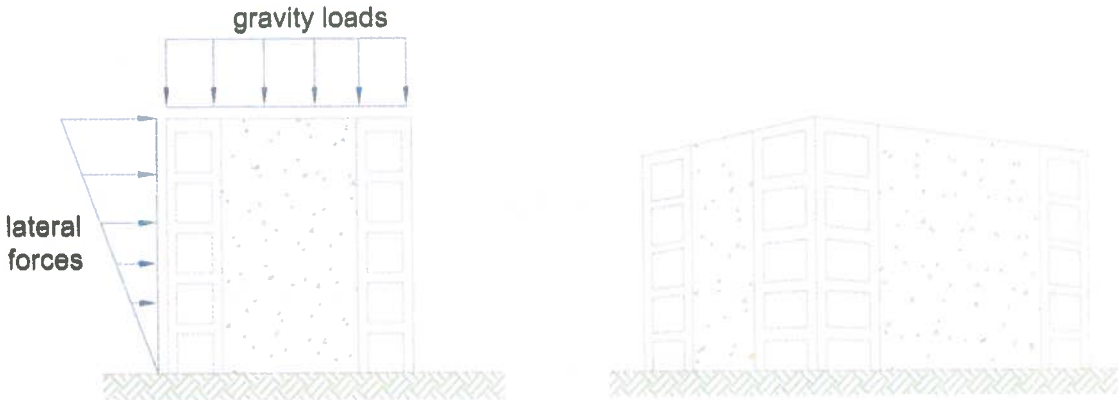


Figure 8.6 Shear Wall-Frame Interaction Systems (Ref. 10.1)

G. UNDEFINED SYSTEM

Undefined structural systems do not fit into any of these categories. The designer of such system must submit a rational basis for the design force level used.

8.4 DRIFT

Drift is the lateral displacement (deflection) of one floor relative to some point below it. *Total drift* of the building or structure is shown in Fig. 8.7 and is measured with respect to the ground.

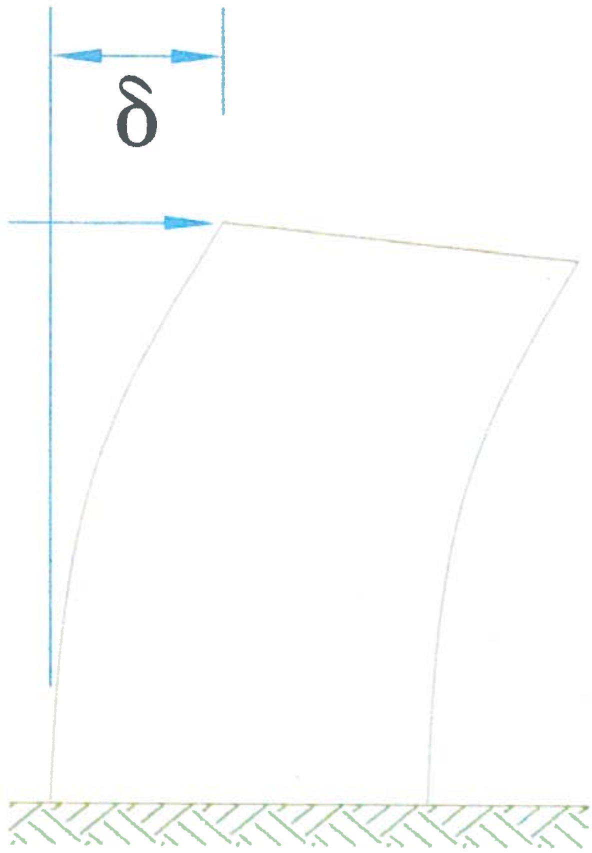


Figure 8.7 Total Drift (Ref. 10.1)

Story drift Δ is shown in Fig. 8.8 and is measured with respect to the story below.

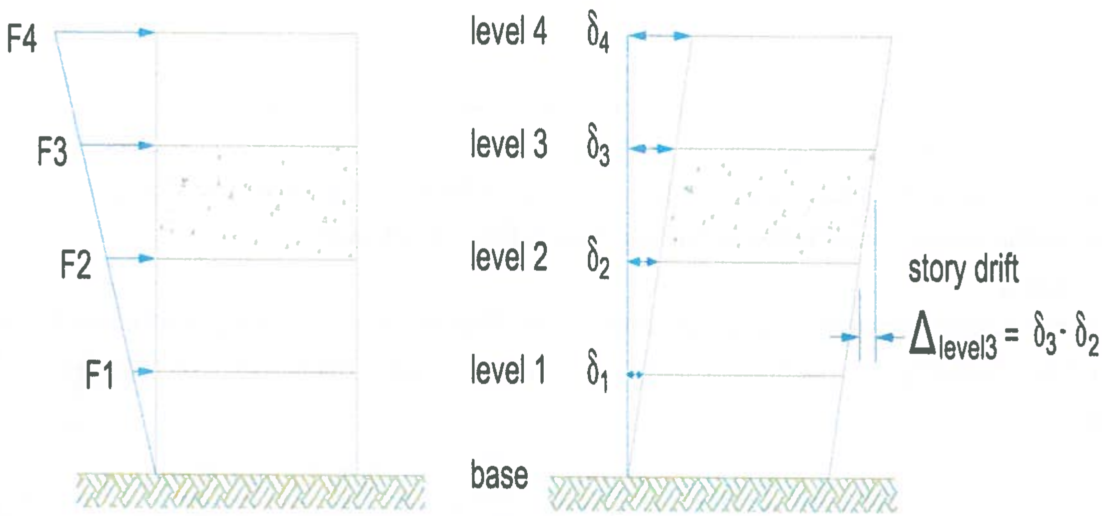


Figure 8.8 Story Drift (Ref. 10.1)

There are two main reasons to control drift. First, excessive movements in upper stories have strong adverse psychological and physical effects on the occupants. Second, it is difficult to ensure structural and architectural integrity with large amount of drifts. Architectural failures are such nonstructural damages as failure of partitions, windows and hung ceilings. In low-rise construction damage to stairwells and elevator shafts can also be considered as non-structural damages.(Ref. C10-1). However, in high-rise construction stairwells and elevator shafts usually constitute the most critical structural elements in the structural core.

Excessive drift can be accompanied by large secondary bending and inelastic behavior. The *story drift ratio* is the story drift divided by the height (floor to floor) of the story.

BNBC15 in Section 1.5.6 (Part 6) has provided the following procedure to calculate the story drift Δ (m/ft) for loads other than earthquake loads depending on the fundamental period of the building:

$$\Delta \leq 0.005\, h \text{ for } T < 0.7 \text{ seconds} \qquad \text{(Eq. 8.1)}$$

$$\Delta \leq 0.004\, h \text{ for } T \geq 0.7 \text{ seconds} \qquad \text{(Eq. 8.2)}$$

where;

h = story height from floor to floor m (ft)

T is the fundamental period in seconds calculated by Equation 10.4 of this manual which is the same equation as provided in BNBC15 Section 2.5.7.2, Equation 6.2.38.

The overall sway (horizontal deflection) at the top of the building or structure due to wind loading shall be limited to $\frac{1}{500}$ times of the total height of the building above ground.

It may be stated here that the allowable story drift Δ_a for earthquake loading is different and has been discussed in Section 2.5.7.7 of BNBC15 and shown in Table 6.2.21.

8.5 OVERTURNING MOMENT

The distribution of lateral forces over the height of a structure causes the structure to experience overturning effects. According to BNBC15 Section 1.5.5 every structure shall be designed to resist the overturning effects caused by wind or earthquake forces as well other lateral forces like earth pressure, tidal surge etc. The design overturning moment is distributed to the various elements.

The summation of moments due to the distributed lateral forces is the *overturning moment,* often given the symbol OTM as shown in Fig 8.9. If the overturning moment is large enough, it can reverse the compression that normally exists in the outer column caused by dead and live building loads. Because the footings, concrete walls and columns can be placed in a state of tension, the overturning moment is more of a problem for concrete frame and shear wall construction (which cannot tolerate much tension) than it is for steel frame construction.

The overturning moment will increase the compression stress in the outer columns on the opposite side of the building. Such an increase must be compensated by increasing the thickness of shear walls and using extra steel reinforcement in concrete column.

Overturning moments should be calculated for each building level (See Fig.8.9). The first overturning moment is the sum of all moments taken about the ground level. This moment should be used to size footings and to design the primary outer columns. The overturning moment for each subsequent floor considers only lateral forces above that floor. This moment is used to design the shear walls and other supporting walls in that floor.

The overturning at the base of the structure is given by Equation 8.3

OTM at base = $\sum_{i=1}^{n} F_i h_i$ (Eq. 8.3)

where,
F_i = Lateral force applied at level i, i= 1 to n
h_i = height at level- i

OTM at any story height x = $\sum_{i=1}^{n} F_i(h_i - h_x)$ (Eq. 8.4)

where,
h_i, h_x, h_n = heights at level i, x, n respectively.

For example, OTM at level 4 = $\sum_{i=1}^{4} F_i(h_i - h_4)$ (See Fig. 8.9)

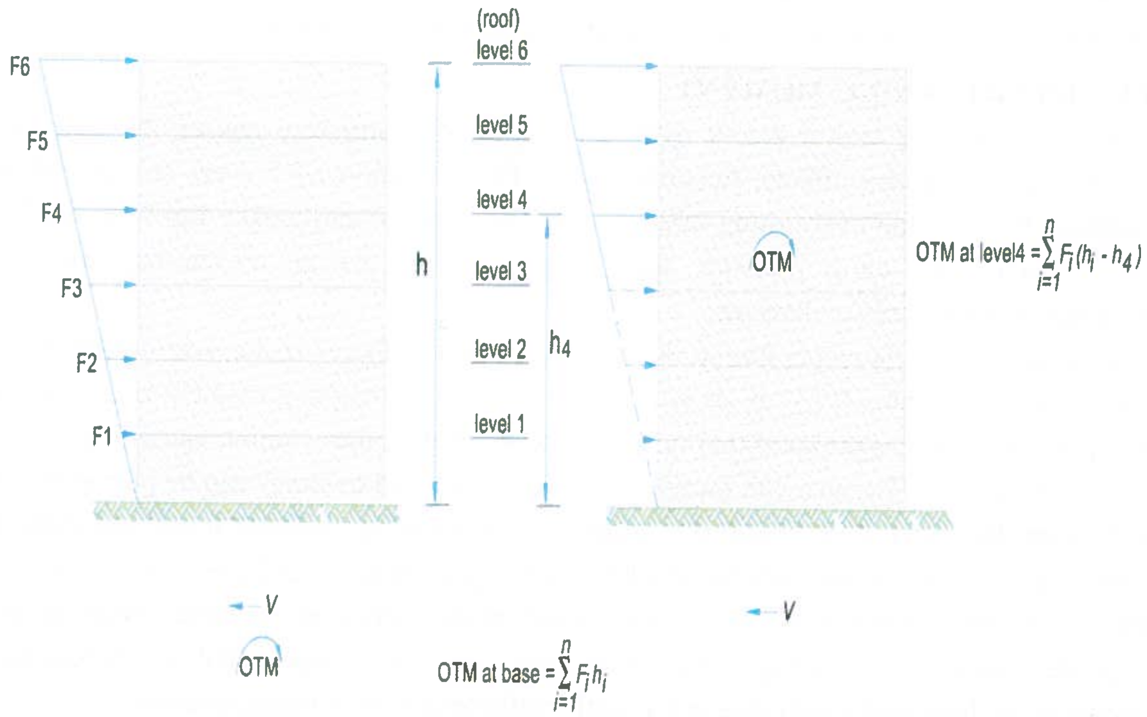


Figure 8.9 Overturning Moment (OTM) (Ref. 1.1)

8.6 STEPS FOR NON-SEISMIC STRUCTURAL STRENGTH EVALUATION

Several steps shall be followed to assess the structural capability of Main Wind-Force Resisting System (MWFRS) against wind load which is shown in Table 8.3.

Table 8.3 Steps to Assess the Structural Capability of MWFRS

Step	Description	This manual's Section/Table reference
1	Select the building to be analyzed	-
2	Identify appropriate structural system	Section 8.3
3	Determine risk category or occupancy category of the building	Table 10.2
4	Collect information related to type of materials used and their strength, reference of the code used, design criteria, design drawings etc	Section 6.5, 8.8, 8.9
5	Determine basic wind speed	Table 10.1
6	Determine wind load parameters	Section 11.2
7	Select appropriate lateral force procedure	Section 10.1, 10.2
8	Select gravity loads, live loads, wind loads	Section 8.10
9	Calculate velocity pressure	Section10.2.9 and Table 11.2
10	Calculate wind pressure on each building surface	Section 10.3, Table 11.3 to 11.6
11	Calculate forces acting on MWFRS due to various wind load combination	Section 9.3
12	Collect test core- concrete for in-situ strength test if sufficient information is not available as per Step 4	–
13	Study story drift limitations	Section 8.4
14	Design and evaluate elements of MWFRS based on data as per Step 4 and Step 12	Section 8.6
15	Compare the capacity of existing MWFRS with strength calculated by Step 14	–
16	Evaluate overturning effects caused by wind forces	Section 8.5
17	Verify structure's continuous load path and redundancy	–
18	Comment on the safety of individual members of MWFRS against wind load combination	–

8.7 STRENGTH EVALUATION OF MAIN WIND –FORCE RESISTING SYSTEM

The evaluation method depends on factors such as structural framing system, information known about its existing condition and logistic and economic consideration.
There are two methods of strength evaluation of existing structures. These are:

- Analytic evaluation based on member dimensions and material properties
- Load test, if it is not possible to determine member dimensions and material properties

If the effect of the strength deficiency is well understood and if it is feasible to measure the dimensions and material properties required for analysis, analytic evaluation of strength based on those measurements shall suffice. An acceptable methodology for analyzing the type of structural system should exist based on analytic method for reinforced concrete buildings in BNBC15/ACI 318 and text books on structural analysis and reinforced concrete. A structure should be analyzed to determine the bending moments, torsional moments, shear forces and axial forces at the critical sections. Most engineers conduct this part of the analysis assuming that individual members have linear elastic behavior which is acceptable for wind load combination, though may not be acceptable for earthquake load combination. But due to lack of information about the material properties, strength of individual members, it might be necessary to evaluate the strength of members by field test. A strength evaluation by field test may also be necessary for the following reasons:

- The materials are considered to be deficient in quality
- There is evidence indicating faulty construction
- Condition of structure has deteriorated
- Building will be used for a new function
- For any reason the structure or part thereof does not appear to satisfy the requirements of Code

If the dimensions and material properties are available then:

- Dimension of structural elements shall be established at critical sections
- Location and size of the reinforcing bars shall be determined by measurement. It shall be permitted to base reinforcement location on available drawings if spot checks are made confirming the information on the drawing. In large structures, determination of this data for about five percent of reinforcements in critical regions may suffice if these measurements confirm the data provided in the construction drawings (Ref.C1-3).
- Concrete strength shall be based on the results of cylinder tests from the original construction or test of cores removed from the part of the structure where the strength is in question. For strength evaluation of an existing structure cylinder or core test data shall be used to estimate an equivalent f'_c. The method for obtaining and testing cores shall be in accordance with ASTM C42.
- The number of core tests may depend on the size of the structure and sensitivity of the structural safety to concrete strength. Core tests having an average of 85 percent of

specified strength are realistic. To expect core test to be equal to specified strength is not realistic, since difference in the size of specimen, conditions of obtaining samples and procedure for curing may be different from the procedure adopted during construction. The number of tests required depends on the uniformity of materials and is best determined by the licensed design professional responsible for the evaluation.

Apart from core test there are few other non-destructive methods of testing in-situ concrete.

- Probe penetration (ASTM C803)
- Impact hammer (ASTM C805)
- Ultrasonic pulse velocity (ASTM C597)

If the required dimensions and material properties are determined through measurement and testing and if calculations can be made by normal analytic procedure it shall be permitted to increase strength reduction factor from those specified in BNBC15 and Section 6.11.2.5 and Section 9.3 of ACI318-11 but shall not be more than as specified in Table 8.4:

Table 8.4 Strength Reduction Factor

Type of member	Increased strength reduction factor	Strength reduction factor Specified in BNBC15/ ACI 318-11
Member with spiral reinforcement	0.90	0.75
Other reinforced member	0.80	0.65
Shear and/or torsion	0.80	0.75
Bearing on concrete	0.80	0.65

Strength reduction factors given in Table 8.4 are larger than those specified in the code. These increased values are justified by the use of accurate field –obtained material properties, actual in place dimensions and well understood method of analysis.

If the effect of strength deficiency is not well understood or if it is not feasible to establish the dimensions and material properties by measurement ACI318-11suggested a load test shall be required if the structure is to remain in service. But load test may be impractical and unsafe because of the needed load magnitude, complexity of the loads and testing arrangements required. Performance of load test is beyond the scope of this document.

The size, number and location of steel reinforcing bars need to be established to make an accurate assessment of structural capacity. A variety of electromagnetic devices known as cover meters are used for the purpose. The accuracy of cover meters depends on the meter design, bar spacing and thickness of concrete cover.

Results of cover meters should be verified by drilling or chipping a selected area or areas as deemed necessary to confirm or calibrate the measured the concrete cover and bar size.

8.8 BUILDING CODE

In general, Bangladesh National Building Code (BNBC15) shall be used for design criteria and minimum requirements.

For any load or other data, not available in BNBC 15, the following design code/standard or design guidelines shall be used:

1. International Building Code (IBC) 2006

2. Minimum Design Loads for Buildings and other structures: ASCE/SEI 7-05 Published by American Society of Civil Engineers
3. Minimum Design Loads for Buildings and other structures: ASCE/SEI 7-10 Published by American Society of Civil Engineers
4. The Federal Emergency Management Agency (FEMA) Coastal Construction Manual (CCM)
5. Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary

8.9 MATERIAL PROPERTIES

Concrete. Building structure including foundation, constructed of concrete to resist wind load shall be designed and detailed as per BNBC15 and ACI 318-11 including reference documents like International Building Code 2006, Minimum Design Loads for Buildings and other Structures ASCE/SEI 7-05, Seismic and Wind Design of Concrete Buildings, 2006 IBC/ASCE-SEI 7-05/ACI 318-05 and Minimum Design Loads for Buildings and other Structures ASCE/SEI 7-10

Minimum concrete strength for structural use of reinforced concrete shall be 20 N/mm^2 (3000 psi). However, for buildings up to 4-storey, the minimum concrete strength may be relaxed to 17N/mm^2 (2500psi).

Cement shall conform to the requirements of BDS EN197-1: 2003.
Coarse and fine aggregate and water shall conform to the requirements of BNBC15 and BSTI.
Reinforcement (both Plain and Deformed) shall conform to the requirements of BNBC15 and BSTI (BDS ISO 6935-2:2006).

8.10 DESIGN LOADS (OTHER THAN SEISMIC) AS PER CODE

8.10.1 Dead Load

Dead load consists of self-weight of structure and any superimposed dead load. Self-weight of the structure can be estimated using field measured dimensions of the structure and material densities as presented in Table 8.5. Dimensions obtained solely from design drawing should be used with caution because significant differences can exist between dimensions shown on the design drawing and actual as-built dimensions. The magnitude of superimposed dead load can be estimated by performing a field survey of the building. Consideration should be given to superimposed dead load that may not be present at the time of evaluation but may be applied over the ;life of the building.

In determining dead load for purposes of design, the actual weights of materials and constructions shall be used provided that in the absence of definite information, values approved by the authority having jurisdiction, shall be used.
In determining dead loads for the purpose of design, the weight of fixed service equipment's, such as plumbing stacks and risers, electrical feeders and heating, ventilation and air conditioning system shall be included.

To establish uniform practice among designers, it is desirable to present a list of materials generally used in building construction.

8.10.2 Soil Loads

In the design of structure below grade, provision shall be made for the lateral pressure of adjacent soil. If the soil loads are not given in the soil investigation report approved by the authority having jurisdiction, the soil loads specified in Table 8.6 shall be used as the minimum design lateral load. Due allowance shall be made for possible surcharge from fixed or moving loads.

When a portion or the whole of the adjacent soil is below a free water surface, computations shall be based upon the weight of the soil diminished by buoyancy plus full hydrostatic pressure.

The lateral pressure shall be increased if soils with expansion potential are present at the site as determined by a geological investigation.

In the design of basement floors and similar approximately horizontal elements below grade, the upward pressure of water, where applicable, shall be taken as the full hydrostatic pressure applied over the entire area. The hydrostatic load shall be measured from the underside of the construction.

When expansive soils are present under foundations or slab-on-ground, the foundation slab or other components shall be designed to tolerate the movement or resist the upward loads caused by the expansive soil, or the expansive soil shall be removed or stabilized around and beneath the structure.

In estimating dead load, unit weight of materials and construction shall be used as per Table 8.5.

Table 8.5 Minimum Densities for Design Load from Materials (Ref. C1-2)

Material	Density		
	lb/ft^3	Kg/m^3	kN/m^3
Cement Portland, loose	90	1437	14.1
Ceramic tile	150	2405	23.6
Concrete, plain (stone aggregate)	144	2300	22.6
Concrete plain (brick aggregate)	140	2245	22.0
Concrete reinforced (stone aggregate)	150	2400	23.6
Concrete, reinforced (brick aggregate)	146	2340	23.0
Earth, clay dry (not submerged)	63	1009	9.9
Earth, clay damp (not submerged)	110	1765	17.3
Earth, clay and gravel, dry (not submerged)	100	1600	15.7
Earth, silt, moist, loose (not submerged)	78	1254	12.3
Earth, silt, moist packed (not submerged)	96	1540	15.1
Earth, silt flowing (not submerged)	108	1733	17
Sand and gravel, dry, loose	100	1600	15.7
Sand and gravel, dry, packed	110	1764	17.3
Sand and gravel wet (not submerged)	120	1926	18.9
Earth clay (submerged)	80	1284	12.6
Earth, soil (submerged)	70	1120	11.0
Earth, river mud (submerged)	90	1440	14.1
Sand and gravel	60	960	9.4
Sand or gravel and clay	65	1040	10.2
Glass	160	2560	25.1

Material	Density		
	lb/ft^3	Kg/m^3	kN/m^3
Cast Iron	450	7200	70.7
Wrought iron	480	7685	75.4
Hydrated lime, loose	32	510	5.0
Hydrated lime, compacted	45	725	7.1
Masonry brick (hard, low absorption)	130	2080	20.4
Masonry brick (medium, medium absorption)	115	1885	18.1
Masonry brick (soft, high absorption)	100	1600	15.7
Masonry, Concrete (Light Weight)	105	1682	16.5
Masonry, Concrete (Medium Weight)	125	2003	19.6
Masonry, Concrete (Normal Weight)	135	2163	21.2
Mortar, Cement or Lime	130	20.83	20.4
Granite	153	2450	24.0
Marble	156	2500	24.5
Sand stone	137	2190	21.5
Particle board	45	724	7.1
Plywood	36	580	5.7
Sand, clean & dry	90	1437	14.1
River sand dry	106	1700	16.7
Steel, cold drawn	492	7880	77.3
Water, fresh	62	990	9.7
Water, sea	64	1030	10.1
Tin	459	7350	72.1

6.351 lb. $/ft^3$= 1 kN/m^3= 101.92 kg/m^3 1.0 lb/ft^3 = 16.02 kg/m^3 =0.1572 kN/m

Table 8.6 Design Lateral Soil Load (Ref. C1-2)

Description of Backfill Materials	Design Lateral Soil Load [a]	
	psf per foot of depth	kN/m² per metre of depth
Well graded, clean graved; gravel-sand mixes	35	5.50[b]
Poorly graded clean gravel, grovel-sand mixes	35	5.50[b]
Silty gravel, poorly graded gravel-sand mixes	35	5.50[b]
Clayey gravel, poorly graded gravel-clay mixes	45	7.07[b]
Well graded, clean sand; gravelly-sand mixes	35	5.50[b]
Poorly graded clean sand, sand gravel mixes	35	5.50[b]
Silty sand, poorly graded sand-silt mix	45	7.07 [b]
Sand-silt-clay mix with plastic fines	45	14.35[c]
Clayey sands, poorly graded sand-clay mixes	85	13.35[c]
Inorganic silts and clayey silts	85	13.35[c]
Mixture of inorganic silt and clay	85	13.35[c]
Inorganic clay of low to medium plasticity	100	15.71
Organic silt and silt clays, low plasticity	Unsuitable as backfill materials	
Inorganic clayey silts, elastic silt,		
Inorganic clay of high plasticity		
Organic clays and silty clays		

[a] Design lateral soil loads are given for moist conditions for the specified soils at their optimum densities. Actual field condition shall govern. Submerged or saturated soil pressures shall include the weight of the buoyant soil plus the hydrostatic loads.

[b] [c] For relatively rigid walls, as when braced by floor, the design lateral soil load shall be increased to 60 psf (9.53 kN/m^2) per ft./m for sand and gravel type soil and 100 psf. (15.71 kN/m^2) per foot (m) for silt and clay type soil.. Basement walls extending not more than 8 ft. (2.44m) below grade and supporting light floor system are not considered as relatively rigid walls.

8.10.3 Live Load

The live loads used in the design of buildings and other structures shall be the maximum loads expected by the intended use or occupancy, but shall in no case be less than the minimum uniformly distributed unit loads required by BNBC15.

In office buildings or other buildings where partitions will be erected or rearranged, provision for partition weight shall be made, whether or not partitions are shown on the plan. Partition loads shall not be less than 0.72 kN/m^2 (15 psf)

A partition live load is not required where the minimum specified live load exceeds 3.83 kN/m^2 (80 psf).

Floors, roofs and other similar surfaces shall be designed to support safely the uniformly distributed live loads or the concentrated load described in BNBC15 , whichever produces the greater load effects. Unless otherwise specified, the indicated concentrated load shall be assumed to be uniformly distributed over an area of 0.76x0.76m (2.5x2.5 ft.) and shall be located so as to produce the maximum load effects in the structural members.

Live Load Reduction: Except for roof uniform live loads, all other minimum uniformly distributed live loads may be reduced according to the provisions of BNBC15.

8.10.4 Wind Load

In general, the application of wind force to a building is in the form of pressure that act normal to the surface of the building. Positive (or above ambient) wind pressure (commonly referred to as just pressure) acts towards the surface of the building while negative (or below ambient) pressure (or suction) act away from the surface. For a simple building, positive pressure acts on the windward wall and negative pressure acts on leeward wall, the walls parallel to the direction of the wind and the leeward portion of the roof. Either positive or negative pressure acts on the windward portion of the roof, depending on its slope.

The windward wall receives the wind pressure by bending vertically between lateral supports provided by floor and roof diaphragm. The diaphragm, in turn, transfers these forces to the elements of the lateral force resisting system. The lateral force resisting system transfers these forces to the foundation.

The design of structural members of wind force is based on linear behavior; the structure is assumed to remain elastic under the design wind force.

High wind like cyclone imposes significant forces on a building and its structural elements, specially in the coastal areas. Damage potential increases when the wind forces occur in combination with flood forces. In addition, as a structure is elevated to minimize the effects of flood forces the wind load in the elevated structure may be increased, depending on the amount of elevation and the structure's exposure to wind forces. Therefore, in the coastal areas, wind load should be considered in the design process at the same time as hydrostatic, hydrodynamic, impact, building dead load and live loads.

For coastal areas, where cyclone is normally accompanied by cyclone induced storm surge and coastal flooding, while considering load combination, the maximum effect of appropriate load combination should be considered in design.

The following are the basic parameters in determining wind loads:

- Basic wind speed
- Wind directionally factor
- Building exposure category

- Importance factor
- Topographic factor
- Gust effect factor
- Enclosure classification
- Internal pressure coefficient
- External pressure coefficient

Earthquake and wind load need not be assumed to act simultaneously. In some instances, forces due to wind might exceed those due to earthquake, while ductility requirements might be determined by earthquake load.

Scope and design procedure for wind loads have been discussed in detail in Chapter 10.

8.10.5 Flood Load

8.10.5.1 Introduction

Building or other structures located in flood prone areas may be affected by the flood due to overflow of stream channels (Riverine flood), storm surge due to cyclone, unusually high astronomical tide or tsunami. Flood can also be the result of accidental situation such as breaching of a levee or dam. Flood actions describe those effects that a flood could directly impose on a building, potentially causing damage or even structural failures.
These flood actions include:

- hydrostatic forces
- buoyancy (hydrostatic force acting in the upward direction)
- hydrodynamic forces
- forces generated by the impact of flood borne debris or other objects
- forces generated by the impact of breaking waves

The adverse effect of flood actions can be aggravated by water-induced scour and by long-term erosion. These can lower the ground surface around the building foundation which could cause lowering of load-bearing capacity and thus the loss of structural resistance to lateral and uplift force. There might also be sediment deposition and aggradations against building components generating additional unforeseen loading. Coastal areas subjected to flooding can be designated into two categories: (Ref. C1-2)

- Coastal A-Zone (Risk area as per Fig. 12.1)
- Coastal High Hazard Area (V-Zone) (High risk area Fig. 12.1)

To be classified as coastal A-Zone, the principal source of flooding must be astronomical tides, storm surges, seiches or tsunami, not riverine flooding. Coastal A-Zones lie landward of V-Zones or landward of a open coast shoreline where V-Zones have not been demarcated. Coastal A- zones are subjected to the effects of waves, high velocity flows, and erosion, although not to the extent those V-zones are. Like V-zones, flood force in coastal A-zones will be highly correlated with coastal winds or coastal seismic activity.

In order for a Coastal A-Zone to be present, two conditions are required:

- a still water flood depth greater than or equal to 0.61m (2.0 ft.)
- breaking wave heights greater than or equal to 0.46m(1.5 ft.)
- forces generated by the impact of flood borne debris.

It is to be noted that still-water depth requirement is necessary but is not sufficient by itself, to render an area as Coastal A-zone. Many flood affected areas will have still water flood depth in access of 0.61m (2.0 ft.) but will not experience breaking wave heights greater than or equal to 0.46m (1.5 ft.) and therefore should not be considered Coastal A-Zone.

Coastal High Hazard Area (V-zone) extends from offshore to the inland limit of a primary frontal dune along an open coast and any other area that is subjected to high velocity wave action from storm or seismic sources.

Generally speaking, A-Zones are designated where wave less than 0.9m (3.0 ft.) is expected. V-Zones are designated where wave height greater than 0.9m (3.0 ft.) is expected.

8.10.5.2 Hydrostatic Loads

Hydrostatic loads are those that exert pressure by still and slow moving water having velocities less than 1.52m/s (5.0 fps) on a building or building components such as columns, walls, doors and windows etc. During any point of flood water contact with a structure, hydrostatic pressures are equal in all direction and always act perpendicular to the surface on which they are applied. Pressure increases linearly with depth or "head" of water above the point under consideration. The summation of pressure over the surface under consideration represents the load acting on that surface.

Fore structural analysis, hydrostatic forces, as shown in Fig. 13.2 of Chapter13 are defined to act:

- Vertically downward on structural elements such as flat roofs and similar overhead members having a depth of water above them
- Vertically upward (uplift) from underside of generally horizontal members such as slabs, floor diaphragms and footings (also known as buoyancy); and
- Laterally, in a horizontal direction on walls, piers and similar vertical surfaces. (For design purpose, this lateral pressure is generally assumed to act on the receiving structure at a point one-third of the water depth above the base of the structure or two third of the altitude from the water surface, which correlates to the centre of gravity for a triangular pressure distribution).

Hydrostatic forces include lateral water pressure, combined water and soil pressure, equivalent hydrostatic pressure due to velocity flows, and vertical (buoyancy) water pressure. The computation of each of this pressure is illustrated in Chapter 13.

For the purpose of this manual, it has been assumed that hydrostatic conditions prevail for still water and water moving with a velocity of less that 3m/sec (10 ft/sec).

Hydrostatic loads generated by velocities up to 3m/sec (10ft/sec) may be converted to a hydrostatic load using conversion equation presented in Chapter 13

8.10.5.3 Hydrodynamic Load

When flood water flows around structures it imposes additional loads on the structure. These loads are a function of flow velocity and structural geometry.

Low velocity hydrodynamic forces are defined as situations where flood water velocities do not exceed 3m/sec (10 ft/sec) while high velocity hydrodynamic forces involve flood water velocities in excess of 3m/sec (10 ft/sec).

Hydrodynamic loads includes frontal impact on the upstream side of the structure, drag along the sides, and suction or negative pressure on down stream side. These load are induced by flow of water moving at moderate to high (>3m/sec) velocity. They are usually called the drag force, which are combination of lateral loads caused by the impact of the moving mass of water, and the frictional forces as the water flows around the obstruction.

8.10.5.4 Impact Loads

Impact loads are imposed on the structure by object carried by the moving water such as driftwood, small boats, portion of houses, tree logs etc. The magnitude of these loads is very difficult to predict but some reasonable allowance must be made in the design of retrofitting measures for potentially affected buildings. To arrive at a realistic allowance, considerable judgment must be used and consideration of the degree of exposure of the structure. Impact loads are classified as:

- no impact (for areas of little or no velocity or potential source of debris)
- normal impact loads result from isolated impacts of normally encountered objects.
- special impact loads result from large objects such as broken up ice floats and accumulation of debris, cither striking or resting against a building, structure or part thereof.
- extreme impact loads result from very large objects such as boats, barges or collapsed building striking the building, structure or part thereof.

Normal impact forces relate to isolated occurrence of typically sized debris or floating objects striking the structure. For design purpose, this can be considered a concentrated load acting horizontally at the flood elevation or any point below it, equivalent to the impact force created by a typical object traveling at the velocity of the flood water acting on a .093 sqm (1 sq. foot) surface of submerged structure at perpendicular to the flow.

Special impact forces occur when large object or conglomerates of floating objects, such as ice floats, or accumulation of floating debris, strike a structure. When stable natural or artificial barriers exist that would effectively prevent these special impact forces from occurring, these forces may not need to be considered in design.

Details for calculating special impact loads are outlined in Chapter 13.

Extreme impact forces occur when large floating objects such as runway barges or collapsed buildings and structures strikes the structure or component of the structure. These forces generally occur within the floodway or areas of flood plain that experience the highest velocity flow.

Design for extreme impact loads is not practical for most buildings and structures. However, in cases where their is high probability that a Category III or IV structure (see Table 10.2 of Chapter 10) will be exposed to extreme impact loads during the design flood and where the resulting damage will be very severe, consideration of extreme impact load may be justified. Unlike extreme impact loads, design for special and normal impact loads is practical for most buildings and structure.

8.10.5.5 Breaking Wave Loads

Breaking wave loads are those loads that result from water waves propagating over the water surface and striking a building or other structures. Design and construction of buildings or other structures subject to wave loads shall account for the following loads:

- Waves break on any portion of the building or structure;
- Uplift forces cause by shoaling waves beneath a building or structure or portion thereof;
- Wave run-up striking waves beneath a building or structure or portion thereof;
- Wave- induced drag or inertia forces;
- Wave induced scour at the base of the building or structure, or its foundation.

Wave loads shall be included for both V-zones and A-zones. In V-zones waves are 0.91m(3.0 ft.) high or higher; in coastal flood plains landward of the V-zone, waves are less than 0.91 (3.0 ft.)

The impact of waves is one of the most important factors in the estimation of vulnerability and flood damage to coastal zones. As discussed in FEMA (2000) only highly engineered, massive structural elements are capable of withstanding breaking wave forces.
The magnitude of wave forces (kN/m^2) (lb/ft^2) acting against buildings or other structures can be 10 or more times higher than wind forces and other forces under design conditions (Ref. 1.2). As such it is always preferable to elevate the building above the wave crest for the survival of the building where there is possibility of large waves striking the building. Even for elevated buildings the wave shall strike on the small surface areas of supporting structures like columns and can also cause erosion of foundation.

There are two breaking wave load cases that are relevant to buildings:

- Breaking wave loads on vertical columns
- Breaking wave loads on vertical walls.

The net force resulting from breaking waves acting on a rigid column is assumed to act at the still water level.

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:

- Where the wave breaks against a vertical wall of an enclosed dry space.
- Where the still water level on both side of the wall is equal.

Case 1 is equivalent to a wave breaking against an enclosure in which there is no flood water below the still water level.

Case 2 is equivalent to a wave breaking against a wall with openings that allow flood water to equalize on both sides of the wall.

The computation of each of these forces is illustrated in Chapter 13.

CHAPTER 9
LOAD COMBINATION

9.1 SYMBOLS AND NOTATIONS

D = dead load

E = earthquake load

F= load due to fluid with well-defined pressure and maximum height

F_a= flood load

H = load due to lateral earth pressure, ground water pressure or pressure of bulk materials.

L= live load

L_r = roof live load

R = rain load

T = self-straining force

W= Wind load

9.2 APPLICABILITY

Load factors and load combinations given in this section shall apply to both ultimate strength design(USD) as well as allowable stress design (WSD).

The basic idea of the load combination scheme to that in addition to dead load, which is considered to the permanent, one of the variable loads takes on its maximum life time value while the other variable loads assume "arbitrary point-in-time" values, the latter being loads that would be measured at any instant of time. This is consistent with the manner in which loads actually combine in situations in which strength limit states may be approached.

9.3 COMBINING FACTORED LOADS USING STRENGTH DESIGN

When strength design method is used, structural members, components and foundations shall be designed to have strength not less than that required to resist the most unfavorable effects of the combination of factored loads listed below as per BNBC15 and ASCE7-5:

1. $1.4\,(D+F)$
2. $1.2\,(D+F+T) + 1.6\,(L+H) + 0.5\,(L_r \text{ or } R)$
3. $1.2\,D + 1.6\,(L_r \text{ or } R) + (1.0\,L \text{ or } 0.8\,W)$
4. $1.2D + 1.6W + 1.0L + 0.5\,(L_r \text{ or } R)$
5. $1.2D + 1.0E + 1.0\,L$
6. $0.9D + 1.6W + 1.6\,H$
7. $0.9D + 1.0E + 1.6\,H$

Exception (Ref C1-1 and C1-2)

1. The load factor in live load L in combinations (3) (4) and (5) is permitted to be reduced to 0.5 for all occupancies in which minimum specified uniformly distributed live load is less than or equal to 4.8 kN/m^2 (100 psf) with the exception of garages or areas occupied as places of public assembly.
2. The load factor on H shall be set equal to zero in combinations (6) and (7) if the structural action due to H counteracts that due to W or E.

   Where lateral earth pressure provides resistance to structural action from other forces, it shall not be included in H but shall be included in the design resistance.

   Each relevant strength limit state shall be investigated. Effects of one or more loads not acting shall be investigated. The most unfavorable effects from both wind and earthquake loads shall be investigated, where appropriate, but they need not be considered to act simultaneously.

9.4 LOAD COMBINATION INCLUDING FLOOD LOAD

When a structure is located in a flood zone or in tidal surge area (see sec. 8.6.5), the following load combination shall be consider (Ref. C1-2).

1. In V-Zones or Coastal A-Zones, $1.6W$ in combinations (4) and (6) shall be replaced by $1.6W + 2.0\ F_a$. (For V-zones and Coastal A-Zones refer Section 8.7.5.1)
2. In non-coastal A-Zones, $1.6W$ in combination (4) and (6) shall be replaced by $0.8W+1.0\ F_a$.

The relatively high flood load factor stems from the high variability in floods relative to other environmental loads. The presence of $2.0F_a$ in both combinations (4) and (6) in V- Zones and Coastal A- Zones is the result of high stochastic dependence between extreme wind and flood in cyclone-prone coastal zones (Ref. C1-2).

Flood loads are unique in that they are initiated only after the water level exceeds the local ground elevation. As a result statistical characteristics of flood loads vary with ground elevation. The load factor 2.0 is based on calculations (including hydrostatic, steady flow and wave forces) with still-water flood depths ranging from approximately 1.22 - 2.74m (4.0-9.0 ft) and applies to a wide variety of flood conditions. The load factor 2.0 is based on the recognition that flood loads of most importance to structural design occur in situations where the depth of flooding is greatest (Ref. C1-2).

No separate load combination has been given for tsunami load. However tsunami load and storm surge load effects on building and other structures are strikingly similar. Similar load combinations can be adopted for design. In case of tsunami, surge front velocity may be taken as twice the flood water velocity due to storm surge which is considered by many engineers as a conservative value. (Refer Table 13.5)

For combination (4), in case of cyclone shelter or other infrastructures used as shelter during cyclone and tidal surge, the combination 0.5 (L_r or R) shall be replaced by L_r and no reduction is live load shall be considered.

Load combinations (6) and (7) apply specifically to the cases in which the structural actions due to lateral forces and gravity loads counteract one another.

Fluid load, F, defines structural actions in structural supports, framework, or foundations of a storage tank, vessel or similar container due to stored liquid products. The product in a storage tank shares characteristics of both dead and live loads. It is similar to a dead load in that its weight has a maximum calculated value. However, it is not permanent; emptying and filling causes fluctuating forces in the structure, the maximum load may be exceeded by overfilling; and densities of stored products in a specific tank may vary. Adding F to combination 1 provides additional conservation for situations in which F is the dominant load.

It should be emphasized that uncertainties in lateral forces from bulk materials, included in H, are higher than those in fluids, particularly when dynamic effects are introduced as the bulk materials is set in motion by filling on emptying operation. Accordingly, the load factor for such load is set equal to 1.6.

Wind and earthquake loads need not be assumed to act simultaneously. However, the most unfavorable effects of each should be considered separately in design, where appropriate. ***In some instances, forces due to wind might exceed those due to earthquake, while ductility requirements must be determined by earthquake loads.***

9.5 IMPACT LOADING

The live load specified in BNBC shall be assumed to include adequate allowance for ordinary impact conditions. Provision shall be made in the structural design for uses and loads that involve unusual vibration and impact forces.

For the purpose of design, the weight of machinery and moving loads shall be increased as follows to allow for impact:

Table 9.1 Load increase due to Impact and Vibration

Type of Machinery	Increase in percentage
Elevator machinery	100 percent
Light machinery, shaft- or motor driven	20 percent
Reciprocating machinery or power driven unit	50 percent
Hanger for floor or balconies	33percent

All percentages shall be increased where specified by the manufacturer.

9.6 COMBINING NOMINAL LOADS USING ALLOWABLE STRESS DESIGN

Provision of this section shall apply to all construction materials permitting their use in proportioning structural members by allowing stress design method. When this method is used in designing structural members, all loads listed here shall be considered to act in the following combination. The combination that produces the most unfavourable effects shall be used in the design.

1. D
2. $D + L$
3. $D + F$
4. $D + H + F + L + T$

5. $D + H + F + (L_r \text{ or } R)$
6. $D + H + F + 0.75(L + T) + 0.75 (L_r \text{ or } R)$
7. $D + H + F + (W \text{ or } 0.7E)$
8. $D + H + F + 0.75 (W \text{ or } 0.7E) + 0.75L + 0.75(L_r \text{ or } L)$
9. $D+L+(W \text{ or } 0.7E)$
10. $0.6D+ W + H$
11. $0.6D+0.7E + H$

When a structure is located in a flood zone or tidal surge zone, the following load combination shall be considered:

1. In coastal zones vulnerable to tidal surge 1.5 F_a shall be added to other loads in combination (7), (8), (9) and (10) and E shall be set equal to zero in (7), (8) and (9).
2. In non- coastal zone, $0.75F_a$ shall be added to combination (7), (8), (9) and (10) and E shall be set equal to zero in (7), (8) and (9).

There is slight difference between BNBC15 and ASCE7- 05 in that the load combinations (1), (2) and (9) of BNBC is not there in ASCE7-05.

9.7 LOAD COMBINATION FOR EXTRAORDINARY EVENTS

There is no load combination for extraordinary events both in BNBC 13 and ASCE 7-05. ASCE 7-05 also states that traditionally, extraordinary events are not considered explicitly in the design of ordinary buildings and structures for the reason that probability of exposing to such events like fire, explosion of volatile materials, sabotage, tornado etc. is very low and usually of shorter duration. The occurrence of any of these events is likely to lead to structural damage or failure.

Good design practice requires that structures be robust and that their safety and performance not be sensitive to uncertainties in loads, environmental influences and other situations not explicitly considered in design. The structure should be designed in such a way that if an extraordinary event occurs, the probability of damage disproportionate to the original event is sufficiently small.

In general, structural system should be designed with sufficient continuity and ductility that alternate load path can develop following individual member failure so that failure of the structure as a whole does not ensure.

ASCE 7-10 has suggested load combination for extraordinary event.

Applicability: Where required by the owner or applicable code, strength and stability of the structure shall be checked to ensure that the structure is capable of withstanding the effects of extraordinary (low-probability) events such as fires, explosions etc. without disproportionate collapse.

For checking the capacity of the structure to withstand the effect of an extraordinary event, the following gravity load combination shall be considered:

$(0.9 \text{ or } 1.2)D + A_s + 0.5L$

in which A_s = load or load effect resulting from extraordinary event A.

9.8 LOAD COMBINATION AS PER ASCE 7-10 AND ACI 318-11

ASCE7-10 has modified and suggested the following load combinations which has been adopted by ACI318-11.

9.8.1 Combining Factored Loads using Strength Design

1. $1.4\,D$
2. $1.2\,D + 1.6\,L + 0.5\,(L_r \text{ or } R)$
3. $1.2\,D + 1.6\,(L_r \text{ or } R) + (1.0\,L \text{ or } 0.5\,W)$
4. $1.2\,D + 1.0\,W + 1.0\,L + 0.5\,(L_r \text{ or } R)$
5. $1.2D + 1.0\,E + 1.0\,L$
6. $0.9D + 1.0\,W$
7. $0.9D + 1.0E$

9.8.2 Combining Nominal Loads using Allowable Stress Design

1. D
2. $D + L$
3. $D + (L_r \text{ or } R)$
4. $D + 0.75\,L + 0.75\,(L_r \text{ or } R)$
5. $D + (0.6\,W \text{ or } 0.7\,E)$
6. $D + 0.75\,L + 0.75\,(0.6\,W) + 0.75\,(L_r \text{ or } R)$
7. $D + 0.75\,L + 0.75\,(0.7\,E)$
8. $0.6\,D + 0.6\,W$
9. $0.6\,D + 0.7\,E$

For further details consult ASCE 7-10 and ACI 318-11.

HAPTER 10
WIND LOAD ANALYSIS

10.1 METHOD 1- SIMPLIFIED PROCEDURE

10.1.1 Scope

BNBC15 Section 2.4.2 as well as ASCE 7-05-6.4 contain a simplified method that is allowed to be used for determining wind forces on low-rise enclosed building with flat, gabled or hipped roof, provided it satisfied the requirements of Section 10.1.2.

10.1.2 Main Wind Force Resisting System

For the design of Main Wind-Force-Resisting System, the building must meet all of the following conditions:

1) The building is a simple diaphragm building, that is, a building in which both windward and leeward wind loads are transmitted through floor and roof diaphragm to the same vertical MWFRS (e.g., no structural separation).

2) The building is a low rise building that complies with the following conditions:
   a) Mean Roof height h is less than or equal to 18.3m (60.0ft)
   b) Mean roof height h does not exceed least horizontal dimension

3) The building does not comply with the requirements for open or partially enclosed buildings.
   a) Open Building: A building having each wall at least 80 percent open. This condition is expressed for each wall by the following expression:

      $A_o \geq 0.8 A_g$

      where;

      A_o = total area of opening in a wall that receives positive external pressure in m^2 (ft^2)

      A_g = the gross area of that wall in which A_o is identified, in m^2 (ft^2)

   b) Partially Enclosed Building: A building that complies with both of the following conditions:

   i) The total area of opening in a wall that receives positive external pressure exceeds the sum of the areas of opening in the balance of the building envelope (walls and roof) by more than 10 percent

   ii) The total area of openings in a wall that receives positive external pressure exceeds $0.37m^2$(4.0 sft) or 1 percent of the area of that wall, whichever is smaller and the percentage of openings in the balance of the building envelope does not exceed 20 percent.

   These conditions are expressed by the following expressions:

   $A_o > 1.10 A_{oi}$

   $A_o > 0.37m^2$ (4sft.) or $> 0.01 A_g$ whichever is smaller and $A_{oi} / A_{gi} \leq 0.20$

   where;

   A_o, A_g are as defined for open building.

A_{oi} = the sum of the areas of openings in the building envelope (walls and roof) not including A_o, in m^2 (ft^2)

A_{gi} = the sum of the gross surface areas of the building envelope (walls & roof) not including A_g, in m^2 (ft^2)

4. The building is a regular-shaped building having no unusual geometrical irregularity in spatial form.
5. The building is not a flexible (slender) building and has a fundamental natural frequency greater than or equal to 1 Hz.
6. The building does not have response characteristics making it subject to across wind loading, vortex shedding, and instability due to galloping or flutter and does not have a site location for which channeling effect or buffeting in the wake of upwind obstruction warrants special consideration.
7. The building has an approximately symmetrical cross section in each direction with either a flat roof or a gable or hip roof with $\Theta \leq 45^0$.

10.1.3 Components and Claddings

For the design of components and cladding the building must meet all of the following conditions:

1. The mean roof height h must be less than or equal to18.3 m (60.0 ft.).
2. The building is enclosed as defined in Section 10.1.2 (3).
3. The building is a regular shape building as defined in Section 10.1.2(4).
4. The building does not have response characteristics as defined in section 10.1.2(6).
5. The building has either a flat roof, a gable roof with $\Theta \leq 45^0$ or a hip roof with $\Theta \leq 27^0$.

10.1.4 Design Procedure

1. *The basis wind speed V* used in the determination of design wind load shall be as per Table 10.1. The wind shall be assumed to come from any direction.

Table10.1 has been prepared on the basis of Table 6.2.8 Part6 of BNBC15

Table 10.1 Basic Wind Speed (3-second gust speed) for selected locations of Bangladesh
(Ref. BNBC15: Table 2.4.1 Part6) (1 m/s = 3.60 km/h = 2.236 mph)

Location	Basic Wind Speed		
	m/s	Km/h	mph
Angorpota	47.8	172.10	106.88
Bagerhat	77.5	279.00	173.30
Bandarban	62.5	225.00	140.00
Barguna	80.0	288.00	179.00
Barisal	78.7	283.32	176.00
Bhola	69.5	250.20	155.40
Bogra	61.9	222.84	138.40
Brahmanbaria	56.7	204.12	126.78
Chandpur	50.6	182.16	113.14
Chapai Nowabgonj	41.4	149.04	92.57
Chittagong	80.0	288.00	179.00
Chuadanga	61.9	222.84	138.40
Comilla	61.4	221.04	137.30
Cox's Bazar	80.0	288.00	179.00
Dahagram	47.8	172.10	106.88
Dhaka	65.7	236.52	146.90
Dinajpur	41.4	149.04	92.57
Faridpur	63.1	227.16	141.10
Feni	64.1	230.76	143.33
Gaibanda	65.6	236.16	146.68
Gazipur	66.5	239.40	148.70
Gopalgonj	74.5	268.20	166.58
Habigonj	54.2	195.12	121.20
Hatiya	80.0	288.00	179.00
Ishurdi	69.5	250.20	155.40
Joypurhat	56.7	204.12	126.78
Jamalpur	56.7	204.12	126.78
Jessore	64.1	230.76	143.33
Jhalokathi	80.0	288.00	179.00
Jhenaidah	65.0	234.00	145.34
Khagrachari	56.7	204.00	126.78
Khulna	73.3	263.88	163.90
Kutubdia	80.0	288.00	179.00
Kishoregong	64.7	232.92	144.67
Kurigram	65.6	236.16	146.68
Kushtia	66.9	240.84	149.59
Laksmipur	51.2	184.32	114.48

Location	Basic Wind Speed		
	m/s	Km/h	mph
Lalmonirhat	63.7	229.32	142.43
Madaripur	68.1	245.16	152.27
Magura	65.0	234.00	145.34
Manikgonj	58.2	209.52	130.14
Meherpur	58.2	209.52	130.14
Maheshkhali	80.0	288.00	179.00
Moulovibazar	53.0	190.80	118.51
Munshigonj	57.1	205.56	127.68
Mymensingh	67.4	242.64	150.71
Naogoan	55.2	198.72	123.43
Norail	68.6	246.96	153.40
Narayangonj	61.1	220.00	136.62
Narsinghdi	59.7	214.92	133.49
Natore	61.9	222.84	138.41
Netrokona	65.6	236.16	146.68
Nilphamari	44.7	160.92	100.00
Noakhali	57.1	205.56	127.68
Pabna	63.1	227.16	141.10
Panchagorh	41.4	149.04	92.57
Patuakhali	80.0	288.00	179.00
Pirojpur	80.0	288.00	179.00
Rajbari	59.1	212.76	132.15
Rajshahi	49.2	177.12	110.00
Rangamati	56.7	204.12	126.78
Rangpur	65.3	235.08	146.01
Satkhira	57.6	207.36	128.80
Shariatpur	61.9	222.84	138.41
Sherpur	62.5	225.00	139.75
Sirajgonj	50.6	182.16	113.14
Srimongal	50.6	182.16	113.14
St. Martin Island	80.0	288.00	179.00
Sunamgonj	61.1	220.00	136.62
Sylhet	61.1	220.00	136.62
Sandwip	80.0	288.00	179.00
Tangail	50.6	182.16	113.14
Teknaf	80.0	288.00	179.00
Thakurgaon	41.1	147.96	91.90

Table10. 2 Occupancy Categories of Buildings and Other Structures for Flood, Surge, Wind and Earthquake Loads (Table 6.1.1 of BNBC 15)

Nature of Occupancy	Occupancy Category
Building and other structures that represents 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 buildings and other structures except those listed in Category I,III, and IV	II
Building and other structures that represent a substantial hazard to human life in the event of failure, including, but not limited to: • Buildings and other structures where more than 300 people congregate in one area • Buildings and other structures with daycare facilities with a capacity greater than 150 • Buildings and other structures with elementary school or secondary school facilities with capacity greater than 250 • Building and other structures with capacity greater than 500 for colleges or adult education facilities • Health care facilities with capacity of 50 or more residential patients but not having surgery or emergency treatment facilities • Jails and detention facilities Building and other structures, not included in Occupancy Category IV, with potential to cause a substantial economic impact and/ or mass disruption of day- to- day civilian life in the event of failure, including, but not limited to: • Power generating station[1] • Water treatment facilities • Sewage treatment facilities • Telecommunication centres Building and other structures not included in Occupancy Category IV (including, but not limited to, facilities that process, manufacture, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released	III
Building or other structures designated as essential facilities, including, but not limited to: • Hospitals and other health care facilities having surgery or emergency treatment facilities • Fire, rescue, ambulance, and police station and emergency vehicle garage • Designated earthquake, cyclone, or other emergency shelters • Designated emergency preparedness, communication, and operation centers and other facilities required for emergency response • Power generating stations and other public utility facilities required in an emergency • Ancillary structures (including, but not limited to, communication towers, fuel storage tanks, cooling towers, electrical substation structures, fire water storage tanks or other structures housing or supporting water or other fire-suppression material or equipment) required for operation of Occupancy Category IV structures during an emergency • Aviation control towers, air traffic control centers, and emergency aircraft hangers • Water storage facilities and pump structures required to maintain water pressure for fire suppression • Buildings and other structures having critical national defense function Building and other structures(including, but not limited to, , facilities that process, manufacture, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals hazardous waste) containing highly toxic substances where the quantity of the material exceeds a threshold quantity established by the authority having jurisdiction.	IV

[1] Power generating plants that do not supply power to the national grid shall be designated Occupancy Category II

2. *An importance factor I* shall be determined for the building from Table 10.3 based on Table 10.2

Table10.3 Importance Factor *I* (Wind Loads) (BNBC15: Table 6.2.9: Part6)

Category or Importance Class	Non-cyclone[1] Prone Regions and Cyclone Prone Regions with V= 38- 44m/s (38m/s =137km/h = 85mph)	Cyclone Prone Regions with V > 44 m/s (44m/s = 158.4km/h = 98.4mph)
I	0.87	0.77
II	1.00	1.00
III	1.15	1.15
IV	1.15	1.15

[1]Cyclones in Indian Ocean and hurricanes in Atlantic Ocean and Eastern Pacific Ocean are synonymous

3. *An exposure category* shall be determined for each wind direction based on ground surface roughness that is determined from natural topography, vegetation and constructed facilities as per section 10.1.8.

4. *A height and exposure adjustment coefficient* λ shall be determined from Table 10.4

Table 10.4 Height and Exposure Adjustment Coefficient λ

[BNBC15: Fig. 6.2.2 Part6]

Adjustment Factor For Building Height and Exposure λ				
Mean roof height		Exposure		
ft	meter	A	B	C
15	4.6	1.00	1.21	1.47
20	6.0	1.00	1.29	1.55
25	7.6	1.00	1.35	1.61
30	9.1	1.00	1.40	1.66
35	10.7	1.05	1.45	1.70
40	12.2	1.09	1.49	1.74
45	13.7	1.12	1.53	1.78
50	15.2	1.16	1.56	1.81
55	16.8	1.19	1.59	1.84
60	`18.3	1.22	1.62	1.87

10.1.5 Exposure

For each wind direction considered, the upwind exposure category shall be based on ground surface roughness that is determined from natural topography, vegetation and constructed facilities.

10.1.6 Wind Directions and Sectors

For each selected wind direction at which the wind loads are to be evaluated, the exposure of the building shall be determined for the two upwind sectors extending 45^0 either side of the selected wind direction. The exposure in these two sectors shall be determined in accordance with Section10.1.7 and 10.1.8 and the exposure resulting in the highest wind loads shall be used to represent the wind from that direction.

10.1.7 Surface Roughness Categories

A ground surface roughness within each 45^0 sector shall be determined for a distance upwind of the site from the categories defined in the following text for the purpose of assigning an exposure category as defined in Section 10.1.8

Surface Roughness A: Urban and suburban areas, wooded areas or other terrain with numerous closely spaced obstructions having the size of single family dwellings or larger.

Surface Roughness B: Open terrain with scattered obstructions having heights generally less than 9.1m (30.0 ft). This category includes flat open country, grasslands, and all water surfaces in cyclone prone regions.

Surface roughness C: Flat, unobstructed areas and water surfaces outside cyclone prone areas.

10.1.8 Exposure Categories

Exposure A (Exposure B of ASCE): For a building with a mean roof height of less than 9.1m(30.0 ft),Exposure A shall prevail where the ground surface roughness, as defined by Surface Roughness A, prevails in the upwind direction for a distance greater than 457.0m (1500.0 ft).

For a building with a mean roof height greater than 9.1m (30.0 ft) Exposure A shall apply where Surface Roughness A prevails in the upward direction for a distance greater than 793.0 m (2600.0ft) or 20 times the height of building, whichever is greater.

This definition of Exposure A is shown pictorially in Fig 10.1.

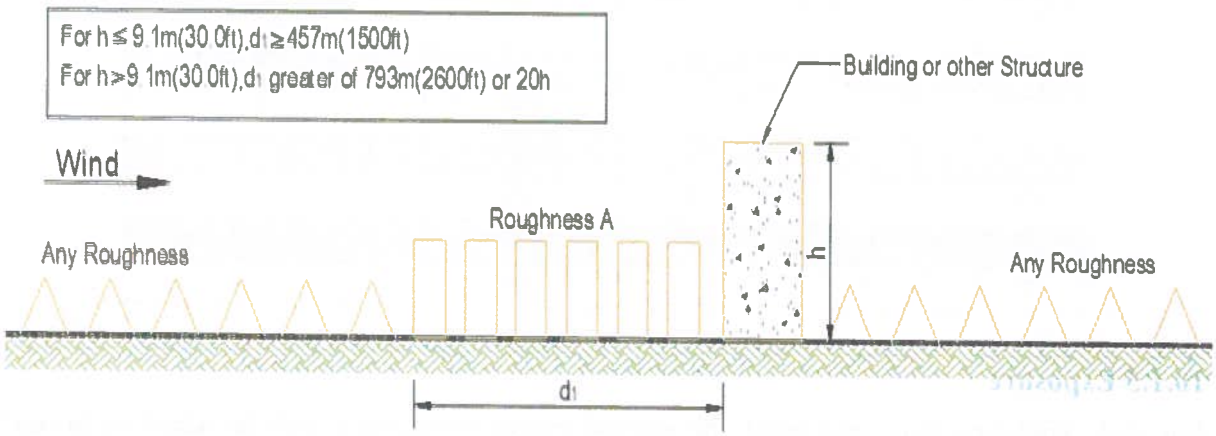


Figure 10.1 Upwind Surface Roughness Condition Required for Exposure A (Surface Roughness/ Exposure A of BNBC 15 is equivalent to B of ASCE7)

This definition of Exposure A applies for the Surface Roughness A condition prevailing 793.0m (2600.0 ft) upwind with insufficient "***open patch***" as defined in the following text to disqualify the use of Exposure A.

a) An opening in the Surface Roughness A large enough to have a significant effect on the exposure category determination is defined as an "***open patch***". An open patch is defined as an opening greater than or equal to approximately 50.0 m (164.0 ft) on each side [i,e, greater than 50.0m x 50.0m (164.0 ft. x164.0 ft.)]. Opening smaller than this need not be considered in the determination of exposure category.

10.1.9 Design of Main Wind Force Resisting System

The effect of open patches of Surface Roughness B or C on the use of Exposure A is shown pictorially in Fig.10.2 and Fig.10.3.

10.1.10 Design of Components and Claddings

10.2 METHOD 2- ANALYTIC PROCEDURE

10.2.1 Scope

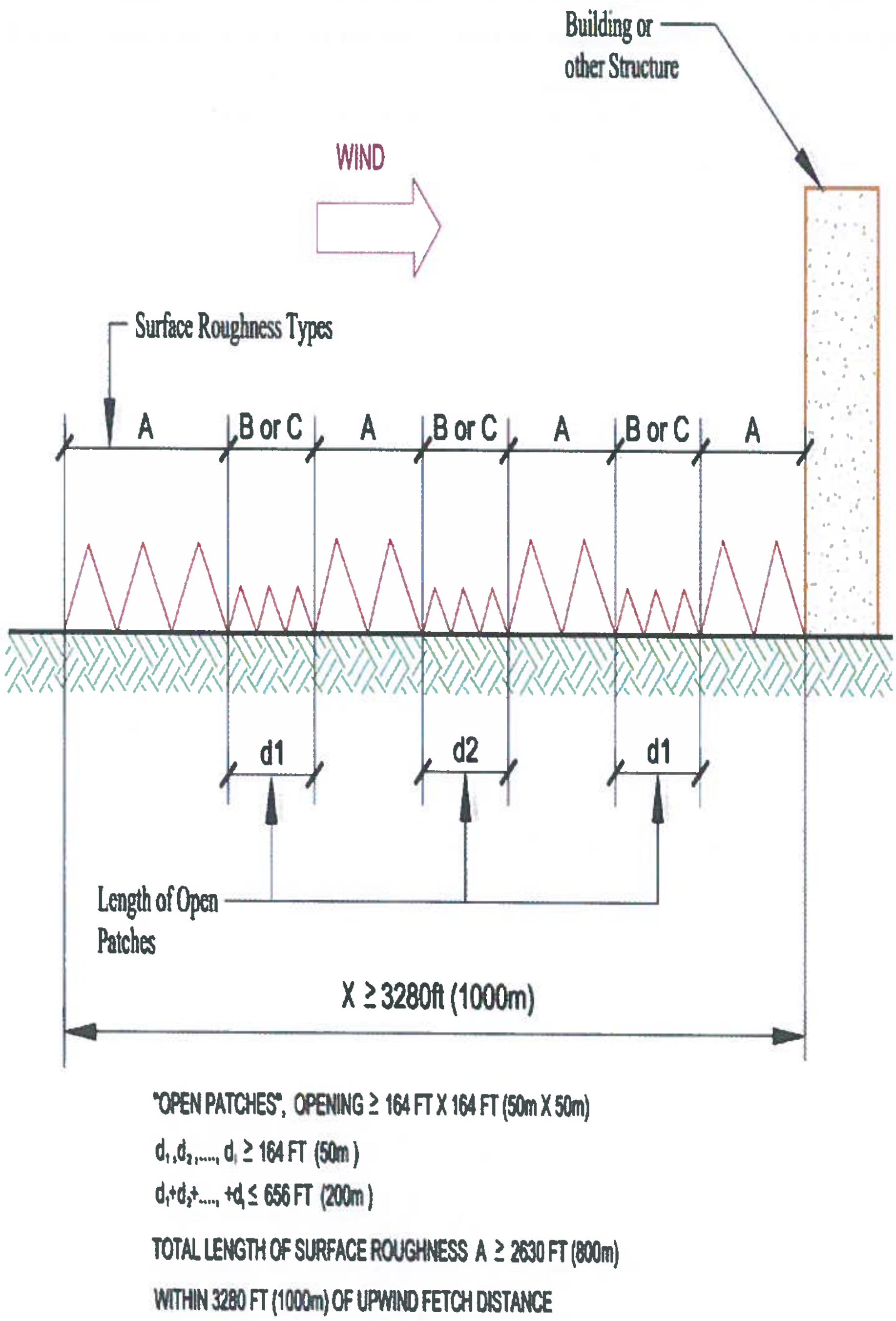
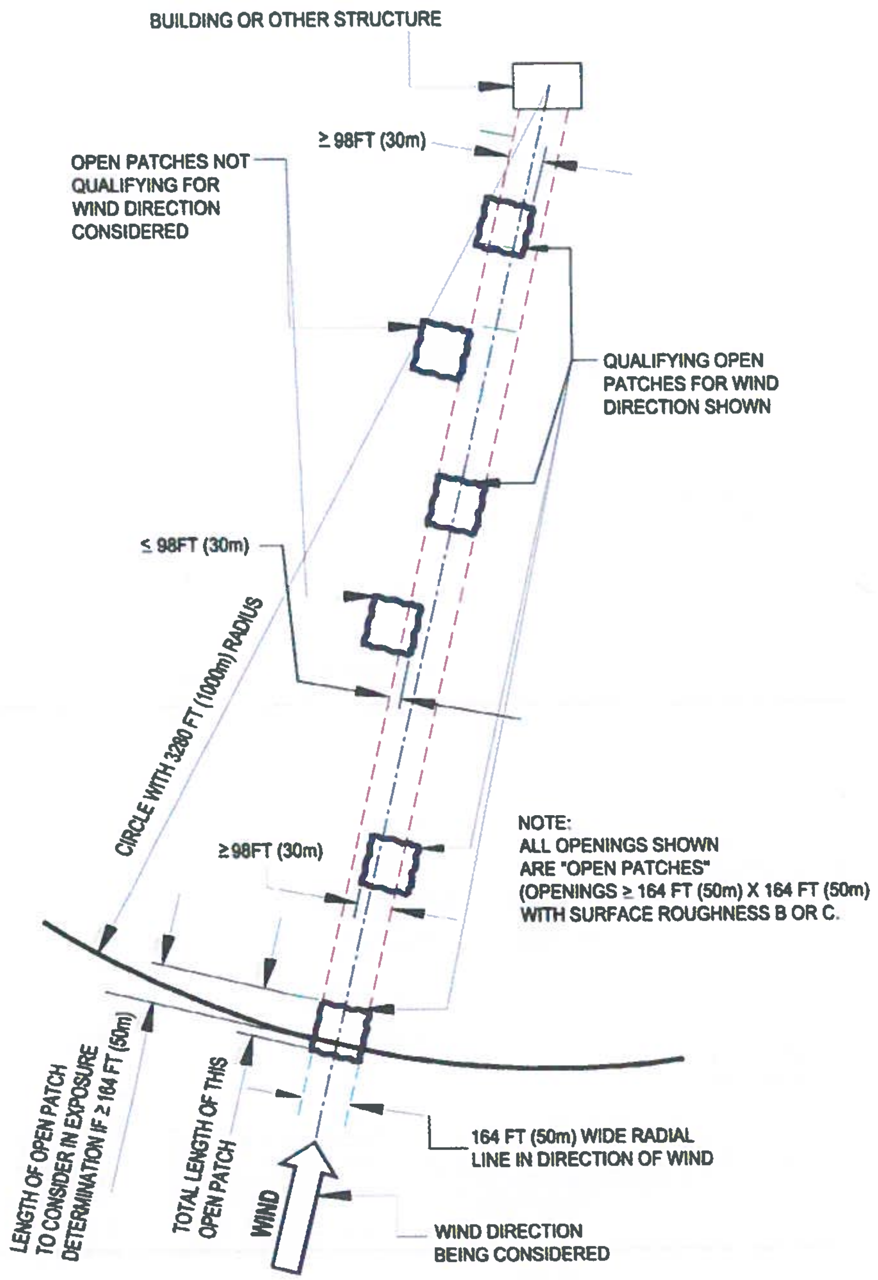


Figure 10.2 Exposure A with Upwind Open Patches



[Exposure as per BNBC. For ASCE 7, A shall be replaced by B.]

Figure 10.3 Exposure A with Upwind Open Patches

Exposure B shall apply for cases where *Exposure A* or *Exposure C* does not apply.

Exposure C shall apply where the ground surface roughness as defined by Surface Roughness C, prevails in the upwind direction for a distance greater than 1524m (5000 ft.) or 20 times the building height, whichever is greater. Exposure C shall also apply where the ground surface roughness immediately upwind of the site is A or B and the site is within a distance of 200.0 m (600.0 ft) or 20 times the height of building whichever is greater from an Exposure C condition as defined in previous sentence.

10.1.7 Surface Roughness Categories

Upwind surface roughness conditions required for Exposure C are shown schematically in Figs.10.4 (a) and (b)

Surface Roughness A

Surface Roughness B

d1 ≥ greater of 1525 m (5000 ft) or 20h

Surface roughness C

10.1.8 Exposure Categories

Exposure A (Exposure B of ASCE)

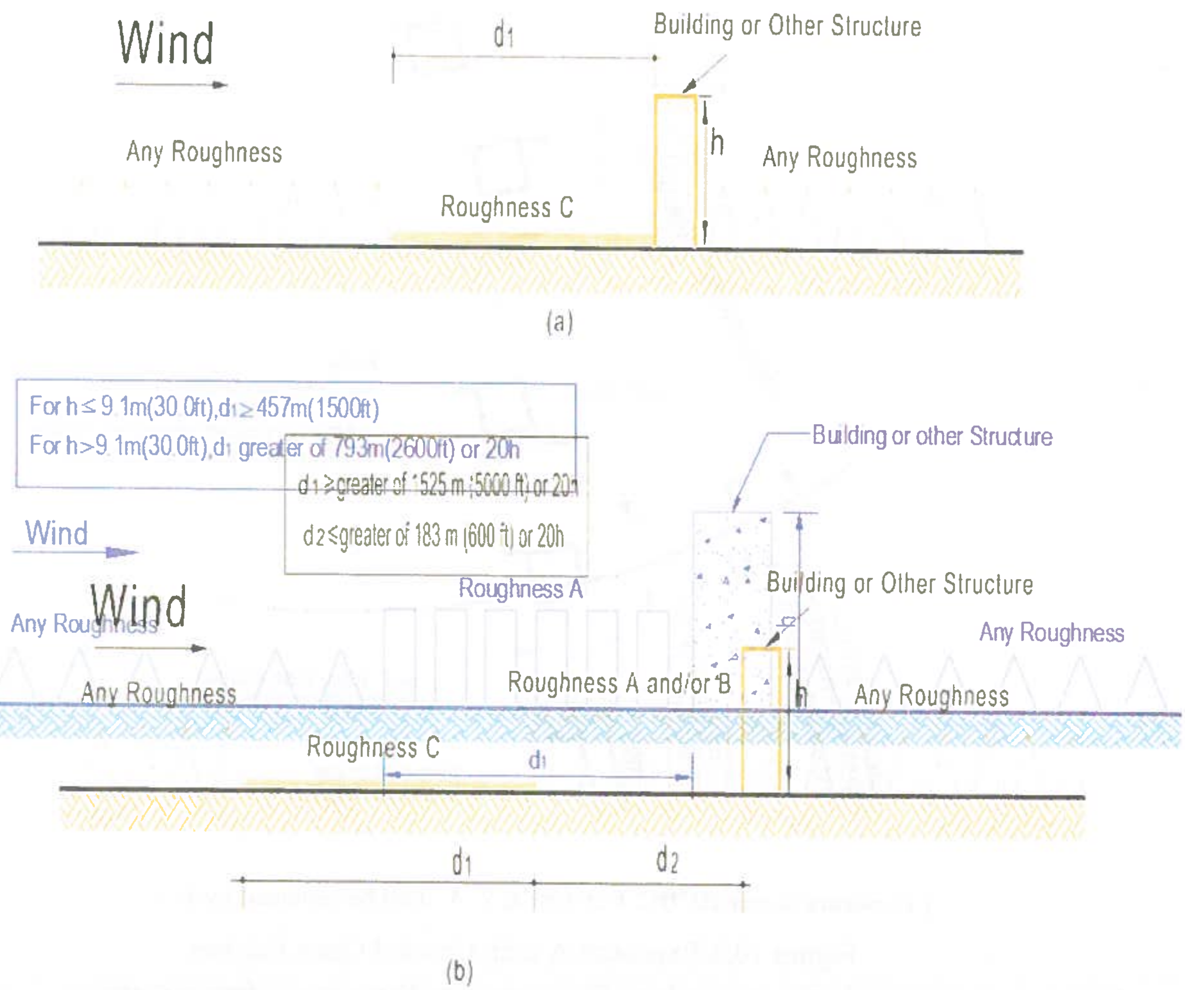


Figure 10.4 Upwind Surface Roughness Conditions Required for Exposure C for the Cases with (a) Surface Roughness C Immediately Upwind of the Building (b) Surface Roughness A and/or B Immediately Upwind of the Building

(Surface Roughness/ Exposures A, B, C of BNBC 15 is equivalent to B, C, D of ASCE7)

For a site located in the transition zone between exposure categories, the category resulting in the largest wind forces shall be used.

10.1.9 Design of Main Wind-Force Resisting System

Simplified design wind pressure p_s N/m^2 (lb./ft^2) for MWFRS of low-rise simple diaphragm buildings represent the net pressure (sum of internal & external) to be applied to the horizontal & vertical projections of building surface as shown in Fig. 6.2.2 Part6 of BNBC15. For horizontal pressure (zones A,B C,D) p_s is the combination of the windward and leeward net pressure p_s shall be determined by the following equation:

$p_s = \lambda K_{zt} I p_{s9.1(30)}$ (Eq.10.1)

where;

λ = adjustment factor for building height and exposure from Table 10.4

K_{zt}= topographic factor as defined in Section 10.2.5.2 evaluated at mean roof height h

For this document K_{zt} may be taken as 1 as most of the lands in Bangladesh are flat.

I = Importance factor is a factor that accounts for the degree of hazard to human life and damage to property as per Table 10.3

$p_{s9.1(30)}$ = simplified design wind pressure for Exposure A, at h = 9.1m(30.0 ft) and for I = 1.0

Importance factor for the building shall be determined on the basis Table 10.3.

10.1.10 Design of Components and Claddings

Net design wind pressure p_{net} for components and claddings of buildings designed by using Method 1 represent the net pressure (sum of internal and external) to be applied normal to each building surface as shown in Fig. 6.2.3 Part6 of BNBC15

p_{net} in N/m^2 (lb./ft^2) shall be determined by the following equation:

$p_{net} = \lambda K_{zt} I p_{net9.1(30)}$ (Eq. 10.2)

where;

λ = adjustment factor for building height and exposure from Table 10.4

K_{zt}= topographic factor as defined in Section 10.2.5.2 evaluated at mean roof height h

For this document K_{zt} may be taken as 1 as most of the lands in Bangladesh are flat

I = Importance factor as per Table 10.3

$p_{net9.1(30)}$= net design wind pressure for Exposure A, at h = 9.1m (30 ft) and for I =1.0 from Fig.6.2.3 Part6 of BNBC15

10.2 METHOD 2- ANALYTIC PROCEDURE

10.2.1 Scope

A building whose design wind loads are determined in accordance with this section shall meet all of the following conditions:

1. The building is a regular shaped building having no unusual geometrical irregularity in spatial form.
2. The building does not have response characteristics making it subject to across wind loading, vortex shedding, instability due to galloping or flutter; or does not have a site location for which channeling effects or buffeting in the wake of upwind obstruction warrant special consideration.

10.2.2 Design Procedure

1. *The basic wind speed V* used in the determination of design wind load shall as per Table 10.1.

   The wind shall be assumed to come from any direction.

   The wind directionality factor, K_d shall be determined from the Table 10.5. This factor shall only be applied when used in conjunction with load combinations as specified in Chapter 9.

Table 10.5: Wind Directionality Factor K_d (BNBC 15 Table 6.2.12)

Structure Type	Directionality Factor K_d
Buildings Main Wind-Force-Resisting System Components and Cladding	 0.85 0.85
Arched Roofs	0.85
Chimneys, Tanks, Similar structure Square Hexagonal Round	 0.96 0.95 0.95
Solid Signs	0.85
Open Signs & Lattice Frame work	0.85
Trussed Towers Triangular, square, rectangular All other cross sections	 0.85 0.95

2. *An importance factor I,* for the building shall be determined from Table 10.3 based on building and structure Occupancy Category listed in Table 10.2.
3. *An exposure category or exposure categories* as applicable shall be determined for each wind directions based on ground surface roughness that is determined from natural topography, vegetation and constructed facilities, as specified in Section 10.1.7.and 10.1.8.

   Velocity pressure exposure co-efficient K_z or K_h, as applicable, shall be determined for each wind direction from Section 10.2.8.
4. *A topographic factor K_{zt}* shall be calculated considering the wind speed-up effect due to variation in the topography as per Section 10.2.5.
5. *A gust effect factor G or G_f* as applicable, shall be determined as per Section 10.2.3.
6. *An enclosure classification* shall be determined in accordance with Section 10.2.4.
7. *Internal pressure coefficient GC_{pi}* shall be determined from Table 10.9 based on building enclosure classification determined from Section 10.2.4.
8. *External pressure coefficient C_p or GC_{pf}* as applicable, shall be determined in accordance with Section 10.2.7.
9. *Velocity pressure q_z* or q_h as applicable shall be determined at required height as per Section 10.2.9.
10. Design wind load *p* or *F* shall be determined in accordance with Section 10.3

10.2.3 Gust Effect Factor

The guest effect factor G or G_f, for rigid or flexible building, as applicable, shall be determined as per Section 10.2.3.2 or by computer codes used in the three dimensional analysis of the structure.

10.2.3.1 Frequency Determination

To determine whether a building is rigid or flexible, the fundamental natural frequency n_1 shall be established using the structural properties and deformation characteristics of the resisting elements in a properly substantiated analysis. Low rise building as defined in Section 10.1.2 is permitted to be considered as rigid buildings (Ref. C1-6). As an alternative to performing an analysis to determine n_1, the approximate building natural frequency n_a shall be permitted to be calculated in accordance with the Section 10.2.3.2 for concrete buildings meeting the following requirements (Ref. C1-6):

1. The building height is less or equal to 91m (300 ft)
2. The building height is less than 4 times its effective length L_{eff}
3. The effecting length L_{eff} in m (ft.) in the direction under consideration shall be determined from the Equation 10.3

$$L_{eff} = \frac{\sum_{i=1}^{n} h_i L_i}{\sum_{i=1}^{n} h_i} \qquad \text{(Eq. 10.3)}$$

The summations are over the height of the building,
where;
h_i is the height above the grade of level i in m(ft.)
L_i is the building length at level i parallel to the wind action in m(ft.).

10.2.3.2 Natural Period and Frequency

When a lightly damped (Damping is the dissipation of energy from a oscillating system, primarily through friction) building is displaced laterally by an earthquake, wind or other forces, it will oscillate back and forth with a *regular period or natural period.* The time for a complete cycle of oscillation of a system is known *as fundamental or natural period T* usually expressed in seconds. The reciprocal of natural period is the *linear natural frequency n* usually called *natural frequency* or just *frequency,* and expressed in H_z (i, e, cycles per seconds)

It is important to distinguish between the building period with site period or with the period of earthquake. The natural period or frequency of a building has nothing to do with an external force.

Natural Frequency $n = \frac{1}{T}$ or Fundamental Period $T = \frac{1}{n}$

As an alternative to performing an analysis to determine the fundamental period T, BNBC15 as well as ASCE7 has permitted to use the approximate building period T_a in seconds calculated in accordance with the Equation10.4 as a seismic design requirements. This method will probably be used for all preliminary designs and many final designs.

$T_a = C_t h_n^x$ (Eq. 10.4)

where;

T_a = approximate fundamental period in seconds

h_n = height in m(ft.) above the base to the highest level of the structure and coefficients C_t and x are shown in Table 10.6 (Table 6.2.20 of BNBC 15)

Table 10.6 Values of Approximate Period Parameters C_t and x

Structure Type	C_t		x
	SI	fps	
Moment-resisting frame system in which the frames resist 100% of required seismic force and are not enclosed or adjoined by components that are more rigid and will prevent the frames from deflecting when subject to seismic force:			
Steel moment-resisting frame	0.0724	0.028	0.8
Concrete moment resisting frame	0.0466	0.016	0.9
Eccentrically braced steel frame	0.0731	0.03	0.75
All other structural system	0.0488	0.02	0.75

For the example building in Chapter 11 in east-west direction,

$T_a = 0.0466\,(45.12)^{0.9} = 1.437$ sec. $\quad n_1 = \dfrac{1}{1.437} = 0.70$

Given: Building height 21.95m (72.0 ft). Calculate fundamental period.

Building type:

1. Bearing Wall System
2. Building Frame System
3. Moment Resisting Frame System
4. Dual System

Solution No. 1 (Bearing Wall System)

The Approximate period given by Equation 10.4 is:

$T_a = C_t h_n^x$

Since the Bearing Wall System is more rigid than the Moment Resisting Frame, this shall fall under category "all other structural wall system". From Table 10.6, for all other systems, C_t is 0.0488 and x is 0.75, h_n is the building height.

$T_a = C_t h_n^x$

$= (0.0488)\,(21.95)^{0.75}$

$= 0.49$ s

In fps system,

$C_t = 0.02$, x = 0.75

$T_a = C_t h_n^x = (0.02)\,(72)^{0.75} = 0.49$s

Fundamental frequency $n_1 = 1/T_a = 1/0.49 = 2.04\ H_z \geq 1.0\ H_z$

So the building is rigid.

Solution No.2 (Building Frame System)
Building Frame system is a three dimensional self-contained space frame to carry vertical loads with separate system of non- bearing shear walls or braced frame to resist the lateral loads.
As the system is more rigid than Moment resisting frame system, this system shall have the same fundamental period of bearing wall system.

Solution No.3 (Moment Resisting Frame System)
For the Moment Resisting Frame System the value of C_t is 0.0466 and x is 0.9
$T_a = C_t\, h_n^x = (0.0466)\,(21.95)^{0.9} = 0.75$ s
In fps system,
$T_a = C_t\, h_n^x = (0.016)\,(72)^{0.9} = 0.75$ s
Fundamental frequency $n_1 = 1/\,T_a = 1/0.75 = 1.33\ H_z$
Though the fundamental frequency of the Moment Resisting Frame is less than the Bearing Wall System, it is still a rigid structure as the fundamental frequency is more than 1.0 H_z

Solution No. 4 (Dual System)
Dual System is also more rigid than the Moment Resisting Frame System. As such it shall fall under "all other structural system" category.
So, $T_a = 0.49$ s, $n_1 = 1/\,T_a = 1/0.49 = 2.04\ H_z$ (Rigid)

Alternately, it is permitted to determine the approximate fundamental period (T_a) in seconds, from the following equation for structures not exceeding 12 stories in height in which the seismic forces resisting system consists entirely of concrete or steel moment resisting frames and the story height is at least 3m(10.0 ft).

Flexible or Dynamically Sensitive Structure

$T_a = 0.1\,N$ (Eq. 10.5)

where;
N = number of stories

But in the commentary of ASCE 07-5 Section C 6.5.8, it has been suggested that the above expressions are based on recommendations for earthquake design with inherent bias toward higher estimates of fundamental frequencies. For wind design applications, these values may be unconservative because an estimated frequency higher than the actual frequency would yield lower values of the guest effect factor and concomitantly a lower design wind pressure. However, commentary suggested some lower bound estimates of frequency that are more suited for use in wind application. These expressions are:

For steel Moment-Resisting Frames (MRFs):

$$n_1 = \frac{8.58}{H^{0.8}} \quad \text{(Eq.10.6)}$$

$$n_1 = \frac{22.2}{H^{0.8}} \quad \text{in fps system}$$

For concrete MRFs:

$$n_1 = \frac{14.93}{H^{0.9}} \quad \text{(Eq.10.7)}$$

$$n_1 = \frac{43.5}{H^{0.9}} \quad \text{in fps system}$$

where;

H = height of the building in m (ft)

Equation 10.7 has also been suggested by ASCE7-10 as an approximate lower bound natural frequency (n_a) which satisfies the conditions of 10.2.3.1 (Ref. C1-6)

Observation from wind tunnel testing of buildings where frequency is calculated using analysis software reveals the following expression for frequency, applicable to all buildings in steel or concrete. (Ref.C1-2)

$$n_1 = \frac{30.49}{H} \text{ (m) average value} \quad \text{(Eq. 10.8)}$$

$$n_1 = \frac{100}{H} \text{ (ft) average value in fps system}$$

$$n_1 = \frac{22.86}{H} \text{ (m) lower bound value} \quad \text{Eq. 10.9)}$$

$$n_1 = \frac{75}{H} \text{ (ft) lower bound value in fps system}$$

These equations are more appropriate for buildings less than about 122m (400 ft) in height (Ref.C1-2).

Based on full scale measurements of buildings under the action of wind, the following expression has been proposed for wind application (Ref. C1-2)

$$f_{n1} = \frac{45.73}{H} \quad \text{(Eq. 10.10)}$$

$$f_{n1} = \frac{150}{H} \text{ (ft.)}$$

This frequency expression is based on older buildings and overestimates the frequency common in U.S construction for smaller buildings less than 122m (400 ft.) in height but becomes more accurate for tall buildings, greater than 122m (400 ft.) in height.

The Australian and New Zealand standard AS/NZs 1170.2, Euro code ENV 1991-2-4, Hong Kong Code of practice on Wind Effects Draft (1996) and others have adopted Equation 10.10 for all building types and all heights.

Recent studies in Japan involving a suite of buildings under low amplitude excitations have led to the following expressions for natural frequency of buildings:

$n_1 = \frac{67}{H}$ (m) concrete buildings (Eq. 10.11)

$n_1 = \frac{220}{H}$ (ft) concrete building in fps system

$n_1 = \frac{50}{H}$ (m) steel building (Eq10.12)

$n_1 = \frac{164}{H}$ (ft) steel building in fps system

Equations 10.6 through 10.9 are more appropriate for preliminary design calculations, as they provide conservative frequency and thereby wind load estimates.

Table 10.7 gives a comparative study of frequency of the example RCC building in Chapter 11 for determining frequency for preliminary design.

Table 10.7 Comparative Values of Frequency of Building for Different Equations (Height of Building 45.12m /148.0 ft as per example of Chapter11)

Equation No.	Equation (fps)	Equation (SI)	η_1	Type
10.4	$T_a = C_t h_n^x$ $n_1 = \frac{1}{T_a}$	$T_a = C_t h_n^x$ $\eta_1 = \frac{1}{T_a}$	0.70(1) 1.17(2)	Flexible Rigid
10.5	$T_a = 0.1N$ $n_1 = \frac{1}{T_a}$	$T_a = 0.1N$ $n_1 = \frac{1}{T_a}$	0.83	Flexible
10.7	$n_1 = \frac{43.5}{H^{0.9}}$	$n_1 = \frac{14.93}{H^{0.9}}$	0.48	Flexible
10.8 10.9	$n_1 = \frac{100}{H}$ (Average value) $n_1 = \frac{75}{H}$(Lower bound value)	$n_1 = \frac{30.49}{H}$ $n_1 = \frac{22.86}{H}$	0.68 0.51	Flexible Flexible
10.10	$f_{n1} = \frac{150}{H}$	$f_{n1} = \frac{45.73}{H}$	1.014	Rigid
10.11	$n_1 = \frac{220}{H}$	$n_1 = \frac{67}{H}$	1.49	Rigid

(1)Flexible in east- west direction (2) Rigid in north- south direction (Ref. Section 11.2.5)

It will be observed from Table 11.3 that there is wide variation in the value of fundamental frequency vis-a-vis period of buildings according to different codes and standards.

However, most computer codes used in the analysis of structure can provide more accurate estimates of the natural frequencies of the structure being analyzed. It is also possible that a building may have two different natural frequencies in x-axis and y-axis depending on configuration, structural system, arrangements of shear walls in the building framing system. This may result in a rigid building in y-axis and a flexible building in x-axis. This is exactly the case with Example building of Chapter 11, where the building is rigid in y-axis (n_1 = 1.17 H_z) as the lateral force resisting system in the y-axis is a reinforced concrete shear wall-frame interactive system (Dual system). In the x-axis the lateral force resisting system consists of R.C moment resisting frame. Computer analysis shows natural frequency $n_1 = 0.7$. As such the building is flexible in that direction.

1.0

For rigid structures having a fundamental frequency greater than or equal to 1 Hz, the gust effect factor shall be taken as 0.85 or calculated by the equation:

$$G = 0.925\left(\frac{(1+1.7g_Q I_{\bar{z}} Q)}{1+1.7g_v I_{\bar{z}}}\right) \qquad \text{(Eq. 10.13)}$$

$$I_{\bar{z}} = c\left(\frac{10}{\bar{z}}\right)^{1/6} \qquad \text{(Eq.10.14)}$$

$$I_{\bar{z}} = c\left(\frac{33}{\bar{z}}\right)^{1/6} \text{ in fps}$$

where;

$I_{\bar{z}}$ = intensity of turbulence at height $\bar{z}$, which is the equivalent height of the structure defined as 0.6h but not less than z_{min} for all building height h.

z_{min} and c are listed for each exposure in Table 10.8

g_Q and g_v shall be taken as 3.4

The background response Q is given by the Equation 10.15

$$Q = \sqrt{\frac{1}{1+0.63\left(\frac{B+h}{L_{\bar{z}}}\right)^{0.63}}} \qquad \text{(Eq. 10.15)}$$

where;

B = horizontal dimension of building measured normal to wind direction in m (ft.)

h = mean roof height of a building, except that eave height shall be used for roof angle θ of less than or equal to 10^0, in m (ft.)

$L_{\bar{z}}$ = the integral length scale of turbulence at the equivalent height given by Equation 10.16

$L_{\bar{z}} = \ell\,(\bar{z}/10)^{\epsilon}$ (Eq. 10.16)

$L_{\bar{z}} = \ell\,(\bar{z}/33)^{\epsilon}$ in fps system

where;

ℓ and ϵ are constants listed in Table 10.8

Table 10.8 Terrain Exposure Constants in SI system (BNBC Table 6.2.10)

Exposure	α	z_g (m)	$\hat{a}$	$\hat{b}$	$\bar{\alpha}$	$\bar{b}$	c	ℓ (m)	ϵ	z_{min}* (m)
A	7.0	365.76	1/7	0.84	1/4.0	0.45	0.30	97.54	1/3.0	9.14
B	9.5	274.32	1/9.5	1.0	1/6.5	0.65	0.20	152.4	1/5.0	4.57
C	11.5	213.36	1/11.5	1.07	1/9.0	0.80	0.15	198.12	1/8.0	2.13

*z_{min}= minimum height used to ensure that equivalent height $\bar{z}$s greater of 0.6h or z_{min}.

For buildings with h ≤ z_{min}, $\bar{z}$ shall be taken as z_{min}

Table 10.8A Terrain Exposure Constants in fps system

Exposure	α	z_g (ft)	$\hat{a}$	$\hat{b}$	$\bar{\alpha}$	$\bar{b}$	c	ℓ (ft)	ϵ	z_{min}* (ft)
A	7.0	1200	1/7	0.84	1/4.0	0.45	0.30	320	1/3.0	30
B	9.5	900	1/9.5	1.0	1/6.5	0.65	0.20	500	1/5.0	15
C	11.5	700	1/11.5	1.07	1/9.0	0.80	0.15	650	1/8.0	7

*z_{min}=minimum height used to ensure that equivalent height $\bar{z}$ is greater of 0.6h or z_{min}.

For buildings with h ≤ z_{min}, $\bar{z}$ shall be taken as z_{min}

2. Flexible or Dynamically Sensitive Structure

Flexible or dynamically sensitive structures are those which satisfy any one of the following conditions:

a) A slander building or structure having a height exceeding five times the least horizontal dimension. For those cases in which the horizontal dimensions vary with height, the least horizontal dimensions at mid height shall be used.

b) A building or structure that has a fundamental natural frequency less than 1 Hz.

For flexible or dynamically sensitive structures, the gust effect factor shall be calculated by:

$$G_f = 0.925\left(\frac{1+1.7 I_{\bar{z}}\sqrt{g_Q^2\, Q^2+g_R^2\, R^2}}{1+1.7 g_v\, I_{\bar{z}}}\right) \qquad \text{(Eq. 10.17)}$$

g_Q and g_v shall be taken as 3.4 and g_R is given by Eq.10.18

$$g_R = \sqrt{2\ln(3600 n_1)} + \frac{0.577}{\sqrt{2\ln(3600 n_1)}} \qquad \text{(Eq.10.18)}$$

R, the resonant response factor, is given by Equation 10.19

$$R = \sqrt{\frac{1}{\beta} R_n R_h R_B (0.53 + 0.47\, R_L)} \qquad \text{(Eq.10.19)}$$

$$R_n = \frac{7.47 N_1}{(1+10.3 N_1)^{5/3}} \qquad \text{(Eq.10.20)}$$

$$N_1 = \frac{n_1 L_{\bar{z}}}{\bar{V}_{\bar{z}}} \qquad \text{(Eq.10.21)}$$

$$R_\ell = \frac{1}{\eta} - \frac{1}{2\eta^2}(1-e^{-2\eta}) \quad \text{for } \eta > 0 \qquad \text{(Eq.10.22a)}$$

$$R_\ell = 1 \text{ for } \eta = 0 \qquad \text{(Eq.10.22b)}$$

where the subscript ℓ in Equation 10.22 shall be taken as h, B and L respectively.

where;

h = mean roof height of a building or height of other structures, except that the eave height shall be used for roof angle θ of less than or equal to 10^0 in m(ft)

B = horizontal dimension of building measured normal to wind direction in m (ft.)

L = horizontal dimension of a building measured parallel to the wind direction m(ft)

n_1 = building natural frequency

$R_\ell = R_h$ setting $\eta = 4.6\frac{n_1 h}{\bar{V}_{\bar{z}}}$

$R_\ell = R_B$ setting $\eta = 4.6\frac{n_1 B}{\bar{V}_{\bar{z}}}$

$R_\ell = R_L$ setting $\eta = 15.4\frac{n_1 L}{\bar{V}_{\bar{z}}}$

β = damping ratio, percent of critical

$\bar{V}_{\bar{z}}$ = mean hourly wind speed m/s (ft/sec) at height $\bar{z}$ determined from Equation 10.23

$$\bar{V}_{\bar{z}} = \bar{b}\left(\frac{\bar{z}}{10}\right)^{\bar{\alpha}} V \qquad V = \text{m/s} \qquad \text{(Eq. 10.23)}$$

$$\overline{V}_{\bar{z}} = \overline{b}\left(\frac{\overline{z}}{33}\right)^{\overline{\alpha}} V\left(\frac{88}{60}\right) \quad V = \text{mph in fps system}$$

where $\overline{b}$ and $\overline{\alpha}$ are constants listed in Table10.6.

10.2.4 Enclosure Classification

An enclosure classification shall be determined in accordance with the following:

(1) General. For the purpose of determining internal pressure co-efficient, all buildings shall be classified as enclosed, partially enclosed or open as defined in section 10.1.2.

(2) Openings. A determination shall be made of the amount of openings in the building envelope to determine the enclosure classification as stated in the previous paragraph.

(3) Wind-Borne Debris. Glazing in building located in wind-borne debris regions shall be protected with an impact resistant covering or be impact resistant glazing.

(4) Multiple Classification. If a building by definition complies with both the "open" and "partially enclosed" definitions, it shall be classified as "open" building. A building that does not comply with either the "open" or "partially enclosed" definitions shall be classified as "enclosed" building.

10.2.5 Topographic Effect

10.2.5.1 Wind Speed-up over Hills, Ridges and Escarpments

Wind speed-up effects at isolated hills, ridges, and escarpments constituting abrupt changes in the general topography, located in any exposure category shall be included in the design when buildings and other site conditions and locations of structures meet all of the following conditions:

1. The hill ridge or escarpment is isolated and unobstructed upwind by other similar topographic features of comparable heights for 100 times the height of the topographic feature (100*H*) or 3.22 km (2.0 miles), whichever is less. This distance shall be measured horizontally from the point at which the height *H* of the hill, ridges or escarpment is determined.
2. The hill, ridge or escarpment protrudes above the height of the upwind terrain features within a 3.22 km (2.0 miles) radius in any quadrant by a factor of two or more.
3. The structure is located as shown in Fig 2.4.4: Part6 of BNBC12 in the upper one-half of a hill or ridge or near the crest of an escarpment
4. $\frac{H}{L_h} \geq 0.2$
5. *H* is greater than or equal to 4.5m (15 ft) for Exposure B and C and 18.0m (60.0ft.) for Exposure A

10.2.5.2 Topographic Factor K_{zt}

The wind speed up effect shall be included in the calculation of design wind loads by using the factor K_{zt};

$K_{zt} = (1+K_1 K_2 K_3)^2$ where K_1, K_2, K_3 are given in Fig 6.2.4. Part6.2.4 of BNBC15. If site conditions and location of structure do not meet all the conditions specified in Section 10.2.5.1, then $K_{zt} = 1$.

10.2.6 Internal Pressure Co-efficient GC_{pi}

Internal Pressure Co-efficient GC_{pi} shall be determined from Table 10.9 based on building enclosure classification determined from Section 10.2.4

Table10.9 Internal Pressure Coefficient GC_{pi} (Fig. 6.2.5 of BNBC 15)

Enclosure Classification	GC_{pi}
Open building	0.00
Partially Enclosed Building	+0.55 -0.55
Enclosed Building	+0.18 -0.18

Notes:

1. Plus and minus signs signify pressure acting toward and away from internal surfaces respectively.
2. Values of GC_{pi} shall be used with q_z or q_h as specified in Section10.2.9
3. Two cases shall be considered to determine the critical load requirement for the appropriate condition:
   a) a positive value of GC_{pi} applied to all internal surfaces.
   b) a negative value of GC_{pi} applied to all internal surfaces

10.2.7 External Pressure Coefficient C_p or GC_{pf}

1. External pressure coefficient C_p of MWFRSs of enclosed, partially enclosed buildings are given in Table 10.10

Table 10.10 External Pressure Co-efficient, C_p of Walls and Roof for Enclosed, Partially Enclosed Building (Figure 6.2.6 of BNBC 15)

Wall Pressure Co-efficient, C_p			
Surface	L/B	C_p	Use With
Windward Wall	All values	0.8	q_z
Leeward Wall	0-1	-0.5	q_h
	2	-0.3	
	$\geq$ 4	-0.2	
Side wall	All value	-0.7	q_h

Roof pressure coefficient C_p for use with q_h												
Wind Direction	Windward									Leeward		
	Angle, θ (degrees)									Angle, θ(degrees)		
	h/L	10	15	20	25	30	35	45	≥60#	10	15	≥20
Normal to ridge for θ ≥ 10^0	≤ 0.25	- 0.7 - 0.18	- 0.5 0.0*	-0.3 0.2	-0.2 0.3	-0.2 0.3	0.0 0.4	0.4	0.01 θ	-0.3	-0.5	-0.6
	0.5	- 0.9 - 0.18	- 0.7 -0.18	-0.4 0.0*	-0.3 0.2	-0.2 0.2	- 0.2 0.3	0.0* 0.4	0.01 θ	-0.5	-0.5	-0.6
	≥1.0	-1.3** - 0.18	-1.0 -0.18	-0.7 -0.18	-0.5 0.0*	-0.3 0.2	- 0.2 0.2	0.0* 0.3	0.01 θ	-0.7	-0.6	-0.6

Wind Direction	h/L	Horiz distance from windward edge	Cp
Normal to ridge for θ <10 and Parallel to ridge for all θ	≤ 0.5	0 to h/2	- 0.9, - 0.18
		h/2 to h	- 0.9, - 0.18
		h to 2 h	- 0.5, - 0.18
		> 2h	- 0.3, - 0.18
	≥1.0	0 to h/2	-1.3**, - 0.18
		> h/2	- 0.7, - 0.18

* Value is provided for interpolation purposes.
** Value can be reduced linearly with area over which it is applicable as follows

Area (sqft)	Reduction Factor
≤ 100 (9.3 sqm)	1.0
200 (23.2 sqm)	0.9
≥1000 (92.9 sqm)	0.8

Notes:

1. Plus and minus signs signify pressures acting toward and away from the surfaces, respectively.
2. Linear interpolation is permitted for values of *L/B*, *h/L* and θ other than shown. Interpolation shall only be carried out between values of the same sign. Where no value of the same sign is given, assume 0.0 for interpolation purposes.
3. Where two values of *Cp* are listed, this indicates that the windward roof slope is subjected to either positive or negative pressures and the roof structure shall be designed for both conditions. Interpolation for intermediate ratios of h/L in this case shall only be carried out between *Cp* values of like sign.
4. For monoslope roofs, entire roof surface is either a windward or leeward surface.
5. For flexible buildings use appropriate G_f as determined by Section 10.2.3
6. Refer to BNBC Figure 2.4.7 for domes and Figure 2.4.8 for arched roofs.
7. Notation:
   B: Horizontal dimension of building, in meter (feet), measured normal to wind direction.
   L: Horizontal dimension of building, in meter (feet), measured parallel to wind direction.
   h: Mean roof height in meters (feet), except that eave height shall be used for θ < 10 degrees.
   z: Height above ground, in meters (feet).
   G: Gust effect factor.
   $q \geq qh$: Velocity pressure, in N/m^2 (psf), evaluated at respective height.
   θ: Angle of plane of roof from horizontal, in degrees.
8. For mansard roofs, the top horizontal surface and leeward inclined surface shall be treated as leeward surfaces from the table.
9. Except for MWFRS's at the roof consisting of moment resisting frames, the total horizontal shear shall not be less than that determined by neglecting wind forces on roof surfaces.
   \# For roof slopes greater than 80^0, use $Cp = 0.8$

Combined gust effect factor and external pressure coefficient GC_{pf} are given in Fig 2.4.10 of BNBC15 for low-rise buildings. The pressure co-efficient values and gust effect factor in Fig 2.4.10 shall not be separated.

(2) Combined guest effect factor and external pressure co-efficient for components and cladding GC_p are given in Fig 6.2.11 through 6.2.17 of BNBC15. The pressure co-efficient values and gust effect factor shall not be separated.

(3) Force coefficients for other structures C_f are given in Fig 6.2.20 through 6.2.22 of BNBC15.

(4) Roof overhang of MWFRS shall be designed for a positive pressure on the bottom surface of windward roof overhangs corresponding to C_p= 0.8 in combination with the pressure determined from using Figs 6.2.6 and 6.2.10 of BNBC15

(5) For components and claddings of all building's roof overhangs shall be designed for pressures determined from pressure coefficients given in Fig. 6.2.11 b,c,d.

(6) The pressure coefficients for the effects of parapet on the MWFRS loads are given in Section10.3.3

10.2.8 Velocity Pressure Exposure Coefficient K_z

The velocity pressure exposure coefficient K_z may be determined at any height from ground level from the following equations:

$$K_z = 2.01\left(\frac{4.57}{z_g}\right)^{2/\alpha} \quad \text{for } z < 4.57\text{m} \qquad \text{(Eq. 10.24)}$$

$$K_z = 2.01\left(\frac{15}{z_g}\right)^{2/\alpha} \quad \text{for } z < 15\text{ft} \quad \text{in fps system}$$

$$K_z = 2.01\left(\frac{15}{z_g}\right)^{2/\alpha} \quad \text{for } 4.57\text{m (15 ft)} \le z \le z_g \qquad \text{(Eq. 10.24a)}$$

where;

α = 3 second gust speed power law exponent

z_g = nominal height of the atmospheric boundary layer

α and z_g are tabulated in Table 10.8

Example:10.2 Given z = 18.3m Find K_d for Exposure A, B, C
Exposure A, from Table 10.8 α = 7.0, z_g = 365.85 K_z = 2.01 $(18.3/365.85)^{2/7}$ = 0.854
If Exposure is B then from Table 10.8 α = 9.5, z_g = 274.4 K_z= 2.01 $(18.3 / 274.4)^{2/9.5}$ =1.13
If Exposure is C then from Table 10.8 α = 11.5 z_g = 213.4 K_z = 2.01$(18.3/213.36)^{2/11.5}$ = 1.31

Values are same as those in Table10.9

Table10.11 Velocity Pressure Exposure Coefficient K_h and K_z (ASCE7-10)

Height above ground level		Exposure (Note 1)		
m	ft	A	B	C
0-4.6	0-15	0.57	0.85	1.03
6.1	20	**0.62**	0.90	1.08
7.6	25	0.66	0.94	1.12
9.1	30	0.70	0.98	1.16
12.2	40	0.76	1.04	1.22
15.2	50	0.81	1.09	1.27
18.3	60	0.85	1.13[$]	1.31[$]
21.3	70	0.89	1.17	1.34
24.4	80	0.93	1.21	1.38
27.4	90	0.96	1.24	1.40
30.5	100	0.99	1.26	1.43
36.6	120	1.04	1.31	1.48
42.7	140	1.09	1.36	1.52
48.8	160	1.13	1.39	1.55
54.9	180	1.17	1.43	1.58
61.0	200	1.20	1.46	1.61
76.2	250	1.28	1.53	1.68
91.4	300	1.35	1.59	1.73
106.7	350	1.41	1.64	1.78
121.9	400	1.47	1.69	1.82
137.2	450	1.52	1.73	1.86
152.4	500	1.56	1.77	1.89

[$] See example 10.2

Notes

1. Linear interpolation for intermediate values of height z is acceptable.
2. Exposure categories as defined in Section 10.1.8

10.2.9 Velocity Pressure q_z

Velocity Pressure q_z shall be determined at height z by the following equation:

$q_z = 0.613\, K_z K_{zt} K_d\, V^2 I$ (N/m^2) ; V in m/s (Eq.10.25)

$q_z = 0.00256\, K_z K_{zt} K_d\, V^2 I$ (lb./ft^2) in fps system; V in mph

where;

K_d = wind directionality factor as per Table10.5

K_z = velocity pressure exposure co-efficient as defined in Section 10.2.8

I = importance factor as per Table 10.3 based on Table 10.2
K_{zt} = topographic factor as defined in section 10.2.5
q_z = velocity pressure calculated using Equation 10.25 above at mean roof height h

The constant 0.631 (or 0.00256) reflects the mass density of air for the standard atmosphere, that is, 15^0C (59^0F) and sea level pressure 101.325 kPa (29.29 in. of mercury) and dimensions associated with wind speed in m/s (mi/h).

The constant is obtained as follows:

Constant = ½ [(1.225 kg/m^3) / (9.81 m/s^2)] x [(m/s)]^2 [9.81 N/kg] =0.613
Constant = ½ [(0.0765 lb. /ft^3) / (32.2 ft/s^2)] x [(mi/h) (5280 ft/mi) x (1 h/3600 s)]^2 =0.00256
where;
1.225 (0.0765) is the average air density

10.2.10 Design Wind Loads on Enclosed and Partially Enclosed Building

1. Sign Convention

Positive pressure acts towards the surface and negative pressure acts away from the surface.

2. Critical load conditions

Values of external and internal pressures shall be combined algebraically to determine the most critical load.

3. Tributary areas greater than 65m^2(700 sft.)

Components and cladding elements with tributary areas greater than 65 m^2 (700 ft^2) shall be permitted to be designed using the provisions of MWFRS.

10.3 DESIGN OF MAIN WIND- FORCE RESISTING SYSTEM

10.3.1 Rigid Buildings of All Heights

Design wind pressure for the MWFRS of rigid buildings of all heights shall be determined by the following equation:

$p = q\ GC_p - q_i\ (GC_{pi})$ N/m^2(lb/ft^2) (Eq.10.26)

where;
$q = q_z$ for windward walls evaluated at height z above the ground
$q = q_h$ for leeward walls, side walls and roof, evaluated at height h
$q_i = q_h$ for windward walls, side walls, leeward walls and roofs of enclosed buildings and for negative internal pressure evaluation in partially enclosed building
$q_i = q_z$ for positive internal pressure evaluation in partially enclosed building where height z is defined as the level of the highest opening in the building that could affect the positive internal pressure. For buildings sited in wind-borne debris region, glazing that is not impact resistant or protected with an impact resistant covering, shall be treated as on opening in accordance with Section 2.4.9.3 0f BNBC15. For positive internal pressure evaluation, q_i may conservatively be evaluated at height h ($q_i = q_h$).
G = guest effect factor from Section 10.2.3
C_p = external pressure coefficient from Table 10.10

(GC_{pi}) = internal pressure co-efficient from Table 10.9
q and q_i shall be evaluated using exposure defined in section 10.1.8

Pressure shall be applied simultaneously on windward & leeward walls and on roof surfaces as defined in Table 10.10 of this document and Fig 2.4.6 part6 of BNBC15.

10.3.2 Flexible Building

The design wind pressure p of MWFRS of flexible building shall be determined by the following equation:

$$p = q\,G_f C_p - q_i\,(GC_{pi})\ \text{N/m}^2(\text{lb/ft}^2) \qquad \text{(Eq. 10.27)}$$

where:

q, qi, C_p, and ($GCpi$) are as defined in Section 10.3.1 and G_f = gust effect factors as defined in Section 10.2.3

10.3.3 Parapets

The design wind pressure for the effect of parapet on MWFRS of rigid, low-rise or flexible building with flat, gable or hip roof shall be determined by the following equation:

$$p_p = q_p\,GC_{pn}\quad \text{N/m}^2\ (\text{lb/ft}^2) \qquad \text{(Eq.10.28)}$$

where;

p_p = combined net pressure on the parapet due to combination of the net pressure from the front and back parapet surfaces. Plus (and minus) signs signify net pressure action toward (and away from) the front (exterior) side of the parapet

q_p = velocity pressure evaluated at the top of the parapet.

GC_{pn} = combined net pressure coefficient

= + 1.5 for windward parapet

= - 1.0 for leeward parapet

10.3.4 Design Wind Load Cases

The MWFRS of buildings of all heights, whose wind loads have been determined under the provisions of Sections 10.3.1 and 10.3.2 shall be designed for the wind load cases defined in Fig.6.2.9 of BNBC15 or Fig.6-9 and Section 6.5.12.3 of ASCE7-05.

The eccentricity for the rigid structure and flexible structures shall be determined as per Section 2.4.11.3 of BNBC15 or Section 6.5.12.3 of ASCE7-05.

10.3.5 Components & Claddings

1. Low Rise Building & Building with $h \leq$ 18.3m (60 ft.)

Design Wind pressure on components and cladding elements of low rise building and building with $h \leq 18.3$m (60.0 ft) shall be determined from the following equations:

$p = q_h\,[(GC_p) - (GC_{pi})]$ N/m^2 (lb/ft^2) (Eq.10.29)

where;

q_h = velocity pressure evaluated at mean roof height h using exposure defined in Section 10.1.8

(GC_p) = external pressure coefficient given in Fig.6.2.11 through 6.2.17 of BNBC15

(G_{Cpi}) = Internal pressure coefficient from Table10.9

2. Buildings with $h > 18.3$m (60.0ft)

Design Wind pressure on component and cladding elements for all buildings with $h > 18.3$m(60.0 ft.) shall be determined from the following equation:

$p = q\,(GC_p) - q_i\,(GC_{pi})$ N/m^2 (lb/ft^2) (Eq.10.30)

where;

$q = q_z$ for windward walls calculated at height z above the ground

$q = q_h$ for leeward wall, side walls and roof evaluated at height h

$q_i = q_h$ for windward walls, sidewalls, leeward walls and roof of enclosed buildings and for negative internal pressure evaluation in partially enclosed building

$q = q_z$ for positive internal pressure evaluation in partially enclosed building where height z is defined as the level of the highest opening in the building that could affect the positive internal pressure.

For buildings sited in wind-borne debris regions, glazing that is not impact resistant or protected with an impact-resistant covering, shall be treated as an opening in accordance with Section 10.2.4. For positive internal pressure evaluation, q_i may conservatively be evaluated at height h ($q_i = q_h$).

(GC_p) = external pressure co-efficient from Fig.6.2.17 of BNBC15 or Fig.6-17 of ASCE7-05

(GC_{pi}) = internal pressure co-efficient given in Table 10.9

q and q_i shall be evaluated using exposure defined in Section 10.1.8

CHAPTER 11

ILLUSTRATIVE EXAMPLE OF A HYPOTHETICAL BUILDING

11.1 DESIGN DATA

11.1.1 Basic Information

Building Location: Manikgonj

- 12-storey Office Building with GF height 4.88m (16.0 ft) and other floors 3.66m (12.0 ft).
- Computation for Wind Force (Seismic Force not within the purview of this document) shall be done as per BNBC 15 supplemented by IBC 2006, ASCE 7-05 and ACI 318-11.
- Typical Beams, columns and walls are designed and detailed for combined effects of gravity and wind force
- Resistance to lateral force in the north-south direction is provided by a combination of shear walls and frames acting together (Dual Sustem)
- Resistance to lateral force in the east-west direction is provided by the flexural action of the beams and columns (Moment Resisting Frame System)
- For simplicity, it is assumed that slabs, beams, columns, walls have constant cross section throughout the height of the building and that bases of the lowest story segments are fixed.
- Length of the building = 56.2m (184.33 ft)

  Breadth of the building = 20.83m (68.33 ft)

  Height of the building = 45.1m (148 ft)

11.1.2 Materials Properties

Concrete: f'_c = 24 MPa (3500 psi)

w_c = 2400 kg/m^3 (150 pcf)

Steel: f_y = 415 MPa (60000 psi)

11.1.3 Service Load

- Live Load: As per BNBC15 Table 6.2.3 of Part 6

11.1.4 Wind Design Data

- Basic Wind Speed = 58.20 m/s= 210 Km/h = 130.2 mph (Ref. Table 10.1 of this document which has been prepared on the basis of Table 6.2.8, Part6 of BNBC15.)
- Exposure A as per Section 10.1.8 of this document prepared on the basis of Section 2.4.6.3 Part6 of BNBC15.
- Importance Factor = 1.15 (Refer Table 10.3 of this document prepared on the basis of Table 6.2.9, Part6 of BNBC15).

- Occupancy category III (As per table 10.2 of this document which has been prepared on the basis of Table 6.1.1 Part6 of BNBC15: Special Occupancy Structure).

11.1.5 Member Dimensions

a) Slab = 200 mm (8 in)
b) Beam = 600x600 mm (24 in x 24 in)
c) Column = 700 x 700 mm (28 in x 28 in)
d) Shear Wall thickness = 350 mm (14 in)

11.2 WIND LOAD ANALYSIS

Wind load analysis for any building can be done according to procedure given in Section 2.4 Part 6 of BNBC15. Wind load analysis of the example building shall be done on the basis of procedure given in Chapter 10 of this document which has been prepared on the basis of Section 2.4 Part6 of BNBC15.

As the building has a mean roof height of more than 18.3m (60.0ft.) simplified procedure (Method 1, Section 10.1 of this document) cannot be used to determine the wind forces. The example building is regular in shape as defined in Section 10.1.1.1 (4), i.e. it has no unusual geometrical irregularity in spatial form. Also, the building does not have response characteristics making it subject to across wind loading, vertex shedding, instability due to galloping or flutter. The building has approximately symmetrical cross section in each direction.

Thus, the Analytic Procedure (Method 2) of Section 10.2 may be used to determine the wind forces which is based on Section 2.4.3 Part 6 of BNBC 15.

Steps to Determine MWFRS Wind Loads for Enclosed, Partially Enclosed and Open Buildings of All Heights
Step 1: Determine basic wind speed for the location of the building as per Table 10.1 **Step 2**: Determine risk category or importance category of the building as per Table 10.2 and select Importance Factor I from Table 10.3 **Step 3** Determine wind load parameters: ➢ Wind Directionality Factor K_d from Table 10.5 ➢ Exposure Category from Section 10.1.8 based on Surface Roughness category from Section 10.1.7 ➢ Topographic Factor K_{zt} as per Section 10.2.5.2 ➢ Gust effect factor for rigid or flexible building G or G_f as per Section10.2.3 ➢ Enclosure classification as per Section10.2.4 ➢ Internal Pressure coefficient GC_{pi} from Table 10.9 **Step 4**: Determine Velocity Pressure Exposure coefficient K_z or K_h from Table10.11 **Step 5** : Determine Velocity Pressure q_z or q_h by Equation 10.25 **Step 6**: Determine External Pressure coefficient c_p as per Table 10.10 **Step 7**: Calculate design wind pressure p on each building surface • Equation 10.26 for rigid building • Equation 10.27 for flexible building

The subject of the wind load design as described in this manual stops after forces have been calculated and distributed to stories and members. Designing the members to support these forces is not part of this manual. After finding the forces, a 3-D analysis shall be done by computer application with load combination as applicable as per load combination of Chapter 9 of this manual or as per BNBC15.

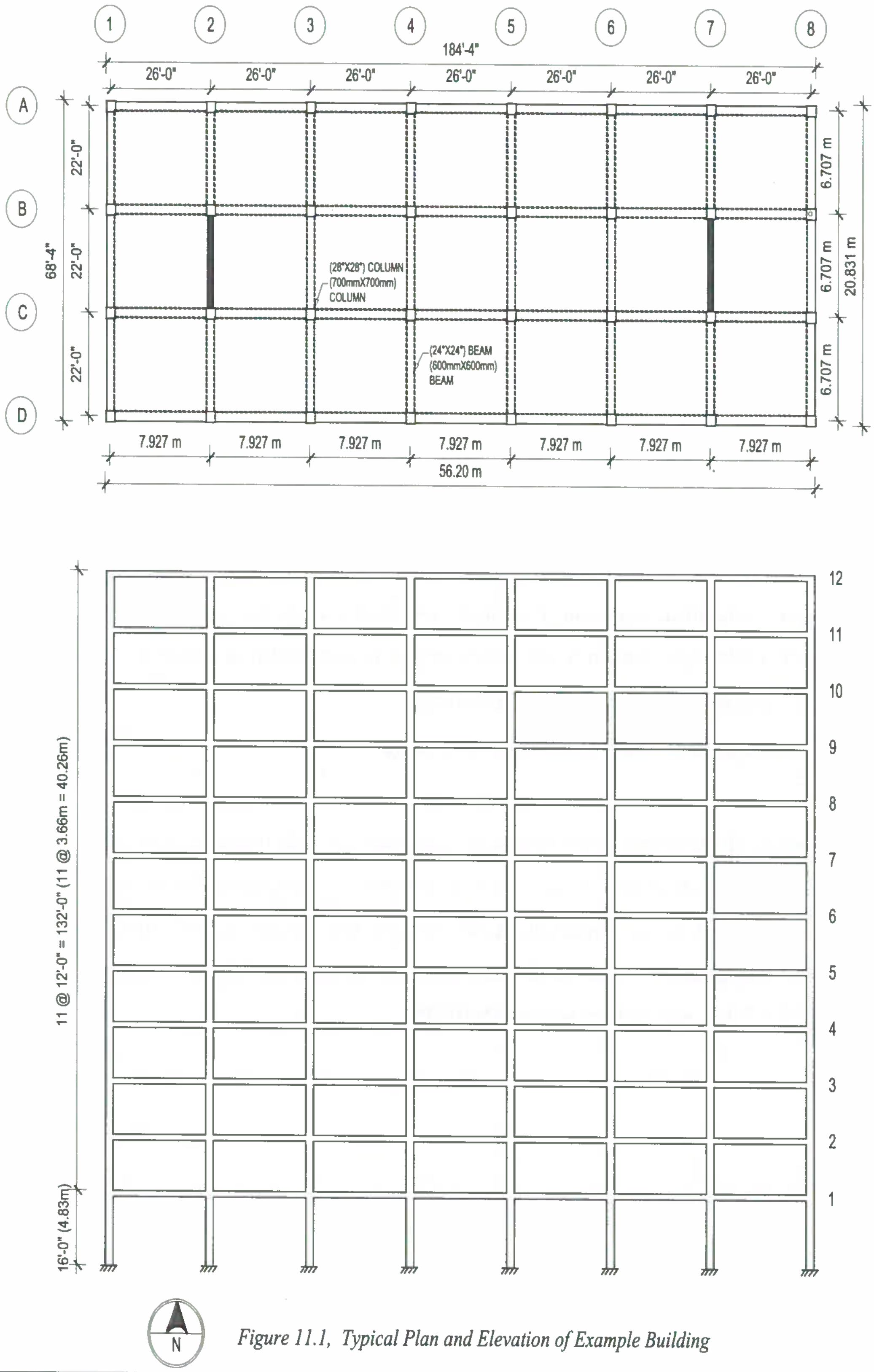


Figure 11.1, Typical Plan and Elevation of Example Building

11.2.1 Basic Wind Speed V and Wind Directionality Factor K_d

Basic wind speed is 58.2m/s = 130 mph= 210 km/h as per Table 10.1 of this document.

The Wind directionality factor K_d is equal to 0.85 as per Table 10.5 of this document.

11.2.2 Importance Factor I

As per Table 10.3, Importance factor $I = 1.15$, based on occupancy category of building as per Table 10.2 (Occupancy Category III)

11.2.3 Exposure Category and Velocity Pressure Exposure Coefficient K_z

K_z at any height may be calculated by using the following equations:

$K_z = 2.01\,(4.57/z_g)^{2/\alpha}$ for z < 4.57m (Chapter10 Eq.10.24)

$K_z = 2.01\,(15/z_g)^{2/\alpha}$ for z < 15ft in fps system

$K_z = 2.01\,(z/z_g)^{2/\alpha}$ for 4.57m (15ft) $\leq z \leq z_g$ (Chapter10 Eq.10.24a)

where;

α is 3-second gust speed power law exponent from Table 10.8

= 7 for Exposure A

z_g = nominal height of the atmospheric boundary layer from Table 10.8

= 365.76 m (1200 ft) for Exposure A

Values of velocity pressure exposure coefficient K_z are summarized in Table 11.1 at the various story heights for the example building.

Example:

In SI

$z = 45.12$m, $z_g = 365.76$ $\alpha = 7$ (F rom Table 10.8)

$K_z = 2.01(45.12/365.76)^{2/7} = 1.105$

Example:

In fps

$z = 148$ ft, $z_g = 1200$ ft. $\alpha = 7$ (F rom Table 10.8)

$K_z = 2.01\,(148/1200)^{2/7} = 1.105$

Table 11.1 Velocity Pressure Exposure Co-efficient K_z (for Exposure A)

Level	Height above ground level z m	z_g (1) m	z/z_g	α (2)	$2/\alpha$	K_z=2.01 $(z/z_g)^{2/\alpha}$
12	45.12	365.76	0.1233	7	0.2857	1.105
11	41.56	365.76	0.1133	7	0.2857	1.079
10	37.80	365.76	0.1033	7	0.2857	1.051
9	34.14	365.76	0.0933	7	0.2857	1.021
8	30.49	365.76	0.0833	7	0.2857	0.988
7	26.83	365.76	0.0733	7	0.2887	0.953
6	23.17	365.76	0.0633	7	0.2857	0.914
5	19.51	365.76	0.0533	7	0.2857	0.870
4	15.85	365.76	0.0433	7	0.2857	0.820
3	12.20	365.76	0.0333	7	0.2857	0.760
2	8.54	365.76	0.0233	7	0.2857	0.687
1	4.88	365.76	0.0133	7	0.2857	0.585

(1)(2) z_g and α as defined in section 11.2.3

For Exposure A, $\alpha = 7$ and $z_g = 365.76$m as per Table 10.8

Table 11.1A Velocity Pressure Exposure Co-efficient K_z (For Exposure A)

(fps system)

Level	Height above ground level z m(ft)	$z_g^{(1)}$ m (ft)	z/z_g	$\alpha^{(2)}$	$2/\alpha$	K_z=2.01 $(z/z_g)^{2/\alpha}$
12	148	1200	0.1233	7	0.2857	1.105
11	136	1200	0.1133	7	0.2857	1.079
10	124	1200	0.1033	7	0.2857	1.051
9	112	1200	0.0933	7	0.2857	1.021
8	100	1200	0.0833	7	0.2857	0.988
7	88	1200	0.0733	7	0.2887	0.953
6	76	1200	0.0633	7	0.2857	0.914
5	64	1200	0.0533	7	0.2857	0.870
4	52	1200	0.0433	7	0.2857	0.820
3	40	1200	0.0333	7	0.2857	0.760
2	28	1200	0.0233	7	0.2857	0.687
1	16	1200	0.0133	7	0.2857	0.585

(1)(2) z_g and α as defined in section 11.2.3

For Exposure A, $\alpha = 7$ and z_g =1200 ft as per Table 10.8

11.2.4 Topographic Factor K_{zt}

The topographic factor is to be determined in accordance with Section 10.2.5 of this document which has been prepared on the basis of Section 2.4.7 Part6 of BNBC15.

As the building does not satisfy all the conditions of Section 10.2.5 (Section 2.4.7.1 of BNBC15) and the example building is situated on level ground, and not on a hill, ridge or escarpment, $K_{zt} = 1$.

11.2.5 Gust Effect Factor G and G_f

Effects due to wind gust depend on whether a building is rigid (G) or flexible (G_f).
According to Equation 10.4

$T_a = C_t\, h_n^x$ (Chapter 10 Eq. 10.4)

where;

T_a = approximate fundamental period in seconds

h_n = height in m(ft) above the base to the highest level of the structure and coefficients C_t and x are shown in Table 10.6

For east-west direction the building is a moment resisting frame for which, C_t = 0.0466 (0.016 for fps system) and x = 0.9 as per Table 10.6. Height of the building is 45.1m (148.0 ft)

$T_a = 0.0466 \times 45.1^{0.9} = 1.436$ $n_1 = 1/1.436 = 0.7 < 1H_z$ which is the same value as per computer code and the building is flexible in this direction.

In the north- south direction, the building is a combination of shear wall and frame (Dual System) for which

$C_t = 0.048$ (0.02 for fps system) and x = 0.75 as per Table 10.6

$T_a = 0.048 \times 45.1^{0.75} = 0.835$

$n_1 = 1/\ 0.835 = 1.2 > 1.0\ H_z$ which is very near to computer code value of 1.18 and the building is rigid in this direction.

11.2.5.1 Rigid Building

A rigid building has a fundamental natural frequency n_1 greater than or equal to 1Hz, while flexible buildings have a fundamental natural frequency less than 1Hz.

For this example building, the computer analysis shows that in the N-S direction where the lateral force resisting system is a reinforced concrete shear wall-frame interactive system (Dual System), the buildings fundamental natural frequency $n_1 = 1.18$ Hz.

Since $n_1 > 1.0$ Hz, the building is considered rigid in this direction. G may be taken as 0.85 or as per Section 10.2.3 may be calculated by Equation 10.13

$$G = 0.925\left(\frac{(1+1.7g_Q I_{\bar{z}} Q)}{1+1.7g_v I_{\bar{z}}}\right) \qquad \text{(Chapter 10, Eq. 10.13)}$$

$$I_{\bar{z}} = c\left(\frac{10}{\bar{z}}\right)^{1/6} \qquad \text{(Chapter 10, Eq.10.14)}$$

$$I_{\bar{z}} = c\left(\frac{33}{\bar{z}}\right)^{1/6} \quad \text{in fps system}$$

For Exposure A, Table 10.8

$z_{min} = 9.14$m, c = 0.30

$I_{\bar{z}}$ = Intensity of turbulence at height $\bar{z}$, where,

$\bar{z}$ = Equivalent height of the structure defined as $0.6h$, but not less than z_{min} for all building height h.

$= 0.6h = 0.6\text{x}45.09 = 27.05$ m. > 9.14 m (z_{min})

g_Q and $g_u = 3.4$ as per Section10.2.3.2 (1)

$I_{\bar{z}} = 0.3\ (10/27.05)^{1/6} = 0.2542$

The background response Q is given by Equation 10.15

$$Q = \sqrt{\frac{1}{1+0.63\left(\dfrac{B+h}{L_{\bar{z}}}\right)^{0.63}}} \qquad \text{(Chapter 10, Eq. 10.15)}$$

B = Horizontal dimension of the building measured normal to the direction of wind

= 56.2m (184.33ft), h = 45.09 (148.0 ft.)

$L_{\bar{z}}$ = Integral length scale of turbulence at equivalent height given by the Equation 10.16.

$L_{\bar{z}} = \ell\,(\bar{z}/10)^{\epsilon}$ (Chapter 10, Eq. 10.16)

$L_{\bar{z}} = \ell\,(\bar{z}/33)^{\epsilon}$ in fps system

Exposure A, $\ell = 97.54$, $\epsilon = 1/3$ (Chapter 10,Table 10.8)

$L_{\bar{z}} = 97.54\,(27.05/10)^{1/3} = 136.0$ m = 446.0 ft.

$$Q = \sqrt{\frac{1}{1+0.63\left(\frac{B+h}{L_{\bar{z}}}\right)^{0.63}}} = \sqrt{.655} = 0.81$$

g_Q and $g_v = 3.4$, $I_{\bar{z}} = 0.2542$, $Q = 0.81$

$$G = 0.925\left(\frac{1+1..7x3.4x0.2544x0.81}{1+1.7x3.4x0.2544}\right)$$

$$= 0.925\left(\frac{2.19}{2.47}\right) = 0.82$$

Though it has been suggested earlier to consider G = 0.85 for simplicity, on actual calculation, it comes to 0.82. As such 0.85 is a conservative value.

11.2.5.2 Flexible Building

In the E-W direction, the lateral-force-resisting system consists of reinforced concrete moment resisting frame. The computer analysis shows that $n_1 = 0.7$ Hz.

Therefore, the building is considered flexible in this direction and the gust effect factor G_f must be computed in accordance with the Eq. 10.17

$$G_f = 0.925\left(\frac{1+1.7I_{\bar{z}}\sqrt{g^2{}_Q Q^2 + g^2{}_R R^2}}{1+1.7g_V I_{\bar{z}}}\right) \quad \text{(Chapter 10, Eq. 10.17)}$$

where;

g_Q and $g_v = 3.4$ and g_R is calculated by:

$$g_R = \sqrt{2\ln(3600n_1)} + \frac{0.577}{\sqrt{2\ln(3600n_1)}} \quad \text{(Chapter 10, Eq. 10.18)}$$

$$= \sqrt{2\ln(3600x.7)} + \frac{0.577}{\sqrt{2\ln(3600x0.7)}}$$

$= 3.96 + 0.15$

$= 4.11$

$I_{\bar{z}}$ = Intensity of turbulence at height $\bar{z}$ is 0.2542, (Ref. rigid structure)

where :

$\bar{z}$ = Equivalent height of the structure defined as 0.6h, but not less than z_{min} for all building height h.

= 0.6h = 0.6x45.09 = 27.05 m. > 9.14 m (z_{min}) [$\bar{z}$ = 0.6xh = 0.6x148.0 = 88.8 ft > 30.0 ft]

Q = background response = 0.81 [Ref: Rigid structure]

$L_{\bar{z}}$ = 136.0m (446.0 ft) [Ref: Rigid structure]

The resonant response factor R is computed from Equation 10.19:

$$R = \sqrt{\frac{1}{\beta} R_n R_h R_B (0.53 + 0.47\, R_L)}$$ (Chapter 10 Eq.10.19)

$$= \sqrt{\frac{1}{0.01} x0.07x0.21x0.38[(0.53 + 0.46x0.08)]} = 0.56$$

[R_n=0.07, R_h = 0.21, R_B =0.38, R_L =0.054]

where;

ß = damping ratio (Assumed = 0.01)

$$R_n = \frac{7.47 N_1}{1 + (10.3 N_1)^{5/3}}$$ (Chapter 10 Eq. 10.20)

$$= \frac{7.47x2.82}{1 + (10.3x2.82)} = 0.07$$

Reduced frequency $N_1 = \frac{n_1 L\bar{z}}{V\bar{z}}$ (Chapter 10 Eq.10.21)

= 0.7x136/33.68 = 2.82 [for $L_{\bar{z}}$ ref: Chapter 10 Eq. 10.16]

where; mean hourly wind speed,

$$\bar{V}_{\bar{z}} = \bar{b}\left(\frac{\bar{z}}{10}\right)^{\bar{\alpha}} V$$ (m/s) (Chapter 10 Eq. 10.23, Exposure A, Chapter 10,Table 10.8)

$$= 0.45\left(\frac{27.1}{10}\right)^{1/4} x\ 58.20$$ [210 km/h = 58.20 m/s, Chapter 10 Table 10.1]

= 33.60 m/s

$$\bar{V}_{\bar{z}} = \bar{b}\left(\frac{\bar{z}}{33}\right)^{\bar{\alpha}} V \left(\frac{88}{60}\right)$$ V = 130.14 mph in fps system, Table 10.1

For Exposure A, Table 10.6

$$\bar{V}_{\bar{z}} = 0.45\left(\frac{88.8}{33}\right)^{1/4} 130.2\left(\frac{88}{60}\right)$$ = 110.31 ft. /s. = 33.60 m/s

$$R_h = \frac{1}{\eta_h} - \frac{1}{2\eta_h^2}(1 - e^{-2\eta_h})$$

$$R_h = \frac{1}{4.32} - \frac{1}{2x4.32^2}(1 - e^{-2x4.32}) = 0.21$$

$$\eta_h = \frac{4.6\eta_1 h}{\bar{V}_{\bar{z}}} = \frac{4.6x0.7x45.1}{33.6} = 4.32$$ [n_1 = 0.7, h = 45.1, $\bar{V}_{\bar{z}}$ = 33.6]

$$R_B = \frac{1}{\eta_B} - \frac{1}{2\eta_B^2}(1 - e^{-2\eta_B})$$

$$= \frac{1}{2.0} - \frac{1}{2x2^2}(1 - e^{-2x2}) = 0.38$$

$$\eta_B = \frac{4.6\eta_1 B}{\overline{V}_{\bar{z}}} = \frac{4.6x0.7x20.83}{33.6} = 2.0 \quad [n_1 = 0.7,\ B = 20.83,\ \overline{V}_{\bar{z}} = 33.6]$$

$$R_L = \frac{1}{\eta_L} - \frac{1}{2\eta^2{}_L}(1 - e^{-2\eta_L})$$

$$= \frac{1}{12.34} - \frac{1}{2x12.34^2}(1 - e^{-2x12.34}) = 0.08$$

$$\eta_L = \frac{15.4 n_1 L}{\vec{V}_{\bar{z}}} = \frac{15.4x.7x56.2}{49.1} = 12.34 \quad [n_1 = 0.7, L = 56.2, \overline{V}_{\bar{z}} = 33.6]$$

So, $G_f = 0.925\left(\dfrac{1 + 1.7 I_{\bar{z}}\sqrt{g^2{}_Q Q^2 + g^2{}_R R^2}}{1 + 1.7 g_V I_{\bar{z}}}\right)$ (Chapter 10 Eq. 10.17)

[g_Q = 3.4, Q =0.81, g_R = 4.11, R= 0.56, g_v= 3.4, $I_{\bar{z}}$ = 0.2524]

$$G_f = 0.925\left[\frac{1 + 1.7x0.2542\sqrt{3.4^2 x0.81^2 + 4.11^2 x0.78^2}}{1 + 1.7x3.4x0.2524}\right] = 0.925(2.55/2.46) = 0.96$$

Say, 1.0

11.2.6 Enclosure Classification

It is assumed that the building is enclosed as per Section 10.2.4

11.2.7 Internal Pressure Co-efficient GC_{pi}

Internal pressure co-efficient GC_{pi} shall be determined from Table 10.9.

For an enclosed building, $GC_{pi} = \pm$ 0.18.

11.2.8 External pressure co-efficient C_p

External pressure coefficients for main wind force-resisting system are given in Table 10.10 of this document which has been prepared on the basis of Fig.2.4.6 Part6 of BNBC15.

For wind in N-S direction,

Windward wall C_p = 0.8

Leeward Wall L/B = 20.83/56.2 =0.37

: C_p = - 0.5 [$^L/_B$ = 0 - 1]

Side wall: - 0.7 [All values]

Roof (h/L = 45.1/20.83 = 2.17) [h/L >1.0]

C_p = -1.3 over entire roof (20.83m< h/2 = 22.55m.)

C_p may be reduced to – 1.3 x 0.8= -1.04 for area greater than 92.90 sqm (1000 sft) (Table 10.10)

For wind in E-W direction,
Windward wall: $C_p = 0.8$
Leeward Wall (L/B = 56.18/20.83 = 2.70
C_p = -0.27 [2< L/B < 3 interpolation]
Side wall: C_p = - 0.7
Roof (h/L = 45.1/56.18 = 0.80 [0.5 < h/L < 1]
C_p = -1.14 from windward edge to h/2 = 22.55 m(74.0 ft.)
C_p = -0.78 from h/2 to h = 22.55m (74 ft.) to 45.11m(148 ft.)
C_p = -0.62 from h to L = 45.11m (148.0 ft.) to 56.18m.(184.33 ft)

11.2.9 Velocity Pressure q_z

The velocity pressure at height z is determined by Eq.10.15 of Chapter 10
$q_z = 0.613\, K_z\, K_{zt} K_d\, V^2 I$ (N/ m^2); V in m/s
$q_z = 0.00256\, K_z\, K_{zt}\, K_d\, V^2 I$ in fps system (lb/ ft^2) ; V in mph
The values of K_z, K_{zt}, K_d and I has already been defined earlier, out of which only K_z varies with height and other factors remain constant, such as,
$K_{zt} = 1$, $K_d = 0.85$, $I = 1.15$
A summary of the velocity pressure for the example building is given in Table 11.2

Table 11.2: Velocity Pressure

[V= 58.3 m/s = 210 km/hr] $K_{zt} = 1$, $K_d = 0.85$, $I = 1.15$

$q_z = 0.613\, K_z\, K_{zt}\, K_d\, V^2 I$ N $\quad$ V= m/s

Level	Height above G.L. z m	K_z	q_z (1) N/m^2
12	45.11	1.105	2250
11	41.45	1.079	2220
10	37.80	1.051	2140
9	34.14	1.021	2080
8	30.48	0.988	2020
7	26.28	0.953	1940
6	23.16	0.914	1860
5	19.51	0.870	1770
4	15.85	0.820	1670
3	12.19	0.760	1550
2	8.53	0.687	1400
1	4.88	0.585	1143

(1) $q_z = 0.613 \times 1 \times 0.85 \times 1.15 \times 58.3^2 \times k_z = 2036.64\, k_z$

Table 11.2A : Velocity Pressure

$[V = 130.5 \text{ mph}]$ $K_{zt} = 1$, $K_d = 0.85$, $I = 1.15$

$q_z = 0.00256\, K_z\, K_{zt}\, K_d\, V^2 I$ psf

(fps system)

Level	Height above G.L. z ft	K_z	q_z [(1)] psf
12	148	1.105	47.10
11	136	1.079	46.00
10	124	1.051	44.77
9	112	1.021	43.50
8	100	0.988	42.10
7	88	0.953	40.60
6	76	0.914	38.94
5	64	0.870	37.06
4	52	0.820	34.93
3	40	0.760	32.38
2	28	0.687	29.27
1	16	0.585	24.92

(1) $q_z = 0.00256 \text{ x}1 \text{ x } 0.85 \text{ x } 1.15 \text{ x } 130.5^2 \text{ x } k_z = 42.616\, k_z$

11.2.10 Design Wind Pressure

Design wind pressure on the main wind-force resisting systems (MWFRS) of enclosed and partially enclosed buildings are determined in accordance with Equation 10.26 for rigid buildings which is;

$p = q\, GCp - q_i\, (GC_{pi})$ N/m^2 (psf) (Chapter 10 Eq.10.26)

For flexible buildings, the wind pressure is calculated by Equation 10.17 which is;

$p = q\, G_f\, C_p - q_i\, (GC_{pi})$ N/m^2 (psf) (Chapter 10 Eq. 10.27)

where;

$q = q_z$ for windward wall evaluated at height z above ground

$q = q_h$ for leeward walls, side walls and roof, evaluated at height h

$q_i = q_h$ for all walls and roofs of enclosed building.

Table11.3 Design Wind Pressure in N-S Direction (Rigid Building n_1 = 1.18)
(V= 58.3 m/s = 210 kph) [1kN/m^2 = 20.89 psf, 1 m = 3.281 ft]
$p = q\,GC_p - q_i(GC_{pi})$

Location	Level	Height above ground level z m	External pressure				Internal Pressure		
			q N/m^2	G (1)	C_p (2)	$q\,G\,C_p$ N/m^2	q_i N/m^2 (3)	GC_{pi} (4)	$q_i\,GC_{pi}$ N/m^2
1	2	3	4	5	6	7 = 4 x 5 x 6	8	9	10 = 8 x 9
Windward	12	45.11	2250	0.82	0.80	1479	2250	±0.18	±405
	11	41.45	2220	0.82	0.80	1456	2250	±0.18	±405
	10	37.80	2140	0.82	0.80	1404	2250	±0.18	±405
	9	34.14	2080	0.82	0.80	1364	2250	±0.18	±405
	8	30.48	2020	0.82	0.80	1325	2250	±0.18	±405
	7	26.28	1940	0.82	0.80	1273	2250	±0.18	±405
	6	23.16	1860	0.82	0.80	1220	2250	±0.18	±405
	5	19.51	1770	0.82	0.80	1161	2250	±0.18	±405
	4	15.85	1670	0.82	0.80	1095	2250	±0.18	±405
	3	12.19	1550	0.82	0.80	1017	2250	±0.18	±405
	2	8.53	1400	0.82	0.80	918	2250	±0.18	±405
	1	4.88	1143	0.82	0.80	781	2250	±0.18	±405
Leeward	--	All	2250	0.82	-0.5	-923	2250	±0.18	±405
Side	--	All	2250	0.82	-0.7	-1292	2250	±0.18	±405
Roof	--	45.11	2250	0.82	-1.04	-1919	2250	±0.18	±405

(1) Section 11.2.5 (2) Section 11.2.8 (3) $q_i = q_h$ (4) Section 11.2.7 and Table 10.9
Note: There may be minor variation in values due to conversion.

Table11.3A Design Wind Pressure in N-S Direction (Rigid Building n_l = 1.18)
(V= 130.5 mph) [1kN/m^2 = 20.89 psf, 1 m = 3.281 ft]
(fps system)

Location	Level	Height above ground level z ft	External pressure				Internal Pressure		
			q psf	G [(1)]	C_p [(2)]	$q\,G\,C_p$ (psf)	q_i (psf)[(3)]	GC_{pi} [(4)]	$q_i\,GC_{pi}$ psf
1	2	3	4	5	6	7 = 4 x 5 x 6	8	9	10 = 8 x 9
Windward	12	148	47.10	0.82	0.80	30.9	47.1	±0.18	±8.48
	11	136	46.00	0.82	0.80	30.18	47.1	±0.18	±8.48
	10	124	44.77	0.82	0.80	29.37	47.1	±0.18	±8.48
	9	112	43.50	0.82	0.80	28.54	47.1	±0.18	±8.48
	8	100	42.10	0.82	0.80	27.62	47.1	±0.18	±8.48
	7	88	40.60	0.82	0.80	26.63	47.1	±0.18	±8.48
	6	76	38.94	0.82	0.80	25.54	47.1	±0.18	±8.48
	5	64	37.06	0.82	0.80	24.31	47.1	±0.18	±8.48
	4	52	34.93	0.82	0.80	22.91	47.1	±0.18	±8.48
	3	40	32.38	0.82	0.80	21.24	47.1	±0.18	±8.48
	2	28	29.27	0.82	0.80	19.20	47.1	±0.18	±8.48
	1	16	24.92	0.82	0.80	16.35	47.1	±0.18	±8.48
Leeward	--	All	47.1	0.82	-0.5	-19.31	47.1	±0.18	±8.48
Side	--	All	47.1	0.82	-0.7	-27.03	47.1	±0.18	±8.48
Roof	--	148	47.1	0.82	-1.04	-40.17	47.1	±0.18	±8.48

[(1)] Section 11.2.5 [(2)] Section 11.2.8 [(3)] $q_i = q_h$ [(4)] Section 11.2.7 and Table 10.9
Note: There may be minor variation in values due to conversion.

Table 11.4 Design Wind Force in N-S Direction (Rigid Building n_1 = 1.18 Hz)
(V = 58.3m/s = 210km/hr.)
[1Kip= 4.4482kN, 1m = 3.281]

Level	Height above ground level, z m	Tributary height m	Windward		Leeward		Total Design Wind Force kN
			Exernal Design Wind Pressure $q_z G C_p$ (1) N/m²	Design Wind Force $P*$ kN	Exernal Design Wind Pressure $q_h G C_p$ (2) N/m²	Design Wind Force $P*$ kN	
1	2	3	4	5=3x4xL	6	7=3x6xL	8 = 5 + 7
12	45.11	1.829	1479	151.99	-923	95.01	247.00
11	41.45	3.657	1456	296.95	-923	189.98	486.93
10	37.80	3.657	1404	288.99	-923	189.98	478.97
9	34.14	3.657	1364	280.80	-923	189.98	470.78
8	30.48	3.657	1325	271.76	-923	189.98	461.74
7	26.28	3.657	1273	262.00	-923	189.98	451.98
6	23.16	3.657	1220	249.94	-923	189.98	439.92
5	19.51	3.657	1161	239.18	-923	189.98	429.16
4	15.85	3.657	1095	225.42	-923	189.98	415.40
3	12.19	3.657	1017	208.98	-923	189.98	398.96
2	8.53	3.657	918	188.92	-923	189.98	378.90
1	4.88	4.268	781	187.27	-923	221.31	408.58

*$P = q_z G C_p$ x Tributary height x L (56.18m). q_h = 2250 x 0.82 x -0.5 = -923
(1) See Table11.3 column 7 (2) $q = q_h$ for leeward wall = 2250 , G = 0.82, C_p = -0.5 for leeward wall (Table11.3)
Note: There may be minor variation in values due to conversion

Table11.4A Design Wind Force in N-S Direction (Rigid Building n_l = 1.18 Hz)
(V = 130.5 mph)
[1Kip= 4.4482kN, 1m = 3.281]
(fps system)

Level	Height above ground level, z ft	Tributary height ft	Windward		Leeward		Total Design Wind Force Kips
			Exernal Design Wind Pressure $q_z G C_p$ (1) psf	Design Wind Force P* Kips	Exernal Design Wind Pressure $q_h G C_p$ (2) psf	Design Wind Force P* Kips	
1	2	3	4	5=3x4xL	6	7=3x6xL	8 = 5 + 7
12	148	6.00	30.9	34.17	-19.31	21.36	55.53
11	136	12	30.18	66.76	-19.31	42.71	109.47
10	124	12	29.37	64.97	-19.31	42.71	107.68
9	112	12	28.54	63.13	-19.31	42.71	105.84
8	100	12	27.62	61.09	-19.31	42.71	103.80
7	88	12	26.63	58.90	-19.31	42.71	101.61
6	76	12	25.54	56.19	-19.31	42.71	98.90
5	64	12	24.31	57.77	-19.31	42.71	96.48
4	52	12	22.91	50.68	-19.31	42.71	93.39
3	40	12	21.24	46.98	-19.31	42.71	89.69
2	28	12	19.20	42.47	-19.31	42.71	85.18
1	16	14	16.35	42.19	-19.31	49.83	92.02

*$P = q_z G C_p$ x Tributary height x L (184.33 ft.). q_h = 47.1x 0.82 x -0.5 = -19.31
(1) See Table11.3 column 7 (2) $q = q_h$ for leeward wall = 47.1, G = 0.82, C_p = -0.5 for leeward wall (Table11.3A)
Note: There may be minor variation in values due to conversion

Table11.5 Design Wind Pressure in E-W Direction (Flexible Building n_{I}= 0.7 Hz)
(V= 58.3 m/s = 210kph)

Location	Level	Height above ground level z m	External Pressure				Internal Pressure		
			q N/m^2	G_f	C_p (5)	$q\,G_f\,C_p$ N/m^2	q_i (6) N/m^2	GC_{pi} (4)	$q_i\,G\,C_{pi}$ N/m^2
1	2	3	4	5	6	7 = 4x5x6	8	9	10 = 8x9
Windward	12	45.11	2250	1	0.80	1800	2250	±0.18	±405
	11	41.45	2220	1	0.80	1776	2250	±0.18	±405
	10	37.80	2140	1	0.80	1712	2250	±0.18	±405
	9	34.14	2080	1	0.80	1664	2250	±0.18	±405
	8	30.48	2020	1	0.80	1616	2250	±0.18	±405
	7	26.28	1940	1	0.80	1552	2250	±0.18	±405
	6	23.16	1860	1	0.80	1488	2250	±0.18	±405
	5	19.51	1770	1	0.80	1416	2250	±0.18	±405
	4	15.85	1672	1	0.80	1336	2250	±0.18	±405
	3	12.19	1550	1	0.80	1240	2250	±0.18	±405
	2	8.53	1400	1	0.80	1120	2250	±0.18	±405
	1	4.88	1193	1	0.80	954	2250	±0.18	±405
Leeward	--	All	2250	1	-0.27	-608	2250	±0.18	±405
Side	--	All	2250	1	-0.70	-1575	2250	±0.18	±405
Roof	--	45.11(1)	2250	1	-1.04	-2340	2250	±0.18	±405
	--	45.11(2)	2250	1	-.0.78	-1755	2250	±0.18	±405
	–	45.11(3)	2250	1	0.62	-1395	2250	±0.18	±405

(1)From windward edge to h/2 = 22.55m (2)From h/2 to h = 22.55m - 45.11m (3)From h to L= 45.11m to 56.88m (4)Section 11.2.7 and Table10.9 (5)Section 11.2.8 and Table10.10 (6)$qi = q_h$ Sec 11.2.10

Table11.5A Design Wind Pressure in E-W Direction (Flexible Building n_{1}= 0.7 Hz)
(V= 130.5 mph) (fps system)

Location	Level	Height above ground level z m (ft)	External Pressure				Internal Pressure		
			q N/m²(psf)	G_f	C_p (5)	$q\,G_f\,C_p$ N/m²(psf)	q_i (6) N/m²(psf)	GC_{pi} (4)	$q_i\,G\,C_{pi}$ N/m²(psf)
1	2	3	4	5	6	7 = 4x5x6	8	9	10 = 8x9
Windward	12	148	47.10	1	0.80	37.68	47.1	±0.18	±8.48
	11	136	46.00	1	0.80	36.80	47.1	±0.18	±8.48
	10	124	44.77	1	0.80	35.82	47.1	±0.18	±8.48
	9	112	43.50	1	0.80	34.80	47.1	±0.18	±8.48
	8	100	42.10	1	0.80	33.68	47.1	±0.18	±8.48
	7	88	40.60	1	0.80	32.48	47.1	±0.18	±8.48
	6	76	38.94	1	0.80	31.15	47.1	±0.18	±8.48
	5	64	37.06	1	0.80	29.65	47.1	±0.18	±8.48
	4	52	34.93	1	0.80	27.94	47.1	±0.18	±8.48
	3	40	32.38	1	0.80	25.90	47.1	±0.18	±8.48
	2	28	29.27	1	0.80	23.41	47.1	±0.18	±8.48
	1	16	24.92	1	0.80	19.94	47.1	±0.18	±8.48
Leeward	--	All	47.1	1	-0.27	-12.72	47.1	±0.18	±8.48
Side	--	All	47.1	1	-0.70	-32.97	47.1	±0.18	±8.48
Roof	--	148(1)	47.1	1	-1.04	-48.98	47.1	±0.18	±8.48
	--	148(2)	47.1	1	-0.78	-36.74	47.1	±0.18	±8.48
	–	148(3)	47.1	1	0.62	-29.2	47.1	±0.18	±8.48

(1)From windward edge to h/2 = 74ft (2)From h/2 to h = 74 ft. to 148 ft. (3) From h to L= 148 ft.-184.33 ft (4) Section 11.2.7 and Table10.9 5) Section 11.2.8 and Table10.10 (6) $qi = q_h$ Sec 11.2.10

Table 11.6 Design Wind Force in E-W Direction (Flexible Building $n_1 = 0.7$)
(V= 58.3m/s=210 kph)
$G_f = 1.0$ $C_p = 0.80$ for windward and -0.27 for leeward wall (see Table 11.5)

Level	Height Above Ground level z m	Tributary Height m	Windward		Leeward		Total design Wind Force kN
			External Design Wind Pressure $q_z G_f C_p$ N/m²	Design Wind Force *P kN	External Design Wind Pressure $q_h G_f C_p$ N/m²	Design Wind Force *P kN	
1	2	3	4	5= 3x4xB	6	7=3x6xB	8 = 5+7
12	45.11	1.829	1800	68.58	608	23.16	91.74
11	41.45	3.657	1776	135.29	608	46.31	181.6
10	37.80	3.657	1712	130.41	608	46.31	176.72
9	34.14	3.657	1664	126.76	608	46.31	173.07
8	30.48	3.657	1616	123.10	608	46.31	169.41
7	26.82	3.657	1552	118.22	608	46.31	164.53
6	23.16	3.657	1488	113.35	608	46.31	159.66
5	19.51	3.657	1416	107.86	608	46.31	154.17
4	15.88	3.657	1336	101.77	608	46.31	148.08
3	12.19	3.657	1240	94.46	608	46.31	140.77
2	8.53	3.657	1120	85.32	608	46.31	131.63
1	4.88	4.268	954	84.81	608	54.05	138.86

*$P = q_z G_f C_p$ x tributary height x width of the building (20.831m)

Table 11.6A Design Wind Force in E-W Direction (Flexible Building $n_l = 0.7$)
(V=130.5 mph)
$G_f = 1.0$ $C_p = 0.80$ for windward and -0.27 for leeward wall (see Table 11.5)
(fps system)

Level	Height Above Ground level ft	Tributary Height m (ft)	Windward		Leeward		Total design Wind Force Kips
			External Design Wind Pressure $q_z G_f C_p$ psf	Design Wind Force *P kN (Kips)	External Design Wind Pressure $q_h G_f C_p$ psf	Design Wind Force *P Kips	
1	2	3	4	5= 3x4xB	6	7=3x6xB	8 = 5+7
12	148	6.00	37.68	15.45	12.72	5.21	20.66
11	136	12	36.80	30.17	12.72	10.43	40.6
10	124	12	35.82	29.37	12.72	10.43	39.80
9	112	12	34.80	28.53	12.72	10.43	38.96
8	100	12	33.68	27.62	12.72	10.43	38.05
7	88	12	32.48	26.68	12.72	10.43	37.11
6	76	12	31.15	25.54	12.72	10.43	35.97
5	64	12	29.65	24.31	12.72	10.43	34.74
4	52	12	27.94	22.91	12.72	10.43	33.34
3	40	12	25.90	21.24	12.72	10.43	31.07
2	28	12	23.41	19.20	12.72	10.43	29.63
1	16	14	19.94	19.08	10.13	11.73	30.81

$*P = q_z\ G_f\ C_p$ x tributary height x width of the building (68.33 ft.)

11.2.11 Load Combination

The main wind-force-resisting system of buildings of all heights, whose wind loads have been determined according to Section 10.3.1 and 10.3.2 must be designed for the full and partial load cases of Fig.2.4.9 of BNBC15 (Case1 through 4). These 4 cases shall have to be considered in the three-dimensional analysis.

Basic strength load combinations are given in Chapter 9 which is same as those of BNBC15and ASCE7-05

1. $U = 1.4\,(D+F)$
2. $U = 1.4\,(D+F+T) + 1.6\,(L+H) + 0.5\,(L_r \text{ or } R)$
3. $U = 1.2\,D + 1.6\,(L_r \text{ or } R) + (1.0\,L \text{ or } 0.8\,W)$
4. $U = 1.2\,D + 1.6\,W + 1.0\,L + 0.5\,(L_r \text{ or } R)$
5. $U = 1.2\,D + 1.0\,E + 1.0\,L$
6. $U = 0.9\,D + 1.6\,W + 1.6\,H$
7. $U = 0.9\,D + 1.0\,E + 1.6\,H$

where;

D = dead load or related internal moments and forces

F = load due to weight and pressure of fluids with well- defined densities and controllable maximum height or related internal moments and forces

T= cumulative effects of temperature, cteep, shrinkage, differential settlement and shrinkage compensating concrete, or combination thereof, or related internal moments and forces

L = live loads due to intended use of occupancy, including loads due to movable objects and movable partitions and loads temporary supported by the structure during maintainance or related internal moments and forces

H = loads due to weight and pressure of soils, water in soil or other materials or related internal moments and forces

L_r = roof live loads or related internal moments and forces

R = rain loafds or related internal moments and forces

W = wind loads or related internal moments and forces

E = load effects of seismic forces or related internal moments and forces

The load foctor on L may be reduced to 0.5 except for garages, areas occupied as places of public assembly and all areas where the live load is greater than 4.79 KN/m^2 (100 psf). But live load shall not be reduced for designed emergy preparedness, communication and operation centers and other facilities required for emergency response such as cyclone shelters.

The loads in this example building are dead, live, wind and earthquake. The load combinations can be conservatively simplified by including L_r with L and using the higher load factor for L or L_r in each of these equations. Finally the load factor can be taken as 0.5 in this example as per Section 9.3(1)[Exception]. Thus the simplified load combination are as follows:

$U = 1.4\,D$

$U = 1.2\,D + 1.6\,L$

$U = 1.2\,D + 1.6\,L + 0.8\,W$

$U = 1.2\,D + 0.5\,L + 1.6\,W$

$U = 1.2\,D + 1.0\,E + 0.5\,L$

$U = 0.9\,D + 1.6\,W$

$U = 0.9\,D + 1.0\,E$

With these load combinations , three dimensional computer analysis shall give bending moments and shear force at different sections of main wind- force- resisting- system. These bending moments and shear forces shall be compared with the capacity of the elements of the existing structure. If any member of the structure is found to be inadequate, necessary retrofitting measures shall be taken.

CHAPTER 12
INUNDATION DEPTH DUE TO STORM SURGE AND TSUNAMI IN COASTAL AREAS

12.1 INTRODUCTION

Bangladesh has approximately 710 Km (441 miles) coastline. 13 coastal districts starting with Satkhira at the south-west corner bordering with West Bengal of India and ending with Cox's Bazar at the south east end bordering with Myanmar are vulnerable to strong tidal surge, wind action, high waves and tropical cyclones and tsunami. These 13 districts are Satkhira, Khulna, Bagerhat, Perojpur, Barisal, Barguna, Patuakhali, Bhola, Laksmipur, Noakhali, Feni, Chittagong, Cox's Bazar.50 Upazilas/Thanas are considered to be exposed directly to vulnerability from natural disaster. All these areas are comparatively low in elevation which makes it more vulnerable to tidal surge and tsunami. Of these areas, about 62% of the lands have an elevation of up to 3 meters (10.0 ft) and 86% up to 5 meters (16.40 ft) from mean sea level.

The area also has a very complex network of rivers which carries huge amount of water heavily laden with sediments, which helps in further rise of water level.

12.2 RISK ZONE AND HIGH RISK AREA

Multipurpose Cyclone Shelter Programme (MPCSP) (Ref. 3.4) has delineated the coastal belt of Bangladesh into Risk Zone (RZ) and High Risk Area (HRA) based on the possible extent of the inland intrusion of the cyclone storm surge (Ref. Fig. 12.1).

The RZ extends from the coast line (sea coast or river bank) to an inland limit up to which surge water can reach.

The HRA includes a strip of land within the RZ. It extends from the coast line up to the limit where the depth of storm surge inundation may reach one meter (3ft 3in). The one meter (3ft 3in) criteria has been selected based upon the assumption that an adult could force his way through water as long as the depth of water remains below waist height.

The area covered by MPCSP is almost identical to the area covered by the following tables of storm surge.

Entire area of the off-shore islands except the Maheshkhali area is included in the HRA. A part of Maheshkhali is covered by hills and therefore free from inundation. However, the western and northern parts of Maheshkhali are of low elevation and risk inundation.

12.3 INUNDATION DEPTH DUE TO STORM SURGE

Islamic Development Bank (IDB) commissioned Institute of Water Modeling (IWM) to carry out a study to determine the inundation depth of about 750 sites due to cyclone under Fael Khair Program, IDB in August 2010 [Ref. 12.1].

The study assessed the storm surge heights in potential locations based on simulation results of historical severe cyclones (1960-2009) and additional cyclones with a combination of different tidal conditions and cyclone tracks.

IWM simulated 44 cyclone to develop baseline conditions for the whole coastal region, with 19 numbers for opposite tidal conditions and 6 numbers for three additional cyclone tracks.

Based on the above study, minimum and maximum surge depths in all the coastal upazilas/thanas due to storm surge is furnished in the following tables of storm surge.

The cyclone induced storm surge depth at different locations is computed by deducting the surveyed ground level from the simulated surge level.

The surveyed ground level (GL) has been calculated by the Consultants engaged for the project Fael Khair Program IDB with reference to PWD Bench Mark (mPWD).

In some areas like Banshkhali, Maheshkhali of Chittagong, Cox's Bazar Sadar, Hatiya, Kabirhat, Subarnachar of Noakhali difference in inundation depth due to storm surge has been found between Digital Elevation Model (DEM) 1991 and surveyed GL calculated by consultants. The difference varies approximately 0.5-1.5 m (1.64-5.0 ft). For design of structures in these areas against storm surge historical data, information from local people should be collected before deciding the inundation depth.

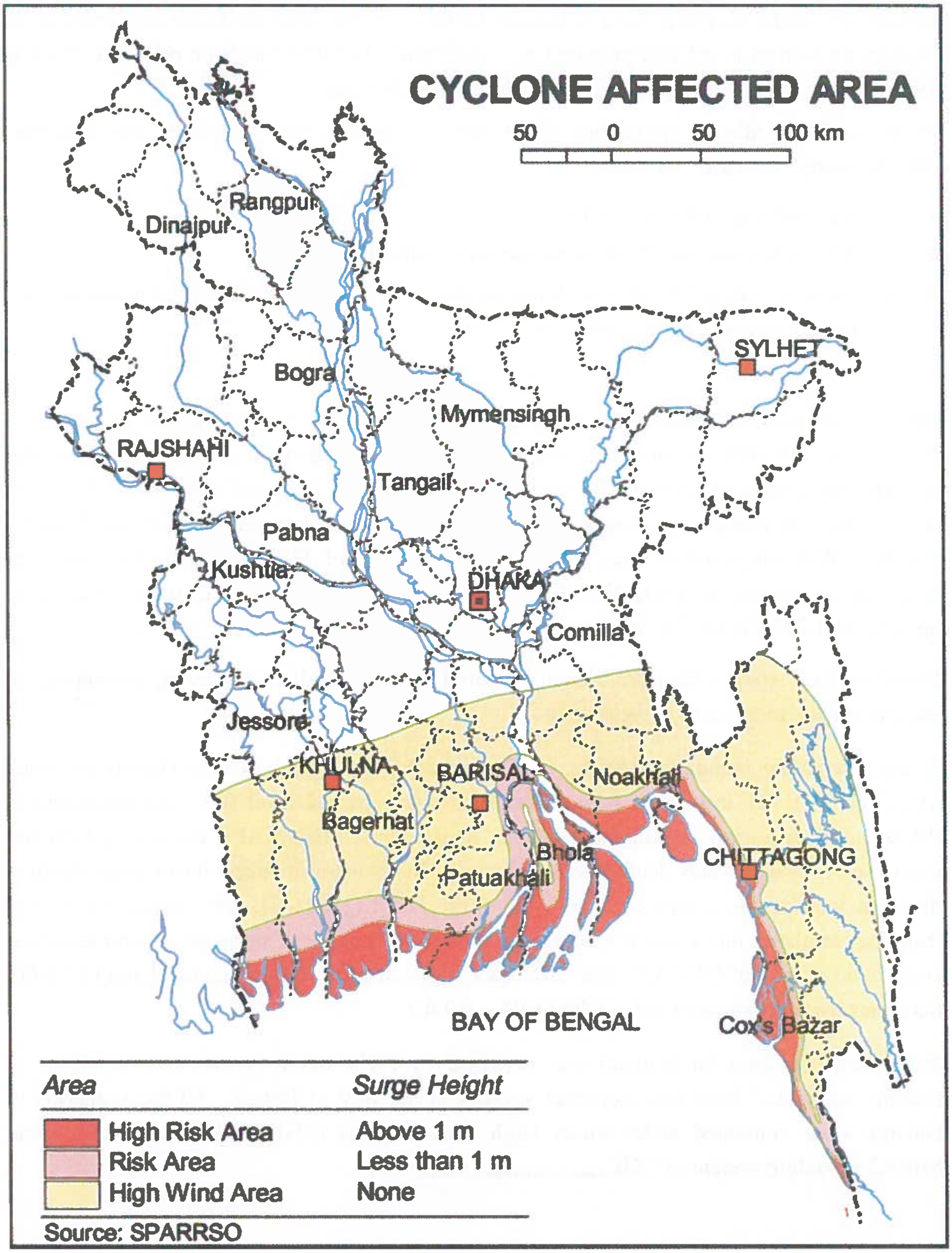


Figure 12.1 High Risk Area and Risk Area of Inundation due to Storm Surge

Inundation depths provided in the following tables of storm surge are based on surveyed GL based with respect to mPWD prepared by consultants. As DEM has been done way back in 1991, there is possibility of change in GL during last 20 years.

IWM, while calculating inundation depth due to cyclone, has considered the following climate change sceneries for 2050:

- Sea level rise of 0.5 m (1.64 ft)
- 10% increase in maximum wind speed of cyclone.

A list of approximately 750 sites with inundation depths have been furnished in Annexure3. GIS location of every site is available in the list.

12.4 INUNDATION DETH DUE TO TSUNAMI

Ministry of Food and Disaster Management under its Comprehensive Disaster Management Programme (CDMP) commissioned Institute of Water Management (IWM), and Associates to carry out a study to 'Identify Tsunami-vulnerable School/ Hospital/ Emergency Response and Control Buildings in Coastal Region and Evaluate Adoption Capacity to Tsunami Events'. IWM submitted its final report in April 2009 (Ref. C12-2). During the study, the consultants assessed the inundation depth due to tsunami of 12 coastal districts covering 43 upazilas and 245 unions. The survey covered about 4700 infrastructures.

Based on that study, tables have been prepared for coastal districts having probability of inundation due to tsunami in these areas.

While calculating inundation depths, land topography has been based on Digital Elevation Model (DEM)1991 instead of taking actual surveyed ground level (GL) corresponding to PWD Datum or Survey of Bangladesh (SoB) Bench Mark. FINNMAP Land survey 1991 has been used to assess water depth due to tsunami. The tsunami induced storm surge depth at different locations is computed by deducting the DEM (1991)-GL with respect to mPWD from the simulated sure level. It would have been more accurate if surveyed ground level was considered instead of DEM-GL. The difference between surveyed ground level and DEM-GL may vary by approximately 0.5 - 1.5m (1.04 – 5.0 ft.)

Inundation risk map for tsunami was prepared by IWM based on the four scenarios of tsunami originated from four potential sources in the Bay of Bengal. All the scenarios of tsunami were simulated under Mean High Water Spring (MHWS) tide condition using MIKE2 modeling system of DHI water. Environment. Health.

12.5 INUNDATION DEPTH OF BAGERHAT DISTRICT

Table 12.1 Inundation Depth due to Storm Surge

District	Upazila (Thana or Sub-district)	Range of inundation depth *d* as per surveyed G.L.		Specific area having greater depth of inundation
		Meter	Feet	
Bagerhat	Mongla	$1.56 < d \leq 2.80$	$5.10 < d \leq 9.18$	-
Bagerhat	Sarankhola	$2.1 < d \leq 3.60$	$6.90 < d \leq 11.81$	-

Table 12.2 Inundation Depth due to Tsunami

District	Upazila (Sub-District or Thana)	Range of inundation depth as per Digital Elevation Model (DEM)		Specific Area having greater depth of inundation
		Meter	Feet	
Bagerhat	Mongla	$0.11 < d \leq 0.94$	$0.36 < d \leq 3.10$	-
Bagerhat	Sarankhola	$0.20 < d \leq 0.88$	$0.66 < d \leq 2.88$	-

Figure 12.2 Upazilas(Thanas) affected by Storm Surge and Tsunami are Mongla and Sarankhola

12.6 INUNDATION DEPTH OF BARGUNA DISTRICT

Table 12.3 Inundation Depth due to Storm Surge

District	Upazila (Thana or Sub-district)	Range of inundation depth *d* as per surveyed G.L.		Specific area having greater depth of inundation
		Meter	Feet	
Borguna	Amtali	$0.85 < d \leq 4.80$	$2.79 < d \leq 15.74$	-
Borguna	Bamna	$0.75 < d \leq 2.82$	$2.46 < d \leq 9.25$	Dowatala: 4.12m (13.5 ft)
Borguna	Borguna Sadar	$0.65 < d \leq 5.00$	$2.13 < d \leq 16.40$	-
Borguna	Betagi	$0.39 < d \leq 4.00$	$1.28 < d \leq 13.12$	Betagi, Bibichini, Mokamia,Sarishamuri $= 5.5 < d \leq 5.87$ m $= 18 < d \leq 19.25$ ft.
Barguna	Patharghata	$1.5 < d \leq 5.60$	$4.92 < d \leq 18.37$	Pathorghata Sadar = 6.51m (21.35 ft)

Table 12.4 Inundation Depth due to Tsunami

District	Upazila (Sub-District or Thana)	Range of inundation depth as per Digital Elevation Model (DEM)		Specific Area having greater depth of inundation
		Meter	Feet	
Barguna	Amtali	dry $= d \leq 0.88$	dry $= d \leq 2.88$	-
Borguna	Bamna	dry$= d \leq 0.85$	dry $= d \leq 2.79$	-
Barguna	Barguna Sadar	dry$= d \leq 1.46$	dry $= d \leq 4.79$	-
Borguna	Betagi	dry$= d \leq 0.87$	dry $= d \leq 2.85$	-
Borguna	Patharghata	dry $= d \leq 0.94$	dry $= d \leq 3.10$	-

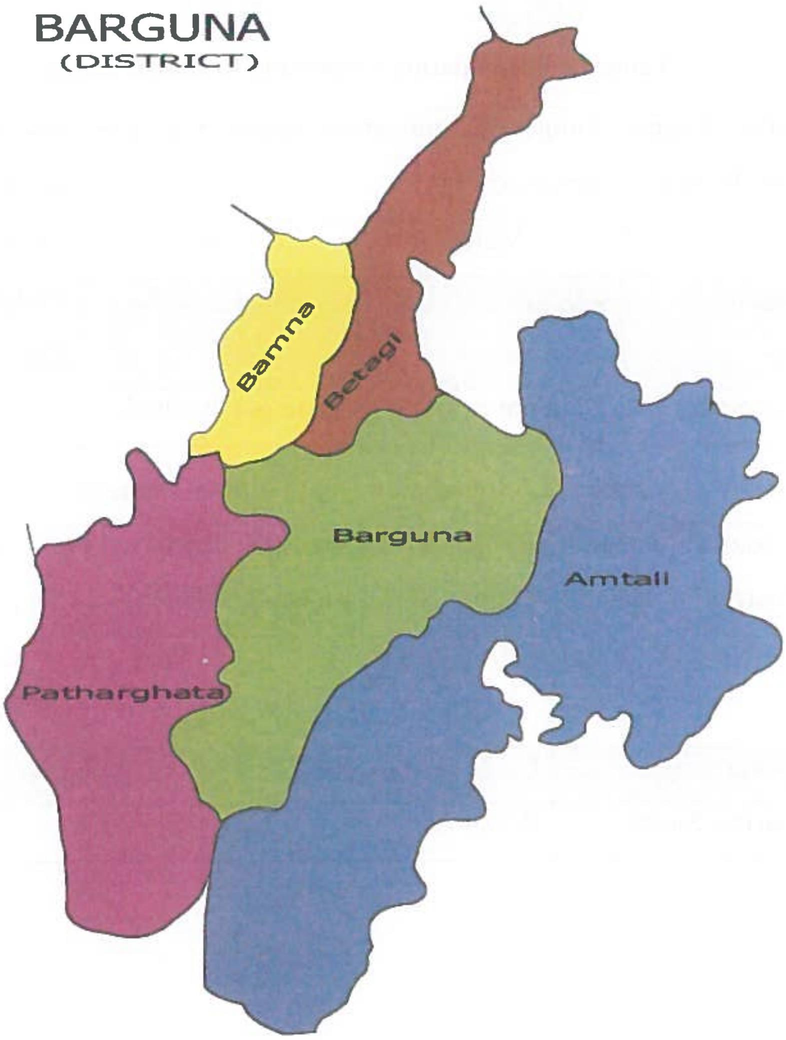


Figure 12.3 Upazilas(Thanas) affected by Storm Surge and Tsunami are Amtali, Bamna, Barguna Sadar, Betagi and Pathargha

12.7 INUNDATION DEPTH OF BARISAL DISTRICT

Table 12.5 Inundation Depth due to Storm Surge

District	Upazila (Thana or Sub-district)	Range of inundation depth d as per surveyed G.L.		Specific area having greater depth of inundation
		Meter	Feet	
Barisal	Bakergonj	$2.0 < d \leq 3.91$	$6.56 < d \leq 12.82$	Patkati= 5m (16.4 ft.)
Barisal	Barisal Sadar	Data not available	Data not available	-

Table 12.6 Inundation Depth due to Tsunami

District	Upazila (Sub-District or Thana)	Range of inundation depth as per Digital Elevation Model (DEM)		Specific Area having greater depth of inundation
		Meter	Feet	
Barisal	Bakergonj	$0.77 < d \leq 1.00$	$2.53 < d \leq 3.28$	-
Barisal	Barisal Sadar	$0.37 < d \leq 1.0$	$1.21 < d \leq 3.28$	-

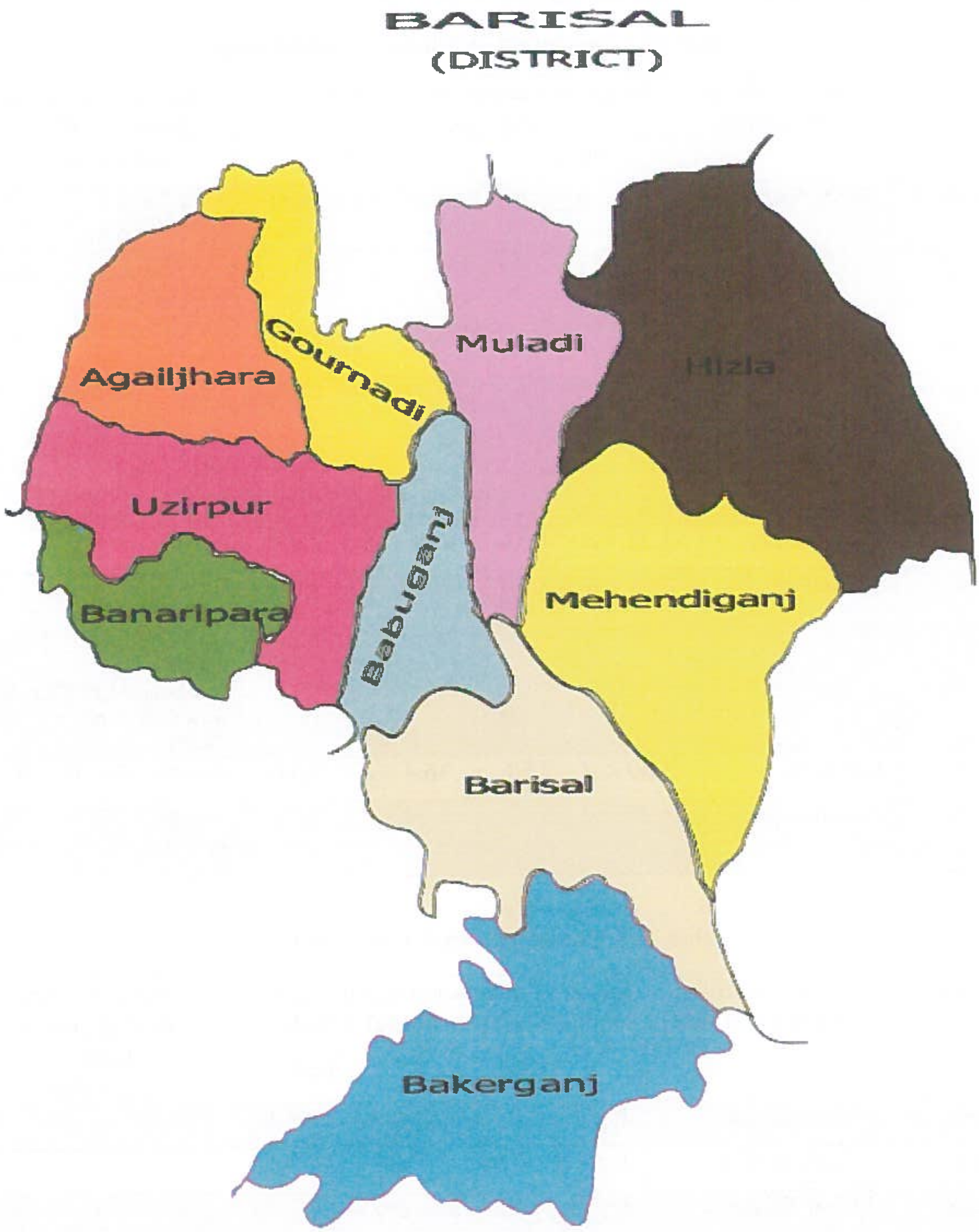


Figure 12.4 Upazilas(Thanas) affected by Storm Surge and Tsunami are Bakergonj, Barisal Sadar

12.8 INUNDATION DEPTH OF BHOLA DISTRICT

Table 12.7 Inundation Depth due to Storm Surge

District	Upazila (Thana or Sub-district)	Range of inundation depth d as per surveyed G.L.		Specific area having greater depth of inundation
		Meter	Feet	
Bhola	Bhola Sadar	$2.11 < d \leq 5.64$	$6.92 < d \leq 18.50$	Chor Samaia = 6.1 m (20 ft) Uttar Dighaldi = 5.64m (18.5 ft.)
Bhola	Burhanuddin	$2.40 < d \leq 6.13$	$7.87 < d \leq 20.10$	-
Bhola	Char Fasson	$1.91 < d \leq 6.00$	$6.26 < d \leq 19.68$	Char Kukrimukri = 10.92m (36.8 ft) Dhal Char = 9.3m (30.5 ft)
Bhola	Daulat khan	$3.22 < d \leq 8.54$	$1056 < d \leq 28.01$	-
Bhola	Lalmohan	$3.11 < d \leq 6.00$	$10.20 < d \leq 19.68$	Dhaligournagar: 7.45m (24.44 ft) Lord Harding=7.15m (23.45 ft) Farashgonj = 6.88 (22.6 ft) West Char Umed = 6.5m (21.32)
Bhola	Manpura	$5.00 < d \leq 7.50$	$16.4 < d \leq 24.60$	Hazirhat: 12m (39.36 ft)
Bhola	Tajumuddin	$1.20 < d \leq 5.72$	$3.94 < d \leq 18.76$	Sonapur: 12.55 m (41.16 ft).

Table 12.8 Inundation Depth due to Tsunami

District	Upazila (Sub-District or Thana)	Range of inundation depth as per Digital Elevation Model (DEM)		Specific Area having greater depth of inundation
		Meter	Feet	
Bhola	Bhola Sadar	dry $= d \leq 1.56$	dry $= d \leq 5.12$	-
Bhola	Borhanuddin	dry $= d \leq 0.94$	dry $= d \leq 3.10$	-
Bhola	Char Fasson	dry $= d \leq 1.00$	dry $= d \leq 3.28$	-
Bhola	Daulat Khan	dry $= d \leq 1.00$	dry $= d \leq 3.28$	-
Bhola	Lalmohan	dry $= d \leq 0.77$	dry $= d \leq 2.53$	-
Bhola	Manpura	$0.27 < d \leq 2.34$	$0.89 < d \leq 7.68$	-
Bhola	Tazumuddin	dry $= d \leq 0.88$	dry $= d \leq 2.42$	-

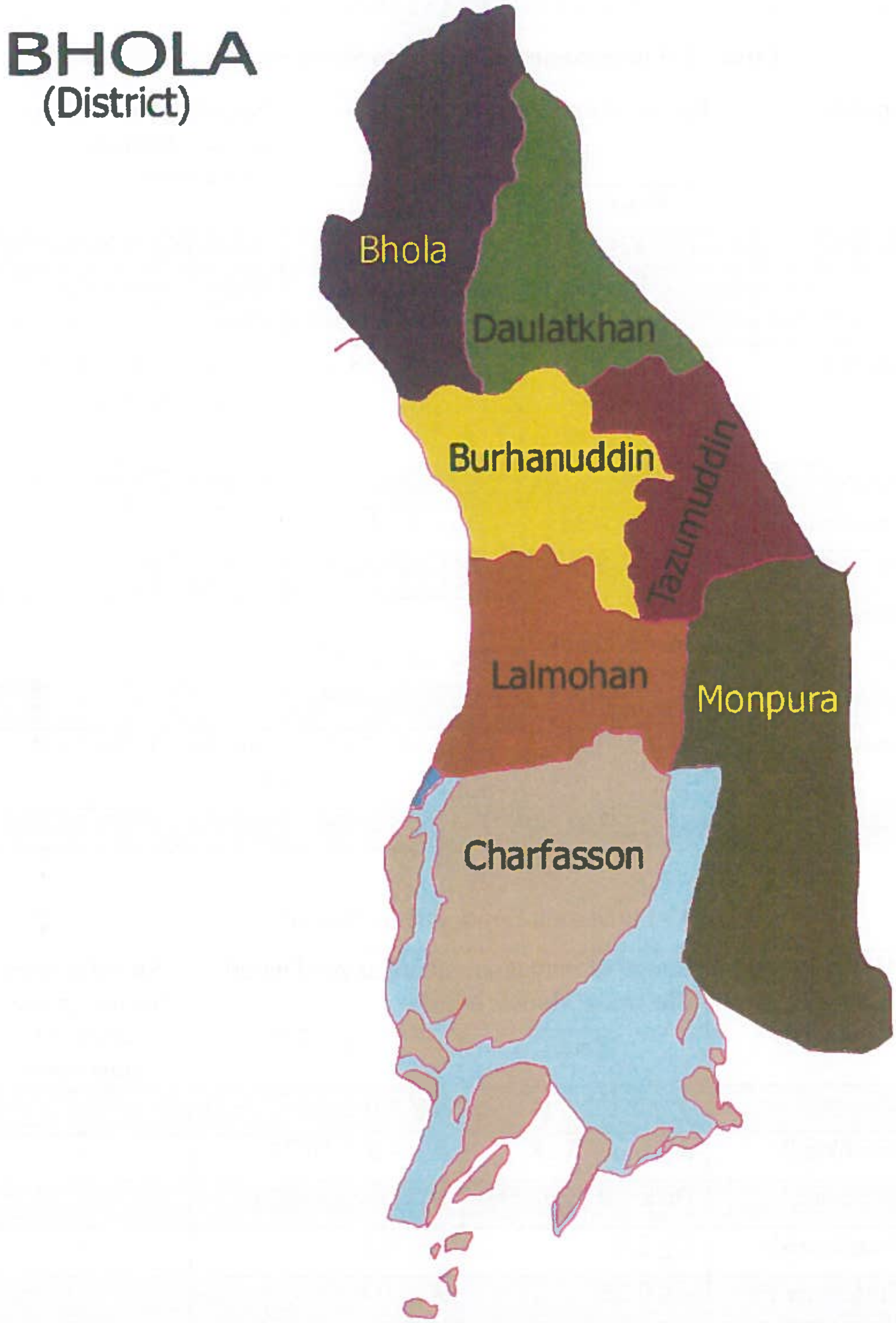


Figure 12.5 Upazilas(Thanas) affected by Storm Surge and Tsunami are Charfasson, Monpura, Lalmohan,Tazumuddin, Borhanuddin, Daulatkhan and Bhola Sadar (Entire District

12.9 INUNDATION DEPTH OF CHITTAGONG DISTRICT

Table 12.9 Inundation Depth due to Storm Surge

District	Upazila	Range of inundation depth as per surveyed G.L.		Specific Area having greater depth of inundation
		Meter	Feet	
Chittagong	Anwara	$1.13 < d \leq 6.67$	$3.71 < d \leq 21.88$	Borumchara: 8.26 m (27 ft) Raypur: 7.64 m (25 ft)
Chittagong	Bashkhali	dry = $d \leq 5.59$	Dry = $d \leq 18.34$	Bahshkhali= 8.10 m (26.57 ft). Khankhanabad, Shilkup=7.54m(24.90 ft).
Chittagong	Satkania	Dry	Dry	Charoti = 5.0 m (16.4 ft)
Chittagong	Chandanaish	$1.10 < d \leq 4.33$	$3.6 < d \leq 14.20$	-
Chittagong	Miresharai	$5.89 < d \leq 10.54$	$19.32 < d \leq 34.57$	-
Chittagong	Chittagong Port	Data not available	Data not available	-
Chittagong	Patiya	Data not available	Data not available	-
Chittagong	Sandwip	$8.52 < d \leq 10.40$	$27.95 < d \leq 34.11$	Urir char; 13.64m (44.74 ft)
Chittagong	Sitakunda	dry = $d \leq 7.80$	dry = $d \leq 25.58$	

Table 12.10 Inundation Depth due to Tsunami

District	Upazila (Sub-District or Thana)	Range of inundation depth as per Digital Elevation Model (DEM)		Specific Area having greater depth of inundation
		Meter	Feet	
Chittagong	Anwara	dry = $d \leq 0.35$	dry = d ≤ 1.15	-
Chittagong	Bonshkhali	dry = $d \leq 3.28$	dry = $d \leq 10.75$	-
Chittagong	Satkania	Data not available	Data not available	-
Chittagong	Chandanaish	$d \leq 2.9$	$d \leq 9.5$	-
Chittagong	Chittagong Port	$d \leq 0.25$	$d \leq 0.82$	-
Chittagong	Mirershari	Dry	Dry	-
Chittagong	Patiya	dry = $d \leq 0.89$	dry = $d \leq 2.92$	-
Chittagong	Sandwip	dry = $d \leq 0.85$	dry = $d \leq 2.79$	-
Chittagong	Sitakunda	dry = $d \leq 2.84$	dry = $d \leq 9.32$	-

Figure 12.6 Upazilas(Thanas) affected by Storm Surge and Tsunami are Anwara, Banshkhali, Satkania, Chandanaish, Mirershari, Patia, Sandwip, Sitakunda, Chittagong Port

12.10 INUNDATION DEPTH OF COX'S BAZAR DISTRICT

Table 12.11 Inundation Depth due to Storm Surge

District	Upazila	Range of inundation depth as per surveyed G.L.		Specific Area having greater depth of inundation
		Metre	Feet	
Cox's Bazar	Chokoria	$0.39 < d \leq 5.00$	$1.28 < d \leq 16.40$	
Cox's Bazar	Cox's Bazar Sadar	dry = $d \leq 2.14$	dry = $d \leq 7.02$	Idgaon= 6.07 m (19.78 ft) Islamabad, Jalalabad = 5.25 m (17.22 ft.)
Cox's Bazar	Kutubdia	$4.32 < d \leq 6.87$	$14.17 < d \leq 22.53$	Uttar Dhurung: 8.12m (26.63 ft) Ali Akbar Dail =7.69m (26.63 ft)
Cox's Bazar	Pekua	$4.33 < d \leq 6.54$	$14.2 < d \leq 21.45$	-
Cox's Bazar	Teknaf	Dry = $d \leq 0.70$	Dry = $d \leq 2.30$	-
Cox's Bazar	Ukhia	Dry = $d \leq 1.37$	Dry = $d \leq 4.5$	-
Cox's Bazar	Maheshkhali	dry = $d \leq 4.90$	dry = $d \leq 16.10$	Dhalghata = 9.43m (30.93 ft)

Table 12.12 Inundation Depth due to Tsunami

District	Upazila (Sub-District or Thana)	Range of inundation depth as per Digital Elevation Model (DEM)		Specific Area having greater depth of inundation
		Meter	Feet	
Cox's Bazar	Chakoria	dry = $d \leq 1.62$	dry = $d \leq 5.31$	-
Cox's Bazar	Cox's Bazar Sadar	dry = $d \leq 1.78$	dry = $d \leq 5.84$	-
Cox's Bazar	Kutubdia	$0.20 < d \leq 4.72$	$0.66 < d \leq 15.48$	-
Cox's Bazar	Pekua	Data not available	Data not available	-
Cox's Bazar	Teknaf	Data not available	Data not available	-
Cox's Bazar	Ukhia	Data not available	Data not available	-
Cox's Bazar	Maheshkhali	$0.10 < d \leq 2.38$	$0.33 < d \leq 7.81$	-

Figure 12.7 Upazilas(Thanas) affected by Storm Surge and Tsunami are Chokoria, Cox's bazar Sadar, Kutubdia, Teknaf, Maheshkhali, Pekua[1]

[1] Pekua not shown in the map(new Upazila)

12.11 INUNDATION DEPTH OF FENI DISTRICT

Table 12.13 Inundation Depth due to Storm Surge

District	Upazila	Inundation depth as per surveyed G.L.		Specific Area having greater depth of inundation
		Meter	Feet	
Feni	Sonagazi	$6.62 < d \leq 8.15$	$21.71 < d \leq 26.73$	-
Feni	Feni Sadar	$2.16 < d \leq 3.63$	$7.10 < d \leq 11.91$	-

Table 12.14 Inundation Depth due to Tsunami

District	Upazila (Sub-District or Thana)	Range of inundation depth as per Digital Elevation Model (DEM)		Specific Area having greater depth of inundation
		Meter	Feet	
Feni	Sonagazi	dry $= d \leq 4.89$	dry $= d \leq 16.04$	-
Feni	Feni Sadar	Data not available	Data not available	-

Figure 12.8 Upazillas(Thanas) affected by Storm Surge and Tsunami are Sonagazi, Feni Sadar

12.12 INUNDATION DEPTH OF KHULNA DISTRICT

Table 12.15 Inundation Depth due to Storm Surge

District	Upazila	Inundation depth as per surveyed G.L.		Specific Area having greater depth of inundation
		Meter	Feet	
Khulna	Dacope	dry = $d \leq 1.74$	dry = $d \leq 5.71$	-
Khulna	Koyra	dry = $d \leq 2.37$	dry = $d \leq 7.77$	-

Table 12.16 Inundation Depth due to Tsunami

District	Upazila	Inundation depth as per surveyed G.L.		Specific Area having greater depth of inundation
		Meter	Feet	
Khulna	Dacope	$0.25 < d \leq 1.04$	$0.82 < d \leq 3.14$	-
Khulna	Koyra	$0.40 < d \leq 2.11$	$1.31 < d \leq 6.92$	-

Figure 12.9 Upazilas(Thanas) affected by Storm Surge and Tsunami are Dacope, Koyra

12.13 INUNDATION DEPTH OF LAKSMIPUR DISTRICT

Table 12.17 Inundation Depth due to Storm Surge

District	Upazila	Inundation depth as per surveyed G.L.		Specific Area having greater depth of inundation
		Meter	Feet	
Laksmipur	Laksmipur Sadar	dry = $d \leq 3.73$	dry = $d \leq 12.23$	Shakchar, Toom Char: 5.16m (16.92 ft.)
Laksmipur	Raipur	$0.74 < d \leq 3.39$	$2.43 < d \leq 11.12$	-
Laksmipur	Ramgati	$3.6 < d \leq 4.17$	$11.80 < d \leq 13.68$	-
Laksmipur	Kamal Nagar	$1.69 < d \leq 6.05$	$5.54 < d \leq 19.84$	-

Table 12.18 Inundation Depth due to Tsunami

District	Upazila (Sub-District or Thana)	Range of inundation depth as per Digital Elevation Model (DEM)		Specific Area having greater depth of inundation
		Meter	Feet	
Laksmipur	Laksmipur Sadar	dry = $d \leq 0.23$	dry = $d \leq 0.75$	-
Laksmipur	Ramgoti	dry = $d \leq 1.31$	dry = $d \leq 4.30$	-
Laksmipur	Raipur	dry = $d \leq 1.08$	dry = $d \leq 3.54$	-
Laksmipur	Kamalnagar	Data not available	Data not available	-

Figure 12.10 Upazilas(Thanas) affected by Storm Surge and Tsunami are Laksmipur Sadar. Raipur, Ramgoti, Kamalnagar [(1)]

[(1)]Kamalnagar not shown in the map(new Upazila)

12.14 INUNDATION DEPTH OF NOAKHALI DISTRICT

Table 12.19 Inundation Depth due to Storm Surge

District	Upazila	Inundation depth as per surveyed G.L.		Specific Area having greater depth of inundation
		Meter	Feet	
Noakhali	Campanygonj	$5.80 < d \leq 8.64$	$19.02 < d \leq 28.34$	
Noakhali	Hatiya	$1.36 < d \leq 6.30$	$4.46 < d \leq 26.66$	Jahajamara: 11.73m (38.47 ft) Charlatia, Char king ,Nijhum Dip =8.32m (22.3ft) Sukchar =8.5m (27.85ft)
Noakhali	Noakhali Sadar	Data not available	Data not available	-
Noakhali	Kabirhat	Dry	Dry	Caprashirhat=7.58m (24.86 ft)
Noakhali	Subarna Char	$1.04 < d \leq 5.23$	$3.42 < d \leq 17.15$	Char Jublee= 9.5m (31.1ft)

Table 12.20 Inundation Depth due to Tsunami

District	Upazila (Sub-District or Thana)	Range of inundation depth as per Digital Elevation Model (DEM)		Specific Area having greater depth of inundation
		Meter	Feet	
Noakhal	Companigonj	Dry $= d < 0.22$	Dry $= d < 0.72$	-
Noakhali	Hatiya	dry $= d \leq 2.55$	dry $= d \leq 8.36$	-
Noakhali	Noakhali Sadar	dry $= d \leq 4.92$	dry $= d \leq 16.14$	-
Noakhali	Kabirhat	Data not available	Data not available	-
Noakhali	Subarnachar	Data not available	Data not available	-

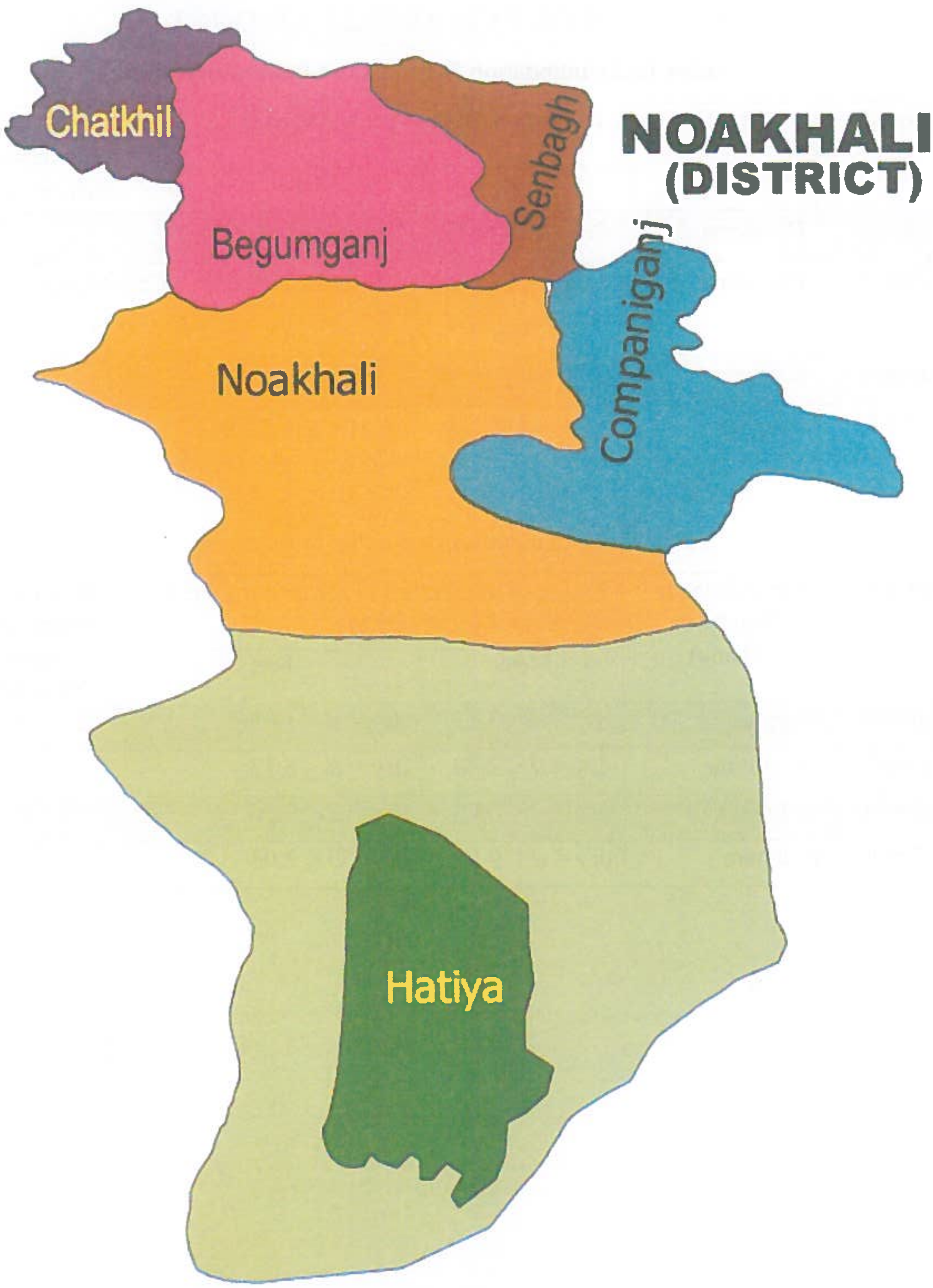


Figure 12.11 Upazillas(Thanas) affected by Storm Surge and Tsunami are Companigonj, Hatiya, Noakhali Sadar, Kabirhat,(1) Subarnachar (1)

(1) Kabirhat and Subarnachar not shown in the map (new Upazila)

12.15 INUNDATION DEPTH OF PATUAKHALI DISTRICT

Table 12.21 Inundation Depth due to Storm Surge

District	Upazila	Inundation depth as per surveyed G.L.		Specific Area having greater depth of inundation
		Meter	Feet	
Patuakhali	Dashmina	$2.49 < d \leq 6.86$	$8.17 < d \leq 22.50$	
Patuakhali	Golachipa	$1.74 < d \leq 5.96$	$5.71 < d \leq 19.55$	Char Montaz = 7.53m (24.7ft.)
Patuakhali	Kalapara	$0.98 < d \leq 4.94$	$3.21 < d \leq 16.20$	
Patuakhali	Bauphal	$2.87 < d \leq 6.69$	$9.41 < d \leq 21.94$	

Table 12.22 Inundation Depth due to Tsunami

District	Upazila (Sub-District or Thana)	Range of inundation depth as per Digital Elevation Model (DEM)		Specific Area having greater depth of inundation
		Meter	Feet	
Patuakhali	Bauphal	$dry = d \leq 3.83$	$dry = d \leq 12.56$	-
Patuakhali	Doshmina	$dry = d \leq 2.48$	$dry = d \leq 8.13$	-
Patuakhali	Golochipa	$dry = d \leq 0.76$	$dry = d \leq 2.50$	-
Patuakhali	Kalapara	$dry = d \leq 0.62$	$dry = d \leq 2.03$	-

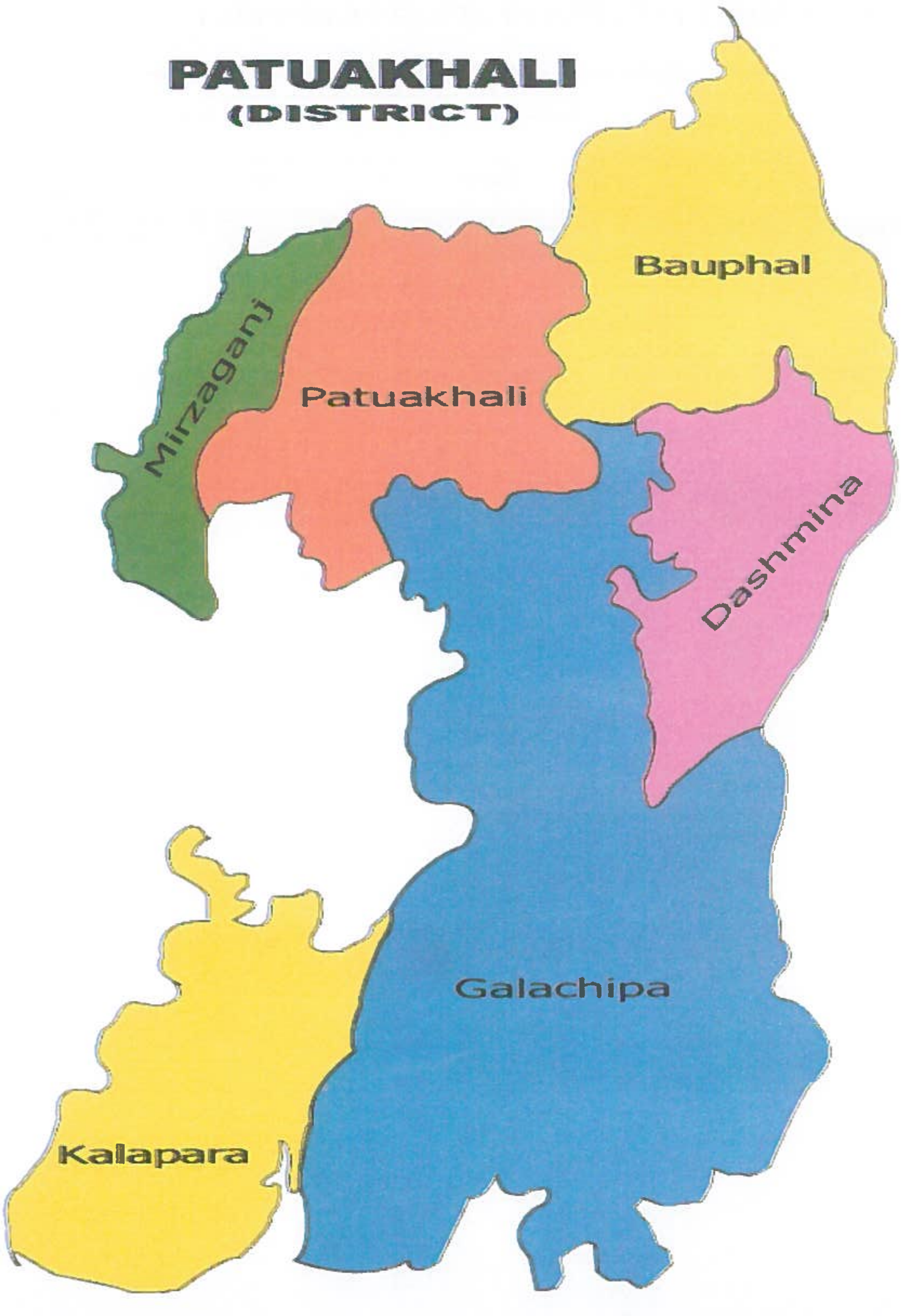


Figure 12.12 Upazilas(Thanas) affected by Storm Surge and Tsunami are Dashmina, Galachipa, Kalapara, Bauphal

12.16 INUNDATION DEPTH OF PIROJPUR DISTRICT

Table 12.23 Inundation Depth due to Storm Surge

District	Upazila	Inundation depth as per surveyed G.L.		Specific Area having greater depth of inundation
		Meter	Feet	
Pirojpur	Matbaria	dry = $d \leq 5.34$	dry = $d \leq 17.52$	-

Table 12.24 Inundation Depth due to Tsunami

District	Upazila (Sub-District or Thana)	Range of inundation depth as per Digital Elevation Model (DEM)		Specific Area having greater depth of inundation
		Meter	Feet	
Perojpur	Matbaria	dry = $d \leq 2.59$	dry = $d \leq 8.50$	-

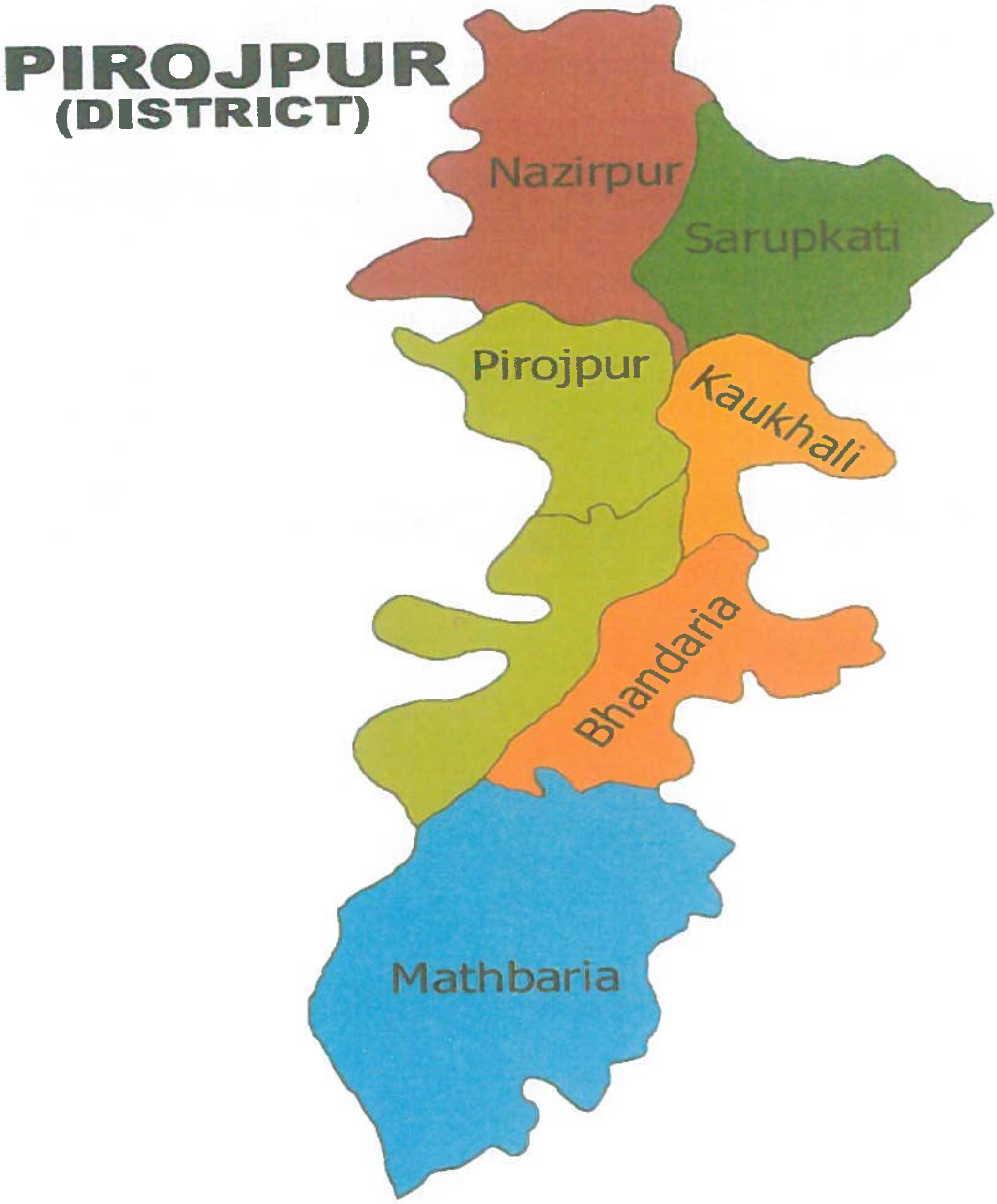


Figure12.13 Upazila(Thana) affected by Storm Surge and Tsunami is Matbaria

12.17 INUNDATION DEPTH OF SATKHIRA DISTRICT

Table 12.25 Inundation Depth due to Storm Surge

District	Upazila	Inundation depth as per surveyed G.L.		Specific Area having greater depth of inundation
		Meter	Feet	
Satkhira	Shyamnagar	dry = $d \leq 3.92$	dry = $d \leq 12.86$	-

Table 12.26 Inundation Depth due to Tsunami

District	Upazila (Sub-District or Thana)	Range of inundation depth as per Digital Elevation Model (DEM)		Specific Area having greater depth of inundation
		Meter	Feet	
Satkhira	Shyamnagar	$0.32 < d \leq 2.32$	$1.06 < d \leq 7.61$	

Figure 12.14 Upazila (Thana) affected by Storm Surge and Tsunami is Shyamnagar

12.18 COMPARISON OF INUNDATION DEPTHS DUE TO STORM SURGE AND TSUNAMI

After comparing the inundation depth due to cyclone induced storm surge and tsunami, (see Table 12.3) it is observed that inundation depth is higher due to tidal surge than tsunami. But as the maximum water velocity in relation to depth of water is double for tsunami compared to tidal surge ($v=\sqrt{gh}$ for tidal surge and $v=2\sqrt{gh}$ for tsunami), the hydrodynamic force, debris impact force shall be same for tsunami in comparison to tidal surge for half the water depth. Moreover, for tidal surge water rises gradually with the increase of intensity of wind velocity, whereas water force due of tsunami is somewhat sudden and surge volume of receding water draining off the land has the devastating power of carrying almost everything with it.

So, even with half the indentation depth compared to tidal surge, the damage and destruction due to tsunami may be much more.

Table 12.27: Comparison of Maximum Inundation Depth due to Tidal Surge and Tsunami

District	Upazila	Maximum inundation depth '*d*' in meter due to		Maximum inundation depth '*d*' in feet due to	
		Storm surge (m)	Tsunami (m)	Storm surge (ft)	Tsunami (ft)
Bagerhat	Mongla	2.80	0.94	9.18	3.10
Bagerhat	Sarankhola	3.60	0.88	11.81	2.88
Barguna	Amtali	4.80	0.88	15.74	2.88
Brguna	Bamna	2.82	0.85	9.25	2.13
Barguna	Borguna Sadar	5.00	1.46	16.40	4.72
Barguna	Betagi	4.00	0.87	13.12	2.98
Barguna	Patharghata	5.60	0.94	18.37	1.87
Barisal	Bakergonj	3.91	1.00	12.82	3.28
Barisal	Barisal Sadar	-	1.00	-	3.28
Bhola	Bhola sadar	5.64	1.56	18.50	5.12
Bhola	Borhanuddin	6.13	0.94	20.10	3.10
Bhola	Charfasson	6.00	1.00	19.68	3.28
Bhola	Doulatkhan	8.54	1.00	28.01	3.28
Bhola	Lalmohan	6.00	0.77	19.68	2.53
Bhola	Monpura	7.50	2.34	24.60	7.88
Bhola	Tajumuddin	5.72	0.88	18.76	2.92
Chittagong	Anwara	6.67	0.35	21.88	1.15
Chittagong	Satkania	Dry except Choroti=5.0	Data not available	Dry except Choroti =16.4	Data not available
Chittagong	Chandanaish	4.33	2.90	14.20	9.5
Chittagong	Chittagong Port	Data not available	0.25	Data not available	0.82
Chittagong	Banshkhali	5.59	3.28	18.34	4.03
Chittagong	Mirersharai	10.54	Dry	34.57	3.28
Chittagong	Patiya	-	0.89	-	2.98
Chittagong	Sandwip	10.40	0.85	34.11	2.79
Chittagong	Sitakunda	7.80	2.84	25.58	9.32
Cox's Bazar	Chokoria	5.00	1.62	16.40	5.31
Cox's Bazar	Cox's Bazar sadar	2.14	1.78	7.02	5.77
Cox's Bazar	Kutubdia	6.87	4.72	22.53	15.48

Cox's Bazar	Pekua	6.54	Data not available	21.45	Data not available
Cox's Bazar	Maheshkhali	4.90	2.38	16.07	7.81
Cox's Bazar	Teknaf	0.70	Data not available	2.30	Data not available
Cox's Bazar	Ukhia	1.37	- Do -	4.50	- Do -
Feni	Sanagazi	8.15	4.89	26.73	
Feni	Feni Sadar	3.63	--	11.91	
Khulna	Dacope	1.74	1.04	5.71	
Kuulna	Koyra	2.37	2.11	7.77	
Laksmipur	Laksmipur sadr	3.73	0.23	12.23	Dry
Laksmipur	Ramgati	4.17	1.31	13.68	4.30
Laksmipur	Raipur	3.39	1.08	11.12	3.54
Laksmipur	Kamalnagar	6.05	Data not available	19.84	Data not available
Noakhali	Companygonj	8.64	0.22	28.34	3.28
Noakhali	Hatiya	6.30	2.55	20.66	8.36
Noakhali	Noakhali Sadar	-	4.92	-	16.14
Noakhali	Subarna char	5.23	Data not available	17.15	Data not available
Noakhali	Kabirhat	Dry except Chaprashirhat = 7.58	-	Dry except Chaprashirhat = 24.86	-
Patuakhali	Bauphal	6.69	3.83	21.94	12.56
Patuakhali	Doshmina	6.86	2.48	22.50	8.13
Patuakhali	Galachipa	5.96	0.76	19.55	2.50
Patuakhali	Kalapara	4.94	0.62	16.20	2.03
Perojpur	Matbaria	5.34	2.59	17.52	8.50
Satkhira	Shyamnagar	3.92	2.32	12.86	7.61

CHAPTER 13

BUILDING DAMAGE ASSESSMENT DUE TO FLOOD, TIDAL SURGE AND TSUNAMI

13.1 INTRODUCTION

Methodology commonly used to estimate flood damage to buildings is typically based on aftermath survey. This methodology does not account for flooding hydrodynamic, as such it can not differentiate between flood water contact and flood water velocity. It is important to estimate the direct impact of flood actions on buildings and its components and to determine the expected damage. Building vulnerability should be modeled based on analytical representation of failure mechanism of individual building elements. Flood actions include,:

- hydrostatic force
- hydrodynamic force
- impact force
- breaking wave force
- time-dependent local soil scour

A stochastic methodology (that is, governed by the law of probability) (Ref. 13.2) shall be discussed in this chapter to assess the expected flood damage to individual building elements which shall have to be aggregated to arrive at the total damage of the building. The assessment is based on both flood water depth as well as flood water velocity. The methodology focuses on the vulnerability of reinforced concrete frame building with infill concrete block walls which is identical to the scope of this manual.

The general building data required for the vulnerability assessment include location, plan area and height of building, among others. Detail data are also required for each of the building component assessed: reinforced concrete frames; infill concrete blocks (brick) walls, doors, windows, utilities and finishes.

In general term *EFD* is defined as

$EFD = (D_i)(\Delta BV)$

where;

EFD = expected flood damage

D_i = flood damage (%) for flood intensity i

BV = replacing value of the building

Damage to each building component is methodically examined and combined to form the overall *EFD* at each depth- velocity combination.

In an extreme event when a load bearing column fails due to localized soil scour or impact of flood borne debris, the associated damages to all other adjacent building components (walls, doors, windows, utilities and finishes) are also accounted for and aggregated to the total damage.

In addition, buildings are considered a total loss when EFD reaches 60%. This threshold indicates that the cost of repairing the building is equal to the value of replacing it. Buildings located particularly in coastal areas are frequently affected by high winds in addition to the flood action. In these situations, both flood and wind action can adversely affect structures and it can be difficult to differentiate the damage caused by hydraulic loading from those caused by wind.

The methodology can serve as a decision making tool to assist engineers and emergency management agencies to identify zones of high risk and to implement the necessary preventive measures and mitigation strategies to minimize the adverse impact of potential flooding events.

13.2 LOADING CASES

Determining the expected flood depth and water velocity at a site is critical for the overall determination of the flood related damages and hazards. The method for making this determination can vary depending on whether the site is subject to riverine flooding, coastal flooding (storm surge) or tsunami. Riverine floods are mainly caused by the overflow of stream channels. Coastal floods can result from storm surge associated with unusually high tides or tsunami.

13.2.1 Riverine Floods

- *The slow rise of flood water* represents typical riverine flood. As the name implies, the flood water depth increases slowly, allowing for infiltration of water into the building through small openings of doors and windows. The situation causes the flood water level to be basically equal at both sides of the external wall, resulting in the cancellation of hydrostatic force. Only the hydrodynamic force acting on the outside of external walls due to flood water velocity is accounted for in this case; and

- *The flash flood, or fast rise flood*, represents an atypical situation where the flood water rises rapidly and moves at very high velocities. This type of flood can be caused by extreme rainstorm events, or by accidental situation such as the breaching of a levee or dam. The key assumption is that the rise of flood water is rapid enough to affect the building without allowing significant infiltration of flood water. Therefore, the inside of the building is considered to be dry. This in the worst-case scenario where it is also assumed that any given combination of flood water depth and flood water velocity occurs simultaneously. This would allow us to consider the maximum feasible flood damage due to riverine flood. Both the hydrostatic and hydrodynamic forces are accounted for in this case.

13.2.2 Storm surge

- *The surging flood* characterizes the most common type of coastal flood caused by a tropical storm or cyclone. Due to the nature of the storm surge event, the depth of still water increments gradually over few days and flooding of coastal areas can occur hours before the system landfall. The case is similar to the slow rise riverine flood, in which the hydrostatic force is cancelled and only the hydrodynamic force is considered;

- The breaking wave case applies to coastal zones, where waves are capable of reaching buildings at the coastline without any obstruction. The occurrence of breaking waves represents the maximum feasible flood damage due to a storm surge event. This case accounts for breaking waves and hydrodynamic forces.

  There is possibility that storm surge shall carry debris and may strike the building or structure. This case considers the impact of debris on building column or external wall on the sea side.

13.2.3 Tsunami

- *Turbulent bores* occur when the tsunami waves break and inundate the coasts as high velocity currents. These turbulent bores can adversely affect buildings even several miles inland. Due to rapid development of this type of event, both hydrostatic and hydrodynamic forces are considered;
- *Tsunami waves* normally break offshore and approach the coast as turbulent bores. However, when an area has been already flooded by long waves or bores, breaking waves can have a direct impact on buildings. This case considers the effects of breaking waves and hydrodynamic forces; and
- *Tsunami waves* shall carry debris either from sea or from the coast as part of an already damage building, broken trees etc. This case shall consider the effects of debris impact on columns as well as walls.

Table13.1: Load Cases and Forces for Different Flooding Conditions

Riverine Flood	Slow rise of water allowing infiltration of water into the building. Flood water level equal at both sides of external wall	Hydrodynamic force due to water velocity on the outside of external column/wall No hydrostatic force
	Flash Flood or first rising flood (Inside of building dry without significant infiltration of flood water) High velocity water	Hydrostatic as well as hydrodynamic force
Storm Surge	Depth of still water increments gradually & flooding of costal area occurs hours before system landfall	Hydrodynamic force due to storm surge No hydrostatic force
	Breaking wave reaches the building located at the coast line	Breaking wave force No hydrostatic force
	Possibility of carrying debris	Debris impact force
Tsunami	High velocity current with turbulent bores	Hydrostatic as well as hydrodynamic forces
	Possibility of breaking waves with direct impact on building	Breaking wave force
	Possibility of carrying debris either from sea or from coast as broken buildings or tree trunks	Debris impact force

13.2.4 Coastal Flood Prone Areas

Coastal flooding can result from unusually high tides, storm surge or tsunami. ***Although storm surge and tsunami are very different events, the effects on the buildings or infrastructures of the low-lying coastal zones can be very similar (Ref. C13-2).Recent examples of these are the tsunami that affected the Indian Ocean region in 2004 and the storm surge generated by Hurricane Katrina in the Gulf Coast of United States in 2005"Despite the differences in flow velocity and inundation duration, the effects on the coastal infrastructure in the inundation zones of Hurricane Katrina and Indian Ocean tsunami in 2004 were remarkably similar ……for this reason numerous parallels have been drawn between the two events." (Ref. 13.4).***

13.3 FLOOD FORCES AND LOADS

Flood water can exert a variety of forces on the building. This section describes these forces, which include hydrostatic, saturated soil, hydrodynamic, debris impact and erosion forces and illustrates how they are computed.

13.3.1 Flood Depth (*d*)

Flood depth can be computed by subtracting the lowest ground surface elevation (grade) adjacent to the structure from the flood elevation for each flood frequency (see Fig.13.1).

$$d = FE - GS \qquad \text{(Eq. 13.1)}$$

where;

d = depth of flooding (m/ft.)

FE = flood elevation for specific flood frequency (m/ft)

GS = lowest ground surface elevation (grade) adjacent to a structure (m/ft).

While computing flood depth be sure to use the lowest ground surface adjacent to the structure in question as shown in Fig 13.1

13.3.2 Design Flood Elevation (*DFE*)

The design flood elevation is always equal to or greater than Base Flood Elevation (BFE) and includes wave effects. One common way of specifying the DFE, using freeboard above Base Flood Elevation is illustrated in equation 13.2.

$$DFE = FE + f \qquad \text{(Eq. 13.2)}$$

where;

DFE = design flood elevation (m/ft.)

FE = flood elevation for a specific flood frequency (m/ft)

f = factor of safety (freeboard), typically a minimum of 0.3m (1.0 ft)

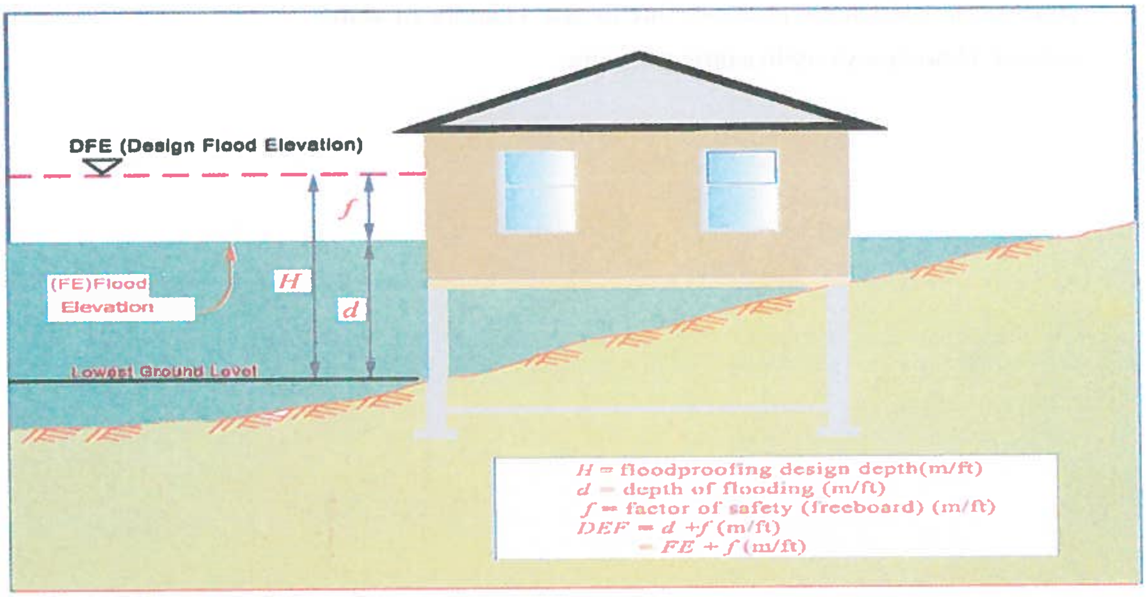


Fig. 13.1 Flood Depth and Design Flood Depth

13.3.3 Flood Proofing Design Depth

Determining the flood proofing design depth at the structure is very important for the flood load calculation process. Nearly every other flood load parameter or calculation (e.g..

hydrostatic load, hydrodynamic load, vertical hydrostatic load, debris impact load and local scour depth) depends directly or indirectly on the flood proofing design depth.

The flood proofing design depth (*H*) is the difference between *DFE* and the lowest grade adjacent to the structure (Fig 13.1). This computation is shown in Equation 13.3

$$H = DFE - GS \qquad \text{(Eq. 13.3)}$$

where;

H = flood proofing design depth over which flood forces are considered (m/ft).

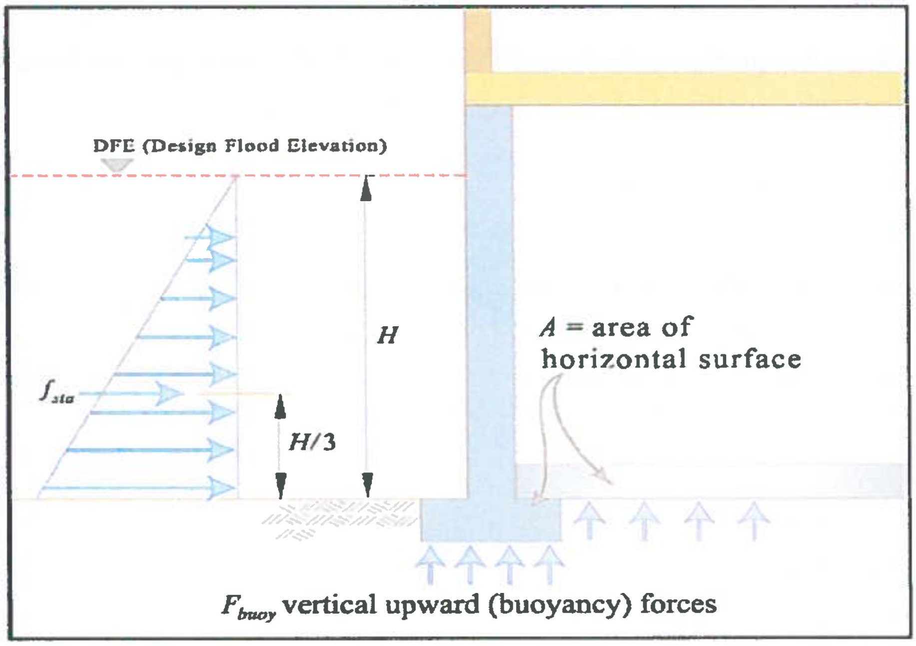
DFE = design flood elevation (m/ft.)

GS = lowest ground surface elevation (grade) adjacent to the structure (m/ft).

13.3.4 Hydrostatic Forces

The pressure exerted by still and slow moving water (velocity less than 3.0m/sec.= 10 ft. /sec) is called "hydrostatic pressure". During any point of flood water contact with a structure, hydrostatic pressures are equal in all direction and always act in perpendicular direction to the surface on which they are applied. Pressure increases linearly with depth or "head" of water above the point under consideration. The summation of pressures over the surface under consideration represents the load acting on that surface as shown in Fig.13.2. Four types of hydrostatics forces take place due to flood load:

- lateral hydrostatic force
- combined water and saturated soil pressure
- equivalent hydrostatic pressure due to low velocity of water
- vertical (buoyancy) hydrostatic pressure.



Hydrostatic Forces
Lateral Water Pressure
Combind Water and Saturated Soil Pressure
Equivalent Hydrostatic Pressure due to Velocity
Vertical (buoyancy) Water Pressure

Fig.13.2 Diagram of hydrostatic Pressure

For structural analysis, the hydrostatic forces are defined to act:

- vertically downward on structural elements such as flat roof or similar overhead members having a depth of water above them
- vertically upward (uplift) from the underside of generally horizontal members such as slabs, floor diaphragm, footings (also known as buoyancy)
- laterally in a horizontal direction on walls, piers, columns and similar vertical surfaces and act on the receiving structures at a point one-third the water depth above the base of the structure

Hydrodynamic force generated by velocities up to 3.m/s (10ft/s) may be converted to an equivalent hydrostatic force using conversion equation (Equation 13.7) presented later in this chapter.

13.3.4.1 Lateral Hydrostatic Force

The basis equation for analyzing the lateral force due to hydrostatic pressure from standing water above the surface of the ground is illustrated in Equation 13.4

$$f_{sta} = \frac{1}{2} P_h H = \frac{1}{2} \gamma_w H^2 \qquad \text{(Eq. 13.4)}$$

where;

f_{sta} = hydrostatic force, kN/lm(lb/lft) from standing water or water moving at a velocity less than 3m/s (10 ft/s) acting at a distance $H/3$ above ground

P_h = hydrostatic pressure due to standing water or water moving at a velocity less than 3.0m/s (10 ft/s) at a depth of H in kN/m^2(lb/ft^2)

$[P_h = \gamma_w H]$

γ_w = specific weight of water = 9.8 kN/m^3 (62.4 lb /ft^3) for fresh water and 10.05 kN/m^3 (64.0 lb/ft^3) for salt water

H = flood proofing design depth (m/ft)

13.3.4.2 Combined Saturated Soil and Water Force

If a portion of a structure is below grade, saturated soil forces must be included in the computation in addition to the hydrostatic forces. Equivalent fluid pressure for various types of soils is included in Table 13.2 and Table 13.2A based on USDA unified soil classification system (Ref.C13-1). The equivalent fluid weight of saturated soil is not the same as the effective weight of saturated soil. Rather the equivalent fluid weight of saturated soil is a combination of the unit weight of water and the effective saturated weight of soil.When a structure is subjected to hydrostatic forces from both saturated soil and standing water (Fig. 13.3) the resultant combined lateral force, f_{comb} is the sum of the lateral water hydrostatic force f_{sta}, and the differential between the water and soil pressure f_{dif} (Fig 13.3 and 13.4).

The basic equation for computing f_{dif} is shown in Equation 13.5

$$f_{dif} = \frac{1}{2}(S - \gamma_w) D^2 \qquad \text{(Eq. 13.5)}$$

where;

f_{dif} = differential soil/water force acting at a distance D/3 from the point under consideration kN/m(lb/ft).

S = equivalent fluid weight of submerged soil and water kN/ m^3(lb/ft^3)
as shown in Table 13.2

D = depth of saturated soil from adjacent grade to the top of the footer (m/ft.).

γ_w = specific weight of water = 9.8 kN/m^3 (62.4 lb/ft^3) for fresh water and 10.05 kN/m^3(64.0 lb/ft^3) for salt water

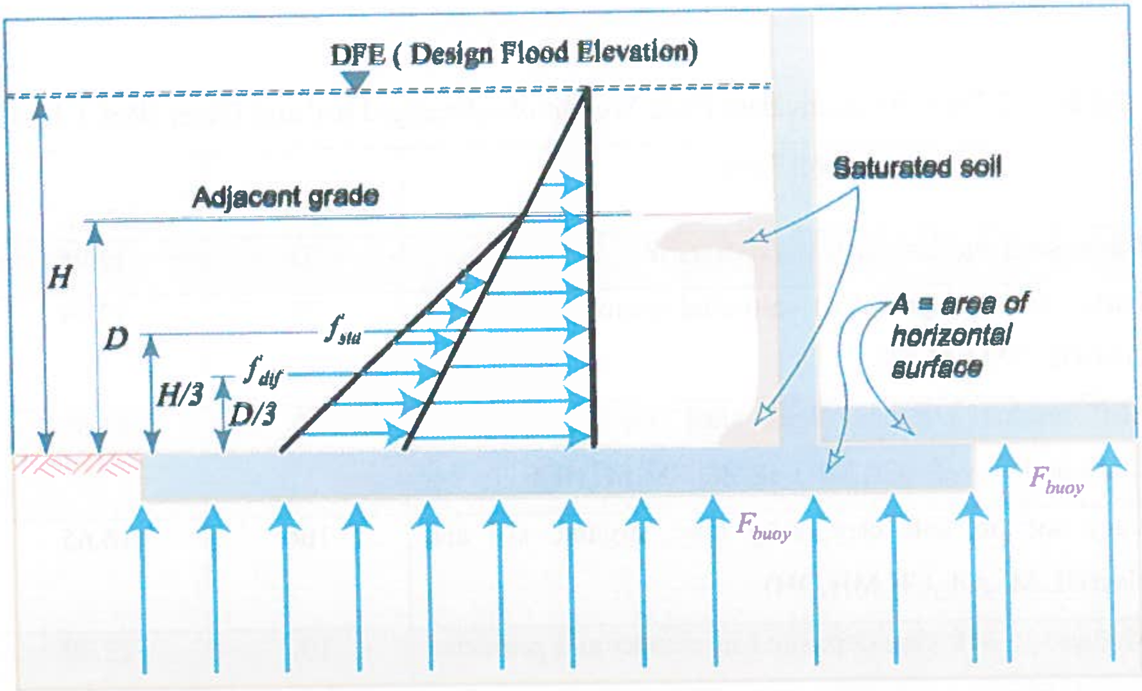
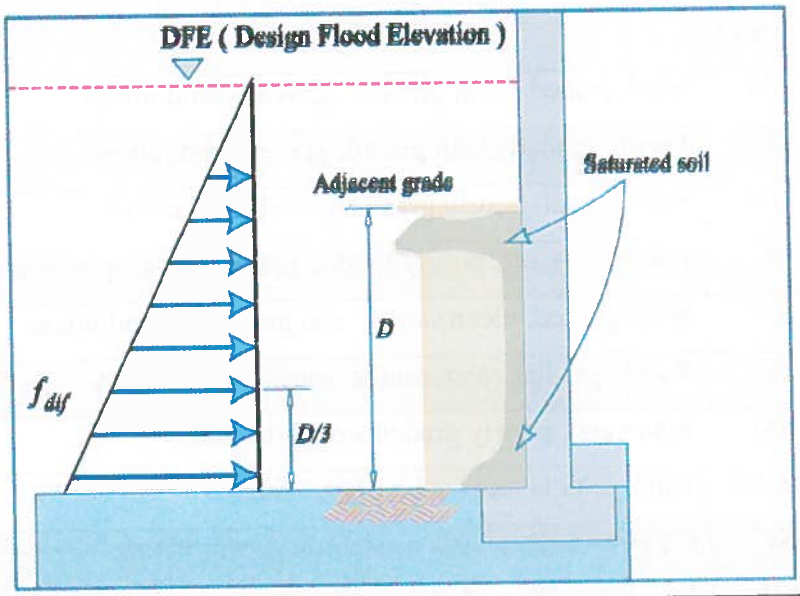


Fig 13.3 Combination of Soil/Water Hydrostatic and Buoyancy Forces



f_{dif} acts at a point $D/3$, where D is the distance from the adjacent grade to the top of the foundation.

$$f_{dif} = \frac{1}{2}(S - \gamma_w)\, D^2$$

Figure 13.4 Diagram of differential soil/water force

Table 13.2 Effective Equivalent Fluid Weight of submerged soil and Water (Ref. C13-1)

Soil Type	lb/ft^3	kN/m^3
Clean sand and Gravel(GW,GP,SW,SP)	75	11.78
Dirty sand and gravel of restricted permeability (GM, GM-GP, SM,SM-SP)	77	12.09
Stiff residual silt and clays, silty fine sands, clayey sands and gravels (CL.ML,CH,MH,SM,SC,GC)	82	12.88
Very soft to soft clay, silty clay, organic silt and clay(CL.ML,OL,CH,MH,OH)	106	16.65
Medium to soft clay deposited in chunks and protected from Infiltration (CL,CH)	102	22.30

$1\ lb./ft^3 = 0.1572\ kN/m^3$ $1\ kN/m^3 = 6.361\ lb/ft^3$

Table 13.2A Soil Type Definitions Based on USDA Unified Soil Classification System

Soil Type	Group Symbol	Description
Gravels	GW	Well-graded clean gravels ; gravels-sand mixes
	GP	Poorly graded clean gravel; gravel-sand mixes
	GM	Silty gravel, poorly graded gravel-sand mixes
	GC	Clayey gravels, poorly graded gravel-and-clay mixture
Sands	SW	Well-graded, clean sands; and gravelly- sand mixes
	SP	Poorly graded clean sands; sand- gravel mixes
	SM	Silty sand, poorly graded sand-silt mixes
	SM-SC	Sand- silt clay mix with plastic fine
	SC	Clayey sands, poorly graded sand-clay mixes
Fine Grain Silt and Clays	ML	Inorganic silts and clayey silts
	ML-CL	Mixture of inorganic silt and clay
	CL	Inorganic clays of low to medium plasticity
	OL	Organic silts and silt- clays of low plasticity
	MH	Inorganic clayey silts, elastic silts

	CH	Inorganic clays of high plasticity
	OH	Organic clays and silty clays

13.3.4.3 Vertical Hydrostatic Force

The basic equation for analyzing the vertical hydrostatic force (buoyancy) due to standing water (illustrated by Fig 13.2 and 13.3) is shown in Equation 13.6

$F_{buoy} = \gamma_w (Vol)$ (Eq. 13.6)

where;

F_{buoy} = vertical hydrostatic force resulting from the displacement of a given volume of flood water kg (lb).

γ_w = specific weight of water = 4.8 kN/m^3 (62.4 lb/ft^3) for fresh water and 10.05 kN/m^3(64.0 lb/ft^3) for salt water

Vol = volume of flood water replaced by a submerged object m^3 (ft^3).

Example 13.1 Calculate loads due to flood water

Given:

- Flood water velocity V in the area is less than 3m/s (10 ft./s) [2.0m/s = 6.56 ft./s]
- Flood water flows parallel to longer side and impacts shorter side of the building
- Flood elevation (*FE*) = +1.83m (6.0 ft)
- Factor of safety (free board) = 0.3m (1.0 ft)
- γ_w =10.05 kN/m^3 (64.0 lb. /ft^3.) for salt water
- Lowest elevation of example buildings = 0.0 (m/ft)
- Size of the building = 20.0 x 15.0 m (65.6 x49.2 ft)
- Depth of submerged soil from top of footing = 1.0 m (3.28 ft)
- Soil type is stiff residual clay with S = 12.88 kN/m^3(82.0lb/ft^3) (see Table 13.2)

Find:

1. Design Flood Elevation (*DFE*)
2. Flood proofing design depth (*H*)
3. Total vertical flood load due to buoyancy (F_{buoy})
4. Lateral hydrostatic force (f_{sta})
5. Submerged soil and water force (f_{dif})

Solution no.1

To find design flood elevation use Equation13.2

DFE= EF+f

= 1.83 +0.30=**2.13m (7.0 ft)**

Solution no.2

To find flood proofing design depth over which flood forces shall be considered use Equation13.3

H=DFE-GS

= 2.13-0.00 = **2.13 m (7.0 ft)**

Solution no.3

To calculate buoyancy force use Equation 13.6

$F_{buoy} = \gamma_w \ (Vol)$

$= \gamma_w A.\ H$

= 10.05 x 20.0 x 15 x2.13

= **6422.0 kN (1444.0 kips)**

Solution no.4

To calculate hydrostatic forces from 2.13 m(7.0 ft.) of water moving at less than 3.0 m/s (10.0 ft/s) use Equation13.4 and Fig 13.2

$f_{sta} = ½P_h H = 1/2\,\gamma_w H^2$

= 0.50 x10.05 x 2.13^2 = **22.8 kN/lm (1568 lb. /lft.)** acting at 0.71m (2.33 ft.) above ground surface

Solution no.5

To calculate submerged soil and water forces use Equation 13.5

$f_{dif} = ½(S-\gamma_w)\ D^2$

= ½ (12.88- 10.05) x1^2 = **1.42 kN/lm (96.83 lb / lft)** acting at D/3 from ground surface

13.3.5 Hydrodynamic Force

As discussed in section 13.3.5.1 and 13.3.5.2, there are two types of hydrodynamic forces acting on a building or structure (Fig 13.5)

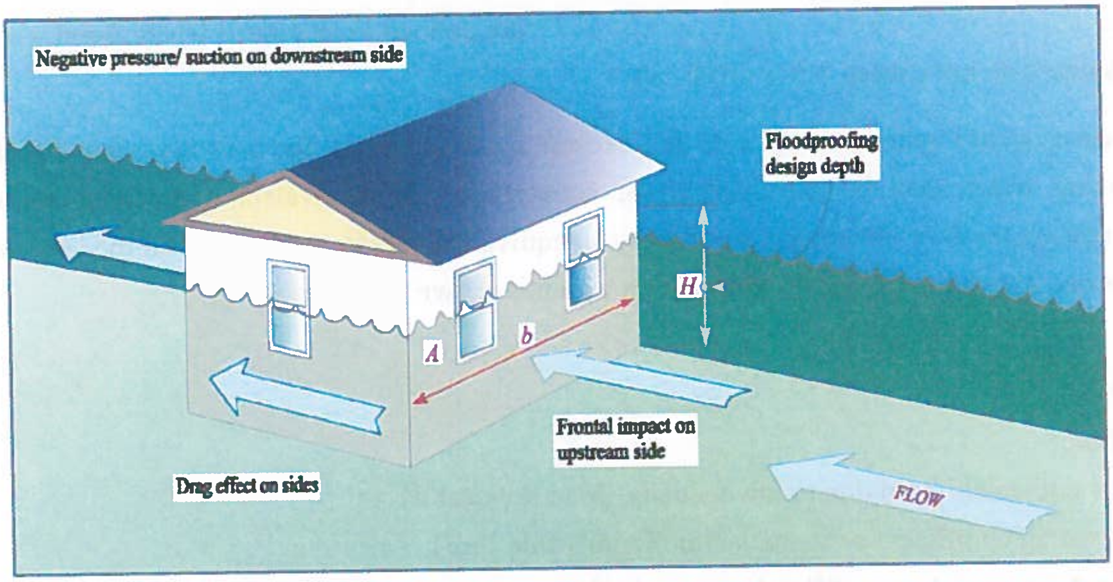


Fig.13.5 Hydrodynamic and Impact Forces

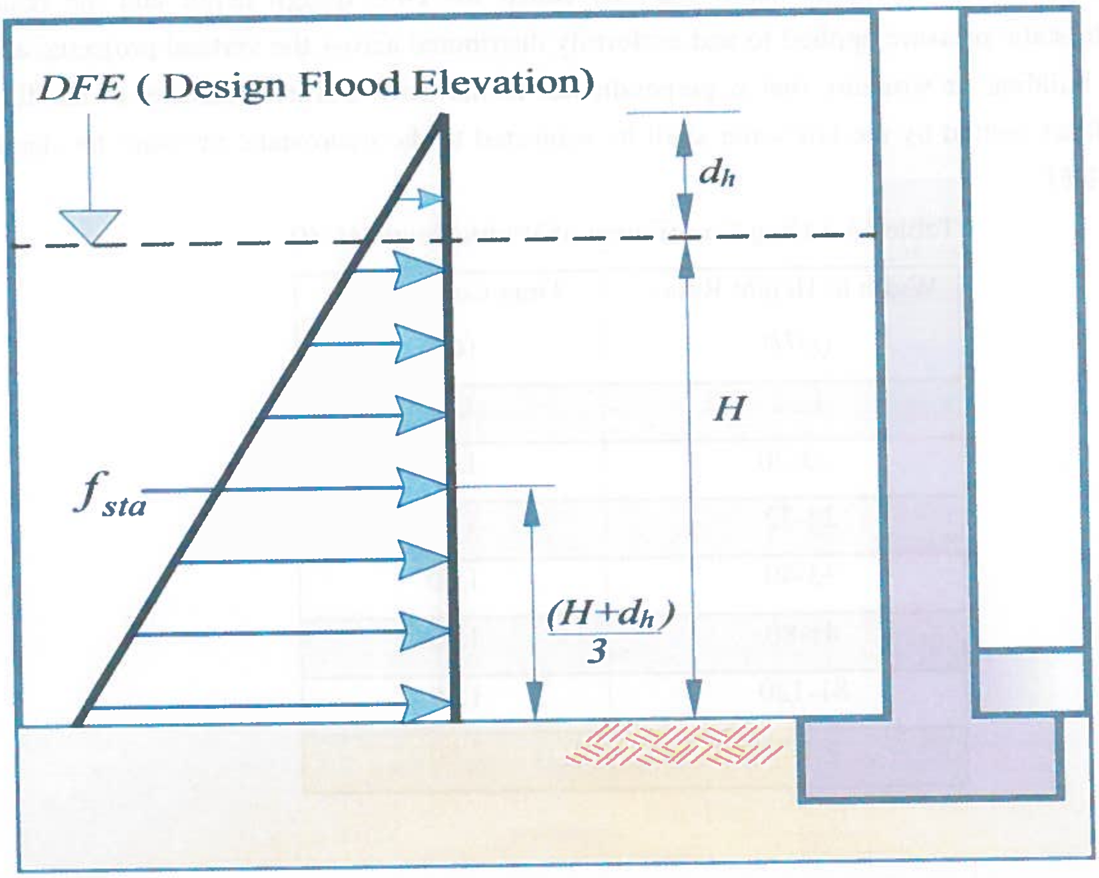


Figure 13.6 Conversion of Equivalent Head to Equivalent Hydrostatic force

- Low Velocity Hydrodynamic Forces
- High Velocity Hydrodynamic Force

13.3.5.1 Low Velocity Hydrodynamic Forces are defined as situations where flood water velocities do not exceed 3 m/s (10 ft. /s).

In cases where water velocities do not exceed 3 m/s (10 ft./s), the hydrodynamic effects of moving water shall be permitted to be converted to an equivalent hydrostatic loads by increasing the DFE for design purpose by an equivalent surcharge depth d_h on the head water side and above the design flood elevation which is shown in Equation 13.7

$$d_h = \frac{C_d V^2}{2g} \qquad \text{(Eq. 13.7)}$$

where:

d_h = equivalent head due to low velocity flood flow (m/ft)

C_d = drag coefficient or shape factor (From Table 13.3)

V = Average velocity of flood water m/s (ft/s)

g = acceleration due to gravity, 9.81 m/s/s (32.2 ft/s/s)

The equivalent surcharge depth shall be added for DFE design depth and the resultant hydrostatic pressure applied to and uniformly distributed across the vertical projected area of the building or structure that is perpendicular to the flow. Surfaces parallel to the flow or surfaces wetted by the tail water shall be subjected to the hydrostatic pressure for depths to the DFE .

Table 13.3 Drag Co-efficient of Width/Height (*b/H*)

Width to Height Ratio (*b/H*)	Drag Co-efficient (C_d)
1-12	1.25
13-20	1.30
21-32	1.40
33-40	1.50
41-80	1.75
81-120	1.80
> 120	2.00

Example 13.2 Convert low velocity hydrodynamic force to equivalent hydrostatic force based on example 13.1

Solution :

Since V is less than 3.0 m/s (10.0 ft/s), use Equation 13.7 to convert dynamic effects of moving water into equivalent hydrostatic load by increasing DEF by an equivalent surcharge depth:

$$d_h = \frac{C_d V^2}{2g}$$

Determine drag coefficient C_d by calculating b/H and using Table 13.3

$b/H = 15/2.13 = 7$ $\quad C_d = 1.25$

$d_h = (1.25 \text{x} 2^2) / (2 \text{x} 9.81) =$ **0.25 m (0.82 ft)**

Total depth = DEF+ $d_h = 2.13 + 0.25 =$ **2.38m (7.81 ft)**

To calculate low velocity hydrodynamic force, use Equation 13.4

$f_{sta} = ½ P_h H = 1/2\ \gamma_w H^2 = ½ \text{ x } 10.05 \text{ x } 2.38^2 =$ **28.46 kN/lm (1950 lb/lft)**

13.3.5.2 High Velocity Hydrodynamic Force

For special structures and conditions and for velocity greater then 3m/s (10ft/sec), a more detail analysis and evaluation should be made utilizing basic concepts of fluid mechanics and/or hydraulic models. The basic equation for hydrodynamic pressure is shown in Equation 13.8

$$P_d = C_d \rho \frac{V^2}{2} \qquad \text{(Eq. 13.8)}$$

where:

P_d = hydrodynamic pressure kN/m^2 (lb/ft^2)

C_d = drag coefficient (taken from Table 13.3)

ρ = mass density of fluid = 1.94 slugs/ft^3 for fresh water and 1.99 slugs/ft^3 for salt water

V = velocity of flood water m/sec (ft/sec)

After determining hydrodynamic pressure *(P_d)* the total force F_d against the structure can be computed as the pressure times the area over which the water is affecting.

$$F_d = P_d A \qquad \text{(Eq. 13.9)}$$

where;

F_d = total force against the structure (kN/lb)

P_d = hydrodynamic pressure kN/m^2 (lb /ft^2)

A = submerged area of the upstream face of the structure (m^2/ ft.^{2})

One of the complexities when calculating forces generated by a storm surge is determining the flood water velocity. Both the direction and velocity of flood water vary drastically throughout the course of a storm system. The velocities of flood water current can vary from near zero to extreme velocities during a single event. FEMA (2000) recommended that flood water velocities due to storm surge should be assumed to lie between specific lower and upper bounds.

The lower bound is given by Equation 13.10

$V_l = {}^{h}/_{t\,sec}$ (Eq. 13.10)

where;

V_l = lower bound velocity of water in m/s (ft/s)

h = flood water depth in m (ft)

t is defined as 1s is recommended as a safety factor for design purpose instead of considering near zero velocities.

The upper bound is given by

$V_u = (gh)^{1/2}$ (Eq. 13.11)

The magnitude of the forces generated by tsunami can be approximated by the same equations used for cases of storm surge. However, it is essential to consider the greater magnitude of the flood water velocity. It is recommended that flood water velocities due to tsunami should be assumed to lie between a lower and upper bound given by Equations 13.11 and Equation 13.12 respectively. (Ref.C13.2)

$V_u = 2\,(gh)^{1/2}$ (Eq. 13.12)

1 slugs/ft^3 = 32.16 lb. /ft^3 62.4 lb./ft^3 = 1.94 slugs/ft.^{3} = 1000 kg/m^3 = 9.81 kN/m^3

It is to be noted here that Equation 13.12 yields conservative estimates, since it derived based on the speed of a surge- front travelling over a frictionless horizontal plane.

Table 13.4 and Table 13.5 show a relationship between flood water depth and flood water velocity both for storm surge and tsunami.

Multipurpose Cyclone Shelter Programme (Ref C3-4) has suggested that the surge height decreases at the rate of ½ m per km inland as friction and slope loss for Chittagong coastal plane and $^1/_3$ m per km for the rest of the coastal area.

Table 13.4 Relation between Floodwater Depths and Floodwater Velocity due to Storm Surge

Flood water depth		Lower bound flood water velocity (1) (V_l)		Upper bound flood water velocity (2)(V_u)	
ft	m	ft/sec	m/s	ft/s	m/s
2.0	0.60	2.0	0.60	8.00	2.43
3.0	0.91	3.0	0.91	9.80	3.00
4.0	1.22	4.0	1.22	11.34	3.46
5.0	1.52	5.0	1.52	12.67	3.86
6.0	1.83	6.0	1.83	14.00	4.24
7.0	2.13	7.0	2.13	15.00	4.57
8.0	2.44	8.0	2.44	16.05	4.89
9.0	2.74	9.0	2.74	17.02	5.18
10	3.05	10.0	3.05	17.44	5.47
11	3.35	11	3.35	18.82	5.73
12	3.66	12	3.66	19.66	6.00
13	3.96	13	3.86	20.46	6.24
14	4.27	14	4.27	21.23	6.47
15	4.57	15	4.57	21.98	6.70
16	4.88	16	4.88	22.70	6.92
17	5.18	17	5.18	23.40	7.13
18	5.49	18	5.49	24.07	7.34
19	5.79	19	5.79	24.73	7.54
20	6.10	20	6.10	25.38	7.74

(1) $V_l = h/1s$ (2) $V_u = (gh)^{1/2}$ $g = 9.81\ m/s^2\ (32.2\ ft./s^2)$

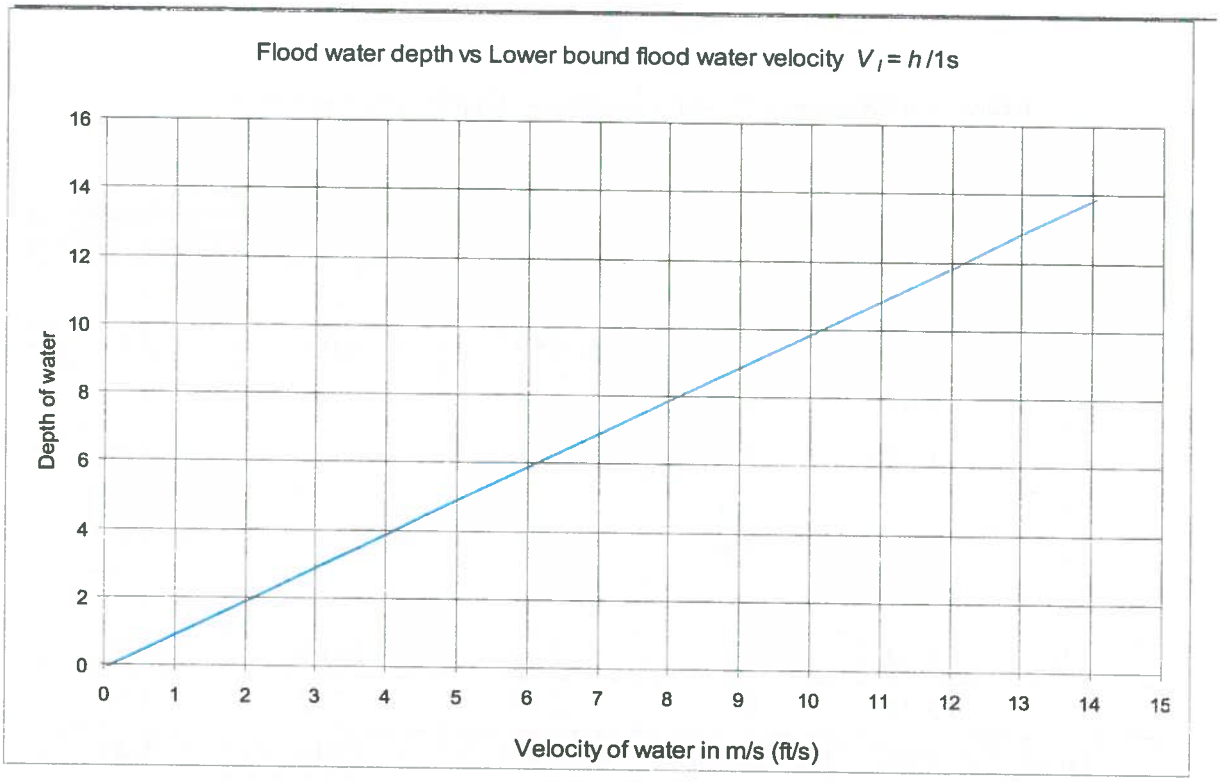


Fig. 13.7 Flood water depth vs Lower bound flood water velocity

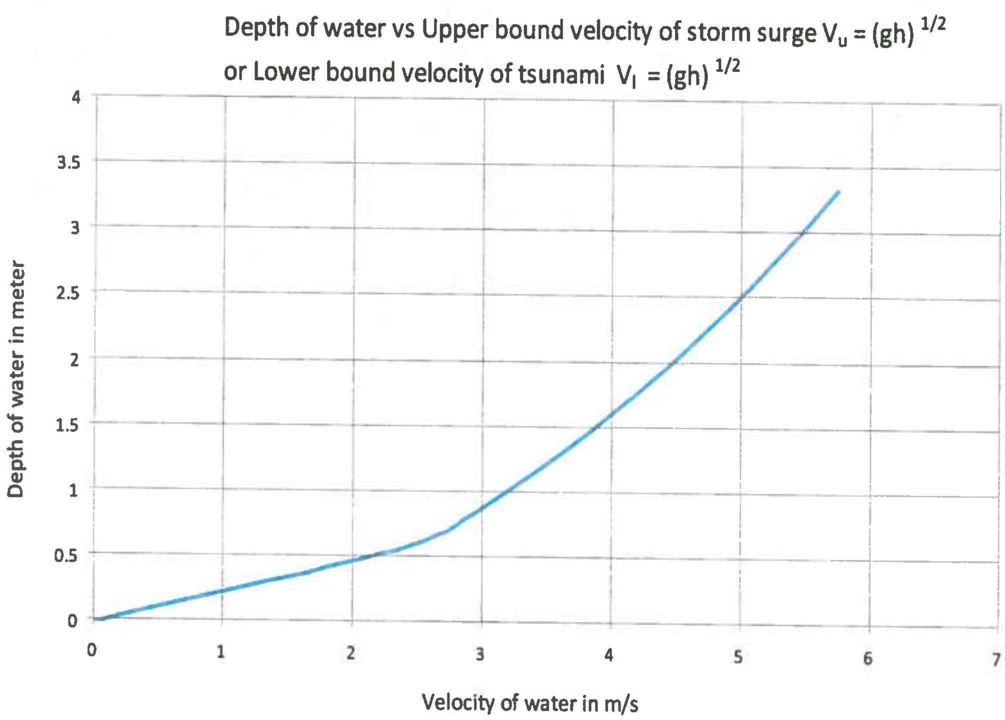


Fig 13.8 Flood water vs Upper bound storm surge velocity
or Lower bound velocity of tsunami

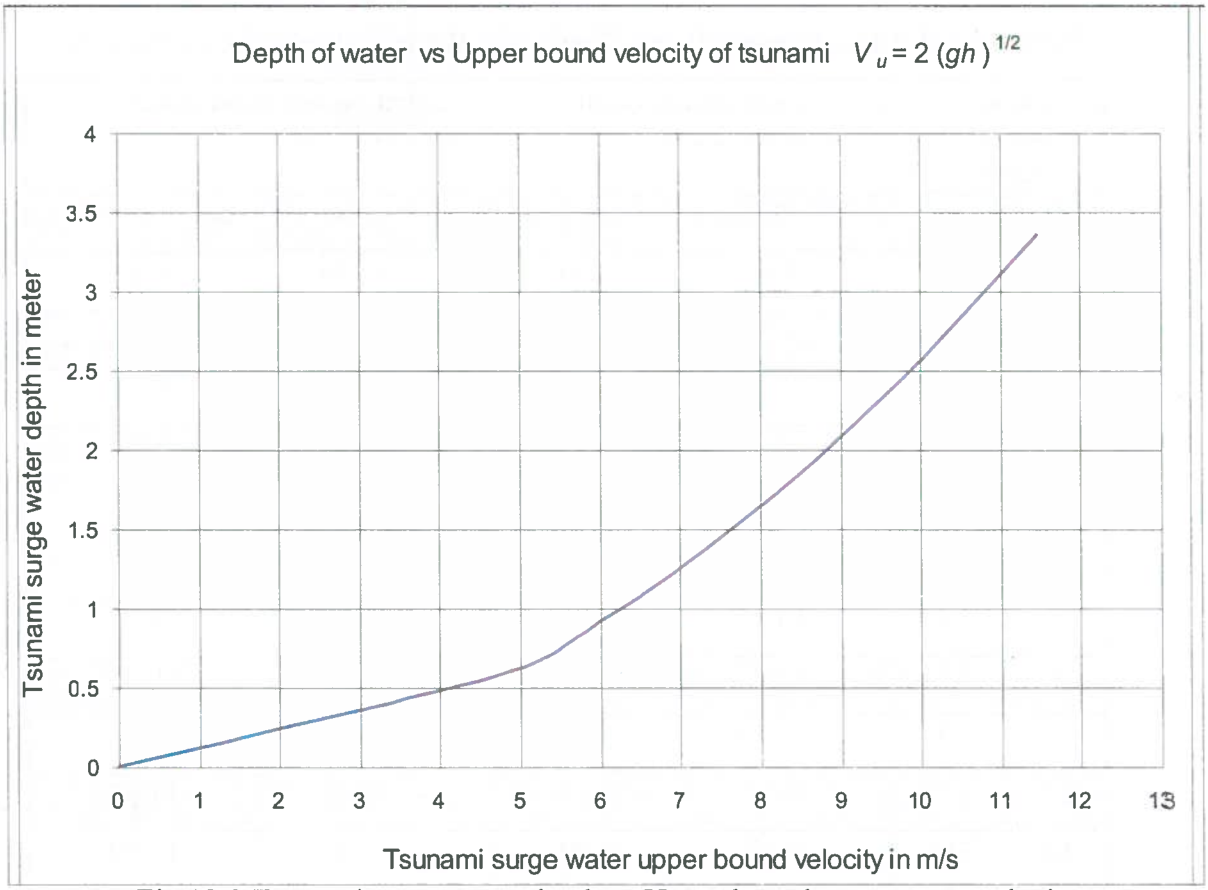


Fig.13.9 Tsunami surge water depth vs Upper bound surge water velocity

Table 13.5 Relation between Water Depths and Water Velocity due to Tsunami

Flood water depth		Lower bound flood water velocity (1) (V_l)		Upper bound flood water velocity (2) (V_u)	
ft	m	ft/s	m/s	ft/s	m/s
2	0.60	8.00	2.43	16.00	4.86
3	0.91	9.80	3.00	19.60	6.00
4	1.22	11.34	3.46	22.68	6.92
5	1.52	12.76	3.86	25.52	7.72
6	1.83	14.00	4.24	28.00	8.48
7	2.13	15.00	4.57	30.00	5.14
8	2.44	16.05	4.89	32.10	9.78
9	2.74	17.02	5.18	34.04	10.36
10	3.05	17.94	5.47	35.88	10.94
11	3.35	18.82	5.73	37.64	11.48
12	3.66	19.66	6.00	39.32	11.99
13	3.96	2046	6,24	49,92	12,48
14	4.22	21.23	6.47	42.46	12.45
15	4.57	21.98	6.70	43.96	13.40
16	4.88	22.70	6.92	45.40	13.84
17	5.18	23.40	7.13	46.80	14.27
18	5.49	24.07	7.34	48.14	14.68
19	5.79	24.73	7.54	49.46	15.08
20	6.10	25.38	7.74	50.46	15.38

(1) $V_l = (gh)^{1/2}$ (2) $V_u = 2\,(gh)^{1/2}$ (conservative value) $g = 9.81\ m/s^2\ (32.2\ ft./s^2)$

13.3.6 Impact Forces

As discussed in Chapter 8 (Section 8.10.5.4) impact loads are classified as:

- no impact
- normal impact
- special impact
- extreme impact

13.3.6.1 Normal Impact Forces

Normal impact forces related to isolated occurrences of typically sized debris or floating objects striking the building (see Fig. 13.5). For design purpose, this can be considered concentrated load acting horizontally at the flood elevation, or any point below it, equal to impact force created by a typical object travelling at the velocity of the flood water acting on 0.09 sqm (1 sft) surface of the submerged building area perpendicular to the flow of flood water.

The assumption that the debris velocity is equal to the flood velocity may overstate the velocity of large debris object because a part of the object may drag along the bottom and/or being slowed down by prior collision; therefore, engineering judgment may be required in some instances. Designer may wish to reduce debris velocity for larger objects.

ASCE7-10 in its commentary on flood load has suggested Equation 13.13 as a rational approach for calculating the magnitude of impact load due to a floating object (debris) which is same as Eq. 6.2.81 of BNBC15.

$$F = \frac{\pi W V_b C_I C_o C_D C_B R_{max}}{2g\Delta t} \qquad \text{(Eq.13.13)}$$

where;

F = impact force, in N (lb)

W = debris weight in N (lb)

V_b = velocity of object (assume equal to velocity of water V) in m/s (ft/s)

g = acceleration due to gravity = 9.81 m/s^2 (32.2 ft/s^2)

Δt = impact duration (time to reduce object velocity to zero) in s

C_I = importance coefficient (See Table 13.6)

C_O = orientation coefficient = 0.8

C_D = depth coefficient (See Table 13.7)

C_B = blockage coefficient (See Table 13.8)

R_{max} = maximum response ratio for impulsive load (See Table 13.9).

The coefficients C_I C_O C_D C_B and R_{max} have been added to allow design professionals to "calibrate" the resulting force to local flood, debris and building characteristics. The approach is similar to that employed by ASCE7-05 in calculating wind, seismic and other loads. $\pi/2$ factor results from the half sine form of the applied impulse load. With the coefficients set equal to 1, the equation reduces to $F = \frac{\pi W V_b}{2g\Delta t}$ and calculates the maximum static load from a head-on impact of a debris object.

Example 13.3 Calculate normal debris impact force striking a building

Given:	Find: Debris impact Force
W = 4480N (1000 lb) V_b = 2 m/s (6.59 ft/s) Δt = 0.03s	

$F = \pi W V_b / 2g \Delta t$

$= (3.14 \times 4480 \times 2) / (2 \times 9.81 \times 0.03) = 47.8$ kN

In fps system

$F = (3.14 \times 1000 \times 6.59) / (2 \times 32.2 \times 0.03) = 10710$ lb

Debris Object Weight

ASCE7 suggested considering a 4.5 kN (1000 lb) to 9 kN (2000 lb) flood-borne debris. But in coastal areas where large logs are not expected, the debris will likely be derived from failed decks, building components or parts of small boats and will likely average less than 2.3 kN (500 lb.) in weight.

Debris Velocity

The velocity of debris with which a piece of debris strikes a building or structure will depend on the nature of debris and the velocity of the flood water. Small pieces of floating debris, which are unlikely to cause damage to buildings or other structure will typically travel at the velocity of flood water in both riverine and coastal flood situation. However, large debris such as trees, logs, other large debris capable of causing damage, will likely to travel at something less than the velocity of flood waters. This reduced velocity of large debris objects is due in large part to debris dragging along the bottom and/or being slowed by prior collision.

Large riverine debris travelling along the flood way (the deepest part of the channel that conducts the majority of flood flow) is most likely to travel at speeds approaching that of the flood water. Large riverine debris travelling in the flood plain (the shallow area outside the flood flow) is more likely to be travelling at speeds less than that of flood waters.

Large coastal debris is also likely to be travelling at speeds less than that of the flood waters. Equation 13.11 and Equation 13.12 should be used for storm surge and tsunami respectively with debris velocity equal to flow velocity because the equations allow for reduction in debris velocity through application of a depth coefficient C_D and an upstream blockage coefficient C_B in Equation 13.13.

Duration of Impact

A detail review of available literature, supplemented by laboratory testing, concluded the previously suggested 1.0 s duration of impact is much too long and not realistic. Laboratory tests showed that measured impact duration (from initial impact time to time of maximum force) varies from 0.01s to 0.05 s. Over all the test conditions, the impact duration averaged about 0.026s. The recommended value for use in Equation 13.13 is 0.03s. (Ref.C1-2)

Coefficients C_I, C_O, C_D, and C_B

The importance coefficient C_I is generally used to adjust design loads for the structure category and hazard to human life following Table 13.6.

The orientation coefficient C_O is used to reduce the load calculated by Eq. 13.13, for impacts that are oblique, not head-on. During laboratory test, it was observed that while some debris impacts occurred as direct or head-on impact that produced maximum impact loads, most impacts occurred as eccentric impacts or oblique impacts with reduced values of the impact force. Based on these information, an orientation coefficient of $C_O = 0.8$ has been adopted.

The depth coefficient, C_D is used to account for reduced debris velocity in shallow water due to debris dragging along the bottom. Recommended values of this coefficient are based on typical diameter of logs and trees or on the anticipated diameter of root mass from drifting trees that are likely to be encountered in a flood hazard zone. References suggest that trees with typical root mass diameters will drag the bottom in depth of less than 1.5m (5 ft.) while most logs of concern will drag the bottom in depth of less than 0.3m (1 ft). The recommended values of depth coefficient C_D are given in Table 13.7(Ref.C1-2)

The blockage coefficient C_B is used to account for the reduction in debris velocities expected for due to screening and sheltering provided by trees and other structures within about 10 log-length (91.5m/300 ft.) upstream from the building or structure of interest. The effectiveness of screening depends primarily on the spacing of the upstream obstructions relative to the design log length of interest. Recommended values for the blockage co-efficient are given in Table 13.8.(Ref.C1-2)

The maximum response ratio R_{max} is used to increase or decrease the computed load, depending on the degree of compliance of the building or building component being struck by the debris. Impact loads are impulsive in nature, with the force rapidly increasing from zero to the maximum value in time Δt, then decreasing to zero as debris rebound from structure. The actual load experienced by the structure or component will depend on the ratio of impact duration Δt relative to the natural period T_n of the structure or component. Stiff or rigid building or structures with natural period similar to impact duration will see an amplification of the impact load. More flexible buildings or structures with natural period greater than approximately four times the impact duration will see a reduction in impact load. Likewise stiff or rigid components will see an amplification of the impact load; more flexible components will see a reduction of the impact load. Successful use of Eq. 13.13, then, depends on estimation of the natural period of the building or component being struck by flood borne debris.

Natural periods of building generally vary from approximately 0.05s to several seconds (for high rise, moment frame structures). For flood borne debris impact loads with duration of 0.03s, the critical period (above which loads are reduced) is approximately 0.11s. [Ref. C1-2] Buildings and structures with natural periods above approximately 0.11s will see a reduction in the debris impact loads, while those with natural periods below approximately 0.11 will see an increase. For one to three story buildings, elevated on concrete piles or columns, a natural period of 0.2 to 0.5 is recommended by ASCS7-05[Ref. C1-2]. For the purpose of flood-borne debris impact load calculation, an approximate natural period for one to 12-story building (story height equal to or greater than 3m /10 ft.) with concrete and steel moment resisting frame can be approximated by the Equation 13.14.

$$T_a = 0.1\,N \qquad \text{(Eq. 13.14)}$$

where;
T_a = Natural period
N = Number of stories

Table 13.6 Values of Importance Coefficient C_I

Building Category[(1)]	C_I
I	0.6
II	1.0
III	1.2
IV	1.3

(1) See Table 10.2 of Chapter 10

Table 13.7 Values of Depth Coefficient C_D

Building Location in Flood Hazard Zone and Water Depth	C_D
Floodway or V-Zone (Coastal high hazard area)[1]	1.0
A-Zone Still water Depth > 1.52m (5ft)	1.0
A-Zone Still water Depth = 1.22m (4 ft)	0.75
A-Zone Still water Depth = 0.91m(3 ft)	0.50
A-Zone Still water Depth = 0.61m(2 ft)	0.25
Any flood zone, still water Depth < 0.3m(1ft)	0.0

[1]For V-Zone and A-Zone refer Section 8.10.5 of Chapter 8

Table 13.8 Values of Blockage Coefficient C_B

Degree of screening or sheltering within 30.5m (100 ft.) upstream	C_B
No upstream screening, flow path wider than 9.15m (30ft.)	1.00
Limited upstream screening, flow path 6.1m(20ft.) wide	0.60
Moderate upstream screening, flow path 3.05m (10ft.)	0.20
Dense upstream screening, flow path less than 1.5m (5 ft.) wide	0.00

Table 13.9 Values of Responsive Ratio for Impulsive Loads R_{max}

Ratio of Impact Duration to Natural Period of Structure	R_{max} (Response Ratio for Half Sine Wave Impulsive Load)
0.00	0.00
0.10	0.40
0.20	0.80
0.30	1.10
0.40	1.40
0.50	1.50
0.60	1.70
0.70	1.80
0.80	1.80
0.90	1.80
1.00	1.70
1.10	1.70
1.20	1.60
1.30	1.60
> 1.4	1.50

FEMA 259 suggested modified Equation 13.15 based on assumptions appropriate for the typical structures that are covered in that document. The focus on Manual FEMA 259 is on new residential construction and substantial improvement to existing residential buildings, principally detached single family homes and low rise (three story or less) multi-family buildings. The equation gives a much lower value compared to Equation 13.13.

Normal impact force is given by the Equation 13.15

$F_i = WV\, C_D\, C_B\, C_{sta}$ (Eq. 13.15)

where;

F_i = impact force acting at the Base Flood Elevation (BFE) in kN(lb)

W= weight of the object in kN (lb)

V = velocity of water in m/s (ft/s)

C_D = depth coefficient (see Table 13.7)

C_B = blockage coefficient (see Table 13.8)

C_{Str} = building structure coefficient

= 0.2 for timber pile and masonry column supported structure 3 stories or less in height above grade

= 0.4 for concrete pile or concrete or steel moment resisting frame 3 stories or less in height above grade

13.3.6.2 Special and Extreme Impact Forces

Special impact forces occur when large objects or conglomerates or floating objects such as accumulation of floating debris strike a structure.

Special impact loads can be estimated as a uniform load of 1.48 kN/m (100 lb per ft) acting over a 0.31m (1 ft.) high horizontal strip at the design flood level or lower (Ref C1-2). However, Ref.13-1 suggests that impact load from flood-borne debris as suggested above may be too small for some large accumulation of debris. It proposed an alternative approach involving application of standard drag force expression.

$F = (^1/_2)\, C_D \rho A V^2$ (Eq. 13.16)

where;

F = drag force due to debris accumulation N (lb.)

V = flow velocity upstream of debris accumulation in m/s (ft/s)

A = projected area of the debris accumulation into the flow, approximated by depth of accumulation times width of accumulation perpendicular to flow in m^2 (ft^2).

ρ = density of water in 1000 kg/m^3 (1.94 slugs/ft^3) for fresh water and 1026 kg/m^3 (1.99 slugs/ft^3) for salt water [1.0 slug/ft^3=32.2 lb/ft^3]

C_D = drag co-efficient = 1

The expression produces loads similar to the 1.48 kN/m (100 lb/ft), when the debris depth is assumed to be 0.3m (1 ft.) and when the velocity of flood water is 3.0 m/s (10.0 ft/s). But sometimes, the depth of debris accumulation may be more than 0.3m (1.0 ft.) and may be of concern. In that case, the design professionals should specify the projected area of the debris accumulation based on local observation and experience and apply the proceeding equation to predict the debris load on building or other structures.

Extreme impact loads occur when large floating objects such as runaway barges or collapse buildings and structures, strike the structure (or a component of the structure). These forces generally occur within the floodway or areas of the flood plain that experiences the highest velocity flow. It is impractical to design buildings in coastal areas with heights normally not more than 4-storey to have adequate strength to resist extreme impact forces.

13.3.7 Breaking Wave Force

There are two breaking wave forces cases that are most relevant to buildings as discussed in Chapter 8.

- Breaking waves on walls
- Breaking waves on columns/piles

Breaking wave heights used in this section shall be calculated for V-zones and Coastal A-zones (High Risk Area and Risk Area) using Equations 13.17 and 13.18.

$H_b = 0.78\ d_s$ (Eq. 13.17)

where;

H_b = breaking wave height in m (ft)

d_s = local still water depth in m (ft)

The local still water depth shall be calculated using Equation 13.18 unless more advanced procedure or laboratory test results are available.

$d_s = 0.65\ (BFE\text{-}G)$ (Eq. 13.18)

where;

BFE = base flood elevation (the flood having a 1 percent chance of being equaled or exceeded in any given year is base flood) in m (ft)

G = ground elevation in m (ft)

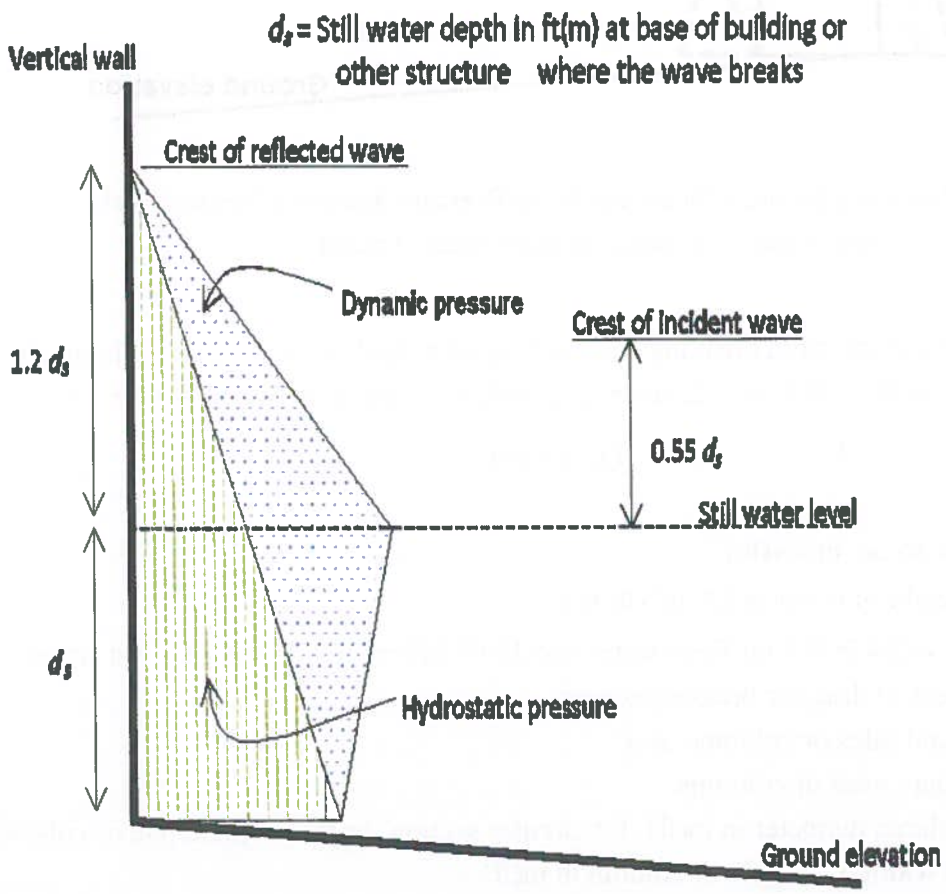


Figure 13.10 Normally Incident Breaking Wave Pressure against a Vertical Wall (Space behind vertical wall is dry)

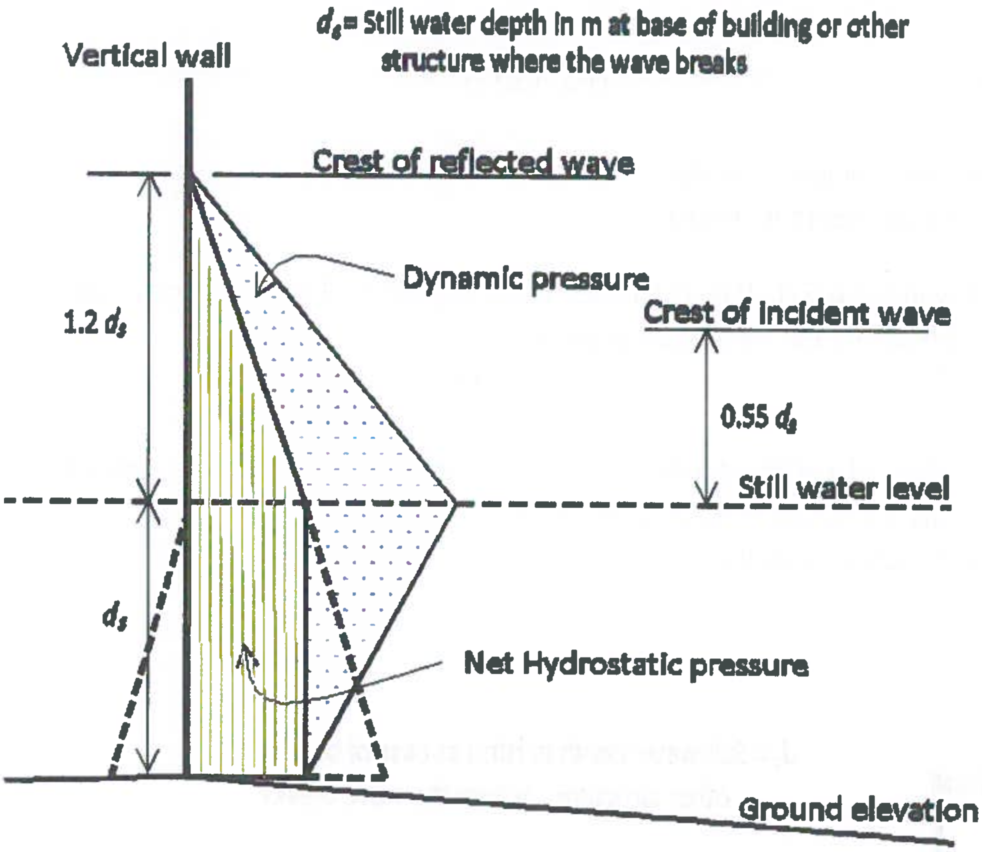


Figure 13.11 Normally Incident Breaking Wave Pressure against a Vertical Wall (Still water level equal on both sides of wall)

13.3.7.1 Breaking Wave Force on Vertical Column

The net force resulting from breaking wave acting on a rigid vertical pile or column shall be assumed to act at the still water elevation and shall be calculated by Equation13.19

$$F_D = 0.5\ \gamma_w\ C_D\ D\ H_b^2 \qquad \text{(Eq. 13.19)}$$

where;

F_D = net wave force, in kN(lb)

γ_w = Unit weight of water in kN/m^3 (lb/ft^3)

= 9.80 kN/m^3 (62.4 lb/ft^3) for fresh water and 10.05 kN/m^3 (64.0 lb/ft^3) for salt water.

C_D = coefficient of drag for breaking waves

= 1.75 for round piles or columns, and

= 2.25 for square piles or columns

D = pile or column diameter in m(ft) for circular section, or for a square pile or column, 1.4 times the width of the pile or column in m(ft).

H_b = breaking wave height in m(ft) as per Equation 13.17

13.3.7.2 Breaking Wave Force on Vertical walls

Maximum pressures and net forces resulting from a normally incident breaking wave (depth limited in size, with H_b=0.78 d_s acting on a rigid vertical wall shall be calculated by the following:

$P_{max} = C_p\, \gamma_w d_s + 1.2\, \gamma_w d_s$ (Eq. 13.20)

$F_t = 1.1\, C_p\, \gamma_w d_s^2 + 2.4\, \gamma_w d_s^2$ (Eq. 13.21)

where;

P_{max} = maximum combined dynamic ($C_p \gamma_w d_s$) and static ($1.2\, \gamma_w d_s$) wave pressure, also referred to as shock pressure in kN/m^2(lb/ft^2)

F_t = net breaking wave force per unit length of structure, also referred to as shock impulse, or wave impact force in kN/m (lb./ft) acting near the still water elevation

C_p = dynamic pressure co-efficient (see Table 13.10)

γ_w = Unit weight of water in kN/m^3 (lb/ft^3) = 9.80 kN/m^3(62.4 lb/ft^3) for fresh water and 10.05 kN/m^3 (64.0 lb/ft^3) for salt water.

d_s = still water depth in m (ft.) at base of building or other structures where the wave breaks (see Fig.13.10).

This procedure assumes the vertical wall causes a reflected or standing wave against the water ward side of the wall with the crest of the wave at a height of 1.2d_s above the still water level. The dynamic, static and total distribution of pressure is shown in Fig.13.10

This procedure also assumes that the space behind the vertical wall is dry, with no fluid is balancing the static component of the wave force on the outside of wall. If free water exists behind the wall, a portion of hydrostatic component of the wave pressure and force disappears and the net force shall be computed by the Equation 13.22

$F_t = 1.1\, C_p\, \gamma_w d_s^2 + 1.9\, \gamma_w d_s^2$ (Eq. 13.22)

where:

F_t = net breaking wave force per unit length of structure, also referred to as shock impulse, or wave impact force in kN/m (lb/ft) acting near the still water elevation

C_p = dynamic pressure co-efficient (see Table 13.10)

γ_w = Unit weight of water in kN/m^3 (lb/ ft^3) = 9.80 kN/m^3(62.4 lb/ft^3) for fresh water and 10.05 kN/m^3 (64.0 lb/ft^3) for salt water.

d_s = still water depth in m (ft.) at base of building or other structures where the wave breaks (see Fig. 13.10)

The maximum combined wave pressure P_{max} is still computed with Equation 13.20

Table 13.10 Value of Dynamic Pressure Coefficient, C_p

Building category	C_p
I	1.6
II	2.8
III	3.2
IV	3.5

Example 13.4 Calculate breaking wave load on vertical pilings and columns

Given:

Base flood elevation= 2.82m (9.25 ft)

Ground elevation = 0.00

Vertical column size =0.60 x0.60 m (2 x2 ft)

C_D =2.25 (see Eq. 13.19)

D = 1.4 x 0.6 = 0.84 m (2.76 ft) (see Eq. 13.19)

γ_w as per Eq. 13.20 for salt water

Find:

1.Local still water depth

2.Breaking wave height

3.Breaking wave load on vertical column

Solution no.1

To find local still water depth, use Equation 13.18

$d_s = 0.65\ (BFE\text{-}G)$

= 0.65 (2.82-0.00) =**1.83 m (6ft)**

Solution no.2

To find breaking wave height, use Eq.13.17

$H_b = 0.78 d_s$ = 0.78 x1.83 =**1.43 m (4.7 ft)**

Solution no.3

To calculate net force resulting from a breaking wave action on a rigid vertical column shall be calculated by the Eq. 13.19

$F_D = 0.5\ \gamma_w C_D D H_b^2$

$= 0.5 \times 10.05 \times 2.25 \times 0.84 \times 1.43^2$

$=$ **19.42 kN (4366 lb)**

The force F_d shall act at the still water level

Example 13.5 Calculate breaking wave load on vertical wall

Given

- $d_s = 1.83$ m (6.0 ft) as per example 13.4
- $\gamma_w =$ As per Equation 13.20 and 13.21
- Category of the building = Category IV
- $C_p = 3.5$ (see Table 13.10)

Find:

1. Combined maximum dynamic and static wave pressure when the space behind the vertical wall is dry
2. Net breaking force per unit length of structure when the space behind the vertical wall is dry
3. Net breaking force per unit length of the structure when free water exists behind the wall
4. Combined maximum wave pressure when the free water exists behind wall

Solution no.1

To find maximum pressure from a normally incident breaking wave with $H_b = 0.78 d_s$ acting on a rigid vertical wall use Equation 13.21

$P_{max} = C_p \gamma_w d_s + 1.2\ \gamma_w d_s$ (Eq. 13.20)

$= 3.5 \times 10.05 \times 1.83 + 1.2 \times 10.05 \times 1.83$

$= 64.37 + 22.07 =$ **86.44 kN/m² (1086 lb/ft²)**

Solution no.2

To find net breaking force per unit length of structure when the space behind the vertical wall is dry, use Equation 13.21

$Ft = 1.1\ C_p\ \gamma_w d_s^2 + 2.4\ \gamma_w d_s^2$

$= 1.1 \times 3.5 \times 10.05 \times 1.83^2 + 2.4 \times 10.05 \times 1.83^2$

$= 129.60 + 80.780 =$ **210.38 kN/m (14419 lb/ft)**

Solution no.3

To find net breaking force per unit length of structure when free water exists behind the structure, use Equation 13.22

$F_t = 1.1\, C_p\, \gamma_w d_s^2 + 1.9\, \gamma_w d_s^2$

$= 1.1 \times 3.5 \times 10.05 \times 1.83^2 + 1.9 \times 10.05 \times 1.83^2$

= 129060 + 63.95 = **193.55 kN/m (13266 lb /ft)**

Solution no.4

Even if there exists free water behind the wall in question, maximum combined wave pressure is still computed by Equation 13.20 (Ref.C1-2)

Breaking wave forces given by Equations 13.20 and 13.21 shall be modified in instances where the walls or surfaces upon which the breaking waves act are non-vertical. The case is very rare or almost non-existent in the flood prone and coastal areas of Bangladesh. If necessary ASCE 7-05 may be consulted to calculate the force.

13.4 EROSION AND SCOUR

The term ***"erosion"*** indicates a lowering of the ground surface in response to a flood event or in response to the gradual erosion of the shore lines. The term ***'scour"*** indicates a localized lowering of the ground surface during a flood due to interaction of currents and/ or waves with a structural element. Erosion and scour can affect the stability of foundation, and can increase the local flood depth and flood loads acting on buildings and other structures. For these reason erosion and scour should be considered during load calculations and design process. Design professionals often increase the depth of foundation embedment to mitigate the effects of erosion and scour and often site buildings away from receding shorelines.

ASCE7-05 indicates that during load calculations erosion and scour shall be considered for design but did not provide any method how to calculate the load for erosion and scour and how to protect the foundation from erosion and scour.

BNBC15 has not discussed anything about erosion and scour.

13.5 COMPONENTS OF BUILDING AFFECTED BY FLOOD

Following are the major components of building that are affected by flood;

- Foundation
- Reinforced concrete frame
- Infill external brick/block wall
- Doors and windows
- Utility services, building contents and finishes

13.5.1 Foundation

The local soil scour is the main source of foundation damage. Foundations located at the corner of the building facing moving flood waters are more vulnerable to local scour than other columns. Failure of column is a function of flood water depth, velocity, and duration of flow exposition. The probability of failure of lateral column footings is much less compared to corner column.

Corner footing of column that are prone to scour shall be deepened to around 2.0m (6.50 ft.) below ground level.

The probability of scouring is maximum for loose sand (as high as 80% of the inundation depth due to tsunami) which is as low as 10% of inundation depth for silty clay.

13.5.2 Reinforced Concrete Frame

The vulnerability of column depends on several factors including the number and dimensions of columns, the total area, tensile strength of steel, compressive strength of concrete and the load supported by the column.. The bending moments and shear forces induced by flood water are calculated using structural mechanics. The vulnerability analysis focuses on the reinforced concrete columns, since these are the frame elements that are directly impacted by the flood water action and thus, where the failure is deemed to occur.

The magnitude of flood water forces acting on the reinforced concrete column can be modeled as per load combination given in Chapter 9 as well as BNBC15 and ASCE7-05.

A linear elastic analysis shall determine the bending moment and shear force acting on both axis of reinforced concrete column.

13.5.3 Brick/Concrete Block Wall

The vulnerability of concrete block / brick wall is estimated by applying the forces generated by flood water. Unsupported wall panels under external force develop a plastic hinge in a region of high moment. This hinge resists the moment by transferring the moment to other regions which also yields and become a part of the hinge. The yield lines are formed across the unsupported wall panel, dividing it into slabs that rotate plastically due to the applied force. When the external work exceeds the internal works the static equilibrium is broken, causing the wall panel to collapse.

13.5.4 Doors and Windows

The vulnerability of doors and windows is to be assessed considering the damage to their respected connections as the primary failure mechanism. As per British standard the resistance of typical door locks range from 0.50 to 4.00 kN (112.40-900 lb.). The strength of window connections is provided by the shear force capacity of the screws/hold fasts that secure the windows to the wall or concrete.

13.5.5 Building Utility Services, Contents and Finishes

Building utility services and finishes divisions differ from all other divisions in that their vulnerability cannot be assessed directly by load resistance analysis. These divisions include electrical and plumbing system, cement plaster, paintings and wood works, among others. It is also pointed out that damage to utilities and finishes tend to occur after the flood water level has risen to a threshold elevation in the building. In some cases this damage can be negligible.

13.6 FLOOD DAMAGE COMPUTATION

The flood damage is initially computed for each building component individually as a function of both flood water depth and velocity. The expected flood damage (*EFD*) defined as the expected value of flood damages, is then computed per building unit by considering the aggregated damage to all five building components.

CHAPTER 14
MITIGATION MEASURES AGAINST NON-SEISMIC NATURAL HAZARDS

14.1 SCOPE

This chapter covers buildings which shall be designed and constructed as per relevant BNBC 15 standard specifications including the effects of incidental loads like wind, flood, and tsunami. This shall help in reducing the risk of damage due to non-seismic natural hazards. These guidelines may be useful in planning, design and construction aspects for improving non-seismic hazard resistance of buildings.

14.2 PLANNING AND SITE CONSIDERATION

Whereas different categories of buildings need to be treated differently in view of their relative importance, some aspects of their planning and design are essentially the same. It is therefore, appropriate that the features common to all buildings are given first and special consideration.

Though cyclonic storms always approach from the direction of the sea towards the coast and inland, the wind velocity and direction relative to a building remain random. Hence, reduction coefficients for directionality and orientation of the buildings in a preferential direction are not feasible. The general guidelines on planning include:

a) As far as possible, the building shall be on good ground. Part of the building on good ground and partly on made up ground shall be avoided. Also, whenever possible, advantage of natural shielding available due to hillock or cluster of trees should be made use of.

b) Regular plan shapes are preferred. Re-entrant corner are to be avoided. A symmetrical building with a compact plan form is better than an asymmetrical building with a zigzag plan, having empty pockets as the later is more prone to wind/cyclone related damage.

c) For individual building, a circular or polygonal plan is preferred over rectangular or square plans but from the view point of functional efficiency, often a rectangular plan form is desirable. Where most prevalent wind direction is known, a building should be so oriented, where feasible, that its smallest facade faces the wind.

   Ornamental architecture involving vertical or horizontal cantilever projections, facets etc. should be avoided. If possible, the building should be oriented in such a way so that a corner rather than a wall faces the sea. Ratio of the length to breadth of the building should be minimum.

d) While planning a layout for group of housing, if the inter-building spacing is less than twice the width of the building, considerable shielding is available for the interior buildings, though the first two columns/rows of buildings attract larger forces compared to a stand alone building. In case of constructing a group of buildings with a row type or cluster arrangement, the later can be followed in preference to the former. However, in certain cases, both may give rise to adverse wind pressure due to tunnel action and studies need to be conducted to look into this aspect.

For flood and tsunami, row type arrangement is preferable for easy flow of waters between the rows.

e) Building should not be located in low-lying areas as cyclones are invariably associated with flood & tidal surge. Also in regions where storm surges lead to coastal inundation, building should be located at higher ground levels. If higher ground is not available, building may be constructed on raised earthen mounds with specified slope, proper compaction of soil to avoid settlement of render-lying soil. Alternately, plinth height may be raised to avoid inundation due to tidal surge. Where tidal surge is of higher magnitude, building may be constructed on stilt, keeping the ground floor open for unobstructed flow of tidal surge, except the column and the stair area. Suitable bracing may be provided in case of multiple hazard zones, particularly due to earthquake, to avoid failure arising out of large variations in stiffness between stilt & higher floor levels. Elevated structure may also encounter additional wind force on walls and roofs. Open ground flood is also subjected to erosion, secure, debris impact. This factors should be considered while designing the structure.

Elevating a building to prevent flood water from reaching the damageable portion is also an effective retrofitting technique. The structure is raised so that the lowest floor is at or above the Design Flood Elevation (DFE) to avoid damage from a base flood.

f) Long walls having lengths in access of about 3.5m (11.5 ft.) shall be provided with cross walls.

g) In hilly regions, construction along ridges should be avoided since they experience an accentuation of wind velocity whereas valleys experience lower speeds in general.

h) Providing at least two means of site egress is prudent for all office building, but is particularly important for office buildings used for cyclone shelters and emergency response after a storm. Two means of egress facilitate emergency vehicles that need to reach or leave the site. With multiple site egress roads, if one route becomes blocked by tress or other debris or flood waters, another access route should be available.

i) It is always preferable to locate the facility on a site in Exposure A, instead of placing it in Exposure B or Exposure C as defined in BNBC15. Also where possible, avoid locating a building on an escarpment or upper half of a hill, otherwise, if the building is located on an escarpment or upper half of a hill, the abrupt change in topography would result in increased wind load.

j) Trees in excess of 150 mm (6 in) in diameter, poles (e.g. light fixture poles, flag poles, power poles) or tower (e.g. electrical transmission or communication towers) should not be placed near office or shelter buildings. Blow-down of large tress, poles, and towers can severely damage an office or other buildings and injure occupants.

14.3 INSPECTION, PERIODIC MAINTENANCE, REPAIR AND REPLACEMENT

The owner of the building should understand the importance of periodic inspection, maintenance, timely repair and replacement. It is important to understand that, over time, a facility's wind- resistance will degrade due to exposure to weather unless it is periodically maintained and repaired.

The building envelope and exterior- mounted equipment should be once a year by persons knowledgeable of the system and materials they are inspecting. Items that require maintenance repair or replacement should be documented and scheduled for work. Special attention should be given to glazing. After several years of exposure glazing along with its frame and fixation system gets weaker. It is always better to repair or replace an item before they fail by storm. This approach is less expensive than waiting for failure and repairing or replacing the failed component and consequential damages.

14.4 EXTERIOR DOORS

ICB2006 requires that door assembly (i.e. door, hardware, frame and attached wall) be of sufficient strength to resist negative and positive wind pressure. Designer should specifically design the attachment of the door frame to the wall (i.e., specify size, type, and spacing of frame fasteners).

When corrosion is problematic, anodized aluminium or galvanized doors and frames and stainless steel hardware are recommended.

To account for the infiltration problem, outer doors can be provided with weather-stripping. With respect to weather-stripping, out-swinging doors offer an advantage compared to in-swinging doors. With out-swinging doors, the weather-stripping is located on the interior side of the doors, where it is less susceptible to degradation. For in-swinging external doors, a concrete threshold of about 40mm (1.5 in) height offers enhanced resistance to wind-driven water infiltration. However, this might create problems for a physically disabled person from entering the premises. So before putting permanent threshold government regulation in this matter should be consulted and compliant threshold should be provided.

14.5 WALL OPENING

Openings in walls in general are sources of weakness and stress concentration, but are needed essentially for lighting and ventilation. In general, large opening close to the corners or too many opening should be avoided.

The following norms are recommended in respect of openings:

a) Opening just below roof level is avoided except that two small vents without shutter may be provided in opposite walls.

b) Since the failure of any door or window on windward side may lead to adverse uplift pressure under roof, door and window frames should have adequate anchorage with hold fast and the openings should have strong closing/locking arrangement and glass/wooden panels be securely fixed.

c) The percent of the total opening in the cross-section of any wind resisting walls shall be less than 50% of the width of the wall.

14.6 GLASS PANELLING

a) One of the most damaging effects of strong winds or cyclones is the extensive breakage of glass panes caused by high local wind pressure or impact of flying object in air. The large size door or window glass panes may shatter because they are too thin to resist the local wind pressure. A broken glass pane of a windward side opening increases internal pressure abnormally and may lead to a chain of events. A wooden board may be securely fixed outside all large size glass panels as and when cyclone/wind storm warning is issued.

b) One way to reduce this problem is to provide well-designed glass panels. In cyclonic region where the exposure to high wind and gustiness is sustained it is recommended that in designing glass panels, no relief by way of increase in permissible stresses on account of the consideration of wind load be allowed

c) Further, recourse may be taken to reduce the panel size to smaller dimension. Also glass panes can be strengthened by pasting this plastic film or paper strips. This will help in holding the debris of glass panes from flying in case of breakage. It will also introduce some damping in the glass panels and reduce their vibration

d) Further, to prevent damage to glass panels from flying wind borne missiles, a metallic fabric/mesh may be provided outside the large panels.

14.7 DESIGN CONSIDERATIONS

RCC buildings are normally carefully planned and properly designed against seismic and non-seismic loads using relevant Codes of practice. Good design practice requires that the structures be robust and that their safety and performance not be sensitive to uncertainties in loads, environmental influences, and other situations not explicitly considered in design. Structural system should be designed with sufficient continuity and ductility that alternate load paths can develop, following individual member failure, so that failure of structure as a whole does not ensure. Following guidelines may be adopted for wind loads for such structures.

a) Basic wind speed shall be taken as specified in Table 10.1 of this manual.

b) Pressure and Force

i) The pressure and forces, shall be computed using the co-efficient provided in BNBC 15 for various types of buildings and structures

ii) Unless measures have been taken to ensure that doors and windows would stay in position during storm, failure of the closing element over the largest opening shall be considered for computing the percentage opening (permeability) in addition to any fully vented opening. The effect of opening on total design pressure on walls and other components of structure shall be considered.

c) Load effects

Load effects shall be determined considering all critical combinations of Dead Load, Live load and Wind load. In the design of elements, stress reversal under wind suction should be given due consideration. Members or flanges which are usually in tension in dead and live loads may be subjected to compression under dead load and wind, requiring consideration of buckling resistances in their design.

d) Wind direction

Since cyclonic wind could blow from any direction, building must have wind resistances along both the axes.

e) Resistance to corrosion

Resistance to corrosion is a definite requirement in cyclone prone sea coastal areas. In RCC construction, a mix proportion of minimum 24 Mpa grade or richer with increased clear cover to the reinforcement has to be adopted(See Section 8.2.2). Low water-cement ratio with densification by means of vibrators will minimize corrosion. The external surface should be treated with water proofing paints. All concrete mix shall be made with portable waters.

14.8 CAUSES OF DAMAGE PROPAGATION

There are a number of factors that contribute to the risk of damage propagation in modern structure. Among them:

1. There is an apparent lack of general awareness among engineers that structural integrity against collapse is important enough to be regularly considered in design.
2. To have more flexibility in floor plans and to keep cost down, interior walls and partitions are often non-load bearing and hence may be unable to assist in containing damage.
3. In attempting to achieve economy in structure through greater speed of erection and less site labour, systems may be built with minimum continuity, ties between elements and joint rigidity.
4. Un-reinforced or lightly reinforced load bearing walls in multistory structure may also have inadequate continuity and joint rigidity.
5. In eliminating excessively large safety factors, code changes over the past several decades have reduced the large margin of safety inherent in many older structures. The use of higher-strength materials permitting more slender sections compounds the problem in that modern structures may be more flexible and sensitive to load variations and, in addition, may be more sensitive to construction errors.

From a public-safety view point, it is reasonable to expect all multistory structures to possess general structural integrity comparable to that of properly designed conventional frame structures.

14.9 GENERAL STRUCTURAL INTEGRITY

Generally, connections between structural components should be ductile and have a capacity for relatively large deformation and energy absorption under the effect of abnormal conditions. This criterion is met in many different ways, depending on the structural system used. Details that are appropriate for resistance to moderate wind load and earthquake load often provide sufficient ductility.

There are a number of ways of designing for the required integrity to carry loads. A few examples of design concepts and details are:

1. Good plan Layout. An important factor in achieving integrity is the proper plan layout of walls and columns. In bearing-wall structures there should be an arrangement of interior longitudinal wall to support and reduce the span of long sections of cross walls, thus enhancing the stability of individual walls and of the structure as a whole. In the case of local failures, this will also decrease the length of wall likely to be affected.
2. Integrated tie system. Provide an integrated system of ties among the principle elements of the structural system. These ties may be designed specifically as components of secondary load carrying system, which often must sustain very large deformation during catastrophic events.
3. Change direction of span of floor Slab. Where a one way floor slab is reinforced to span, with a low safety factor, in its secondary direction if a load bearing wall is removed, the collapse of the slab will be prevented and the debris loading of other parts of the structure will be minimized. Often, shrinkage and temperature steel will be enough to enable the slab to span in a new direction.
4. Load-bearing Interior partition. The interior walls must be capable of carrying enough load to achieve the change of span direction in the floor slab.
5. A part of the detailed design effort. Continuity of load path is very important. Load path need to accommodate design uplift, overturning loads etc. Land path continuity obviously applies to MWFRs elements, but it also applies to building envelope elements. Conceptions are a key aspect of load path continuity between various structural and nonstructural elements. For example, consider a window, the glass must be strong enough to resist the applied load and the glass must be adequately anchored to the window frame, the frame adequately anchored to the wall, the wall adequately anchored to the MWFRS and the MWFRS adequately anchored to foundation and the foundation adequately anchored to the ground.
6. Ductile Detailing. Avoid low ductility detailing in elements that might be subject to dynamic loads or very large distortions during localized failures (e.g.s consider the implications of shear failures in beams or supported slabs under the influence of building weights falling from above).

14.10 DURABILITY

Because some locales have very aggressive atmospheric corrosion (such as coastal areas) special attention needs to be given to specification of adequate protection to ferrous metals. Attention also needs to be given to dry rot avoidance, for example, by specifying preservative-treated wood.

In some locales, termites present a significant threat to building performance. Where termites are problematic, it is recommended that the soil be treated with a germicide applied by a professional company experienced in termite treatment. It is also recommended that, if wood or wood-based products are specified, they be preservative treated as per requirements of BNBC 13.

Also, the surfaces that are cut or drilled after treatment, are to be field protected with a suitable preservative applied in accordance with the manufacturers recommendations. Where corrosion is problematic, anodized aluminium or galvanized doors and frames and stainless steel frame anchors and hardware are recommended. Durable materials are particularly important for components that are concealed, which thereby prohibit knowing that the component is in imminent danger of falling.

14.11 NON-LOAD BEARING WALLS

Exterior non-load bearing walls, wall coverings shall have sufficient strength to resist the positive and negative design wind pressure.

Particular care should be given to the design and construction of exterior non-load bearing walls constructed of masonry. Although, these walls are not indented to carry gravity loads, they must be designed to resist the positive and negative wind loads in order to avoid collapse. Because of their weight, when these types of walls collapse, they represent a serious risk to life.

Special consideration should also be given to interior non-load bearing masonry walls. Although these walls are not required by building codes to be designed to resist wind loads, if glazing is broken, the interior walls could collapse after being subjected to significant load as the building rapidly become fully pressurized. To avoid occupant injury, it is recommended that interior non-load bearing walls that are adjacent to occupied areas be designed to accommodate loads exerted by the design wind load, using partially enclosed pressure co-efficient. By doing so, wall collapse may be prevented, if the building envelope is breached. This recommendation is applicable to office building in tornado prone areas that do not have shelter space designed for tornado (FEMA 361), to office buildings located in areas with a basic wind speed greater than 120 mph (193.2 km/h) and to office buildings that will be used for cyclone shelters.

14.12 LIGHTING PROTECTION SYSTEM

A *lightning rod* or *lightning conductor* is a metal rod or metallic object mounted on top of a building, electrically bonded using a wire or electrical conductor to interface with ground or "earth" through an electrode, engineered to protect the building in the event of lightning strike. If lightning hits the building it will preferentially strike the rod and be conducted to ground through the wire, instead of passing through the building, where it could start a fire or cause electrocution.

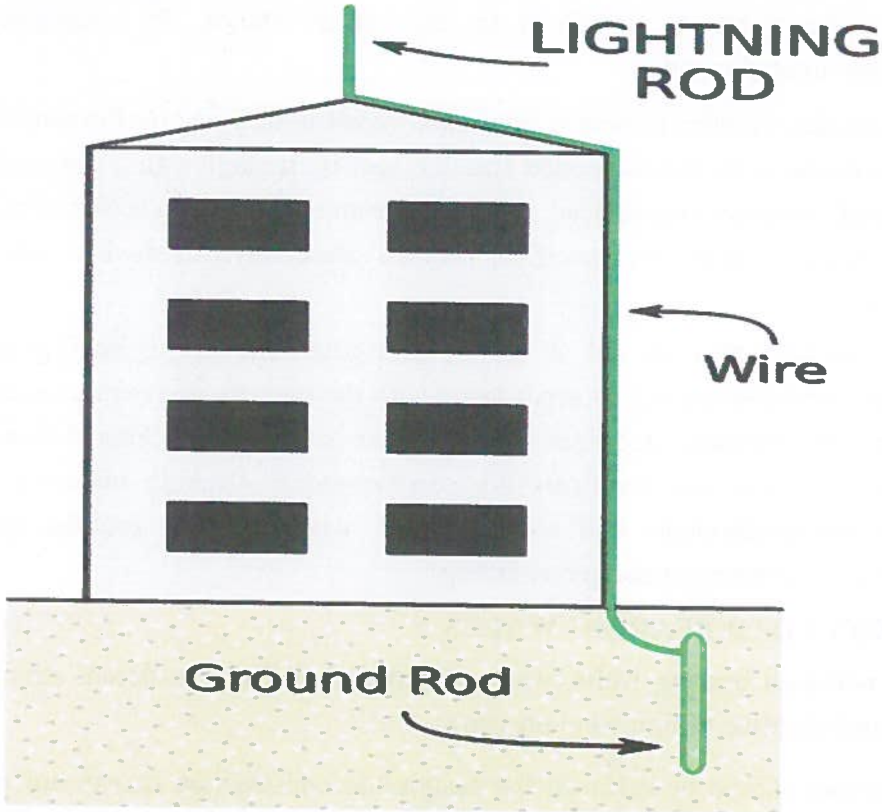


Figure 14.1 Lightning Protection Systems

A *lightning rod* is a single component in a *lightning protection system*. Lightning rods are also called *finials, air terminals* or *strike termination devices*. The lightning rod requires a connection to earth to perform its protective function. Lightning rods come in many different forms, including hollow, solid, pointed, rounded, flat strips or even *bristle brush-like*. The main attribute of all lightning rods is they are conductive.

Copper and its alloys are the most common materials used in lightning protection.

When not adequately integrated into a roof system, a lightning protection system can become detached from the roof during high wind. In such a situation, the detached system is no longer capable of providing lighting protection. It is, therefore, important to adequately design the attachment of the lightning protection system and it should be firmly fixed with the roof system. Same is the case with solar power generation system.

14.13 ELEVATOR PENT HOUSE

Maintaining water tight integrity of elevator penthouse is critical. Proper waterproofing membrane should be provided in external doors and windows of elevator penthouse or machine room so that water does not infiltrate the elevator machine room during high wind accompanied by rain.

14.14 PROTECTION OF UTILITY SYSTEM

Elevation refers to the location of a component and/or utility system above DFE (Design Flood Elevation).

Elevation is highly recommended for all utility system components in new structures except where the component needs to extend below the DFE for service connection or code compliance.

New structures located in A-zones, (Risk Area) the lowest floor be above DFE for dry flood proofing. New structures located in V-zones, (High Risk Area) the lowest horizontal structural member of the lowest floor be above the DFE.

Both residential and non-residential buildings including cyclone and flood shelters may also be dry flood proofed to DFE.

When the lowest horizontal structural member of the lowest floor in a structure is located above DFE, utility system components can be protected from flood damage by locating them anywhere on or above the lowest floor of the structure.

If the lowest floor is above DFE, it is also possible to achieve elevation by hanging utility system components such as pipes, wires from the bottom of the lowest floor as long as the bottom of every component is above the DFE.

14.15 MITIGATION MEASURES FOR TORNADO: SAFE ROOM FOR RESIDENTIAL HOMES

It is difficult to protect a building from tornado when the wind speed is as high as 400 km/h (250 mph). Normal design for the effect of wind does not consider a wind speed as high as 400 km/h (250 mph). Maximum wind speed shown in BNBC 15 Table 6.2.8 of Part 6 is 80 m/s (174 mph/289 km/h)] in islands like Hatiya, Kutubdia, Maheshkhali, St. Martin Island, Sandwip and also in Teknaf and district towns of Barguna, Chittagong, Cox's Bazar, Jhalakathi, Patuakhali Perojpur. Most of these places do not normally face tornado. Unfortunately most of the tornados that devastated Bangladesh lie in mainland like Manikgonj, Narayangonj, Tangail, Magura, Jamalpur, Dhaka, Sirajgonj etc.

FEMA 320 (Ref. C14-2) as well as FLASH (Ref.14.3) suggested some measures for residential house which they call 'Safe Room', building inside the house to protect inhabitants from the onslaught of severe winds produced by tornado. A safe room or tornado shelter is a hardened structure that provides life-safety protection from an extreme-wind event. It is a place of last resort providing protection from the effect of an extreme wind event. In the Bangladesh context this may look over ambitious, but it outlines a solution for protection of human line against tornado. In tornado prone regions of Bangladesh, consideration may also be given to designing and constructing portion of any office building with the same principle to provide protection of occupants.

The following information shall be considered while building a safe room in a residential house or office buildings.

- Safe room can be located anywhere in the house or even outside

- Safe room must be designed for wind speeds up to 112 m/s (250 mph/400 km/hr) 3 second gust speed and debris impact from a 6.7 kg (15 lb) board travelling at 45m/s (100 mph /161 km/h)
- Exposure B as per BNBC 15 and Exposure C as per ASCE7- 05
- Partially Enclosed
- Safe room shall be structurally isolated from the main structure of the house
- Safe room shall be securely anchored to the foundation
- All components of the safe room, including walls ceilings, door assemblies must be designed and tested to resist the specified wind forces and prevent perforation by wind-borne debris
- Safe room must have adequate ventilation
- Site built safe room shall be constructed in accordance with the prescriptive design of the FEMA 320 (Ref. C14-2).

Nothing has been discussed about tornado in BNBC15.

14.16 MITIGATION MEASURES FOR TSUNAMI

One of the key factors to minimize damages caused by tsunami is to build structures that can withstand damage of such events. In order to achieve that, several basic requirements shall have to be satisfied to have a tsunami proof building. Some of these are:

- Elevate the structure above the ground level with deeper foundation and open ground floor so that the wave passes through, thus reducing the pressure on the building. Even if the elevation of such a floor is modest, the forces from rushing water will be much less if the water can go under the building as well as round it. All structural members have to be strongly fixed to the frame and to the foundation to prevent the building from floating off and becoming a missile. All columns should be braced both ways at foundation level and for sandy soil the foundation should be deeper.

  As in seismic design, the most heavily loaded members and the ones which take most bending are the columns from ground to suspended first floor. As such, the columns should be firmly fixed to the foundation, also braced to each other.
- Design the walls of ground floor so that walls at ground-to-first floor level fail due to water pressure of tsunami but make the frame strong enough to support the floors above without the help from walls in the ground floor..
- As much as possible, leave vegetations and reefs intact. A rough ground reduces the effects of the waves. It is not good idea to cut down all the vegetation and produce a smooth and unprotected beach. Mangrove swamps are particularly good at stopping tsunamis. Reefs too should be left intact and not destroyed for shipping channels.
- Do not build building at low level on the shore line at the top of a smooth shallow beach.

- Buildings should not be close together in a way that makes a wider dam. It is much better if gaps are left between buildings so that water can dissipate.
- Narrow side of the building should face the sea.
- Construct small sea walls parallel to the sea shore by maintaining certain gaps between them for receding water to pass. Small sea walls cause a skyward defection of an incoming tsunami wave, which consequently reduces wave energy and force on structure. These sea walls are a sustainable tsunami defense measure applicable for most coastal communities.
- Construct multilevel buildings within the inundation zone which allows people inside to reach heights above the wave crest to reduce casualty.
- Depending on the extend of tsunami forces travelling inland, a setback may be established and best location for high-priority buildings such as schools, hospitals, tsunami evacuation structures should be selected
- Orient the building at an angle to the shore line. It also helps if the building is not square on to the wave front. If diagonal, the wave hits the pointed corner first and is diverted around the sides. Pressure is much reduced.

  Walls that face the ocean, allowing for a perpendicular impact from the tsunami waves, sustain considerably higher amount of damage than walls oriented in the direction of the water flow.

  Orientation is also important due to the massive amount of debris that can be found in the flow resulting from tsunamis. In fact, more tsunami victims are injured or die from debris pushed along by tsunami waves than by any other secondary cause.
- Construct building with reinforced concrete materials. When comparing building materials, it was found that reinforced concrete structures were more likely to survive the wave to masonry and wood structures. Even brick buildings, when properly reinforced have been found to be effective..
- Timber buildings are much liked in earthquake areas round the world because they are light and thus reduce earthquake effects. But they are the worst possible choice in tsunami prone areas. Like the ships, they float, and there is nothing to hold them down. The wood becomes weapons which destroy buildings and lives.

ANNEXURE

Extent of Damage as per Saffir-Simpson Hurricane Scale (Ref. C3-1) Annexure 1

Category	Wind	Effects
One	74-95 mph 119-155 km/hr 33-42.5 m/s	No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery and trees. Also some coastal flooding and minor pier damage
Two	96-110 mph 156-177 km/hr 43-49 m/s	Some roofing materials, door and window damage to buildings. Considerable damage to vegetation, mobile homes, and piers. Coastal and low lying escape routes flood 2-4 hours before arrival of center. Small craft in unprotected anchorages break moorings.
Three	111-130 mph 179-209 km/hr 50-58 m/s	Some structural damages to small residences and utility buildings with a minor amount of curtain wall failures. Mobile homes are destroyed. Flooding near the coast destroys smaller structures with larger structures damaged by floating debris. Terrain continuously lower than 5 feet ASL may be flooded inland 8 miles flooded inland 8 miles or more.
Four	131-155 mph 211-250 km/hr 58.6-112 m/s	More extensive curtain wall failure with some complete roof structure failures on small residences. Major erosion of beach. Major damage to lower floors of structures near the shore. Terrain continuously lowers than 10 feet ASL may be flooded requiring massive evacuation of residential areas inland as far as 6 miles.
Five	Greater than 155 mph >260 km/hr > 112 m/s	Complete roof failures on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. Major damage to lower floors of all structures located less than 15 feet ASL or within 500 yards of the shore line. Massive evacuation of residential areas on low ground within 5 to 10 miles of the shorelines may be required.

Extent of Damage as per TORRO Scale Parameters (Ref. C3-1) Annexure2

TORRO Intensity	Wind speed	Tornado description	Damage description
FC (Funnel cloud)	-	Funnel cloud aloft(Not a tornado)	No damage of structures, unless on top of tallest towers, or to radiosondes, balloons, and aircrafts. No damage to the country, except possibly agitation to highest tree tops and effect on birds and smoke. Record FC not known to have reached ground level. A whistling or rushing sound aloft may be noticed.
T0	17-24 m/s 61-86 km/h 39-54 mph	Light	Loose light litter raised from ground-level in spirals. Tents, marquees seriously disturbed; most exposed tiles, slates on roofs dislodged. Twigs snapped; trail visible through crops.
T1	25-32 m/s 87-115 km/h 55-72 mph	Mild	Deckchairs, small plants, heavy litter becomes airborne; minor damage to sheds. More serious dislodging of tiles, slates, chimney pots. Wooden fences flattened. Slight damage to hedges and trees.
T2	33-41 m/s 116-147 km/h 73-92 mph	Moderate	Heavy mobile homes displaced, light caravans blown over, garden shed destroyed, garage roofs torn away, much damage to tiled roofs and chimney stacks. General damage to trees, some big branches twisted or snapped off. Small trees uprooted.
T3	42-51 m/s 148-184 km/h 93-114 mph	Strong	Mobile homes overturned/badly damaged; light caravans destroyed; garages and week buildings destroyed; house roof timbers considerably exposed. Some of bigger trees snapped or uprooted.
T4	52-61 m/s 221-259 km/h 137-160 mph	Severe	Motor cars levitated. Mobile homes air borne /destroyed; shed air borne for considerable distances; entire roof removed from some houses; roof timbers of stronger brick or stone houses completely exposed; gable ends torn away. Numerous trees uprooted or snapped.
	62-72 m/s		Heavy motor vehicles levitated; more serious building

T5	221-259 km/h 137-160 mph	Intense	damage than for T4 yet house walls usually remaining; the oldest, weakest buildings may collapse.
T6	73-83 m/s 260-299 km/h 161-186 mph	Moderately devastating	Strongly- built houses loose entire roofs and perhaps also a wall; windows broken on skyscrapers, more of the less - strong buildings collapse.
T7	84-95 m/s 300-342 km/h 181-212 mph	Strongly-devastating	Wooden framed houses wholly demolished; some walls of stone or brick beaten down or collapse; skyscrapers twisted; steel framed warehouses type constructions may buckle slightly. Locomotives thrown over. Noticeable de-barking of trees by flying debris.
T8	96-107 m/s 343-385 km/h 213-240 mph	Severely-devastating	Motor cars hurled great distances. Wooden-framed houses and their contents dispersed over long distances; stone or brick houses irreparably damaged; skyscrapers badly twisted and show a visible lean to one side; shallowly anchored high rises may be toppled; other steel-framed buildings buckled.
T9	108-120 m/s 386-432 km/h 241-269 mph	Intensely-devastating	Many steel-framed buildings badly damaged; skyscrapers toppled; locomotives or trains hurled some distances. Complete debarking of any standing tree-trunks.
T10	121-134 m/s 433-482 km/h 270-299 mph	Super	Entire frame houses and similar buildings lifted bodily from foundations and carried some distances' Steel-reinforced buildings may be severely damaged.

T0	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
Weak				Strong				Violent			

Cyclone classification in different countries Annexure3

Indian System of Tropical Cyclone Classification

Category	**Sustained winds –knots, 3-minute average**	**Sustained winds – kilometers per hour, 3-minute average**
Super Cyclonic Storm	Over 120 knots	Over 222 kph
Very Severe Cyclonic Storm	64 to 119 knots	118 to 221 kph
Severe Cyclonic Storm	48 to 63 knots	88 to 117 kph
Cyclonic Storm	34 to 47 knots	62 to 87 kph
Deep Depression	28 to 33 knots	52 to 61 kph
Depression	Under 27 knots	Under 51 kph

United States System of Hurricane Classification

Description	**Category**	**Central Pressure** **Mb** **Inches**	**Wind Speed** **Miles per Hr** **Knots**	**Wind Speed** **KPH** **Meters/Sec**	**Storm Surge** **Feet** **Meters**
Tropical Depression			38 33	61 17	
Tropical Storm			39 to 72 mph 34 to 63 kt	63 to 117 kph 17.5 to 33 m/s	
Typhoon/ Hurricane	1	Under 980 mb Under 28.84"	74 to 95 mph 64 to 82 kt	118 to 153 kph 33 to 42 m/s	4 to5 ' 1.5 m
"	2	965 to 979 mb 28.5 to 28.91"	96 to 110 mph 83 to 95 kt	154 to 177 kph 43 to 49 m/s	6 to 8 ' 2 to 2.5 m
"	3	945 to 964 mb	111 to 130 mph	178 to 209 kph	9 to 12 '

		27.91 to 28.47"	96 to 113 kt	49 to 58 m/s	2.5 to 4 m
"	4	920 to 944 mb 27.17 to 27.88"	131 to 155 mph 114 to 135 kt	210 to 249 kph 59 to 69 m/s	13 to 18 ' 4 to 5.5 m
Super Typhoon			Over 150 mph Over 130 kt	Over 241 kph Over 65 m/s	
Typhoon/ Hurricane	5	944 to 920 mb 27.88 to 27.17"	Over 155 mph Over 135 kt	Over 250 kph Over 70 m/s	Over 18' > 5.5 m

The system below is based on the World Meteorological Organization with the nomenclature slightly different from nomenclature used in Bangladesh. That system is listed below, with additional information on wind speeds in knots and miles hour in brackets.

Hong Kong Observatory System

Tropical Cyclone Classification	**Maximum winds (10-minute mean)**
Tropical Depression	Up to 62 kph [33 knots or 38 mph]
Tropical Storm	63 to 87 kph [34 to 47 knots or 38 to 54 mph]
Severe Tropical Storm	88 to 117 kph [48 to 63 knots or 55 to 73 mph]
Typhoon	Over 118 kph [64 knots or 74 mph]

Storm Surge Inundation Depth in the Coastal Areas of Bangladesh

Annexure 4

*Value in red indicates maximum inundations in the Upazillas

Upazila	Union	Latitude	Longitude	IWM Surge Level (mPWD)	DEM (1991)-GL (mPWD)	Surveyed GL(mPWD) by Consultant	Surge Water Depth (m) based on DEM	Surge water depth (m) based on surveyed GL
Amtali	Amtali	22°6'46.90"	90°13'0.38"	3.05	1.691	-	1.359	-
Amtali	Amtali	22°07'05.68"	90°14'08.85"	6.06	3.35	1.769	2.71	4.291
Amtali	Amtali	22°06'14.32"	90°14'54.62"	4.31	1.73	0.071	2.58	4.239
Amtali	Amtali Pourashava	22°8'29.50"	90°13'55.90"	4.12	2.94	-	1.18	-
Amtali	Arpangashia	22°5'36.05"	90°10'28.50"	2.8	2.019	1.953	0.781	0.847
Amtali	Arpangashia	22°05'43.87"	90°11'40.72"	2.77	1.766		1.004	
Amtali	Arpangashia	22°5'41.44"	90°13'16.40"	2.78	1.878	1.768	0.902	1.012
Amtali	Atharagashia	22°12'52.19"	90°20'12.70"	4.37	1.593	1.315	2.777	3.055
Amtali	Barabogi	21°53'50.03"	90°4'1.05"	4.36	1.904	-	2.456	-
Amtali	Barabogi	21°57'24.32"	90°05'03.70"	4.73	2.719	-	2.011	-
Amtali	Barabogi	21°54'42.92"	90°3'51.21"	4.36	1.817	-	2.543	-
Amtali	Barabogi	21°56'40.59"	90°7'40.98"	3.57	1.83	-	1.74	-
Amtali	Barabogi	21°58'16.87"	90°5'53.14"	3.62	2.117	-	1.503	-
Amtali	Barabogi	21°55'23.24"	90°2'26.77"	4.36	2.235	-	2.125	-
Amtali	Barabogi	21°54'48.35"	90°2'4.41"	7.159	2.21	-	4.949	-
Amtali	Chawra	22°9'11.64"	90°15'1.28"	4.21	1.587	-	2.623	-
Amtali	Chawra	22°9'53.34"	90°15'4.62"	4.15	3.246	2.103	0.904	2.047
Amtali	Chawra	22°08'16.53"	90°15'25.24"	6.032	1.53	1.241	4.502	*4.791
Amtali	Chawra	22°10'47.27"	90°16'12.61"	4.13	1.497	-	2.633	-
Amtali	Guilshakhali	22°13'21.07"	90°14'0.50"	3.32	1.993	-	1.327	-
Amtali	Guilshakhali	22°10'28.34"	90°15'24.27"	2.49	1.52	0.956	0.97	1.534
Amtali	Guilshakhali	22°11'06.36"	90°14'25.51"	2.66	2.362	-	0.298	-
Amtali	Guilshakhali	22°14'44.55"	90°16'07.53"	4.71	2.1	0.838	2.61	3.872
Amtali	Holodia	22°06'08.06"	90°19'55.79"	6.538	1.713	-	4.825	-
Amtali	Holodia	22°05'52.06"	90°16'50.05"	5.971	2.11	1.183	3.861	4.788
Amtali	Holodia	22°8'39.41"	90°17'45.43"	4.48	1.812	2.007	2.668	2.473
Amtali	Holodia	22°9'20.91"	90°19'23.29"	5.26	1.929	-	3.331	-
Amtali	Koraibaria	22°2'10.58"	90°7'9.28"	3.72	1.991	-	1.729	-
Amtali	Koraibaria	22°3'33.42"	90°11'10.06"	2.85	1.608	-	1.242	-
Amtali	Pancha Koralia	22°04'16.98"	90°10'3.28"	6.355	1.89	1.963	4.465	4.392
Amtali	Pancha Koralia	22°2'50.03"	90°6'44.37"	3.85	2.025	1.206	1.825	2.644
Amtali	Pancha Koralia	22°2'50.39"	90°9'44.69"	3.04	1.579	-	1.461	-
Anowara	Barakhan	22°11'35.8"	91°54'33.4"	8.558	3.9	1.89	4.658	6.668
Anowara	Barohat	22°12'39"	91°50'36.9"	9.89	4.2	3.56	5.69	6.33
Anowara	Baruchara	22°10'17.2"	91°53'41.2"	10.086	3.2	1.83	6.886	8.256
Anowara	Barumchara	22°10'59.7"	91°53'00.2"	9.95	2.5	1.95	7.45	8
Anowara	Barumchara	22°10'10.2"	91°53'31.4"	10.137	3	2.49	7.137	7.647
Anowara	Chatory	22°14'29.4"	91°52'48"	7.02	2.8	1.72	4.22	5.3

Upazila	Union	Latitude	Longitude	IWM Surge Level (mPWD)	DEM (1991)-GL (mPWD)	Surveyed GL(mPWD) by Consultant	Surge Water Depth (m) based on DEM	Surge water depth (m) based on surveyed GL
Anowara	Guapanchak	22°14'03.3"	91°51'43.5"	4.59	2.5	3.46	2.09	1.13
Anowara	Panikuna	22°14'36.5"	91°56'46.0"	6.668	2.2	1.7	4.468	4.968
Anowara	Raypur	22°10'18 3"	91°50'04.0"	10.541	2.6	2.9	7.941	7.641
Bakerganj	Bhar Pasha	22°30'39.53"	22°30'39.53"	4.798	1.666	2.49	3.132	2.308
Bakerganj	Dudal	22°35'10"	22°35'10"	6.198	2.127	2.59	4.071	3.608
Bakerganj	Durga Pasha	22°33'44"	22°33'44"	6.818	2.077	2.91	4.741	3.908
Bakerganj	Niamati	22°30'14"	22°30'14"	4.624	1.577	2.64	3.047	1.984
Bakerganj	Niamati	22°29'00"	22°29'00"	4.707	1.38	2.18	3.327	2.527
Bakerganj	Padri Shibpur	22°29'47"	22°29'47"	4.258	1.078	-	3.18	
Bakerganj	Padri Shibpur	22°29'51"	22°29'51"	4.654	1.315	-	3.339	
Bakerganj	Patkati	22°34'07.72"	22°34'07.72"	6.472	1.72	1.46	4.752	5.012
Bamna	Bamna Sadar	22°19'59"	90°05'00"	2.69	1.549	1.089	1.141	1.601
Bamna	Bamna Sadar	22°17'36"	90°05'32"	2.7	1.754	1.95	0.946	0.75
Bamna	Bamna Sadar	22°17'32.75"	90°04'35.74"	2.69	1.869	1.275	0.821	1.415
Bamna	Bukabunia	22°19'30"	90°03'20"	2.86	2.752	1.521	0.108	1.339
Bamna	Bukabunia	22°20'00"	90°03'27"	2.86	2.314	1.552	0.546	1.308
Bamna	Dowatala	22°15'37"	90°01'35"	4.782	2.349	1.967	2.433	2.815
Bamna	Dowatala	22°13'20.86"	89°59'33.55"	6.122	1.57	1.998	4.552	4.124
Bamna	Ramna	22°16'07"	90°03'26"	2.69	1.586	1.412	1.104	1.278
Banshkhali	Banshkhali	22° 0' 41.34"	91°56'46.44"	9.909	3.4	1.84	6.509	8.069
Banshkhali	Barghuna	21° 56' 51.30"	91°54'56.28"	8.924	2.4	10.9	6.524	Dry
Banshkhali	Barghuna	21°56'42.57"	91°55'43.91"	12.489	1.9	13.67	10.589	Dry
Banshkhali	Chambal	21° 57' 44.10"	91°57'34.26"	9.718	3.8	14.32	5.918	Dry
Banshkhali	Gondamara	21° 57' 36"	91°55'6.48"	9.074	2.4	13.15	6.674	Dry
Banshkhali	Gondamara	21°59'47.46"	91°53'27.30"	12.293	2.9	13.41	9.393	Dry
Banshkhali	Katharia	22°2'23.16"	91°54'38.76"	9.486	3.5	5.54	5.986	3.946
Banshkhali	Khankhanabad	22° 6' 9.60"	91°53'35.58"	10.403	3.3	11.87	7.103	Dry
Banshkhali	Khankhanabad	22°6'58.08"	91°53'29.82"	9.985	2.6	2.4	7.385	7.585
Banshkhali	Khankhanabad	22° 6' 10.80"	91°53'7.92"	10.388	2.2	3.61	8.188	6.778
Banshkhali	Puichari	21° 55' 7.92"	91°57'25.86"	9.325	2.7	11.35	6.625	Dry
Banshkhali	Pukuria	22° 8' 36.06"	91°54'36.6"	10.943	3.3	6.25	7.643	4.693
Banshkhali	Pukuria		91°55'45"	8.339	4.3	2.75	4.039	5.589
Banshkhali	Pukuria	22°9'39.30"	91°56'41.16"	7.452	2.72	3.3	4.732	4.152
Banshkhali	Sanua	21°54' 45.90"	91°56'21.72"	9.01	3.9	12.66	5.11	Dry
Banshkhali	Sanua	21° 56'9.42"	91°55'47.34"	9.003	2.6	12.66	6.403	Dry
Banshkhali	Sanua	21°55'12.24"	91°55'32.52"	9.102	1.5	11.4	7.602	Dry
Banshkhali	Sanua	21° 54' 14.40"	91°54'49.02"	8.619	2.4	11.13	6.219	Dry
Banshkhali	Sanua	21° 53' 0.90"	91°56'9.12"	8.651	1.7	11.93	6.951	Dry
Banshkhali	Sanua	21° 54' 0.84"	91°55'42.96"	8.761	1.7	11.41	7.061	Dry
Banshkhali	Saral	22° 0' 30.60"	91°53'58.14"	9.217	2.6	1.1	6.617	8.117
Banshkhali	Shekherkhil	21° 56' 19.44"	91°56'5.28"	9.137	2.4	11.2	6.737	Dry
Banshkhali	Shekherkhil	21° 55' 59.34"	91°57'32.28"	9.502	4.3	14.34	5.202	Dry
Banshkhali	Shekherkhil	21° 56' 43 5"	91°56'33.24"	9.336	2.1	12.13	7.236	Dry
Banshkhali	Shilkup	21° 59' 0.78"	91°56'8.04"	9.523	2.5	2.1	7.023	7.423

Upazila	Union	Latitude	Longitude	IWM Surge Level (mPWD)	DEM (1991)-GL (mPWD)	Surveyed GL(mPWD) by Consultant	Surge Water Depth (m) based on DEM	Surge water depth (m) based on surveyed GL
Barguna Sadar	Ayla Patakata	22°10'47.87"	90°12'12.38"	4.42	1.855	1.871	7.023	2.549
Barguna Sadar	Ayla Patakata	22°11'14.9"	90°13'00.1"	2.65	1.301		2.565	-
Barguna Sadar	Ayla Patakata	22°13'27.2"	90°12'04.8"	3.705	2.231	2.078	1.349	1.627
Barguna Sadar	Badarkhali	22°10'56"	90°04'03"	3.99	1.778	2.871	1.474	1.119
Barguna Sadar	Badarkhali	22°12'06"	90°05'38"	4.663	1.736	3.142	2.212	1.521
Barguna Sadar	Badarkhali	22°11'47"	90°02'48"	3.97	2.006	2.436	2.927	1.534
Barguna Sadar	Badarkhali	22°11'37"	90°06'09"	3.59	1.533	2.475	1.964	1.115
Barguna Sadar	Badarkhali	22°11'46"	90°02'20"	3.92	1.894	2.536	2.057	1.384
Barguna Sadar	Badarkhali	22°12'20"	90°03'43"	6.397	1.878	2.412	2.026	3.985
Barguna Sadar	Barguna Sadar	22°06'16.3"	90°05'49.4"	5.595	2.055	0.593	4.519	5.002
Barguna Sadar	Burirchar	22°07'47.4"	90°10'55.3"	5.381	2.686		3.54	-
Barguna Sadar	Burirchar	22°09'11.43"	90°10'51.37"	5.93	1.56	1.202	2.695	4.728
Barguna Sadar	Burirchar	22°05'53.3"	90°07'12.6"	5.585	2.514		4.37	-
Barguna Sadar	Dhalua	22°07'02.4"	90°02'29.1"	5.892	2.163	1.836	3.071	4.056
Barguna Sadar	Dhalua	22°07'23"	90°03'40"	6.03	2.989	1.576	3.729	4.454
Barguna Sadar	Dhalua	22°05'52"	90°03'40"	6.011	1.96	2.69	3.041	3.321
Barguna Sadar	Dhalua	22°09'17.81"	90°04'26.71"	5.949	1.644	2.82	4.051	3.129
Barguna Sadar	Fuljuri	22°13'19.6"	90°09'44.1"	2.68	2.134	1.657	4.305	1.023
Barguna Sadar	Fuljuri	22°11'57.9"	90°09'37.9"	2.76	2.396	2.114	0.546	0.646
Barguna Sadar	Gourichanna	22°12'48.0"	90°06'46.7"	3.02	2.01	2.217	0.364	0.803
Barguna Sadar	Keorabunia	22°14'26.37"	90°09'17.89"	2.62	1.619	-	1.01	-
Barguna Sadar	Keorabunia	22°13'26.4"	90°11'54.9"	2.64	1.745	-	1.001	-
Barguna Sadar	M. Baliatali	22°05'01.9"	90°06'32.0"	5.368	1.698	0.907	0.895	4.461
Barguna Sadar	M. Baliatali	22°05'01.7"	90°06'55.9"	5.369	1.985	-	3.67	-
Barguna Sadar	M. Baliatali	22°04'24.1"	90°05'48.2"	5.26	1.778	-	3.384	-
Barguna Sadar	M. Baliatali	21°59'30.93"	90°03'01.67"	5.894	1.591	2.197	3.482	3.697
Barguna Sadar	M. Baliatali	22°02'39"	90°03'06"	6.19	2.51	2.434	4.303	3.756
Barguna Sadar	Noltona	22°02'14"	89°59'29"	6.01	2.804	1.29	3.68	4.72
Barguna Sadar	Noltona	22°01'10"	89°59'54"	6.59	1.57	2.143	3.206	4.447
Barguna Sadar	Noltona	22°02'27"	90°02'18"	6.28	2.217	1.958	5.02	4.322

Upazila	Union	Latitude	Longitude	IWM Surge Level (mPWD)	DEM (1991)-GL (mPWD)	Surveyed GL(mPWD) by Consultant	Surge Water Depth (m) based on DEM	Surge water depth (m) based on surveyed GL
Bauphal	Adabaria	22°21'54"	90°28'11"	4.129	1.734	-	2.395	-
Bauphal	Adabaria	22°21'30"	90°26'27"	4.78	2.938	1.45	1.842	3.33
Bauphal	Boga	22°24'36"	90°26'14"	3.945	2.306	-	1.639	-
Bauphal	Boga	22°22'49"	90°28'22"	3.987	1.775	1.12	2.212	2.867
Bauphal	Boga	22°25'08"	90°29'34"	4.131	1.147	1.22	2.984	2.911
Bauphal	Daspara	22°23'08"	90°33'40"	4.399	1.781	0.98	2.618	3.419
Bauphal	Daspara	22°24'05"	90°34'30"	4.527	1.861	-	2.666	-
Bauphal	Dhulia	22°34'52"	90°33'25"	7.53	2.134	0.84	5.396	6.69
Bauphal	Dhulia	22°32'26.28"	90°33'26.28"	6.852	2.222	1.14	4.63	5.712
Bauphal	Kachipara	22°28'21"	90°26'22"	5.457	1.83	0.48	3.627	4.977
Bauphal	Kachipara	22°31'38"	90°28'00"	6.122	2.023	-	4.099	-
Bauphal	Kachipara	22°28'55"	90°26'50"	5.636	2.401	2.42	3.235	3.216
Bauphal	Kalaiya	22°23'31"	90°35'04"	5.297	2.898	-	2.399	-
Bauphal	Keshabpur	22°31'22"	90°33'08"	6.667	1.678	1.53	4.989	5.137
Bauphal	Keshabpur	22°30'36"	90°32'43"	6.345	2.128	-	4.217	-
Bauphal	Keshabpur	22°29'31"	90°33'20"	6.425	2.352	0.83	4.073	5.595
Bauphal	Konokdia	22°28'51"	90°29'09"	5.387	1.606	0.5	3.781	4.887
Bauphal	Madanpura	22°23'34.57"	90°35'07.46"	5.864	2.282	1.15	3.582	4.714
Bauphal	Nazirpur	22°25'45"	90°37'10"	7.434	2.021	0.91	5.413	6.524
Bauphal	Nazirpur	22°23'26"	90°38'18"	7.487	2.062	1.7	5.425	5.787
Bauphal	Nazirpur	22°25'48"	90°34'54"	6.968	1.753	1.36	5.215	5.608
Bauphal	Nazirpur	22°26'18"	90°34'03"	6.584	2.199	-	4.385	-
Betagi	Betagi	22°23'48"	90°08'50"	7.578	1.71	-	5.868	-
Betagi	Betagi	22°24'09"	90°09'39"	5.452	1.82	TBC	3.632	-
Betagi	Betagi	22°24'26"	90°10'13"	5.092	1.174	-	3.918	-
Betagi	Betagi	22°25'27"	90°11'35"	5.075	2.101	-	2.974	-
Betagi	Betagi	22°26'01.22"	90°10'53.69"	7.507	2.33	TBC	5.177	-
Betagi	Bibichini	22°27'45"	90°11'13"	7.379	1.875	-	5.504	-
Betagi	Bibichini	22°26'42"	90°11'15"	5.212	1.928	-	3.284	-
Betagi	Bibichini	22°26'22"	90°12'06"	4.869	1.799	2.11	3.07	2.759
Betagi	Buramojumder	22°19'04"	90°08'17"	4.634	1.63	3.46	3.004	1.174
Betagi	Buramojumder	22°18'58"	90°07'26"	4.475	2.562	TBC	1.913	-
Betagi	Buramojumder	22°18'20"	90°08'15"	4.258	2.197	-	2.061	-
Betagi	Buramojumder	22°20'06"	90°07'10"	5.102	1.65	1.08	3.452	4.022
Betagi	Hosnabad	22°21'37"	90°10'42"	4.626	1.617	-	3.009	
Betagi	Hosnabad	22°23'21"	90°10'07"	4.899	1.617	3.00	3.282	1.899
Betagi	Hosnabad	22°21'20"	90°08'38"	4.895	1.692	-	3.203	-
Betagi	Hosnabad	22°23'42.51"	90°10'22.77"	4.888	1.221	-	3.667	-
Betagi	Hosnabad	22°21'23"	90°09'24"	4.717	1.642	1.43	3.075	3.287
Betagi	Kazirabad	22°14'51"	90°09'31"	2.62	1.69	2.23	0.93	0.39
Betagi	Kazirabad	22°16'24"	90°07'18"	4.447	1.909	3.00	2.538	1.447
Betagi	Kazirabad	22°14'25"	90°08'47"	2.62	1.522	-	1.098	-
Betagi	Kazirabad	22°15'18"	90°08'40"	4.086	1.55	-	2.536	-
Betagi	Mokamia	22°22'31"	90°07'36"	5.537	1.857	-	3.68	-

Betagi	Mokamia	22°20'04"	90°06'23"	7.771	2.25	-	5.521	-
Betagi	Mokamia	22°22'46"	90°07'41"	3.24	1.824	-	1.416	-
Betagi	Mokamia	22°22'19"	90°08'50"	4.917	1.637	-	3.28	-
Betagi	Mokamia	22°22'31"	90°08'16"	5.254	1.942	-	3.312	-
Betagi	Sarishamuri	22°15'39"	90°06'25"	7.722	2.075	TBC	5.647	-
Betagi	Sarishamuri	22°15'28"	90°05'41"	7.638	2.113	-	5.525	-
Betagi	Sarishamuri	22°12'59"	90°05'29"	4.473	1.926	TBC	2.547	-
Betagi	Sarishamuri	22°13'57"	90°05'53"	4.347	1.755	2.28	2.592	2.067
Bhola Sadar	Bhelu Miah	22°37'30.0"	90°34'05.6"	7.73	2.14	3.663	5.59	4.067
Bhola Sadar	Bhelu Miah	22°34'45.9"	90°36'04.8"	7.85	2.1	2.657	5.75	5.193
Bhola Sadar	Bhelu Miah	22°37'45.9"	90°33'35.2"	7.63	2.2	3.367	5.43	4.263
Bhola Sadar	Bhelu Miah	22°36'56.8"	90°35'20.8"	7.93	2.69	3.759	5.24	4.171
Bhola Sadar	Char Samaia	22°38'39.4"	90°35'44.2"	7.95	3.19	1.853	4.76	6.097
Bhola Sadar	Char Shibpur	22°40'03.1"	90°40'28.4"	7.126	2.67	2.485	4.456	4.641
Bhola Sadar	Char Shibpur	22°38'56.6"	90°39'43.8"	7.182	2.7	2.707	4.482	4.475
Bhola Sadar	Dakshin Dighaldi	22°35'23.3"	90°39'27.6"	7.395	3.5	3.265	3.895	4.13
Bhola Sadar	Dhania	22°41'56.9"	90°39'58.9"	6.807	2.86	2.532	3.947	4.275
Bhola Sadar	Ilisha	22°45'57.6"	90°37'26.4"	5.929	2.84	3.572	3.089	2.357
Bhola Sadar	Ilisha	22°43'31.5"	90°36'56.7"	6.423	3.66	2.467	2.763	3.956
Bhola Sadar	Ilisha	22°45'26.7"	90°38'12.6"	6.047	2.95	2.705	3.097	3.342
Bhola Sadar	Ilisha	22°46'49.2"	90°38'49.3"	7.193	3.68	3.046	3.513	4.147
Bhola Sadar	Paschim Ilisha	22°44'32.1"	90°34'42.5"	6.373	2.65	2.609	3.723	3.764
Bhola Sadar	Rajapur	22°45'39.4"	90°35'51.9"	6.03	3.18	3.922	2.85	2.108
Bhola Sadar	Rajapur	22°47'01.4"	90°34'57.6"	7.98	2.38	3.374	5.6	4.606
Bhola Sadar	Uttar Dighaldi	22°37'12.1"	90°38'00.8"	7.277	2.04	1.634	5.237	5.643
Bhola Sadar	Veduria	22°41'49.1"	90°35'16.6"	6.642	3.7	2.466	2.942	4.176
Borhanuddin	Baro Manika	22°33'48.3"	90°42'57.7"	5.5	2.44	2.88	3.06	2.62
Borhanuddin	Borhanuddin Sadar	22°30'00.2"	90°42'52.7"	5.57	2.55	2.857	3.02	2.713
Borhanuddin	Borhanuddin Sadar	22°30'07.7"	90°42'55.7"	5.71	2.51	2.663	3.2	3.047
Borhanuddin	Deula	22°25'19.3"	90°41'26.2"	7.007	2.27	1.946	4.737	5.061
Borhanuddin	Gangapur	22°29'42.4"	90°40'54.2"	5.56	2.12	1.302	3.44	4.258
Borhanuddin	Hassan Nagar	22°28'21.9"	90°48'03.0"	6.22	2.18	1.691	4.04	4.529
Borhanuddin	Hassan Nagar	22°29'31.9"	90°47'38.7"	6.59	2.7	1.557	3.89	5.033

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Borhanuddin	Kachia	22°26'39.2"	90°44'25.2"	7.546	1.83	1.869	5.716	5.677
Borhanuddin	Kachia	22°25'34.6"	90°45'40.0"	7.705	2.17	1.769	5.535	5.936
Borhanuddin	Kachia	22°27'49.5"	90°44'45.1"	7.658	1.92	1.795	5.738	5.863
Borhanuddin	Kachia	22°24'50.2"	90°44'59.0"	7.57	1.75	1.44	5.82	6.13
Borhanuddin	Kutuba	22°31'47.1"	90°40'53.7"	5.95	2.25	2.192	3.7	3.758
Borhanuddin	Kutuba	22°31'13.3"	90°43'03.5"	5.79	2.55	3.388	3.24	2.402
Borhanuddin	Sachra	22°24'47.2"	90°40'38.8"	6.852	2.91	1.698	3.942	5.154
Borhanuddin	Sachra	22°28'24.1"	90°40'49.7"	6.76	1.91	2.421	4.85	4.339
Borhanuddin	Sachra	22°27'56.8"	90°41'57.0"	7.112	2.16	2.32	4.952	4.792
Borhanuddin	Sachra	22°25'26.9"	90°40'50.7"	6.887	2.72	2.079	4.167	4.808
Borhanuddin	Tabgi	22°28'50.4"	90°47'53.2"	6.31	2.06	1.897	4.25	4.413
Borhanuddin	Tabgi	22°29'37.8"	90°47'03.6"	6.21	2.19	1.585	4.02	4.625
Borhanuddin	Tabgi	22°25'58.6"	90°46'39.6"	7.875	2.59	1.515	5.285	6.36
Borhanuddin	Tabgi	22°29'11.6"	90°46'20.7"	5.93	2.11	1.463	3.82	4.467
Chakoria	Badarkhali	21°43'11.6"	91°57'10"	6.415	1.8	2.69	4.615	3.725
Chakoria	Badarkhali	21°43'4.7"	91°57'6.9"	6.395	1.4	2.16	4.995	4.235
Chakoria	Baraitali	21°48'18.4"	92°2'27.7"	5.75	1.7	3.04	4.05	2.71
Chakoria	Baraitali	21°49'53.3"	92°4'14.9"	8.52	6.1	8.05	2.42	0.47
Chakoria	Demushia	21°45'47.2"	91°57'42.8"	6.715	1.8	1.72	4.915	4.995
Chakoria	Dulahazara	21°39'52.5"	92°4'27.4"	7.13	4.8	2.96	2.33	4.17
Chakoria	Kaiarbil	21°47'20.8"	92°3'8.1"	6.68	4	4.77	2.68	1.91
Chakoria	Kakhara	21°45'15.7"	92°6'35.4"	8.14	7.1	7.75	1.04	0.39
Chakoria	Khuntakhali	21°38'0.65"	92°04'4.7"	6.79	2.82	10.12	3.97	Dry
Chakoria	Khuntakhali	21°36'30.4"	92°3'41.9"	6.55	0.1	3.32	6.45	3.23
Chakoria	Khuntakhali	21°36'49.5"	92°3'56"	6.58	3.6	2.42	2.98	4.16
Chakoria	Paurashava	21°44'55.7"	92°4'4.6"	7.84	4	4.05	3.84	3.79
Chakoria	Paurashava	21°44'5"	92°4'6.3"	7.69	3.7	3.22	3.99	4.47
Chakoria	Saharbil	21°44'58"	92°2'12.7"	8	2.1	2.36	5.9	5.64
Chakoria	Saharbil	21°45'36.4"	92°3'36.7"	7.85	3.7	1.78	4.15	6.07
Chandanaish	Bailtoli	22°09'10.4"	92°00'0.2"	5.59	4.17	4.53	1.42	1.06
Chandanaish	Bailtoli	22°09'14.3"	92°01'05.7"	5.7	4.4	4.37	1.3	1.33
Chandanaish	Barkal	22°13'02.4"	91°59'04.8"	6.842	2	2.49	4.842	4.352
Chandanaish	Barma	22°10'43.1"	91°59'00.3"	6.755	2.47	2.94	4.285	3.815
Chandanaish	Chandanaish	22°12'40.2"	92°00'52.3"	7.241	3.7	3.71	3.541	3.531
Chandanaish	Dohazari	22°09'39.0"	92°03'33.1"	4.97	3.41	5.33	1.56	Dry
Chandanaish	Kanchanbad	22°14'12.3"	92°01'21.4"	7.5	5.6	5.64	1.9	1.86
Chandanaish	Satbaria	22°10'23.6"	92°01'27.3"	6.39	4.7	3.83	1.69	2.56

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Charfession	Abu Bakarpur	22°12'17"	90°41'44"	5.17	1.9	2.5	3.27	2.67
Charfession	Abu Bakarpur	22°10'59.27"	90°41'46.25"	5.101	1.7	1.03	3.401	4.071
Charfession	Aslampur	22°13'38"	90°45'51"	5.451	2.3	2.09	3.151	3.361
Charfession	Awaijpur	22°07'30"	90°41'19"	4.997	1.7	1.91	3.297	3.087
Charfession	Char Kalmi	22°05'52"	90°39'31"	5.343	1.6	3.43	3.743	1.913
Charfession	Char Kalmi	22°07'03"	90°35'47"	7.392	2.2	1.4	5.192	5.992
Charfession	Char Kalmi	22°06'28.75"	90°38'32.37"	6.68	1.6	2.26	5.08	4.42
Charfession	Char Madraj	22°09'22.25"	90°48'24.27"	5.992	3	1.74	2.992	4.252
Charfession	Char Madraj	22°09'12.80"	90°47'18.53"	5.796	1.9	1.88	3.896	3.916
Charfession	Char Manika	22°01'44.47"	90°38'40.36"	5.92	1.7	1.05	4.22	4.87
Charfession	Char Manika	22°01'35.15"	90°40'52.24"	5.523	1.7	1.4	3.823	4.123
Charfession	Charfession	22°11'21"	90°45'33"	5.329	2.7	1.48	2.629	3.849
Charfession	Dhalchar	21°55'02.99"	90°44'55.63"	9.949	2.6	0.69	7.349	9.259
Charfession	Hazariganj	22°05'32"	90°46'30"	5.925	1.6	2.51	4.325	3.415
Charfession	Jinnagar	22°11'17.25"	90°45'19.61"	6.51	1.2	1.4	5.31	5.11
Charfession	Kukri Mukri	21°55'15.04"	90°38'16.97"	13.481	1.6	2.9	11.881	10.581
Charfession	Kukri Mukri	21°57'17"	90°40'37"	12.661	2	1.74	10.661	10.921
Charfession	Nazrulnagar	22°02'12.56"	90°36'37.06"	5.95	1.8	1.43	4.15	4.52
Charfession	Nilkomol	22°13'20"	90°40'02"	6.71	1.7	1.03	5.01	5.68
Charfession	Nurabad	22°09'39"	90°39'01"	5.077	1.9	-0.44	3.177	5.517
Charfession	Osmanganj	22°14'38"	90°41'54"	6.99	1.6	2.28	5.39	4.71
Charfession	Rasulpur	22°03'20.82"	90°39'05.02"	5.743	2	1.74	3.743	4.003
Companiganj	Char Elahi	22°45'11.8"	91°15'42.71"	11.59	4.71	3.758	6.88	7.832
Companiganj	Char Elahi	22°44'37.00"	91°14'50.45"	11.06	4.52	3.58	6.54	7.48
Companiganj	Char Fakira	22°47'47.22"	91°16'7.20"	11.539	4.78	3.437	6.759	8.102
Companiganj	Char Fakira	22°49'0.94"	91°15'9.01"	10.16	4.72	4.169	5.44	5.991
Companiganj	Char Fakira	22°48'04.00"	91°15'23.98"	10.44	4.18	3.617	6.26	6.823
Companiganj	Char Fakira	22°48'45.29"	91°14'40.61"	9.992	5.1	4.191	4.892	5.801
Companiganj	Char Hazari	22°52'26.50"	91°18'31.42"	10.54	4.7	3.635	5.84	6.905
Companiganj	Char Parbati	22°53'55.87"	91°19'47.06"	9.4	4.5	3.601	4.9	5.799
Companiganj	Char Parbati	22°52'45.6"	91°18'46.86"	11.156	4.62	3.886	6.536	7.27
Companiganj	Musapur	22°49'29.83"	91°18'44.55"	11.93	4.56	3.29	7.37	8.64
Companiganj	Musapur	22°48'44.81"	91°18'40.25"	11.84	4.5	3.455	7.34	8.385
Companiganj	Rampur	22°49'16.40"	91°17'30.22"	11.5	4.86	4.056	6.64	7.444
Companiganj	Rampur	22°50'53.96"	91°18'00.07"	10.64	5.31	3.252	5.33	7.388

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Cox's Bazar Sadar	Bharuakhali	21°29'56.2"	92°2'39.7"	4.91	2.5	10.94	2.41	Dry
Cox's Bazar Sadar	Idgaon	21°33'25.2"	92°3'41.1"	7.56	4.45	1.53	3.11	6.03
Cox's Bazar Sadar	Islamabad	21°33'13.2"	92°3'16.9"	7.27	4.42	2.25	2.85	5.02
Cox's Bazar Sadar	Islampur	21°35'18.6"	92°3'52"	7.36	3.82	11.37	3.54	Dry
Cox's Bazar Sadar	Jalalabad	21°33'25.2"	92°3'51.9"	7.26	4.15	2.98	3.11	4.28
Cox's Bazar Sadar	Jalalabad	21°32'21.7"	92°2'50.9"	6.358	2.3	0.82	4.058	5.538
Cox's Bazar Sadar	Jhilwanja	21°25'36.7"	92°3'14.5"	4.52	3.4	2.38	1.12	2.14
Cox's Bazar Sadar	Khurushkul	21°28'7.8"	91°59'42.4"	5.62	4.1	8.95	1.52	Dry
Cox's Bazar Sadar	Khurushkul	21°28'08.32"	91°59'43.54"	5.62	3.2	9.27	2.42	Dry
Cox's Bazar Sadar	Patali Machhuakhali	21°26'39.6"	92°1'39.4"	3.8	2.3	15.28	1.5	Dry
Cox's Bazar Sadar	Patali Machhuakhali	21°27'16.7"	92°2'4.2"	3.51	2.4	6.28	1.11	Dry
Cox's Bazar Sadar	Paurashava	21°26'1.6"	91°59'28.5"	4.31	2.34	19.28	1.97	Dry
Cox's Bazar Sadar	Paurashava	21°26'38.3"	91°58'13.5"	6.433	3.11	6.83	3.323	Dry
Cox's Bazar Sadar	Paurashava	21°26'20.3"	91°59'29.5"	6.107	3.23	7.57	2.877	Dry
Dacope	Bajua	22°31'43.62"	89°34'06.42"	3.05	1.39	1.986	1.66	1.064
Dacope	Banishanta	22°28'40.38"	89°34'36.6"	3.2	1.96	-	1.24	-
Dacope	Banishanta	22°28'24.42"	89°32'30"	4.08	4.02	2.44	0.06	1.64
Dacope	Banishanta	22°29'26.1"	89°34'51.12"	3.2	1.9	-	1.3	-
Dacope	Banishanta	22°29'35.06"	89°29'27.49"	3 2	1.566	1.55	1.634	1.65
Dacope	Chalna	22°38'38.46"	89°28'42.3"	3.49	2.71	2.05	0.78	1.44
Dacope	Dacope	22°33'31.2"	89°29'54.6"	2.75	1.31	2.38	1.44	0.37
Dacope	Kailasganj	22°29'3'	89°30'59.46"	3.2	2.363	1.46	0.837	1.74
Dacope	Kailasganj	22°30'22.8"	89°31'24.3"	3.1	1.44	2.043	1.66	1.057
Dacope	Kamarkhola	22°31'59.76"	89°29'1.14"	2.25	1.73	2.44	0.52	Dry
Dacope	Kamarkhola	22°33'13.56"	89°27'47.03"	2.82	2.01	1.863	0.81	0.957
Dacope	Pankhali	22°37'32.46"	89°27'45.18"	1.41	1.341	2.298	0.069	Dry
Dacope	Sutarkhali	22°30'8.4"	89°27'30.06"	1.61	1.4	1.915	0.21	Dry
Dacope	Sutarkhali	22°26'10.32"	89°26'48.78"	3.49	1.52	2.525	1.97	0.965
Dacope	Sutarkhali	22°29'58.74"	89°28'48.54"	2.5	1.94	1.73	0.56	0.77
Dacope	Tildanga	22°30'58.24"	89°25'47.12"	3.11	1.49	1.377	1.62	1.733
Dacope	Tildanga	22°31'10.2"	89°26'09.6"	1.61	1.265	2.19	0.345	Dry
Dashmina	Alipur	22°14'12"	90°30'14"	4.746	1.644	0.47	3.102	4.276
Dashmina	Banshbaria	22°18'02"	90°36'18"	5.39	1.89	-	3.5	-
Dashmina	Banshbaria	22°19'14.94"	90°36'31.28"	5.55	2.094	-	3.456	-
Dashmina	Batagi Sankipura	22°20'36"	90°29'41"	3.997	1.656	1.51	2.341	2.487

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Dashmina	Batagi Sankipura	22°20'57.53"	90°31'58.82"	4.177	1.433	-	2.744	-
Dashmina	Dasmina	22°14'41"	90°33'23"	5.448	2.559	-	2.889	-
Dashmina	Ranogopaldi	22°12'33.25"	90°31'27.03"	4.138	1.544	1.12	2.594	3.018
Dashmina	Ronogopaldi	22°09'08.37"	90°33'41"	7.883	1.598	1.02	6.285	6.863
Daulatkhan	Char Khalifa	22°36'26.4"	90°40'54.3"	7.394	2.12	2.7	5.274	4.694
Daulatkhan	Char Khalifa	22°36'44.2"	90°41'54.5"	7.425	2.13	2.278	5.295	5.147
Daulatkhan	Char Khalifa	22°36'19.2"	90°42'56.5"	7.522	3.82	2.199	3.702	5.323
Daulatkhan	Char Khalifa	22°36'10.2"	90°41'23.0"	7.424	2.2	1.36	5.224	6.064
Daulatkhan	Char Pata	22°38'35.9"	90°41'14.6"	10.98	4.1	2.71	6.88	8.27
Daulatkhan	Char Pata	22°36'57.6"	90°42'32.9"	11.03	3.22	2.69	7.81	8.34
Daulatkhan	Char Pata	22°37'11.3"	90°42'10.9"	11.14	2.59	2.597	8.55	8.543
Daulatkhan	Hazipur	22°34'14.9"	90°51'22.9"	10.94	2.94	3.476	8	7.464
Daulatkhan	Sayedpur	22°33'48.3"	90°44'43.8"	6	2.52	2.16	3.48	3.84
Daulatkhan	Sayedpur	22°34'35.3"	90°44'43.5"	6.06	2.56	2.841	3.5	3.219
Daulatkhan	Sayedpur	22°34'49.6"	90°43'46.7"	7.64	2.94	2.678	4.7	4.962
Daulatkhan	Sayedpur	22°33'13.5"	90°45'13.9"	6.89	2.29	2.298	4.6	4.592
Daulatkhan	Sayedpur	22°34'33.3"	90°44'59.3"	6.12	1.76	2.262	4.36	3.858
Daulatkhan	Sayedpur	22°35'30.4"	90°44'51.6"	6.31	2.27	1.707	4.04	4.603
Daulatkhan	Uttar Joynagar	22°37'22.2"	90°40'04.7"	7.318	4.12	1.624	3.198	5.694
Daulatkhan	Uttar Joynagar	22°35'33.9"	90°41'25.2"	7.46	1.55	1.56	5.91	5.9
Daulatkhan	Uttar Joynagar	22°38'15.1"	90°40'19.9"	7.261	3.25	1.736	4.011	5.525
Daulatkhan	Uttar Joynagar	22°34'36.9"	90°39'41.0"	7.419	2.73	2.208	4.689	5.211
Feni Sadar	Baligoan	22°59'28.0"	91°22'14.0"	8.136	5.24	4.5	2.896	3.636
Feni Sadar	Kazirbug	23°02'21.0"	91°25'15.0"	7.425	5.7	5.27	1.725	2.155
Galachipa	Amkhola	22°15'33"	90°20'14"	3.905	2.535	1.58	1.37	2.325
Galachipa	Amkhola	22°14'41.16"	90°23'25.61"	7.67	4.217		3.453	
Galachipa	Amkhola	22°16'24.6"	90°24'08.8"	7.67	4.217	2.49	3.453	5.18
Galachipa	Bakulbaria	22°17'00"	90°29'01"	4.128	1.598	1.75	2.53	2.378
Galachipa	Bakulbaria	22°18'01"	90°29'06"	3.988	1.677	-	2.311	-
Galachipa	Bara Baisdia	21°58'03"	90°21'46"	6.201	1.956	-	4.245	-
Galachipa	Bara Baisdia	21°57'1.01"	90°21'23.00"	6.333	1.892	2.92	4.441	3.413
Galachipa	Char Biswas	22°01'9.48"	90°30'30"	5.525	1.994	1.77	3.531	3.755
Galachipa	Char Biswas	22°03'22.00"	90°32'18.71"	6.103	2.794	3.09	3.309	3.013
Galachipa	Char Kajol	22°05'27.67"	90°31'05.67"	6.97	2.443	4.05	4.527	2.92

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Galachipa	Char Montaj	21°52'11.21"	90°31'15.20"	8.86	2.079	1.33	6.781	7.53
Galachipa	Char Montaj	21°57'57"	90°34'49"	6.393	1.71	3.13	4.683	3.263
Galachipa	Char Montaj	21°56'27.49"	90°34'38.89"	6.126	1.491	3.06	4.635	3.066
Galachipa	Chiknikandi	22°12'27.20"	90°29'2.50"	4.4	1.506	2.45	2.894	1.95
Galachipa	Chotto Baisdia	22°01'05.99"	90°25'41.99"	6.503	2.285	1.94	4.218	4.563
Galachipa	Dakua	22.09083	90.51833	7.043	2.569		4.474	
Galachipa	Dakua	22°10'14.99"	90°26'2.00"	5.073	1.703	2	3.37	3.073
Galachipa	Galachipa	22°05'29.00"	90°25'05.99"	4.44	1.89	2.276	2.55	2.164
Galachipa	Galachipa	22°07'31"	90°24'27"	3.878	1.895	1.6	1.983	2.278
Galachipa	Galachipa	22°09'34"	90°26'16"	4.109	2.36		1.749	
Galachipa	Galachipa Pourashaba	22°10'09'	90°24'41"	7.92	3.394		4.526	
Galachipa	Gazalia	22°14'29.08"	90°25'07.02"	7.67	3.371	1.71	4.299	5.96
Galachipa	Golkhali	22°08'53"	90°23'11"	5.162	1.777	1.47	3.385	3.692
Galachipa	Panpotty	22°05'55.70"	90°26'16.80"	3.858	1.341	2.12	2.517	1.738
Galachipa	Panpotty	22°06'15.49"	90°26'54.93"	3.867	1.982		1.885	
Galachipa	Rangabali	21°56'27.58"	90°25'00.57"	7.027	1.818		5.209	
Hatiya	9 .Burirchar	22°11'15.7"	91°7'34.8"	6.577	1.9	4.492	4.677	2.085
Hatiya	Burirchar	22°11'20.73"	91°8'56.99"	6.837	1.8	4.258	5.037	2.579
Hatiya	Burirchar	22°14'26.42"	91°9'43.58"	7.576	1.9	4.296	5.676	3.28
Hatiya	Burirchar	22°15'1.86"	91°6'34.88"	8.602	1.6	4.205	7.002	4.397
Hatiya	Burirchar	22°12'38.23"	91°9'52.56"	7.101	2.2	5.069	4.901	2.032
Hatiya	Burirchar	22°11'52.44"	91°7'59.90"	6.597	2.4	4.86	4.197	1.737
Hatiya	Burirchar	22°12'1.66"	91°8'1.93"	6.699	1.9	4.663	4.799	2.036
Hatiya	CharIswar	22°16'12.88"	91°9'45.16"	9.191	2.4	3.538	6.791	5.653
Hatiya	Charking	22°21'37.94"	91°6'16.57"	9.697	2.1	2.261	7.597	7.436
Hatiya	Charking	22°18'43.28"	91°4'58.18"	9.476	1.9	1.158	7.576	8.318
Hatiya	Charking	22°19'9.23"	91°4'57.95"	9.309	3.3	1.509	6.009	7.8
Hatiya	Charking	22°19'52.54"	91°5'59.97"	9.478	2.3	2.427	7.178	7.051
Hatiya	Charking	22°20'52.6"	91°6'9.27"	9.703	1.9	1.597	7.803	8.106
Hatiya	Charking	22°19'52.54"	91°5'59.97"	9.478	2.3	2.427	7.178	7.051
Hatiya	Charking	22°20'52.6"	91°6'9.27"	9.703	1.9	1.597	7.803	8.106
Hatiya	Charking	22°18'48.69"	91°7'7.99"	9.316	2.2	4.197	7.116	5.119
Hatiya	Charking	22°18'31.86"	91°7'50.58"	9.331	1.8	3.591	7.531	5.74
Hatiya	Charking	22°19'39.72"	91°6'16.72"	7.635	1.9	1.304	5.735	6.331
Hatiya	Charking	22°20'15.23"	91°7'9.7"	9.564	1.5	4.474	8.064	5.09
Hatiya	Charking	22°21'17.36"	91°6'2.72"	9.707	2.6	1.902	7.107	7.805
Hatiya	Charking	22°19'30.19"	91°5'23.85"	9.383	1.9	2.345	7.483	7.038
Hatiya	Jahajmara	22°7'42"	91°2'47.87"	12.724	2.2	3.281	10.524	9.443

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Hatiya	Jahajmara	22°7'9.17"	91°3'35.21"	6.389	2.2	2.557	4.189	3.832
Hatiya	Jahajmara	22°9'43.89"	91°4'10.81"	6.292	1.6	1.238	4.692	5.054
Hatiya	Jahajmara	22°6'27.24"	91°3'34.72"	13.638	1.9	1.908	11.738	11.73
Hatiya	Jahajmara	22°9'45.19"	91°6'13.18"	6.366	2.1	2.222	4.266	4.144
Hatiya	Jahajmara	22°8'33.75"	91°4'7.77"	6.319	1.8	2.578	4.519	3.741
Hatiya	Jahajmara	22°9'16.18"	91°3'43.75"	8	1.8	2.221	6.2	5.779
Hatiya	Nalchira	22°21'58.5"	91°7'18.6"	9.843	2.2	3.545	7.643	6.298
Hatiya	Nijhumdwip	22°2'27.79"	90°58'57.87"	8.777	2	0.271	6.777	8.506
Hatiya	Pourashava	22°14'52.87"	91°8'42.13"	8.857	1.5	4.458	7.357	4.399
Hatiya	Pourashava	22°15'50.8"	91°7'24.2"	8.79	1.9	4.044	6.89	4.746
Hatiya	Pourashava	22°17'37.28"	91°8'38.36"	9.262	2.1	5.356	7.162	3.906
Hatiya	Pourashava	22°15'3.67"	91°8'11.72"	8.838	1.5	4.545	7.338	4.293
Hatiya	Pourashava	22°17'28.34"	91°7'31.55"	9.092	1.7	4.494	7.392	4.598
Hatiya	Shukchar	22°22'28.7"	91°4'39.94"	9.753	2	1.688	7.753	8.065
Hatiya	Shukchar	22°22'2.39"	91°4'44.08"	9.919	2.4	2.369	7.519	7.55
Hatiya	Sonadia	22°12'16.02"	91°4'17.23"	6.438	1.8	5.081	4.638	1.357
Hatiya	Sonadia	22°15'34.22"	91°5'14.81"	8.904	1.5	5.34	7.404	3.564
Hatiya	Sonadia	22°10'39.48"	91°4'45.58"	6.273	1.7	4.835	4.573	1.438
Hatiya	Sonadia	22°12'14.74"	91°3'57.26"	6.435	1.7	4.386	4.735	2.049
Hatiya	Sonadia	22°13'40.81"	91°4'21.17"	9.558	1.9	5.559	7.658	3.999
Hatiya	tomuraddi	22°15'59.94"	91°5'20.7"	8.936	2	5.268	6.936	3.668
Kabirhat	Chaprashirhat	22°48'37.0"	91°13'10.0"	9.843	5.14	2.811	4.703	7.032
Kabirhat	Chaprashirhat	22°48'58.0"	91°14'29.0"	9.96	4.73	2.378	5.23	7.582
Kalapara	Chakamoya	22°01'08.00"	90°11'11.00"	3.751	2.114	2.23	1.637	1.521
Kalapara	Dhankhali	22°04'14.99"	90°21'29.02"	6.86	3.438	1.92	3.422	4.94
Kalapara	Dhankhali	22°05'17.02"	90°19'58.02"	6.494	1.676	1.56	4.818	4.934
Kalapara	Dhankhali	22°02'34.01"	90°18'15.01"	6.072	1.926	2.92	4.146	3.152
Kalapara	Dhulashar	21°51'25.99"	90°12'02.02"	4.395	2.116	1.92	2.279	2.475
Kalapara	Dhulashar	21°51'16.98"	90°15'12.14"	4.872	1.919	1.77	2.953	3.102
Kalapara	Khaprabhanga	21°52'59.02"	90°11'16.01"	5.32	1.132	2.21	4.188	3.11
Kalapara	Khaprabhanga	21.85917	90.12556	3.728	4.167	-	-0.439	-
Kalapara	Lalua	21.95722	90.28861	7.145	1.775	-	5.37	-
Kalapara	Lalua	21°54'00.50"	90°15'54.50"	6.905	1.52	2.32	5.385	4.585
Kalapara	Latachapli	21.84389	90.16694	2.206	1.877	-	0.329	-
Kalapara	Latachapli	21°49'34.33"	90°07'58.28"	3.09	1.93	2.11	1.16	0.98
Kalapara	Latachapli	21.84306	90.15361	2.356	1.807	-	0.549	-
Kalapara	Mithaganj	21°55'12.28"	90°11'48.45"	5.548	1.683	2.081	3.865	3.467
Kalapara	Nilganj	21.95786	90.20683	6.495	1.788	-	4.707	-
Kalapara	Nilganj	21°58'13.58"	90°12'22.10"	6.472	1.981	2.27	4.491	4.202
Kalapara	Nilganj	21°57'24.80"	90°11'6.90"	6.142	2.45	2.51	3.692	3.632
Kalapara	Nilganj	21°56'25.01"	90°9'11.41"	5.79	1.857	2.23	3.933	3.56
Kalapara	Tiakhali	22°01'0.19"	90°15'36.11"	5.215	1.591	2.4	3.624	2.815
Komol Nagar	Char Falkon	22°43'52"	90°51'53"	7.657	4.428	-	3.229	-
Komol	Char Larencha	22°45'12"	90°49'09"	7.61	3.293	-	4.317	-

Nagar								
Komol Nagar	Char Larencha	22°49'00"	90°50'49"	7.295	3.426	-	3.869	-
Komol Nagar	Char Martin	22°50'49"	90°48'48"	8.579	3.48	4.675	5.099	3.904
Komol Nagar	Patari Hat	22°41'39"	90°50'30"	10.134	3.201	4.083	6.933	6.051
Komol Nagar	Patari Hat	22°42'49"	90°51'36"	7.671	4.033	-	3.638	-
Komol Nagar	Shahaber Hat	22°45'52"	90°50'36"	6.629	3.498	-	3.131	-
Komol Nagar	Shahaber Hat	22°46'02"	90°49'51"	6.751	2.991	5.064	3.76	1.687
Koyra	Amadi	22°29'17.36"	89°19'27.91"	3.602	1.142	1.229	2.46	2.373
Koyra	Amadi	22°27'27.48"	89°16'39.93"	3.1	2.11	2.38	0.99	0.72
Koyra	Amadi	22°30'07.58"	89°17'17.02"	3.598	0.818	1.32	2.78	2.278
Koyra	Amadi	22°29'51.93"	89°20'16.47"	3.6	1.993	1.905	1.607	1.695
Koyra	Bagali	22°26'59.41"	89°16'14.30"	4.905	3.455	2.768	1.45	2.137
Koyra	Bagali	22°26'47.94"	89°15'01.76"	3.1	1.239	1.87	1.861	1.23
Koyra	Bagali	22°26'23.46"	89°15'59.89"	3.098	1.158	-	1.94	-
Koyra	Dakhin Bedkashi	22°14'12.51"	89°19'09.04"	2.714	1.219	3.06	1.495	Dry
Koyra	Koyra	22°20'25.36"	89°15'43.66"	3.397	1.367	3.06	2.03	0.337
Koyra	Koyra	22°20'17.76"	89°19'29.74"	2.366	1.446	-	0.92	-
Koyra	Koyra	22°21'13.14"	89°18'51.79"	1.743	1.323	1.916	0.42	Dry
Koyra	Maharajpur	22°22'10.57"	89°16'11.94"	3.465	1.255	1.938	2.21	1.527
Koyra	Maharajpur	22°22'52.14"	89°18'34.39"	2.205	1.895	1.656	0.31	0.549
Koyra	Maharajpur	22°24'3.39"	89°18'13.19"	2.531	1.541	-	0.99	-
Koyra	Maheshwaripur	22°24'31.5"	89°19'22.14"	2.97	1.274	0.815	1.696	2.155
Koyra	Maheshwaripur	22°27'29.10"	89°20'13.00"	3.6	1.02	1.816	2.58	1.784
Koyra	Moheswaripur	22°26'48.25"	89°20'48.60"	3.559	0.949	1.684	2.61	1.875
Koyra	Moheswaripur	22°28'1.90"	89°21'0.43"	3.657	1.107	1.755	2.55	1.902
Koyra	Moheswaripur	22°25'43.71"	89°20'12.62"	3.199	1.229	-	1.97	-
Koyra	Uttar Bedkashi	22°17'47.53"	89°18'13.65"	3.316	1.166	1.082	2.15	2.234

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Koyra	Uttar Bedkashi	22°15'37.45"	89°19'21.83"	2.763	1.006		1.757	
Kutubdia	Ali Akbar Dail	21°46'31.4"	91°51'15.6"	10.558	2.5	2.868	8.058	
Kutubdia	Ali Akbar Dail	21°47'50.1"	91°50'59.1"	9.211	2.5	4.631	6.711	4.58
Kutubdia	Baraghope	21°48'19.2"	91°52'07.5"	9.479	2.7	2.608	6.779	
Kutubdia	Baraghope	21°48'32.9"	91°51'19.9"	9.005	2.2	3.817	6.805	5.188
Kutubdia	Baraghope	21°49'02.3"	91°51'08.7"	9.878	3.8	4.48	6.078	5.398
Kutubdia	Kaiyarbil	21°50'26.1"	91°51'28.2"	9.112	2.1	3.535	7.012	5.577
Kutubdia	Kaiyarbil	21°50'11.0"	91°52'22.0"	9.21	2.8	4.294	6.41	4.916
Kutubdia	Kaiyarbil	21°50'02.7"	91°51'17.1"	9.087	2.4	3.542	6.687	5.545
Kutubdia	Lemshikhali	21°51'12.3"	91°52'36.8"	9.315	2.1	3.644	7.215	5.671
Kutubdia	Lemshikhali	21°52'17.4"	91°52'48.3"	9.573	2	3.045	7.573	6.528
Kutubdia	Lemshikhali	21°50'36.5"	91°52'06.1"	9.22	1.8	3.184	7.42	6.036
Kutubdia	Lemshikhali	21°52'27.9"	91°53'38.4"	9.816	2.8	3.563	7.016	6.253
Kutubdia	Lemshikhali	21°51'24.9"	91°52'42.0"	9.353	2	3.263	7.353	6.09
Kutubdia	Lemshikhali	21°51'24.8"	91°52'37.9"	9.353	2.3	3.41	7.053	5.943
Kutubdia	Uttar Dhurung	21°53'54.0"	91°53'07.2"	9.921	2.2	3.165	7.721	6.756
Kutubdla	Uttar Dhurung	21°54'50.7"	91°52'45.9"	11.985	2.2	3.867	9.785	
Kutubdia	Uttar Dhurung	21°53'22.2"	91°52'10.8"	9.629	2	3.528	7.629	6.101
Kutubdia	Uttar Dhurung	21°53'35.8"	91°53'32.9"	9.13	3.8	4.808	5.33	4.322
Kutubdia	Uttar Dhurung	21°54'09.5"	91°51'16.6"	9.277	2.1	2.626	7.177	6.651
Kutubdia	Uttar Dhurung	21°53'29.5"	91°51'26.9"	9.535	2.2	3.487	7.335	6.048
Lakshmipur Sadar	Bhabanigonj	22°49'42"	90°50'47"	7.226	3.521	3.497	3.705	
Lakshmipur Sadar	Char Ruhita	22°55'38"	90°47'05"	7.755	4.45	-	3.305	-
Lakshmipur Sadar	Char Ruhita	22°57'0.4"	90°46'14.4"	6.891	3.908	-	2.983	-
Lakshmipur Sadar	Dallal Bazar	22°58'41.7"	90°47'1.5"	5.441	3.473	-	1.968	-
Lakshmipur Sadar	Shak Char	22°53'07"	90°47'22"	9.3	3.62	4.14	5.68	
Lakshmipur Sadar	Shak Char	22°54'28"	90°47'54"	8.47	3.89	4.367	4.58	4.103
Lakshmipur Sadar	Shak Char	22°54'09"	90°49'24"	7.12	3.356	-	3.764	
Lakshmipur Sadar	Shak Char	22°54'20"	90°49'48"	6.914	3.363	-	3.551	-

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Lakshmipur Sadar	Tewazugonj	22°51'54"	90°52'18"	6.873	3.821	4.018	3.052	2.855
Lakshmipur Sadar	Toom Char	22°52'16"	90°48'59"	8.371	3.335	3.277	5.036	
Lakshmipur Sadar	Toom Char	22°53'21"	90°48'38"	7.913	3.236	3.844	4.677	4.069
Lalmohon	Badarpur	22°23'06.05"	90°41'38.60"	7.03	2.7	2.229	4.33	4.801
Lalmohon	Badarpur	22°22'29.03"	90°42'1.96"	7.13	2.3	1.891	4.83	5.239
Lalmohon	Charvuta	22°18'05"	90°44'59"	7.41	2	3.41	5.41	4
Lalmohon	Charvuta	22°19'31"	90°46'32"	7.63	2	2.107	5.63	5.523
Lalmohon	Dhaligournagar	22°16'56"	90°48'55"	5.702	2.6	-0.485	3.102	6.187
Lalmohon	Dhaligournagar	22°20'47"	90°46'42"	7.69	2.1	4.163	5.59	3.527
Lalmohon	Dhaligournagar	22°17'22"	90°48'15"	7.78	1.8	0.7	5.98	7.08
Lalmohon	Dhaligournagar	22°18'38"	90°48'29"	7.84	2.7	0.395	5.14	
Lalmohon	Dhaligournagar	22°19'51"	90°48'14"	7.85	1.9	4.732	5.95	3.118
Lalmohon	Forajgong	22°18'56"	90°41'15"	6.92	1.6	0.04	5.32	
Lalmohon	Kalma	22°21'07"	90°42'43"	7.16	2.2	1.808	4.96	5.352
Lalmohon	Kalma	22°21'28"	90°44'13"	7.37	2.5	2.287	4.87	5.083
Lalmohon	Kalma	22°23'25"	90°45'53"	7.66	2.2	2.831	5.46	4.829
Lalmohon	Lalmohon	22°20'27.73"	90°44'0.85"	7.32	2.3	2.45	5.02	4.87
Lalmohon	Lord Hardinge	22°16'49"	90°50'03"	8.47	2.3	1.321	6.17	
Lalmohon	Ramganj	22°16'02"	90°45'36"	5.445	2.3	4.45	3.145	0.995
Lalmohon	Ramganj	22°22'39"	90°46'06"	7.65	2.2	1.738	5.45	
Lalmohon	Ramganj	22°16'39"	90°44'56"	5.359	2.8	5.268	2.559	0.091
Lalmohon	Ramganj	22°15'27.84"	90°44'40.08"	7.34	2.9	4.283	4.44	3.057
Lalmohon	West Char Umed	22°17'16"	90°42'13"	7	1.6	0.519	5.4	6.481
Maheshkhali	Bara Maheshkhali	21°31'44.6"	91°56'46.6"	5.76	4.4	4.221	1.36	1.539
Maheshkhali	Bara Maheshkhali	21°32'44.2"	91°55'56.3"	4.42	2.45	7.576	1.97	Dry
Maheshkhali	Bara Maheshkhali	21°32'17.0"	91°56'23.8"	4.79	2.45	5.125	2.34	Dry
Maheshkhali	Chhota Maheshkhali	21°32'31.9"	91°58'44.6"	5.49	2.76	13.896	2.73	Dry
Maheshkhali	Dhalghata	21°41'47.0"	91°52'14.0"	12.294	1.7	2.861	10.594	9.433
Maheshkhali	Dhalghata	21°40'54.6"	91°51'53.3"	8.265	1.8	2.983	6.465	5.282

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Maheshkhali	Gorakghata	21°31'17.8"	91°57'38.5"	8.285	3.6	3.52	4.685	4.765
Maheshkhali	Hoanak	21°37'56.2"	91°55'10.2"	9.233	3.35	7.077	5.883	2.156
Maheshkhali	Hoanak	21°34'4.1"	91°55'32.5"	8.055	2.97	9.138	5.085	Dry
Maheshkhali	Kalarmarchara	21°39'50.0"	91°55'16.0"	9.347	3.17	7.455	6.177	1.892
Maheshkhali	Kutubjom	21°30'07.0"	91°52'12.2"	7.631	2.5	3.541	5.131	4.09
Maheshkhali	Maheshkhali Sadar	21°31'22.6"	91°57'20.7"	5.93	3.3	3.605	2.63	2.325
Maheshkhali	Matarbari	21°42'37.1"	91°52'46.6"	8.036	2.5	3.169	5.536	4.867
Maheshkhali	Matarbari	21°43'33.3"	91°52'54.6"	7.931	2.3	3.387	5.631	4.544
Maheshkhali	Matarbari	21°44'00.9"	91°54'17.1"	8.048	4.25	3.147	3.798	4.901
Maheshkhali	Matarbari	21°44'29.6"	91°54'11.9"	8.012	2.1	3.835	5.912	4.177
Maheshkhali	Shaplapur	21°37'47.0"	91°58'46.0"	7.295	3.14	4.555	4.155	2.74
Maheshkhali	Shaplapur	21°38'50.9"	91°58'00.4"	4.47	2.72	7.007	1.75	Dry
Maheshkhali	Shaplapur	21°38'45.3"	91°58'20.2"	9.062	3.1	5.133	5.962	3.929
Manpura	1 No Manpura	22°19'12.9"	90°58'49.9"	10.711	2.2	3.242	8.511	
Manpura	1 No Manpura	22°9'42"	90°56'21.3"	8.241	1.5	1.989	6.741	6.252
Manpura	2 No Hazir hat	22°16'7.5"	90°58'27.7"	13.224	2	3.371	11.224	9.853
Manpura	2 No Hazirhat	22°17'20.5"	90°58'27.7"	9.681	2.2	2.767	7.481	6.914
Manpura	Hazirhat	22°11'45.5"	90°58'50.3"	12.646	1.7	2.413	10.946	10.233
Manpura	Hazirhat	22°14'52.3"	90°58'54.4"	13.155	1.9	2.437	11.255	10.718
Manpura	Hazirhat	22°14'33.9"	90°58'9.1"	9.492	1.6	3.054	7.892	6.438
Manpura	Hazirhat	22°15'26.8"	90°57'54.1"	15.284	3	3.228	12.284	12.056
Manpura	Manpura	22°17'37.4"	90°59'4"	11.071	2.1	4.045	8.971	7.026
Manpura	N. Shakuchia	22°12'3.2"	90°57'14.5"	8.74	1.6	3.269	7.14	5.471
Manpura	Shakuchia	22°12'40.2"	90°57'30.6"	8.855	1.8	3.079	7.055	5.776
Manpura	Shakuchia	22°8'19.7"	90°56'35.3"	8.05	1.5	2.564	6.55	5.486
Manpura	Shakuchia	22°10'18.1"	90°56'55.6"	8.336	1.7	2.081	6.636	6.255
Manpura	Shakuchia	22°11'0.15"	90°56'8.14"	8.495	1.7	3.207	6.795	5.288
Manpura	Shakuchia	22°8'42.1"	90°55'41.2"	8.057	1.8	3.124	6.257	4.933
Manpura	Shakuchia	22°9'39.7"	90°57'2.2"	8.207	1.8	2.709	6.407	5.498
Manpura	Shakuchia	22°12'1.4"	90°56'23.7"	8.717	1.4	2.224	7.317	6.493
Manpura		22°18'7.8"	90°58'55.1"	10.651	2.1	3.61	8.551	7.041
Mathbaria	Amragachia	22°15'21"	89°56'43"	4.653	2.431	1.45	2.222	3.203
Mathbaria	Baramasua	22°18'36"	89°53'52"	5.252	1.959	0.27	3.293	4.982
Mathbaria	Baramasua	22°19'48"	89°53'51"	5.5115	2.38	-	3.1315	-
Mathbaria	Betmore	22°16'05"	89°54'43"	4.605	2.009	-	2.596	-
Mathbaria	Betmore	22°16'25"	89°54'13"	4.693	1.683	1.08	3.01	3.613

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Mathbaria	Betmore	22°15'48"	89°52'53"	6.21	2.55	1.3	3.66	4.91
Mathbaria	Daudkhali	22°21'41"	90°02'03"	4.893	1.826	1.65	3.067	3.243
Mathbaria	Daudkhali	22°21'40"	90°02'10"	4.892	1.855	-	3.037	-
Mathbaria	Dhanisafa	22°21'42"	89°56'06"	5.758	2.204	0.42	3.554	
Mathbaria	Guilshakhali	22°12'40"	89°59'10"	4.492	1.438	TBC	3.054	-
Mathbaria	Guilshakhali	22°13'46"	89°59'52"	4.491	1.882	-	2.609	-
Mathbaria	Sapleza	22°11'36"	89°56'12"	5.287	1.76	3	3.527	2.287
Mathbaria	Tikikata	22°17'48"	90°01'35"	2.87	2.085	4.66	0.785	Dry
Mathbaria	Tikikata	22°21'21"	89°58'41"	5.072	1.462	-	3.61	-
Mathbaria	Tushkhali	22°20'29"	89°55'01"	5.771	2.048	1.29	3.723	4.481
Mirsharai	Esakhali	22°48'26.7"	91°28'11.6"	14.728	4.5	4.184	10.228	10.544
Mirsharai	Esakhali	22°48'57.4"	91°29'36.1"	13.192	5.4	4.089	7.792	9.103
Mirsharai	Esakhali	22°49'13"	91°28'49.6"	14.663	5	4.102	9.663	10.561
Mirsharai	Haith Kandi	22°41'8.4"	91°35'7.9"	12.395	5.6	3.909	6.795	8.486
Mirsharai	Katachora	22°49'14.1"	91°30'42.2"	12.773	4.8	3.425	7.973	9.348
Mirsharai	Katachora	22°48'0.2"	91°30'49.1"	12.837	5.4	5.064	7.437	7.773
Mirsharai	Mayani	22°44'2.40"	91°32'32.03"	12.128	4	3.8	8.128	8.328
Mirsharai	Mithanala	22°46'48.52"	91°30'56.19"	12.89	4.8	7.005	8.09	5.885
Mirsharai	Mogadia	22°44'48.4"	91°33'25.3"	12.634	4.5	4.865	8.134	7.769
Mirsharai	Shaherkhali	22°42'48.4"	91°33'55.2"	12.624	4	3.643	8.624	8.981
Mongla	Chandpai	22°26'32.34"	89°36'37.74"	4.669	3.01	1.87	1.659	2.799
Mongla	Chilla	22°25'33.3"	89°39'18.36"	4.436	1.57	1.698	2.866	
Mongla	Chilla	22°26'18.96"	89°38'19.68"	3.919	1.871	-	2.048	-
Mongla	Chilla	22°22'53.83"	89°38'02.66"	4.519	2.02	-	2.499	-
Mongla	Mithakhali	22°27'10.26"	89°41'53.94"	4.069	2.11	-	1.959	-
Mongla	Mithakhali	22°26'56.7"	89°42'32.22"	4.138	2.071	2.216	2.067	1.922
Mongla	Sonailtala	22°31'37.14"	89°38'44.58"	3.357	1.934	-	1.423	-
Mongla	Sundarban	22°26'7.08"	89°40'28.02"	3.643	2.47	1.57	1.173	2.073
Mongla	Sundarban	22°26'49.32"	89°41'13.38"	4.043	2.04	2.48	2.003	1.563
Nazirpur	Shekmatia	22°41'40	89°55'25"	2.1	1.77	-	0.33	-
Noakhali Sadar	Darmapur	22°48'43.71"	91°02'42.37"	7.83	4.34	5.979	3.49	1.851
Noakhali Sadar	Noakhali	22°48'46.0"	91°04'43.0"	8.46	4.22	5.804	4.24	2.656
Patharghata	Charduani	22°02'56"	89°56'00"	6.33	1.789	2.36	4.541	3.97
Patharghata	Kalmegha	22°04'00"	89°57'48"	6.57	1.694	1.98	4.876	4.59
Patharghata	Kalmegha	22°04'36"	89°59'34"	5.782	2.32	2.033	3.462	3.749
Patharghata	Kalmegha	-	-	3.77	2.319	-	1.451	-
Patharghata	Kathaltoli	22°09'19"	89°56'29"	6.39	1.307	0.761	5.083	

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Patharghata	Kathaltoli	22°05'57"	89°57'48"	6.54	1.859	1.715	4.681	4.825
Patharghata	Kathaltoli	22°06'29.6"	89°57'54.57"	6.183	1.57	1.704	4.613	4.479
Patharghata	Nachnapara	22°10'30"	89°57'28"	6.282	2.68	2.735	3.602	3.547
Patharghata	Nachnapara	22°08'18"	89°57'00"	6.44	5.026	1.452	1.414	4.988
Patharghata	Patharghata Sadar	22°03'13"	89°58'14"	6.64	2.016	2.467	4.624	4.173
Patharghata	Patharghata Sadar	22°02'39"	89°58'14"	6.65	5.645	1.455	1.005	5.195
Patharghata	Patharghata Sadar	22°00'06"	89°56'19"	7.153	2.553	0.643	4.6	6.51
Patharghata	Raihanpur	22°11'08"	89°59'20"	3.69	2.313	2.175	1.377	1.515
Patharghata	Raihanpur	22°11'12"	89°58'02"	6.55	2.865	2.285	3.685	4.265
Patharghata	Raihanpur	22°12'48"	89°57'50"	6.46	2.449	2.09	4.011	4.37
Pekua	Magnama	21°49'24.3"	91°56'08.1"	7.449	3	3.124	4.449	4.325
Pekua	Magnama	21°49'11.1"	91°55'19.3"	7.092	1.9	2.512	5.192	4.58
Pekua	Pekua	21°49'46.6"	91°58'24.1"	7.243	1.6	1.381	5.643	5.862
Pekua	Rajakhali	21°52'48.4"	91°56'39.0"	8.748	1.7	2.708	7.048	6.04
Pekua	Rajakhali	21°53'04.2"	91°56'48.3"	8.767	3.3	2.773	5.467	5.994
Pekua	Taitong	21°52'10.0"	91°58'31.0"	8.91	2.6	2.375	6.31	
Raipur	Bamni	23°01'46"	90°48'53"	4.606	3.532	3.867	1.074	0.739
Raipur	Char Ababil	23°01'03"	90°40'27"	6.551	3.349	4.125	3.202	2.426
Raipur	Char Ababil	23°01'05"	90°41'00"	7.667	3.744	-	3.923	-
Raipur	Char Ababil	23°01'01"	90°40'58"	7.584	3.716	-	3.868	
Raipur	Char Bangshi	22°58'58"	90°42'58"	7.712	3.623	-	4.089	-
Raipur	Char Bangshi	23°00'01"	90°41'04"	7.966	3.716	-	4.25	-
Raipur	Char Mohana	23°00'24"	90°44'24"	5.769	3.875	3.625	1.894	2.144
Raipur	Char Mohana	23°00'57"	90°44'41"	5.555	3.763	-	1.792	-
Raipur	Dakhin Char Ababil	23°02'38"	90°42'48"	5.75	3.812	-	1.938	-
Raipur	Dakhin Char Bangshi	22°57'52"	90°43'41"	8.163	4.088	4.778	4.075	
Raipur	Dakhin Char Bangshi	22°56'34"	90°44'59"	8.028	4.094	-	3.934	-
Raipur	Dakhin Char Bangshi	22°55'41"	90°44'37"	8.823	3.212	-	5.611	-
Raipur	Raipur	23°03'20.73"	90°45'15.45"	4.522	3.5	3.495	1.022	1.027

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Raipur	Raipur	23°01'59"	90°42'49"	5.579	3.811	4.065	1.768	1.514
Raipur	Uttar Char Bangshi	22°58'52.53"	90°42'03.72"	5.6	3.587	-	2.013	-
Raipur	Uttar Char Bangshi	22°58'47.94"	90°41'33.26"	6.6	4.587	-	2.013	-
Raipur	Uttar Char Bangshi	22°59'39"	90°41'49"	7.884	4.193	-	3.691	-
Ramgati	Boro Khari	22°35'35"	90°59'38"	8.061	3.223	-	4.838	-
Ramgati	Char Alexander	22°42'25"	90°52'37"	7.626	4.085	3.567	3.541	4.059
Ramgati	Char Alexander	22°39'20"	90°54'45"	8.03	4.124	-	3.906	-
Ramgati	Char Badam	22°41'38"	90°56'05"	7.925	4.062	4.329	3.863	3.596
Ramgati	Char Badam	22°41'46"	90°54'41"	7.666	3.898	-	3.768	-
Ramgati	Char Badam	22°40'42"	90°58'44"	8.85	3.67	4.681	5.18	
Ramu	Dakshin Mithachhari	21°25'10.9"	92°3'26.7"	4.54	3.14	2.79	1.4	1.75
Ramu	Haldia Palong	21°18'30.35"	92°05'59.18"	5.61	2.98	10.8	2.63	Dry
Ramu	Jalia Palong	21°17'10.3"	92°3'16.6"	5.16	3.8	6.5	1.36	Dry
Ramu	Khunia palong	21°19'37.2"	92°4'52.7"	5.53	3.38	5.01	2.15	0.52
Ramu	Raja Palong	21°13'23"	92°9'42.8"	4.44	3.12	4.07	1.32	0.37
Ramu	Sabrang	20°49'43.9"	92°17'59.5"	3.78	2.47	7.61	1.31	Dry
Ramu	Whykong	21°3'5.2"	92°13'59.1"	4.61	2.2	2.11	2.41	2.5
Sandwip	Bauria	22°31'9.72"	91°28'56.49"	12.276	4.1	3.748	8.176	8.528
Sandwip	Gachuia	22°32'25.48"	91°28'33.33"	12.683	4.1	3.324	8.583	9.359
Sandwip	Haramia	22°30'15.97"	91°28'51.71"	12.2	3.4	2.827	8.8	9.373
Sandwip	Haramia	22°29'10.78"	91°28'57.03"	12.0444	3.4	3.3	8.6444	8.7444
Sandwip	Haramia	22°29'45.81"	91°28'56.91"	12.155	4	3.411	8.155	8.744
Sandwip	Maitvanga	22°26'56.18"	91°29'50.52"	11.303	3.8	1.738	7.503	9.565
Sandwip	Maitvanga	22°26'31.13"	91°29'41.57"	11.65	3.2	1.879	8.45	9.771
Sandwip	Maitvanga	22°26'17.60"	91°28'25.18"	11.618	3.5	2.005	8.118	9.613
Sandwip	Maitvanga	22°26'11.64"	91°28'08.52"	11.591	2.7	1.945	8.891	9.646
Sandwip	Maitvanga	22°26'18.20"	91°29'34.63"	11.606	4.1	2.006	7.506	9.6
Sandwip	Mogdhara	22°29'33.45"	91°30'47.24"	12.386	3.5	2.752	8.886	9.634
Sandwip	Mogdhara	22°28'18.20"	91°30'54.74"	12.054	3.9	2.461	8.154	9.593

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Sandwip	Mogdhara	22°25'45.44"	91°31'29.56"	11.503	3.2	2.989	8.303	8.514
Sandwip	Mogdhara	22°27'26.40"	91°32'41.69"	12.039	2.9	2.308	9.139	9.731
Sandwip	Mogdhara	22°26'38.35"	91°31'05.32"	11.62	3	2.294	8.62	9.326
Sandwip	Mogdhara	22°25'06.90"	91°31'31.31"	11.411	3.1	2.127	8.311	9.284
Sandwip	Mogdhara	22°28'57.48"	91°30'21.07"	12.191	4	2.617	8.191	9.574
Sandwip	Mogdhara	22°26'53.58"	91°30'38.90"	11.751	3.4	2.637	8.351	9.114
Sandwip	Mushapur	22°27'27.16"	91°27'54.39"	11.875	3.1	2.344	8.775	9.531
Sandwip	Mushapur	22°27'27.55"	91°28'32.77"	11.809	3.4	2.443	8.409	9.366
Sandwip	Mushapur	22°27'48.49"	91°30'21.65"	11.853	3.5	2.772	8.353	9.081
Sandwip	Mushapur	22°28'11.47"	91°29'28.93"	11.951	3.25	2.737	8.701	9.214
Sandwip	Mushapur	22°28'24.23"	91°29'36.82"	11.9	3.4	2.837	8.5	9.063
Sandwip	Mushapur	22°28'17.16"	91°28'14.00"	11.946	3.1	2	8.846	9.946
Sandwip	Mushapur	22°28'26.48"	91°28'41.12"	11.996	3.1	3.112	8.896	8.884
Sandwip	Rahmatpur	22°29'01.36"	91°27'23.48"	12	3	3.332	9	8.668
Sandwip	Sandwip Pourashava	22°30'19.84"	91°28'04.30"	12.252	2.9	2.966	9.352	9.286
Sandwip	Sandwip Pouroshava	22°30'37.07"	91°26'19.74"	12.484	3.1	3.26	9.384	9.224
Sandwip	Sharikait	22°25'32.17"	91°28'23.42"	11.401	3.1	1.443	8.301	9.958
Sandwip	Sharikait	22°25'46.98"	91°30'21.01"	11.524	3.7	2.068	7.824	9.456
Sandwip	Sontoshpur	22°33'57.48"	91°27'20.92"	14.088	4.3	3.703	9.788	
Sandwip	Sontoshpur	22°33'29.66"	91°27'58.50"	12	4.6	3.792	7.4	8.208
Sandwip	Sontoshpur	22°33'37.77"	91°27'47.61"	12.891	4.6	4.162	8.291	8.729
Sandwip	Sontoshpur	22°33'50.93"	91°27'34.88"	12.9	4.2	3.946	8.7	8.954
Sandwip	Urir Char	22°40'49.50"	91°20'08.10"	15.944	4.7	2.307	11.244	
Satkania	Amilaish	22°08'21.6"	92°00'42.1"	5.35	3.8	5.96	1.55	Dry
Satkania	Charothi	22°09'55.2"	91°56'55.6"	7.895	3.5	2.91	4.395	
Satkania	Charothi	22°08'48.8"	91°58'49.2"	5.55	4.3	3.45	1.25	2.1
Satkania	Dhamsa	22°05'32.72"	92°02'51.29"	5.17	4.1	5.63	1.07	Dry
Satkania	Nalua	22°06'37.6"	92°02'01.4"	5.14	3.18	5.99	1.96	Dry
Sharankhola	Dhansagar	22°22'56.4"	89°48'52.2"	4.629	2.394	1.9	2.235	2.729
Sharankhola	Dhansagar	22°22'00.86"	89°46'30.33"	4.483	2.218	2.19	2.265	2.293
Sharankhola	Rayenda	22°18'50.76"	89°51'11.28"	5.988	2.523	2.408	3.465	
Sharankhola	Southkhali	22°14'02.00"	89°48'27.70"	5.133	1.873	3.026	3.26	2.107
Sharonkhola	Dhansagar	22°20'00.60"	89°48'34.91"	4.457	1.786	2.18	2.671	2.277
Sharonkhola	Dhansagar	22°16'05.89"	89°48'15.55"	4.8	1.635	-	3.165	-
Sharonkhola	Royenda	22°15'54"	89°49'47.64"	5.354	2.911	-	2.443	-
Sharonkhola	Southkhali	22°16'58.73"	89°48'36.82"	4.938	1.839	-	3.099	-
Sharonkhola	Southkhali	22°15'6.72"	89°49'57.84"	5.43	2.74	-	2.69	-
Shyamnagar	Atulia	22°20'44.50"	89°11'44.40"	3.422	1.016	0.228	2.406	3.194

Upazila	Union	Latitude	Longitude	IWM Surge Level (mPWD)	DEM (1991)-GL (mPWD)	Surveyed GL(mPWD) by Consultant	Surge Water Depth (m) based on DEM	Surge water depth (m) based on surveyed GL
Shyamnagar	Bhurulia	22°21'59.11"	89°04'58.81"	2.1	1.947	3.188	0.153	Dry
Shyamnagar	Bhurulia	22°22'31.7"	89°04'09.4"	2.1	1.703	3.054	0.397	Dry
Shyamnagar	Buri Goalini	22°16'21.2"	89°11'46.2"	1.917	3.268	0.584	-1.351	1.333
Shyamnagar	Buri Goalini	22°17'27.7"	89°12'59.2"	4.176	1.179	0.244	2.997	3.932
Shyamnagar	Buri Goalini	22°16'24.8"	89°14'41.2"	4.952	2.051		2.901	
Shyamnagar	Gabura	22°16'36.9"	89°16'05.5"	4.65	2.501	1.429	2.149	3.221
Shyamnagar	Gabura	22°13'19.9"	89°16'48.3"	2.976	2.966	1.28	0.01	1.696
Shyamnagar	Kashimari	22°22'45.5"	89°08'47.4"	2.762	2.209	2.807	0.553	Dry
Shyamnagar	Munshiganj	22°13'41.5"	89°09'17.3"	1.242	2.569	0.963	-1.327	0.279
Shyamnagar	Paddma Pukur	22°19'18.8"	89°13'13.2"	3.229	1.459	-0.253	1.77	3.482
Shyamnagar	Padma Pukur	22°18'14.54"	89°15'59.60"	2.019	1.286	1.977	0.733	0.042
Shyamnagar	Ramjan Nagar	22°17'41.8"	89°05'11.4"	2.72	2.51	0.892	0.21	1.828
Shyamnagar	Ramzan Nagar	22°15'19.4"	89°03'44.3"	2.72	1.515	0.293	1.205	2.427
Shyamnagar	Shyamnagar	22°19'05.9"	89°04'51.2"	2.72	1.164	0.577	1.556	2.143
Shyamnagar	Shyamnagar	22°20'49.0"	89°06'08.1"	2.72	2.366	1.609	0.354	1.111
Sitakunda	Barabkunda	22°34'38.37"	91°40'56.23"	5.04	3.86	7.659	1.18	Dry
Sitakunda	Bariadyala	22°40'12.88"	91°37'43.47"	12.337	3.77	5.79	8.567	6.547
Sitakunda	Bhatiary	22°25'23.00"	91°44'48.00"	11.16	8.3	5.619	2.86	5.541
Sitakunda	Solimpur	22°24'10.00"	91°45'25.00"	11.1	8.4	4.829	2.7	6.271
Sitakunda	Sonaichhari	22°27'57.48"	91°43'34.91"	11.33	6.3	5.075	5.03	6.255
Sitakunda	Syedpur	22°38'41.46"	91°38'0.17"	12.206	4.06	4.739	8.146	7.467
Sitakunda	Syedpur	22°39'25.91"	91°35'35.27"	12.25	3.9	4.459	8.35	
Sonagazi	Char Chandia	22°49'40.0"	91°24'21.0"	13.087	4.24	4.933	8.847	
Sonagazi	Char Chandia	22°48'35.4"	91°22'45.6"	13.285	4.71	6.359	8.575	6.926
Sonagazi	Char Durbas	22°51'32.0"	91°21'13.0"	12.812	4.46	5.199	8.352	7.613
Sonagazi	Sonagazi Pourashava	22°50'56.0"	91°23'13.0"	12.823	4.95	5.199	7.873	7.624
Sonagazi	Sonagazi Pourashava	22°50'55.0"	91°23'26.0"	12.922	4.73	6.298	8.192	6.624
Subarnachar	Char Aman Ullah	22°38'53.0"	91°07'55.0"	9.83	4.14	8.021	5.69	1.809
Subarnachar	Char Jabber	22°42'19.86"	91°04'51.42"	8.76	4.57	4.94	4.19	3.82
Subarnachar	Char Jubli	22°39'39.0"	91°05'57.0"	9.45	4.16	8.414	5.29	1.036
Subarnachar	Char Jubli	22°39'28.0"	91°07'01.0"	9.63	4.39	7.944	5.24	1.686
Subarnachar	Char Jubli	22°37'29.0"	91°14'41.0"	13.195	3.94	3.706	9.255	
Subarnachar	Char Wapda	22°42'05.0"	91°06'25.0"	8.93	4.63	5.139	4.3	3.791
Subarnachar	Charbata	22°38'06.0"	91°07'50.0"	9.94	4.16	7.698	5.78	2.242

Upazila	Union	Latitude	Longitude	IWM Surge Level (mPWD)	DEM (1991)-GL (mPWD)	Surveyed GL(mPWD) by Consultant	Surge Water Depth (m) based on DEM	Surge water depth (m) based on surveyed GL
Subarnachar	Charbata	22°37'02.0"	91°07'53.0"	10.2	3.53	6.744	6.67	3.456
Subarnachar	Danarchis	22°42'13.0"	91°09'22.0"	10.57	4.69	5.339	5.88	
Subarnachar	Mohammadpur	22°38'24.38"	91°14'01.82"	9.38	4.95	4.712	4.43	4.668
Subarnachar	Noyapara	22°37'37.0"	91°09'28.0"	10.53	3.86	8.458	6.67	2.072
Tajumuddin	Sonapur	22°32'48"	90°53'37"	13.595	3.1	1.4	10.495	12.195
Tajumuddin	2 No. Sonapur	22°27'27"	90°48'16"	6.594	2.4	5.295	4.194	1.299
Tajumuddin	2 No.Sonapur	22°27'18"	90°48'53"	6.388	3.5	5.252	2.888	1.136
Tajumuddin	3 No. Chandpur	22°25'08"	90°51'13"	6.669	2.5	2.46	4.169	4.209
Tajumuddin	3 No. Chandpur	22°25'27.83"	90°49'20.67"	8.2	2.3	2.48	5.9	
Tajumuddin	Chandpur	22°23'57.5"	90°50'53"	6.616	2.4	2.11	4.216	4.506
Tajumuddin	Chandpur	22°25'48"	90°49'55"	6.451	2.1	3.41	4.351	3.041
Tajumuddin	Chandpur	22°25'08.38"	90°51'12.44"	6.669	2.4	2.31	4.269	4.359
Tajumuddin	Chandpur	22°24'59"	90°51'9.52"	6.497	3	3.412	3.497	3.085
Tajumuddin	Chandpur	22°25'08.96"	90°51'07.78"	6.637	2.6	3.41	4.037	3.227
Tajumuddin	Kalma Ramganj	22°25'26"	90°48'32"	5.996	2.9	3.61	3.096	2.386
Tajumuddin	Kazikandi	22°25'08"	90°50'06"	6.412	2.3	3.728	4.112	2.684
Tajumuddin	Shombhupur	22°22'03.13"	90°48'32.96"	7.94	2.1	5.315	5.84	2.625
Tajumuddin	Shombhupur	22°24'51"	90°47'33"	7.94	2.4	4.316	5.54	3.624
Tajumuddin	Shombhupur	22°23'2.43"	90°48'33.03"	6.618	2.6	4.24	4.018	2.378
Tajumuddin	Shombhupur	22°25'54.82"	90°48'21.18"	5.972	2.8	4.726	3.172	1.246
Tajumuddin	Sonapur	22°32'19.10"	90°53'39.43"	13.627	3.2	2.465	10.427	11.162
Tajumuddin	Sonapur	22°32'47.85"	90°53'36.01"	13.595	3.1	1.043	10.495	
Tajumuddin	Sonapur	22°26'8.36"	90°49'27.96"	6.497	3.2	1.91	3.297	4.587
Teknaf	Bharchhara	21°0'11.2"	92°11'29.6"	4.24	3.16	9.04	1.08	Dry
Teknaf	Nhilla	20°56'26.5"	92°15'35.2"	4.13	2.77	7.97	1.36	Dry
Teknaf	Nhilla	20°59'22.3"	92°14'29.4"	4.07	2.86	3.37	1.21	0.7
Teknaf	Sabrang	20°49'5.7"	92°18'22.3"	3.65	2.43	7.34	1.22	Dry
Teknaf	Teknaf sadar	20°52'25.1"	92°17'55.1"	4.17	2.78	5.16	1.39	Dry
Teknaf	Teknaf sadar	20°53'43.8"	92°14'53.9"	4.05	2.63	8.96	1.42	Dry
Teknaf	Teknaf sadar	20°50'45.5"	92°17'57.9"	3.97	2.81	6.94	1.16	Dry
Teknaf	Teknaf sadar	20°53'2"	92°15'29.5"	4.46	3.12	8.8	1.34	Dry
Teknaf	Whykong	21°2'26.8"	92°13'44"	4.41	2.79	4.19	1.62	
Teknaf	Whykong	21°6'43.1"	92°11'13.4"	4.53	2.94	5.4	1.59	Dry
Ukhia	Haldia Palong	21°18'22.5"	92°8'36.1"	5.16	2.92	14.62	2.24	Dry
Ukhia	Haldia Palong	21°17'54.8"	92°5'0.2"	5.61	3.21	4.24	2.4	
Ukhia	Haldia Palong	21°18'20"	92°6'40"	5.61	3.22	8.29	2.39	Dry

Upazila	Union	Latitude	Longitude	IWM Surge Level (mPWD)	DEM (1991)-GL (mPWD)	Surveyed GL(mPWD) by Consultant	Surge Water Depth (m) based on DEM	Surge water depth (m) based on surveyed GL
Ukhia	Haldia Palong	21°16'38.4"	92°5'44.4"	4.86	3.56	4.94	1.3	Dry
Ukhia	Jalia Palong	21°5'21.9"	92°8'33"	4.23	2.84	11.22	1.39	Dry
Ukhia	Raja Palong	21°15'5"	92°8'32.3"	4.62	2.89	9.68	1.73	Dry

List of Tsunami Vulnerable Infrastructures (Ref. C12-2) **Annexure5**

*Value in red indicates maximum inundations in the upazillas

	Upazila	Type of Structure	Name of Structure	Inundation Depth (m)	Inundation Depth
Bagerhat	Mongla	Pucca	Malgachi High School	0.11	<1m
		Pucca	Bno Kanaymari Ideal Govt. Primary School	0.33	
		Pucca	Upazila Resource Centre	0.34	
		Pucca	1no Kanaynagar Aysa Siddiqa Reg Non Govt. Primary	0.84	
		RCC frame	Joymoni Govt. Primary School	0.22	
		Pucca	South Holdibunia Regl. Non Govt. Primary School	0.22	
		Pucca	Family Health Centre	0.31	
		Pucca	North Hodibunia Govt. Primary School	0.33	
		RCC frame	Holdibunia High School	0.5	
		RCC frame	Holdibunia High School	0.47	
		Pucca	Holdibunia Hogh School	0.5	
		Pucca	Moddho Holdibuna Govt. Primary School	0.48	
		Pucca	Chila Bangladesh Govt. Primary School	*0.94	
		Pucca	Gabbunia Regi Non Govt. Primary School	0.8	
		Pucca	Khilrkhan Kul Chobed Khan Regi. Non Govt. School	0.7	
		Pucca	North Joymoni Regi Non Govt Primary School	0.85	
		Pucca	Joymoni High School	0.8	
		RCC frame	South Chila Siddiqa Ahmadia Dakhil Madrassa	0.85	
		Pucca	South Chila Govt. Primary School	0.85	
	Sharankhula	Pucca	Kadam Tala Regi Non Govt Primary School	0.4	
		RCC frame	Kadam Tala Red Crescent Ahory Kandro	0.39	
		Pucca	43no Rejesor Regi Non Govt. Primary School	0.83	
		Pucca	North kadam Tala Regi Non Govt Primary School	0.18	
		Pucca	Royanda Pilot High School	0.88	
		Pucca	Royenda Pilot High School	0.76	
		Pucca	R K D S Semmilito Girls High School	0.7	
		Pucca	R K D S Semmilito Girls High School	0.78	
Barguna	Amtali	Semi pucca	Kaliatoli Chor Gacia Dakil Madrasha	0.88	
		Tin	Amtali Wohapda Hadia Madrasha	0.05	
		RCC frame	Taltoli Salehla Islamia Alia Madrasha	0.45	
		RCC frame	Taltoli Degree College	0.08	
		RCC frame	Saton Para Reg. Primary School	0.04	
		Semi pucca	Begum Murgahan Modoh Balika School	0.02	
		Semi pucca	Saton Para Govt. Primary School	0.01	
		RCC frame	Taltoli Ghoto Bigoda Senior Madrasha	0.08	
		RCC frame	Lalu Para Reg. Primary School	0.1	
		RCC frame	Manopara Reg. Primary School	0.01	
		RCC frame	Takur Para Reg. Primary School	0.01	
		Pucca	Chorpara Govt. Primary School	0.26	
		Semi pucca	Choto Bogi Gabtoli Dikil Madrasha	0.08	
		Semi pucca	Gabtoli Govt Primary School	0.06	
		Semi pucca	Abdul Gopur Dakil Madrasha	0.01	
		RCC frame	Bogir Hat High School	0.08	
		RCC frame	Bogir Hat Govt Primary School	0.14	
		RCC frame	Bogir Hat Health Center	0.13	
		Pucca	Koditola Reg Primary School	0.13	
	Bamna	Pucca	Ruhita Govt Primary School	0.05	<1m
		RCC frame	Bamna Degree College	0.08	
		RCC frame	Bamna Sardar Jan Pilot High School	0.01	
		RCC frame	Bamna Up Health Centre	0.02	
		Semi pucca	Bamna Govt Primary School	0.1	
		Tin	Bamna Sodor Al Roshid Fazil Madrasha	0.47	
		RCC frame	Begum Fozilatunnesa Mohila Degree College	0.58	
		Pucca	East Sonakali Govt Primary School	0.01	
		RCC frame	North Kakcira High School	0.15	
		Semi pucca	North kakcira Reg Primary School	0.15	
		Pucca	Gudi Kata Agrorsho Reg Primary School	0.16	
		Tin	Chola Banga Reg Primary School	0.05	
		Pucca	South Ramna Govt Primary School	0.09	
		RCC frame	North Ramna Govt Primary School	0.85	
		RCC frame	Ramna Sera Bangla High School	0.25	
		Tin	Kolpotua Senior Alim Madrasha	0.03	
	Barguna Sadar	Pucca	East Kadoa Bunia Dakil Madrasha	0.29	
		Pucca	Pura Kata Sel Ter Rez Primary School	0.4	
		Pucca	East Kodabunia Govt Primary School	0.4	
		Pucca	Kodomtola Govt Primary School	0.01	
		RCC frame	Kodomtola B M College	0.01	
		Tin	It Baria Kodomtola High School		
		Semi purcca	Gangalia Govt Primary School	0.51	
		Tin	Gangalia Islamia Dakil Madrasha	0.3	
		RCC frame	Dangalia Adorsho Reg Primary School	0.4	
		RCC frame	Ayla Pata Kata Shnar Bangla High School	0.13	
		Semi pucca	Ayla Pata Kata Govt Primary School	0.14	
		Pucca	Pata Kata Govt Primary School	0.54	
		RCC frame	Ayla Pata Kata Darul Ulum Madrasha	0.12	

List of Tsunami Vulnerable Infrastructure (continued)

District	Upazila	Type of Structure	Name of Structure	Inundation Depth (m)	Inundation Depth
Barguna	Barguna Sadar	RCC frame	Modo Burir Chor Reg Primary School	0.66	<1m
		Pucca	Kmodakali Govt Primary School	0.01	
		Pucca	Baoul Kor Govt Private School	0.01	
		Pucca	Baoullor D K Primary School	0.01	
		Tin	South Baoul Ko r Govt Primary School	0.11	
		RCC frame	Ruma Reg Primary School	0.22	
		RCC frame	West Dema Govt Primary School	0.6	
		Tin	Dema Gulisakana Hakknla High School	1.0	
		Tin	Dema Pulisakkli Girls Dakil Madrasha	0.51	
		RCC frame	East Gulisakali Privae Primary School	0.08	
		Tin	Fulzuri Pata Kata Suria Madrasha	0.03	
		Pucca	Fulzudl Bohumukl High School	0.27	
		Pucca	Fulzudi Govt Primary School	0.28	
		Pucca	Bodor Kali Govt Primary School	0.57	
		Pucca	East Bodor Kali Govt Primary School	0.57	
		RCC frame	Hazar Boga Govt Primary School	0.16	
		RCC frame	Uttor Ghoto Lobon Gola Aoroso Primary School	0.01	
		RCC frame	Budir Char	0.32	
		Pucca	Surir Ghur High Sonologho Provate Primary School	0.31	
		Pucca	Burir Chur Govt Primary School	0.31	
		RCC frame	Kamarabad Govt Primary School	0.47	
		Tin	South Burir Chopr Primary School	0.58	
		Pucca	Napitkali Reg Primary School	0.78	
		Tin	Napit Poncho Gram High School	0.81	
		RCC frame	West Napti Kali Adorso Reg Primary School	0.8	
		Tin	East Hazar Biga Alim Madrasha	0.47	
		Tin	Dhoto Lobon Go Hazar Biga High School	0.15	
		RCC frame	Choto Lobon Gola Govt Primary School	0.03	
		Pucca	Manik Kali Bodo Lobon Primary School	0.18	
		Tin	Purbo Chorok Gacia Reg Primary School	0.02	
		Pucca	Mostur Tona Reg. Primary School	0.01	
		Pucca	Ayla Chor Gacia Govt Primary School	0.45	
		Tin	Chorgacia Fazil Madrasha	0.01	
		Pucca	Choroagia Reg Primary School	0.14	
		Pucca	Moli Health & Family Planning Centre	0.48	
		Tin shed	Ray Bog Kodom Tola Primary School	0.8	
		Tin	East Raybag Girls School	0.5	
		Pucca	Portkakall Govt. Primary School	0.1	
		Pucca	Lamua Kagura P.K High School	0.88	
		RCC frame	Lamua Ragura Govt Primary School	0.98	
		Pucca	Fil Dhalua Katal Tou High School	0.86	
		RCC frame	F D Katal Tou Govt Primary School	0.86	
		Pucca	West Ful Dhulua Reg Primary School	0.28	
		RCC frame	Kakbunia Fazil Madrasha	0.62	
		Semi pucca	Kakbunia Govt Primary School	0.61	
		Pucca	Noli Muslim High School	0.48	
		Pucca	Noli Govt Primary School	0.48	
		Semi Pucca	Noli Chorok Gacia Atim Mongll Sinior Madrasha	0.58	
		RCC frame	East Chorok Gacia Govt Primary School	0.41	
		Pucca	Noll Chor Gacia Govt Prymary School	0.78	
		Tin	Dhor Gacia Progoti Govt School	0.77	
		Pucca	Ray Bog A A Kan Govt Primary School	0.5	
		Tin Shed	Ray Bog Govt Primary School	0.88	
		Pucca	Kodomtola Reg Privte Primary School	0.6	
		Semi Pucca	Sosa Toli Reg Primary School	0.36	
		RCC frame	Noli Mansatoli Govt Primary School	0.85	
		Tin	Calikatoli High School	0.36	
		Tin	Dolua Hosania Dakil Madrasha	0.17	
		Tin	Nimtoli Zazabad C M High School	0.37	
		RCC frame	Noli Maita High School	0.33	
		Pucca	Noli Maita Govt Primary School	0.36	
		Tin	Diba Naita Dakil Madrasha	0.58	
		Tin	Monsatoli Lakurtola High School	0.85	
		Pucca	Rokha Chondl Reg Primary School	0.88	
		RCC frame	Rokha Chodi Islamia Dakil Madrasha	0.85	
		Pucca	Rustom Azad Dakil Madrasha	1	
		Pucca	Sun Sunia Govt Primary School	0.3	
		RCC frame	Calitatoli Govt Primary School	0.36	
		RCC frame	Amtoli Reg Primary School	0.54	
		Tin shed	Nesara Bad Fozilul Haq Dakil Madrasha	0.02	
		Pucca	Zelkana Govt Primary School	0.04	
		Tin shed	Goalbuna Govt Primary School	0.48	
		Tin shed	Agjor Kati A B F DA School	0.43	
		Semi pucca	Nisan Barir Near Primary School	0.68	
		RCC frame	West nisan Beria Reg. Primary School	0.93	
		Tin	Modo Gaji Mahmud Primary School	0.87	
		Tin	Sonatola Islamia Madrasha	0.67	

List of Tsunami Vulnerable Infrastructure (continued)

District	Upazila	Type of Structure	Name of Structure	Inundation Depth (m)	Inundation Depth
Barguna	Barguna Sadar	RCC frame	Goda Podha Reg Primary School	0.5	<1m
		RCC frame	Sialia M I Dimuki High School	0.98	
		RCC frame	Sihalia Govt Primary School	0.98	
		RCC frame	North Gorjonbunia Govt Primary School	0.95	
		RCC frame	Fire Servie	0.95	
		RCC frame	D.C Office	0.01	
		RCC frame	Mollar Koda Govt Primary School	1.19	1m<d<=3m
		Pucca	Bodi Tola Govt Primary School	1.37	
		Semi Pucca	Baliatoli Primary School	1.38	
		Pucca	Baliatoli City Community Primary School	1.38	
		Pucca	Porir Kal High School	1.06	
		Semi Pucca	Porirkal Govt. Primary School	1.08	
		Pucca	Rakian Para B P S High School	1.15	
		Pucca	Chor Para Govt Primary School	1.18	
		Tin	Chorara Mohammadia Dakil Madrasha	1.17	
		Semi Pucca	National Private Reg Primary School	1.26	
		RCC frame	Gorjon Bunia High School	1.24	
		RCC frame	Gorjonbunia Govt Primary School	1.11	
		Pucca	Family Health Center	1.17	
		Tin shed	Uttor Aga Poodha Adarsho Reg Primary School	1.46	
		Tin	Gaji Mahmud Dakil Madrasha	1.28	
		Semi Pucca	Gazi Mahmud Primary School	1.28	
		RCC frame	Agapodha Reg Primary School	1.45	
		RCC frame	Babugonj Govt. Primary School	1.28	
		RCC frame	Babugonj High School	1.27	
		RCC frame	South Gorjonbunia Dakil Madrasha	1.44	
	Betagi	Pucca	Bura Mazumdar Govt Primary School	0.11	<1m
		Pucca	Bolibunia Govt Primary School	0.15	
		Tin	Bolibuni High School	0.15	
		RCC frame	Kazir Hat High School	0.1	
		Pucca	South Koruna Govt Primary School	0.1	
		Semi pucca	West Koruna Govt Primary School	0.18	
		Tin	West Koruna High School	0.18	
		Pucca	North Geramoddon Reg Primary School	0.37	
		RCC frame	Geramoddon Hasania Dakil Madrasha	0.87	
		Semi Pucca	Md. Gera Moddon Govt Primary School	0.01	
		RCC frame	Boda Ka Badi Hatem Ali Reg Primary School	0.02	
		Pucca	Kazi Bari Govt Primary School	0.15	
		Pucca	Gabtoli Reg Primary School	0.14	
		Tin	Gabtoli Dakil Madrasha	0.3	
		Tin	Gabtoli Islamia Alim Madrasha	0.16	
		RCC frame	Dofa Sarisha Muri Govt Primary School	0.25	
		Tin	Sarisha Muri Abdul Lotif Dakil Madrasha	0.33	
		Pucca	Eat Gabtoli Reg Primary School	0.01	
		Pucca	FWC	0.02	
		RCC frame	Boda Gvot Primary School	0.24	
		Semi pucca	Jomadar Bari Reg Primary School	0.25	
		Semi pucca	North Gabtoli Diman Ali Dakil Madrasha	0.29	
		Tin	Boda South Kalika Bari Arsedia High School	0.34	
	Patharghata	RCC frame	Ekorbunia Govt Primary School	0.34	
		Brick wall	Takil Baria Govt Primary School	0.11	
		Tin	Takai Para Salamia Dakil Madrasha	0.09	
		Tin	Gabbaria Govt Primary School	0.11	
		RCC frame	49No Amtoli Govt Primary School	0.13	
		RCC frame	Kali Bari Govt Primary School	0.52	
		RCC frame	Bianchotki High School	0.55	
		Pucca	Modobanchotki Reg Primary School	0.21	
		RCC frame	Singdabunia Primary School	0.58	
		Semi pucca	Singdabunia Govt. Primary School	0.26	
		Pucca	Rupdon Bondor Amibia High School	0.58	
		Semi pucca	Rupdon Bondor Govt Primary School	0.96	
		Tin	Galigata Kasemia Dakil Madrasha	0.1	
		RCC frame	Baditok Reg Primary School	0.94	
		RCC frame	Sultan Bodo Mia Reg Primary School	0.01	
		RCC frame	Nesaria Dakil Madrasha	0.07	
		Pucca	Karchira FWC	0.22	
		RCC frame	East Kanthal Tali Reg Primary School	0.81	
		RCC frame	Kanthal Tali Sopto Gram High School	0.01	
		RCC frame	Shopto Gram Reg Primary School	0.02	
		RCC frame	Kanthal Toli Govt Primary School	0.03	
		RCC frame	Horin Gata Reg Primary School	0.06	
		RCC frame	Gin Tola Reg Primary School	0.43	
		RCC frame	Chor Badur Tola Reg Primary School	0.57	
				0.39	
		RCC frame	Podha Govt Primary School	0.03	
		RCC frame	Hazir Kal Reg Primary School	0.39	

List of Tsunami Vulnerable Infrastructure (continued)

District	Upazila	Type of Structure	Name of Structure	Inundation Depth (m)	Inundation Depth
Barguna	Patharghata	Tin	Anowara Hossain Girls High School	0.26	<1m
		RCC frame	South Kupodon Adorsho Reg Primary School	0.35	
		RCC frame	Mother Toli High School	0.29	
		Semi Pucca	Mother Toli Got Primary School	0.28	
		Pucca	East Lamua Reg Primary School	0.14	
Barisal	Bakergonj	Semi pucca	Pathkathi Nessia de madrasha	0.82	<1m
		RCC frame	Pathkathi Secandari School	0.33	
		Semi pucca	Girali South Primary School	0.92	
		RCC frame	Durga pasha Union Secondary School	0.89	
		RCC frame	South Gobindopur Government Primary School	0.89	
		Semi Pucca	D G L Association School	1.00	
		Semi pucca	Girali azizia Tagli Madrasha	0.8	
		RCC frame	West girali Primary School	0.9	
		RCC frame	Girali Majidia Azizia bair South Madrasha	0.85	
		Semi pucca	North Gobindopur Govt Primary School	0.98	
		Tin shed	Kathaghali Govt. Primary School	0.78	
		Semi pucca	Gobindopur Salehia South Madrasha	0.81	
		Tin shed	Durgapasha Govt. Primary School	0.87	
		Pucca	HFWC	0.8	
		RCC frame	Gosh Khali Reg. Primary School	0.77	
	Barisal Sadar	Tin shed	Chandramohan Dakil Madrasha	0.37	< 1 m
		Tin shed	Chandramohan Rusiam Mamorial Ma. School	0.54	
		Semi pucca	Chandramohan High Song Sarkeri Primary School	0.59	
		RCC frame	Tuom char sarkeri primary school	0.62	
		Semi pucca	Tuom Chair Kasmalia South Madrasha	0.62	
		Semi pucca	Vedihuria Govt. Primary School	0.47	
		RCC frame	D.C Office	0.25	
		Semi pucca	Red Crescent Office	0.28	
		Semi pucca	Red Crescent Office	0.27	
		Semi pucca	South tuom char Kami Primary School	0.85	
		RCC frame	Sul. majid Khan Secendari School	0.89	
		Semi pucca	East Chandramohan Govt. Primary School	0.98	
Bhola	Bhola Sadar	Pucca	East West Chondro Prashad Reg Primary School	0.79	<1 m
		RCC frame	Uttar Chondro Prashed Govt. Primary School	0.64	
		Tin shed	Middle Chor Kali Reg. Primary School	0.02	
		Pucca	Poschim Chor Kali A Latif Bawil Reg. Primary School	0.02	
		Pucca	Dokhin Chor Kali Shar e Banga Reg. Primary School	0.16	
		Pucca	Chor Kali Govt. Primary School	0.3	
		Semi pucca	Banker Hut Govt. Primary School	0.48	
		Pucca	Banker Hut Cooperative High School	0.45	
		Pucca	Banker Hut Somobya Degree College	0.51	
		Semi pucca	Chor Bhadaria Govt. Primary School	0.12	
		Pucca	Chor Bhaderia Islamia Reg. Primary School	0.7	
		Pucca	Middle Bhadaria REg. Primary School	0.84	
		3+1	Chor Romes Govt. Primary School	0.77	
		Pucca	Dokkhin Poschim Bhodaria M Hossain Reg. School	0.72	
		Pucca	O Poschim Chor Bhadaria A Haque Reg. School	0.75	
		Pucca	Chor Hossain Reg. Primary School	0.82	
		Pucca	Chor Gazi Halam AB Reg. School	0.76	
		Pucca	Chondro Preashed Govt. Primary School	0.57	
		RCC frame	Toom chondro Prashed Govt. Primary School	0.95	
		Pucca	Middle Baghmara REg. Primary School	0.77	
		Pucca	Uttar Baghmara Reg. Primary School	0.31	
		Pucca	Dokkhin Poschim Shibpur Sharif Govt. Reg. Primary	0.02	
		Pucca	Poschim Shibpur Reg. Primary School	0.01	
		Semi pucca	Shibpur Govt. Reg. School	0.34	
		Pucca	Uttar Purbo Shibpur Roksa Reg. Primary School	0.97	
		1+2	Kali Kil Notun Govt. Primary School	0.2	
		Tin shed	Kali K Govt. Primary School	0.42	
		RCC frame	Ganga Kalli Govt. Primary School	0.05	
		Tin shed	Uttar Ganga Kirily Govt. Primary School	0.62	
		Tin shed	Dakkhin Dhania Reg. Primary School	0.73	
		Pucca	West Dhania Govt. Primary School	0.12	
		Pucca	Al Haj Dakhil Madrasha	0.01	
		Pucca	Moddha Dhania Reg. Primary School	0.02	
		RCC frame	Mowlvir Hut Govt. Primary School	0.35	
		Pucca	Gazipur Mdddhomik School	0.37	
		RCC frame	Murad Subullah Govt. Primary School	0.12	
		Semi pucca	Purbo chor Illisha Govt. Primary School	0.04	
		Pucca	Dokkhin Illisha Govt. Primary School	0.05	
		Tin shed	Kachia Banghabari Govt. Primary School	0.01	
		Pucca	Poschim Kachia Reg. Primary School	0.24	
		Tin shed	Uttar poschim Kachia Reg. Primary School	0.21	
		RCC frame	Gura Miar Hut Govt. Primary School	0.84	
		Pucca	Kharki Govt. Primary School	0.71	

List of Tsunami Vulnerable Infrastructure (continued)

District	Upazila	Type of Structure	Name of Structure	Inundation Depth (m)	Inundation Depth
		RCC frame	Kachia Dotto Bari Govt. Primary School	0.04	
		RCC frame	Majidpur Govt. Primary School	0.81	
		RCC frame	Uttar Ramdaspur Govt. Primary School	0.42	
		Tin shed	Uttar Chor Silaram Reg. Primary School	0.32	
		1+2	Ramdaspur Govt. Primary School	0.2	
		Pucca	Ramdaspur Govt. Primary School	0.2	
		Pucca	Chor Sultani Soniespur Reg. School	0.49	
		3+3	2nd Rajapur Govt. Primary School	0.4	
		Pucca	Purbo Chondrokpur Reg. Primary School	0.01	
		Pucca	8no Kondrokpur Reg. Primary School	0.02	
		Pucca	Obaydul Haque Primary School	0.02	<1 m
Bhola	Bhola Sadar	Tin shed	Chor Hajipur Reg. Primary School	0.47	
		RCC frame	Mayduya Reg Primary School	0.11	
		Semi pucca	Chor Bhadaria 2 No. Govt. Primary School	0.8	
		Pucca	Middle Chor Romas Reg. Primary School	0.9	
		Pucca	Chor Rupapur Reg. Primary School	0.95	
		RCC frame	Moddha Chor Prashad Govt. Primary School	1.07	
		Pucca	South Chondro Prashed Reg. School	1.49	
		Pucca	Chor Chondro Primary Adarsho Reg. School	1.49	
		Pucca	Purbo Chondro Prashad Reg. Primary School	1.02	
		Tin shed	Dhania Govt. Primary School	1.56	1 m<d<= 3m
		RCC frame	Tule Tuli Khandakar Bari Govt. Primary School	1.27	
		Pucca	Rajapur Govt. Reg. School	1.27	
		Pucca	Rajapur High School	1.14	
		RCC frame	17 No. Gangapur Govt. Primary School	0.49	
		Kacha Ghor	Gangapur High School	0.49	
		Pucca	Uttar Purbo Joya Reg. Primary School	0.17	
		Pucca	Uttar Joya REg. Primary School	0.20	
		Pucca	18 Sakuchia Govt. Primary School	0.03	
		1+3	Poschim Joya Govt. Primary School	0.38	
		RCC frame	Dharia Govt. Primary School	0.11	
		Pucca	Dokshin Poschim Joya Reg. Primary School.	0.08	
		Pucca	Middle Hasan Nagar Reg P4rimary School	0.1	
	Burhanuddin	RCC frame	Giarpur Govt. Primary School	0.94	
		RCC frame	Utter Hasan Nagar Govt. Primary School	0.15	
		Pucca	Hakim Uddin Govt. Primary School	0.54	
		Pucca	Hasan Nagar Ideal Reg. Primary School	0.82	
		RCC frame	Uttar Char Lamchi Dholi Reg. Primary School	0.02	
		Pucca	Uttar Dalapur Reg Primary School	0.03	
		Pucca	34 Dalalpur	0.01	
		1+2	Moth Khola Govt. Primary School	0.31	
		3+2+1	Ayasbag Govt. Primary School	0.05	
		RCC frame	Poshim Khodeja Reg. Primary School	0.48	
		RCC frame	Char Kalmi Govt. Primary School	0.07	
		Semi Pucca	Char Kalmi High School	0.02	
		Pucca	Purbo Char Manika Reg. Primary School	0.22	
		Semi pucca	Char Manika Govt. Primary School	0.14	
		RCC frame	Dokhin Char Icha Comunity Primary School	0.17	<1 m
	CharFashion	RCC frame	Soudi Hospital	0.02	
		Pucca	Char Icha High School	0.01	
		Pucca	Char Fakira Reg. Primary School	0.65	
		Pucca	Purbo Hazariganj Reg. Primary School	0.17	
		Pucca	Dokshin Nikamal Reg. Primary School	0.03	
		Pucca	Poshim Char Nurul Amin Reg. Primary School	0.05	
		RCC frame	Moddho Char Nurul Amin Reg Primary School	0.22	
		Pucca	Uttr Char Nurul Amin Reg. Primary School	0.25	
		RCC frame	Uttar Aysabagh Reg. Primary School	0.8	
		RCC frame	Dokshin Char Kelmi Reg. Primary School	0.82	
		Pucca	Dowtotpur Reg. Primary School	0.98	
		Pucca	Khadija Khanom High School	0.07	
		Pucca	Uttar Kola Kopa Reg. Primary School	0.07	
		RCC frame	Dider Ullah Govt. Primary School	0.39	
		Pucca	Serejul Haque Ideal Reg. Primary School	0.1	
		Pucca	Kola Kopa Senior Madrasha	0.03	
		Pucca	Poschim Kola Kopa Govt. primary School	0.01	
		Pucca	Uttar Purbo Didar Ullah Reg. Primary School	0.06	
		RCC frame	Poschim Char Khalifa Govt. Primary School	0.11	
	Daulatkhan	RCC frame	Uttar Purpo Khalifa Govt. Primary School	0.88	
		Pucca	Shukdeb High School	0.81	
		Pucca	Dokkhin Poschim Char Pala Hawlader Para Reg.	0.78	
		RCC frame	Char Pala H.A Govt. Primary School	0.07	
		Pucca	Char Pala High School	0.07	
		Pucca	Char Pala Baitul Faish Senior Madrasha	0.45	
		RCC frame	Purbo Char Pala Govt. Primary School	0.48	
		RCC frame	Moddho Char Pala Govt. Primary School	0.74	
		2+1	Madanpur Dayra Govt. Primary School	0.17	

List of Tsunami Vulnerable Infrastructure (continued)

District	Upazila	Type of Structure	Name of Structure	Inundation Depth (m)	Inundation Depth
Bhola	Daulatkhan	Pucca	Uttar Purbo Char Lamchi Gucha Reg. Primary School	0.26	< 1 m
		RCC frame	Char Lamohi Rala Govt. Primary School	0.07	
		Semi Pucca	Ghaer Hut Govt. Primary School	0.17	
		Pucca	Khaer Hut High School	0.17	
		Pucca	Poachim Joynagar Hall Hanif Reg. Primary School	0.43	
		Semi pucca	Haya Hawia Govt. Primary School	0.02	
		RCC frame	South Moedua Govt. Primary School	0.35	
		RCC frame	North South Medua Govt. Primary School	0.27	
		RCC frame	Poschim Madua Govt. Primary School	0.29	
		RCC frame	Shrtram Majhi Govt. Primary School	0.56	
		Pucca	Dokkhin Boro Dholi Haji Reg. Primary School	0.95	
		RCC frame	Kalla Govt. Primary School	0.93	
		Pucca	Saidpur Sat Baria Reg. Primary School	0.99	
		Pucca	25 Dokkhin Saidpur Mohajon Reg. Primary School	0.87	
		RCC frame	48 Saidpur Govt. Primary School	0.81	
		RCC frame	North South Saidpur Hawlader Para Reg. Primary sch	0.02	
		Pucca	Dokkhin Chor Shuvi Reg. Primary School	0.07	
		Tin Shed	Chor Shuvi High School	0.07	
		Pucca	Saidpur High School	0.9	
		Pucca	Moddiha Chor Shuvi Reg. Primary School	0.77	
		RCC frame	Madanpur Board Govt. Primary School	0.06	
		Tin shed	15 South Saidpur Nurullah REg. School	0.06	
		RCC frame	58 Redha Bollov Govt Primary School	0.5	
		RCC frame	Maddha Bhabanipur Govt. Primary School	0.45	
		Tin shed	Bamonpur Govt. Primary School	0.6	
		Pucca	Durlovpur Govt. Primary School	0.8	
		1+3	Dakaila Govt. Primary School	0.57	
		RCC frame	50 Maddha Hajipur Govt. Primary School	0.7	
		Tin shed	South Nal Dugi Boikantho Reg Primary School	0.54	
		RCC frame	North South Chor Boro Lamchi Govt Primary School	0.35	
		RCC frame	Gupto Gong Govt Primary School	0.15	
		Pucca	Hajipur High School	0.45	
		Tin shed	Dokkhin Poschim Hajipur Govt Primary School	0.58	
		Tin shed	Hajipur S M govt Primary School	0.52	
		RCC frame	Uttar Bijoypur Govt Primary School	0.78	
		Tin shed	Boro Dhail Govt Primary School	0.87	
	Lalmohan	RCC frame	Poschim Char Kocchopt Reg Primary School	0.08	
		RCC frame	Najirpu8r Govt Primary School	0.19	
		Pucca	Najirpur De Hossain Alim Madrasha	0.22	
		Pucca	Dokshin Badarpur Reg Primary School	0.32	
		RCC frame	Poschim Char Tilia Govt Primary School	0.02	
		Pucca	Hajir Hul Tia High School	0.03	
		RCC frame	Dhali Gaumagr 2 Govt Primary School	0.3	
		Pucca	Dhail Gaumagar High School	0.14	
		RCC frame	Purbo Dhali Gaumagar Reg Primary School	0.14	
		RCC frame	Kamarer Hut Govt. Primary School	0.07	
		RCC frame	Purbo Kunder Hawla Govt Primary School	0.7	
		Semi pucca	Poschim Kunder Hawla Govt Primary School	0.45	
		RCC frame	Kumer Kahali Reg Primary School	0.01	
		RCC frame	Lord Hardinja Ino Govt Primary School	0.08	
		RCC frame	Lord Hardinja 2 no Govt Primary School	0.45	
		Pucca	Lord Hardinja Islamia Senior Madrasha	0.48	
		RCC frame	Sheidabad Govt Primary School	0.48	
		Pucca	Poshim Shiadabad Reg Primary School	0.02	
		RCC frame	Sheidabad Reg Crrescent Astory Kendro	0.02	
		Semi Pucca	Moddha Annoda Presed Govt Primary School	0.77	
		RCC frme	Maheskhali Govt Primary School	0.07	
		RCC frame	Kochoskhali govt. Primary School	0.07	
		RCC frame	Char Udolikali Reg Primary School	0.68	
		Pucca	Uttar Purbo Falimabad Reg Primary School	0.55	
	Manpura	Pucca	Mechua Kali Reg Primary School	0.62	
		RCC frame	Uttar Sakuchis Govt Primary School	0.51	
		RCC frame	Uttar Sakuchia High School	0.34	
		Pucca	Sakuchia Boduzzaman Dakhil Madrasha	0.34	
		Pucca	Alampur Reg Primary School	0.83	
		RCC frame	A R Khan Govt Primary School	0.17	
		RCC frame	Dokhin Sakuchia Govt Primary School	0.07	
		Pucca	Dokhin Kali Piari Mohon Reg Primary School	0.27	
		Pucca	Hajir Char Faizuddin Reg Primary School	2.46	1 m<d <3m
		Pucca	Bhjiyanhut Reg. Primary School	2.12	
		Pucca	Uttar Char Foizuddin Govt Primary School	2.27	
		RCC frame	Char Foizuddin Char Reg Primary School	2.21	
		RCC frame	Hajirhat Ideal Govt Primary School	2.34	
		Pucca	Hajirhat High School	1.61	
		Pucca	Char Khailin Reg Primary School	1.49	
		RCC frame	Eashor Gonj Reg Primary School	1.33	

List of Tsunami Vulnerable Infrastructure (continued)

District	Upazila	Type of Structure	Name of Structure	Inundation Depth (m)	Inundation Depth
	Manpura	Pucca	Manpura Fajil Madrasha	1.33	1m<d<=3m
		Pucca	Manpura High School	1.3	
		Pucca	Char Dhab Reg Primary School	1.54	
	Tazumuddin	Pucca	Chor Lakkhi Govt. Primary School	0.63	<1m
		Pucca	Dokkahin Chanchra Rahmania Reg. Primary School	0.87	
		RCC frame	Moddha Chanchra Govt Primary School	0.53	
		RCC frame	Dokshin Chanclva Tara Gazi Reg. Primary School	0.08	
		Pucca	Fajilatunnssa REg. Primary School	0.42	
		Pucca	Fajilatunnassa Govt. Primary School	0.35	
		Pucca	Moddha Chadpur Govt. Primary School	0.36	
		Pucca	Chadpur Islamia Senior Madrasha	0.15	
		RCC frame	Janganthpur 2 Govt. Primary School	0.02	
		RCC frame	Chandpur Model Govt. Primary School	0.36	
		RCC frame	Ram Krishno Sen Govt. Primary School	0.03	
		Pucca	Uttar Jeypur Govt. Primary School	0.01	
		RCC frame	Char Zahiuddin Reg. Crescent Primary School	0.2	
		Semi Pucca	Nischinlopur Sikdar High School	0.12	
		RCC frame	Jagannathpur Govt. Primary School	0.3	
		Semi pucca	Poshim Bichanmpur Govt Primary School	0.8	
		RCC frame	Uttar Chanchra Govt Primary School	0.75	
		RCC frame	Uttar Chanchra Momin Uddin Reg Primary School	0.58	
		RCC frame	Dokahin Chandra Govt Primary School	0.59	
		RCC frame	Chandpur Govt Primary School	0.85	
		RCC frame	Kanchonpur Govt. Primary School	0.88	
		Pucca	Kaya Multo Mir Reg. Primary School	0.57	
		Semi pucca	Khos Nadi Board Govt Primary School	0.69	
		Pucca	Dori Chandpur Mostafizur Rahman Reg. Primary Schl	0.58	
Chittagong	Anowara	Semi pucca	South bandar Govt. Primary School	0.02	
		Brick wall	Barasat Govt. Primary School	0.01	
		Brick wall	East boalla Govt Primary School	0.02	
		RCC frame	Gundip Adorsha Reg. Primary School	0.01	
		RCC frame	Hajral Charpir Sulia Sinior Madrasha	0.01	
		RCC frame	Chira Battola Primary School	0.01	
		RCC frame	Gundip Govt. Primary School	0.01	
		Semi pucca	Baliali Govt Primary School	0.01	
		RCC frame	Vaktia Para Cherpir Govt Primary School	0.02	
		RCC frame	Upakullo adorsho Secondary School	0.21	
		RCC frame	East Gahira Non-govt. primary school	0.35	
		Brick wall	Heatlh and Paribar Kallan Kendro	0.2	
		RCC frame	South Parue Govt Primary School	0.19	
		RCC frame	Chunna Para Manirul	0.21	
	Banshkhali	RCC frame	North Chunna Para Govt. Primary School	0.44	
		RCC frame	Pashchim Baharachhara 28 No. Govt. P. School	0.13	
		RCC frame	20 No. Uttar Beherchhara Govt. P. School	0.14	
		RCC frame	Mohajarpara Reg. Crescent Sheilar Center	0.19	
		RCC frame	Upokullo Channua Khudukkhali Hossain Madrasha	0.04	
		RCC frame	Chhanua Kaderia High School	0.31	
		RCC frame	Seiban Reg. Primary School	0.05	
		RCC frame	Union Shetho Peribar Kallyan Kendro	0.29	
		Fenced	Modinatul Monowar Madrasha	0.85	
		RCC frame	Modhukhali Community Clinic	0.01	
		Fenced	Poshchim Mattobbor Para P. School	0.36	
		RCC frame	Mohajar Para Red Crescent Shelter Center	0.09	
		RCC frame	Gendamara Chanpar Azizia Rg. Primary School	0.2	
		RCC frame	Poshchim Banshkhali Gandamara Rahimania Madrasha	0.07	
		RCC frame	West Gandamara Govt. Primary School	0.05	
		RCC frame	West Gandamara Matborpara Primary School	0.94	
		RCC frame	Kahankabad Abdul Salam Srity Primary School	0.33	
		RCC frame	Khankabad Ideal High School	0.06	
			Modo Kodomrosul Reg. Primary School	0.1	
		RCC frame	Kodom Rosul Hamedia Dakil Madrasha	0.16	
		RCC frame	Red Crescent Sheller Center	0.37	
		RCC frame	Khankhanabad Govt Primary School	0.36	
		RCC frame	Health Center	0.33	
		RCC frame	North Khankabad Private Primary School	0.08	
		Pucca	16 No. Kodom Rosul Govt. Primary School	0.96	
		RCC frame	26 No. North Kodom Roseul Govt. Primary School	0.21	
		RCC frame	Dongrakupia Govt. Primary School	0.06	
		RCC frame	Jaliagala Kanun Gokhal Komi Primary School	0.01	
		Mud Wall	Minirtola Hakimia Dakhil Madeasha	0.11	
		RCC frame	West Raychota Govt. Primary School	1.19	1m<d<3m
		RCC frame	North Raycora Govt. Primary School	1.23	
		RCC frame	North Pramania Govt. Primary School	3.28	3m<d<=6m
	Chandanaish	Brick Wall	Pathandondi Taheria Sabaria Munia Senior M	2.9	1m < d < ,3m

List of Tsunami Vulnerable Infrastructure (continued)

District	Upazila	Type of Structure	Name of Structure	Inundation Depth (m)	Inundation Depth
	Chittagong Port	RCC frame	D.C Office	0.25	
	Mirsharai	RCC frame	Domkhali Govt Primary School	0.01	
		RCC frame	Domkhali Govt Primary School	0.01	
	Patiya	RCC frame	West Che Lakshya Community Primary School	0.19	
		RCC frame	West Char Lskshya Govt. Primary School	0.05	
		RCC frame	Cher Lakshya Sirajul Manir Dakhil Madrasha	0.03	
		RCC frame	North Char Lakshya Govt Primary School	0.1	
		RCC frame	Ajurbibi City Corporation School & College	0.01	
		RCC frame	Khoaj Nagar Community Primary School	0.4	
		RCC frame	Schia Motalab Rizia Junior School & College	0.39	
		RCC frame	Khoaj Nagar Govt Primary School	0.07	
		RCC frame	Esst Jukthe Govt Primary School	0.04	
		Brick Work	Juktha Sha Amir Secondary School	0.04	
		RCC frame	North Juktha Reg. Primary School	0.02	
		RCC frame	Union Sastha o Paribar Kallan Kendra	0.48	
	Patiya	RCC frame	Dunggar Char Junior High School	0.44	
		RCC frame	Dunger Char Govt Primary School	0.86	
		Brick wall	Lakhera Govt Primary School	0.01	
		RCC frame	Takhera Secondary School	0.02	
		RCC frame	Amena Rahman Govt. Primary School	0.89	
		RCC frame	Sikalbaha Govt. Primary School	0.04	
		RCC frame	S A Kader Secondary & Primary School	0.01	
		RCC frame	West Sha Mirpur Govt. Primary School	0.5	
		RCC frame	North Sikalbaha Schsania Govt. Primary School	0.58	
		RCC frame	Katgor G L Govt primary school	0.01	
		RCC frame	West Azimpur Govt Primary School	0.29	
		RCC frame	Family Health Care Centre	0.02	
		RCC frame	Azimpur High School	0.02	
		RCC frame	Dl Palo Private School	0.01	
		RCC frame	Bauria East West Govt Primary School	0.07	
		RCC frame	West Bauria Habibia Reg. School	0.13	
		RCC frame	Sonowip Gaghhua Scouts REg. Primary School	0.22	
		RCC frame	Rohima Govt. Primary School	0.02	
		RCC frame	Hazi Abdul Malek Dakil Madrasha	0.02	
		RCC frame	Dublapara Govt Primary School	0.41	
		RCC frame	Hazi Bodirudoln Reg Primary School	0.85	
		RCC frame	Modo Horsish Pur Govt Primary School	0.04	
		TIN	Sondiep Govt Primary School	0.05	
		RCC frame	Sondip Hospital	0.04	
		TIN	Momena Govt Primary School	0.06	
		RCC frame	Kagil Govt Primary School	0.26	
		RCC frame	Sondip Tawon Govt Primary School	0.07	
		RCC frame	Ralapania Health Complex	0.25	
		RCC frame	Kalpania Gojoth Govt Primary School	0.2	
		RCC frame	Kalpania Govt Primary School	0.16	
		RCC frame	Kalpania High School	0.15	
		RCC frame	Modo Kalapania Govt Primary School	0.05	
	Sandwip	RCC frame	Kalapania Dirgapara Govt Primary School	0.07	
		RCC frame	North Kalapania Mistafizur Rahman Reg. School	0.01	
		RCC frame	Magdhana Mallvanga Fari Ghat Reg. School	0.22	
		RCC frame	East Magdhara Govt. Primary School	0.25	
		RCC frame	East Salosahar Fulmla Reg. School	0.52	
		RCC frame	Urirchar G U Salkat Primary School	0.03	
		RCC frame	Nurerhut Govt. Primary School	0.17	
		RCC frame	South Sandwip College	0.05	
		Tin Shed	Maitbhanga Govt. Primary School	0.14	
		RCC frame	Maitbhanga Di Mukhi High School	0.11	
		RCC frame	Boshinia Ahmadia Siddique Madrasha	0.41	
		Tin shed	Rehmatpur Dakshin Purba Govt Primary School	0.02	
		RCC frame	Rehmatpur Anontomol Govt Primary School	0.2	
		RCC frame	MKoddho Rahmatpur Govt Primary School	0.33	
		RCC frame	Rahmatpur Paschim Govt Primary School	0.49	
		RCC frame	West Sontoshpur Govt Primary School	0.44	
		RCC frame	West Saikat Govt. Primary School	0.3	
		Tin Shed	Puch Baria Govt. Primary School	0.31	
		Tin shed	North Sarikait Reg. Primary School	0.37	
		TIN	Chowdury Biddha Niketon High School	0.45	
		RCC frame	South Kalapania Govt. Primary School	0.85	
		RCC frame	Bijaisarani Degree College	0.09	
		RCC frame	Vetleri Haji Tarokali Govt. Primary School	0.17	
	Sitakunda	RCC frame	Bheliari Govt. Primary School	0.17	
		RCC frame	Madam Bibir Hut Secondary School	0.42	
		RCC frame	Talafuli Chabld Nasim Primary School	0.14	
		RCC frame	Kumira Shasik Girls Secondary School	0.13	

List of Tsunami Vulnerable Infrastructure (continued)

District	Upazila	Type of Structure	Name of Structure	Inundation Depth (m)	Inundation Depth
		RCC frame	Kolpara Govt. Primary School	0.86	
		RCC frame	Hazrat Khadijaiul Dakhil Madrasha	0.83	
		RCC frame	Kumira Govt. Primary School	0.55	
		RCC frame	Kumira Abasik Secondary SChool	0.13	
		RCC frame	Kajipara Govt. Primary School	0.26	
		RCC frame	Majida Govt. Primary School	0.02	
		RCC frame	Masjidda Secondary School	0.02	
		RCC frame	Masjidda Govt. Primary School	0.04	
		RCC frame	Latifa Siddiq Girls School	0.04	<1m
Chittagong	Sitakunda	RCC frame	Latifa Siddiq Degree College	0 0r	
		RCC frame	Latifpur Alhaj Abdul Jalil Secondary School	0.01	
		RCC frame	Cha u ka Salimpur Reg. Primary School	0.01	
		RCC frame	M A Kasam Reg. Non-Govt. Primary School	0.94	
		RCC frame	M A Kasem Secondary School	0.05	
		RCC frame	Sonaichari Secondary School	0.51	
		RCC frame	Ghoramara Govt. Primary School	0.16	
		Semi pucca	Latifpur alhaj Abdul Jalil Secondary School	1.24	
		Semi pucca	Silalpur Govt. Primary School	1.33	
		RCC frame	Silalpur Bahumukhi Secondry School	1.23	1m<d<=3m
		RCC frame	Rajapur Govt. Primary School	2.84	
		Pucca	Badarkhali Majharul Munna Senior Madrasha	0.42	
		Semi pucca	Badarkhali Majharul Munna Senior Madrasha	0.43	
		RCC frame	Badarkhali Kaloni Jeson High School	0.44	
		RCC frame	Badarkhali Govt. Primary School	0.45	
		RCC frame	Midalbana Govt. Primary School	0.47	
		RCC frame	Badarkhali College	0 48	
		Semi pucca	Badarkhali College	0.46	
		RCC frame	Sayed Khurhida Begum Reg. Primary School	0.22	
		RCC frame	Habiba non-govt. Primary School	0.4	
		RCC frame	Ajimngor Mojida Dakhil Madrasha	0.02	
		RCC frame	Ajomnagor Govt. Primary School cum cpp	0.02	
		RCC frame	Al Ajhar High School	0.03	<1m
		Semi pucca	Al Ajhar High School	0.03	
		RCC frame	Kutub Nagor Govt. Primary School cum cpp	0.43	
		RCC frame	Kutub Nagor Govt. Primary School cum cpp	0.43	
		RCC frame	Derbesh Kala High School	0.14	
		RCC frame	Derbesh Kala High School	0.15	
	Chakaria	RCC frame	Derbesh Kala Govt. Primary School cum cpp	0.05	
		RCC frame	Rfwc	0.02	
		RCC frame	Rejkhali Falema Khatun Reg. Primary School	0.26	
		RCC frame	Rejakhali Islamia Dakhil Madrasha	0.42	
		RCC frame	Rejakhali Islamia Dakhil Madrasha	0.41	
		Semi pucca	Rakkhali Foyjunnessa High School	0.16	
		RCC frame	Tuar All High School	1.19	
		RCC frame	Rajakhali Govt. Primary School cum cpp	1.19	
		RCC frame	Blkshia Ghons Reg Primary School	1.45	
		RCC frame	U.P rejakhali Reg. Primary School	1.62	
Cox's Bazar		RCC frame	Rajakhali Foyjunnessa High School	1.02	
		RCC frame	Foyjunnessa Govt. Primary School	1.04	1m<d<=3m
		RCC frame	Foyjunnessa Govt. Primary School	1.04	
		RCC frame	Foyjunnessa Govt. Primary School	1.05	
		RCC frame	Jamal Mohor Govt. Primary School cum cpp	1.3	
		RCC frame	South Rekheln Reg. Primary School	0.1	
		RCC frame	South Rakhain Para Reg. Primary School	0.1	
		Pucca	North Rakiain Reg. Primary School	0.2	
		RCC frame	Haki Mia Primry School cpp	0.24	
		RCC frame	Khonkhamil Govt. Primary School cum cpp	0.16	
		RCC frame	West Choufaldandi Govt. Primary School cum cpp	0.15	
		Semi pucca	Sayadia Ebiadia Madrasha	0.14	
		RCC frame	Khurushkul Kacarpara Reg. Primary School	0.05	<1m
	Cox's Bazar Sada	RCC frame	Khurushkul Govt. Primry School cum cpp	0.05	
		RCC frame	Moddha Khushkul Govt. Primary Schol cum cpp	0.28	
		RCC frame	Lelia Govt Primary School cum cpp	0.09	
		RCC frame	South Khunushikul Govt. Primary School cum cpp	0.1	
		RCC frame	South Khunushikul Govt. Primary School cum cpp	0.1	
		RCC frame	Fire Brigades	0.65	
		RCC frame	West Pokkhali Govt. Primary School com cyclone	0.01	
		Semi pucca	North Rakhain Reg. Primary School	1.38	
		RCC frame	D. C. Office	1.01	
		Semi pucca	Red Crescent Office	1.78	
		RCC frame	Ali Akbar Deli Dakhil Madrasha	0.73	
		RCC frame	Ali Akbar Deli Dakhil Madrasha	0.72	
	Kutubdia	RCC frame	Purba Ali Akbar Deli Govt. Primary School cum cpp	0.81	
		RCC frame	Labalerchor Reg. Primary School	0.87	
		RCC frame	Kutub Solia Dakhil Madrasha	0.93	

List of Tsunami Vulnerable Infrastructure (continued)

District	Upazila	Type of Structure	Name of Structure	Inundation Depth (m)	Inundation Depth
Cox's Bazar	Kutubdia	RCC frame	Baraghop Reg. Primary School sum cpp	0.51	<1m
		RCC frame	Kutubdia Govt. High School	0.52	
		RCC frame	Kutubdia High School	0.21	
		RCC frame	Kutubdia Model Govt Primary School cum cpp	0.44	
		RCC frame	Kutubdia Model Primary School cum cpp	0.44	
		RCC frame	Kutubdia Adorsho High School	0.28	
		RCC frame	Kutubdia Adorsho High School	0.4	
		RCC frame	Kutubdia Adorsho High School	0.41	
		RCC frame	Baraghop Mala Fajil Madrasha cum cpp	0.28	
		RCC frame	Kutubdia Mala Mia Fajil Madrasha cum cpp	0.28	
		RCC frame	Kutubdia College	0.28	
		RCC frame	Kutubdia College	0.9	
		RCC frame	Monuhor Khala Govt. Primary School	0.8	
		RCC frame	Monuhar Mala Govt Primary School	0.79	
		RCC frame	Pilolkafa Govt. Primary School cum cpp	0.9	
		RCC frame	Pliolkafa Govt. Primary School cum cpp	0.9	
		RCC frame	Murolia Govt. Primary School cum cpp	0.87	
		RCC frame	Amjakhali Reg. Primary School	0.51	
		RCC frame	Purba Dhunung Govt Primary School	0.45	
		RCC frame	Pecharpara Efal cpp	0.44	
		RCC frame	Dekshin Dhurung Govt. Primary School cpp	0.14	
		RCC frame	Dhunung Adorsho Pilot High School	0.16	
		RCC frame	Dhunung Adorsho Pilot High School	0.19	
		RCC frame	Khilasori Govt Primary School cum cpp	0.55	
		RCC frame	Khilasori Govt Primary School	0.55	
		RCC frame	Moddhom Kaiyarbil Govt. Primary School cum cpp	0.33	
		RCC frame	Kalyarbil Ideal High School cum cpp	0.34	
		RCC frame	FWC	0.23	
		RCC frame	Kaiyarbil Abu Hanif Dakhil Madrasha	0.5	
			Kalyarbil Abu Hanif Dakhil Madrasha	0.56	
		RCC frame	Kalyarbil Govt Primary School cum cpp	0.54	
		RCC frame	Nurania Girls Madrasha	0.52	
		RCC frame	Nurania Girls Madrasha	0.51	
		RCC frame	Uttar Ismsikhali Govt Primary School	0.74	
		RCC frame	Dakhin Dhupipara Reg. Primary School	0.63	
		RCC frame	Shahajirpara REg Primary School	0.68	
		RCC frame	Lamshikhali High School	0.83	
		RCC frame	Lamshikhali High School	0.84	
		RCC frame	Cantral Ismsikhali Reg. Non-govt. Primary School	0.78	
		Semi pucca	Al Fanuk Dakhil Madrasha	0.51	
			Al Fanuk Dakhil Madrasha	0.74	
		Brick Wall	CPP	0.74	
		RCC frame	Pochim Lemsikhali Govt Primary School cum cpp	0.57	
		RCC frame	Dakshin Lemsikhali Govt Primary School	0.66	
		RCC frame	Dhurung Samdia Alim Madrasha	0.48	
		RCC frame	Dhurung Samdia Alim Madrasha	0.48	
		RCC frame	Samdia Govt Primary School cum cpp	0.47	
		RCC frame	Samadia Govt Primary School cum cpp	0.48	
		RCC frame	Samadia Govt Primary School cum cpp	0.45	
		RCC frame	Uttoran Rimno Maddhomik School	0.36	
			Uttoran Nimno Maddhomik School	0.38	
		RCC frame	Chandhurung Primary School cum cpp	0.39	
		RCC frame	Char Dhurung Govt Primary School	0.39	
		RCC frame	Poshim Dhurung Govt Primary School	0.41	
		RCC frame	Algoria Govt Primkary School cum cpp	0.18	
		RCC frame	Musa Shiraj Govt Primkary School	0.24	
		RCC frame	Baindanghala Reg. non-Govt School	0.24	
		RCC frame	Bakkhali Govt Primary School	0.38	
		RCC frame	Kekuakata Govt Primary school	0.18	
		RCC frame	Sabor Uddin Para Govt Primary School cum cpp	0.61	
		RCC frame	Fit left Kaimul Huda Govt Primary School cum cpp	1.06	1m<d<3m
		RCC frame	Ali Akbar Deli High School	1.02	
		RCC frame	CPP	1.03	
		RCC frame	Ali Akbor Deli Govt Primary School cum cpp	1.4	
		RCC frame	Kobi Jasimuddin High School	1.4	
		RCC frame	Kobi Jashimuddin High School	1.4	
		RCC frame	CPP	1.24	
		RCC frame	Isbeler Chor Govt School cum cpp	1.33	
		RCC frame	Bara Ghop Mala	1.15	
		RCC frame	Anoara Reg. Primary School	1.29	
		RCC frame	Rajakhali Primary School cum cpp	1.48	
		RCC frame	M Reg. Non-govt. Primary School cum cpp	4.06	3m<d<6m
		RCC frame	M Reg. Non-govt. Primary School	4.07	
		RCC frame	M. Reg. Primary School	4.44	
		RCC frame	Rahman Reg. Primary School	3.91	
		RCC frame	Hossain Reg. Primary School	4.28	
		RCC frame	Rahman REg. Primary School	4.72	

List of Tsunami Vulnerable Infrastructure (continued)

District	Upazila	Type of Structure	Name of Structure	Inundation Depth (m)	Inundation Depth
Cox's Bazar	Maheshkhali	RCC frame	Gorkghata Upojela Shashio Complex	0.01	< 1 m
		RCC frame	Gorakghata Upojila Shashto Complex	0.01	
		RCC frame	Gorakghata Upojila Shashto Complex	0.01	
		RCC frame	Gorakghata Govt Primary School	0.05	
		RCC frame	Gorakghata Govt Primary School	0.05	
		RCC frame	Lidarghip University College	0.16	
		RCC frame	Lidership University College	0.1	
		RCC frame	Chorpara Reg. Primary School cum cpp	0.34	
		RCC frame	Maheshkhali Govt. Girls School	0.01	
		RCC frame	Maheshkhali Govt. Girls School	0.01	
		RCC frame	Maheshkhali Govt. Girls School	0.01	
		RCC frame	Maheshkhali Model Govt Primary School	0.02	
		RCC frame	Maheshkhali Model Govt Primary School	0.02	
		RCC frame	Maheshkhali Model Govt Primary School	0.02	
		RCC frame	Maheshkhali Adorsho High School	0.02	
		RCC frame	Maheshkhali Adorsho High School	0.02	
		RCC frame	Hoanak Nimne Maddhomik Adorsho Biddapith	0.14	
		RCC frame	Poschim kalagagir para REg. Primary School	0.26	
		RCC frame	Time bajar Govt. Primry Schol cpp	0.03	
		RCC frame	Time bajar Govt. Primary School cpp	0.21	
		RCC frame	Time bajar hoanak Islamia Madrasha	0.2	
			Hoanak Dakhil Madrasha	0.19	
		RCC frame	Horier Chona Govt. Primary School	0.36	
		RCC frame	Hoanak Balika High School	0.24	
		RCC frame	Hoanak Balika High School	0.18	
		RCC frame	Hoanak College	0.13	
			Hoanak College	0.13	
		RCC frame	Hoanak Bohumukhi High School	0.44	
		RCC frame	Hoanak Bohumukhi High School	0.43	
		RCC frame	Hoanak Bohumukhi High School	0.12	
		RCC frame	Baniapara Govt. High School	0.49	
		RCC frame	Baniapara Govt. High School	0.42	
		RCC frame	Baniakata cpp	0.44	
		RCC frame	Hoanak Govt. Primary School	0.37	
		RCC frame	Hoanak Govt. Primary School	0.37	
		RCC frame	Chanak Roshidia Dakhil Madrasha	0.36	
		RCC frame	Abdul Mabud High School	0.23	
		RCC frame	Kallakafa Govt. Primary School	0.25	
		RCC frame	Kimlols Govt. Primary School	0.24	
		RCC frame	Dhoighala REg. Primary School	0.28	
		RCC frame	Penir Chora Govt. Primary School	0.11	
		RCC frame	Panirchore Govt. Primary School	0.11	
		RCC frame	Panirchora Adorsho High School	0.11	
		RCC frame	Panirchora Adorsho High School	0.11	
			Panirchora Dakhil Madrasha	0.09	
		RCC frame	Niggimpara Govt. Primary School	0.14	
		RCC frame	Niggimpara Govt. Primary School	0.14	
		RCC frame	Adharghona Govt. Primary School	0.11	
		RCC frame	Kalamarchbara Dakhil Balika Madrasha	0.11	
		RCC frame	Kalamarchbara Dakhil Balika Madrasha	0.1	
		RCC frame	Nonachbori Govt. Primary School cum cpp	0.04	
		RCC frame	Nonachbori Govt. primary School cum cpp	0.04	
		Tin shed	Kalamarchbara Moinul Islamia Alim Madrasha	0.09	
		RCC frame	Kalamarchbara Moinul Islamia Alim Madrasha	0.03	
		RCC frame	Kalamarchbara High School	0.08	
			Kalamarchbara Dakhil Madrasha	0.09	
		RCC frame	Kalamarchbara Govt. Primary School cum cpp	0.1	
		RCC frame	Chinkipara Govt. Primary School cum cpp	0.04	
		RCC frame	Chinkipara Govt. Primary School	0.04	
		RCC frame	Sordar Ghona Govt Primary School cum cpp	0.19	
		RCC frame	Younus Ali Govt Primary School cum cpp	0.1	
		RCC frame	Younus Ali Nasir Uddin High School	0.1	
		RCC frame	Younus Ali Nasir Uddin High School	0.1	
		RCC frame	Uttor Nalbila Maohammadia Dakhil Madrasha	0.1	
		RCC frame	Uttor Nalbila Primary School	0.28	
		RCC frame	South Salbar Del Reg. Primary School	0.82	
		RCC frame	Tolotia Girls Madrasha	0.56	
		RCC frame	Puran Bajar Govt Primary School cum cpp	0.75	
		RCC frame	Puran Bajar Govt Primary School	0.74	
		RCC frame	Malarbari Govt Primary School cpp	0.63	
		RCC frame	Malarbari High School	0.64	
		RCC frame	Malarbari High School	0.64	
		RCC frame	FWC	0.47	
		RCC frame	North Raj Ghat REg Primary School	0.34	
		RCC frame	Raj Ghat Govt Primary School cum cpp	0.16	
		RCC frame	Dhalghala Adorsho High School cum cpp	1.76	1m<d<=3m

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List of Tsunami Vulnerable Infrastructure (continued)

District	Upazila	Type of Structure	Name of Structure	Inundation Depth (m)	Inundation Depth
Cox's Bazar	Maheshkhali	RCC frame	Dhalghala Adorsho High School cum cpp	1.71	1m < inundation n <= 3m
		RCC frame	Sapmar Del Govt Primary School cum cpp	1.95	
		RCC frame	Sapmar Del Govt Primary School cum cpp	2.38	
			Asma Binte Abu Bakor Girls Madrasha	1.87	
		Pucca	FWC	1.87	
		RCC frame	Moha Jailemia Senior Madrasha	1.88	
		Semi pucca	Moha Islamia Madrasha	1.49	
		RCC frame	Chaliatoli Reg Non-govt Primary School	1.76	
Feni	Sonagazi	RCC frame	Dakkhin Char Chandia Communist Primary School	0.03	< 1 m
		RCC frame	Deserhat Govt. Primary School	4.89	3m < d <= 6m
		Semi pucca	Mangazo Primary School	4.81	
Khulna	Dacope	Pucca	Amtala Northpara Reg. Non Govt Primary School	0.25	1m < inundation
		Kacha Tiner	Amiala Banishania Nimno Maddhomik School	0.76	
		Pucca	Family Heath Centre	0.79	
		Semi pucca	Poshu Hospital	0.8	
		Pucca	Dhangmari Vochonkhali Reg Non Govt Primary School	0.78	
		Pucca	South Gunary Open Nagar REg Non Govt Primary School	0.57	
		Pucca	Nolian Alim Madrasha	0.28	
		Tin shed	Nolian High School	0.45	
		Pucca	Family Heath Centre	0.04	
		Tin shed	35 No. Nolian Kajaripara REg Non Govt Primary School	1.04	
	Koyra	Pucca	South Bedkhashi High School	0.37	1m < Inundation
		Pucca	South Bedkhashi High School	0.41	
		Semi Pucca	Bondobon Siddiqui Dakhil Madrasha	0.38	
		Pucca	Ghorliel REg Non Govt Primary School	0.54	
		Pucca	Padma Pukur Sanlimoyi Non Govt. Primary School	0.84	
		Pucca	Padma Pukur Sanlimoyi Non Govt Primary School	0.84	
		Pucca	Kopolakho High School	0.85	
		1+2	Galkhali Govt Primary School	2.11	1m <d <=3m
	Lakshmipur Sadar	Tin	Kaderia Siadia Dakil Madrasha	0.02	<1m
		RCC frame	Shakohor Union Health Centre	0.06	
		RCC frame	East Chor Romani Mohon Govt Primary School	0.08	
		RCC frame	South Rosulpur Govt Primary School	0.23	
		Semi pucca	South Rosulpur Govt Primary School	0.22	
Lakshmipur	Ramgoti	RCC frame	Ramjoti Govt Primary School	0.04	<1m
		RCC frame	Ramgoti Govt Primary School	0.05	
		RCC frame	South Char Abdullah Govt Primary School	0.78	
		RCC frame	Balur Chor High School	0.01	
		RCC frame	Balur Chor Govt Primary School	0.12	
		RCC frame	Chor Gachpar Govt Primary School	0.09	
		RCC frame	Chor Cachpar Govt Primary School	0.15	
		RCC frame	Lombaxali Govt Primary School	0.02	
		RCC frame	Bisho Gram Govt Primary School	0.31	
		TIN	Sobuz Gram Reg Primary School	0.01	
		RCC frame	Chor Alexander Govt Primary School	0.3	
		Semi pucca	Chor Alexander Govt Primary School	0.29	
		RCC frame	South Balur Chor Govt Primary School	0.01	
		Semi pucca	South Balur Chor Govt Primary School	0.01	
		TIN	Balur Chor Islamia Sinior Alim Madrasha	0.01	
		RCC frame	Bangla Bazar Dakil Madrasha	0.06	
		RCC frame	West Balur Chor Govt Primary School	0.34	
		Semi pucca	West Balurchor Govt Primary School	0.23	
		TIN	North South Chor Alexander Govt Primary School	0.39	
		RCC frame	Ramgoti Ammadia College	0.16	
		RCC frame	Ramgoti Station Govt Primary School	0.48	
		RCC frame	Ramgoti Station Primary School	0.43	
		Semi pucca	Ramgoti B B K Pilot Adorsho High School	0.48	
		Semi pucca	Ramgoti BBK Adorsho High School	0.43	
		RCC frame	Ramgoti BBK Adorsho Pilot High School	0.42	
		RCC frame	Ramgoti BBK Adorsho Pilot High School	0.51	
		RCC frame	Ramgoti Chor Loki Govt Primary School	0.57	
		RCC frame	North Chor Loki Govt Primary School	0.49	
		RCC frame	South Chor Gaji Govt Primary School	0.02	
		RCC frame	South Chor Gaji Govt Primary School	0.02	
		Semy pucca	BIBIR Hat Rasedia High School	0.01	
		RCC frame	Bibirhat Rasedia High School	0.01	
		RCC frame	BIBIR Hat Rasedia High School	0.02	
		RCC frame	Health Centre	0.06	
		RCC frame	Ramgoti Robania Fazil Madrasha	1.23	1m<inundatio n<=3m
		Semi pucca	Ramgoti Robania Fazil Madrasha	1.25	
		Semi pucca	Ramgoti Robania Fazil Madrasha	1.23	
		RCC frame	Ramgoti Girls Govt Primary School	1.24	
		RCC frame	Ramgoti Girls Govt Primary School	1.28	
		Semi pucca	Ramgoti Girls School	1.25	
		RCC frame	Ramgoti Girls School	1.28	
		RCC frame	Roguna Thpur Govt. Primary School	1.22	
		Semi Pucca	Rogunath Pur govt. Primary School	1.31	

List of Tsunami Vulnerable Infrastructure (continued)

District	Upazila	Type of Structure	Name of Structure	Inundation Depth (m)	Inundation Depth
	Ramati	Semi pucca	Rogunia Th pur Polli Motsho High School	1.08	1m<d<=3m
		RCC frame	North Ghor Ababil Community Primary School	0.04	
		RCC frame	West Chor Ababil Govt Primary School	0.01	
		RCC frame	Haider Gong Rokeya Girls High School	0.01	
		RCC frame	Haider Gong Rokeya Girls School	0.01	
		Pucca	Haidergong Rokya Girls School	0.01	
		RCC frame	Chor Ababil Govt Primary School	0.02	
		RCC frame	Chor Abibil Rosimuddin High School	0.02	
		RCC frame	Chor Ababil Rosimuddin High SChool	0.02	
		RCC frame	Halder Gong T R M Govt Primary School	0.01	
		RCC frame	1 No Char Bangshi Govt Primary SChool	0.29	
		Semi pucca	1' No Char Bangshi Govt Primary School	0.29	
		Semi pucca	Char Induria Govt Primary School	0.29	
		RCC frame	Char Induria Govt Primary School	0.3	
		RCC frame	Char Bangshi Girls Dakil Madrasha	0.07	<1m
Lakshimpur	Raipur	RCC frame	Char Bangshi Balika Dakil Madrasha	0.07	
		RCC frame	Char Induria Com Primary School	0.4	
		RCC frame	Char Bangshi Mozidia Govt Primary School	0.07	
		RCC frame	Char Bongshi S S Amigia High School	0.06	
		RCC frame	Haolader Reg Primary School	0.01	
		RCC frame	2 No Char Bangshi Govt Primary school	0.02	
		RCC frame	2 No. Char Bangshi Govt Primary School	0.02	
		RCC frame	2 No Char Bangshi Govt Primary SChool	0.02	
		RCC frame	Char Bangshi Motinalia High School	0.02	
		RCC frame	North Chor Bongshi Union Heal Th Complex	0.04	
		RCC frame	South Kuciagora Govt Primary School	0.02	
		RCC frame	South Kandi Govt Primary School	0.11	
		RCC frame	Char Mazia Reg Primary School	0.43	
		Pucca	South Musapur So Bazar Govt Primary School	0.22	
	Companiganj	RCC frame	Soli Mania Private Primary School	0.07	<1m
		Semi pucca	Soli Mania Private Primary School	0.08	
		RCC frame	Modo Koroni Govt Primary School	0.26	
		RCC frame	Modo Koroni Govt Primary School	0.22	
		RCC frame	East Choto Dail A Halim Reg School	0.41	
		RCC frame	East Choto Dail Chamrani Reg School	0.19	
		RCC frame	East Bodo Dail 1B Reg School	0.34	
		RCC frame	Bodo Dail Govt Primary School	0.26	
		RCC frame	Bodo Dail Govt Primary School	0.22	
		Tin	Chandnandi Bumihin Bazar Private School	0.06	
		Tin	Rasel Bazar Primary School	0.2	
		Tin	Jonoter Bazar Private Primary School	0.79	
		Tin	Dorbesh Bazar Private Primary School	0.01	
		Tin	Alamin Gram Private Primary School	0.03	
		Tin	Azim Nogor Tanar Hat Privae Primary School	0.03	
		Semi pucca	North South Char Ishwar Govt Primary School	0.79	
		RCC frame	Ranu Miar Hat Govt Primary School	0.14	
		RCC frame	Chor Lotia Govt Primary School	0.1	
		Tin	Char Lotia Junior High School	0.11	
		Tin	Razar Haoula Govt Primary School	0.26	
		RCC frame	Lokldia Promodia Private Primary School	0.12	
		Tin	Got Kali Private Primary School	0.57	
		RCC frame	Noblnogor Private Primary School	0.55	
		RCC frame	Ali Bazar Private Primary School	0.46	
		RCC frame	Hatia Jonokolan Junior High School	0.61	<1m
Noakhali	Hatiya	Tin	Boyer Chor Private Primary School	0.62	
		RCC frame	Jahanjmara High School	0.38	
		Tin	Hazi Fazil Ahmed Dakil Madrasha	0.18	
		Tin	Hazi Wozamel Hoq Reg Primary School	0.24	
		RCC frame	Horini Bat Govt. Primary School	0.18	
		RCC frame	AMtoli Reg Primary School	0.35	
		RCC frame	Amtoli Reg Primary School	0.34	
		RCC frame	CXhor Hear Govt Primary School	0.04	
		RCC frame	South Mamtion Reg Primary School	0.16	
		RCC frame	K A Kasan Reg Primary School	0.26	
		RCC frame	South East Mamption Govt Primary School	0.02	
		RCC frame	South Biribiri Govt Primary School	0.07	
		RCC frame	Dopkkhin Purbo Naichira Haji Kalamia Reg. Primary School	0.5	
		RCC frame	Primary Bhishu Bilkash Centre	0.58	
		RCC frame	Hazi Shah Alam Primary School	0.84	
		RCC frame	East Canondi Govt Primary School	0.18	
		RCC frame	Sourasta Hasan Reg School	0.01	
		RCC frame	Chor Gase Al Habib Reg Primary School	0.03	
		RCC frame	M C S High School	0.52	
		Tin	M C S High School	0.73	
		RCC frame	Chor Canga Islamia Fazil Madrasha	0.35	
		RCC frame	Chor Canga Govt Primary School	0.35	
		Semi pucca	Chor Canga Govt Primary School	0.35	

List of Tsunami Vulnerable Infrastructure (continued)

District	Upazila	Type of Structure	Name of Structure	Inundation Depth (m)	Inundation Depth
Noakhali	Hatiya	Tin	Chor Amanullah High School	0.19	<1m
		RCC frame	Samsudia Govt Primary School	0.14	
		RCC frame	Kirodia Reg Primry SChool	0.12	
		RCC frame	Sirazia Govt Primary School	0.15	
		RCC frame	Sirazia Govt Primary School	0.14	
		RCC frame	Health And Family Planning Centre	0.42	
		RCC frame	Tomurudi High School	0.38	
		RCC frame	Tomurudi High SChool	0.35	
		RCC frame	Tomurudi Ahmahdia Fazil Madrasha	0.31	
		RCC frame	Tomurudi Govt Primary School	0.3	
		RCC frame	Tomurudi Govt Primary SChool	0.27	
		Semi pucca	G Hoq Azifa Reg Primary School	0.01	
		Tin	Niloki City Govt Primary School	0.02	
		RCC frame	Gor Kali Agfaria Reg Primary School	0.74	
		RCC frame	Comunity Clinic	0.51	
		RCC frame	North Koralia Reg Primary School	0.66	
		Tin	Tomurudi Koralia Govt Primary School	0.44	
		Tin	Chandandi Bazar Private Primary School	1.2	1m < inundation <= 3 m
		RCC frame	Charman Gat Private Primary School	1.74	
		Tin	Haoladerhat Reg Primary SChool	1.35	
		Tin	West Sukchor Govt Primary School	2.55	
		RCC frame	Modo Chor Aminullah School	2.4	
	Noakhali Sadar	RCC frame	Anowar Mirja Nunior High School	0.02	
		Tin shed	Harunur Rashid Private Primary School	0.31	
		RCC frame	Selimbazar Asraon Primary School	0.72	
		Pucca	Jonota Bazar Privae Primary School	0.02	
		Tin shed	Banu Miar Bazar High School	0.02	
		RCC frame	Noapara Govt Primary School	0.01	
		RCC frame	Naopara Govt. Primary School	0.01	
		RCC frame	Chaar Alauddin Registered Primary School	0.02	
		Semi Pucca	Dokkhin Rameshorpur Govt Primary School	4.92	3m<inundation<=6m
		RCC frame	Dokkhin Purbo Naro Sighopur Govt Primary School	4.55	
		RCC frame	Moddho Sundalpur Govt Primary School	4.71	
Patuakhali	Bauphal	Pucca+Tin	North Dashpara Dakhil Madrasha	0.17	<1m
		Pucca+Tin	East Para Nasaria Dakhil Madrasha	0.06	
		RCC frame	East Khajur Bheria Govt. Dakhil Madrasha	0.04	
		RCC frame	East Khajur Bharia Dakhil Madrasha	0.01	
		Pucca+Tin	Chadkalhi Secondary School	0.96	
		Semi Pucca	Chadkalhi Govt Primary School	0.97	
		Pucca	Dhulia Govt Primary School	0.57	
		Semi pucca	Dhulia Bangiri Govt Primary School	0.99	
		RCC frame	Jamal Kathi Reg Primkary School	0.96	
		Semi pucca	Aloid Donvas Govt Primary School	0.96	
		RCC frame	Kalaiya Rabbania Sinior Madrasha	0.25	
		RCC frame	Kalaiya Secendary School	0.24	
		Pucca	Kiddris Mollah Degree College	0.18	
		Pucca	HFWC	0.22	
		Pucca	Kalaiya Kortpara South Primary School	0.38	
		Tin Shed	Kolparha Salahia South Madrasha	0.36	
		Pucca	Maddha Kalaiya Reg Primary School	0.1	
		Tin shed	Kasra Rabea Basri South Madrasha	0.09	
		Semi Pucca	North Sola Govt. Primary School	0.01	
		RCC frame	Purba Kalaiya Hasan Siddiq Secondary School	0.15	
		Pucca	Purba Kalaiya Govt. Primary School	0.16	
		Pucca	Hayasiunnessa Girls School	0.25	
		Pucca	Ali Akbor Adorshow Reg. Primary School	0.22	
		Semi pucca	Mominpur Govt. Primary School	0.85	
		RCC frame	Vari pasha Reg Primary School	0.88	
		Semi pucca	Mominpur Adorsha Seconary School	0.86	
		RCC frame	Mahendipur Govt. Primary School	0.88	
		Tin shed	Chad Kalhi Nessaria Dakhil Madrasha	0.87	
		Semi Pucca	Keshahpur College	0.82	
		Semi pucca	Boro Dalima Govtr. Primary School	0.01	
		Semi pucca	Choto Delima Salam Primary School	0.89	
		Tin shed	Chad Kathi Z N Islamia Dakhil Madrasha	1.2	1m<inundation<=3m
		Pucca	Middle Ched Kathi Reg. Primary School	1.18	
		Pucca+tin	Dhulia Secondary School	1.28	
		RCC frame	HFWC	1.25	
		Tin shed	Dhulia Abdur Rahman Senior Girls Dakhil Madrasha	1.37	
		Tin shed	Ched Kathi D & Dakhil Madrasha	1.05	
		RCC frame	Char Chad Kalhi Reg primary School	1.19	
		RCC frame	Middle Ghurcha Kalhi Reg Primary School	1.5	
		Tin shed	Dhulia Dakhil Madrasha	2.91	
		Semi pucca	Dhulia N K Govt. Primary School	1.74	
		Tin shed	Taltola Vri Pasta Ismalia South Madrasha	1.14	
		RCC frame	Tallali Reg. Primari School	1.19	

List of Tsunami Vulnerable Infrastructure (continued)

District	Upazila	Type of Structure	Name of Structure	Inundation Depth (m)	Inundation Depth
Patuakhali	Bauphal	Pucca	Varipoasha Secondary School	1.24	1m<inundation<= 3 m
		RCC frame	East Varipasha Govt. Primary School	1.28	
		Tin shed	Vari Pasha Saiyed Mariuja Dakhil Madrasha	1.34	
		Tin shed	VAri Pasha Giris Dakhil Madrasha	1.4	
		RCC frame	Vari Pasha Munshi Hasan Ali Reg Primary School	1.18	
		RCC frame	Baje Mahol and Baidia Fajil Madrasha	1.08	
		Pucca	Baje Mohol Govt. Primary School	1.07	
		RCC frame	HFWC	1.06	
		Semi pucca	Maminpur Ragabia Dakhil Madrasha	1.23	
		RCC frame	South Mominpur Reg Primary School	1.2	
		RCC frame	Kashabpur Fazlul Haq Sinior Madrasha	1.2	
		Semi pucca	Kashabpur N S Govt Primary School	1.15	
		RCC frame	Jahabad Reg Primary School	1.15	
		Semi pucca	Kashabpur Secondary SChool	1.05	
		Semi pucca	Kashabpur Govt. Primary School	1.07	
		Tin shed	Kashabpur Primary School	1.1	
		Semi pucca	Akkamia Govt. Primary School	1.11	
		Pucca+Tin	Ram Nagar Talar Kathi South Madrasha	1.18	
		RCC frame	Cholhissa taler Kathi Govt Primary School	1.39	
		RCC frame	Bakla Talar Kaihi Reg Primary School	1.32	
		RCC frame	Ramnagor Talar Kaihi Govt Primary School	1.53	
		RCC frame	Dhandi Sinior Madrasha	2.25	
		Pucca	HFWC	2.17	
		Pucca+Tin	Dhandi Adorsha Secondary School	2.35	
		Pucca	South Dhandi Reg Primary School	2.44	
		RCC frame	Baro Dalima Govt. Primary School	2.14	
		Pucca	Char Mia Jan REg Primary SChool	2.61	
		Tin shed	Boro Dalima South Madrasha	2.12	
		Semi Pucca	Kachua Dalima Govt. Primary School	1.85	
		RCC frame	Smali Dalima Govt. Primary School	1.37	
		Pucca	Najirpur Smali Dalima Secondary School	1.38	
		RCC frame	Sultanabad Islamia South Madrasha	1.23	
		Semi pucca	Math Baria a g t secondary School		3m<inundation<= 6 m
		RCC frame	Math Baria Govt. Primary School	3.83	
	Dashmina	Semi pucca	Dandania Govt Primary School	0.08	<1m
		Pucca	Middle Bashabaria Govt. Primary School	0.84	
		Tin shed	Bashaberia akram Khan Reg Primary School	0.28	
		Pucca+tin	S A Arosa Beghi Secondary School	0.08	
		Pucca+Tin	Saliyed Jalor Reg Primary School	0.01	
		Pucca	South Sasi Deshminareg Primary School	0.02	
		Pucca+Tin	Guli Suliapur Adorsho Secondary School	0.05	
		Pucca+Tin	Middle Guli Authapur Govt Primary School	0.06	
		Pucca	Char Guli Reg Primary School	0.68	
		Tin shed	Middle Char Guni Reg Primary School	0.46	
		Pucca+Tin	Auliapur Dakhil Madrasha	0.64	
		Pucca+Tin	East Auliapur Govt. Primary School	0.02	
		Pucca	South Bashbaria Islamia Reg Primary School	1.02	1m<inundation<=3m
		RCC frame	Saiyed Govt Primary School	2.48	
		RCC frame	East Deshmina Govt. Primary School	1.08	
		Pucca+Tin	North Deshmina Govt Primary School	1.38	
		Tin shed	Hazir Hut Primary School	1.3	
		Pucca+Tin	Palar Char Govt Primary School	1.38	
	Galachipa	Tin shed	Diggri Govt Primary School	0.18	<1m
		Semi pucca	Fela Bunia Govt. Primary School	0.16	
		Tin shed	West Gabbunia Dakhil Madrasha	0.06	
		Pucca	Bara Baisdia Hakim Secondary School	0.01	
		Pucca	Bara Baisdia Reg Primary School	0.01	
		Tin shed	Hungtharia Primary School	0.01	
		Semi Pucca	Tumgibaria Govt. Primary School	0.01	
		Pucca	Hawladar Bary Reg Primary School	0.06	
		Pucca	Mawdubi Kagikanda Govt. Primary School	0.11	
		Tin shed	Char Kajal Islamia Dakhil Madrasha	0.68	
		Tin shed	Maddha Char Kajal Govt. Primary School	0.51	
		Semi Pucca	Hosainia Dakhil Madrasha	0.45	
		Semi pucca	Chaito Chur Kajal Govt. Primary School	.45	
		Pucca	HFWC	0.63	
		Tin shed	Chato Siba Saishia Dakhil Madrasha	0.4	
		Pucca	Char Biraj Reg Primary School	0.08	
		Tin shed	Bara Siba REg Primary School	0.4	
		Pucca	Sibar Char Govt. Primary School	0.5	
		Tin shed	Char Kapal Barah Govt. Primary School	0.12	
		Tin shed	Char Kapal Berah Adorsha Secondary School	0.12	
		Pucca	Chato Char Siba Reg Primary School	0.47	
		Pucca	Char Kajal Secondary School	0.56	
		Tin shed	Choto Baisdia Reg Primary School	0.36	
		Pucca	Kawkhali Govt. Primary School	0.07	

List of Tsunami Vulnerable Infrastructure (continued)

District	Upazila	Type of Structure	Name of Structure	Inundation Depth (m)	Inundation Depth
Patuakhali	Galachipa	Pucca+Tin	Siboalia SaSalehia Dakhil Madrasha	0.05	<1m
		Ti n shed	BPC	0.02	
		Semi pucca	South Char Khali Govt Primary School	0.02	
		Pucca	North Char Ghali Govt. Primary School	0.54	
		Pucca+tin	North Char Ghali Secondary School	0.49	
		Tin shed	North Char Khalimahila Dakhil Madrasha	0.51	
		Pucca+Tin	Relandi Govt Primary School	0.08	
		Pucca	West Badura Reg Govt Primary School	0.32	
		Semi pucca	West Natursbagi Govt Primary School	0.32	
		Tin shed	South Balal Bania Dakhil Madrasha	0.26	
		Pucca	South Balal Bania Govt. Primary School	0.3	
		Tin shed	Maddha Balal Bania Reg Primary School	0.57	
		Pucca	Nalua Bagi Secondary School	0.58	
		Tin shed	Nalua Bagi Govt Primary School	0.58	
		Tin shed	West Nalua Bagi Dakhil Madrasha	0.77	
		Pucca	West Nalua Bagi Reg Primary School	0.76	
		Pucca	Char Bedura Govt Primary School	0.04	
		Tin shed	South East Goikhali Secondary School	0.02	
		Pucca+Tin	Soth Goikhali Govt Primary School	0.02	
		Tin shed	Sulvi Secondary school	0.11	
		Semi pucca	Suhri Govt Primary School	0.15	
		Pucca+tin	Haridebpur Secondary School	0.17	
		Semi pucca	Hridebpur Govt Primary School	0.17	
		Pucca	Relandi Talioli Govt Primary School	0.04	
		Pucca	Semuda Bad Govt Primary School	0.02	
		Pucca	Posivi Bunia Govt Primary School	0.01	
		Semi Pucca	Pala bunia Govt Primary School	0.28	
		Tin shed	Tairi Bunia Primary School	0.26	
		Pucca+tin shed	Siandi taltoli Secondary School	0.1	
		Tin shed	South East Ulania Govt Primary School	0.09	
		Pucca	Gramorihon govt Primary School	0.05	
	Kalapara	RCC frame	Dhankhali Girls Dekhil Madrasha	0.01	
		Tin shed	Dhankhali Technical and b m College	0.01	
		RCC frame	Pachjunia Dhankhali Secondary School	0.01	
		Pucca	South Dhankhali Seleha Memorial Reg Primary School	0.62	
		RCC frame	Masuakhali Reg Primary School	0.59	
		RCC frame	Palua Govt Primary School	0.38	
		Tin shed	Palua Salua Alamin Secondary School	0.36	
		Tin shed	North Masuakhali Dakhil Madrasha	0.44	
		RCC frame	East Palua Govt Primary School	0.39	
		RCC frame	North East Palua Secondary School	0.36	
		Pucca	Goolbunia Reg Primary School	0.64	
		RCC frame	South Goolbunia Reg Primary School	0.38	
		RCC frame	Dhankhali High Sangiaona Primary School	0.39	
		RCC frame	Dhankhali M A Secondary School	0.41	
		Pucca	Pachjunia Reg Primary School	0.03	
		RCC frame	Dhankhali College	0.13	
		Tin shed	Maddha Pachjunia Reg Primary School	0.01	
		RCC frame	Nisanberia Dakhil Madrasha	0.04	
		RCC frame	Manahorpur Govt Primary School	0.51	
		Tin shed	Fulbunia Govt Primary School	0.61	
		RCC frame	Dalbu Genua Secondary School	0.12	
		Semi pucca	Dalbu Ganza Govt Primary School	0.13	
		RCC frame	Nijampur Govt Primary School	0.04	
		Pucca	North Nisan Baria Primary SChool	0.02	
		Semi pucca	North Lakua High Saglaona Primary School	0.14	
		RCC frame	North Lalua U C Secondary School	0.14	
		RCC frame	Maharun Nisab Reg Primary School	0.1	
		Pucca	Momina Khatun Reg Primary School	0.08	
		Tin shed	Lalua Nayapara Islamia Dakhil Madrasha	0.03	
		Tin shed	Hosan Para Reg Primary School	0.08	
		Pucca	Kuakata Kakasu Secondary School	0.01	
		RCC frame	Islachapli Govt Primary School	0.05	
		Semi pucca	West Madhukhali Govt Primary School	0.01	
		Tin shed	Daulalpur Salea Alim Madrasha	0.04	
		Tin shed	South Daulatpur Govt Primary School	0.04	
		RCC frame	Isskarpur Govt Primary School	0.08	
		Semi pucca	Akkalpur Govt Primary School	0.03	
		RCC frame	Hazipur Govt Primary School	0.13	
		RCC frame	Hazipur Secondary School	0.15	
		RCC frame	Umidpur Islamia Dakhil Madrasha	0.01	
		Tin shed	Sultanganj Dakhil Madrasha	0.7	
		Tin shed	Maddha Liakhaku Dakhil Madrasha	0.01	
		Pucca	South Liakhali Govt Primary School	0.07	
Pirojpur	Mathbaria	Tin shed	South Amragahhia Nahsi Uddin Dakhil Madrasha	0.07	<1m
		RCC frame	Hoglapali Necharia Islamia Fajil Madrasha	0.18	

List of Tsunami Vulnerable Infrastructure (continued)

District	Upazila	Type of Structure	Name of Structure	Inundation Depth (m)	Inundation Depth
Pirojpur	Mathbaria	Semi pucca	Hoglapali Govt Primary School	0.14	<1m
		Pucca	82no Gobunia Govt Primary School	0.61	
		RCC frame	Golbunia Ideal Maddhomik School	0.38	
		Pucca	East Golbunia Reg Non Govt Primary School	0.36	
		Pucca	KLalikabari REg Non Govt Primary School.	0.38	
		Pucca	Sastho & Poribar Kallayan Kendro	0.07	
		Pucca	76no Moddho Amragachhia Reg Non Govt Primary School	0.07	
		RCC frame	Amragachhia High School	0.06	
		RCC frame	Amragachhia High School	0.06	
		Pucca	Amragachhia High School	0.06	
		Semi pucca	84 no Amragachhia Govt Primary School	0.06	
		Tin shed	North Manik Khali Monshi A Karim Girls Dakhil Madrasha	0.23	
		Pucca	North Manik Khali Reg Non Govt Primary School	0.19	
		Pucca	86 no Pukuria Govt Primary School	0.18	
		Pucca	Dhupoly Pokuria Reg Non Govt Primary School	0.16	
		Pucca	80 no BN Hai Govt Primary School	0.7	
		Pucca	Balmora Rajpara Union Adorsho Maddhomik School	0.5	
		Pucca	Balmora Rajpara Union Adorsho Maddhomik School	0.48	
		RCC frame	75 no. Ghopkhali Govt Primary School	0.85	
		Pucca	72 no. Poschim Ghopkhali Adorsho Reg Non Govt. school	0.79	
			Nijamia Ghopkhali Asania Darul Madrasha	0.9	
			Jankhali Ulubaria Hamidia Dakhil Madrasha	0.61	
			Jankhali Sammillo Adkhmoik School	0.52	
		Pucca	51no. Charalkhali Reg Primary School	0.4	
		Pucca	51 no Belmore Reg Primary School	0.38	
		RCC frame	Balmora Union Fajil Madrasha	0.27	
		Pucca	Balmora Unionj Fajil Madrasha	0.27	
		Pucca	Motahar Uddin Reg Primary School	0.37	
		Pucca	77 no. Balmora Kosor Uddin Govt Primary School	0.37	
		Semi pucca	73 no. Rajpara Govt Primary School	0.36	
		Pucca	73 no. Rajpara Govt. Primary School	0.39	
		Pucca	Balmora Paribarik Shasto Complex	0.6	
		Pucca	75 no. Balmora Rajpara Govt. Primary School	0.52	
		Pucca	47 No. Peschim Rajpara Adorsho Primary School	0.62	
		Pucca	Poschim Rajpara Reg Primary School	0.77	
		Pucca	Poschim Rajpara Reg. Primary School	0.88	
		Pucca	65 no. Balmore Moddho Rajpara non govt. Reg. School	0.58	
		Semi Pucca	Jorther Chor	0.41	
		RCC frame	79 no. Purbo Mihskhali Govt Primary School	0.02	
		RCC frame	74 no. Mitha Khali Govt Primary School	0.05	
		RCC frame	74 no. Mithakhali Govt Primary School	0.05	
		RCC frame	Sapjeza Lalia Maleka Girls Dakhil Madrasha	0.28	
		Pucca	Saplaza Nesaria Senior Madrasha	0.3	
		RCC frame	Saplaza Govt. Primary School	0.22	
		Semi pucca	91 no. Kochu Baria Govt. Primary School	0.78	
		Pucca	91 No. Kochubaria Govt Primary School	0.84	
		Pucca	Khalachira Govt Primary School	0.75	
		RCC frame	35 no. Purba Khelachira REg. Primary School	0.59	
			Hajigonj Maddhomik School	0.59	
		RCC frame	89 no. Sapieza Govt Primacy School	0.1	
		Semi pucca	89 No. Saplazza Govt. Primary School	0.1	
		RCC frame	Saplaza Model High School	0.14	
		Pucca	Poribar Kollan Kendro	0.14	
		Semi pucca	98 no. Jalibunia Govt Primary School	0.19	
			Jalibunia Islamia Dakhil Madrasha	0.03	
		Pucca	33 no. Uttor Tafal Baria Reg Primary School	0.14	
			Shahadat Hossain Mohabiddaloy	0.14	
		Pucca	Tamijia Maddhomik School	0.27	
		Semi pucca	83 No. Noli Charok Gasa Govt. Primary School	0.28	
		Pucca	97 no. Dakshin Saplaza Govt Primary SChool	0.37	
		Pucca	80 no. Moddha Saplaza Reg. Primary SChool	0.22	
		RCC frame	Tafalbaria Hasania Senior Alim Madrasha	0.43	
		Semi pucca	92 No. Charohessia Govt Primary School	0.43	
		Pucca	89 No. Tafal Baria Govt. Primary School	0.44	
		Pucca	100 no. Moddho Noli Tula Tala Govt. Primary School	0.28	
			Noli Fulatala High School	0.1	
		RCC frame	Noli Joy Nagar Kadaria Dakhil Madrasha	0.2	
		Pucca	West Hoglapali Azizia Reg No Govt. Primary School	1.2	1m<inundation<=3m
		Pucca	73 No. West Golbunia Reg. Non Govt.Primary SChool	1.17	
		Pucca	82 No. Golbunia Govt. Primary School	1.17	
		RCC frame	89 no. Ulubaria Govt. Primary School	2.59	
		Pucca	112 No. Badurtoli Govt. Primary School	1.51	
Satkhira	Shyamnagar	Pucca	Gabura Family Health Centre	0.54	<1m
		1+2	Chandi Mukha P J Alim Madrasha	0.32	
		Pucca	Chandi Mukha M M High School	0.32	
		Semi pucca	53 No. Chandi Mukha Govt. Primary School	0.89	
		Pucca	52 No. Dumuria Govt Primary School	2.32	1m<d<=3m

Chronology of major cyclonic storms in Bangladesh

Annexure 6

1584 Bakerganj (presently Barisal) and Patuakhali; hurricane with thunder and lightening continued for five hours; the houses and boats were swallowed up, leaving only Hindu temples on a height; about 2,000,000 living creatures perished.

1585 Mouth of the Meghna estuary; severe storm wave swept up the eastern side of Bakerganj; number of living creatures perished, standing crops destroyed.

1797 (November) Chittagong; severe cyclonic storm; every hut levelled to the ground and 2 vessels sunk in chittagong port.

1822 (May) Barisal, Hatiya Island and Noakhali district; severe cyclonic storm with storm wave; Collectorate records swept away, 40,000 people killed and 100,000 cattle lost.

1831 (October) Barisal; storm-wave; many lives lost and cattle destroyed (exact figures not available).

1872 (October) Cox's Bazar; cyclonic storm; exact figures of the loss of lives and cattle are not available.

1876 (31 October) Meghna estuary and coasts of Chittagong, Barisal, Noakhali; most severe storm-surge of about 12.2m (40 ft) height; about 200,000 people died during the storm, but perhaps more people died from the after-effects of the storm, such as epidemic and famine, and enormous properties destroyed by tidal bore. Considering the population at that time, a death figure of 200,000 was indeed too heavy.

1897 (24 October) Chittagong; hurricane reached maximum intensity with series of storm-waves; Kutubdia Island and coastal villages were swept over, 14,000 people killed and 18,000 died in epidemics (cholera) that followed.

1898 (May) Teknaf; cyclonic storm-waves; exact figures of damage not available.

1904 (November) Sonadia; cyclonic storm; 143 killed and fishing fleet wrecked.

1909 (16 October) Khulna; cyclonic storm-waves; killed 698 people and 70,654 cattle.

1913 (October) Muktagachhaupazila (Mymensingh); cyclonic storm; demolished many villages killing about 500 persons.

1917 (24 September) Khulna; hurricane; 432 persons killed and 28,029 cattle lost.

1941 (May) Eastern Meghna estuary; cyclonic storm with storm-wave; exact figures of the loss of lives and cattle aer not available.

1942 (October) sundarbans; severe cyclonic storm; number of human lives, exact figures of the loss of wildlife and boats are not available.

1948 (17-19 May) Between Chittagong and Noakhali; cyclonic storm; about 1,200 persons killed and 20,000 cattle lost.

1958 (16-19 May) East and west Meghna estuary, east of Barisal, Noakhali; cyclonic storm along with surge; 870 persons killed, 14,500 cattle lost and standing crops destroyed.

1958 (21-24 October) Chittagong coast; cyclonic storm; about 100,000 families lost their homes and government had to provide house-building loans.

1960 (9-10 October) Eastern Meghna estuary (Noakhali, Bakerganj, Faridpur and Patuakhali); severe cyclonic storm, maximum wind speed 201 km/hr, maximum storm wave 3.05m; considerable damage to Char Jabbar, Char Amina, Char Bhatia, Ramgati, Hatiya and Noakhali; 3,000 lives lost, 62,725 houses damaged, crops on 94,000 acres of land were fully damaged and thousands of cattle perished.

1960 (30-31 October) Chittagong, Noakhali, Bakerganj, Faridpur, Patuakhali and eastern Meghna estuary; severe cyclonic storm, maximum wind speed 210 km/hr, surge height 4.5-6.1m; about 10,000 persons killed, 27,793 cattle lost and 568,161 houses destroyed (especially 70% of houses in Hatiya blown off), two large ocean liners washed ashore, 5-7 vessels capsized in Karnafuli river.

1961 (9 May) Bagerhat and Khulna; severe cyclonic storm with a wind speed of 161 km/hr, surge 2.44-3.05m; rail track between Noakhali and Harinarayanpur damaged, heavy loss of life in Char Alexander, 11,468 people killed and about 25,000 cattlehead destroyed.

1962 (26-30 October) Feni; severe cyclonic storm with a wind speed of 161 km/hr, surge 2.5-3.0m; heavy loss of life; about 1,000 people died and many domestic cattle perished.

1963 (28-29 May) Chittagong, Noakhali, Cox's Bazar and the offshore islands of Sandwip, Kutubdia, Hatiya and Maheshkhali were badly affected; severe cyclonic storm with storm-wave rising 4.3-5.2m in Chittagong, maximum wind speed 203 km/hr and at Cox's Bazar 164 km/hr; more than 11,520 people killed, 32,617 cattle lost, 376,332 houses, 4,787 boats and standing crops destroyed.

1965 (11-12 May) Barisal and Bakerganj; most severe cyclonic storm, maximum speed 162 km/hr with storm-wave rising 3.7m; total loss of life 19,279; in Barisal alone 16,456 people killed.

1965 (14-15 December) Cox's Bazar along with adjacent coastal area and Patuakhali; severe cyclonic storm with storm-wave rising 4.7-6.1m; maximum speed 210 km/hr in Cox's Bazar, and Hamidia islands, and Patuakhali; 40,000 salt beds in Cox's Bazar inundated and 873 people killed.

1966 (1 October) Sandwip, Bakerganj, Khulna, Chittagong, Noakhali and Comilla; severe cyclonic storm with storm-waves of 4.7-9.1m, maximum wind speed 146 km/hr; affected 1.5 million people, loss of human life and livestock were 850 and 65,000 respectively in Noakhali and Bakerganj.

1969 (14 April) Demra (Dhaka district); tornado locally known as Kalbaishakhi with wind speed of 643 km/hr; 922 people killed and 16,511 injured; estimated loss Tk 40 to 50 million.

1970 (12-13 November) The most deadly and devastating cyclonic storm that caused the highest casualty in the history of Bangladesh. Chittagong was battered by hurricane winds. It also hit Barguna, Khepupara, Patuakhali, north of Char Burhanuddin, Char Tazumuddin and south of Maijdi, Haringhata and caused heavy loss of lives and damage to crops hoisted danger signal #10 at Cox's Bazar and along the coast of Sonadia, Rangadia and property. Officially the death figure was put at 500,000 but it could be more. A total of 38,000 marine and 77,000 inland fishermen were affected by the cyclone. It was estimated that some 46,000 inland fishermen operating in the cyclone affected region lost their lives. More than 20,000 fishing boats were destroyed; the damage to property and crops was colossal. Over one million cattlehead were reported lost. More than 400,000 houses and 3,500 educational institutions were damaged. The maximum recorded wind speed of the 1970 cyclone was about 222 km/hr and the maximum storm surge height was about 10.6m and the cyclone occurred during high-tide.

1971 (5-6 November) Chittagong coast; severe cyclonic storm; exact figures of the loss of lives and cattle are not available

1971 (28-30 November) Sundarban coast; cyclonic storm with a wind speed of 97-113 km/hr and storm surge of less than 1m; Khulna district experienced stormy weather and low lying areas of Khulna town inundated.

1973 (6-9 December) Sundarban coast; severe cyclonic storm accompanied by storm surge; low-lying coastal areas of Patuakhali and adjoining offshore islands inundated.

1974 (13-15 August) Khulna; cyclonic storm with a wind speed of 80.5 km/hr; about 600 lives lost and number of cattlehead destroyed.

1974 (24-28 November) Coastal belt from Cox's Bazar to Chittagong and offshore islands; severe cyclonic storm with a wind speed of 161 km/hr and storm surge of 2.8-5.2 m; 200 people killed, 1000 cattle lost and 2,300 houses perished.

1975 (9-12 May) Bhola, Cox's Bazar and Khulna; severe cyclonic storm with a wind speed of 96.5 to 112.6 km/hr; 5 persons killed and a number of fishermen missing.

1977 (9-12 May) Khulna, Noakhali, Patuakhali, Barisal, Chittagong and offshore islands; cyclonic storm with a wind speed of 112.63 km/hr; exact figures of the loss of lives and cattle are not available.

1983 (14-15 October) Offshore islands and *chars* of Chittagong and Noakhali; severe cyclonic storm with a wind speed of 122 km/hr; 43 persons killed, 6 fishing boats and a trawler lost, more than 150 fishermen and 100 fishing boats missing and 20% aman crops destroyed.

1983 (5-9 November) Chittagong, Cox's Bazar coast near Kutubdia and the low lying areas of St Martin's Island, Teknaf, Ukhia, Moipong, Sonadia, Barisal, Patuakhali and Noakhali; severe cyclonic storm (hurricane) with a wind speed of 136 km/hr and a storm surge of 1.52m height; 300 fishermen with 50 boats missing and 2,000 houses destroyed.

1985 (24-25 May) Chittagong, Cox's Bazar, Noakhali and their offshore islands (Sandwip, Hatiya, and Urirchar); severe cyclonic storm, wind speed Chittagong 154 km/hr, Sandwip 140 km/hr, Cox's Bazar 100 km/hr and storm surge of 3.0-4.6m; about 11,069 persons killed, 94,379 houses damaged, livestock lost 135,033 and road damaged 74 km, embankments damaged.

1986 (8-9 November) Offshore island and *chars* of Chittagong, Barisal, Patuakhali and Noakhali; cyclonic storm hit 110 km/hr at Chittagong and 90/hr at Khulna; 14 persons killed, damaged 97,200 ha of paddy fields, damage to schools, mosques, warehouses, hospitals, houses and buildings at Amtaliupazila in Barguna.

1988 (24-30 November) Jessore, Kushtia, Faridpur, offshore islands and *chars* of Barisal and Khulna; severe cyclonic storm with core wind speed 162 km/hr, storm surge of 4.5m at Mongla point; killed 5,708 persons and lot of wild animals - deer 15,000, Royal Bengal Tiger 9, cattle 65,000 and crops damaged worth about Tk 9.41 billion.

1991 (29 April) The Great Cyclone of 1991, crossed the Bangladesh coast during the night. It originated in the Pacific about 6,000 km away and took 20 days to reach the coast of Bangladesh. It had a dimension of more than the size of Bangladesh. The central overcast cloud had a diameter exceeding 600 km. The maximum wind speed observed at Sandwip was 225 km/hr. The wind speeds recorded at different places were as follows: Chittagong 160 km/hr, Khepupara (Kalapara) 180 km/hr, Kutubdia 180 km/hr, Cox's Bazar 185 km/hr, and Bhola 178 km/hr. The maximum wind speed estimated from NOAA-11 satellite picture obtained at 13:38 hours on 29 April was about 240 km/hr. The cyclone was detected as a depression (wind speed not exceeding 62 km/hr) on the 23rd April first in the satellite picture taken at SPARRSO from NOAA-11 and GMS-4 satellites. It turned into a cyclonic storm on 25 April. The cyclone in its initial stage moved slightly northwest and then north. From 28 April it started moving in a north-easterly direction and crossed the Bangladesh coast north of Chittagong port during the night of the 29th April. The cyclone started affecting the coastal islands like NijhumDwip, Manpura, Bhola and Sandwip from the evening of that day. The maximum storm surge height during this cyclone was estimated to be about 5 to 8m. The loss of life and property was colossal. The loss of property was estimated at about Tk 60 billion. The death toll was estimated at 150,000; cattle head killed 70,000.

1991 (31 May to 2 June) Offshore islands and *chars* of Patuakhali, Barisal, Noakhali and Chittagong; cyclonic storm, maximum wind speed 110 km/hr and surge height of 1.9m; people killed, cattlehead perished, boats lost and standing crops destroyed.

1994 (29 April 3 May) Offshore island and *chars* of Cox's Bazar; severe cyclonic storm with maximum wind speed of 210 km/hr; people killed about 400, cattle lost about 8,000.

1995 (21-25 November) Offshore island and *chars* of Cox's Bazar; severe cyclonic storm with maximum wind speed of 210 km/hr; about 650 people killed, 17,000 cattlehead perished.

1997 (16-19 May) Offshore islands and *chars* of Chittagong, Cox's Bazar, Noakhali and Bhola; severe cyclonic storm (hurricane) with a wind speed of 225 km/hr, storm surge of 3.05m (similar strength to that of 1970 cyclone); only 126 people killed because of better disaster management measures taken by the government and the people.

1997 (25-27 September) Offshore islands and *chars* of Chittagong, Cox's Bazar, Noakhali and Bhola; severe cyclonic storm (hurricane) with a wind speed of 150 km/hr, storm surge of 1.83 to 3.05m.

1998 (16-20 May) Offshore islands and *chars* of Chittagong, Cox's Bazar and Noakhali; severe cyclonic storm (hurricane) with a wind speed of 150 km/hr, storm surge of 1.83 to 2.44m.

1998 (19-22 November) Offshore islands and *chars* of Khulna, Barisal and Patuakhali; cyclonic storm with maximum wind speed of 90 km/hr, storm surge of 1.22 to 2.44m.

2007 (15^{th} November) The Cyclone "Sidr" hit the south and south-western parts of Bangladesh on November 15th 2007. The storm arrived as a Category-4 Super Cyclone during the evening with peak winds of 250 km/h. A seven foot high tidal surge crossed through the country's southern Barisal-Khulna belt from the Bay of Bengal, killing about 4,000 people, flattening houses, uprooting trees, snapping telephone and power lines. After cyclone Sidr that inflicted severe damages to the lives and livelihood of the people and concurrent floods in 2007.

2009 (25^{th} May) Cyclone Aila hit 14 districts on the south-west coast of Bangladesh.190 immediate deaths, injuries to 7,103 people, damage to 6,000 kilometres of roads, more than1,700 kilometres of embankments to collapse, more than 500,000 people to become homeless, complete destruction of 275 primary schools and damage to 1,942 schools.

Courtesy: Banglapedia

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References:

References, Chapter1

1.1. Bangladesh National Building Code2013: Housing and Building Research Institute; Bangladesh Standard and Testing Institute.

1.2. Minimum Design Load for Buildings and Other Structures: American Society of Civil Engineers

ASCE Standards ASCE/SEI 7-05 including supplement No.1 and Errata.

1.3. Building Code Requirements for Structural Concrete (ACI 318-11)

An ACI Standard and Commentary; American Concrete Institute

1.4. International Building Code 2006

International Code Council

1.5. Ali, A., Vulnerability of Bangladesh to Climate Change and Sea Level Rise through Tropical Cyclones and Storm Surge

1.6. Minimum Design Load for Buildings and Other Structures: American Society of Civil Engineers

ASCE Standards ASCE/SEI 7-10 including supplement

References, Chapter3

3.1. Wikipedia, the free encyclopedia: Wikimedia Foundation

3.2. Smith, Tom,. Wind Safety of Building Envelope (2010) T L Smith Consulting Inc.

3.3. Khan, S.R., Damen, Michiel ITC

Cyclone Hazards in Bangladesh

3.4. Multipurpose Cyclone Shelter Programme, Bangladesh University of Engineering and Technology, Bangladesh Institute of Development Studies,1991

3.5. Bhandari, N.M.; Krishna, Prem; Kumar,Kishen

Wind Storm, Damage and Guidelines for Mitigation Measures

Department of Civil Engineering, Indian Institute of Technology, Roorke, India

3.6. Storm Surge Overview

National Weather Service, National Hurricane Center, US

3.7. Live Science, o1 Nov. 2012

3.8. Hurricanes: Science and Society,

" Hurricane Impacts due to Storm Surge, Wave and Coastal Flooding"

References Chapter 5

5.1. Allen, D. E., and Schriever, W(1973)

"Progressive collapse, abnormal loads and building codes." In structural failures: Modes, Causes, Responsibilities (ASCE) Newyork,21-48

5.2. FEMA Publication 259- Engineering Principles and Practices of Retrofitting Flood-prone Residential Structures

References, Chapter 7

7.1. Unanwa, Christian O and MacDonald, James R (2000)

"Building Wind damage Prediction and Mitigation Using Damage Bands"

7.2. Unanwa C., and Ihekweazu, S (1999).

"Conceptual Framework for Simulating Building Damage in Extreme Winds"

7.3. Unanwa, C.D., MacDonald, J.R., Mehta, K.C., and Smith, D.A. (2000)

"The Development of Wind Damage Bands for Buildings"

7.4. Linstone, H.A., and Turrof, M, (1975)

The Delphi Method: techniques and applications,

Addison-Wesley, Reading, Mass

Reference Chapter 8

8.1. ACI 437R-03: STRENGTH EVALUATION OF EXISTING CONCRETE

BUILDING, Reported by ACI Committee 437

Reference, Chapter10

10.1. Lindeburg, Michael, R.; McMullin, Kurt,M. : Seismic Design of Building Structures

A Professional's Introduction to Earthquake Forces and Design Details, Ninth Edition2008

Reference, Chapter 11

11.1. Ghosh, S.K., Shen, Qiang., Seismic and Wind Design of Concrete Building.

References, Chapter 12

12.1. Institute of Water Modeling: "Storm Surge Modeling Study for Construction of Cyclone Shelters in the Coastal Region of Bangladesh under FAEL KHAIR PROGRAM, IDB, 2011".

12.2. Institute of Water Modeling: "Identify Tsunami-Vulnerable School/Hospital/Emergency Response and Control Buildings in the Coastal Regions and Evaluate Adaptation Capacity to Tsunami Events 2009".

References, Chapter 13

13.1. ENGINEERING PRINCIPLES AND PRACTICES FOR Retrofitting Flood – Prone Residential Structures: Determination of Hazards

FEMA 259: Federal Emergency Management Agency:FEMA259: *Engineering Principles and Practices of Retrofitting Flood Prone structures*

13.2. Nadal, Norberto, C; Zapata, Raul, E; Pagan, Ismail; Lopez, Recardo; Agudelo, Jairo

Building Damage due to Riverine and Coastal Flood

Journal of Water resources Planning and Management, ASCE/May/June2010

13.3. Camfield, F. E. (1980) "Tsunami Engineering" Special Rep. No. 6, Coastal Engineering ResearceCenter, U.S. Army Corps of Engineers, Vieksburg, Miss.

13.4. Robertson, I.N.; Riggs, H.R.; Yim, S.; and Young, Y.L.(2006) : " Lessons fron Katrina" *Civ. Eng. (N.Y.),* 76(4) 56-63

13.5. Kriebel, D.L., Buss, L., and Rogers, S (2000) "Impact Load from Flood Borne Debris" Report to the American Society of Civil Engineers

References, Chapter 14

14.1. Breen, J.E.,ed (Sept. 197 6) "Progressive collapse of building structures (summary report of a workshop held at the University of Texas at Austin, Oct. 1975)" US Department of Housing and Urban Development Rep. PDR-182, Washington, D.C.

14.2. FEMA 320: Taking Shelter From the Storm: Building a Safe Room

14.3. FLASH

5

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