Coastal Protection Measures for Shoreline of Mumbai: Review and Case Studies

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***Abstract*— Mumbai is a thickly populated city of Maharashtra, India where the coastal lines are heavily developed on infrastructure. According to Maharashtra Shoreline Management Plan 2017, the continuous coastal erosion over the past years poses a high risk to the infrastructure. Dadar beach, Priyadarshani Park in Malabar Hill, Mahim and Versova are subjected to major erosion risk whereas areas like Girgaum Chowpatty, Aksa and Gorai beaches has 'minor' erosion risk to infrastructure. If critical evaluation and preventive measures are not taken at this juncture as early as possible, it would be hazardous by 2050 [1]. The aim of this paper is to propose soft measure solutions for this adverse condition in Mumbai, analysing reviews and a few case studies which had happened across India.**

Keywords—c Soft measure solutions, Coastal Protection, Geotextile, Artificial reef

I. INTRODUCTION

The Indian peninsula is bordered by the Arabian Sea in the west and south-west, Indian Ocean in the south and the Bay of Bengal in the east and south-eastern part. The total coastal length of India is 7516.6 km. Out of this length, Maharashtra has originally 512km long coastal stretch but In the 11th Meeting of CPDAC (January, 2010) a re-evaluation of coastal length is being taken up based on Survey of India wherein Maharashtra now has 896.98km of coastal line available [2]. Mumbai, the state capital of Maharashtra and the Financial capital of India, is the most populous city with a population of 13 Million. [3] The city has an enviable 149-km coastline and nearly 16 km of beaches stretching from Colaba in the south to Madh and Marve up north. [4]. The coastal length of Maharashtra has 17% of Sandy beach, 37% of rocky coast and 46% of muddy flats.

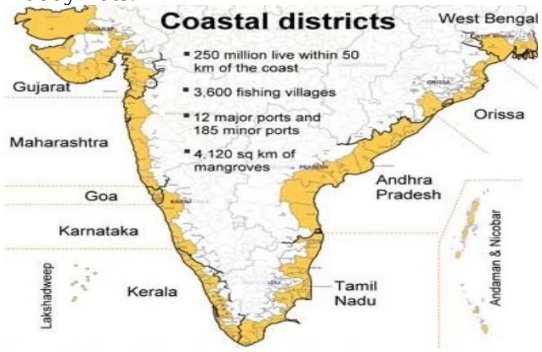

Fig 1 The Coastal Zone of India

One of the prime threat which Mumbai and other fast-growing coastal megacities in Asia are facing is the climate-related flooding. Out of the thirty-one megacities, twenty-one hug a coastline, of which half of them are in Asia. According to a report, in addition to flooding, these megalopolises could face water supply disruptions, dangerous heatwaves, increased food insecurity and many epidemic outbreaks. Mumbai's flood risk makes the city a "high risk" place for climate change vulnerability — the second-most worrying category after "extreme risk," according to Verisk Maplecroft's 2018 hazard index. Mumbai ranks as the ninth riskiest megacity in the list of 31, based on 50 factors from preparedness to exposure to climate shocks like heat waves, drought, hurricanes and flooding. As a result of Global warming, there is a change in the climate, which changes the ocean temperatures, including in the Arabian Sea, causing both sea-level to rise and the rainfall pattern to change across India. Moreover, Mumbai's west coast is predicted to receive more of cyclones than previous years as per the data provided by the government. The seasonal shift in winds adds an extra layer of uncertainty to projecting the amount of sea level rise in Mumbai. Many of the coastal cities are at high risk, as the frequency of extreme weather is alarmingly increasing, resulting in a significant rise of sea level. Places like Marie Drive is risky and comprises of marginal land which is completely unstable and unsafe to build on. [5]

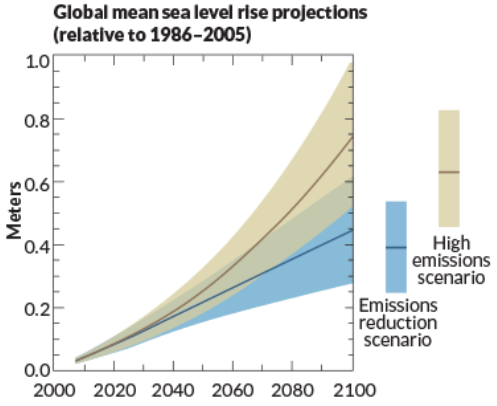

Fig 2: Global Mean sea level rise [6]

II. CAUSES OF COASTAL EROSION

Coastal Erosion a physical process where the sediments of the shoreline are weared off and redistributed by natural forces such as waves, tidal and currents. Erosion occurs when the material removed exceeds the supply, which results in the reduction of beachline and landward shifting of the shoreline.

Waves, the major cause of coastal erosion are developed in the mid ocean and moves towards the shore. Waves bring an enormous amount of energy to the coast that is dissipated through wave breaking, water level changes, and movement of sediment. Wave energy is the result of the speed of the wind

blowing over the surface of the sea, the distance of sea over which the wind has been blowing and the duration of windblown. The redistributed coastal sediments, develops into dunes, beaches, and reefs. These results in permanent changes in beach shape and structure.

The causes of erosion are natural, man-made, or a combination of both. Natural erosion can be either due to Long-shore or Cross shore sand loss like Breaching and over wash etc. But our cause of alarm is the sea level rise which is due to the climatic change. The sudden change in the meteorological conditions like wind, weather and precipitation changes the sea level. [7] So does the effect of global warming, which results in a rise of the sea level globally. Manmade reasons include building of houses, jetties, groynes, harbours and dredging which interferes with the littoral transport. [8]This disturbs the dynamic equilibrium of the coast and promotes erosion to re-establish the equilibrium.

A. Case Study 1:

Fig 3: Coastal erosion in Chennai

In 2012, The National Centre for Sustainable Coastal Management conducted a study on the coastal erosion in Chennai, which showed that 41.4% of Tamil Nadu's long coastline was vulnerable to erosion. The reason for erosion was manmade, which is because of the new groynes structures built along the Kovalam coast in South Chennai. The Regional Meteorological Department's warns the coasts of Tamil Nadu and Puducherry of high wave action as their wind speed may reach up to 45-55 km per hour. Experts suggest that this is the effect of the change in climate, South West monsoon being felt even along the eastern coast of the country. [9]

B. Case Study 2:

According to a study by National Institute of Oceanography, the net sea level rise of Mumbai is around 1.2mm a year. The average sea level rise is 3.2mm a year when compared between 1993 and 2012. The unpredictable climate change and Global warming has led to the increase in the sea level rise in Mumbai [10].

Fig 4: A woman poses as a high tide wave crashes over Mumbai's seaside in July during the seasonal monsoon rains. [11]

III. COASTAL PROTECTION MEASURES

The measures for protecting coast is of two fold: Hard structural / engineering options and Soft structural / engineering options.

A. Hard coastal protection structures include the following methods:

1) Groyne: A coastal structure constructed perpendicular to the coastline from the shore into the sea to trap longshore sediment transport or to control currents.

Fig 5 : Groynes

2) Seawall : A seawall is a coastal structure constructed parallel to the coastline for reducing the erosion.

Fig 6 : Sea walls

3) Offshore Breakwater: An offshore breakwater is a structure that is parallel to the shore and serves as a wave absorber. There are two types of breakwaters; detached breakwaters, straight shore-parallel structures which are built as rubble-mound structures with fairly low crest levels.

Submerged detached breakwaters which is under water, but causes a hazard to boats and swimmers because of no visibility.

Fig 7: Offshore detached breakwater

4) Artificial Headland: This coastal structure is constructed to promote the natural beaches. [12]

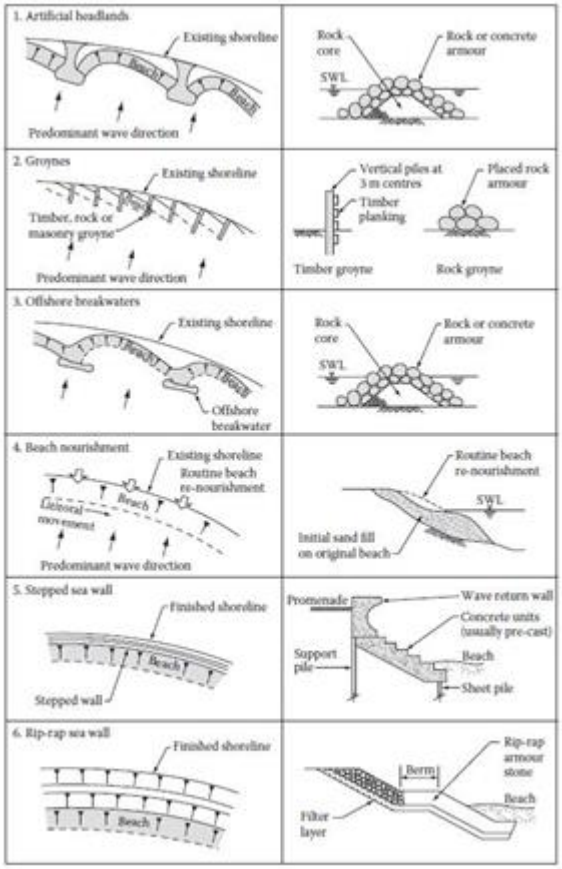

Fig 8: Common types of coastal protection structures [13]

B. Soft Engineering Techniques

1) Beach Nourishment: In this method, sand and shingle are added to a beach in order to make it wider which increases the travel distance for the waves by when it loses energy and hence have less erosive power when it reaches the cliffs.

2) Land Management: Sand dunes act as a natural defence against the sea. These dunes are left undisturbed and sections of sand dune systems are marked as out of bounds to the public to reduce the erosion of the dunes by humans.

3) Marshland Creation: Marshland are used to break up the waves and reduce their speed, whereby energy is dissipated which reduces the waves erosive power. The marshlands are created by growing marshland vegetation such as mangroves, glassworts etc.

4) Beach Stabilisation: The goal is to widen the beach and dissipate the wave energy before it reaches the cliffs. Beach stabilisation involves planting dead trees in the sand inorder to stabilise it and lower the profile of the beach while widening the beach. [14]

The soft solutions are considered to be more environmentally friendly than traditional hard protection works. But when human life may be at risk, the use of hard elements of a defence may be unavoidable.

C. Special methods

Other than the above mentioned methods, Ecosystem-based and hybrid approaches combining ecosystems and built infrastructure are also popular. [6]

1) Geotextiles: Geotextile systems utilize a high-strength synthetic fabric as a form for casting large units like bags, mattresses, tubes, containers and inclined curtains by filling with sand or mortar . These allows the bigger waves to dissipate energy and allows the smaller waves to reach the cliffs. [15]

2) Beach Drainage Systems: The Beach Drainage Systems (BDS) works on the principle of keeping the groundwater level low. Percolation of 'swash water' into the beach reduces the energy, which helps the suspended sand to settle out on the beach face [15].

3) Ecological engineering: Ecological engineering integrates engineering principles with ecological and geomorphological processes to create or restore ecosystems that have experienced degradation [15].

4) Bio-technical structures: Bio-technical structures are soft measures which simulate natural coastal structures and enhance the growth of marine flora.

5) Artificial reefs: They are equivalent to submerged breakwaters, and are made up of coils or bags of geotextile, sand, large blocks, concrete.

6) Artificial Mangrove Root Systems: Plantation of mangrove trees, act as live sea walls and bind the soil together preventing coastal erosion by minimising the action of waves.

D. Case Studies and Reviews on Soft measures

1) Usage of Geo-tubes along sea line in Kerala: [16]:

Geo-tubes are giant tubes with sediment-filled sleeves of geotextile fabric, which were placed in a trench parallel to seashore that will check acute sea erosion, and also lessen the wrath of waves during high tides on the coasts.


Fig 9: Geotubes on Kerala shoreline

2) Usage of Geotextile Sand Container Artificial reefs, Kerala: A feasibility study on usage of Geotextile Sand Container Artificial reefs for the Alappad Coast, Kerala.


Fig 10: GSC reefs

A design proposal was given for Tsunami affected coast line of kerala using GSC which are eco-friendly soft measures. The result showed a significant progress in reduction of wave energy. A cost comparison was also done with the hard measures and was found to be very economic. [17]

3) Oumeraci et al., (2010): studied on semi-analytical formulae and numerical models for the stability of coastal structures made of geotextile sand containers. Investigations were done on the internal movement of sand in the containers and its effect on the stability, variation of contact areas among neighbouring GSCs during wave action, types of displacement of GSCs within a coastal structure and the effect of the deformations on the stability of GSC-structures experimentally and analytically with the aid of RANS-VOF model. [18]

4) Jackson (2010): gives a brief description of the design and construction of low crested reef breakwaters using sand filled geotextile containers. The effects which natural and artificial reefs have on the shoreline are listed. They depend upon the site conditions, submergence depth, length, width and water depth and also the offshore distance. The wave transmission behaviour is also studied. The percentage of energy reduction is less than that for emerged breakwaters, but increases with incident wave energy i.e., it works most efficiently in storm conditions. [19]

5) Lawson et al., (2010): discusses about the three types of geotextile containment – geotextile tubes, geotextile containers and geotextile bags. Their various applications are covered along with performance aspects related to design life and hydraulic environment. Their installation procedures, protection measures to be adopted are discussed. Several international case studies are also included. [20]

6) Mocke (2010) studied on use of Geotextile containers for the creation of artificial reefs. Numerical models are also proposed learning the feasibility. It focuses on the design effort required to ensure that reef structures provide amenity value, namely in terms of surfing enhancement. Both physical and numerical modeling has been used to support this process. It also demonstrates how such reef structures can enhance shoreline stability through creation of shoreline salient resistant to erosion through a movable bed scale physical model. [21]

7) Pilarczyk (2010) presents a brief overview of alternative systems for shore stabilization and beach erosion control with reference to artificial reefs and geosystems. The general design considerations and design aspects are discussed along with a detailed note on durability aspects. The results of durability tests on geosynthetic ropes are presented which shows that the geosynthetics under water and in the intertidal zone show very little degradation in strength in comparison with geosynthetics placed on land. In the inter-tidal zone, it provides good UV protection as it is covered with algae. [22]

8) ASR (2009) submitted a detailed project report on Multipurpose Reef at Kovalam using Geotextile Sand Container, Kerala. The goal is to protect the beach from erosion, while at the same time improve ecology and enhance tourism growth. The report includes a detailed design of the multi-purpose reef and numerical designing using their ASR software and the construction methodology description and also the execution of the same on Kovalam beach. [23]

9) Corbet et al., (2005) assesses the safety aspects and tolerances for reef breakwaters for coastal protection. Monitoring is done on the Narrowneck Artificial Reef, Gold coast, Australia and physical modelling was conducted at DHS laboratory. The risk of impact on the geocontainters by the surfers are governed by the crest and offshore distance. The risk of impact with reef due to turbulent wave action in shallow water is dependent on the wave breaking, size and type of break, water depth etc. [24]

10) Fowler et al., (2002) as proposed preliminary conceptual design of offshore breakwaters for Amwaj Islands, which has Venice style resort on a new island off the northeast shore of Muharraq Island in Bahrain. Sand filled Geotubes forms the island perimeter for containment of 12 million cubic meter of dredged sand that formed the basic platform for the development project. [25]

IV. PROPOSALS

- From the above mentioned reviews and Case studies, it can be proposed that the shore lines of Mumbai can be protected with biotechnical methods of submerged artificial reefs which would enhance the flora and fauna of the region. Moreover, these being submerged will not be viewable from the shoreline but the purpose should be definitely checked.
- Further, siltation problem, if arises can be tackled by increasing the water velocity by using pumping or varied techniques.

V. CONCLUSION

The coast of Mumbai which has greater range of biodiversity and a flat beach profile. Though there are many measures available for protection, the existing hard protected shores may require further strengthening due to the upcoming increase in water level due to climatic change. This can be protected and enhanced using submerged artificial reef breakwaters which disperse the wave energy and enhance the flora and fauna in the region. This would also increase the beachline and control erosion of the beach. Being environmental friendly, these are suitable to solve coastal problems with saving our ecosystem and reduce the protection cost. The case studies suggest that usage of eco-friendly measures produces significant result on the problems faced without impacting the environment. Moreover, further development of the threatened regions should be held until the issues are resolved. Further work needs to be done to identify whether more innovative techniques are suitable for the coast of Mumbai. Also, experimental and numerical investigation needs to be done in order to validate these techniques.

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