RESEARCH ARTICLE

Sea dike construction challenges in coastal waters for storage of river flood waters: a sustainable strategy for water resource development using coastal reservoirs

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Abstract: In this paper, marine civil engineering structures such as breakwater and sea dikes are discussed along with the challenges of constructing a sea dike in coastal waters close to the coast for storage of flood waters or coastal reservoirs. Here the solution in utilizing or storing the abundant monsoon water which runs off to the ocean close to the coast itself using coastal reservoirs bounded by sea dikes with suitable modifications is proposed. Sea dike is an earthen dike, often meant to prevent flooding of the hinterland and the primary function is to protect low-lying coastal areas from inundation by the sea. For creating coastal reservoirs for storing river flood waters within the shallow waters of the coast close to the point where river joins the ocean. Breakwaters and sea dikes are structures which provide protection against the wave action of the sea and provide coastal protection. The same can be suitably modified for construction of coastal reservoir dikes. Each type of structures which are being considered in the marine environment will be discussed along with their advantages and disadvantages. Construction types of the sea dike or breakwater with specific modifications and alternatives will be presented with necessary design principles and different types of structures which are feasible in this marine environment. A case study of Ennore coal project, India is briefly presented, where a construction of breakwater has been done to protect coal harbour and incoming ships. This case study will be presented in brief to highlight the need for new construction technologies for building sea dikes using geotextiles. Emerging geosynthetic materials and innovative geosynthetic applications are presented for the construction of sea dikes for the creation of coastal reservoirs.

Keywords: sea dikes, coastal reservoirs, flood waters, water resource development, geosynthetics

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1 Introduction

A sea dike is an embankment widely used to protect low-lying areas against inundation and acts as a backwater to prevent erosion of the coast and encroachment of the sea. The purpose of a sea dike is to protect areas of human habitation like towns & villages, and conservation and leisure activities from the action of tides and waves. Storage of the abundant monsoon water is done close to the coast using coastal reservoirs, which otherwise runs off to the ocean. Coastal reservoirs are bounded by these impermeable sea dikes and the coast on one side. These sea dikes with suitable modifications can be used for creating coastal reservoirs with in the shallow waters of the coast. Sea dike is a static feature and it will conflict with the dynamic nature of the coast and impede the exchange of sediment and salt water between land and sea at the mouth of rivers. Sea dikes are classified as a hard engineering shore based structure used to provide protection and to lessen coastal erosion. Sea dikes may also be constructed from a variety of materials, most commonly: geosynthetic tubes, geocells, reinforced concrete, boulders, steel, or gabions. A sea dike is also used for land reclamation projects. Sea dikes are primarily used at exposed coasts, but they are also used at moderately exposed coasts and in this case, use of sea dikes is presented for the separation of ocean salt water from the flood water from rivers stored in coastal reservoirs (bounded by sea dikes). These sea dikes can protect populated areas, economic areas like aquaculture areas, tourism places and also reduce coastal erosion. The dikes across estuarine can reduce the impacts of tides and waves from the sea and also help in reducing salt intrusion into the river course through the estuaries.

Due to erosion and accretion, the shoreline changes are natural processes that take place over a range of time scales. They may occur due to small scale events, such as storms, wave action, tides and winds, or in response to large-scale long-term events such as glaciations or cycles that may significantly alter sea levels (rise/fall) and further, tectonic activities that cause coastal land subsidence. Hence, coastlines are dynamic, and cycles of erosion are often an important feature of their ecological character. Winds, waves and currents are natural forces that easily move the unconsolidated sand and soils in the coastal area, resulting in rapid changes in the position of the shoreline. The sea dike as part of coastal reservoir actually is a boone to reduce these ill effects permanently and bring economic prosperity to the coastal areas. Here, the objective of the sea dike is to store abundant monsoon flood waters close to the coast in the ocean by replacing salt water with fresh river flood waters.

2 Sea Dike Design Aspects

Sea dike route is selected based on the basis of techno-economical reasoning after considering following points:

i) Topographic and geological conditions

ii) Master plan of the entire area development including transportation system, national security and defense

iii) Evolution of coast lines, beaches and estuaries

iv) Location of existing structures

v) Protection of the cultural, historical remains and administrative land boundaries and projects of national importance if any in that area

vi) Design of sea dike shall conform to navigation development strategy and also adaptable to the impacts of climate change

Sea dike alignment shape is also critical and it shall be designed as straight lines or smooth curves without many zigzags which can cause the local concentration of wave energy. Orientation should be favorable avoiding the perpendicular direction for the prevailing wind direction. Techno-commercial aspects are also critical in selecting the shape of the sea dike route shape. Appropriate solutions to wave attenuation or dike resistance shall be adopted by conforming with the planning of river channel system, enclosure dike system and drainage sluices in the reservoir so created.

Hydrodynamic conditions at the connection zone, waves, nearshore sediment flow, imbalance of sand transport in nearby areas, forecast of development trend of the foreshore in the future needs to be considered in designing the reservoir bounded by sea dikes. Recent topographic survey data for at least 100 m from the dike toe on either side (up to 200m in case of variability of sea bottom) along with coastline evolution in the last 20 years is needed for sea dike design. In addition, geological data which is based on actual conditions along with meteorological, hydrological and oceanographical data shall be collected for studying the impacts of typhoons and natural disasters within the project area. Further, data on existing population and development trend along with current economic condition and development orientation is needed for dike project.Environmental conditions and evaluation of the impact level of the dike on the surrounding environment in the future are needed. For these sea dikes, which are generally closer to the developed industrial urban areas, a return period of 100 years has to be used for safety standards.

3 Typical Sea Dike Cross Section Design

Items of sea dike cross section design include: crest level, cross sections dimensions, crest structure, dike body and dike toe which fulfil the technical and economical requirements. Design cross sections of the dike are selected on the basis of geological conditions, materials used for the construction of dyke, filling materials, external forces, layout of the dike and also the operational requirements. Sloping dikes, wall-type dikes and composite dikes are three different types of sea dikes based on geometrical shape. One needs to carefully design the dike crest level, dike body, filter layers, slope protection layers (both on sea side and land side/coastal reservoir side), toe protection. There is a different usage of sea dikes and mainly it reduces the amount of energy dissipated by the waves reaching the coastlines. It also protects the coastline from the tidal action and provides coastal defense. Further, it prevents the erosion of the coastline and creates a calm water in the coastal reservoir area for many activities. Most important function of the dike, in this case, is to separate the salt water and the freshwater in the coastal reservoir and also allow freshwater fishing and other activities in calm water conditions and it can also provide dock or quay facilities along with the support of floating solar panels for energy production.

The main features of the sea dike can be seen in Figure 1. Figure 2 shows the different sea dike cross sections such as sloping dikes, wall-type dikes and composite dikes with geometrical shapes.

The energy of the waves approaching is partially destroyed by breaking, partially reflected, and partially expended in run-up on the sea side. The wave height, water depth, and wave period determine the initial wave steepness. It is obvious that a more complicated situation exists when irregular waves are involved. If the crest elevation is lower than that corresponding to maximum run-up, then up-rushing water will spill on and over the crest of the structure. The usual unit of measurement of overtopping is volume per unit time and crest length. This quantity of overtopping is sometimes used as damage criteria for sea dikes and this is the critical design aspect in the sea dikes for coastal reservoirs. This is not permitted in this case for coastal reservoirs. The variety of armor unit shapes are available and no single type of armor unit is universally acceptable for all applications. Quarry stone armor is usually cheapest per ton but a larger volume is needed than when concrete units are used. It is advantageous to limit the area covered by primary armor units as much as possible consistent with the stability needs. Filter layers are the important layers of a rubble mound breakwater which serve to prevent excessive settlement of the structure. This is accomplished by hindering the erosion of bottom material by water moving through the pores of the breakwater. Thus, filter construction is the most necessary, when the natural bottom consists of easily eroded material such as fine sand.

4 Impermeable Sea Dike for Coastal Reservoir

A freshwater reservoir located in the sea close to the mouth of a river is bounded by sea dike to store required quantity of river flow/flood water. Flood water is a natural resource, and water quality is more closed to drinking water. Sea dike which bounds the coastal reservoir shall be impermeable so that salt water on the sea side does not mix with the fresh water stored.

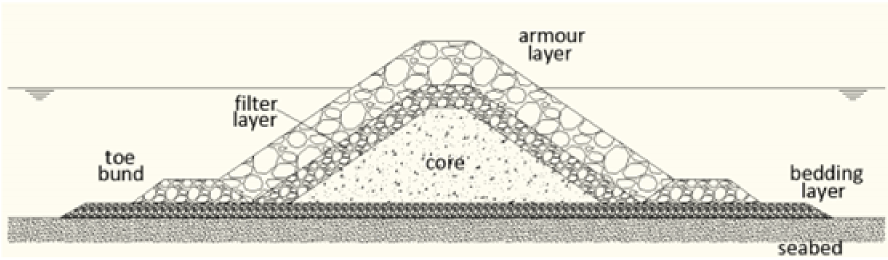

Figure 1. Typical features of sea dike

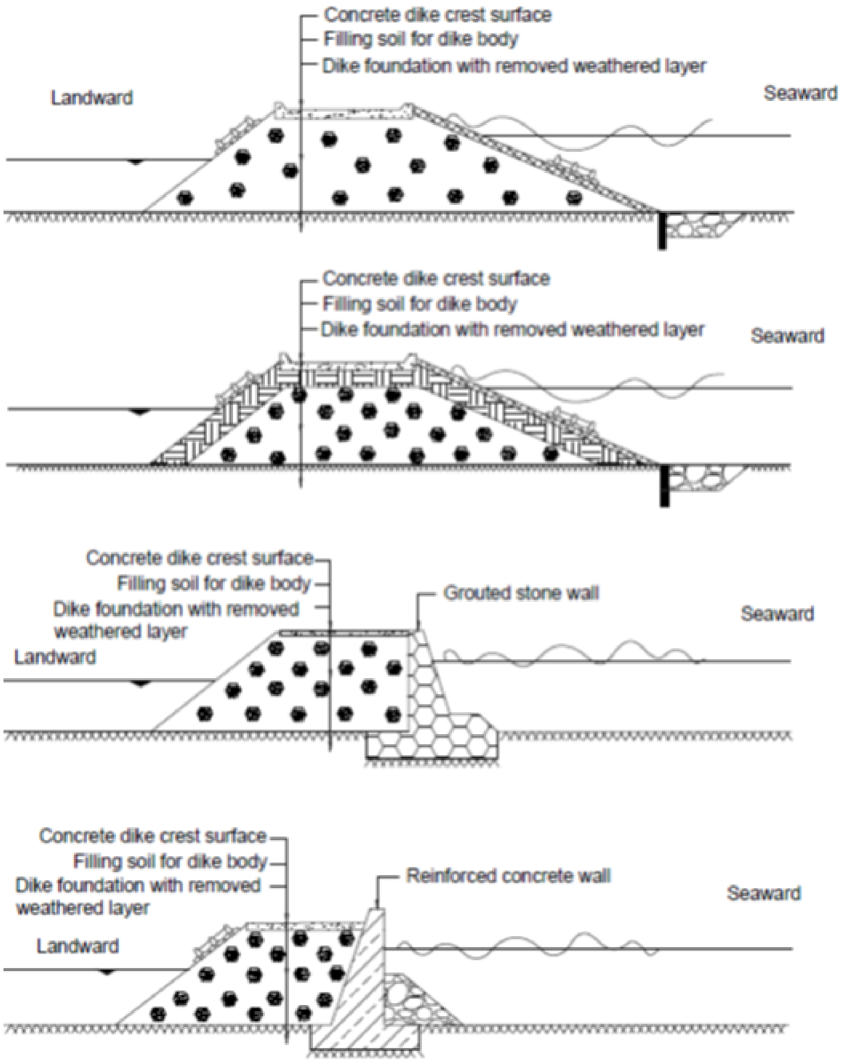

Figure 2. Different types of sea dike cross sections

in the coastal reservoir. The walls/wall with barrier lining is so designed that it will prevent mixing of surrounding sea water with the impounded flood water. An effective impermeable barrier between the fresh water (flood water) and the salty sea water is needed to do the following. Separation of clean river water from salt water. Protection of collected fresh water against external pollution. Prevention of salt water intrusion into the stored fresh water. A typical cross section of the sea dike for the coastal reservoir is suggested in Figure 3, as shown below.

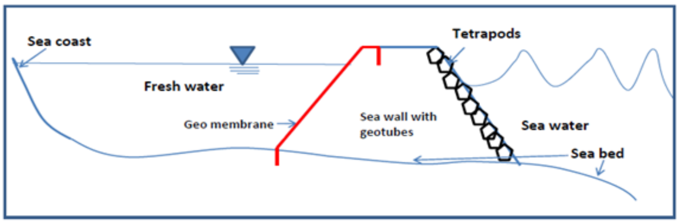

Figure 3. A typical impermeable sea dike for the coastal reservoir (Thallak G Sitharam (2016))

Further development (after Yang, 2016) has been the one using soft dam to separate fresh water from salt water or brackish water in the buffer zone. This is a patented technology of soft dam coastal reservoir by Yang and Lin (2011) [Ref: Yang et al 2013]. Soft dams will be built using a membrane at the river mouths to uphold the river runoff lost to the sea in front of the primary barrier. This provides an additional safety against mixing of salt water into freshwater stored. To be effective as a soft dam, the motions of a floating structure holding the membrane must be of small amplitude so that the structure does not generate waves into the protected harbor side. Thus soft dam has to be protected a primary barrier such as a breakwater or a sea dike. Although at resonance the oncoming waves can be out of phase with the transmitted waves (resulting in lower coefficients of transmission), the structure must respond to a spectrum of incident wave conditions. Hence, the design of a floating structure for resonance characteristics is possible behind a primary barrier given the wide spectrum of ocean waves.

Table 1 shows the list of some of the coastal reservoirs constructed across the world. Sea dikes are constructed to a total of

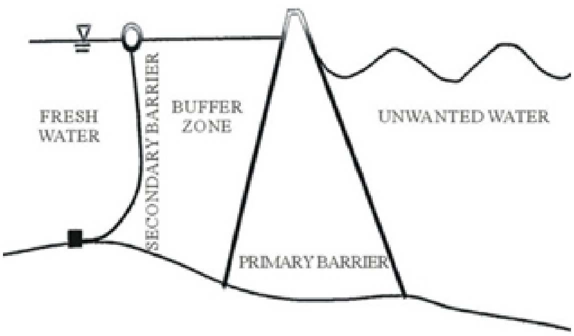

Figure 4. Soft dam concept by S Q Yang, et al., (2005)

43 km in Qingcaosha reservoir in China. However, the longest sea dike constructed in Saemanguem bay is 33.9 km (slightly longer than the one Afsluitdijk causeway in Netherlands). One can clearly see that construction of sea dikes for coastal reservoir is not new and good experience exists across the world including the oldest sea dike in Netherlands as early as 1932 (Afsluitdijk causeway constructed between 1927 -1932 between Wadden sea and freshwater lake of Ijssemeer).

5 Current and Future Development of Geotextiles in Coastal Constructions

Geosynthetics and geotextiles have contributed to many new innovations in Geotechnical engineering, which comprises of new textile products used in geotechnical applications pertaining to soil, rock or earth. This class of products is loosely called as Geotextiles and they refer to flat, permeable, polymer-synthetic or natural textile materials which can be non-woven, woven, knitted or knotted textile materials. They are used in contact with soil or rock in civil engineering earthworks and building constructions. In fact, geotextiles is one of the members of the geosynthetic family which comprises of geogrids, geonets, geotextiles, geomembranes, geosynthetic clay liners, geopipes, and geo-composites. The conventional coastal structures (i.e., breakwater, groins, revetment, and seawalls) have been constructed using wood, rock, and concrete materials in earlier days and still being constructed that way. The recent consideration of environmental approaches and the limited resources of natural rocks in certain regions led to an increase in the application of geosynthetics in coastal protection and coastal structures. The design of new, cost effective shore protection structures as well as for the repair of restoration of existing threatened coastal barriers and structures involves geotextile materials effectively. This has been done even for dune reinforcement and scour protection measures. Geotextiles are more versatile materials and innovative solutions in recent days which are economical and also supplement the conventional methods.

Problematic soils in shallow subsea in particular soft and liquefiable soils to support the dike and ground improvement of these materials is inevitable. Bearing capacity improvement, settlement reduction, long term liquefaction resistance is some of the critical aspects one has to deal under severe coastal conditions for dike construction. Mechanical modification (compaction, blasting, dynamic compaction), hydraulic modification (grouting), physical (stone columns, micropiles, jet grouting, Geosynthetics)& chemical modification (admixtures, soil cement, freezing, dewatering) along with inclusion and confinement (reinforcements, geotubes, geotextile tubes, geofabrics, geogrids, etc) or combination of the above is available for the use of development of foundation of sea dikes. Development of new machinery, barges for the construction of sea dikes are already available. In particular, for foundation improvement new construction materials like geosynthet-

Table 1. Coastal reservoirs dike length and capacities

Coastal reservoir name	Catchment (km^2)	Dike length, km	Capacity (million m^3)	Year completed	Country / river
Qingcaosha	66.26	43	435	2011	China/Yangtze
Saemanguem	332	33.9	530	2010	South Korea
Silhwa	56.5	12.4	323	1994	South Korea
Marina Barrage	113	0.35	42.5	2008	Singapore
Yu Huan	166	10.80	64.1	1998	China/Zhejiang
Plover Cove	45.9	2	230	1968	Hongkong

ics in particular geotextiles, geotubes, geocells are available and emergence of better guidelines for determining the suitability of specific t echniques f or c ertain t ypes o f c oastal conditions and soils/site conditions is neceessary. In todays context, we have better understanding of the geotechnical and marine processes involved and appreciation of the significance of construction sequence and challenges in the difficult conditions. Refinement of methods of analysis and computer modeling technique provides a better option for engineered solutions for dike construction for coastal reservoris. Advances in the techniques of performance evaluation of the modified ground conditions, advance geotechnical and geophysical techniques put us in better spot in designing, constructing and maintaining these sea dikes under different enviornments. Due to sea or river current, fine s oils o f t he b ank s tart m igrating causing erosion. Conventional design of cementing the banks is not a solution due to hydraulic pressure of the soil. Only feasible solution is the application of geotextiles or geosynthetics. Geotextiles allow water to pass through but resist the fine soil migration. Geotextile tubes are made of high-strength geosynthetic fabrics that enable the water to flow t hrough p ores retaining sand materials that have been used for the filling.

Figure 5. Breakwater constructed in New Ennore coal project (http://www.ennoreport.gov.in/)

6 Breakwater Constructed in India for the New Ennore Coal Port Project

The primary purpose of the new coal port at Ennore in north of Chennai city in Tamilnadu, India is for the importation of coal for the north madras thermal power station and other power stations in south Indian region. Eastern coast is subject lot of storms and cyclones during monsoon and also the littoral drift creates a sand transport along the coast more when compared to the west coast of India in Arabian sea. Two new break wa-ters have been constructed to create the port on this coast at Ennore coal port project. The breakwater consists of south and north breakwater, which are of lengths 1040 m and 3070 m re-spectively, out of which the north breakwater is considered to be the longest in India. The rocks were supplied from a quarry (karikkal) 125 km away. The Karikkal quarry is a virgin nar-row and high hill rocks interspersed by layers of murrum and other soft material making quarrying of rock difficult. Special-ized and controlled drilling and blasting was used to get vari-ous rock sizes (1 kg to 18 tons). Specially fabricated steel skips of 20 tons capacity were loaded on trucks/trailers for transport-ing rocks to a railway siding 25 km away, and loaded in railway wagons by gantry. Each railway wagon carried 3 skips and travelled 100 km away carrying 1800 tons of rock and unloaded at a specially designed stacking area near the breakwater to hold up to 1.5 million tons of rocks. The total quantity of rock required for the two breakwaters is about 3 million tons having seven grades of rock from 1 kg to 18 tons to form the quarry run, filter layer, toe layer, and the armor layers, etc. One could have used the geotextiles very effectively in this project.

7 Conclusion

Sea walls constructed for storage of flood w aters w ill b e a remedial measure for an increasing hazard to the coastline and provides protection against the wave action of the sea and in addition to store river flood w aters i n c oastal reservoirs. Coastal reservoirs use the sustainable storm flood waters which are reasonably cleaner. This will emerge as a sustainable strategy for water resource development in the coming years. Emerging geosynthetic materials and innovative geosynthetic applications are essential for the construction of sea wall dikes. Construction of coastal reservoirs using sea dikes will increase the use of innovative materials and new construction techniques are required to build these sea dikes to safely harvest the river flood waters.

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