



**Government of the People's Republic of Bangladesh
Local Government Engineering Department (LGED)**

**Climate Adaptation Design, Construction and
Maintenance Manual**



December, 2025



Message

It is a matter of great satisfaction that the Climate Adaptation Design, Construction and Maintenance Manual has been developed under the Program for Supporting Rural Bridges (SupRB), jointly funded by the Government of Bangladesh (GoB) and the World Bank. This Manual marks a significant milestone in LGED's efforts to integrate climate adaptation into rural bridge infrastructure, ensuring that investments remain sustainable, resilient, and responsive to changing environmental conditions.

The Manual provides clear directions for engineers and planners to incorporate climate-adaptive features in bridge design, construction, and maintenance. It emphasizes practical approaches to address climate risks such as flooding, riverbank erosion, and extreme weather events, thereby enhancing the durability, safety, and serviceability of rural bridges and culverts.

I am confident that this Manual will greatly benefit LGED officials at Upazila, District, and program levels in planning, constructing, and maintaining climate-adaptive bridge projects. It will also strengthen institutional knowledge and capacity, enabling LGED to safeguard rural connectivity and protect infrastructure investments against future climate challenges.

LGED reaffirms its commitment to building resilient infrastructure and ensuring that bridge asset management remains forward-looking, efficient, and sustainable in the face of climate change.


(Kazi Golam Mustafa)
Chief Engineer

Local Government Engineering Department



Message

It is a great pleasure to present the Climate Adaptation, Design, Construction and Maintenance Manual, developed under the SupRB project. This Manual represents a significant advancement in LGED's bridge asset management practices, providing systematic guidance for climate-adaptive planning, design, construction, and maintenance operations.

The Manual emphasizes the fundamentals of climate adaptation in bridge and culvert infrastructure, offering step-by-step directions for incorporating resilience measures, selecting appropriate construction techniques, and ensuring effective maintenance based on inspection results. It has been designed to complement the RuBIMS database, software, and Mobile App, making bridge asset management more adaptive, technology-driven, and accountable.

This Manual will serve as a practical tool for contractors, engineers, and LGED officials at all levels, helping them to adopt standardized practices, minimize risks, and ensure the durability, serviceability, and climate resilience of bridge structures. It will also contribute to the future development and strengthening of LGED's Climate Resilient Infrastructure Policy.

I extend my sincere appreciation to the World Bank Task Team and subject matter experts for their valuable comments and feedback during the preparation of this Manual. Together, we reaffirm our commitment to building infrastructure that is not only strong and resilient but also safe, responsible, and sustainable.

A handwritten signature in blue ink, appearing to read 'Md. Belal Hossain', with a stylized flourish at the end.

(Md. Belal Hossain)
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Acronyms

WB	World Bank
ADB	Asian Development Bank
UN	United Nations
USAID	United States Agency for International Development
PMP	Periodic maintenance program
XEN	Executive engineer
UE	Upazila engineer
SAE	Sub assistant engineer
CAPEX	Capital expenditure
CBA	Cost-benefit analysis
IPCC	Intergovernmental panel on climate change
PPTA	Project preparation technical assistance
NAPA	National adaptation program for action
NAP	National adaptation plan
BCCASAP	Bangladesh climate change adaptation strategy and action plan
CEGIS	Centre for environmental and geographic information services
EIQC	Engineering indefinite quantity contract
ACI	American Concrete Institute
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
ASTM	American Society for Testing and Materials
BIS	Bureau of Indian Standards
BS	British Standards
CFRP	Carbon Fiber Reinforced Polymer

FRP	Fiber Reinforced Polymer
GDP	Gross Domestic Product
GFRP	Glass Fiber Reinforced Polymer
IRC	Indian Roads Congress
ISO	International Organization for Standardization
JICA	Japan International Cooperation Agency
JIS	Japanese Industrial Standards
LGED	Local Government Engineering Department
LVDT	Linear Variable Differential Transformer
MORTH	Ministry of Road Transport and Highways
NDT	Non-Destructive Testing
PCU	Passenger Car Unit
PMMA	Polymethyl Methacrylate
PSC	Pre-Stressed Concrete
PU	Polyurethane
RCC	Reinforced Cement Concrete
RHD	Roads and Highways Department
SupRB	Program for Supporting Rural Bridges
UNI	Ente Nazionale Italiano di Unificazione (Italian Standards Body)
CFP	Carbon Fiber Plate
WARPO	Water resources planning organization
BWDB	Bangladesh water development board
CDD	Consecutive dry season
SSP	Shared socio-economic pathway
BBS	Bangladesh bureau of statics
BDP	Bangladesh delta plan
NWMP	National water management plan

WMO	World metrological organization
MoEFCC	Ministry of environment, forest and climate change
SST	Sea surface temperature
SSA	Social security administration
CEIP	Coastal embankment improvement project
ITS	Intelligent transport system
ISO	International organization for standardization
RRBMP	Rural roads and bridge maintenance policy
ESMF	Environment and social management framework
MCA	Multi- criterion analysis
RAMS	Road asset management system
GDP	gross domestic product
OPEX	Operational expenditure
PMP	Periodic maintenance program
SSH	Second southern highway
IDA	International development agency

Chapter – 1

Climate change impact on bridge and associated risk

1.1 Climate

The climate is an atmospheric blanket which is consist of several layers of gases around the earth to protect all living beings and the nature of the earth planet or it is relates with another definition like, Climate is the long-term pattern of weather in a particular area. Weather can change from hour to hour, day to day, month to month or even year to year. A region's weather patterns, usually tracked for at least 30 years, are considered its Climate.

1.2 The effects of climate change are widespread and intensifying and include:

- Rising global temperatures and more frequent heatwaves
- Changes in rainfall patterns, leading to more frequent droughts and floods
- Rising sea levels due to melting ice sheets and glaciers
- More severe storms and extreme weather events
- Threats to food and water security
- Loss of biodiversity and harm to ecosystems like coral reefs

1.3 Major Climatic Impacts on Bridge:

- Increased concentration and high frequency of rainfall are some of the causes of severe scour on bridge pier foundations and abutments due to increased river flow.
- Higher atmospheric temperature is the cause of expansion and contraction of the bridge's superstructure which could be one of the reasons for degradation of sustainability of Bridges.
- Sea level rising causes saline water height in coastal areas which are another reason for scouring and a reduction of the bridge clearance.
- Strong wind speeds due to Cyclone/Tornado could be a risk, especially for long bridges in Coastal areas.
- Bridges can potentially change the water flow which affects water velocity, depth, sedimentation patterns, and river/khal bed morphology. These kinds of changes may enhance the risk of flooding and river bank erosion.

- Surface water quality could be affected by a number of factors during operations on-site.
- Bush/tree/turf clearing near the approach and abutments of a Bridge enhances the erosion of approach roads and adjacent to Bridges.

1.4 The global trend of negative change of climate

Climate change will likely exacerbate existing roadway issues and further deteriorate the condition of bridges in both developed and developing countries.

In 2014, the Intergovernmental Panel on Climate Change (IPCC) forecasted:

- The effects of climate change will continue even if greenhouse gas concentrations were to stabilize at existing levels; average temperature increases and sea level rise will continue due to the timescales associated with climate processes and feedback effects.
- Global mean temperature may rise between 1.0oC to 3.7oC by the end of 2100, according to various climate change scenarios and models;
- Sea level rise will most likely reach 40-63 centimeters during the 21st century;
- In most regions, there will be more instances of hotter, and fewer instances of cold temperature extremes as global mean temperatures increases.

(Source: Intergovernmental Panel on Climate Change (IPCC). 2014 Fifth Assessment Report <http://ipcc.ch>)

1.5 Causes of climate change:

Climate change does not occur from day to day like weather, but it does change over time. The study of historic climate change is called paleoclimatology. Climate change happen slowly over hundreds or even thousands of years, for example, periodic glacial periods have covered large portion of earth with ice caps. Some paleoclimatology evidence shows that the Sahara Desert was once covered by plants and lakes during a warm "wet age".

Climate change can happen for many reasons:

- The movement of tectonic plates
- Volcanic activities and
- The tilt of earth's axis

Climate change is here in the earth is a practical phenomenon beyond doing everything, we can to cut emissions and slow pace of global warming, we must adapt to climate consequences. So, we can protect ourselves and our communities. The fallout varies

depending on where live. It might mean fire or flood, droughts, hotter or colder or sea level rise.

1.6 Impacts and risks of general climate changing indicators on bridges

Bridges, belonging to the transportation infrastructure are vulnerable to excesses in Tidal/Flood/Storm surges, Precipitation and Temperature which can cause structural damage of different elements including roadway deck and approaches of bridges. Indicator wise impacts and risks are illustrated in the Following tables (table 1.1 and table 1.2).

Table-1.1: Impacts and Risks of General Climate Changing Indicators on Bridges

Climate Changing	Impacts	Risks Indicator
Precipitation	If moisture levels of soil borne from increased and prolonged precipitation become extremely high, the bridge structure especially the foundation or substructure become prone to lose the structural integrity.	<ul style="list-style-type: none"> □ The structural integrity of aged or weak bridges could be damaged severely and finally may fail/become out of order/out of use. □ To restore the status of general use it may need for repair/ rehabilitation/ reconstruction.
Tidal/Flood / Storm surges	<ul style="list-style-type: none"> □ Gradual increases in prolonged/sustained rainfall events and catastrophic cyclone increase the risk of flooding. □ Any increase in the intensity of Cyclone/Storm is most likely to increase subsequent surges, causing more frequent or severe flooding of low-lying infrastructure. □ Wave action and stagnancy of water generally results in significant erosion in riverbeds and river banks which ultimately causes damaging scouring of bridge foundations. 	<ul style="list-style-type: none"> □ The result may be devastating causing significant structural damages resulting in terminating the use of bridge. □ To restore the status of general use it may need for repair/ rehabilitation/ reconstruction.
Temperatures	<ul style="list-style-type: none"> □ Extremely Increased temperature affect the thermal expansion and movement of joints resulting increased stress on bridges. □ Higher Range variation of maximum and minimum temperature may generate more freeze-thaw conditions of Steel or Iron elements 	<ul style="list-style-type: none"> □ The result may be severe causing damage of bridge expansion joints and Bearings □ Easy and unrestricted movement of traffic may be hindered. □ Replacement/Rehabilitation of joint/Bearings may be needed

Table-1.2 Climate drivers impacts/ effects on Bridges.

Extreme heat/heat waves:	Extreme temperatures are location specific. Heatwaves are prolonged periods of excessively hot weather. Likely increase in extreme air temperature and heat waves in most areas.
Drying trend/drought:	A prolonged dry period in a natural climate cycle which results in a shortage of water. Likely increase in drought conditions in some areas through a warming of air temperature and decrease in precipitation.
Extreme precipitation/flooding:	Extreme precipitation events are location specific and can cause flooding when down pours exceed the capacity of river or urban drainage systems. Uncertain climate projections, expected to intensify in some areas.
Storm surge:	The difference between the actual water level under the influence of a meteorological disturbance (storm tide) and the level which would have been attained in the absence of the meteorological disturbance (i.e. astronomical tide). Sea level rise exacerbate storm surge height.
Sea level rise:	Anticipated sea level changes due to the greenhouse effect and associated global warming. Leads to changes in erosion and accretion, long term inundation, exacerbate storm surge and tsunami height.
Damaging storms:	Severe weather systems involving damaging winds and heavy rainfall downpour, including tornados, hailstorms, tropical cyclones and Uncertain climate projections.

1.7 The significant climate impacts on bridge and consequences

- Drought
- Flood
- Extreme heat
- Cyclone & tornado
- Storm Surge
- Excess precipitation
- Sea level rise
- Subsidence etc.

1.7.1 Drought

The dry regions of Bangladesh located along the western border are most vulnerable to meteorological droughts in pre- and post-monsoon periods. The mean annual rainfall in the dry zone is around 1,250-1,750 mm, mainly from May-June to September-October (Ahmed and Suphachalasa, 2014). Due to the combined effect of soils with low moisture-holding capacity (<200 mm available moisture), an increasing number of dry days (precipitation <0.5 Potential Evapo-Transpiration) and extreme summer temperatures of more than 40°C, the drought situation in the dry areas become extremely severe during April and May. Nineteen droughts occurred in Bangladesh between 1960 and 1991. The average occurrence is once in 2.5 years. Bangladesh experienced severe droughts in 1951, 1957, 1961, 1972, 1976.



Fig: 1.1 Water way condition due to Drought

1.7.2 River bank erosion due to flood

Every year in Bangladesh, rivers erode around 10,000 hectares of land (NWMP, 2001). According to CEGIS estimates, between 1973 and 2021, erosion along the Jamuna River was 93,965 ha and accretion was 14,545 ha. During this period, erosion along the Ganges River was 30,300 ha while accretion was 29,100 ha. Along the Padma River, erosion was 33,585 ha and accretion were 5,485 ha.



Fig: 1.2 Bridge affected by River bank Erosion

The map and table describe the geographic coverage of the hazards and potentially vulnerable populations across the climate stress areas. Most areas face five or more disasters. With all disasters intensifying or becoming more frequent due to climate change, the climate stress areas face larger risks in the future.

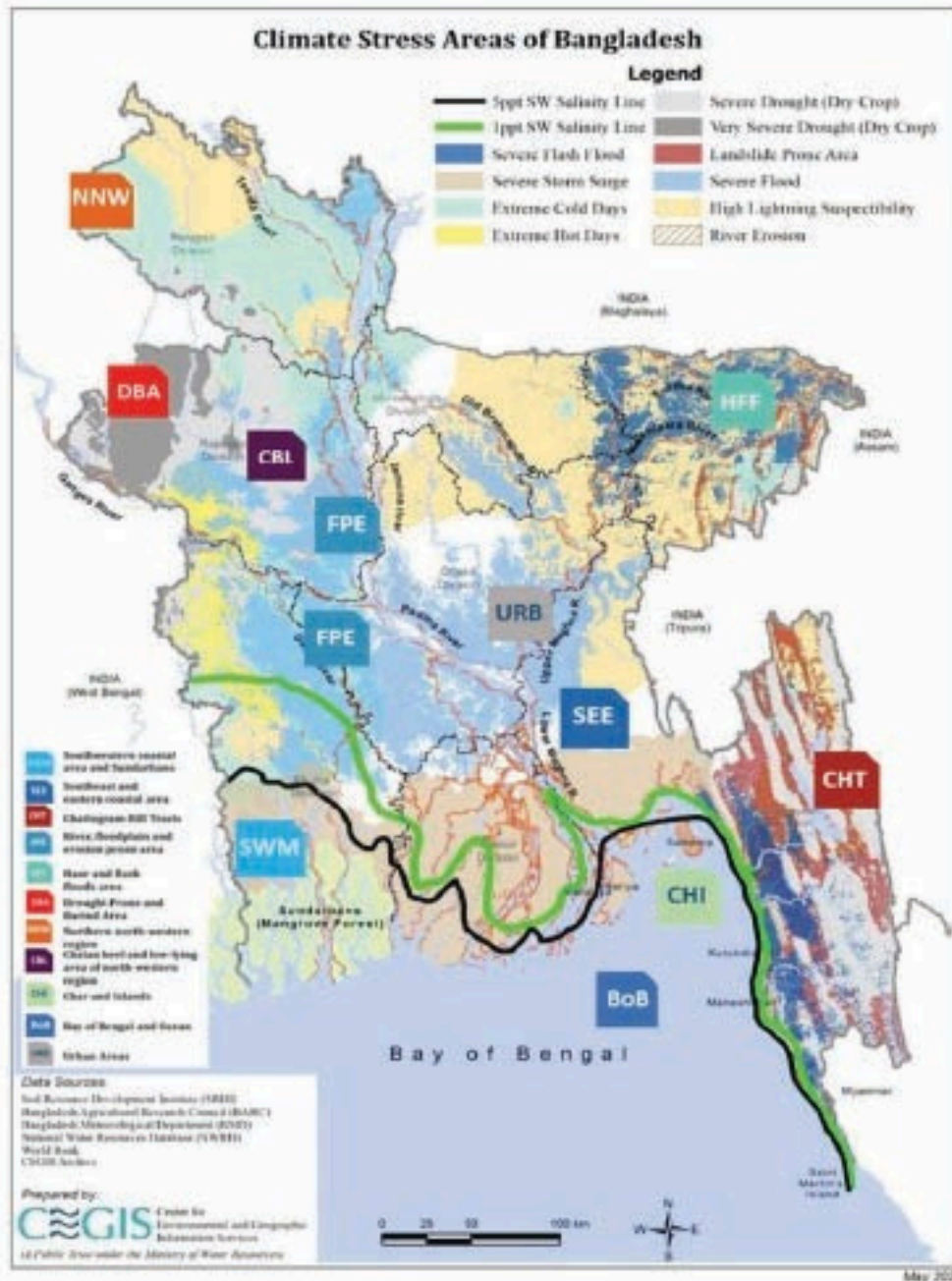


Fig: 1.3 Climate Stress Areas of Bangladesh

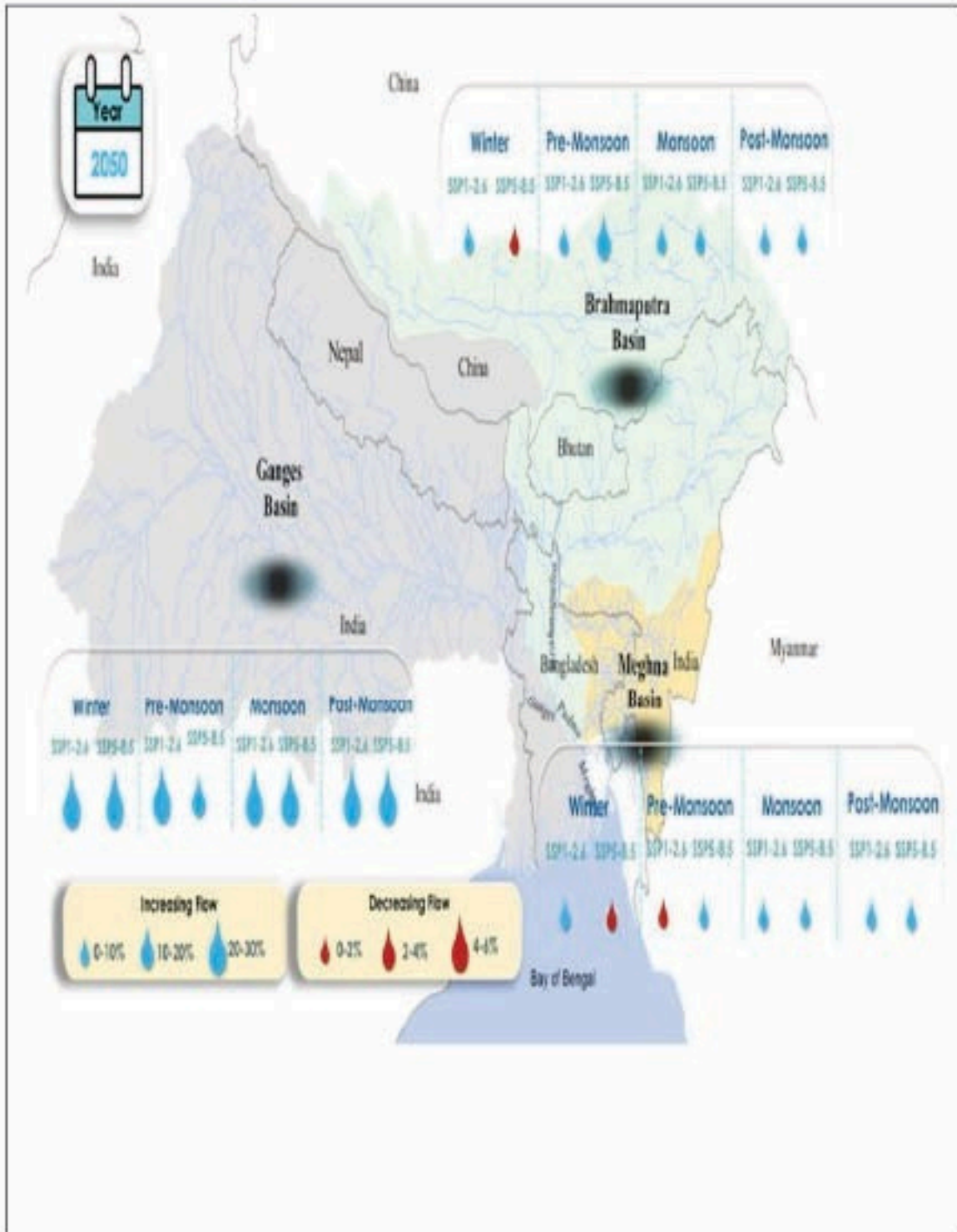


Figure: 1.4 Future seasonal flow variation in the Ganges, Bhrmaputra and Meghna basins Source: CEGISGBM

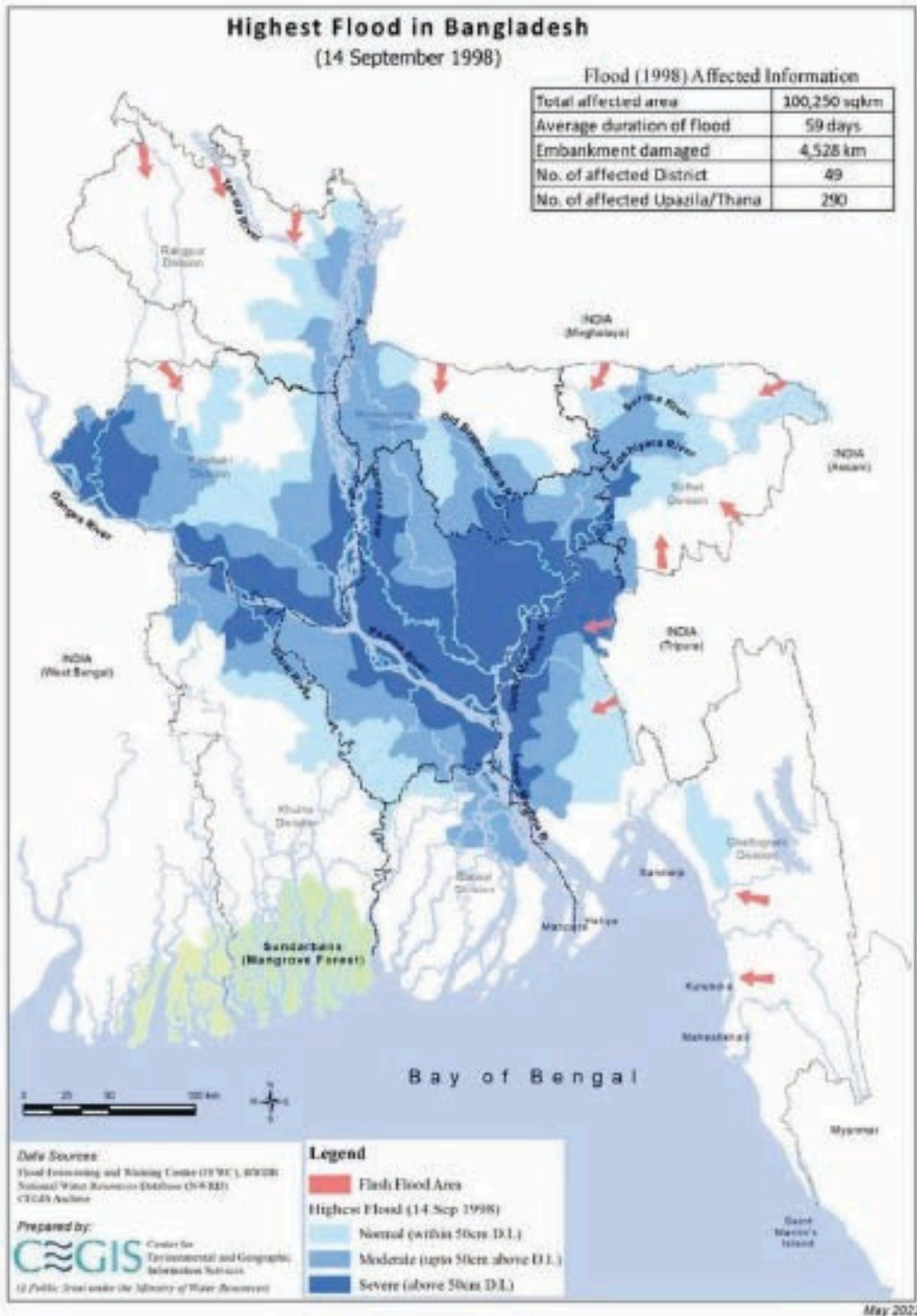


Fig: 1.5 Highest flood level in Bangladesh

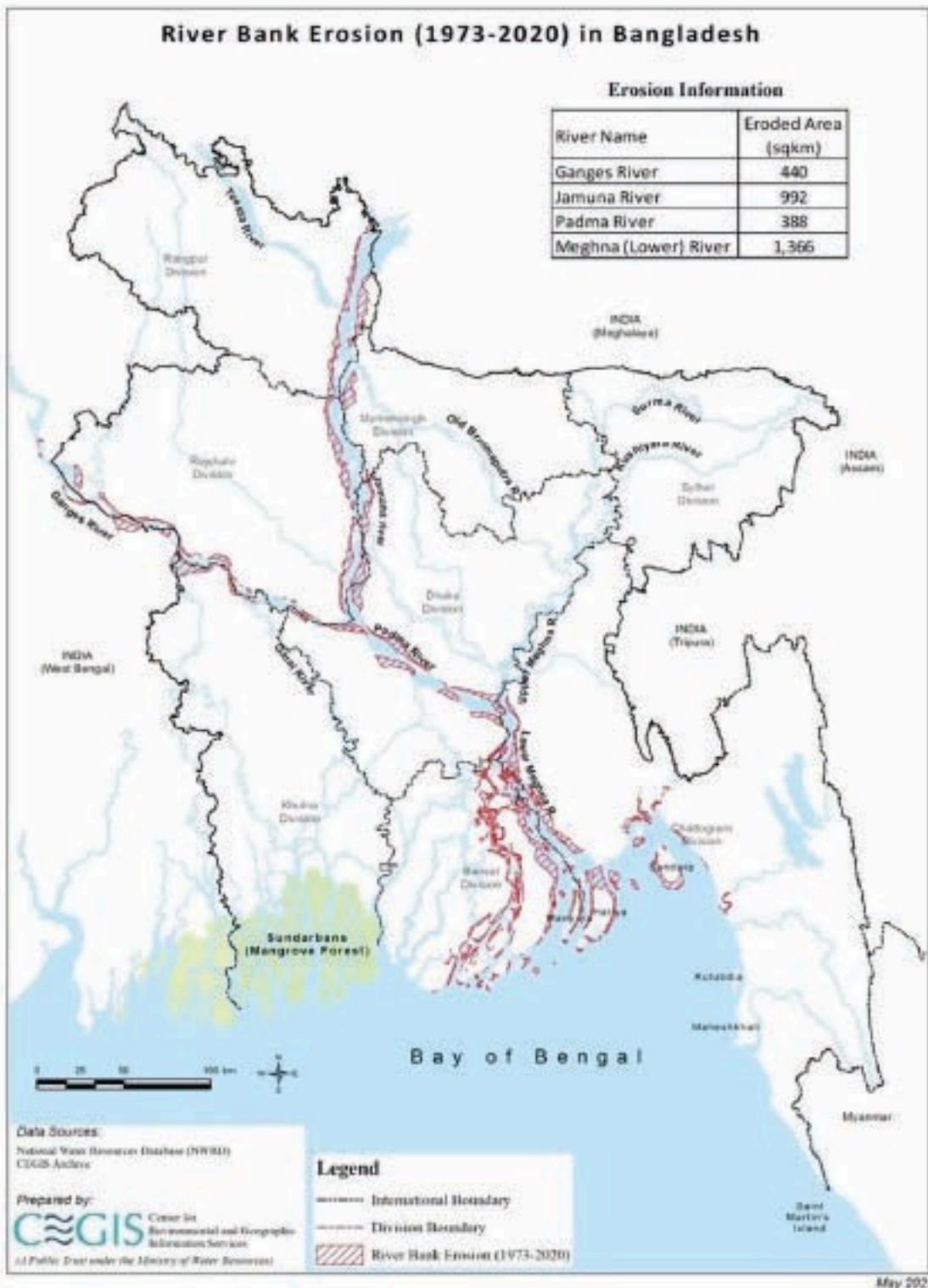


Fig: 1.6 River bank erosion in Bangladesh

1.7.3 Flash floods

Flash floods are caused by heavy or excessive rainfall or upstream flooding in a short period of time. Flash floods are most common from April to July and from September to October (WMO, 2003). The north-eastern areas of Bangladesh are more prone to flash flooding than other parts of the country.

The Eastern hill regions are also very prone to flash floods. During 1985 to 2015, 12 flash flood events occurred in the region. Flash floods suddenly inundate crops near the harvesting time, damage infrastructure and often cause losses of lives and properties.

The flash flood event of 2017 was the most devastating early flash flood, disturbing roads and embankments and damaging pre-mature dry season crops worth \$1.49 billion, which posed a threat to the overall food security of the country.

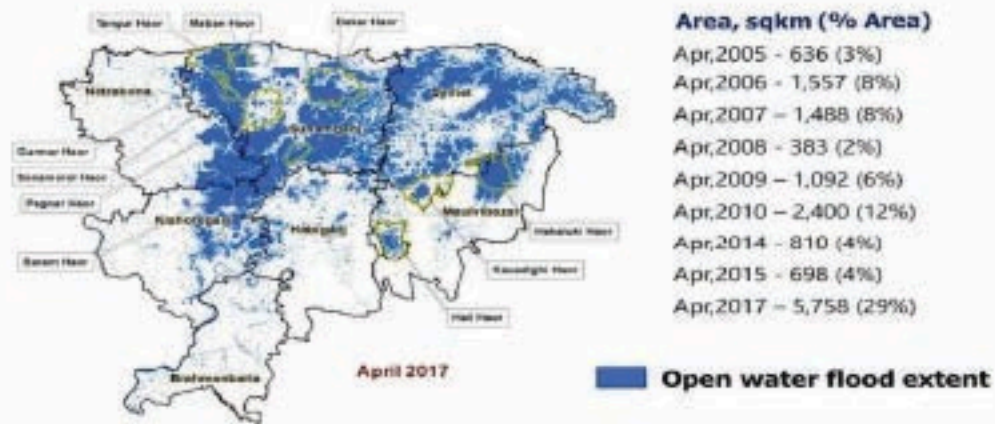


Fig: 1.7 Flash flood-affected areas in north-eastern Bangladesh Source: CEGIS analysis based on satellite images.



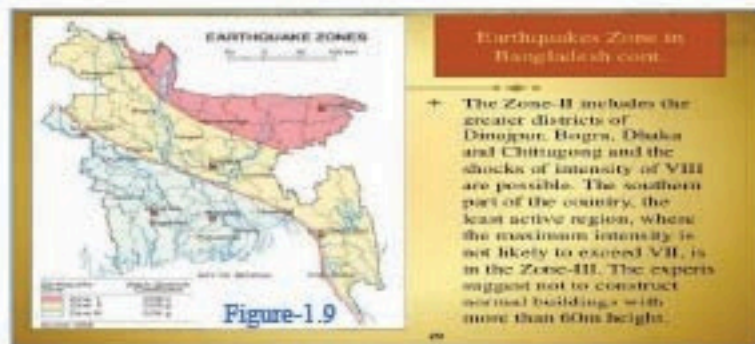
Fig: 1.8 Bridge Protection work affected by Flood.

1.7.4 Sea-level rise

Climate change will further aggravate historical sea-level rise and projections for the coastal areas. This will substantially affect coastal communities, infrastructure and livelihoods. Potential coastal inundation estimated by CEGIS (2021) for variable sea-level rise, incorporating the existing coastal polder set-up, shows that by the mid-term, around 18 percent of the coastal area might be inundated due to sea-level rise projections, based on the SSP5-8.5 scenario. The inundated areas are mostly behind the coastal polders in the south-central region and are low-lying. Some existing polders have flooded due to lower polder height caused by previous damage. In case of a breach or damage to the polder, which was not considered in the simulation, the inundated area will be much greater. This will impact the coastal population and livelihoods, exacerbate salinity intrusion, and damage infrastructures and assets.

1.7.5 Impacts of Earthquake:

Impacts of Earthquake have to be considered in the design of structures. The urban area of Bangladesh, particularly densely populated urban areas, due to rapid growth of densely populated urban areas, infrastructures lacks quality and more important, the most of the infrastructures lack in earthquake resistant design. During the seven or eight years, the occurrence and damage caused by some earthquakes (magnitude between 4 and 6) in the south-eastern part of the country has raised the level of



of awareness among the general people and the government as well. The planners and designers are concerned earthquake resistant design and construction of physical infrastructures. Geographically Bangladesh is located close to the boundary of two active Plates: the Indian Plate in the West and Eurasian Plate in the East & North. Recently Bangladesh lies in an active tectonic zone, which extends throughout Himalayan, Shillong plateau and Rakan-Yoma region, and parts of the adjoining Indo-Ganges floodplains (Brammer 2004). Between 1869 and 1950, seven major earthquakes with magnitude exceeding 7 on the Richter scale occurred in the region which had some major effects on Bangladesh. Of the seven events two (1885 and 1918) had their epi-centers within Bangladesh. Consequent damages have been noted due to those.

Bangladesh being a part of Bengal basin is one of the most seismically active zones of Asian countries. No detail has been undertaken till now, but on the basis of geological finding. Geological Survey of Bangladesh (GSB) has the divided country into three earthquake zones as shown. Recently, with the support of multi-donor financing, Asian Disaster Preparedness Center (ADPC), Bangkok, an international NGO has undertaken comprehensive surveys using latest equipment and computer programs, updating the vulnerability mapping of Bangladesh which is an improvement of what we used to know from GSB.

- Zone-1: Less risky zone (includes Jessore, Khulna and Barisal Districts)
- Zone-2: Medium vulnerable zone (includes Dhaka, Rajshahi, Dinajpur, Bogra, Chittagong and Noakhali Districts)
- Zone-3: Most vulnerable zone (includes Sylhet, Mymensingh, and Rangpur Districts).

1.7.6 Cyclone, tornado and storm surges

Twenty-one severe cyclones (winds between 87 to 117 km/hour) and severe cyclonic storm with hurricane intensity (winds >117 km/hour) struck the Bangladesh coast between 1960 and 2010 (MoEFCC, 2018b). Among them, 33 percent happened pre-monsoon and 67 percent post-monsoon. In the three decades since 1990, Bangladesh has experienced category four cyclones with wind speeds of 209-251 km per hour. Besides cyclones, Southern and central Bangladesh is very prone to tornados. Tornados in Bangladesh generally form during April and cause damage to lives and properties in 25 Mar 2013, a deadly tornado happened in Brahmanbaria, causing death of 31 persons and injury of 388 persons (DMIC, 2013).

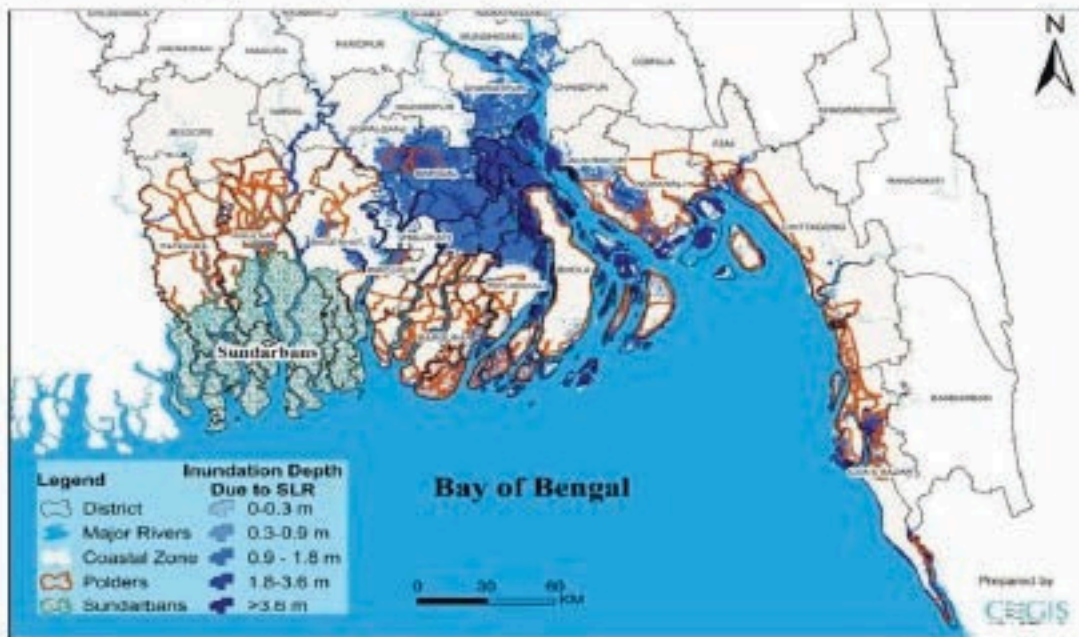


Fig: 1.10 Potential inundation due to sea-level rise and cyclone storm surges in the coastal areas by the 2050s (Source: CEGIS Bay of Bengal Model, 2021)

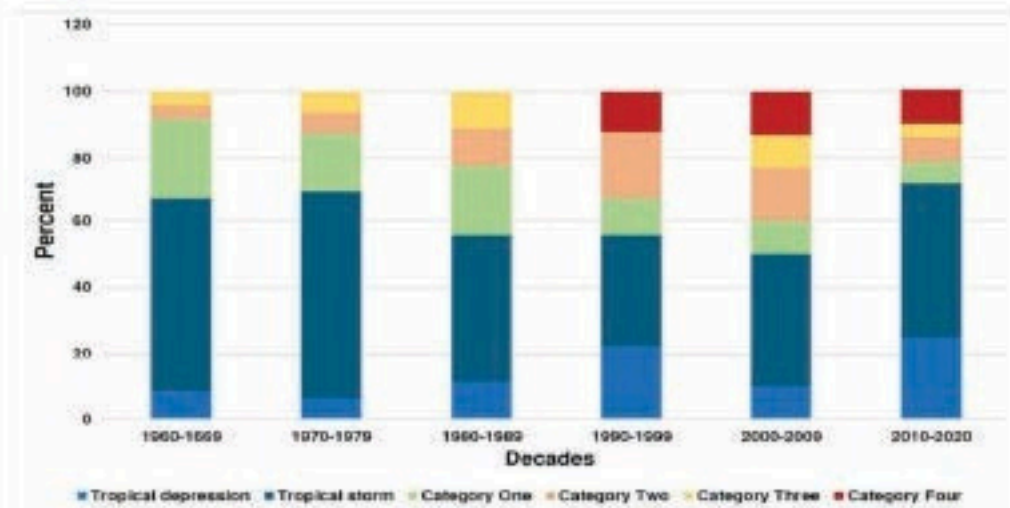


Fig. 1.11 Distribution of different categories of cyclones, 1960-2020 (Source: CEGIS analysis based on BMD data)

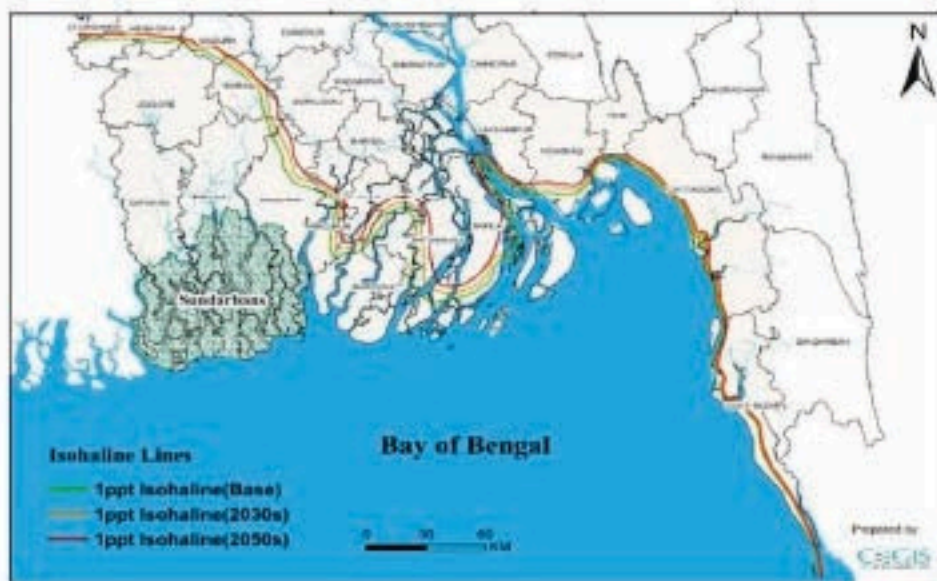


Fig. 1.12 Surface water salinity distribution in coastal Bangladesh due to climate change (Source: CEGIS Bay of Bengal Model)

1.7.7 Salinity

The coastal zone covers about 19 districts of southern part of Bangladesh. The salinity level (surface water, ground water or soil) generally increases almost linearly from October to late May with the gradual reduction of upstream freshwater flows. Low salinity (0-2 ppt) in the south-central zone, results from the significant volume of freshwater flow from the Padma River and the Lower Meghna River. Salinity intrusion in the south-west region reduces the freshwater-supported area, resulting in decreased agricultural production in many parts of the coastal zone and as well as damaged infrastructures and assets.

Climate change-induced sea-level rise will significantly increase river salinity during the dry season which is further aggravated due to less water availability in the major rivers.



Fig: 1.13 Bridge Pier affected by Saline water

1.7.8 Extreme heat waves

The seasonal trends in surface urban heat island intensity (SUHI) ($^{\circ}\text{C}$ per year) from 2003 to 2019 in major Bangladesh cities exhibit significant increases during the pre-monsoon and winter seasons in most cities. Winter nights show a strongly increasing trend in central (Dhaka) and western cities. There is a significantly decreasing trend in north-east (Sylhet) and south-west (Khulna) cities.

Extreme heat events impact on road work like flexible pavement is continuously rutting and effected many ways. also, the bridge structures causes damages due to extreme heat like expansion joints are affecting and other part of sub structures and supper structures degradation occurs randomly.

1.7.9 Extreme cold

Extreme cold is expressed as the days with temperatures below 10°C . During the winter, northern part of Bangladesh experiences cold waves regularly. Extreme cold occurred in 2001, 2003, 2011, 2013, 2017 and 2018, with extreme

temperatures below 6°C in 2003, 2013 and 2018. Such extreme weather events often have severe impacts, hindering the livelihoods of the most vulnerable people. For example, fog and winter rain can reduce cash crop yields and thus income. Cold waves can also have significant health impacts, contributing to acute respiratory infections (ARI), fever, pneumonia, asthma, coughs and skin diseases, especially among the elderly and children. Overall, future climate change is expected to increase the impact of extreme cold in Bangladesh.

1.7.10 Landslide

Since 1990, Bangladesh has experienced more than 30 landslide events in the hilly regions, with a death toll of approximately 200 people and massive economic and property losses. The causes of landslides are topography, weakening slopes through saturation by water, steeper slopes due to erosion, soil properties (sandy soil), torrential rain and high-velocity surface run-off. According to

the geological timescale, the hilly area of Bangladesh developed in the tertiary age and is mainly composed of unconsolidated sedimentary rocks such as sandstone, siltstone, shale and conglomerate. The areas are underlain by tertiary and quaternary sediments that have been folded, faulted and uplifted, and then deeply dissected by rivers and streams. Future climate change is expected to increase the monsoon and post- monsoon rainfall in the hilly regions by 5-10 percent. This might further aggravate the landslide risk for vulnerable areas.



Fig: 1.14 Landslides in bridge approaches due to heavy rainfall

1.7.11 Precipitation and storms impacts on bridges

Flash Floods and Extended Flooding Conditions: When a swollen river passes under a bridge during a flood event, the high-water level can cause debris to come in contact with the bridge. If the impact doesn't damage the bridge immediately, the weight of the piled-up debris combined with the force of the flowing water pushing on it can cause the bridge to collapse.

Tropical Storms are Becoming More Powerful: As hurricanes are expected to increase in intensity (and frequency in some regions), bridges may encounter stronger and more powerful storm surges and waves causing direct physical damage.

Scour: Scour is a process involving the erosion of streambed or bank material due to flowing water at or around piers and foundations. Scour causes stabilizing material, (e.g. the streambed

or bank) to move away from the bridge substructure, causing instability of the bridge's foundation.

Climate change will likely increase the intensity of river flows and exacerbate bridge scour. Extensive damage associated with scour can cause a bridge to collapse.



Fig: 1.15 Affected Bridge Protection work due to river bank erosion and scour

1.7.12 Precipitation changes effects in approach road and bridges

It is projected that the precipitation could decrease in most areas of Asia. This would have a favorable influence on most roads, where sub grade and construction materials will tend to operate under higher negative pore water pressure (high soil suction) conditions and thus have significantly higher strengths than normal. However, it is also projected that the precipitation that does occur could be in the form of less frequent but more severe storm events. Provided that the pavement drainage is such that the water is removed from the pavement structure rapidly, the temporary increased precipitation associated with these events would have little effect on the road performance. It will be essential, however, that drainage designs are improved and maintenance techniques are enhanced and implemented regularly and probably more frequently. Water will have to be removed from the road vicinity rapidly and completely.



Fig: 1.16 Affected bridge approach due to precipitation

Table: 1.4 Effect of Increased precipitation on Bldge Component.

Facility	Consequence - Possible Problems and Damage
Unpaved roads	<ul style="list-style-type: none"> <li data-bbox="574 1136 938 1163"> Flooding (excessive surface water) <li data-bbox="574 1171 906 1199"> Softening of surfacing material <li data-bbox="574 1220 1052 1247"> More frequent impassability on poor materials <li data-bbox="574 1268 927 1295"> Increased erosion of road surface <li data-bbox="574 1316 818 1344"> Loss of shape of road <li data-bbox="574 1365 883 1392"> Blockage (siltation) of drains
Paved roads	<ul style="list-style-type: none"> <li data-bbox="574 1440 1349 1497"> Loss of strength of layer materials, especially in the upper base and subbase layers <li data-bbox="574 1505 857 1533"> Damage to thin surfacing <li data-bbox="574 1554 883 1581"> Damage to pavement edges <li data-bbox="574 1602 906 1629"> Blockage of drains and culverts

	<ul style="list-style-type: none"> ⌚ Erosion of unpaved shoulders
Earthworks	<ul style="list-style-type: none"> ⌚ Increased slope instability ⌚ Saturation and weakening of embankment soils ⌚ Erosion of soil surfaces and drains ⌚ Undercutting of roads by embankment erosion ⌚ Excessive (luxuriant) vegetation growth ⌚ Siltation and blocking of drains
Subgrade soils	<ul style="list-style-type: none"> ⌚ Expansion and cracking of volumetrically unstable materials ⌚ Collapse and settlement of collapsible soils ⌚ Softening of pavement support materials ⌚ More movement and deposition of saline materials ⌚ Deformation of rigid structures ⌚ Erosion in road reserve ⌚ Increased likelihood of sinkholes in karst areas
Drainage (water from within road reserve)	<ul style="list-style-type: none"> ⌚ Accumulation of water adjacent to road ⌚ Erosion of road surface, shoulders and side and mitre drains ⌚ Softening of materials beneath road ⌚ Weakening of unpaved shoulders ⌚ More outer wheel track failures due to increased subgrade moisture contents
Drainage (water from outside road reserve)	<ul style="list-style-type: none"> ⌚ Erosion of embankments and abutments of culverts and bridges ⌚ Silting/sedimentation of culverts and bridges ⌚ Scour of bridge foundations ⌚ Overtopping of bridges and damage or destruction ⌚ Damage to bridge structures by debris in flood-waters
Construction	<ul style="list-style-type: none"> ⌚ Excessive moisture in materials – construction delays ⌚ Reduced working periods and increased delays ⌚ Water damage to partially completed works ⌚ Need for more coffer dams or flood-control measures during drainage and bridge construction

Maintenance	<ul style="list-style-type: none"> Additional maintenance costs incurred More frequent bush clearing Additional repairs required to drains Need to retain good shape of unpaved road surfaces – more frequent maintenance Increased and improved unpaved shoulder maintenance Increased pothole patching and crack sealing of paved roads
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1.7.13 Impacts from increase in average temperature and extreme heat

Damage to Expansion Joints: Under current climate projections, extreme heat events and heat waves are likely to become more frequent and to last longer than in the past. Bridges are subject to many modes of heat transfer and variation in the average daily temperature can cause bridges to extend or shorten. Although the effect is minimal in the short-term, the impact can be cumulative and reduce the service life of a bridge, increase the costs of bridge inspection, maintenance and repair.

Greater variability and range of maximum and minimum ambient temperatures will also cause an increase in freeze-thaw cycles, which can damage bridge expansion joints.



Fig: 1.17 Damage of Expansion Joint

1.7.14 Degradation of the bridge deck material due to extreme heat and excess precipitation:

Most large-scale bridges are built with asphalt or concrete pavement surfacing bridge decks. One reason for using asphalt layers is to protect the bridge deck structures from water, dirt, de-icing agents, or other intrusions. Asphalt pavement can experience softening and traffic-related

rutting, as well as the migration of liquid asphalt to the bridge deck surface from older or poorly constructed pavements as well as resurfacing maintenance of the deck material. Asphalt rutting may become a larger problem during longer periods of summer heat on roads with truck traffic, whereas some bleeding or flushing could occur with older pavements or those with excess asphalt content. These problems should be avoidable with proper design and construction.



Fig: 1.18 Degradation of Deck Materials

Table: 1.6 Effect of increased temperatures on bridge component

Facility	Consequence - Possible Problems and Damage
Unpaved roads	<ul style="list-style-type: none"> □ More rapid drying out of road □ Increased cracking of clayey materials □ Increased development of roughness (corrugation) □ Quicker generation of dust and loose material
Paved roads	<ul style="list-style-type: none"> □ More rapid ageing of bituminous binders □ Softening of bitumen in asphalt and more rapid deformation when hot □ Expansion and buckling of concrete roads
Earthworks	<ul style="list-style-type: none"> □ More rapid drying out and cracking □ Loss of vegetation (or changes of species) on side slopes due to insufficient water □ More wildfires causing loss of root binding □ Increased erosion due to loss of vegetation
Subgrade soils	<ul style="list-style-type: none"> □ Minimal effects □ Some shrinkage of clayey soils □ More movement of salts in saline materials caused by increased

	evaporation
Drainage (water from within road reserve)	<ul style="list-style-type: none"> □ More rapid drying out, cracking and erosion □ Loss of vegetation (or change of species) on side slopes □ More wildfires causing loss of root binding
Drainage (water from outside road reserve)	<ul style="list-style-type: none"> □ Greater expansion/contraction of bridge elements □ Larger temperature gradients in thick concrete members □ More erosion and siltation due to drier ground conditions
Construction	<ul style="list-style-type: none"> □ Reduced window of safe working and productivity of outdoor workforces □ Quicker reactions when cement stabilizing □ Quicker drying of concrete □ Greater water requirements for curing concrete and stabilized layers
Maintenance	<ul style="list-style-type: none"> □ Ensuring vegetation is kept cut to minimize wild-fires □ Regular maintenance of bridge movement components (bearings and construction joints)

Table: 1.7 Effect of sea-level rise and storm-surges on bridge component.

Facility	Consequence - Possible Problems and Damage
Unpaved roads	<ul style="list-style-type: none"> □ Flooding and storm damage □ Increased subgrade moisture contents □ Increased erosion and siltation □ Loss of pass ability
Paved roads	<ul style="list-style-type: none"> □ Damage to road surfacing by salts and water hammering □ Deposition of debris □ Increased subgrade moisture contents and reduced support □ Loss of possibility □ Increased salinity of soil water
Earthworks	<ul style="list-style-type: none"> □ Increased soil moisture contents with sea-level rise □ Fluctuating moisture levels with storm surges □ Reduced soil strengths
Sub grade soils	<ul style="list-style-type: none"> □ Increased moisture contents

Drainage (water from within road reserve)	<ul style="list-style-type: none"> □ Accumulation of water adjacent to road □ Erosion □ Softening of materials □ Accumulation of debris in drains
Drainage (water from outside road reserve)	<ul style="list-style-type: none"> □ Scour of foundations □ Deposition of debris □ Increased salt damage to concrete and steel structures
Construction	<ul style="list-style-type: none"> □ Wetter conditions – reduced working windows □ More saline waters
Maintenance	<ul style="list-style-type: none"> □ Increased maintenance in coastal and low-lying areas □ Increased repairs of damage caused by high storm events (waves)

1.7.15 Subsidence

Subsidence is a general term for downward vertical movement of the Earth's surface, which can be caused by both natural processes and human activities. Subsidence involves little or no horizontal movement, which distinguishes it from slope movement.

Processes that lead to subsidence include dissolution of underlying carbonate rock by groundwater; gradual compaction of sediments; withdrawal of fluid lava from beneath a solidified crust of rock; mining; pumping of subsurface fluids, such as groundwater or petroleum, or warping of the earth's crust by tectonic forces. Subsidence resulting from tectonic deformation of the crust is known as tectonic subsidence and can create accommodation for sediments to accumulate and

Land subsidence can occur in various ways during an earthquake. Large areas of land can subside drastically during an earthquake because of offset along fault lines. Land subsidence can also occur as a result of settling and compacting of unconsolidated sediment from the shaking of an earthquake.⁽¹⁷⁾

1.7.15.1 Seasonal effects

Many soils contain significant proportions of clay. Because of the very small particle size, they are affected by changes in soil moisture content. Seasonal drying of the soil results in a lowering of both the volume and the surface of the soil. If building foundations are above the level reached by seasonal drying, they move, possibly resulting in damage to the building in the form of tapering cracks.

Trees and other vegetation can have a significant local effect on seasonal drying of soils. Over a number of years, a cumulative drying occurs as the tree grows. That can lead to the opposite of subsidence, known as heave or swelling of the soil, when the tree declines or is felled. As the cumulative moisture deficit is reversed, which can last up to 25 years, the surface level around the tree will rise and expand laterally. That often damages buildings unless the foundations have been strengthened or designed to cope with the effect.¹

1.7.15.2 Increase of flooding potential

Land subsidence leads to the lowering of the ground surface, altering the topography. This elevation reduction increases the risk of flooding, particularly in river flood plains and delta areas.

1.7.15.3 Earth fissures

Earth fissures are linear fractures that appear on the land surface, characterized by openings or offsets. These fissures can be several meters deep, several meters wide, and extend for several kilometers. They form when the deformation of an aquifer, caused by pumping, concentrates stress in the sediment. This inhomogeneous deformation results in the differential compaction of the sediments. Ground fissures develop when this tensile stress exceeds the tensile strength of the sediment.

1.7.15.4 Machine learning simulating and predicting land subsidence

Machine learning has become a new approach for tackling nonlinear problems. It has emerged as a promising method for simulating and predicting land subsidence.

Instances worldwide

Location	Depositional environment	Maximum subsidence rate (mm/year) and period	Cause	Impacts	Remedial or protective measurements	References
Bangkok, Thailand	Fluvial and marine deposits from the Holocene	<120 (1981)	Ground water extraction	Intensification of city flooding, shoreline regression, intrusion of salt water and foundation	Groundwater pricing policies, the expansion of tap water supply from surface sources in underserved industrial suburban areas	29

				engineering problems.	and strict implementation of the groundwater usage ban	
Beijing, China	Alluvial sediments	>100 (2010-2011)	Groundwater extraction		The South-to-North Water Diversion Project Central Route (SNWDP-CR) was built to redistribute water resources.	(57)(58)(59)(60)
Datong coal field, China	Jurassic and Carboniferous coal seams	17 (2003-2010) <1146 (2022-2023)	Groundwater over pumping from mines and coal mining subsidence.	Soil avalanche, landslide, mud-rock flow, surface settlement, earth fissures and surface sandstone stack..		(61)(62)(63)
Guadalentin, Spain	Alluvial and fluvial sediments	>110 (1992-2012)	Groundwater extraction	Increase of flooding potential		(64)(65)(66)
Gediz River Basin, Türkiye	Graben filled with approximately 500 m of Pliocene and Quaternary alluvial material.	64.0 (2017-2021)	Groundwater extraction and tectonics	Several earth fissures and damage on buildings		(68)
Jakarta, Indonesia	Alluvial sediments	260 (1991-1997) 100 (1997-2002)	Groundwater extraction	Cracking of permanent structures, expanded flooding areas. lowered groundwater		(69)(70)(71)

				r levels, and increased inland seawater intrusion.		
Karapınar, Turkey	Miocene–Pliocene conglomerate, sandstone, marl, limestone, tuff, and evaporites		Dissolution			[70]
La Unión, Spain	Sandstones, conglomerates, phyllites and limestones	7 (2003–2004)	Underground mining activities	Collapse of one building and damage on surrounding buildings	Prohibition of construction in the urban area affected by subsidence.	[71][72]
México City, Mexico	Alluvial and lacustrine sediments	387 (2014–2020)	Groundwater extraction	Development of earth fissures. Damage on buildings.		[73][74]
Murcia, Spain	Alluvial and fluvial sediments	26 (2004–2008)	Groundwater extraction	Damage on 150 buildings	Closure of urban wells	[75][76][77]
Patos-Marinza oil field, Albania	Carbonates and siliciclastic deposits	15 (2015–2018)	Extraction of petroleum			[78]
San Joaquin Valley, California, USA	Alluvial and lacustrine sediments.	500 (1923–1970) 80 (1921–1960)	Groundwater extraction		Importation of surface water to agricultural areas in the San Joaquin Valley, California, via the California Aqueduct from the late 1960s.	[79][80][24]
Shanghai	Marine	87 (2019–	Groundw	The	Restriction of	[81][82]

, China	sediments	2020)	ater extraction	economic loss caused by ground subsidence in Shanghai from 2001 to 2020 amounted to over 24.57 billion yuan.	groundwater use, artificial recharge with treated river water, and adjustment of pumping patterns	
Tehran, Iran	Alluvial sediments	217 (2017- 2019)	Groundw ater extraction			(12)(10)(10)
Venice, Italy	Deltaic and lagoon deposits	1 (before 1952) 6.5 (1952- 1968) 4 (2003- 2010)	Groundw ater extraction		Decrease of groundwater extraction. Some areas were supplied from water from inland.	(12)(10)

1.7.15.5 Causes of Subsidence

|| Human Activities:

- o Groundwater, Oil, and Gas Extraction: Pumping out these resources can cause aquifers and surrounding sediments to compact.
- o Mining and Excavation: Underground mining and the construction of tunnels or large structures can lead to the removal of supporting material.
- o Soil Compaction: Adding water to fine-grained soils, such as those deposited by wind (loess), can cause them to compact.

|| Natural Processes:

- o Tectonic Activity: Earthquakes and other tectonic movements can cause large-scale sinking of land.

- o **Glacial Isostatic Adjustment:** The Earth's crust can slowly adjust after the removal of glaciers.
- o **Erosion and Dissolution:** Erosion of underground materials, especially soluble rocks like limestone, can create empty spaces that lead to ground collapse.

Signs and Impacts

- ▮ **Structural Damage:** Visible signs include cracks in walls, ceilings, and floors, as well as misaligned doors and windows.
- ▮ **Infrastructure Problems:** Roads can buckle, and coastal infrastructure can be submerged.
- ▮ **Environmental Consequences:** It can affect water supplies and damage vital infrastructure.

Mitigation and Prevention

- ▮ **Addressing Root Causes:** Implementing sustainable water management practices and regulating groundwater withdrawal is crucial.
- ▮ **Structural Reinforcement:** Buildings can be secured by processes like underpinning to support the sinking foundations.
- ▮ **Monitoring:** Techniques like the Global Positioning System (GPS) and satellite-based radar (InSAR) are used to monitor subsidence rates and identify areas at risk.

1.8 Environmental impact on coastal structure

The arrangement and details of piers, abutments, approaches, training works, and temporary construction facilities, so far as it is compatible with requirements of structural adequacy, safety, economy, and aesthetics, should be designed to minimize local scour, obstruction of flow, and inconvenience to legitimate interests.

Coastal structures: are the structures that are constructed near to the coastal areas for different purposes. Different types of coastal structures are constructed under different circumstances but the criteria to be used for the selection and design of specific type of coastal structure must be authentic and comply with the standards. There are a various set of criteria that need to be considered in the selection and design of coastal structures.

- Structural stability criteria
- Functional performance criteria

These two areas are of primary concern for selection and evaluation of coastal structures. Structural stability criteria are usually associated with extreme environmental conditions, which may cause severe damage to, or failure of a coastal structure. These stability criteria are, therefore, related to episodic events in the environmental (severe storms, hurricanes, earthquakes) and are often evaluated on the basis of risk of encounter probabilities.

Table 1.8 Climate Change Impacts on Coastal Zone Infrastructure

Climate Change	Impacts
Increase of temperature	<p>Higher rate of evaporation of water bodies containing sweet water, leading to increasing scarcity of potable drinking water.</p> <p>The material expansion will impact structures, such as buildings, roads, embankments, bridges, culverts, sluices, etc.</p>
Increase of monsoon rainfall and intensity	<p>Monsoon rain causes floods, erosion of embankments and road infrastructure and damage to market and housing.</p> <p>The rainwater accumulating within the polders will cause water logging and inhibit normal land-use practice and impact livelihoods.</p>
Sea level rise	<p>Increasing normal tide levels will flood more lands of the coastal zone in terms both of extent and inundation time. In some areas the extreme tide will overtop the polders. The road and infrastructures will be affected and increased consequent salinity will impact land-use and local ecosystems. Overall increased risk to life and livelihoods.</p>
High winds	<p>Potential damage to buildings, ghats, etc. as well as secondary damage from trees and other debris. Impact by wind driven wave action on embankments, bridge abutments etc.</p>
Increase of the frequency of strong cyclones including storm surges	<p>Cause damages to, environment, infrastructure, resources, economy and livelihood. Increased risk to life. Water bodies are contaminated causing scarce of drinking water and impacting on health.</p> <p>Roads are partially damaged when surge height is less than 1m, and more fully damaged when the depth of inundation exceeds 1m.</p>

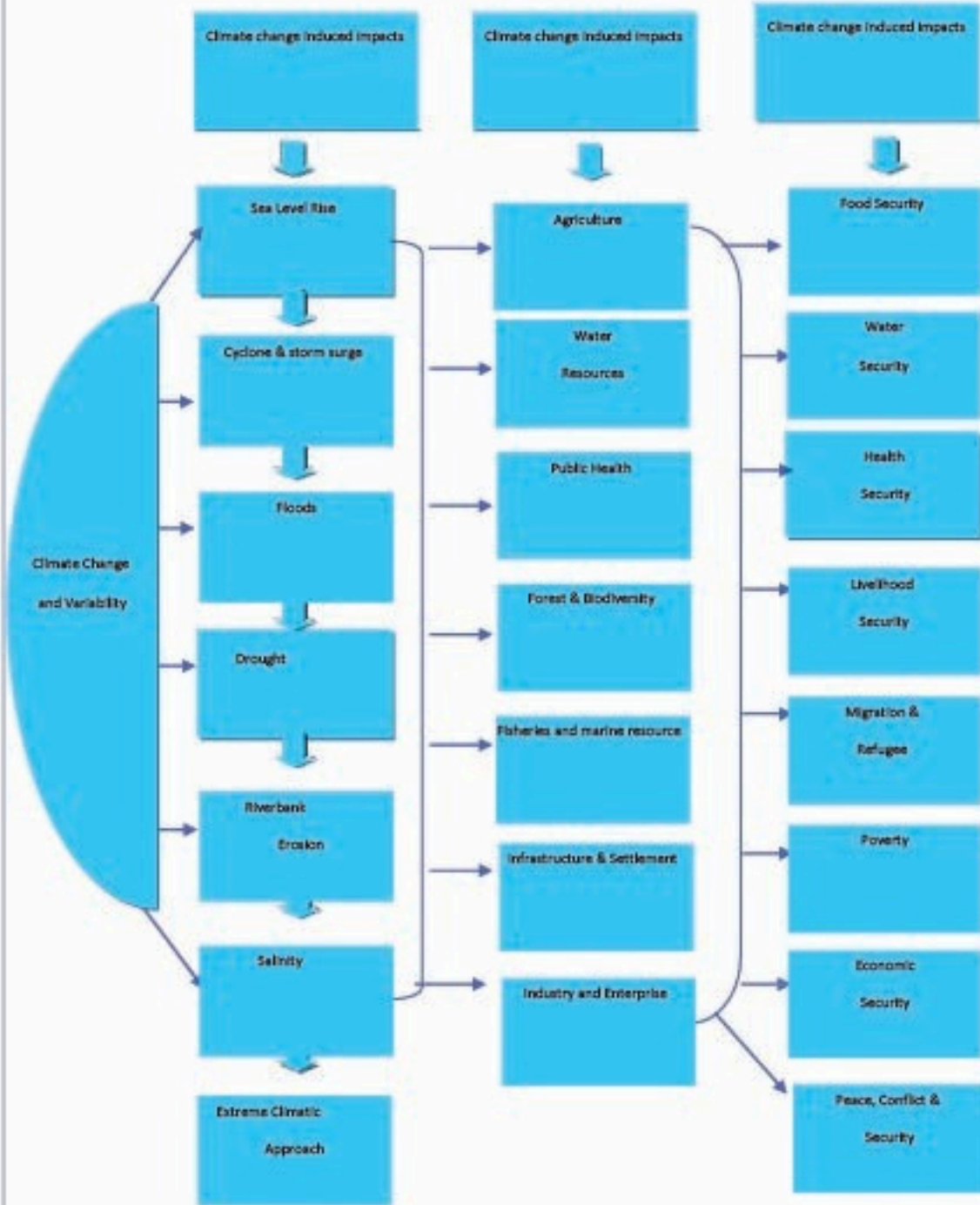
Table 1.9 Climate stress area coverage and related hazards

Climate stress area	Districts	Prominence of climate hazards
South-western coastal area and Sundarbans (SWM)	Satkhira, Khulna, Bagherhat, Pirojpur, Barguna, Barisal, Patuakhali, Jhalokhathi, Bhola, Shariatpur, Gopalganj, Jashore, Sundarbans	Rainfall variability, river floods, sea-level rise, salinity, tropical cyclone, storm surges, drought, extreme heat waves, extreme cold, riverbank erosion and lightning
South-east and eastern coastal area (SEE)	Noakhali, Feni, Lakshmipur, Chattogram, Cox's Bazar, Chandpur	Rainfall variability, river floods, sea-level rise, salinity, tropical cyclone, storm surges, drought, extreme heat waves, extreme cold, riverbank

		erosion, lightning and landslides
Rivers, floodplains, and erosion-prone areas (FPE)	Nilphamari, Kurigram, Lalmonirhat, Gaibandha, Rangpur, Bogura, Sirajganj, Pabna, Rajshahi, Jamalpur, Tangail, Manikganj, Dhaka, Munshiganj, Mymensingh, Sunamganj, Netrokona, Habiganj, Kishorganj, Sylhet, Brahmanbaria, Narsingdi, Narayanganj, Rajbari, Faridpur, Madaripur, Gopalganj, Narail, Sariatpur, Barisal, Patuakhali, Bhola, Jhalokathi, Khulna, Chandpur, Cumilla, Noakhali, Lakshmpur, Cox's Bazar	Rainfall variability, river floods, tropical cyclones, tornado, extreme heat waves, extreme cold, riverbank erosion and lightning
Haor and flash floods areas (HFF)	Sunamganj, Netrokona, Habiganj, Kishorganj, Sylhet, Maulvibazar, Brahmanbaria	Rainfall variability, flash floods, tropical cyclone, tornado, extreme heat waves, intense cold, riverbank erosion, lightning and landslides
Drought-prone and barind areas (DBA)	Naogaon, Chapai Nawabganj, Rajshahi, Bogura, Joypurhat, Rangpur, Dinajpur, Meherpur, Chudanga, Kushtia, Jashore, Magura, Jhenaidah	Rainfall variability, tropical cyclone, tornado drought, extreme heat waves, extreme cold and lightning
Northern, north-western region (NNW)	Panchagarh, Thakurgaon, Nilphamari, Lalmonirhat, Rangpur, Kurigram, Dinajpur	Rainfall variability, river floods, flash floods, tropical cyclone, tornado, drought, extreme heat waves, extreme cold, riverbank erosion, lightning and landslides
Chalanbeel and low-lying area of the north-western region (CBL)	Pabna, Natore, Sirajganj, Rajshahi, Naogaon	Rainfall variability, river floods, , tropical cyclone, tornado, , extreme heat waves, extreme cold, riverbank erosion and lightning
Char and islands (CHI)	Nilphamari, Lalmonirhat, Kurigram, Gaibandha, Sirajganj, Jamalpur, Mymensingh, Manikganj, Munshiganj, Shariatpur, Chandpur, Bhola, Patuakhali, Feni, Noakhali, Lakshmpur, Chattogram, Cox's Bazar	Rainfall variability, river floods, sea-level rise, salinity, , tropical cyclone, tornado, storm surges, extreme heat waves, extreme cold, river bank erosion, lightning, higher sea surface temperature and ocean acidification
Bay of Bengal and ocean (BoB)	Bay of Bengal (maritime boundary)	Rainfall variability, sea-level rise, tropical cyclone, tornado, storm surges, extreme heat waves, lightning, higher sea surface temperature, hypoxia and ocean acidification

1.9 Climate change impacts, vulnerability and linkage with development in Bangladesh

Figure 14: Impact of Climate Change on Bangladesh



Source: Bangladesh: Strategic Program for Climate change (SPCC); Prepared for the Pilot Program for Climate change (PPCC).

Chapter – 2

Adaptation strategy and methodology

2.1 Defining adaptation:

Climate change is a long-term shift in the planet's average temperatures and weather patterns, caused primarily by human activities like the burning of fossil fuels. Climate change adaptation refers to the actions taken to prepare for and adjust to the unavoidable impacts of these changes. Climate change adaptation is the process of making adjustments to natural or human systems in response to actual or expected climate change impacts, such as sea-level rise and extreme weather events, to reduce harm or take advantage of beneficial opportunities. Actions can range from large-scale infrastructural projects like building flood defenses to behavioral changes like planting drought-resistant crops or developing early warning systems. The goal of adaptation is to build resilience and moderate the negative effects of a changing climate on people, communities, infrastructures, ecosystems and economies.

2.2 Adaptation can involve different types of interventions, including:

❑ **Infrastructural:**

Building seawalls, upgrading infrastructure to withstand extreme weather, and developing water storage systems.

❑ **Institutional:**

Creating new insurance schemes, implementing new policies, and improving access to disaster information and early warning systems.

❑ **Behavioral:**

Farmers planting different crop varieties, individuals checking on vulnerable neighbors during heatwaves, and changing planting times.

❑ **Nature-based Solutions:**

Planting mangroves, restoring ecosystems, and developing green roofs to reduce urban heat.

Reactive vs. Proactive Adaptation

❑ **Proactive:** Actions taken in anticipation of future climate change impacts, based on projections and available data.

❑ **Reactive:** Steps taken in response to climate impacts as they are already occurring.

2.2.1 Explanation of necessity of adaptation

Even with efforts to reduce greenhouse gas emissions, some climate change impacts are unavoidable. Adaptation is therefore essential to protect vulnerable populations, ensure food and water security, infrastructures and maintain economic stability in the face of increasing climate variability and extreme events.

2.2.2 Climate Change Adaptation Strategies

Climate change adaptation refers to actions that help reduce vulnerability to the current or expected impacts of climate change like weather extremes and hazards, sea level rise, biodiversity loss, food and water insecurity and damages of infrastructures or assets.

Adaptation refers to adjustments in ecological, social or economic systems in response to actual or expected climatic stimuli and their effects. It refers to changes in processes, practices and structures to moderate potential damages or to benefit from opportunities associated with climate change.

In simple terms, countries and communities need to develop adaptation solutions and implement actions to respond to current and future climate change impacts.

2.2.3 Climate Change Adaptation actions

Adaptation actions can take on many forms, depending on the unique context of a community, business, organization, country or region. There is no 'one-size-fits-all- solution'—adaptation can range from building flood defenses, setting up early warning systems for cyclones, switching to drought-resistant crops, to redesigning communication systems, business operations and government policies.

Many nations and communities are already taking steps to build resilient societies and economies. However, greater action and ambition will be needed to cost-effectively manage the risks, both now and in the future. Successful adaptation not only depends on governments but also on the active and sustained engagement of stakeholders, including local communities, national, regional, multilateral and international organizations, public and private sectors, civil society and other relevant actors, as well as an effective management of knowledge. Parties to the UNFCCC and its Paris Agreement recognize that adaptation is a global challenge faced by all with local, sub national, national, regional and international dimensions.

2.2.4 Longterm climate Change Adaptation Strategies

Adaptation is a critical component of the long-term global response to climate change to protect people, livelihoods and ecosystems. Parties acknowledge that adaptation action should follow a country-driven, gender-responsive, participatory and fully transparent approach, considering vulnerable groups, communities and ecosystems. Adaptation should be based on and guided by the best available science and as appropriate, traditional knowledge, knowledge of indigenous peoples and local knowledge systems, with a view to integrating adaptation into socioeconomic and environmental policies and actions.

A Methodology for Incorporating Climate Change Adaptation in Infrastructure Planning and Design. More details, including the advantages and disadvantages of specific adaptation strategies, are discussed in this document. Climate change practitioners, engineers, and other stakeholders will find the components to develop a preliminary cost estimate that is valid for a proposed project. Other aspects, such as technical feasibility and schedule, are also discussed in this Section. It is recommended that an in-depth inspection and load rating analysis be conducted for a bridge as part of preliminary design considerations. Most international standards require an engineer's report for the basis of design.

There are many comprehensive solutions and adaptation options that address climate change. Some involve technology or innovative design, while others involve the use of different materials. All options have their advantages and disadvantages, for instance: concrete is less sensitive to climate change effects, but harder to maintain. Some adaptation options may involve a substantial one-time, capital expenditure (CAPEX), other solutions require incremental increases in normal business operational expenditures (OPEX). Nonetheless, all strategies are intended to assist with decision-making for building bridges that are climate-proofed. It is important to note that schematic designs and graphic illustrations should be prepared at the start of a project to convey the concept or intervention to decision makers and community stakeholders. Not all adaptation strategies that make bridge structures more resilient to climate can be applied to existing infrastructure. Some solutions involve modified design, such as raising the elevation of the structure, and cannot be applied simply to existing bridges. However, when a bridge is destroyed after a major weather event or near the end of its service life, it will be important for practitioners to take opportunities to incorporate climate-proof designs into the repair and reconstruction activities.

Climate change adaptation is an evolving field, with best practices and as-built case study examples being refined globally in multiple environments and contexts. This Annex is not intended to be exhaustive.

Future bridge structures will have to adjust for the direct and indirect impacts from climate change. If these risks are not carefully considered in new construction activities, they could prevent emerging countries like Bangladesh from continuing their economic and social development.

Design guidance revision is necessary to provide more robust bridges in the future. Revising existing guidelines requires changes to design criteria, including considerations for new and higher traffic loads, stronger foundations, and greater freeboard between the water level and the bridge surface.

Climate adaptive technic/procedure
2.5 Adaptation Strategy/cycle

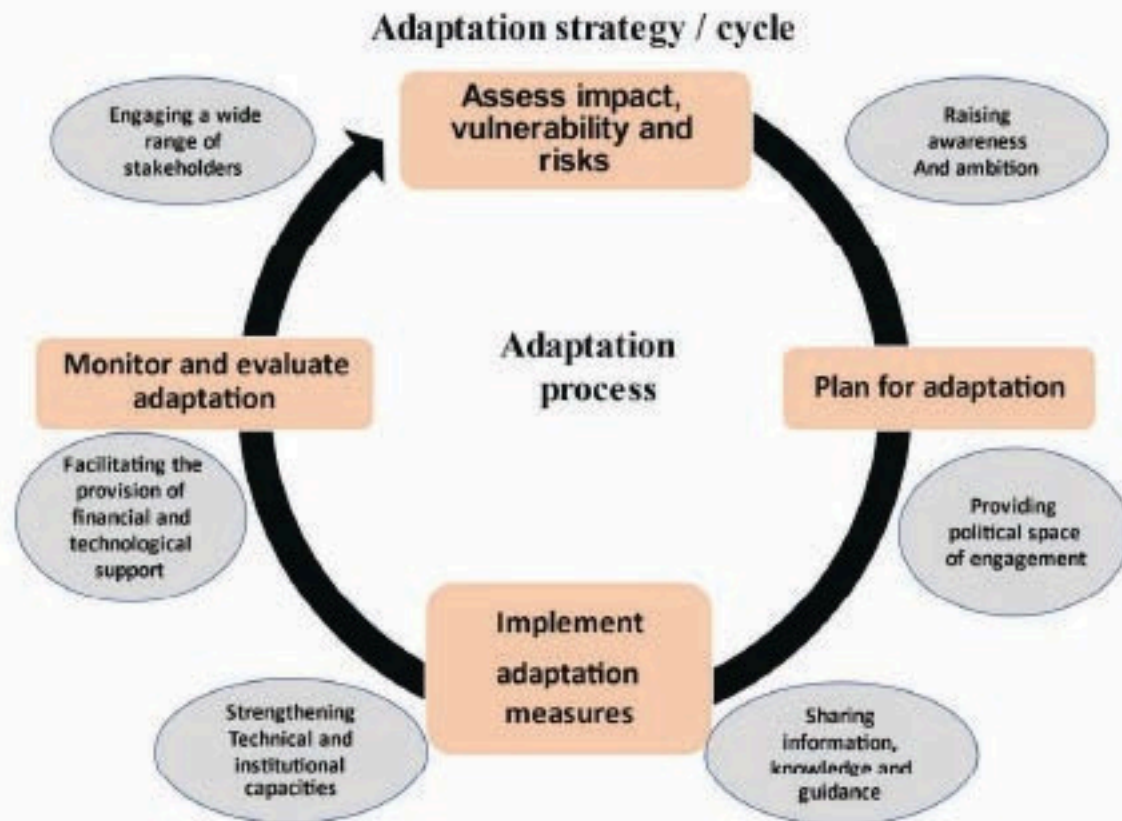


Fig: 2.1 The figure above shows the adaptation policy cycle and support offered under the UN Climate Change regime

2.6 Climate adaptive technic/procedure

Table 2.1 Adaptation Measures for Infrastructure

Climate Change Impact	Adaptation Measure	Additional Requirements
Extreme temperatures	Use stronger materials	Research and technology transfer
More intense rainfall	Use stronger materials Improve surface drainage capacity Increase pumping capacity at high value sites and critical infrastructures Traffic information system for the public	Modelling studies Improve design and construction standards & codes
More river flooding	Raise embankments Stronger erosion protection for embankments (geo-textiles) Increase lead-time for flood forecasting system Increase pumping capacity at high value sites and critical infrastructures Increase river conveyance capacity Increase capacity of drainage structures (culverts, regulators, bridges, etc.) Traffic information system for the public	Modelling studies
Debris damage and blockage	Use stronger material Improve storm and flood warning system Employ emergency response team in key districts	Research, training and technology transfer
Storm surges	Raise embankments Stronger erosion protection for embankments Increase river conveyance capacity Traffic information system for the public	Modelling studies
Saline intrusion	Improve embankment protection Augment dry season river flows	Integrated water resources management
Refugees during disasters	Improve early warning systems Increase shelter capacities Traffic information system for the public	Modelling studies
Localized subsidence	Improve monitoring system	Training

2.6.1 Factors would be mainly considered in Bangladesh Perspective

Table 2.2 Engineering Environmental Factors

Impact Factor	Description
Construction Materials	Very limited options with respect to locally available natural materials—deltaic fine sediments with some sand for embankment construction and locally produced engineering quality bricks. Stone aggregate has to be imported from outside the region.
Climate/rainfall	As discussed in the above sections—a monsoonal climate with regular extreme cyclone events dominates the environment.
Surface and sub-surface hydrology	The relative protection afforded by the polder system is a crucial issue in deciding on the climate adaption measure. Saline flooding and consequent lack of suitably salt-free water is a significant factor in the use of concrete in construction.
Terrain	The flatter rain reflects the geological and geomorphological history and together with the climatic factors contributes to the high static and erosive flood risk for the region.
Sub-grade and foundation conditions	The natural sub-grade and foundation materials are weak and compressible. CBRs likely to be 2-3%.
Road Task (Traffic)	Limited traffic data indicates a preponderance of light vehicles but consideration still needs to be given to the possibility of at least some heavy vehicles and the risk axle over loading.
Construction Regime	Evidence gained form site visit sand in discussion with local engineers indicates a weak construction regime characterized by generally poor specification compliance, and in particular: Lack of adequate earthwork compaction Inadequate construction supervision Difficulties with appropriate plant availability Some modifications to specifications required
Maintenance Regime	Although the Government of Bangladesh is officially committed to the principles of routine and periodic maintenance, which for the rural road network is primarily handled through LGED, there is still an evident shortfall in funding.

2.6.2 Adaptation strategies aim to reduce the impacts of specific types of climate effects by identifying and prioritizing adaptation options, which could include:

- Protecting existing assets or relocating assets away from vulnerable areas to preserve functionality
- Retrofitting vulnerable facilities
- Improving overall catchment/storm-water drainage
- Constructing new facilities
- Do little or nothing and divert funds/efforts to facilities with greater priority.

Alternatively, a strategy aims to reduce or mitigate the consequences of the impacts to infrastructure for impacts that have already occurred, with the purpose of, for instance:

- Preserving human life
- Reinstatement of former accessibility
- Minimizing economic impact
- Replacing damaged infrastructure as quickly as possible
- Changing maintenance regimes.

As discussed in the accompanying Visual Assessment Manual and in the introduction to this Guideline, all adaptation measures implemented are dependent on the available funding and in countries like Bangladesh with limited budgets, most adaptation measures on the existing infrastructure are likely to be reactive, using emergency funding after events occur.

2.6.3 Adaptation strategies determination of wave parameters:

The AASHTO Guide Specifications include three analysis levels for determining wave parameters. A Level I analysis is the simplest and generally most conservative method. Level II hydrodynamic analysis is a mid-level approach based on using improved data usually determined through simulations of the sea state. Level III hydrodynamic analysis involves advanced numerical simulation of the sea state.

A Level I analysis is used for superstructure replacement or maintenance projects. A Level II hydrodynamic analysis is used for new or full replacement projects unless the State Structure and Bridge Engineer determines a Level III hydrodynamic analysis is necessary. The hydraulics engineer will perform the Level I, Level II or Level III analysis.

The following project specific design parameters are to be included for hydrodynamic analysis:

- Location of the bridge
- Elevation of the bridge
- Bridge span dimensions, shape, and low chord height above storm water level
- Water bathymetry
- Storm fetch length orientation relative to the bridge location
- Fetch and fetch angle for the wave segments
- Fetch and fetch angle segment for local wind set-up/set-down
- Design storm wave height and period (wave length)
- Design wind velocity
- Design storm water surface which comprises of astronomical tide, storm surge, and local wind set up
- Sea Level Rise projection for the design storm year (which shall be taken as 4 feet for all vulnerable new or full replacement bridges)
- Design water current velocity should be defined and then implemented.

2.6.4 Raise the elevation of proposed structure to avoid flooding

An option to protect bridges is to increase the elevation of the structure by raising it to protect against flooding and accommodate changes in higher tides and storm surges, associated with sea level rise. This strategy allows roads to be built and located in vulnerable and exposure areas, with a low risk of flooding or susceptible to mud flow, geological collapse, or foundation deterioration.

Since the design of most structures utilizes historical climatic data, including documented peak flows, the new design elevation should be above the historical peak and projected future high-water level to offset the alteration brought by changes in precipitation.

If raising the structure and associated approach roadways is feasible, this option can be effective in protecting against flooding.

Advantages

- A protective measure against increased frequency of flooding, mud slides, or physical deterioration of bridge structural systems due to climate or severe weather
- Allow infrastructure to be built on low-lying or vulnerable areas

Disadvantages

- Raising the elevation of the structure can pose a design challenge to engineers

- Notable increase in CAPEX; substantial amount of material needed to raise the structure

Indicative Costs

Cost of additional building material

Timing for Implementation

Planning and design time required. Actual construction time needed should be similar to typical bridge projects.

Feasibility and Technical Requirement

Requires project engineer to consider the alternatives, technical feasibility and consequence of raising the structure.

2.6.5 Deepen bridge footings to protect against the effects of changes in the flow of river

The flow of water can turn from slow to rapid in a short amount of time that can exert a strong force on a bridge foundation. A stronger foundation can protect a bridge from collapse due to the effects of the stronger flows associated with extreme precipitation events.

For new bridge projects, engineers can deepen the bridge footings – the enlarged portions of bridge foundations that rest directly on soil, bedrock, or piles – to protect against the effects of changes in the flow of rivers. Designing and constructing deeper bridge footings can provide a stronger, more resilient foundation.

Advantages

- A protective measure against unanticipated changes in the flow of rivers.
- Protect a bridge from collapsing due to incapability of withstanding unexpected force – resulting in potential savings due to avoided damages.

Disadvantages

- May encounter design challenges if geological conditions are complex
- Higher CAPEX that often involves all elements of a bridge (e.g., deck, foundation, approach roadway, and utilities)

Indicative Costs

Cost of additional material

Timing for Implementation

Could be incorporated into design immediately

Feasibility and Technical Requirement

- Needs to be re-designed according to professional bridge guidelines and standards, and by a licensed engineer
- Alteration of the roadway connecting to the bridge may be needed as well as relocation of utilities that are often affixed to the bridge deck

2.7 Infrastructure protection and drainage

2.7.1 Improve or upgrade stormwater management system

Storm water runoff coming in contact with the different components of a bridge structure, thereby creating conditions for deterioration and instability. Insufficient capacity of the drainage system can cause water to remain either on or within the bridge structure. Damage may be minimized by improving or upgrading the storm water drainage system in the catchment draining through the bridge structure to increase water infiltration and reduce excess runoff. Improvements to bridge-related storm water management also can reduce bridge deck runoff pollutants that flow into a receiving river and landscape.

Advantages

Can be integrated into existing bridge system

Disadvantages

- Increase in both the CAPEX and OPEX due to costs associated with assessment, prioritization, design, and installation of retrofit opportunities for storm water system, bridge deck drainage, and the conveyance network.
- Need careful planning and may not be suitable in all locations.
- Maintenance is required and necessary in maintaining proper drainage.

Indicative Costs

- One-time capital and installation costs.
- Recurring maintenance costs.

Timing for Implementation

- Installation of bridge deck drainage retrofit or other storm water management improvement over 3 to 6 months.

Feasibility and Technical Requirement

- Engineers and storm water specialists to design storm water management for the deck surface runoff
- Skilled labor to perform maintenance

2.7.2 Stabilize stream banks to prevent erosion and to protect against bridge scour

Bridges that are located near stream banks or traverse across streams or waterways are exposed to severe erosion that can deteriorate foundations and eventually damage a bridge. Extreme weather events can cause erosion to occur more frequently as they can generate flash floods.

Stabilized stream banks can prevent erosion and protect against bridge scour. Bridge scour is one of the main causes of bridge failure and collapses; protecting bridges against scour is very important when evaluating adaptation options. Protection against bridge scour and stabilization of stream banks can be done by installing revetments, gabions, riprap or other measures such as an increase in vegetation.

Advantages

- Could be implemented in the near-term as a generally cost-effective and efficient measure
- Stream bank stabilization can have numerous positive impacts on the environment
- Minimizing erosion can indirectly reduce the risk of flooding

Disadvantages

Some level of maintenance needed to ensure objects installed (culvert, gabion, etc.) are not damaged after rainstorms and are maintained in good working order.

Indicative Costs

Cost of material, landscaping and professional design services.

Timing for Implementation

Immediately

Feasibility and Technical Requirement

Technical expertise required to assess and incorporate stabilization techniques.

2.7.3 Adaptation options to protect against sea level rise and increased intensity, duration and frequency of storm surge

Sea level rise along with combined threats from strong storm surges pose a great risk to coastal bridges. Several measures should be considered and used individually, or in combination, on future bridge projects to protect against these climate stressors. Decision-makers can integrate numerous adaptive measures into the new bridge design to increase the structure's resilience. A sample list of measures includes:

- Open-faced railings – to reduce wave forces and distribute water flow on a bridge deck. Railings need to adhere to testing and crash-worthiness standards;
- Raising piers – to elevate the structure above historic and future peak wave height and water levels. Ideally, a new structure should be constructed above historic and future peak levels; however, depending on the bridge structure and its footing design along with other components

like location and expected life of the bridge, the new elevation can vary and feasibility challenges may prohibit implementation;

- Lengthening piles – depending on the bridge type and compressive loads on a bridge, to accommodate large anticipated wave loads, longer columns can be used and driven deeper into the soil and bedrock, in order to provide a stronger support to the structure;
- Use more rigid connections made of formed concrete to prevent decks from floating off bridge piers when strong storm surges and waves exert extreme force on bridge decks; and
- Site-specific protective structural or soft armoring measures applied around the base of a bridge including scour apron or blanket.

The design for these types of protective measures can be challenging and very costly. Decision makers need to consider the quantity of traffic utilization, scale, expected service life of the structure, and cost-effectiveness before applying these protective measures.

Advantages

- If installed, these protective measures can be very effective in building resilience against storm surge, wave and water forces
- If elevated above historical peak or future heights, bridges could operate during extreme events and provide a safe evacuation route
- Possibly reducing or avoiding costs to implement future remediation
- Longer service life for bridges compared to those without protective measures

Disadvantages

- Significant increase in CAPEX – variable depending on whether one or more type of measure is

Selected

Indicative Costs

- High upfront cost, specific cost will be dependent on the type of protective measure implemented

and design factors

Timing for Implementation

The time frame varies depending on the type of protective measure implemented and design factors.

Feasibility and Technical Requirement

A high level of technical expertise in multiple disciplines is generally needed, and varies depending on type and scale of structure

2.8 Operation and maintenance

2.8.1 Increase frequency of bridge inspection and repair

Increased frequency of bridge inspection and repair is another possible adaptation option. While some damages caused by climate stressors can cause bridges to collapse, other damages are minor in nature and would not pose an immediate threat to the structure or safety of travelers, but could build up over time and ultimately result in bridge failure.

Conducting bridge inspections and repairs more frequently can ensure that incremental damages do not worsen and are repaired before causing substantial damages to the bridge.

Advantages

- Prevent minor damages from becoming severe
- Protect against extreme weather conditions
- Preserve the expected life of bridges
- Eliminate the need for emergency repairs

Disadvantages

- Disruption to traffic during inspection and repair; disturbance to traffic can be minimized by scheduling maintenance at low traffic hours or weekends.
- Higher OPEX – need additional workers to conduct inspections.

Indicative Costs

Minor increase in operational costs

Timing for Implementation

Immediately

Feasibility and Technical Requirement

Requires experienced workers to inspect and identify damages

2.8.2 Traffic and loading management

Regardless the type of adaptation strategy selected to improve the resiliency of a bridge to climate change, it needs to be accompanied by traffic (multi-modal and pedestrian in some cases) and truck load management. Climate change is likely to intensify severe storms, storm surges and intense precipitation, and require more frequent emergency response from transportation officials. Therefore, transportation and traffic officials should take a pro-active approach in dealing with climate extremes, for instance:

- Mapping, rating and prioritization of vulnerable travel routes, such as those that are becoming more susceptible to flooding that is combined with route statistics (usage, infrastructure type, access to travel markets, etc.);

- Establish emergency plan in coordination with other jurisdictions to divert traffic to alternative routes when primary route becomes inaccessible due to climate-related events, safety or security concerns; and
- Create and maintain an emergency operation budget that can immediately be used for emergency response purposes.

Having emergency response plans established before a disaster occurs can improve the preparedness of officials to deal with the impacts of such climate extremes.

In addition, traffic management policies can be applied to further protect bridges from damage from climate extremes, including:

- Apply a loading restriction that manages the incidence of heavy traffic traveling on a bridge structure during the time of a day when bridge usage is the highest. This action can reduce bridge fatigue and maintain expected service life of bridges; and
- Increase frequency of temporary road closure to perform maintenance on road and repair minor damages before damages worsen the condition of the bridge.

Advantages

- Low CAPEX.
- Further protects bridges and its users.

Disadvantages

Requires broad government coordination across sectors and levels

Indicative Costs

Policy an administrative cost

Timing for Implementation

Immediately

Feasibility and Technical Requirement

Knowledge in emergency planning and response needed.

2.9 Steps of methodology for incorporating climate change adaptation.

Step -1. Establishes the context of the assessment defining the asset and the climate impacts that will be the focus of the assessment.

Step -2. Considers the vulnerability (exposure, sensitivity, and adaptive capacity) of the assets screening those that require more detailed analysis.

Step -3. Identifies, analyzes and evaluates the subsequent risks (combining likelihood with consequences).

Step - 4. Develops adaptation strategies to address the most significant risks.

Step - 5. Guides the implementation, monitoring and evaluation of adaptation solutions.

2.10 Approach to Risks Management

Risk management may be viewed as sequential and iterative process of managing project risk required to be repeated throughout the lifetime of the Program and starting with the identification of risks that threaten the success of the project. The risk management process comprises a cycle of measures/ actions as shown in Figure -2.2

The areas are as follows:

Identifying Risks:

In this first step of the risk management process potential risks, events, factors, and other items that threaten the success of the project are identified. The risks are threats to the scope, quality, schedule, budget, personnel, procurements, and other things of importance. The goal of the first pass through this Identify Risks step is to create a master list of all potential risks to the project. New risks whenever identified are added to the risk register/ Spread sheet.

Analyzing & Prioritizing Risks:

In this second step of the risk management process, each identified risk is analyzed to create a prioritized ranking.

Planning of Risk Responses:

In this step, responses are developed for the various risks in the risk register. These responses are essentially the individual plan or plan that to be implemented to minimize the likelihood and/or impact of each significant risk.

Monitoring Risks:

Once the risk register is complete, the role of project management is to monitor the individual risks contained therein and update the register on a period basis and/or as new risks surface.

Communication with Stakeholders:

A primary role of Project Management is communicating to key stakeholders about the status of project risks, their collective cost/schedule/quality/scope exposure, response plans, and the resolution of issues as they arise.

Response to Issues:

When a risk is realized, it is no longer technically considered to be a "risk," but instead it is referred to as an "issue." In the diagram above, this is illustrated by the fact that the Respond to Issues step is technically outside of the Risk Management process; it is an issue that the project needs to schedule/budget/plan.

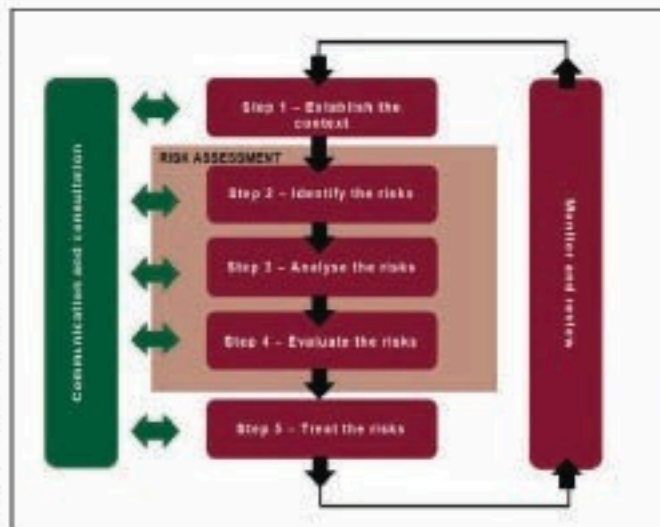


Figure 2.2: Risk Management Process

2.11 Adaptation framework (from USAID global research on climate change)

2.11.1 Step 1. Establishing the context



Fig: 2.3 (Establishing the Context)

The first step in the overall approach is to define the service to be delivered by the infrastructure activity in the face of future climate change. Establishing the context notably includes defining the service to be delivered by the bridge infrastructure within the context of future climate change.

2.11.2 Step 2: Vulnerability assessment

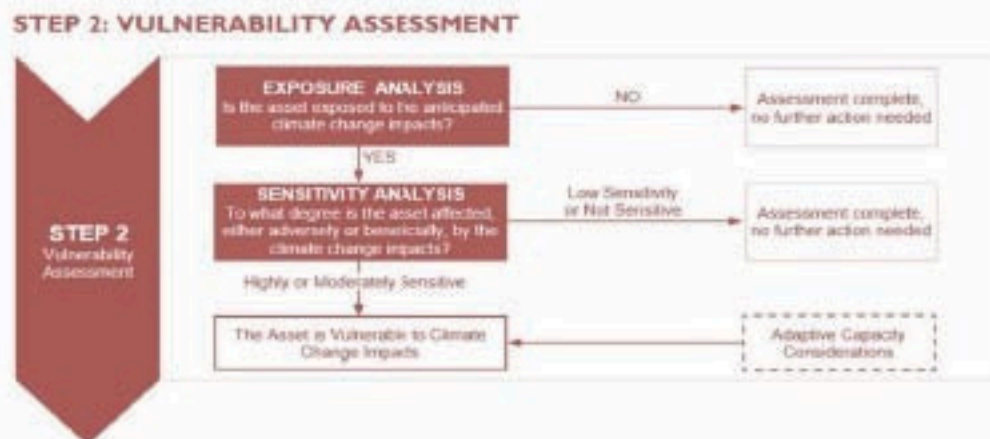


Fig: 2.4 (Vulnerability Assessment)

The second step in the overall approach considers the degree to which an infrastructure asset is susceptible when exposed to hazards identifying those that warrant more detailed investigation in Step 3.

The vulnerability screening involves understanding an asset's vulnerability to specific climate change impacts over time. Climate-Resilient Development: A Framework for Understanding and Addressing Climate Change 4 defines vulnerability as a function of an asset's exposure, sensitivity and adaptive capacity to a specific climate hazard.








2.11.3 Determining asset sensitivity

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate stressors. For example, a wooden bridge may be more sensitive to wildfire than a concrete bridge due to the potential damage that fire may cause to the wooden construction materials compared to concrete construction materials. Table 3 outlines the levels of sensitivity ranging from Not Sensitive to High Sensitivity. Using this scale, project elements that are rated as having a Moderate or High Sensitivity would be deemed vulnerable to the climate impacts associated with the relevant climate hazard and be the focus of the risk assessment. To help inform sensitivity assessments, Table 4 provides a summary of the likely sensitivity of different types of bridge infrastructure to different climate hazards. Noting, that the sensitivity of a bridge will be dependent on its construction materials, Table 5 summarizes the sensitivity of different materials to various climate variables in temperate climates.

Table 2.1: Levels of sensitivity to climate change impacts

Level of Sensitivity	Definition
NOT Sensitive	<ul style="list-style-type: none"> No infrastructure service disruption or damage
LOW Sensitivity	<ul style="list-style-type: none"> Localized infrastructure service disruption; no permanent damage Some minor restoration work required
MODERATE Sensitivity	<ul style="list-style-type: none"> Widespread infrastructure damage and service disruption requiring moderate repairs Partial damage to local infrastructure
HIGH Sensitivity	<ul style="list-style-type: none"> Permanent or extensive damage requiring extensive repair
<p>Moderate or high sensitivity impacts are considered vulnerable and should be the focus of the risk assessment.</p>	

Table 2.2: Probable sensitivity to climate change impacts

THEME	PROJECT							
		Extreme Heat	Drying Trend/Drought	Extreme Precipitation/Flooding	Storm Surge	Sea Level Rise	Damaging Storms (wind, lightning, snow/ice)	Wildfire
Bridges	Large scale bridges	LOW	LOW	HIGH	LOW	LOW	LOW	LOW
	Small scale bridges	LOW	LOW	HIGH	LOW	LOW	LOW	LOW

NOT SENSITIVE
 LOW SENSITIVE
 MODERATE SENSITIVE
 HIGH SENSITIVE

Table 2.3: Differential impact of climate effects on materials

Material	Carbon Dioxide	Cyclones & Storms	Sea Level Rise	Extreme Rainfall & Floods	Annual & Max Temp	Ultraviolet Radiation	Wildfire	Drought
Concrete	M	S	S	M	M	L	M	M
Metals	M	S	S	M	M	L	S	M
Mortar	M	M	M	M	L	L	M	S
Timber	M	M	M	S	M	L	H	M
Coatings	M	M	L	M	M	S	H	M
Polymers	M	M	L	L	M	S	H	M

M	Minimum	M	Moderate	S	Severe	H	Highly Severe
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2.11.4 Step 3: Risk assessment

STEP 3: RISK ASSESSMENT

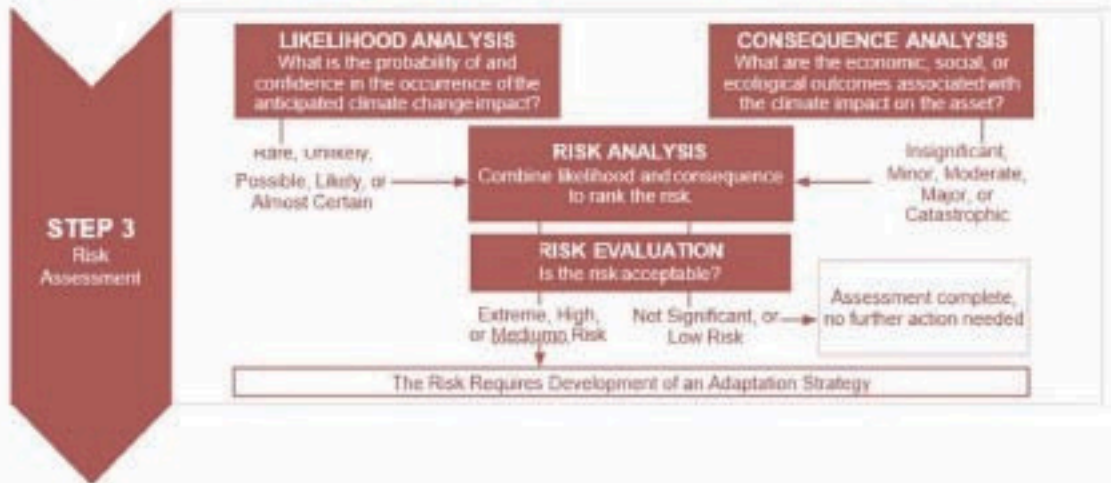


Fig: 2.5 (Risk Assessment)

The third step of the approach enables practitioners to consider risks once the vulnerability of an asset or project has been established. A risk assessment provides an analytical framework with qualitative descriptors for likelihood and consequences in a resulting risk matrix. Only those assets that have been identified as vulnerable in Step 2 need to be analyzed for risk.

Risks are often expressed as the combination of the consequences of an event and the associated likelihood of it occurring:

$$\text{RISK} = \text{CONSEQUENCES} \times \text{LIKELIHOOD}$$

This approach is aligned with traditional risk management principles (e.g. ISO 31000:2009 Risk management—Principles and guidelines). Exposure and sensitivity data gathered in Step 2 can be used to inform the rating of likelihood and consequences.

2.11.5 Determining risk acceptability and adaptation

Based on the outcomes of the risk analysis, it is necessary to determine and prioritize those risks requiring treatment with appropriate adaptation measures. Risk acceptability criteria need to be defined to guide the determination of which risks are determined to be acceptable and the most significant risks requiring treatment (i.e. adaptation planning).

Often the risk evaluation is led by a project funder or leader, rather than the technical staff who lead the risk analysis. Decisions on risk treatment should take into account the acceptability of external stakeholders that are likely to be affected.

Table 2.4 : Example

Qualitative definitions of likelihood

Level of Likelihood	Definition
Almost Certain	More likely than not, probability greater than 50%
Likely	As likely as not, 50 / 50 chance
Possible	Less likely than not but still appreciable, probability less than 50% but still quite high
Unlikely	Unlikely but not negligible, probability low but noticeably greater than zero
Rare	Negligible, probability very low, close to zero

Table 2.5: Example

Descriptor for consequences

Level of Likelihood	Definition
5 Disastrous	<ul style="list-style-type: none"> • Asset Damage: Permanent damage and / or loss of infrastructure. • Loss of Service: Wide spread and extended (several weeks) interruption of service of the agreed Level of Service; result in extreme contractual penalties or contract breach. • Financial Loss: Asset damage > annual maintenance budget or 75% of CAPEX value. • Health/Safety: Substantial changes to the health and safety profile ;risk of multiple fatalities as a result of extreme events. • Reputation: Irreversible damages to reputation at the national and even in tarnation all evel/Publicoutrage.
4 Severe	<ul style="list-style-type: none"> • Asset Damage: Extensive infrastructure damage requiring extensive repair/Permanent loss of local infrastructure services. • Loss of Service: Wide spread and extended (several days) interruption of service for less than 50% of the agreed Level of Service; result in severe contractual penalties. • Financial Loss: Asset damage 50%+ of annual maintenance budget or 25% of CAPEX value. • Health/Safety: Marked changes in the health and safety profile risk of severe injuries and even fatality as a result of extreme events. • Reputation: Damage to reputation at national level; adverse national media coverage; Government Agency questions or enquiry; significant decrease in community support.

<p>3 Moderate</p>	<ul style="list-style-type: none"> • Asset Damage: Damage recoverable by maintenance and minor repair / Partial loss of local infrastructure. • Loss of Service: Widespread interruption of service for less than 20% of the agreed Level of Service; result in minor contractual penalties. • Financial Loss: Asset damage > 10% but < 25% of annual maintenance budget or 5% of CAPEX value. • Health/Safety: Noticeable changes to the health and safety profile, risk of severe injuries as a result of Extreme events. • Reputation: Adverse news in media /Significant community reaction.
<p>2 Minor</p>	<ul style="list-style-type: none"> • Asset Damage: No permanent damage /Some minor restoration work required. • Loss of Service: Localized interruption of service for less than 10% of the agreed Level of Service. • Financial Loss: Asset damage > 5% but < 10% of annual maintenance budget or 1% of CAPEX value. • Health/Safety: Slight changes to the health and safety profile ;risk of minor injuries as a result of Extreme events. • Reputation: Some adverse news in the local media /Some adverse reactions in the community.
<p>1 Insignificant</p>	<ul style="list-style-type: none"> • Asset Damage: No infrastructure damage. • Loss of Service: Localized interruption of service for less than 1% of the agreed Level of Service (LoS). • Financial Loss: Asset damage < 5% of annual maintenance budget or negligible CAPEX value. • Health/Safety: Negligible or no changes to the health and safety profile or fatalities as a result of Extreme events. • Reputation: Some public awareness.

Table 2.6: Risk rating matrix

Level of Risk		Consequence Level				
		Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Likelihood Level	Almost Certain (5)	Moderate (5)	Moderate (10)	Severe (15)	Highly severe (20)	Highly severe (25)
	Likely (4)	Minimum (4)	Moderate (8)	Severe (12)	Severe (16)	Highly severe (20)
	Possible (3)	Minimum (3)	Moderate (6)	Moderate (9)	Severe (12)	Severe (15)
	Unlikely (2)	Minimum (2)	Minimum (4)	Moderate (6)	Moderate (8)	Moderate (10)
	Rare (1)	Not Significant (1)	Minimum (2)	Minimum (3)	Minimum (4)	Moderate (5)

Table 2.7: Example responses and acceptability for different levels of risk

Level of Risk	Definition
HIGHLY SEVERE ≥20	<ul style="list-style-type: none"> • Extreme risks demand urgent attention at the most senior level and cannot be simply accepted as a part of routine operations • These risks are not acceptable without treatment
SEVERE 12-16	<ul style="list-style-type: none"> • High risks are the most severe that can be accepted as a part of routine operations without executive sanction, but they are the responsibility of the most senior operational management and reported upon at the executive level • These risks are not acceptable without treatment
MODERATE 5-10	<ul style="list-style-type: none"> • Medium risks can be expected to form part of routine operations, but they will be explicitly assigned to relevant managers for action, maintained under review and reported upon at the senior management level • These risks are possibly acceptable without treatment
MINIMUM ≤4	<ul style="list-style-type: none"> • Low risks will be maintained under review, but it is expected that existing controls will be sufficient and no further action will be required to treat them unless they become more severe • These risks can be acceptable without treatment

2.11.6 Step4:Developing anadaptation strategy

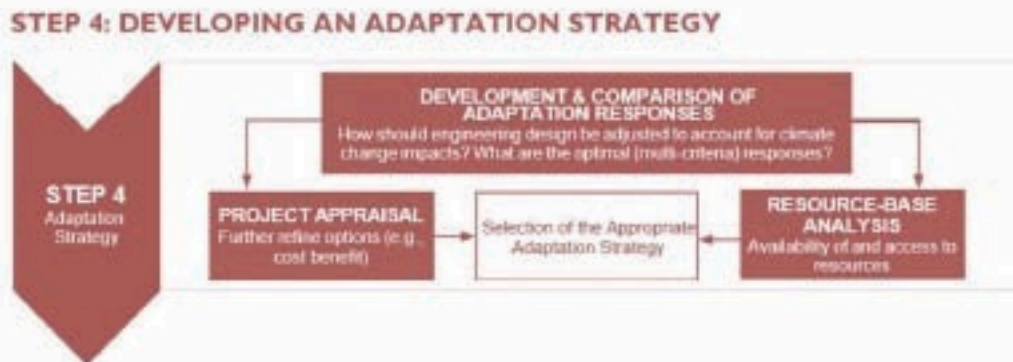


Fig: 2.6 : Developing and adaptation Strategy

Once the degree of vulnerability has been established and the most critical risks have been identified, a decision can be made regarding how to address the risks. A range of appropriate adaptation strategies are available when preparing for and adapting to climate change impacts. Selection of a strategy is dependent on a number of factors, including location, temporal scale, and the specific impacts faced.

Understanding the available resource base to implement the infrastructure activity will also be important. While some adaptation options may require little resources (e.g., training or monitoring) others may prove more cost-intensive.

Four generally accepted types of adaptation responses that can be implemented include: 1) accommodate and maintain; 2) harden and protect; 3) relocate; and 4) accept or abandon. These strategies can help categorize various adaptation responses for new and existing infrastructure (Table 10) and understand the various advantages and disadvantages of selected responses (Table 11).

Examples of adaptive engineering design options specific to bridge infrastructure are provided in Table 12.

Table 2.8: Approach To adaptation strategies


Strategic Approach	Adaptation Strategy	
	Existing Infrastructure	New Infrastructure
Accommodate and Maintain	<ul style="list-style-type: none"> Extend, strengthen, repair or rehabilitate over time Adjust operation and maintenance 	<ul style="list-style-type: none"> Design and build to allow for future upgrades, extensions or regular repairs
Harden and Protect	<ul style="list-style-type: none"> Rehabilitate and reinforce Add supportive or protective features Incorporate redundancy 	<ul style="list-style-type: none"> Use more resilient materials, construction methods, or design standards Design for greater capacity or service

Relocate	<ul style="list-style-type: none"> Relocate sensitive facilities or resources from direct risk 	<ul style="list-style-type: none"> Site in an area with no, or lower, risk from climate change
Accept or Abandon	<ul style="list-style-type: none"> Keep as is, accepting diminished level of service or performance 	<ul style="list-style-type: none"> Construct based on current climate, accepting possibly diminished level of service or performance

Table 2.9: Advantages and disadvantages of adaptation approaches

Strategic Approach	Advantages	Disadvantages
Accommodate and Maintain	<ul style="list-style-type: none"> Less costly More pragmatic and flexible, allows adjustment over time as more climate change data becomes available 	<ul style="list-style-type: none"> Requires monitoring, possibly frequent repairs, adjustments, or more rigorous operations Necessitates design for more flexible or upgradeable structure
Harden and Protect	<ul style="list-style-type: none"> Proactive Straightforward to implement and justify 	<ul style="list-style-type: none"> More costly Assumes reasonably accurate climate forecasts
Relocate	<ul style="list-style-type: none"> Proactive 	<ul style="list-style-type: none"> More costly Sub-optimal location may decrease period of performance or service
Accept or Abandon	<ul style="list-style-type: none"> No extra up-front cost 	<ul style="list-style-type: none"> Proper communications needed to inform decision-makers and beneficiaries to expect lower performance or service

TABLE 2.10: Examples of engineering adaptation options for climate adaptation bridge infrastructure

Climate Drivers	Adaptation Measures
 <p>Extreme Precipitation Events, Flooding and Damaging Storms</p>	<p>Adaptation strategies that address flooding and reduce its impacts on bridges fall under two broad categories:</p> <ul style="list-style-type: none"> Protect bridges from damages caused by flooding by strengthening the bridge piers and foundations, or by increasing the hydraulic capacity of the bridge by raising the bridge deck Minimize the occurrence of flooding or reduce its magnitude by increasing infiltration within the catchment area draining through the bridge structure, or diverting high flows to drainage systems with a higher drainage capacity

 <p>Sea Level Rise and Storm Surge</p>	<ul style="list-style-type: none"> • To protect bridges from powerful storm surges and waves, at-risk structures can be reinforced, particularly to protect against scouring of bridge piers, columns, or foundations • Treat metal components of the bridge to resist corrosion due to increased exposure to salinity
 <p>Extreme Heat, Heatwaves and Wildfires</p>	<p>Extreme heat and increases in diurnal temperature variation can damage expansion joints and deck surface materials:</p> <ul style="list-style-type: none"> • Replace or reconstruct bridge deck expansion joints to mitigate the impacts of higher temperature • Use paving materials that are more resistant to expansion in extreme heat conditions • Small-scale bridges built with timber are at risk of destruction in extreme heat causing wildfires • Build small-scale bridges with heat resistant materials or use coatings • Maintain and implement vegetation management practices that aim to minimize fire risk

2.11.7 STEP 5: IMPLEMENTATION



Fig: 2.7: Implementation

2.11.8 Monitoring and evaluation

Most projects and programs include monitoring and evaluation activities that can be adjusted to cover climate change risks. If feasible, embedding climate change risks in an existing monitoring and evaluation framework is the preferred approach, rather than developing a stand-alone climate change risk monitoring and evaluation framework.

Ongoing monitoring and evaluation activities can help consistently adjust the risk assessment and management approach, and support development of risk treatments that are effective, contribute to improvements in risk understanding, detect changes in external and internal conditions, and identify emerging risks.

Monitoring and evaluation should be based on robust and simple to measure quantitative and qualitative indicators. Careful consideration should be given to the cost efficiency and ease of measurement for the proposed measures. Information can be collected and analyzed through both participatory and external evaluation. Local communities can take a very active role in monitoring tasks.

2.11.9 Communication and consultation

Climate change risk communication activities should ideally form part of the overarching outreach and communications plan for each infrastructure asset.

Communication and consultation should ideally take place during all risk management activities. A robust and consistent communications plan including consideration of potential climate change risks and selected adaptation options should be developed in close collaboration with implementing partners and stakeholders. A communication plan should outline how the findings of the analysis will be made accessible to support decision making and general awareness raising for both technical and non-technical audiences.

Different target groups (e.g., government agencies, businesses, communities, and women and children) and different communication vehicles (e.g., workshops, reports, animations, summary sheets, and fact sheets) should be considered. Ongoing communication and consultation activities can support the development of appropriate objectives and understanding of the local context, help ensure that climate risks are correctly identified, and help build consensus among stakeholders on the findings of the risk assessment and the risk treatment selected for implementation.

Chapter 3

Adaptation measures and considerations in design stage

3.1 Design considerations

There are many guidelines and codes available for the design and construction of larger structures using concrete and steel, such as Overseas Road Note 9 (TRL, 2000). However, little guidance is generally available concerning small structures. In this respect, the guideline document *Small Structures for Rural Roads: A Practical Planning, Design, Construction & Maintenance Guide* (Larcher et al, 2010) provides comprehensive information to assist engineers and technicians in the planning and provision of small road structures.

3.2 Climate adaptation considerations in bridge design

Climate resilience is the ability to anticipate, prepare for, and respond to hazardous events, trends, or disturbances related to climate. Improving climate resilience involves assessing how climate change will create new, or alters current, climate-related risks, and taking steps to better cope with these risks.

In the Coastal Zone of Bangladesh there are about 19 districts which are vulnerable to climate change effects of Sea Level Rise, Cyclones & Tidal Surges with heavy wind and rainfall, increased Salinity etc. Effects of these are very much detrimental to the Structures like Bridges & Culverts which are in direct contact with saline water and polluted air. Atmospheric CO₂ is a major cause of reinforcement corrosion of bridges. Temperature rises will also increase corrosion rates. Corrosion damage is disruptive to society and costly to repair. Sea level rise, Cyclones & Tidal surges along with river flow will increase the HWL or SWL of the inland river at bridge point which need to be addressed properly.

For coastal zones, the following climate adaptation measures were considered or undertaken:

- provided climate resilience concrete
- provided epoxy coated reinforcement
- increased clear cover of reinforcement
- increased lap length by 25% for epoxy coated reinforcement
- considered increased HWL or SWL following sea level rise of 47 cm as per BWDB study for Coastal Embankment Improvement Project (CEIP; Phase-I)

The other part of the country outside the 19 districts of the Coastal Zone, there is very few or no effect of salinity. But the effect of climate change is found to be there in the river system as increased rainfall and surface runoff, discharge, water level, sediment flow, river bank erosion, scour under pier and abutment etc. demanding the need for increasing length, height of the bridges, river bank and approach protection and pile capacity (foundation strength) determination for making those climates resilient.

A study conducted by Dr. Mostafa and Imran Khan of BUET on "Potential changes to the water balance of the Teesta River Basin due to Climate Change" was published in the American Journal of Water Resources, 2019. The study reflects the results of GCM solutions for 2080s with four scenarios: Wettest, Driest, Warmest and Coolest. For the wettest scenario, the mean monthly flow at Dalia Point in the month of June will be increased by more than 50%. The Peak flow also will be increased by 18%. Even for the driest lean season, the monsoon flow may be increased by as much as 15% creating more unbalanced condition in the future.

Another study conducted by Mondal et al on "Assessing High-End Climate Change Impacts on Floods in Major Rivers of Bangladesh using Multi-Model Simulation" published in Global Science and Technology Journal Vol.6 No 2, June-2018, provides the changes in Peak water levels and discharges at 7 locations in Ganges, Brahmaputra and Meghna Rivers under potential climate change by the end of this Century which ranges from 25 cm to 72 cm increase in peak water level and 5% to 29% increase in peak discharge.

National Adaptation Plan of Bangladesh (2023-2050) published in October 2022 provides the future climate scenarios where it is mentioned that due climate change, the mean annual flow of the Ganges, Brahmaputra and Meghna river basins will increase by 17%- 28%, 2%-5% and 1%- 4% respectively under SSP5-8.5 scenario in 2050s (CEGIS 2021). The seasonal flow will increase from 18% to 30% in Ganges and there will be smaller increase in Brahmaputra and Meghna River.

BWDB being the principal organization regarding Flood & River management in Bangladesh conducted a detail analysis for High Water Level for different Return Period of the different riversystem of the country and published a report, "Criterion for Determining the Crest Level of Flood Control Embankment" in December 2020 considering Climate Change Effect.

Thereby observing all these studies and guidelines, the increase of flow considered in design in the area both the coastal and non-coastal zone due to climate change is about 15% which will be added to the maximum discharge of the river at the bridge point.

And increase of design maximum High Water Level or Standard High-Water Level for the River at Bridge site considered in the design is about 48 cm in the Coastal zone and outside the coastal area is about 30 cm which will be added to MHWL or SHWL along with navigational clearance to get the free board.

3.3 Adaptation measures in bridge design stage

SL No.	Observation and suggestions	Measures to be taken
1	Adequate freeboard to be provide for every bridge in coastal and non-coastal region	Minimum 60cm freeboard to add with HFL, where there is no navigation. But where is navigation, there BIWTA /LGED guideline to be followed
2	Approach and bank protection	In general, 5-15 m approach road protection to be provide at almost all bridges
3	Scour of river bed	In the design process, pile length should be increased
4	Detailed hydro-morphological assessment	Limited hydro-morphological and hydraulic assessment for river and stream for small bridges
5	Detailed hydro-morphological assessment	Detailed hydro-morphological and hydraulic assessment for river and stream for small and large bridges

3.4 Some other factors

3.4.1 Site selection

The site selected should enable construction of a safe, economical, and easily maintained crossing, having regard to routing and approach requirements, to the nature of the waterway and its environment, and to minimize the use of such training works as may be necessary to deal with adverse natural channel features.

In selecting a site, it is important to examine the physical characteristics of the water course and its drainage basin. These characteristics are determined by geology, topography, climate, and land use, and may be divided into four groups.

- Geographic: Physiographic setting, geological history, channel pattern, etc.
- Hydrologic: Discharge patterns, water levels, ice etc.
- Hydraulic: Slopes, cross-sections, velocities, roughness, etc.
- Geotechnical: Boundary materials, erosion, scour and sedimentation, etc.

The complex interactions between these characteristics produce a wide variety of stream types. The general patterns of variation in all of these characteristics, and the relationships between them, are

often referred to as the river's "regime", in the same sense that "climate" is used in considering meteorological variables. In regard to scour and erosion, behavior of a stream may fall within a wide range, from a very stable bed rock channel to a highly mobile alluvial river. Many rivers exhibit complex changes in behavior from point to point, because of the strong influence of local features associated with glaciations. Careful investigation of past behavior at a particular site is therefore important. The choice of site may greatly affect the difficulties and expense of building a crossing as well as its long-term performance, stability, and amount of maintenance required. It is therefore necessary that field studies be conducted during route selection to choose the best location for the bridge installation.

3.4.2 General route selection

Bridges are a significant component of any new road especially in terrain where streams or flood plains are numerous. A new route should minimize the number and length of crossings required, thereby keeping environmental disruption as well as overall costs to a minimum.

3.4.3 Suitable site characteristics

Stream characteristics and geology often vary significantly over short lengths of river. A suitable crossing site should be at a stable reach having good flow alignment. The liability of scour or bank erosion must be investigated and should be an important site selection criterion. When streams are braided, i.e., split into two or more channels, a single channel location is preferred.

3.4.4 Bridge alignment

The alignment of a bridge relative to the waterway should be at right angles. This will reduce the length of bridge required to cross. In meandering and shifting streams attention must be given to past trends to ensure that the stream at the selected location will not shift. In some instances it may be necessary to construct training works. Straight lengths of channel are preferred for the crossing. Crossings on abrupt bends should be avoided except when the stream is in erosion resistant materials.

3.4.5 Alluvial fans

Crossings of alluvial fans should be avoided because of the aggradations of the channel. The preferred crossing location is near the apex or head of the fan.

3.4.6 Sites of flooding

Bridges should not be located in areas which are known to flood periodically. The presence of a bridge often aggravates the problem. One should also be aware of typical ice jam locations and these should be avoided.

3.4.7 Location of other structures

There are so many possibilities here that possible precautions can only be discussed in general terms. The presence of other structures can have a significant bearing upon site selection. For instance, other crossings may affect or be affected by the proposed bridge. Dams, both upstream and downstream obviously have considerable bearing. In some cases, other structures are not even built but are proposed and may influence a bridge site.

3.4.8 Approaches

Approaches to the proposed bridge must meet requirements of grade and alignment for safety reasons.

Factors consideration for bridge Design:

3.5 Key considerations in identifying impacts to bridges

Climate change is likely to impact bridge infrastructure assets through modification in the pattern of extreme climatic events, which includes storms and storm surge, floods, and drought; or through gradual changes in seasonal or annual patterns of temperature, solar radiation, precipitation, and sea level rise.

When evaluating the impact of climate change and risk to bridge infrastructure there are two overarching concerns the timeframe for the asset's productive lifespan and required capital costs. While engineering design always considers some measure of extreme weather conditions when designing or rehabilitating infrastructure, it is important to consider a temporal scale that is appropriate to the anticipated life of the asset as well as and cost-effectiveness of climate resilience options.

a) Design Flood Frequency - The hydrologic and hydraulic design of a bridge is essentially a two-step process. The first step is to estimate all of the forces or quantities which would impact on the installation for an appropriate return period. The second step is to design all the structural components to accommodate these forces or quantities with some margin of safety. While such factors as the weight of traffic, earthquakes, wind and other forces are of great importance, these guidelines are primarily concerned with the flow and quantity of water, hence the hydrologic and hydraulic design.

Obviously, no structure is designed to last forever. Equally true however, is the fact that the more valuable or important the bridge is, the longer it should be expected to last. The longer a bridge is expected to last, the more likely it is that it will be subjected to an extreme event or flood. The term "return period" is used to indicate a probability that a flood of a certain magnitude will occur. For example, a 100-year return period flood is a flood whose flow would be exceeded on average once every 100 years.

The selection of an appropriate return period as mentioned above depends on the value of the bridge. This includes the cost of repair or replacement if the actual flows exceed the design flow and cause damage to the structure. However, the selected return period must also reflect the importance of the reliability of structure, possible secondary damages to other property and environmental consequences of bridge failure. An economic analysis or cost-benefit analysis should be considered in determining the most economical design of bridges.

Return Periods for Hydrologic Design

b) Capacity - The bridge opening is the product of the width and height plus the cross-sectional area of the stream as shown in Figure 4.4. The rate of flow that can pass through this opening without overtopping is referred to as the capacity. It must be noted however that width and height are

independent of capacity requirements meaning that a bridge dimension may need to be larger than required by the design flow.

Historical Flows

The maximum historical flows as recorded at the site, or as calculated on the basis of recorded water levels, or as calculated on the basis of measured discharges at other points on the river from which corresponding site discharges can reasonably be inferred, may be used.

Flood Frequency Analysis

The discharge derived from a frequency analysis and corresponding to flood and/or tidal conditions of a frequency appropriate to the importance and value of the structure. Results of Regional Flood Frequency Analysis (RFFA) are available from this department.

Other Discharge Estimates

Where insufficient information is available to yield an estimate of the actual maximum discharge at the site over a historical period of reasonable length, or to provide an adequate frequency analysis, the design discharge may be estimated by any other reasonable method such as regional flood frequency, unit hydrograph, maximum probable storm, rational method, etc. Estimates may be made of maximum flow rates based on the area of the drainage basin, rainfall intensity-duration, and other appropriate data, which would indicate the flows that could be anticipated.

Anticipated Land Use Changes

The marginal cost of increasing a proposed design parameter may be small enough to warrant oversizing in order to be assured of good future performance. This is especially true if land use changes are likely to occur in the drainage basin upstream of the bridge.

Design Discharge Verification

When the design discharge is based on historical maxima, frequency analysis, or other empirical methods, it is advisable to check whether the historical record reflects trends or discontinuities in the flow regime resulting from land use changes, engineering works, or other causes; and to consider whether such changes are likely to occur in the foreseeable future.

Discharges Controlled by Reservoir Releases

Before counting on significant reductions in natural flood peaks because of storage reservoirs or other upstream works, the probable operating and routing procedures should be investigated. Where possible, a written statement should be obtained from the competent authorities.

Flow Duration

The probable duration as well as the magnitude of large flows may be significant, especially with reference to scour.

c) **Bridge Height** - The height of the deck should be such that the superstructure is not endangered by the action of flowing water, ice, floating debris, or waves, and the roadway is not rendered impassable except under clearly understood and permitted conditions. The selection of design values and safety margins for high water level and discharge raises difficult questions. The approach recommended here is to adopt design values which set limits of serviceability for the structure, and

then ensure that under design conditions the margins of safety against structural failure are sufficient. This margin should be set by the engineer in each case, having regard to the reliability of the data on which the design values are based, to the probability of occurrence of greater values, to the consequences of failure, to the type of structure chosen, and to economic factors.

For the purpose of selecting a minimum height for the bridge superstructure, the design high-water level should normally be selected after due consideration of the following:

Maximum Historical Water Level

The maximum historical water level as observed or recorded at the site, or as inferred from observed or recorded levels at another point on the river or waterway from which levels can reasonably be transferred to the site in question may be used.

Frequency Analysis

The water level derived from frequency analysis and corresponding to flood, tidal, or ice conditions of a frequency appropriate to the importance and value of the structure may be used for design parameters. The peak stage of flood flows may also be estimated using methods indicated in part (b) above.

Clearances

Additional height should be included if there is a history of ice accumulation, or if floating debris poses a potential problem. On navigable water courses sufficient clearance for vessels must be provided.

Bridge Length - The length of bridge works should be such that the opening is able to pass the maximum flows that may be expected without endangering the bridge or appurtenances by scour, without creating major maintenance problems, without causing unacceptable backwater effects upstream, and without causing currents, waves, or turbulence unacceptable to navigation or other legitimate interests. It should be possible to pass expected quantities of ice, logs, and other debris without endangering the structure or adjacent property as a result of jams and accumulations.

Width on Regular Channels

Where a stream has a single, well-defined channel of fairly regular width, and flood flows are more or less confined to the channel, the bridge should clear the entire channel with abutments set back 0.5 m from the normal high-water edge. Also, in no case should the bridge reduce the channel width by more than 10% of the 1:10 year flood flow width.

Width on Flood Plains

In situations with low flood plains, where a substantial portion of the design discharge normally flows across the overbank areas, the question arises of whether to divert all the overflow through a single waterway opening in the main channel, or to provide relief spans on the flood plain. The former solution is usually more economical, but if the road crosses the valley at an angle, relief spans or culverts may be necessary to prevent excessive backwater effects.

Width on Irregular Streams

In the type of stream where the channel width varies greatly from point to point, the narrower sections may normally be used as a guide to determine a suitable bridge length, provided overbank flow is taken into consideration.

Overtopping

In flat, low-lying terrain subject to widespread flooding it may be acceptable to allow overtopping of roadways in extreme floods, thereby reducing the discharge to be passed through the bridge waterway opening. In such design, provision must be made to prevent any road washout by having a designated overflow section which is suitably protected against erosion.

Existing Bridges

The hydraulic performance and capacity of existing bridge waterway openings should give valuable guidance on the required length of a new bridge at another site on the same stream. In some cases experience may indicate that an existing bridge has been too short, allowing approach washouts, overtopping of the approach roadways, or unacceptably deep scour to occur. The weight to be given to such evidence depends of course on how long the existing bridge has stood, to what extent it has endured severe floods and ice conditions, and to what extent stream bed

Conditions at the new site conform to those at the existing site. A new or replacement bridge will generally be larger than an existing bridge.

d) Bridge Type - Having selected a site for the bridge and having established height and width requirements of the superstructure, the designer must then choose a type of bridge. This choice depends on the functional requirements of the bridge in regard to the hydrologic and hydraulic regime, the economics of construction, live-load requirements, foundation conditions, environmental constraints, maintenance considerations, policies of the owner, availability of materials, and preference of the project designer.

Some variables in bridge design include:

- the geometry and length of the approaches,
- the type and location of the abutments,
- the number and location of piers.

3.6. Infrastructure design and materials

3.6.1. Make greater use of concrete

Concrete is a commonly used construction material that has many benefits, which include the ability to resist high temperatures. Concrete is able to withstand extreme hot climatic condition, and generally has the advantages of being durable and having a long service life. The rehabilitation of bridge deck pavement slabs should consider greater use of concrete and reinforced concrete depending on the structural basis of the bridge.

Indicative Costs

Purchase of concrete pavement material, include aggregates and binders

Feasibility and Technical Requirement

To produce a correct concrete pavement mixture, knowledge of concrete design is needed. A trained engineer is preferred to assess the bridge condition and ability to use concrete materials.

3.3.7 Key terminology

Identifying and understanding the potential impacts of climate change on bridges in Bangladesh is a critical step in developing effective climate adaptation strategies. Here are key considerations to assess and anticipate these impacts:

Hydrological Changes:

River Discharge: Evaluate potential changes in river discharge patterns, considering variations in precipitation, glacial meltwater, and changes in river dynamics. Increased river flow can lead to higher risks of flooding and scour around bridge foundations.

Sea-Level Rise: Assess the impact of sea-level rise on tidal rivers and estuarine areas, as higher water levels can result in more frequent and severe storm surges affecting bridges located in coastal zones.

Extreme Weather Events:

Cyclones and Storms: Consider the increased frequency and intensity of cyclones and tropical storms. Bridges must be designed to withstand strong winds, heavy rainfall, and storm surges associated with these extreme events.

Intense Rainfall: Evaluate the potential for intense and prolonged rainfall, which can lead to flash floods and impact bridge stability. Design features like proper drainage systems are crucial to mitigate the effects of heavy precipitation.

Temperature Changes:

Thermal Expansion: Recognize the potential for increased temperatures, leading to thermal expansion of bridge materials. This expansion and contraction can affect the structural integrity of the bridge, emphasizing the need for materials with thermal resilience.

Riverbank Erosion:

Changes in Sediment Transport: Assess alterations in sediment transport, as changes in riverbank erosion patterns can affect bridge foundations. Frequent monitoring of riverbanks is necessary to identify potential threats to bridge stability.

Salinity Intrusion:

Coastal and Estuarine Areas: Identify areas prone to salinity intrusion due to sea-level rise. Salinity can impact the corrosion resistance of bridge materials, requiring the use of corrosion-resistant materials and protective coatings.

Geotechnical Considerations:

Soil Stability: Analyze the stability of soil beneath and around bridge foundations, especially in low-lying areas. Changes in soil composition and stability can impact the overall integrity of the bridge structure.

Ecosystem Changes:

Biodiversity Impact: Consider the potential impact of climate change on local ecosystems around the bridge. Changes in vegetation and wildlife can influence the surrounding environment and impact bridge maintenance and conservation efforts.

Community and Socioeconomic Factors:

Population Density: Assess the population density in bridge-adjacent areas to gauge the potential impact on community livelihoods and evacuation plans during extreme weather events.

Economic Value: Evaluate the economic importance of bridges in terms of trade routes, transportation networks, and regional connectivity. Understanding the economic value helps prioritize adaptation measures.

Adaptation and Mitigation Measures:

Existing Infrastructure: Evaluate the adaptability of existing bridges and identify retrofitting options to enhance resilience. Consider measures such as elevating bridge decks, strengthening foundations, and incorporating advanced materials.

Early Warning Systems: Implement and enhance early warning systems to provide timely information about extreme weather events, allowing for proactive bridge closures and evacuation plans.

Long-Term Planning:

Climate Projections: Utilize climate projections to anticipate long-term changes. Incorporate future climate scenarios into bridge design and maintenance plans to ensure adaptability over the infrastructure's lifespan.

In summary, comprehensive impact assessments for bridges in Bangladesh must consider hydrological changes, extreme weather events, temperature variations, riverbank erosion, salinity intrusion, geotechnical factors, ecosystem changes, community considerations, and effective adaptation and mitigation measures.

This holistic approach ensures the development of climate-resilient bridges capable of withstanding the evolving climate challenges in the region.

3.8 Key considerations:

3.8.1 Bridges

Various issues regarding bridge design need to be considered as bridges will normally be designed to last between 50 and 100 years (or more for bigger structures). Apart from the loadings that bridges are designed to carry, they need to be designed to handle the expected volume of water that will flow through them during peak flooding as well as other potential issues described below:

3.8.2 Maximum water flows

Maximum water flows can be calculated using various standard techniques which are not described in detail here. However, these make use of return periods, which are probabilistic determinations of the frequency of the calculated peak flows for different storm intensities. The predominant changes to conventional design methods for bridges will be in terms of the return periods. These will need to be updated on a regular basis using the latest projections of expected rainfall, determined from local climate modelling¹⁵. In the absence of such revised return periods, it is also possible to use actual worst-case scenarios based on specific rainstorm intensities, but these will normally result in more conservative and costly designs.

The water flow quantities and velocities are also based on various surface characteristics (e.g., soil type and exposure, vegetation cover, etc.). With climate change, these too are likely to change with time and issues such as this will also need to be considered in the calculation of river flows. Changes in vegetation because of temperature or precipitation changes are also likely to affect the type of debris transported by the rivers (increased or decreased trees, bigger or smaller trees, larger boulders, etc.) and this should also be considered in the design.

To cater for the potential increased water flows, bridge decks will need to be higher, spans may be longer and earthwork volumes in approach fills will be significantly increased (possibly with better quality materials), with inevitable large increases in the costs of the structures.

3.8.3 Abutments

The materials behind bridge abutments must be as resistant to erosion as possible and compacted to as high a density as possible to avoid damage during flooding. They should also be protected from water flows by raising wing-walls, applying mortared rip-rap or other erosion protection methods (gabion baskets or Reno mattresses) and minimizing turbulent flow around them. Numerous techniques for protecting abutments from erosion and scour are included in NCHRP Report 587 (Barkdoll et al, 2007) and the optimum choice will depend on the local situation and materials available.

3.8.4 Piers

Piers are primarily damaged by scouring of their foundations. Scouring is a function of turbulent flow upstream, downstream and surrounding the foundations. This is best reduced by ensuring the optimum shape of the piers and founding the supports on material unlikely to be scoured. The depth and extent of scouring can be estimated from various models (e.g., TRL, 2000) and this, together with the type of foundation and substrate material should be used to optimize the design. The stream-bed characteristics will usually have the most influence on the type of foundation, which will have an effect on the scour potential as well as being affected by the induced scour. If the stream-bed has only thin alluvial material deposits, footings directly on the bedrock or other competent layers can be used. If the stream-bed has thick deposits of fine material, piles are normally used. These can be either end-bearing piles if the bedrock or other hard layers are not too deep, or friction piles where excessive deposits of fine materials occur. Friction piles should be designed to ensure that should Scouring occur, the length of the unexposed pile is still adequate to provide the necessary frictional support.

3.8.5 Structures

The effects of increased temperatures and larger seasonal and diurnal changes on bridge structures and their components will need to be considered during their structural design. These are normal design considerations but should be given a little more thought to handle expected conditions in 50 or 100 years' time. Increased expansion of the materials will require larger expansion joints, which in turn will require better waterproofing and sealing materials, as well as increased maintenance to ensure their continued serviceability. The wider use of monolithic structures that avoid or minimize bearings and expansion joints could also be considered.

A challenge with bridge expansion joints is that they are a flexible component and require a high amount of maintenance. Some types of joints are themselves an entrance point for water which can leak onto substructure elements and accelerate deterioration. The amount of expansion in the bridge depends on the actual structure type, temperature changes, the length of bridge, and the type of material used (reinforced concrete, steel girder, etc.).

Most countries have "bridge design codes" and these will need to be continually updated incorporating features that will make bridges more climates resilient.

3.8.6 Culverts

It is essential that culverts are aligned carefully along the road, preferably perpendicular to streams and drainage paths crossing the road. Where moving water must change direction suddenly, the potential for severe erosion is rapidly increased. Similarly, the protective measures around the culvert should be such that erosion of the adjacent formation or embankment is minimized during normal water flow events. It is not usually economically possible to protect long distances of embankment from erosion, other than to ensure that the embankment is covered with a good deep- rooted local grass, which is kept well maintained.

The capacity of the culverts, like bridges, should be designed to move the expected water through them without causing any damming upstream. Examples have been observed, for instance, where a railway line running parallel to and slightly uphill of a road had several culverts each consisting of 3 one-metre square boxes. The parallel road had culverts in the same locations downhill of the railway culverts but these consisted of only one 600 mm pipe – the capacity was thus obviously inadequate and damage would be expected to occur to the road embankment during heavy rainstorms.

Where overtopping of the culvert is likely, low points should be eliminated and the road should be as flat as possible to avoid localized turbulent flow over the embankment. The downstream slope of the embankment over the length of potential overtopping should also be flattened to reduce water velocities and minimize erosion and undercutting.

In large catchment areas, the use of upstream flood-control dams and structures (usually in cooperation with other national agencies) should be considered to try and minimize the effects of storms where doubt exists in the calculation of the flow volumes. This could be considered as part of water harvesting operations

3.9 Bridge reconstruction, new construction and capacity expansion to be add some climate adaptation measures

Observation & findings and suggested adaptation measures

SL No	Observations and suggestions	Measures to be taken
1	Adequate Freeboard to be provide for every bridge in Coastal or Non-coastal Region.	Minimum 60 cm freeboard to be add with HFL where there is no navigation. But where there is navigation, BIWTA and LGED guideline have been followed.
2	Approach and bank protection	In general, 5-15m approach road protection to be provide at almost all bridges. Considering the erosion trend or if other problem detected in river bank and approach connectivity during field inspection by Design Team/Maintenance Team/ PMU Team, for overcoming the problem.
3	Scour protection of river bed	In the design process, pile length or the pile capacity under pier or abutment is determined to combat increased scour due to climate change effect. Thereby no need of providing extra protection for river bed scour
4	Detailed hydro-morphological assessment	Limited hydro-morphological and hydraulic assessment for all river and stream crossings are being conducted with the available technical data from Technical Appraisal Report, River Cross-sections & Topographic Survey, and Soil Exploration Report etc. Designs & BoQ's are updated following findings of data analysis and international practices and included in the Detail Project Reports (DPR).

It is necessary for bridge reconstruction and new construction under design or procurement, conduct detailed hydrology, morphology assessment for all river and stream crossings regardless of bridge length.

Observation & findings and suggested adaptation measures

Sl No	Observation & suggestions	Measure to be taken
1.	Detailed hydro-morphological assessment	Hydro-morphological and hydraulic assessment for all river and stream crossings should be conduct with the available technical data from Technical Appraisal Report, River Cross-sections & Topographic Survey, and Soil Exploration Report etc. Designs & BoQ's updated following findings of data analysis and international practices and should include in the Detail Project Reports are (DPR).

3.9.1 Sample case study of climate adaptation measures in reconstruction

(1): Climate Resilient Measures incorporated in the replacement of existing 60.00m RCC girder bridge by 70.06m long RCC girder and PSC girder bridge on Kaligonj RHD- Assasuni Upazila via Uzirpur GC Road at CH-12380m Road ID- 287472003, Upazila: Kaliganj, District: Satkhira.

Item No.	Design Parameter/ Component	Without Climate Change	Climate change measures	With Climate Change	Remarks
A.	Coastal Region				
1	Hydrology				
a.	Water Level	RL 0.986 m	48 cm	RL 1.986 m	Including free board
b.	Discharge	179.561 m ³ /s	15% (minimum)	210.00 m ³ /s	Ref. National Adaptati on Plan of Banglad esh (2023-2050)
c.	Regime Width (m)	63.65 m		70.0m	
2	Salinity & Temperature				
a.	Concrete	Normal Concrete		Mar ine Con	

				crete	
b.	Lap length	1000 mm for 16 mm dia	25% increase	1250 mm for 16 mm dia	
c.	Clear Cover	60 mm		75 mm	
d.	Reinforcement bar	Normal reinforcement		Epoxy Coated Reinforcement	
e.	Expansion Joint for temperature effect	Nosing (concrete strength 30Mpa)		Strip Seal (concrete strength 35 Mpa)	Ref. Incorporating Climate Change Adaptation in Infrastructure Planning and Design (2015) by USAID
3.	Morphology				
a.	Scour	2.367m from pile off level for Abutment 1.885m from GL for Pier		3.0m from pile cut-off level for Abutment and 2.45m from GL for Pier	Ref. National Adaptation Plan of Bangladesh (2023-2050)

3.9.2. Sample case study of Climate Adaptation Measures

(2): Climate Resilient Measures incorporated in the Replacement of 69.0m Bridge by 81.06m Long PSC girder bridge on Bormi GC – Janina Bazar RHD via Kawraid UPC road at CH-8300m Road ID-333862008, Upazila: Sreepur, District:Gazipur.

Item No.	Design Parameter/ Component	Without Climate Change	Climate change measures	With Climate Change	Remarks
B.	Non-Coastal Region				
1.	Hydrology				
a.	Water Level	RL 13.11 m	30 cm	RL 14.11 m	Including free board
b.	Discharge	237.259 m ³ /s	15%(minimum)	280.00 m ³ /s	Ref. National Adaptation Plan of Bangladesh (2023-2050)
c.	Regime Width (m)	73.16m		81.00m	
2.	Morphology				
a.	Scour	1.828m from pile cut-off level for Abutment and 0.864m from GL for pier		3.0m from pile cut-off level for Abutment and 3.0m from GL for pier	Ref. National Adaptation Plan of Bangladesh (2023-2050)
b.	Expansion Joint for temperature effect	Nosing (concrete strength 30Mpa)		Strip Seal (concrete strength 35mpa)	Ref. Incorporating Climate Change Adaptation Infrastructure Planning and Design (2015) by USAID

3.9.3. Sample case study of Climate Adaptation Measures in capacity expansion

Capacity expansion of 23.88 m RCC girder bridge beside another 38 m long RCC girder bridge on Maligram (R&H)-Kalamirdha GC Road, ID 329102001, at Ch-4050m, Upazila- Bhanga, District=Faridpur.

Item No.	Design Parameter/ Component	Without Climate Change	Climate change measures	With Climate Change	Remarks
A.	Coastal Region				
1	Hydrology				
a.	Water Level	RL 0.55 m	48 cm	RL 1.63 m	Including free board
b.	Discharge	113.79 m ³ /s	15% (minimum)	130.85 m ³ /s	Ref. National Adaptation Plan of Bangladesh (2023-2050)
c.	Regime Width (m)	41.65 m		47.80m	
2	Salinity & Temperature				
a.	Concrete	Normal Concrete		Marine Concrete	
b.	Lap length	1000 mm for 16 mm dia	25% increase	1250 mm for 16 mm dia	
c.	Clear Cover	60 mm		75 mm	
d.	Reinforcement bar	Normal reinforcement		Epoxy Coated Reinforcement	

e.	Expansion Joint for temperature effect	Nosing (concrete strength 30Mpa)		Strip Seal (concrete strength 35Mpa)	Ref. Incorporating Climate Change Adaptation in Infrastructure Planning and Design (2015) by USAID
3.	Morphology				
a.	Scour	2.367m from pile cut-off level for Abutment and 1.885m from GL for Pier		3.0m from pile cut-off level for Abutment and 2.45m from GL for Pier	Ref. National Adaptation Plan of Bangladesh (2023-2050)

CHAPTER 4

Adaptation measures in construction phase

4.1 Commencement program

1. The program should normally be in the form of a bar chart. As the Contract involving a large number of inter-related activities, the program needs to be in the form of a network diagram and programmed on the Microsoft Project software or similar. Critical activities and the critical path should be identified on the program, as extension of the time of the Works described in this manual is normally examined and measured on the critical path.
2. When a program is submitted by the Contractor, the program should be analyzed and examined for the following points:
 - (a) Whether details shown on the program, in respect of sequence, method and timing, conform to the requirements of the Contract
 - (b) Whether the program is over-optimistic in respect of any critical activity or the Works as a whole.

4.2 Construction

Several climatic change factors could impact on the construction of future road and bridge infrastructure, some negatively and others positively.

During the projected extended dry periods in some areas (also being hotter), the availability of construction water may be limited for longer periods and longer haulage distances may be necessary. The cost of the water is also expected to rise as construction competes with other uses for its limited availability. Simultaneously, the water applied to the layers during these periods for compaction will evaporate much quicker and greater quantities of water will be required for construction.

Where stabilization of materials is used on a wide scale, the working time of the stabilization (i.e. from the addition of water until the time of final compaction and trimming) will be significantly reduced under higher working temperatures.

The rates of other chemical reactions affecting stabilization and mineral degradation may also be increased under high temperatures. A possible benefit, however, of higher temperatures may be longer windows for bituminous paving through the year, i.e., shorter cold periods).

4.3 Workplaces safety management

Workplaces and tasks where accidents/incidents occur frequently, site specific safety precautions to be taken to prevent such accidents/incidents.

- Precautions against Deep Excavation and Shoring.
- Precautions against Demolition/dismantling of Existing Bridge.
- Precautions against fall from height.
- Flying and Falling Object Prevention
- Precautions when Works with heavy Construction Equipment
- Precautions against Scaffolding Installation/Construction
- Precautions during Welding
- Safety during Concrete Casting
- Safety during Pre-tensioning/Post tensioning.
- Launching and handling of PC Girder
- Fire Protection and Prevention measures
- Diversion Construction, Operation & Maintenance

4.4 Adaptation technique for construction

- Manpower deployment
- Machineries and materials mobilization
- Diversion and traffic control
- Safety & security at site
- Environmental aspects
- Covering staged materials
- Ensure toilet for men & women separate
- Site office
- Dust control
- Sound & noise control etc.

4.4.1 Covering staged materials

- Package No. Replace-W-372, Upazila- Kaharol, Dinajpur



Fig: 4.1 Covering staged materials

4.4.2 Dust control

- Package No. Replace-W-372, Upazila- Kaharol, Dinajpur



Fig: 4.2 Dust control

4.4.3 Adaptation measures in construction phase

Epoxy coated rebar & marine concrete used at 24m Bridge, Sonagazi, feni



Fig: 4.3 Adaptation measures in construction phase

4.4.4 Adaptation measures in construction phase

Epoxy coated rebar & marine concrete used at 25m Bridge Pekua, Cox-Bazar



Fig: 4.4 Adaptation measures in construction phase

4.5 Climate adaptation strategies for slope protection of embankment and bridge approaches

The traditional practice to protect embankments against erosion in Bangladesh is to use cement concrete (CC) blocks, sand bags, stone or wood revetments, geotextile, geo-bags and tree plantation. Usually, CC blocks are used where storm surge is high, sand bags or wood revetments are used where flow of water is moderately high. Protection of embankment by plantation is another practice, but it is not effective during cyclone and flood because of overturning or uprooting of plants. It has been widely recognized that plant root systems can improve the soil shear strength. Embankment stability can be augmented by using bio-engineering techniques which techniques may be an alternative option for embankment protection. Bio-engineering techniques are being increasingly favored to control soil erosion in general and for slope protection of embankment and bridge approaches particular. The techniques envisage use of appropriate vegetation, single plants or sown, with minimum artificial human intervention resulting in economical and ecological benefits.

Vetiver grass (*Vetiveria zizanioides*) is a plant distinguished by its strong and massive root system, which is vertical in nature descending 2-3 meters in the first year, ultimately reaching some 5 meters under tropical conditions. This massive, thick and immensely strong root system, with a tensile strength of one sixth that of mild steel, is very difficult to dislodge but can nevertheless be removed easily by man if required. The depth of root structure provides the plant with great tolerance to drought, permits excellent infiltration of soil moisture and penetrates through compacted soil layers. Under dry land salinity conditions, once established this deep root system can exploit the less saline subsoil moisture. Efficacy of vetiver system as bio-technology for slope protection of embankment and bridge approaches has been investigated by many researchers.

4.5.1 Vetiver grass for slope protection of embankment and bridge approaches





Fig: 4.5 (a) Fully grown vetiver grass, (b) young plant and (c) close view of roots

4.5.2 Vetiver grass plantation process in embankment slope and bridge approaches

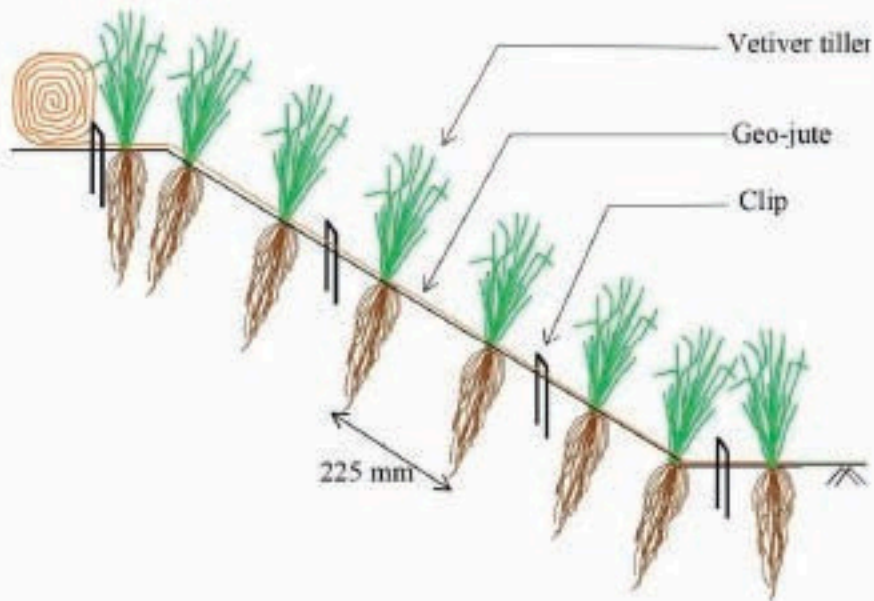


Fig: 4.6 Schematic diagram of vetiver grass plantation

4.5.3 Vetiver grass plantation for slope protection of embankment and bridge approaches



Fig: 4.7 Vetiver grass for slope protection of embankment and bridge approaches at satkhira district.

4.6 The basic concept of adaptation technic for construction

In terms of construction, differentiation should be made between existing infrastructure, which cannot be changed overnight, and infrastructure that needs to be constructed anew. In the case of the latter, ample opportunity would be available to introduce more climate resilient road infrastructure solutions.

In the case of existing infrastructure, the outcomes of a risk analysis would dictate which actions would require immediate attention (e.g., retrofitting of drainage systems). Adaptation actions could be phased in over time (e.g., during scheduled maintenance or rehabilitation/upgrading) depending on the priorities.

Climate change could require some adjustments in construction processes. Drought conditions, for instance, are likely to lead to greater shortages of water, which will drive up the cost of water and simultaneously the cost of construction projects, unless surfactants (compaction aids) are added to the construction water and/or compaction methods are adapted to cater for this water scarcity (e.g., high-energy impact compaction).

As well as affecting availability of resources for road construction (and also maintenance), climate change could also affect the window of safe working and productivity of outdoor workforces, requiring adjustments in operations. In the case of extreme heat, for instance, construction operations could be moved to night time to reduce the risk for heat stress.

In future, construction seasons may shorten or lengthen, and could shift earlier or later within the year. These changes are unknowns at this stage, and will differ from country to country, but relevant ministries or road departments should be made aware of this possibility, record changes to the status quo and plan accordingly.

To minimize problems with climatic changes on roads it is essential that construction at least complies with the minimum requirements in the recommended standard specifications, if not exceeds them. In some cases, it may be necessary to modify or adapt local specifications to take the various potential climate changes into account, and these may be country or even district specific as appropriate. For example, compaction (of subgrades, formations, embankments, abutments and pavement layers) to higher densities than those currently specified immediately increases the stiffness, reduces permeability and erosion potential and reduces voids and rutting potential.

Compaction is one of the cheapest construction activities and should not be skimmed on. The incorporation of improved durability requirements for base materials may be necessary where groundwater or local sea-level rises are expected.

The loss of water during construction on hot and dry days can be minimized by constructing at night as well as by using recycling equipment for the addition of water. If these options are not feasible, quicker delivery of greater quantities of water (more water bowsers on site) and decreased construction processing time (construction of shorter lengths, additional rollers and graders, etc.) will be necessary. Investigations into methods for making use of poorer quality waters (e.g., sea-water, brackish borehole water, recycled effluent, etc.) should be initiated to alleviate these problems.

Various other construction practices will need to be modified to cater for climate change. With cement stabilization for instance, it may be necessary to construct shorter sections at a time, to use alternative slower reacting cements for stabilization (CEM IV and CEM V) or even blends of lime and fly ash. The choice of stabilizer type (e.g., cement grade) will become important to allow maximum

working time. The use of in situ recyclers to mix the stabilizer and decrease the construction time should also be considered. Their high cost may be justified by the potential reduction in construction problems, often encountered with modern cements. The breaking times of bitumen emulsions will be much quicker on hot days, which would also require modification of standard construction techniques.

There is nothing that can be done about more rapid deterioration of non-durable materials in the road structures under higher temperatures (e.g., use of low-viscosity binders in asphalt) – it will be necessary to make sure that all materials used are acceptably durable, although few examples of failures due to material deterioration or pure durability have been observed in low volume roads. On the contrary, durability is seldom a specification requirement for low volume road materials.

When large concrete members are being constructed during hot weather, precautions should be taken to limit any significant heat build-up in the concrete. If final set occurs when the concrete is in an expanded condition due to high temperatures, additional “thermal” shrinkage may result in a large potential overall shrinkage of the member. Similarly, the risk of early age plastic shrinkage cracks or thermal cracking due to temperature gradients may define the requirements for curing and protection of the concrete. Furthermore, increase temperatures mean increased evapotranspiration, therefore the concrete skin should be protected properly against evaporation until a certain maturity or strength is obtained to ensure sufficient strength and durability. Methods and tools to help the concrete producer plan and predict the hardening process of a concrete structure under various and changing ambient conditions will need to be improved. As a minimum, the concrete producer should consult local weather forecasts to obtain temperature data. Increased temperatures may also require the placement of mass concrete for structures and pavements at night. Note that an improved local weather forecast is an example of a low regret adaptation tool.



Fig 4.8 Ongoing Piling work on Bridge Replacement Category Under SupRB

4.7 The basic concept of inspection and testing

- 1 The Employer's Personnel (including the Engineer and his staff) shall at all reasonable times:
 - (a) Have full access to all parts of the Site and to all places from which natural Materials are being obtained, and
 - (b) During production, manufacture and construction (at the Site and elsewhere), be entitled to examine, inspect, measure and test the materials and workmanship, and to check the progress of manufacture of Plant and production and manufacture of Materials.
- 2 The Contractor shall give notice to the Engineer's staff full opportunity to carry out these activities, including providing access, facilities, permission and safety equipment. No such activity shall relieve the Contractor from any obligation or responsibility.
- 3 The Contractor shall give notice to the Engineer wherever any work is ready and before it is covered up, put out of sight, or packaged for storage or transport. The Engineer shall then either carry out the examination, inspection, measurement or testing without unreasonable delay, or promptly give notice to the Contractor that the Engineer does not require to do so.
- 4 Except as otherwise specified in the Contract, the Contractor shall provide all apparatus, assistance, document and other information, electricity, equipment, fuel, consumables, instruments, labour, materials, and suitably qualified and experienced staff, as are necessary to carry out the specified tests efficiently. The Contractor shall agree, with the Engineer, the time and place for the specified testing of any Plant, Materials and other parts of the Works.
- 5 The Engineer's supervision staff should communicate with the Contractor at Daily Coordination Meeting for the schedule of inspection and testing for coming days. When more than 2 inspection and/or testing are demanded at the same time, the Engineer's staff should make arrangements with the Contractor the order of inspection and/or testing minimizing the adverse influence to the Project.

4.8 Inspection and test plan

- 1 The Engineer's staff should also monitor the construction progress closely, may refer to the Contractor's Tree Week and/or three-month rolling program, and manage by themselves to be fully aware the method of inspection/testing, acceptance criteria and other re-equipment's for the coming inspection and testing as scheduled.
- 2 Inspection and test plan (ITP) is the most essential document for control the quality of the Works, which usually be prepared by the Contractor and the Engineer will review the Contractor's ITP carefully and make sure the ITP covers all requirements in the Specification. Further it should be linked between Engineering Works Schedule (EWS) and ITP with no inconsistency.
- 3 Sample form of Inspection and Test Plan (ITP) in Appendix 9 is basically required to include and identify the followings:
 - (a) the sequence of inspection and testing activities;
 - (b) the inspection and testing requirements of either activities or materials;

- (c) the acceptance criteria or relevant specification;
 - (d) the level of inspection required including the provision for witnessing by the Engineer; and
 - (e) Any certification requirements or records to be kept.
- 4 For item (d), Control Points are defined in the ITP as follows:
- (a) Hold Point (H): Approval shall be obtained before subsequent operations proceed. Request for inspection from to be submitted to party before inspection and test is performed.
 - (b) Witness (W): Request for inspection from to be submitted to party for witnessing the test for and for confirming that the results are correctly recorded.
 - (c) Verification (V): Make sure that the required inspection and test is completed and records demonstrating compliance with the specified requirements exist where appropriate.
 - (d) Surveillance (S): Continual monitoring and/or analysis of the inspection and test records ensure that specified requirements have been fulfilled.

In case of procedures of inspection and testing are complicated, it is recommended to prepare "Check List" for Inspectors. It helps to prevent their oversight, misunderstanding or such during inspection and testing.



Fig 4.9 Ongoing Bridge Abutment Casting work



Fig 4.10 Ideal Shuttering



Fig: 4.11 Tool Box Meeting

4.9 Environmental protection

The Contractor shall take all reasonable steps to protect the environment (both on and off the Site) and to limit damage and nuisance to people and property resulting from pollution, noise and other results of his operations.

The Contractor shall ensure that emissions, surface discharges and effluent from the Contractor's activities shall not exceed the values stated in the Specification or prescribed by applicable Laws.

4.9.1 Environmental management plan

The Engineer to review for approval the Contractor's Environmental Management Plan has been prepared complying with the following requirements.

- (a) The Contractor will be issued with the Employer's Environmental Impact Assessment Report. The EIA shall be regarded as the minimum standard to be achieved but it does not relieve the Contractor of any statutory duty.
- (b) The Contractor shall take all reasonable precautions to avoid any nuisance arising from the execution of the Works. This should be accomplished where at all possible by suppression of the nuisance at source rather than abatement of the nuisance once generated.
- (c) The provision listed herein regarding environmental protection shall apply to and be binding upon the Contractor for any part of the Works on the Site and shall apply to and be binding on his subcontractors. The Contractor shall ensure that proper and adequate provisions to this end are included in all subcontracts.
- (d) The Contractor shall employ appropriate construction methods and carry out the Works in a manner as to minimize any adverse impacts on air, noise and water quality and the existing environment within or outside any construction sites during the Contract.
- (e) The Contractor shall submit an Environmental Management Plan indicating how they will comply with the Contract requirements. The plan shall be properly implemented by the Contractor during the Contract.

4.9.2 Air quality

If after commencement of the Works that the Contractor's Equipment and/or method of working are found to be causing serious air pollution impacts, they shall be inspected by the Engineer and remedial proposals shall be drawn up by the Contractor.

4.9.3 Water quality

The Contractor shall not discharge directly or indirectly (by runoff) or cause or permit or suffer to be discharged into any public sewer, storm water drain channel, stream course or river, any effluent or foul or contaminated water. The Contractor shall provide, operate and maintain within the premises or otherwise, suitable works for the treatment and disposal of such effluent or foul or contaminated water.

4.9.4 Waste management

THE Contractor shall be responsible for the control of all waste generated from construction activities, the removal of the waste and implementation of any measures to minimize any adverse impact to the environment and public. Where possible the waste shall be separated into recyclable items and hazardous

waste shall be disposed of. All disposal of waste, including hazardous waste and recycling, shall be in accordance with the relevant local laws and regulations.

4.9.5 Noise control

The Contractor shall take all necessary measures to ensure that the operation of all mechanical equipment and construction processes on or off the Site shall not cause excessive noise which may disturb any occupant of any nearby dwellings, schools, hospitals or premises with similar sensitivity to noise.

The Contractor shall submit details of the Contractor's Equipment including method of use and construction operations together with proposed measures for limiting noise wherefrom that shall include, but not limited to the relocation of noise emitting plant, the use of silencers, mufflers, acoustic shields, shed or screens and shall be based upon the best proven practice.

4.9.6 Vibration control

All mechanical equipment and construction processes on or off the Site shall not cause excessive vibration which may disturb any occupant of any nearby dwellings, schools, hospitals or premises with similar sensitivity to vibration. Vibration caused by any construction activities, including movement of construction equipment, shall be in accordance with the relevant local laws and regulations.

4.9.7 Protection on existing streams or rivers

Natural streams or rivers within or adjacent to the Site where no work is being carried out shall be kept clean and free of any floating debris. All equipment and working methods to be used in or near the natural streams or rivers shall be planned to reduce disturbance. No material storing or no parking of the Contractor's Equipment or other vehicles near the streams or rivers is allowed.

4.10 Safety management during bridge construction work, which should include the following issues

- Deep Excavation and Shoring
- General Safety Measures at Bridge Site / Workplace Safety
- Demolition /dismantling of Bridge under Replacement Category (Hazard identification, measures to be taken to avoid hazard as well as control environmental pollution)
- Safety of workers during work at height
- Work with Heavy Equipment such as Winch Machine, Back Hoe, Crane etc.
- (Measures to be taken to ensure safety)
- Scaffolding installation and inspection (Risk area identification and measures to be taken to avoid risk)
- Welding (Risk area identification and measures to be taken to avoid risk)
- Safety during Bridge Foundation Work [Shallow and deep foundation (Risk area identification and measures to be taken to avoid risk)]

4.10.1. Safety management during bridge construction

- General Safety Management (Safety signs installation, ensure safe drinking water, Hygiene Toilet, Accommodation for workers, Site Lighting etc.).
- Personal Safety Management for Workers, Visitors & General Public (Provide PPEs, First Aid etc.).
- Traffic Safety Management (Prepare Site specific Traffic Management Plan & install accordingly).
- Workplace Safety Management.

4.10.2 Supporting rural bridges (SupRB), gender development activities with climate-adapted bridge projects in conformity with the gender equality strategy of LGED and the world bank

The National Women Development Policy 2011, is the basic foundation of LGED's Gender Equity Strategy (2022-2030). The principal objective of this Strategy is to develop women and to create a women-friendly ambience at all levels of LGED activities in consonance with the incorporation of the National Women Development Policy 2011. The GES is formulated to promote gender equality by ensuring women's involvement, increasing women's accessibility to resources and services as well as developing a women-friendly environment at all levels through all ventures of LGED. The main objective of this GES to integrate measures to promote gender equality in all interventions of LGED and to implement it.

In harmony with this Gender Equality Strategy (GES), ensures that all of its infrastructures are made gender-friendly, creates employment opportunities for women in its different activities increasingly establishes a process of decision-making in every work through the participation of both men and women. The deprived women would be involved in employment as such be empowered gradually through this process.

The World Bank is a co-financier for Supporting Rural Bridges (SupRB) and World Bank (WB) Gender Policy has stressed that gender issues are important dimensions of its poverty reduction, economic growth, human well-being, and development effectiveness agenda. Therefore, the objective of the gender issues and concerns into all aspects of the Supporting Rural Bridges (SupRB) project throughout the project lifecycle detailed planning, implementation, monitoring, and evaluation activities, in conformity with the considering the LGED's Gender Equity Strategy has been followed for the following interventions:

4.10.3 Informal awareness raising group meeting:

Women engagement with equal pay, Occupational health safety, Gender Based Violence(GBV), Sexual Exploitation and Abuse(SEA), Opportunities, norms, duties, responsibilities, climate change adaptation, fair working conditions, Occupational preventive measure, etc.

To Provide Skill training (farming and off-farming): Technical training can be provided to the labor force, especially women for inclusion in the operation and maintenance can target a maximum of 25% of total women. (as per need incorporate technical skills in Masson, rod bending, welding, etc.). For the sake of self-reliant sustainable socio-economic livelihood different Income Generating Activities (IGAs) would be undertaken and enhanced by those who are occupationally skilled and have gained empirical knowledge of ongoing Income Generating Activities (IGAs).



Fig 4.12 Informal awareness session at SupRB



Fig 4.13 Women engaged in SupRB bridge

4.12

4.11 Climate change & adaptation tools of(SupRB):

4.11.1 Focus group discussion:

A Focus Group Discussion (FGD) is a method for collecting qualitative data that gathers community members together to discuss a specific topic. Program for Supporting Rural Bridges always took FGD Meeting to aware local beneficiaries about climate resilient, personal right to complain & how to mitigate Climate & Social barriers with the help of GRS (Grievance Redress System).



Fig 4.14 Focus Group Discussion Meeting

4.11.2 Occupational health & safety (ohs) items

- Frist Aid Box
- PPE

- Dustbin
- Fencing & Safety Measure
- Face Mask
- Hand Wash Arrangement
- Hand Sanitizer
- COVID-19 Awareness Sign Board
- COVID-19 Awareness Leaf Let
- ThermalScanner

4.12 Replace or reconstruct bridge expansion joints

This method is primarily designed for existing structures. Bridge expansion joints can be damaged as a result of prolonged and extreme daily temperature variation occurs. There are several joint types used in bridges that are part of the bridge and foundation design.

- Armor Joint (AJ);
- Sealed Expansion Joints (SEJ);
- Fabric Joint Under seal;
- Header Type Joint;
- Asphalt Plug;
- Finger Joint; and
- Modular Joint.

Bridge expansion joints allow thermal expansion and contraction, translation and rotation of the deck. They also assist in keeping water off of the substructure and protect exposed concrete edges. During extreme conditions, such as extreme hot days, expansion joints prevent bridges from bending out of place and allow enough vertical movement to permit bearing replacement.

Stresses on bridge expansion joints can be exacerbated by fatigue from heavy loading by vehicles and increased frequency of extreme weather conditions. Their failure could cause damage to a bridge substructure and superstructure.

Advantages

- Prevent more severe damages in the future
- Further protect against extreme weather conditions
- Preserve the expected life of bridges
- Reduce the need for emergency repairs

Disadvantages

Traffic disruption since repair requires full or partial closure

Indicative Costs

Cost for construction workers and material for expansion joint

Timing for Implementation

Depends on type of structure, age and length – shorter if bridge is under complete closure

Feasibility and Technical Requirement

Trained worker to ensure replacement work is done properly and performed in accordance with prevailing bridge design guidelines.

4.12.1 Strip seal expansion joint installation in SupRB project at companyganj, Sylhet district.



Fig 4.15 Installation of strip seal expansion joint

4.12.2 Strip seal expansion joint installation in SupRB project at Companyganj, Sylhet district.



Fig 4.16 Installation of strip seal expansion joint

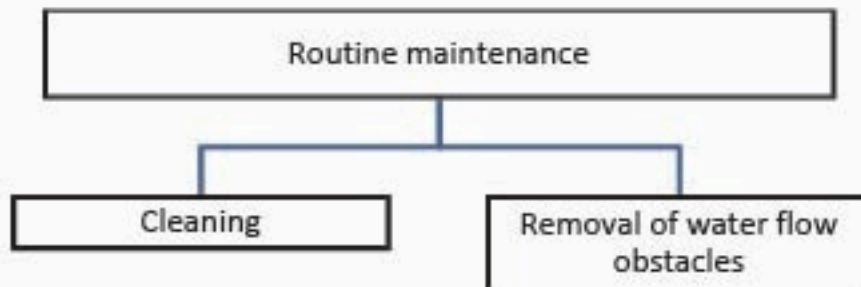
Chapter 5

Adaptation measures in maintenance

5.1 Routine maintenance works

5.1.1 General

Bridge Maintenance Works are classified based on condition of the structure. Routine maintenance work is carried out to prevent the bridge suffering for the deterioration. Cleaning of bridge surface at curbs and railing, deck drainage system, expansion joints and bearing seat are low cost and most effective preventive maintenance for bridges. Also, removing water flow obstruction and weeds mowing are important routine maintenance work. Routine maintenance works and PMP (Periodic Maintenance Program) Minor maintenance works are categorized into preventive maintenance works and in many cases, they are executed under the direct management of the department. While, PMP major maintenance works and repair design are generally outsourced to private professional companies.



Routine Maintenance Works are the primary maintenance procedure. It should be done continuously in each district office by his organized team. The planning of Routine Maintenance works is done by UE or SAE, covering every rout, so that every Bridges and Culverts are covered minimum twice in a year. If it is not possible to cover all Bridges and Culverts, the number of Routine Maintenance Works Team should be increased. It is very important maintenance action for preserve bridges in sound condition. It consists of "Cleaning", "Removal of Obstacles" and "Routine Repair".

5.1.2 Cleaning

Along the Curb or Felloe guard

Along the lower roadway curb or felloe guard, the soil, rubbish and weed are accumulated and cleaned.



Fig. 5.1. Removing of soil and weed by shovel.



Fig. 5.2. Removing of soil and weed by jet water

Expansion joint and Bearing shoe

The opening of Expansion joint is blocked up by debris (soil, rubbish and weed). The debris is accumulated by hook/shovel and cleaned by water. Debris around the Bearing shoe and Shoe bed are accumulated and cleaned.



Fig.5.3 Blocked expansion joint



Fig. 5.4. Cleaning by female worker

Steel Girder and Concrete Girder at bridge end

Cleaning of steel/concrete girder at both bridge ends (each 5.00 meter) shall be done at regular intervals (1-2 times a year). It is very useful preventive maintenance action for bridge elements. At the coastal region, whole bridge shall be cleaned also at same intervals (girders & deck slab).

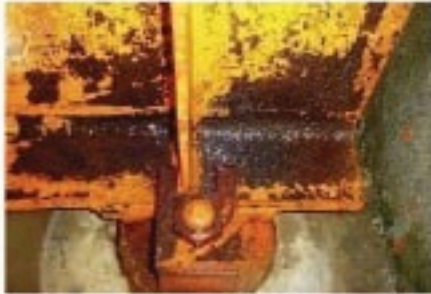


Fig.5.5 Cleaned steel plate by jet water



Fig.5.6 Cleaning concrete surface by jet water

Remark: The ideal jet water pressure is, for example 15 MPa and Volume flow 15 liter/min. If, business jet water cleaner is not available, so a household water cleaner with water pressure of 8 Mpa and Volume flow 5 liter/min also acceptable.

5.1.3 Removal of obstruction

At the routine maintenance work, Flow obstruction shall be removed by hook with long shaft. The Flow obstruction is often observed also at Box-culverts and Pipe-culverts.



Fig.5.7. Pier with flow obstruction



Fig.5.8. Pier with flow obstruction

5.1.4 Removal of vegetation growth

Under/around the bridge shall be the good airy place, otherwise bridge elements absorb moisture and bridge damage is speed up. Therefore, harmful plants shall be removed at regular intervals.



Fig.5.9. Harmful weed around the bridge



Fig. 5.10. Harmful weed under the bridge

5.2 Items for bridge repair/maintenance

Institutional support for capacity building of LGED, Consultant team of Sd -12, given some sort of suggestion and technical assistance in relevant tasks: it is already approved by the honorable Chief Engineer LGED and incorporated in rate schedule of 2022-23.

1. Polymer mortar(10 mm)
2. Polymer mortar (25 mm)
3. Skim Coat
4. Polymer concrete
5. Carbon Fiber Wrap
6. Carbon fiber laminate
7. Light-Duty Suspended Scaffolding LDSS \leq 10m
8. Light-Duty Suspended Scaffolding LDSS $>$ 10m

5.2.1 Skim coat application



Figure 5.11.: Skim Coat Application before and after Condition

5.2.3 Polymer mortar application



Figure 5.12.: Polymer Mortar Application before and after condition

5.2.4 Carbon Fibre Wrap

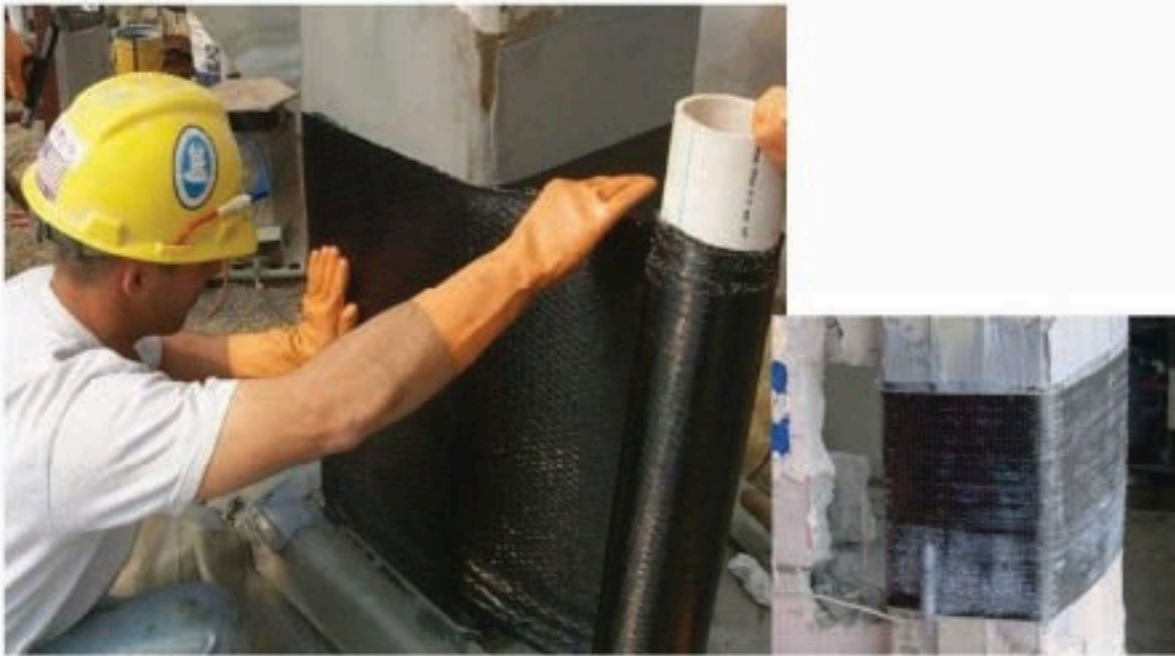


Figure 5.13.: Application of Carbon fibre wrapping without any air gap

5.2.5 Carbon fibre Laminating



Fig: 5.14 Apply epoxy putty at the bottom face of the girder and place Carbon laminate without any air gap

5.3 Minor repair works

5.3.1. General

The Minor repair works are included in many cases partly damaged bridge/culvert elements. Emergency cases such as traffic safety and public safety are taken priority even for Minor repair works.

Typical Minor Repair works for bridges are shown as follows;

- a) Surface
 - Partial Pavement repair (Potholes or small Difference In Level at Expansion Joint)
 - Partial Curb/Sidewalk repair
 - Partial Railing repair/replacement
 - Touch up painting
 - Partial Catch basin repair/replacement
 - Partial Drainage repair/replacement
 - Partial traffic Sign/Markings repair
- b) Superstructure
 - Touch up painting of girder
 - Partial Replacement of Sub-Element small Honey-Comb repair
 - small Spalling repair
- c) Bearing
 - Touch up painting of steel element
 - Small Spalling repair of Seat
- d) Substructure
 - small Honey-Comb repair
 - small Spalling repair
 - Partial Backfill repair
 - Partial Stonemasonry repair
 - Partial Gabion wire mesh repair

Typical Minor Repair Methods and Routine Maintenance Methods are shown in Table 3-1. Plate 1-1 to Plate 1-2 and Plate 2-1 to Plate 2-5 are attached in the Appendix 1 describing detailed method and procedure for each repair method.

Table 5.1 Plate list

Plate name	Defect/Deficiency	Remedial Measure
Routine Maintenance Methods		
Plate 1-1	Debris accumulation	Cleaning
Plate 1-2	Water flow obstruction	Removing obstructions
Minor Repair Methods		
Plate 2-1	Material loss from Mortar masonry	Repairing of stone masonry
Plate 2-2	Damage of gabion wire mesh	Partial repair of gabion mesh
Plate 2-3	Spalling, Minor honey comb	Hand applied mortar
Plate 2-4	Minor corrosion of steel works	Touchup painting
Plate 2-5	Abnormal bituminous pavement	Partial repair of pavement

5.4 Minor maintenance

5.4.1 Description

- Element of the structure with minor deficiencies which signify a progression of deterioration process.
- The structure with elements of condition state is serviceable

5.4.2. Repair methods

Defect/Deficiency	Abnormal Spacing at Expansion Joint	Plate 1 - 5
Remedial Measure	Replacement of Steel joint	

Workdescription

The quality and maintenance of the expansion joints are vital to the behavior of the bridges and their durability. Accordingly, it should be ensured that expansion joints are waterproofed as well as resistant to leakage.

When water leakage occurs at expansion joints, dirt, soil, gravel and water are collected on the bearing seat locations. This condition will initiate corrosion of steel members including the steel bearings, bottom flanges at ends of steel girder and steel connection accessories.

This repair method is intended for damaged steel type and rubber type expansion joints, which would be replaced with suitable water-proof type expansion joints.

Concrete cutter shall be used to cut both joint edges of the concrete surface to form a straight cutting line pattern. The defective expansion joint shall then be dismantled after chipping off the concrete with an electric jack hammer. The new expansion joint shall be installed with its top level matching the required finish surface. Concrete/grout shall be finally poured, leveled, and then cured.

Photo 5.20.1 and 5.20.2 shows example of water proof type steel expansion joint



Figure 5.20.1 Structure of the steel expansion joint



Figure 5.20.2 After Installation

2. Application criteria

Replacement of the steel expansion joint shall be implemented depending on condition of the expansion joint obtained through Bridge Condition Survey and daily maintenance activities or information from road users.

Following conditions can be referred as one of the Standards for decision of replacement of the steel expansion joint.

1. Work description

Function of a bearing shoe is transferring all load from a superstructure including own load of the superstructure to a substructure such as an abutment and a pier.

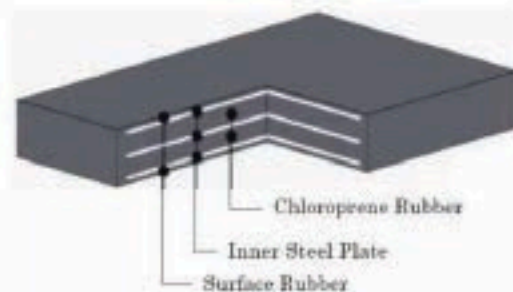
In case the bearing shoe has some defect, a road surface will lose its flatness and causes impact to both of the superstructure and substructures. This impact will to be a cause of damages to the superstructure and substructures.

Meanwhile, rusting condition of the bearing shoe area is one of the most serious areas due to narrow space and concentration of debris and water.

Effective service life of elastomeric bearings is estimated to be 15-25 years. As the material ages during its serviceability period, it exhibits severe bulging or cracking. These are signs that the elastomeric bearings need to be replaced.

Replacement with new bearing shoe should be performed strictly in accordance with the relevant technical requirements and recommendations provided by the bearing manufacturers. Installation should be performed by highly experienced staff subject to close supervision.

Usually, the jack-up girder technique is utilized to allow for replacement of bearings. During replacement of the bearings, traffic may remain opened but with imposed restriction on passing speed as safety precaution. The girder shall be jacked up to around 5 mm to 10 mm, with one jack stroke.



2. Application criteria

Replacement of bearing shall be implemented if existing rubber bearings already exhibited severe cracks and abnormal bulging. Old steel bearings need to be replaced especially if loose connections were found.

The capacity of the new bearing should be the same as the old bearing, subject to approval of the engineer.

5.4.2.1 Case studies

Case Study 1: Minor Maintenance

Uneven concrete surface, fine honeycomb repair by using high performance polymer mortar (Layer thickness 0.40mm to 2mm)



Fig 5.21.1 Concrete surface having fine honeycomb



Fig 5.21.2 Concrete surface having fine honeycomb

Scope

This method statement describes the step by step procedure for patch repair work of concrete blow hole, bug hole and fine honeycomb

System Description

Sika® MonoTop®-711 MY is a high performance, one-part, cementitious polymer modified based filling and levelling plasters for concrete surfaces. Sika® MonoTop®-711 MY consists of finely crushed high quality limestone. Sika® MonoTop®-711 MY is a surfacing mortar as an essential surface preparation to obtain superfine finish coating and painting application.

Uses

- Level uneven substrates such as concrete, aerated concrete, hollow block walls, light-weight blocks, etc.
- Filling compound for level off irregularities and fill blow holes and fine honeycomb.
- Suitable for both internal and external use.

Characteristics/ Advantages

- Provide very fine surface finish on walls, ceilings, etc.
- Great durability and flexibility
- Quick drying and easy to apply
- Thickness of the plaster can be varied to minimize wastage
- Non-cracking when applied at correct thickness and properly cured
- Easy to mix – just add water
- Good adhesion
- Can be applied by spraying

Important Considerations

- Recommended thicknesses of Sika® MonoTop®-711 MY is 0.4 mm min. /2 mm max.
- Do not use Sika MonoTop®-711 MY on painted or gypsum surfaces.
- Saturated surface dry (SSD) Condition is strongly recommended before application of Sika MonoTop®-711 MY.
- If Sika MonoTop®-711 MY is using a protective coating, the compatibility of the coating must be tested, e.g. adhesion

Limitations

- Products shall only be applied in accordance with their intended use.
- The most recent and relevant local Product Data Sheets (PDS) and Material Safety Data Sheets (MSDS) shall apply.
- For specific construction / build information refer to the Architect's, Engineer's or Specialist's details, drawings, specifications and risk assessments.
- All work shall be carried out as directed by a supervising officer or a qualified Engineer.
- This method statement is only a guide and shall be adapted to suit local products, standards, legislation or other local requirements

Products

Name of Product	Function	Packaging
Sika® MonoTop®-711 MY	High performance, one-part, cementitious, polymer modified finish skim-caot	25 kg bag

Material Storage

Materials shall be stored properly in undamaged original sealed packaging, in dry cooled conditions. Refer to specific information contained in the product data sheet regarding minimum and maximum storage temperatures.

Substrate Preparation

The concrete substrate shall be in a good sound condition and free from dust, loose material, surface contamination and materials which reduce bond. Delaminated, weak, damaged and deteriorated concrete shall be removed by suitable means.

If necessary, sound concrete shall also be removed but only as directed by a supervising officer or engineer.



Fig. 5.22. Surface Cleaning before application

Application

Put around 80 to 90% of required water in the mixing drum, followed by Sika® MonoTop®-711 MY and then add the balance water.

Mix powder mechanically with water at water-powder ratio of 0.33 by weight (8.25 L of water for 25 kg bag) with low speed (max. 500 rpm) electric drill until a smooth consistency is achieved.



Fig 5.23: Mixing of materials

The concrete surface must be wet before application. If required, thoroughly wetted down prior to the mortar application.

Apply the mortar by hand with a steel trowel or spatula. The coat is then levelled off to a smooth surface with a steel trowel.

Ensure that the applied coat is dry before application of subsequent coats. Apply the entire mortar within 2 hours (*Pot life at 25° C)

To prevent premature drying out of the mortar, keep it moist if exposed to strong sunshine and wind.

Application Limits

Avoid application in direct sun and/or strong winds.

Do not add water over the maximum recommended dosage.

Always check the material's pot life and adjust for climate conditions

Temperature of the repair mortar and the substrate shall not differ significantly.

Curing

Protect the fresh material from premature drying. Cure exposed area with proper curing methods for at least 3 days or spray with appropriate curing compound once the mortar starts to stiffen. Suitable curing covers include jute and water, plastic sheets or other suitable membranes

5.5 Major maintenance

5.5.1: Case Study

- Element of the structure with advance stage of deterioration.
- The structure with elements of condition state is almost close of danger in providing safe service.



Fig 5.24.1: Girder side Require Maintenance



Fig 5.24.2: Concrete spalling from girder side and rebar exposed exposed.



Fig 5.24.3: Girder bottom rebar

The above figures, fig. : 5.24.1, fig.: 5.24.2 and fig. 5.24.3 cases deterioration are alike to fig.5.25, So the treatment solutions example are described in below :

8.10 m RCC Girder Bridge on Ghorashal Bridge (RHD)- Raniganj GC (Taraganj Bazar) Via Jamalpur GC, Showride GC (Kaliganj Part) at chainage : 9900 m [RI: 333342001, SI: 33334200113], Upazila- Kaliganj, District- Gazipur. Dated: 20 January, 2021



Fig 5.25: Deteriorated deck slab



Fig 5.26.: Close view deteriorated deck slab

Structural observation details:

Existing 8.10m RCC Girder Bridge shows that the bottom rebar of the deck soffit exposed from concrete. There is no clear cover at the bottom rebar of bridge deck slab.

Recommendations

First of all, existing loose concrete from the affected area will be removed and affected rebar from the deck soffit has to be cleaned properly. After cleaning of affected area washed properly by water jetting, rust off chemicals and anti-corrosive chemicals has to be applied in the rebar. Then, Polymer mortar applied on the surface layer by layer, before applying the prime coat old concrete should be in SSD condition. Finally, curing compound will be applied.



Fig 5.27.: Repairing of Deck Soffit (Side)



Fig 5.28.: Repairing of Deck Soffit (Middle)

Major Maintenance 2

Site Situation-1: Corroded concrete pier without exposed rebar



Fig 5.29.: Corroded concrete pier without exposed rebar

Substrate preparation:

The concrete substrate shall be in a good sound condition and free from dust, loose material, surface contamination and materials which reduce bond, delaminated, weak, damaged, and deteriorated concrete shall be removed by suitable means.

If necessary, sound concrete shall also be removed but only as directed by a supervising officer or engineer

Application of Epoxy crack injection

1. Cutting V shaped groove of size 15x15 mm all along the crack line by concrete cutter machine.
2. Create holes of diameter 6 mm at 200 mm along the crack line.
3. Fix MS or GI Nozzles/surface packer (threaded at outer end) shall be fixed by epoxy adhesive at mouth of the same hole. Seal the remaining crackling with Epoxy
4. Inject epoxy with a suitable injection pump.

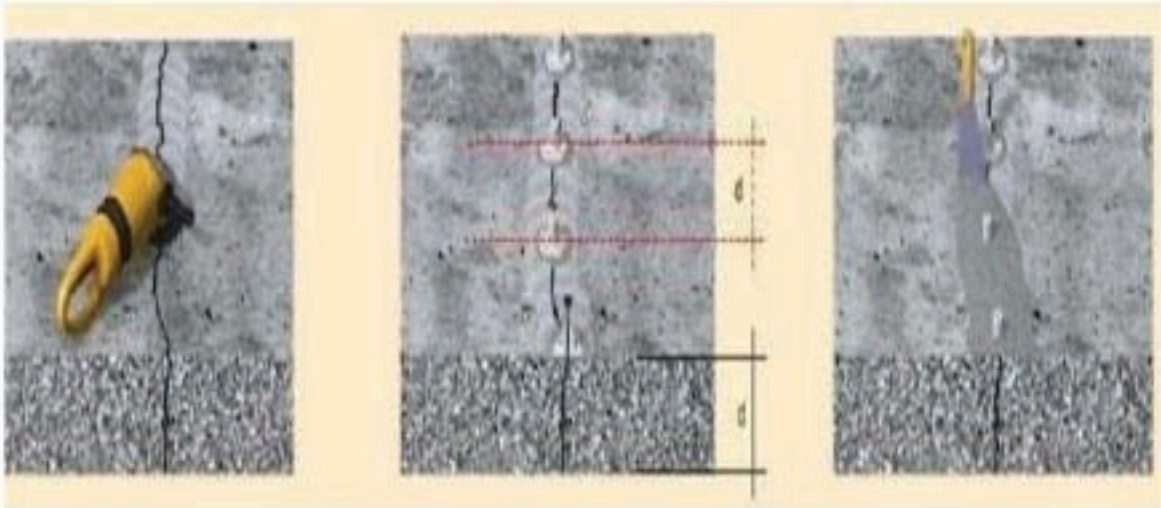


Fig 5.30: Cracked Surface

Site Situation-2: Vertical crack in concrete pier without major damage.



Fig 5.31.: Vertical Crack without Damage

Application of bond coat

- After mixing, apply adhesive directly to the prepared substrate by brush or roller. On damp surfaces, ensure that it is well brushed in.
- Apply the repair mortar onto the bond coat within 4-5 hours, as long as, the coat is still tacky.

Application of repair by using polymer mortar

- Put around 80 to 90% of required water in the mixing drum
- Mix powder mechanically with water at water-powder ratio of 0.15-0.16 by weight (4.5-4.8 ltr of water per bag) with low speed (max. 500 rpm) electric drill to avoid entraining too much air.
- Apply the entire mortar within 20-30 minutes (*Pot life) at 30° C
- To prevent premature drying out of the mortar, keep it moist if exposed to strong sunshine and wind. Cure with proper curing methods for 3 days



Fig 5.32.: Pier Repair by Polymer Mortar

Application of Carbon fibre wrapping using primer

Apply Sikadur®-330 IN on the concrete surface.

Apply SikaWrap® 230 C over Sikadur®-330 IN adhesive by dry/wet application process using wrapping roller.

Follow manufacturer guide line in application process

Site Situation-3: Major honeycomb in I-girder



Fig 5.33.: Major Honeycomb

Substrate preparation:

1. The concrete substrate shall be in a good sound condition and free from dust, loose material, surface contamination and materials which reduce bond. Delaminated, weak, damaged, and deteriorated concrete shall be removed by suitable means.
2. If necessary, sound concrete shall also be removed but only as directed by a supervising officer or engineer

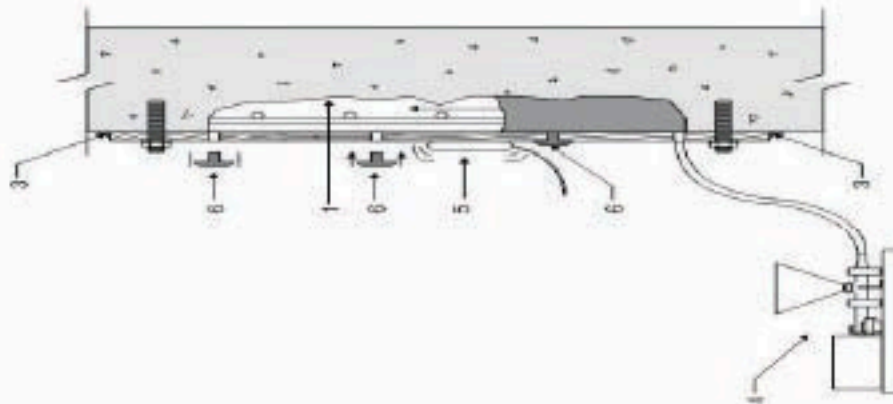


Fig 5.34.: Application of grout using pressure pump

1. Place the formwork with entry and exit opening.
2. Put around 80 to 90% of required water in the mixing drum, followed grout and then add balance water slowly to get the desired consistency.
3. Pump the grout within 20 minutes grout through the "mouth" of the formwork allowing the material to flow to the opposite end.
4. Ensure a process of continuous pouring to avoid air entrapment and prevent the grout flow from coming to a stop before the grouting operation is completed.
5. Follow manufacturer guide line in application method statement.

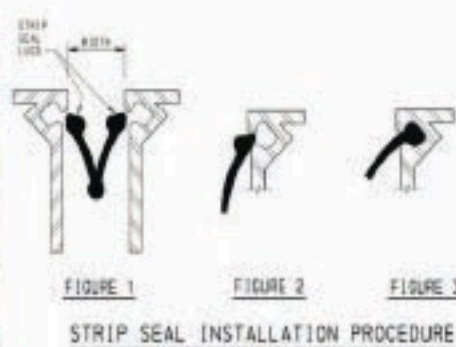


Fig 5.35.: Work on process

Major repair methods

Defect/Deficiency: Water Leakage/Efflorescence

Remedial Measure: Fluid Recasting Mortar/Concrete

Work descriptions

Recasting method, which involves casting of the damaged area, by placing concrete or grouting mortar on the formwork, is usually most suitable for severely damaged concrete, or for largely damaged areas with densely-spaced rebar. If concrete placing by vibration is often a problem, grout and free flowing self-compacting concrete should be adopted to minimize the vibration required.

Typical Damage: Recasting Mortar/Concrete



Fig 5.36.: Rebar Exposed In Girder

Application Criteria

Recasting Concrete/Grout is divided into two methods namely,

- I. Concrete Placing and
- II. Mortar Grouting.

Further, the Mortar Grouting has two categories depending on materials used, i.e.,

- I. Portland cement and
- II. Non-Shrink Cement.

Considering the damaged position, scale of damage, formwork shape and density of rebar, the application of the recasting material such as concrete and grout shall be selected.

Work sequence of Recasting Mortar/Concrete

1. Start
2. Removing damaged concrete
3. Removing rusted rebar s & placing new rebar's
4. Installing form
5. Applying bonding coat on surface of existing concrete and rebar's
6. Casting concrete
7. Curing concrete and removing form

Required Equipment/Tools and Material

The following Tools/Equipment are necessary for the Recasting Mortar/Concrete

- Sawing Equipment

- High Pressure Water Blasting
- Handy Concrete Breaker or Jackhammer
- Handy power Chisel
- Concrete Mixer 30 liters
- Mortar Mixer with Pump (For Mortar)
- Vibrator
- Troweling tools

Material

The following Materials are necessary for the Recasting Mortar/Concrete.

For Concrete

- Portland Cement
- Silica fume
- Aggregate/Sand
- Rebar
- Epoxy Resin Adhesive (Bonding coat)
- Anti-corrosion Primer to Rebar (Zinc Rich Primer)
- Cotton mat (Curing)

For Mortar

- Portland Cement (Cement Mortar)
- Silica fume
- Sand
- Reinforcing steelbar
- Epoxy Resin Adhesive (Bonding coat)
- Anti-corrosion Primer to Rebar (Zinc Rich Primer)

Requirement, Specifications

Material

The material shall be approved by the Engineer through mill certificate of the supplier

Concrete mixture:

The actual mix portion shall be determined during a field mixture test and approved by the Engineer. These quantities will make about 0.03 cubic meters of concrete and would be fully accommodated in a small mixer.

- a) Cement; Portland cement 13.0 kg with Silica fume 0.5 kg (if Silica fume is unavailable, use 13.5kg cement)

- b) Crushed aggregate; 36.0 kg (10mm down graded)
- c) Sand; 18.5 kg (assumed 2% water content)
- d) Water; 5.4 liters (maximum)
- e) Super plasticizer; 25ml (nominal)

Epoxy bonding primer

Epoxy bonding primer shall conform to the Specifications

Specification for Epoxy bonding primer

Property	Test Method	Unit	Specifications
Compressive Strength	ASTM D695M	N/mm ²	70
Flexural Strength	ASTM D790M	N/mm ²	40
Tensile Strength	ASTM D638M	N/mm ²	30
Tensile Shear Bond to Steel	ASTM D1002	N/mm ²	10
Slant Shear Bond to Mortar	ASTM C882	N/mm ²	15

Zinc rich primer

The Zinc-rich primer applied to rebar shall be in accordance with the specifications or equivalent ASTM Specifications

Specifications for Zinc Rich Primer

Property	Test Method	Unit	Specifications
Gloss @ 60 Angle	ASTM D 523	-	Flat

Adhesion	ASTM D 3359	-	Minimum 3A
Salt Spray Resistance	ASTM D3-37	-	Excellent
% Zinc by Weight in Dried Film Test		%	87.5 2

Work requirement

The Contractor shall submit the Methodology Procedure of the Work to the Engineer for his review and approval before commencement of the work.

Removal of damaged concrete

Old concrete shall be removed as approved by the Engineer for all the areas determined to be defective. Saw cuts shall be made on the surface of concrete. Concrete saw shall be used to provide vertical edges with approximately 20 mm depth around the perimeter to be replaced. Girder concrete is removed by breaker and portable electric chisel near the vertical edges.

Removing rusted rebar and supplying new rebar

- Any damage to the rebar to remain in place shall be repaired or replaced to the satisfaction of the Engineer at the Contractor's expense. All existing rebar shall remain in place except those which are significantly corroded.
- Deteriorated old rebar which lost 20 percent or more of their original sectional area shall be cut up and be replaced by new reinforcing bars. New bars to be provided shall be of same or bigger diameter than the existing one, considering the current loading condition.
- The lap length is calculated as 30 times of the new rebar diameter. The new rebar shall be tied to the existing bars using tie wires.
- The new bars shall be coated by zinc rich primer. An approved mechanical bar splice capable of developing in tension at least 3 to 25 percent of the yield strength of the existing bar shall be used when it is not feasible to provide the minimum bar lap.

When replacement of rebar is required, followings shall be taken into consideration:

Necessity of scaffoldings:

In case all main rebar of the girder is required replacement, installation of scaffoldings is necessary.

- Meanwhile, in case of partial replacement of the main rebar of the girder, necessity of the scaffoldings is depending upon stress condition of the girder after removing some of rusted rebar. Examination of stress condition of the girder will be carried out with consideration of load distribution effect by cross beams, traffic restriction and reducing safety factor of remaining rebar.

Installation of the scaffoldings

- In case installation of the scaffoldings required, requirements of the scaffolding are as follows: (Refer Figure 3-5-3 Example of the Scaffolding structure)
- Scaffolding member shall be strong enough against imposed load from the girder.
- Buckling strength of the scaffolding member shall be examined. Stability of the scaffolding system shall be examined.
- Bearing capacity of a foundation of the scaffolding structure shall be examined. Any settlement of the scaffolding structure will not be allowed. Therefore, the foundation of the scaffolding structure shall be designed carefully.
- The scaffolding structure shall be remained until strength of new concrete reaches its design strength.

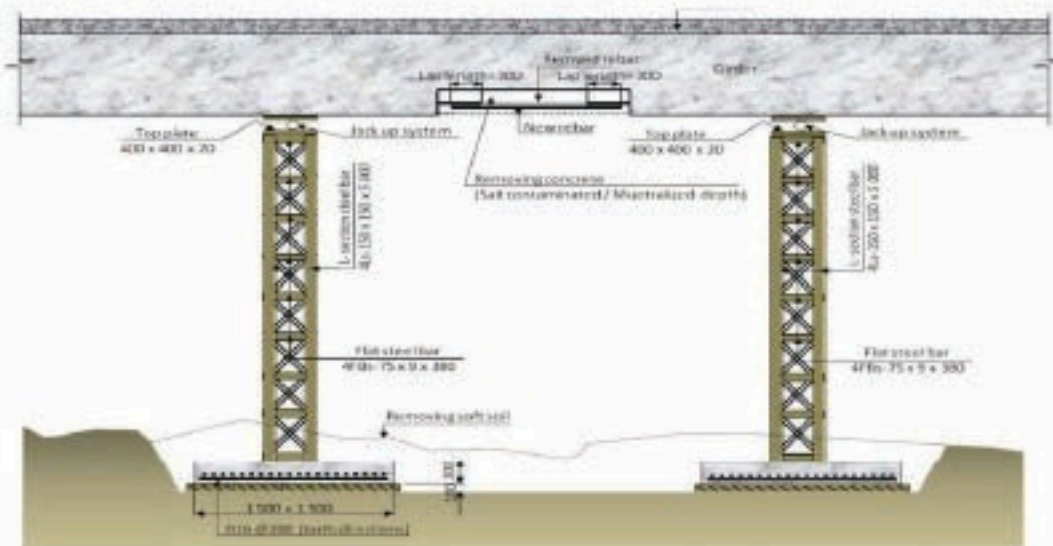


Fig 5.37.: Example of the scaffolding structure

Application of bonding coat

- The concrete surface to which the bonding coat is to be applied shall be wet using potable water to achieve a moisture condition such that the concrete will not absorb moisture from the mortar. The wetting period will depend upon the substrata condition and the bonding coat manufacturer's recommendations, subject to Engineer's satisfaction.
- The surface shall then be left wet until the free water has evaporated before the bonding coat is applied. Using a brush, the coat shall be applied to the exposed concrete surface and exposed concrete reinforcement. The subsequent coat shall be applied while the previous bond coat is still wet or tacky.
- Rebar rust must be removed before placing the new concrete. If the damage is due to chloride contamination, it is essential to remove all the rust from the rebar, as the residual rust (contaminated with chlorides) could restart the corrosion process at a later stage. The surface of cleaned rebar should be coated with zinc rich paint for protection against future corrosion.
- Rebar rust must be removed before placing the new concrete. If the damage is due to chloride contamination, it is essential to remove all the rust from the rebar, as the residual rust (contaminated with chlorides) could restart the corrosion process at a later stage. The surface of cleaned rebar should be coated with zinc rich paint for protection against future corrosion.



Fig 5.38.: Bonding coat application

Installation of formwork

- The Contractor shall submit the shop drawings of the formwork of recasting concrete prior to the commencement of the repair works for obtaining Engineer's approval.
- Casting type of repairs must be very rigid and well-supported to prevent the new concrete from sagging away.
- It shall also withstand pumping forces if concrete is to be poured into forms. The formwork shall also withstand the forces of clamped-on external vibrators.
- Formworks should be provided with slit hoppers and openings where appropriate for placing new concrete or grouting mortar and for inserting poker vibrators. Form-releasing agents to be used should be compatible with the repair materials, particularly Epoxy-based and latex-modified concrete and grouts.

Mixing and casting mortar/concrete

- A mechanical batch mixer should be used to ensure homogeneity, workability and good board life. Clean, potable water shall be used and the maximum amount added shall be consistent with optimum workability. Hand mixing shall not be permitted unless approved in writing by the Engineer, who should outline hand mixing procedures.
- The finished color should not be analyzed until addition and full mixing of the cement materials and water are complete.

- All large damaged areas shall be re-cast to accurately restore the original face of the member.
- Concrete/cement mortar shall be pumped through the pour access holes. Spacing for pour access holes shall not exceed 600 mm. Vibrators, placed on the outside face of the formwork, shall be used to achieve proper consolidation. The maximum time allowed between the delivery of grout to the site and the grouting process shall not exceed 60 minutes.

Curing and protection

- Continuous water cure with spray-water is always preferable as membrane cure, which helps slow down drying process.
- Formworks for load bearing structural members shall remain in position until at least 80% of the 28 day compressive strength of the new concrete is achieved and approved by the Engineer.

Field Test

- Compression tests and fabrication of specimens for cement grout will be performed as specified in ASTM C 109, at intervals selected by the Engineer during construction.
- A set of three specimens will be tested for 1 day, 7 days, 28 days, and additional time period as appropriate.

5.6 Rehabilitation

5.6.1 Sample case study of Climate Adaptation Measures in Rehabilitation

The inspection of the 126m Nakla Bridge was undertaken as part of the SuPRB project's systematic initiative to assess the condition of rural bridge infrastructure and ensure long-term serviceability. The bridge, which serves as a vital connection for local communities, facilitates daily transport of people, agricultural products, and essential goods. Due to increasing traffic demand and exposure to seasonal flooding, the bridge was prioritized for detailed assessment to determine its current structural health and identify emerging risks. The inspection aimed to document the condition of key components—including the deck, girders, bearings, joints, and substructure—while evaluating environmental impacts such as scour and erosion.

Observations and findings:

The back approach abutment eroded and pile exposed

Poor concreting in piers, pile and girders.

Half of the river almost silted i.e., around 55 m at front approach side.

Narrowing water flowing area.

Adaptation measures and design solutions:

Micro concreting to the pile and affected girder.

permanent casing used in head of pile and inject micro concrete through the hole.

Pier columns were treated by polymer mortar

Piers being corroded are treated by polymer mortar to gain its original shape

Dredging from the silted part of the river and filled by the same dredged sand to the eroded approach.

To protect the erosion/scour of the back approach and subsidence from hilly flash flood filled the abutment ditch and laying geo bag over the filled area and its vicinity.

Cutting the silted part of the river and recover the original river shape and ensure the full flow/discharge through around the year.

Reshaping and carpeting the approach for ensure normal traffic movement

Rail bar and rail post coating by thin road marking paint and rail posts wrapping by the retro-reflecting paper.

Both approaches painting by thick road marking paint.

Existing condition before work. Piles rebar exposed.

Before rehabilitation and under ongoing repair work of 126 m bridge ID.389672003 at Ch. 11300m, Upazila Nakla and District- Sherpur.



Fig.5.7 Rehabilitation of 126 m bridge ID.389672003 at Ch. 11300m, Upazila Nakla and District- Sherpur.



After work completion

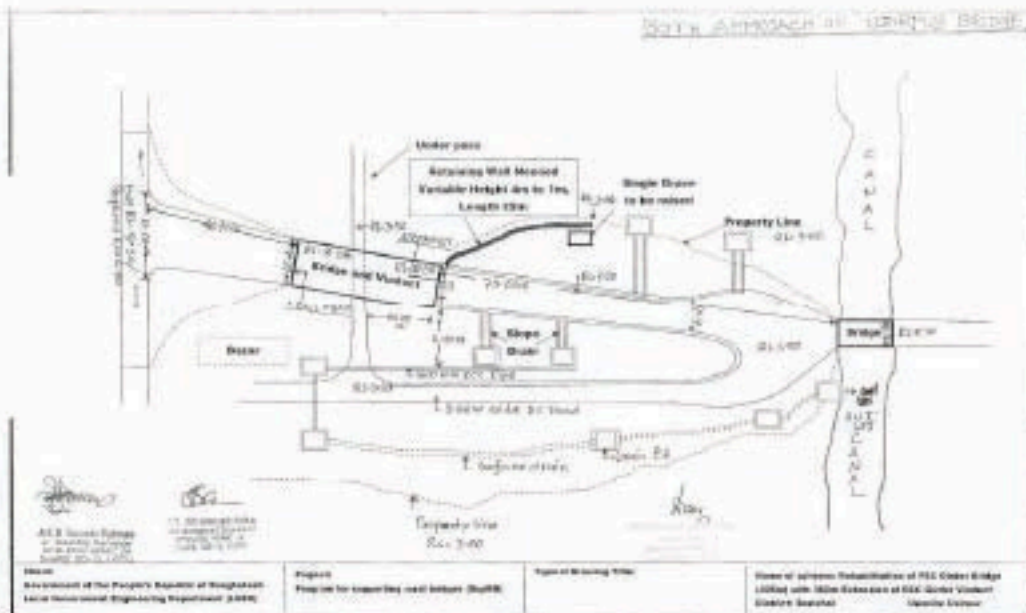
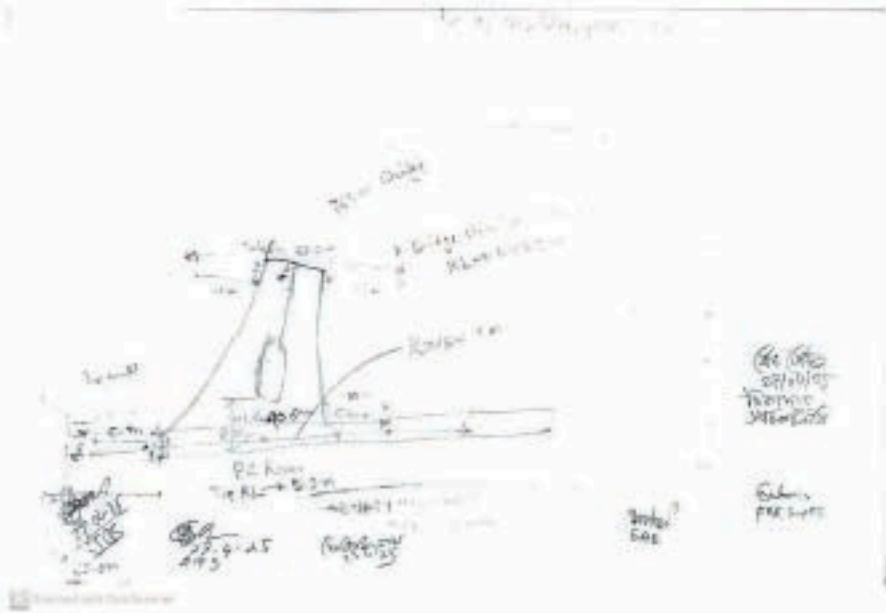
Fig.5.8 Rehabilitation of 126 m bridge ID.389672003 at Ch. 11300, Upazila Nakla and District-Sherpur.

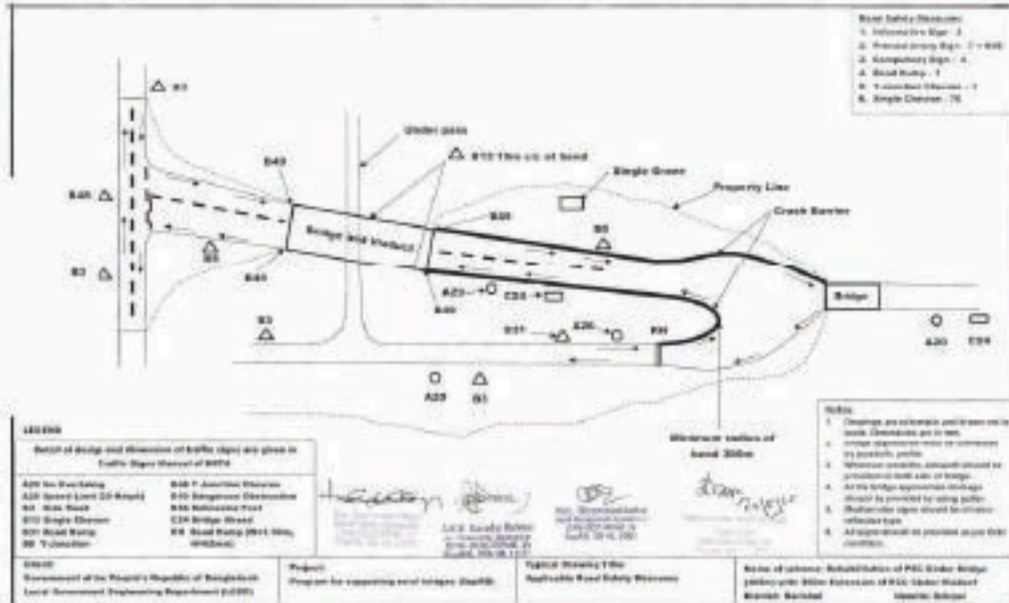
5.6.2 Case study:

5.6.2.1 Example: Rehabilitation of 405 m PSC Girder bridge with extension of viaduct both end, total length is 765 m uzirpur , Barishal.

1. Developing Strip Maps: Collecting the necessary information's of any particular site strip maps is very effective tools.







2. Conducting tests and collect additional data: Generally sub-soil investigation and topo survey was done for all the schemes except the maintenance. To have the in-depth idea about concrete and its reinforcement, we had done some nondestructive test like Ferro scan test, to ascertain rebar condition & its spacing, UPV test, Rebound Hammer test to confirm the concrete strength, on Balata bridge, Gopalpur, Tangail. (Test results Enclosed at the end).
3. Conducting engineering analysis: Having the Ideas from strip maps and test reports, analyze it properly and structural design had also been done where it is needed.
4. Determining the most appropriate repair options: Choose the following treatment options in where it is most appropriate based on the condition assessment of the particular bridge.
 - i) Use polymer mortar: If the depth of the cavity by spalling concrete up to 50mm should be filled by non- shrink polymer. Mortar. (Photo Attached).

5.6.3 Case study:

5.6.3.1 Example: Rehabilitation of 80.5 m Girder bridge at Bolata Gopalpur, Tangail.

The 80.50-meter Bolata Bridge in Gopalpur under the SuPRB project showed varying levels of structural distress, requiring both reconstruction and retrofitting measures. The middle portion of the bridge was found to be severely damaged and will be fully demolished and rebuilt to restore structural integrity. The remaining portions, although less deteriorated, will undergo retrofitting based on findings from Ferroskan, UPV, and Rebound Hammer tests, which confirmed major cracking and material degradation in the girders. The combined approach ensures safety, durability, and



Figure 1: Existing Condition of Gopalpur Bridge



Figure 2: Baily Panel in Mid-Span

continued serviceability of the bridge within the SuPRB framework.

1. **Developing Strip Maps:** Collecting the necessary information's of any particular site strip maps is very effective tools.
2. **Conducting tests and collect additional data:** Generally sub-soil investigation and topo survey was done for all the schemes except the maintenance. To have the in-depth idea about concrete and its reinforcement, we had done some nondestructive test like Ferro scan test, to ascertain rebar condition & its spacing, UPV test, Rebound Hammer test to confirm the concrete strength, on Balata bridge, Gopalpur, Tangail. (Test results Enclosed at the end).

Structural Test Findings & Observations

Rebound/Schmidt Hammer Test

Table- I. Summary of Rebound Hammer Test Result from Test Report

Girder/ Size (mm)/Location	Avg. Rebound	Hammer Position Angle	Comp. Strength (psi)	Comp. Strength (MPa)
H7 (380×1000)/B-6	20	$\alpha = 0^\circ$	1500	10
H8 (380×1000)/C-1	20	$\alpha = 0^\circ$	1500	10
H4 (380×1000)/A-2	32	$\alpha = 0^\circ$	3320	23
H5 (380×1000)/C-5	30	$\alpha = 0^\circ$	2990	21
H6 (380×1000)/A-5	28	$\alpha = 0^\circ$	2800	19
H1 (300×940)/D-4	32	$\alpha = 0^\circ$	3320	23
H2 (300×940)/D-3	30	$\alpha = 0^\circ$	2990	21
H3 (380×1000)/C-2	28	$\alpha = 0^\circ$	2800	19

Table- II. Quality of Concrete According to Rebound Number (As per IS 13311 – Part 2)

Average Rebound Number	Quality of Concrete
> 40	Very good hard layer
30 – 40	Good layer
20 – 30	Fair
< 20	Poor
0	Delaminated

3. Conducting engineering analysis: Having the ideas from strip maps and test reports, analyze it properly and structural design had also been done where it is needed.

Based on the structural assessment and material strength evaluation conducted under the SuPRB project, the middle span of the Bolata Bridge was identified as critically distressed due to extensive structural deterioration. The deck of this span consists of a temporary Bailey panel system, which has

also degraded over time and is no longer capable of safely carrying heavy vehicular loads, making full reconstruction the only technically justified option. Rebound hammer tests performed on the girders of this span recorded average compressive strengths (10 MPa) below 20 MPa—significantly lower than the expected capacity for reinforced concrete members in active service—confirming substantial material degradation and inadequate residual strength.

Ultrasonic Pulse Velocity Test

Table- III. Summary of UPV Test Results of Balata Bridge from test report

Sl. No.	Member	Size (mm)	Member ID	Time (Microsecond)	Crack Depth (m)
UPV-1	Girder	300 × 1000	A-1	554.1	0.306
UPV-2	Girder	300 × 1000	B-1	2166.6	0.069
UPV-3	Girder	300 × 1000	D-3	412.0	0.518
UPV-4	Girder	300 × 1000	C-1	263.0	0.029

Out of the five spans, the four spans excluding the middle span exhibited comparatively less structural damage but still required rehabilitation to ensure safe performance. UPV testing identified the presence of cracks in several girders, and detailed crack mapping was carried out to document their locations and extents. This systematic identification enabled proper marking of distressed zones and facilitated the planning of appropriate rehabilitation measures for restoring the structural integrity of these spans

3. Determining the most appropriate repair options: Choose the following treatment options in where it is most appropriate based on the condition assessment of the particular bridge.



a) **Micro Concrete:** It is flowable high strength concrete. It is use where normal concreting is difficult. For maintenance work micro concrete is very effective. (Photo Attached)



b) **Injected epoxy resin:** Epoxy resin injection using pressure injection machines to seal crack and prevent further deterioration. (Photo Attached)

c) Carbon Fiber Wrap & Carbon fiber laminate: Application of FRP (Fiber Reinforced polymer) lamination and FRP fiber wrapping to enhance load-carrying capacity and extend the service life of the spans. Through these measures, the bridge's structural safety was significantly enhanced while optimizing resources by combining selective reconstruction with retrofitting. (Photo Attached)



5.6.1 Case Study

Rehabilitation of Salepur Bridge at Savar, RHD



Fig 5.39.: Depression of deck



Fig 5.40.: Flexural crack of girder

Working Steps:

- Remove all the poor concrete
- Inject epoxy in cracks
- Rest of the concrete cavity filled by micro concrete
- Apply Putty and
- Apply Carbon fiber wrap without air gap



Fig 5.41.: Concrete cavity filled by micro concrete and epoxy injection apply epoxy putty at the bottom face of the girder and place Carbon laminate without any air gap.

Micro concrete

Pouring micro concrete from the top of deck slab. It is self-flow able, self-compacting and high performance concrete i.e. about 50Mpa. Curing time is only 12 hours. In this case, they are using micro concrete with 15mm thick on the top of 5mm metal sheet having shear key for better anchorage with concrete. Then it becomes an integral part of the deck slab and this metal sheet will act as a reinforcement of the concrete.



Fig 5.42.: 5mm metal sheet



Fig 5.43.: Retrofitting Steel truss place on a pier cap with bearing

5.7 Bridge maintenance, rehabilitation and new construction work under suprb project.

For the maintenance of existing bridge and construct new bridge in rural roads Local Government Engineering Department (LGED) of Bangladesh has start a project name program for supporting rural bridges project financed by World bank. The scope of services under this project is to provide high quality professional advice, management and implementation support to the department for effectively implement the program.

Actually, under this project includes 6 interventions. They are likely below:

- Minor maintenance
- Major Maintenance
- Rehabilitation
- Capacity expansion
- Replacement and
- New Construction

The main activities of maintenance team (sd – 12) are focus on Minor and Major maintenance and rehabilitation scheme which are prepared from field come to consultant office through PD office. Then Maintenance Team (SupRB SD-12) verifies these schemes with need base field visit and send to PMU for approval. And in case of other three interventions only provide estimate preparation on the basis of supplied approved design

5.8 Conclusion and recommendations:

In SupRB project it has create huge opportunity to safe so many bridges from deterioration and increase its life span to improve connectivity for a certain period. LGED should take some step to continue the project for some more years.

Current bridge assets of LGED in UZR & UNR

Existing bridge & culverts in UZR is 436091 m

Existing bridge & culverts in UNR is 347510 m

Total length of existing bridge & culverts in UZR & UNR 783601 m

Total existing gap UZR & UNR is 158039 m

5.8.1 SupRB project achievement with compliance adaptation

Over the past five years, SuPRB has implemented thousands of interventions nationwide, combining traditional engineering with modern materials and methods. The summarized progress is presented below:

Intervention	Total No. of Scheme	Achieved Length (m)	Amount (Lac tk.)
Minor Maintenance	1664	60658.58	18,063.45
Major Maintenance	1314	33029.42	17,579.45
Rehabilitation	26	4036.80	8,037.43
Capacity Expansion	92	2629.60	18,905.25
New Construction	115	5573.66	61,269.97
Replacement	581	16050.39	198,572.90
Total	3792	121978.45	322,428.45

5.8.2 LGED's bridge asset under SupRB project & requirement to address remaining assets.

A huge bridge asset described in above and project coverage comparison given also by data base achievement. A few numbers of existing structures and new construction or any means of said six interventions are addressed. Rest assets need to address by any follow-up project to sustain smooth rural connectivity.

Bangladesh perspective to infrastructure development, it is essential to prepare for long-term adaptation strategy and necessary to identify all present vulnerabilities and future opportunities, adjusting priorities and emphasis the infrastructure and connectivity, promoting training and need assessment of requirement all individual structural health throughout the country's entire assets of LGED.

This manual will be useful for those considering specific engineering design, construction and maintenance options to make bridge infrastructure more resilient in a climate altered future.

5.9 Some good practices picture of executed bridge schemes under different interventions



Fig 5.43. : Before and after Minor Maintenance of 2 vent RCC box Culvert



Fig 5.44.: Before and after minor maintenance of Brick Culvert



Fig 5.45. : Before and after Minor Maintenance work of 3 Span RCC Girder Bridge



Fig 5.46.: Before and after minor maintenance of 2 span RCC Girder Bridge.



Fig 5.47.: Before and after Minor Maintenance PSC Girder Bridge



Fig 5.48.: Ongoing approach road and Completed Road work



Fig 5.49.: Road work before and after Completion



Fig 5.50.: Before and after Major Maintenance PSC Girder Bridge



Fig 5.51: Embankment Slope Compaction work



Fig 5.52.: 50.00m long RCC arch Girder Bridge



Fig 5.53.: 60.05m long RCC Girder Bridge new construction on existing gap

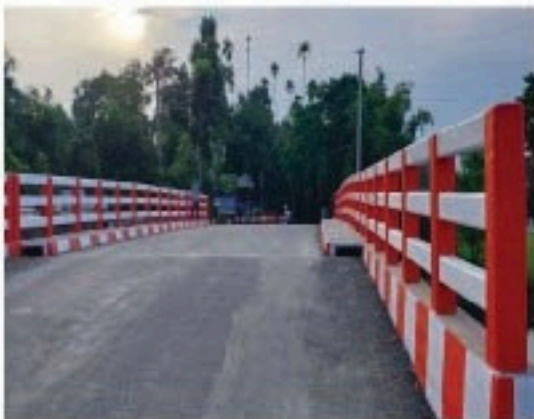


Fig 5.54.: Completed Bridge in under SupRB Project.



Fig 5.55.: Completed Bridge Arch Girder Bridge under SupRB Project.



Fig 5.56.: Completed RCC Girder Bridge under SupRB Project.



Fig 5.57.: Completed Major Maintenance under SupRB Project.



Fig 5.58.: Major Maintenance of Culvert under SupRB.



Fig 5.59.: Completed RCC Girder Bridge under Replacement Category of SupRB Project



Fig 5.60.: Minor Maintenance of Bridge under SupRB Project

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