A Report on

MANAGEMENT OF TIDAL INLETS ALONG WEST COAST

Guidance By

Integrated Coastal and Marine Area Management – Project Directorate (ICMAM-PD)

Ministry of Earth Sciences, Govt. of India

Local Implementing Agency

NATIONAL INSTITUTE OF TECHNOLOGY KARNATAKA

Surathkal, Srinivasanagar – 575 025

JUNE-2007

PREFACE

Mangalore city is situated in the South West Coast of Karnataka State. Mangalore is surrounded by Gurupur and Netravathi rivers. These rivers join to form an estuary at south of Mangalore and empty into Arabian Sea. There are two spits: Ullal spit to the south and Bengre spit to the North of the estuary.

Severe coastal erosion is taking place since 1996 during the monsoon seasons along the coastal stretches of Kotepura in Ullal town of Mangalore Taluk of Dakshina Kannada District in Karnataka State. The site of erosion is a spit over a length of 1.5 Km on the southern side of the Gurupur – Netravathi river estuary. This estuary is fortified with two breakwaters on either side which are in place since 1994. This erosion has shown greater proportions threatening to open another mouth to river Netravathi along the stretch of Ullal spit in the months of July/August, 2000 during South West Monsoon.

It was understood that the many factors such as breakwaters, wave onslaught, the monsoon water discharge through the estuary, tides, currents, decreased sediment load from the land and ground water discharge might be playing major roles in the massive scale erosion of Ullal Spit. Some solutions including rubble mound revetments and Gabion Revetments have been put in place but have not yielded useful results for shore protection. Hence, a need for detailed investigations was felt.

Initially, in 2001 a project proposal to investigate the above problem was jointly submitted to Ministry of Earth Sciences (the then Dept. of Ocean Development), GoI by National Institute of Technology Karnataka (NITK) Surathkal and National Institute of Ocean Technology (NIOT) Chennai. Later, in October 2003 the above project under the title of “Management of tidal inlets along West Coast” was sanctioned (vide letter no. DoD/ICMAM-PD/51/2002 dated 22-10-2003) independently to NITK, Surathkal with the financial and technical support from ICMAM – PD Chennai under

MoES, GoI. Dr. Subba Rao, Assistant Professor in the Dept. of Applied Mechanics took the responsibility of the Coordinator and Principal Investigator of the project and co-opted Dr. Kiran G. Shirlal, Assistant Professor in the Dept. of Applied Mechanics as Joint Coordinator, Dr. G. S. Dwarakish, Assistant Professor in the Dept. of Applied Mechanics and Sri. K. Subrahmanya, Lecturer in the Dept. of Applied Mechanics as Investigators. Later, Dr. Subba Rao also co-opted the services of Dr. J. Dattatri and Dr. N. B. S. Rao, Retd. Professors of NITK, Sri. M. M. Kamath, Retd. Chief Engineer, NMPT and Dr. B. Nagendra Kumar, Deputy Director of NIOT, Chennai as Advisors for the project.

The project was commenced during January 2004 and completed on 30th June 2007. During the project duration, data regarding environmental and oceanographic parameters in and around Netravathi-Gurupur river mouth has been collected using state-of-the art instruments. The method of data collection and observations have been frequently discussed in the progress review meetings held from time to time and the suggestions offered have been duly incorporated. The mathematical modeling using the data has been done at ICMAM-PD, Chennai using MIKE 21 software.

The final results were also presented before an expert review committee chaired by Prof. V. Sundar, IITM, Chennai held on 2nd May 2007. During the above meeting, the committee made observations on some aspect of the study presented as a draft report during the meeting. All the observations made by the committee have been incorporated and the draft report has been revised accordingly.

The final report is compiled as a hard copy and a soft copy consisting of two volumes where the analysis and results are presented in Volume 1 and is made available as a hard copy while Volume 2 consists of the entire data collected as a softcopy.

PROJECT TEAM

Dr. B. R. Subramanian	- Project Director
Sri. R. S. Kankara	- Project Coordinator

Investigators

Dr. Subba Rao	- Principal Investigator and Coordinator
Dr. Kiran G. Shirlal	- Joint Coordinator and Investigator
Dr. G. S. Dwarakish	- Investigator
Sri. Subrahmanya K.	- Investigator

Project Staff from ICMAM

Dr. Manjunath Bhat	- Research Associate
Sri. Edwin Rajan	- Technical Assistant
Sri. Panchachalam	- Junior Research Fellow

Project Staff from NITK

Sri. Radheshyam B.	- Senior Research Fellow (Jan 2004 – Jun 2007)
Sri. Govindaraja K. R.	- Junior Research Fellow (Jan 2005 – Jun 2007)
Sri. Deepak V. Sanil	- Helper (Feb 2004 – Jun 2007)
Sri. Mahaganesha K.	- Junior Research Fellow (Jan 2004 - Apr 2006)
Sri. Satisha	- Junior Research Fellow (Jan 2004 - Dec 2004)
Sri. Sudhir Kumar	- Project Assistant (Jan 2004 - Aug 2004)
Sri. Deepak Chandra	- Project Assistant (Aug 2004 - Oct 2005)

Advisors of the Project

Dr. J. Dattatri	:	Retd. Professor, Dept. of Applied Mechanics, NITK, Surathkal
Dr. N. B. S. Rao	:	Retd. Professor, Dept. of Applied Mechanics, NITK, Surathkal
Sri. M. M. Kamath	:	Retd. Chief Engineer, New Mangalore Port Trust, Mangalore
Dr. B. Nagendra Kumar	:	Coastal Engineering Consultant, Chennai

ACKNOWLEDGEMENTS

The project coordinator and investigators express their deep sense of gratitude to the Integrated Coastal and Marine Area Management - Project Directorate (ICMAM-PD), Ministry of Earth Sciences, Government of India, for sanctioning the project, releasing the grant in time and extending the project period together with the required additional financial support. The timely guidance and help rendered by Dr. B. R. Subramanian, Project Director, ICMAM, Sri. R. S. Kankara, Scientist-D, ICMAM and Sri. M. V. Ramanamurthy, Scientist-E, ICMAM are greatly acknowledged. The efforts, help and co-operation wholeheartedly extended by the Scientists and Officers of Ministry of Earth Sciences, New Delhi and ICMAM-PD, Chennai are highly appreciated.

It is a great pleasure to thank the Directors of NITK-Surathkal, during the tenure of the project for their timely suggestions and for allowing us to make use of various facilities of the Institute. We thank the Head of the Civil Engineering Department for all his help and co-operation during field survey work.

Several Governmental departments and agencies like Karnataka Engineering Research Station, Sub-Division, Mangalore, Port & Fisheries Department, Karwar and Mangalore and New Mangalore Port Trust, Mangalore have helped us during field investigation. We express our sincere thanks to all of them.

We are extremely thankful to Sri. Umanath Udyavar and his team who have helped us in conducting the oceanographic measurements which is the major exercise of this project.

The Registrar and Deputy Registrar (Accounts) have helped us in all administrative and accounts matter and hence are indebted to them.

Coordinator and Investigators are highly indebted to Prof. Lakshman Nandagiri, the present H.O.D. and Prof. S.G.Mayya and Prof. A. Vittal Hegde, former HOD's, Department of Applied Mechanics and Hydraulics, N.I.T.K. Surathkal, for their valuable advises, co-operation and help rendered in innumerable ways during the course of the work.

The Coordinator and Investigators acknowledge their heartfelt gratitude to Dr. J. Dattatri, Dr. N. B. S. Rao, Sri. M. M. Kamath and Dr. B. Nagendra Kumar for being the Advisors of the project and also for their timely guidance and encouragement.

The invaluable inspiration and help of the esteemed colleagues of the Department of Applied Mechanics, NITK, Surathkal are sincerely acknowledged with gratitude.

The Coordinator and Investigators wish to express their special thanks to Sri. C. Dinesh, Steno-D, ICMAM for his the overall support.

Sri. Jagadish, Foreman, showed keen interest during the field studies and helped the authors immensely. Sri. Seetharama, Sri. Ananda Devadiga, Sri. Gopalakrishna, Sri. Padmanabha Achar, Sri. Vasanth Sanil and Sri. Srikanth F.B. have helped the authors during various aspects of the project. Without their interest and support it would have been difficult to complete the project. The authors ever remember their timely help and encouragement.

Finally, the Coordinator and Investigators wish to thank one and all who have contributed to the successful completion of the project.

Date: 30th June 2007

(Subba Rao)
Principal Investigator

CONTENTS

1

INTRODUCTION

1
INTRODUCTION

1.1 General Information

The district of Dakshina Kannada (Mangalore) of Karnataka State is situated on the western coast of India, about half way between Bombay and Kanyakumari. From North to South, it is a long narrow strip of territory and from east to west it is a broken low plateau, which spreads from the Western Ghats to the Arabian Sea. The area is intersected by many rivers and streams and presents a varied and most picturesque scenery.

Dakshina Kannada is the southern coastal district of Karnataka State with an area of 4866 sq. KM. The district lies between 12°57' and 13°50' North Latitude and 74°00' and 75°50' East Longitude. It is about 177 kms, in length and 40 kms in breadth at its narrowest and about 80 kms at its widest part. It has a population of 18,97,730 with a density of 389 per square KM.

The district spreading from the Western Ghats towards the Arabian Sea to the west, is bounded by Udupi district in the North, Shimoga, Chickmagalur and Hassan districts in the East, Arabian Sea in the west, Coorg district and Kasaragod District of Kerala state in the south.

The district can be divided into 3 belts, the coastal strip, the middle belt and the Western ghat section. An interesting feature of the coastal strip and the middle belt is that, it is not a plain but a series of estuarine low lands separated by numerous hill ranges projecting as the extension of Western Ghats. The coastal tract is the most thickly populated part of the district, as it is fertile, has better communication facilities and increased commercial activities. The middle belt consists of hills and valleys and forms into an undulating terrain. The valleys are fertile and boast of several farms of arecanut and coconut, and paddy fields, which are the main crops of the district. The

Western Ghats form the eastern boundary of the district consisting of evergreen forests with patches of paddy fields, arecanut farms and the tea gardens scattered here and there.

The climate of the district shares the wider climatic pattern of the other West Coast districts of India. It is characterized by excessive humidity (78%) during the greater part of the year. There are four seasons viz., 1) Four wet months of June, July, August and September, when the district encounters strong winds, high humidity, heavy showers and a slight fall in temperature. 2) Two warm and damp months of October and November when south west monsoon is retreating. 3) Three cool months of December, January and February when generally dry conditions prevail and 4) Three hot months of March, April and May which is the period of rising temperature. Climate in the district is generally equable with temperature ranging between 21 to 36°C. However, it is colder in the interior than in the coast.

The important rivers of South Kanara District are 1) Suvarna 2) Shambavi (Mulki) 3) Gurpur River 4) Netravathi 5) Pavanje 6) Nandini. Besides there are many other small rivulets and a number of streams, all running from east to west.

1.1.1 Mangalore

Mangalore (Lat:12°51'39"N Long:74°50'08"E) is the chief port city of the state of Karnataka, India. It is situated on the west coast of the country with the Arabian Sea on the West and the Western Ghats to the east.

Mangalore is the administrative headquarters of the Dakshina Kannada (South Kanara) district in the southwestern corner of Karnataka, and developed as a major port along the West Coast of India. Lying on the backwaters formed by the Nethravathi and Gurupur rivers, it has long been a roadstead along the Malabar Coast.

Mangalore is known for its beaches, temples and industries. There are several languages spoken there, including Tulu, Konkani, Kannada, and Beary (somewhat of a mixture of Tulu and Malayalam).

The landscape is dominated by the characteristic coconut palms accompanying rolling hills and streams flowing into the sea. The landscape is dotted with tiled-roof buildings, topped with the famous Mangalore tiles made with the local hard red clay and typically walled with laterite blocks. Older houses are commonly found with elaborate wood-work.

Mangalore's economy is dominated by agricultural processing and port-related activities. Mangalore is home to the automobile leaf spring industry. Currently there are about six or seven units producing about one thousand metric tonnes of leaf springs per month catering to the south Indian market.

The International terminal of Mangalore Airport with night landing facilities, located near Bajpe, around 20km north-east of the city centre, was commissioned on 10 May 2006. At present, daily flights are available to Mumbai, Bangalore and Chennai, and triweekly flights to Dubai are currently operational.

Three National Highways pass through Mangalore connecting the city to the rest of the country. NH-17, which runs from Panvel (in Maharashtra) to Cranganur Junction (near Edapally in Kerala), passes through Mangalore in a north-south direction, while NH-48 runs eastward to the state capital Bangalore (Now known as Bengaluru since 1st Nov 2006). NH-13 runs north-east from Mangalore to Sholapur, and a state highway connects it to the city of Mysore passing through the hill town of Madikeri. There are about 300 buses from Bengaluru to Mangalore on daily basis. Mangalore is well connected to the rest of the country through railways and airways.

Currently this cluster of highways is inadequate to handle the traffic that flows through the region, resulting in a NHAI has decided to upgrade the national highways connecting New Mangalore Port to Surathkal on NH-17 and B.C. Road junction on NH-48. Under the port connectivity programme of the National Highway Development Project (NHDP), a 37.5km stretch of these highways will be upgraded from two-lane to four-lane roads.

The Mangalore Railway Station used to be the last station connecting Mangalore to the state of Kerala in the south and to the rest of the country. The broad gauge track connecting Mangalore to Bangalore via Hassan is open for freight traffic since May 2006. Movement of passenger traffic will start after January 2007.

Since 1997, broadgauge railway line known as Konkan Railway connects Mangalore with Mumbai is fast becoming a popular cargo movement track with railways introducing a Ro-Ro facility for trucks.

The New Mangalore Port Trust was dedicated to the nation during 1975 and since then the Port has been functioning as a catalyst for the economic development of this region and cater the needs of the shippers. Over the years, the Port has grown from the level of handling less than a lakh tonnes of traffic to 34.45 MT handled during 2005-06.

The Mangalore Harbour provides a connection by sea to the rest of the world. Currently dry, bulk and fluid cargos are handled by the New Mangalore Port, providing an important gateway to the state of Karnataka. It is also the station for the Coast Guard. The modern port which is 10 km to the north of city centre, is India's ninth largest cargo handling port.

The major commodities exported through the Port are Iron Ore Concentrates & Pellets, Iron Ore Fines, POL Products, granite stones, containerised cargo, etc. The major imports of the Port are Crude and POL products, LPG, wood pulp, timber logs, finished fertilizers, liquid ammonia, phosphoric acid, other liquid chemicals, containerized cargo, etc.

Major information technology and outsourcing companies have started locating their facilities in Mangalore. IT major Infosys was one of the first to move in and establish a large presence followed soon after by Wipro. Outsourcing major MPhasis BPO was one of the first outsourcing companies to set up their facilities near the city. Many more such projects are in the pipeline.

The Oil and Natural Gas Corporation (ONGC) plans to invest over Rs.35,000 crore in a new 15 million tonnes refinery around MRPL and power and LNG plants at the Mangalore Special Economic Zone. This will be the first Petroleum, Chemicals, Petrochemicals Investment Region (PCPIR) of the country.

Banks such as Corporation Bank, Canara Bank and Vijaya Bank, Syndicate Bank and Karnataka Bank were established in the erstwhile D.K. district during the first half of the 20th century. Out of these, all banks are nationalized except the Karnataka Bank. Mangalore is also the home to the cooperative movement in the Country which has got highest number of cooperative societies and banks serving the people in general and farmers and agriculturists in particular.

Mangalore developed as a fishing town and this has been maintained to this day, with the local diet maintaining a high proportion of fish. The fishing industry employs thousands of people. Some of their produce is exported.

Mangalurean firms have had a major presence in the tile, beedi, coffee and cashewnut industry, although the tile industry has been in decline due to the predominance of concrete in the modern construction.

1.1.2 Ullal Area

Ullal (Lat: 12°49'09"N Long: 74°50'29"E) is a muncipal town in Dakshina Kannada district Karnataka state. It is a small town about 10km south of Mangalore city close to the border between states of Karnataka and Kerala. It has an average elevation of 5 metres above MSL.

It is very famous for historic locations like Someshwara Temple, Summer Sands Beach Resort and Queen Abbakka's Fort at Ranipura. The remains of Rani Abbakka's fort can be seen in the vicinity of Someshwara Temple. This quaint little sea town on the shore of Arabian Sea was the setting for wide scale sea-erosion that occurred in the late 1990's and early this millennium. The local authorities however have tried to reduce the damage by placing sand bags and revetment of dumped stones as an emergency measure to contain the retreating coastline.

As of 2001 India census, Ullal had a population of 49,862. Males constitute 49% of the population and females 51%. Ullal has an average literacy rate of 73%, higher than the national average of 59.5%: male literacy is 77%, and female literacy is 69%. In Ullal, 13% of the population is under 6 years of age. Most of the people are fishermen who have built their dwelling units and coconut farms on the beach ridge which falls under the CRZ. In addition to this, many fish related industries such as fish oil extraction, fish processing and exporting, fish manure industries are located very close to the beach. During the monsoon and rough sea conditions, the waves lash directly on to the houses and the industries. This has left inadequate space to put any designed permanent anti-erosion structural measures in place and even temporary/emergency anti-erosion works do not function up to the mark.

1.1.3 Bengre Area

Bengre (Lat:12°51'6"N Long:74°49'43"E) is a fishing village located in the coastal area of Dakshina Kannada District in Karnataka which is a small sand spit of about 8 Km in length with Gurupur river on one side and Arabian sea on the other, adjoining

Mangalore town. It is a ward of the Mangalore municipal corporation (MCC). The population of 1050 households is mostly from the fishing community. Bengre is an exotic place where nature is at its stupendous best.

Prior to 1993, Bengre was suffering from severe erosion which was arrested by building a seawall. Later in 1994, the two river training jetties in the form of breakwaters were built on the Gurupur-Netravathi river estuary to facilitate natural bypassing of accumulated sediments and maintain the entrance to the old Mangalore port without dredging. After this, the accretion commenced resulting in wide and stable beaches on the North of northern breakwater, i.e; Bengre.

1.2 Problem of erosion along the Mangalore coastline

Severe coastal erosion is taking place since 1996 during the monsoons along the coastal stretches of Kotepura in Ullal town of Mangalore Taluk of Dakshina Kannada District in Karnataka State. The site of erosion is a barrier spit over a length of 1.5 Km connected to main land at one end. The other end of this spit is free to migrate as a part of changes in shoreline around river mouth. Similarly, the northern spit, known as Bengre spit runs parallel to the mainland with one end connected to land and the other end is free to migrate as a part of river mouth. Gurupur River also joins this mouth running from north adjacent to Bengre Spit.

Historically, this river mouth was found to migrate with oscillating positions. When siltation at the mouth was disrupting the navigability of fishing boats, two rubble mound breakwaters (river training jetties) were built on either side of the mouth of the rivers in 1994. Subsequent to these constructions, the erosion at Ullal and accretion at Bengre has been observed.

2

COASTAL ENGINEERING PROBLEMS AND MITIGATION MEASURES

2
COASTAL ENGINEERING PROBLEMS AND MITIGATION MEASURES

2.1 Introduction

The coasts, or shores, of the world are the margins separating the 29 per cent of the earth that is land from the 71 percent that is water. Coastal Zone shown in Fig.2.1 refers to the zone where the land meets the sea, a region of indefinite width that extends inland from the sea to the first major change in topography with bays, lakes and estuaries included. Coastal zone is thickly populated with more than 60% of the world population living within 200km from the coast. Thus coastal hazards such as cyclones, tsunamis, floods and erosion threaten vast majority of life and property.

Shorelines are subject to a broad range of processes, geology, morphology, and land usages. Although winds, waves, water levels, tides and currents affect all coasts, they vary in intensity and relative significance from one location to another. Variations in sediment supply and geological setting also add to the above processes (CEM, 2006).

Coastal erosion is a process occurring worldwide in about *20% of the coasts where 60% of these are sandy beaches*. Many studies have discussed the causes of erosion, in the short and long temporal and spatial scales. Erosion usually results from the combination of multiple factors interacting along the coast. However, regardless of the time and spatial scale, coastal erosion is essentially a consequence of sea level rise and/or negative sediment budget. The increasing interest on coastal processes and shoreline changes reflects the intensification of coastal occupation and beach use, as well as the growing economic importance of beach-related activities.

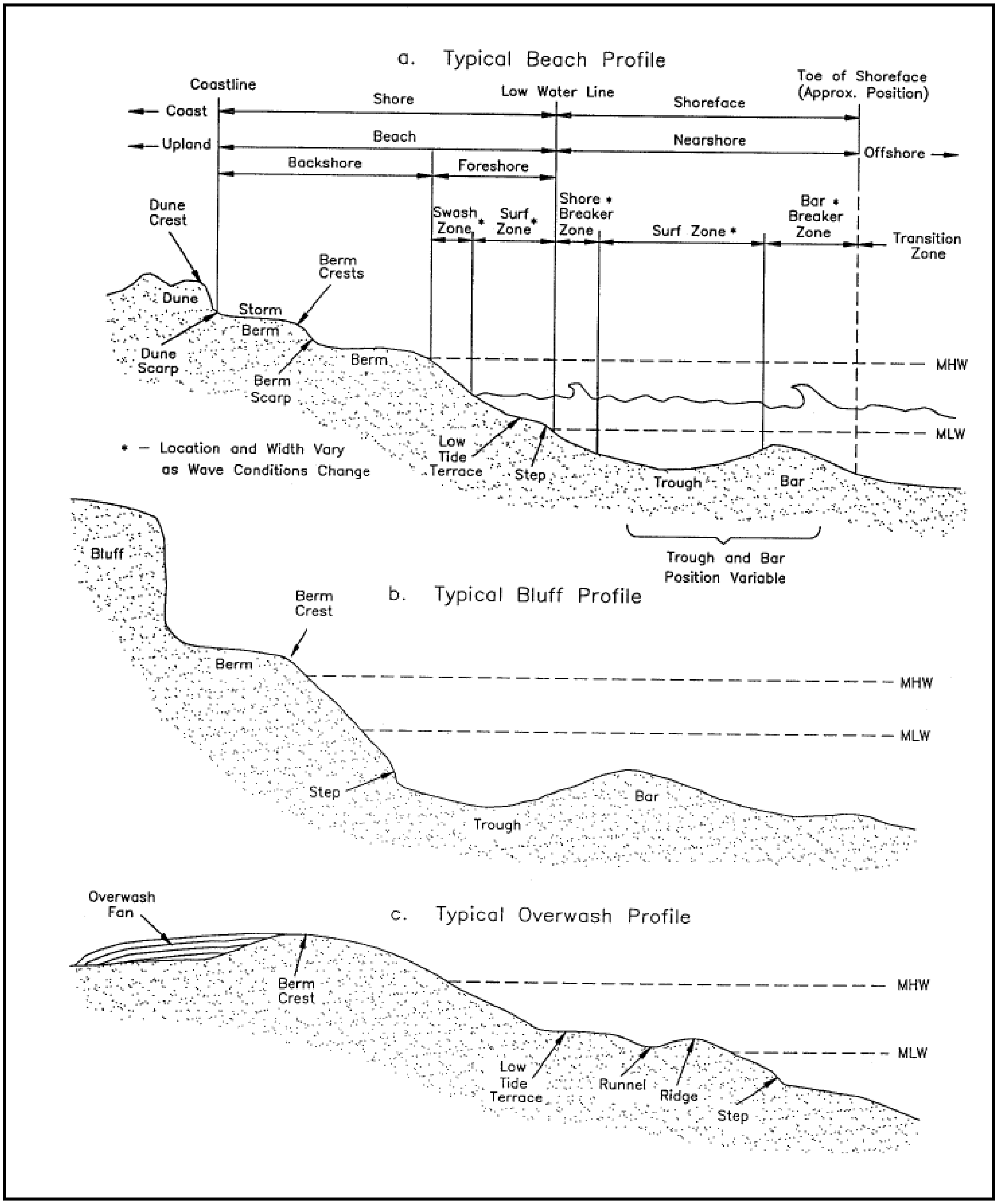


Fig. 2.1 Definition sketch of Coastal Zone *(Courtesy: CEM 2006)*

Most ancient coastal efforts were directed towards port structures, with the exception of a few places where life depended on coastline protection. The sea defenses (hydraulic and military) at Venice and its lagoon were necessary for the survival of the narrow coastal strips, and impressive shore protection works built by the Venetians are still admired. Old breakwaters built by Romans are surviving even after

2000 years (Franco 2001). Very few written reports on the ancient design and construction of coastal structures are available. The history of coastal structures (breakwaters) can be traced to 2000 to 3000 B.C. in Egypt and Myceanae, old name of modern Greece (Tanimoto and Goda 1992). But the proof of construction of breakwaters was unearthed by Jacques Cousteau in late 1970's. He discovered the under water remains of Minoan breakwater, which was 4000 years old, while searching for lost city of Atlantis (Price, 1978). Greek and Latin literatures by Herodotus, Josephs, Suetonius, Pliny, Appian, Polibus, Strabo, and others provide limited descriptions of the ancient coastal works. They show the ancients' ability to understand and handle various complex physical phenomena with limited empirical data and simple computational tools. They understood such phenomena as the Mediterranean currents and wind patterns and the wind-wave cause-effect link (CEM, 2006). The Romans are credited with first introducing wind roses (Franco, 1996).

Coastal engineering is one of several specialized engineering disciplines that fall under the umbrella of civil engineering. It is a composite of many physical science and engineering disciplines having application in the coastal area. It requires the rational interweaving of knowledge from a number of technical disciplines to develop solutions for problems associated with natural and human induced changes in the coastal zone, the structural and non-structural mitigation of these changes, and the positive and negative impacts of possible solutions to problem areas on the coast. Coastal Engineers may utilize contributions from the fields of geology, meteorology, environmental sciences, hydrology, physics, mathematics, statistics, oceanography, marine science, hydraulics, structural dynamics, naval architecture, and others in developing an understanding of the problem and a possible solution.

Coastal science is a suite of interdisciplinary technologies applied to understanding processes, environments, and characteristics of the coastal zone. Coastal Engineers use these understandings to develop physical adaptations to solve problems and enhance the human interface with the coast.

This chapter presents an overview of coastal processes, various coastal problems, their forcing factors and analysis and also briefly describes the various alternative methods of coastal protection as available in literature.

The term ''coastal engineering,'' as discussed in this report, has been limited to the inner continental shelf and near shore zone, ranging from water depths that are just within the zone of wave shoaling to the shoreline, where the energy from these waves is dissipated and the rivers and estuaries where the tidal influence significantly affects the coastal processes.

2.2 Coastal Processes

Coastal processes involve waves, tides, currents and sediment movement in the coastal waters and their influence on shoreline and inlet configuration. These factors are mainly responsible for the erosion and accretion of beach sediments. This is further assisted by the beach sediment characteristics, beach slope, variation in ground water table and human intervention.

2.2.1 Types of Beaches

In general there are three types of beaches, i.e; pocket, mainland and barrier beaches. Beaches are composed of loose sediment particles, ranging in grain size from fine sand to large cobbles.

Pocket beaches form between erosion-resistant headlands and are usually quite small. Because the sediment that constitutes pocket beaches is trapped by adjacent headlands, these beaches respond to prevailing waves; there is little movement of littoral sediment to or from adjacent beaches.

Mainland (also called strandplain) beaches are the most common type along the Pacific coast and on the Great Lakes, where the adjacent bluffs often are over 100 feet high. These beaches develop anywhere that ample sediment supply allows for accumulation along the shoreline. The beach usually is derived from the adjacent erodible cliff material. Slope instability is a major concern along erodible mainland coasts. Slope instability is largely controlled by the local geology, water level, wave action and ground water movement.

Barrier beaches are perhaps the most commonly found dynamic coastal land masses along the open-ocean coast. Barrier beaches can extend continuously for 10 to 100 miles, interrupted only by tidal inlets. Physically separated barrier islands often are linked by the longshore sediment transport system, so that an engineering action taken in any one beach area can have major impacts on adjacent downdrift beaches. Barrier islands are typically low lying, flood prone, and underlain by easily erodible, unconsolidated sediments. Thus, these land forms are especially difficult to develop because they are so dynamic.

2.2.2 Beach Processes-The Natural System

Natural beaches are formed by the accumulation of loose sediment, primarily sand. Their morphology is the result of antecedent conditions and sediment supply as well as the forces of waves, tides, currents, and winds. Beaches respond to changes in these forces and conditions on time scales ranging from hours to millennia.

2.2.3 Beach Sands- Sources and Sinks

Beaches are formed by an accumulation of sediment at the shoreline. The factors that determine coastal change are the rate of rise or fall in sea level relative to the land, the frequency and severity of storms, and the total volume of sand size and coarser sediments available in the sand-sharing system. Many coastal regions can be segmented into compartments; the boundaries are defined by the geologic features and processes that isolate the transport of littoral sediments from adjacent coastal compartments. Each compartment normally is composed of one or more sand sources and sand sinks, and the beach and near-shore serve as a conduit for the flow of sand between the sources and sinks.

Many factors are involved in the natural processes that provide sandy sediment to the coast. Often, the sand sources are local and transport distances are short; however, sometimes sediments are carried great distances before deposition occurs. There are five general sources of beach sediment: (1) terrestrial, (2) headlands, (3) shore face, (4) biogenic production, and (5) the inner shelf. Their contributions vary with geographic location.

Terrestrial erosion and runoff provide rivers with large quantities of sediment of widely varying grain size and composition. These coarse-grained sediments then are carried toward the coast and may eventually reach the shore and be dispersed to adjacent beaches by littoral transport processes. However, to be significant sources of sand, rivers must have fairly high gradients.

Headland and linear bluff areas along coasts offer another major source of beach sand; wave undercutting and slumping make available large volumes of sediment for redistribution by wave action. Sand-size and coarser materials are carried by long-shore currents along the beach, while the finer silts and clays are transported seaward into deep water. These finer materials also may be deposited in backbarrier lagoons if inlets are present.

The shoreface (i.e., the subaqueous portion of a beach) is another source of coastal sediment. Wave action erodes sand from a beach and shore face, and longshore currents transport it downdrift. In this manner sand is recycled continually as the shore retreats.

The inner shelf offshore of wide and gently sloping coastal plains also can be an important source of beach materials where there is an abundance of relict sand on the sea bottom. During the gradual rise in sea level over the past 15,000 years since glacial times, marine sand bodies have been eroded and the sediment redistributed by coastal currents. Over the long-term, sand may be moved landward across the shelf where it can be incorporated eventually into the littoral system.

In contrast to sediment sources, littoral sinks function to reduce the volume of sand along the coast. The most common sinks to beaches are landward transport of sand through tidal inlets to form flood-tide shoals, storm-generated overwash deposits, landward-migrating sand dunes, losses down submarine canyons that extend close to shore and losses from human-induced causes such as mining, dredging, and breakwaters and jetties.

2.2.4 Seasonal Fluctuations

Beaches respond quickly to changing wave conditions. In particular, steep (i.e., storm) waves formed by a combination of large wave heights and short wave periods tend to result in seaward sediment transport and shoreline recession. Thus, stormy waves generally cause erosion, whereas milder and longer period waves promote beach recovery. Thus, beach width fluctuates on a seasonal basis. These natural, inter-annual changes in shoreline position should not be confused with net long-term changes.

Storm surges also contribute substantially to the beach erosion process. These above-normal tides are caused primarily by the high winds (i.e., shoreward-directed wind stress) and the reduced barometric pressures associated with major tropical or extra-tropical (i.e., low pressure) storms. The three most important factors contributing to beach and dune erosion during storms are (1) storm surge heights, (2) storm surge duration, and (3) wave steepness (ratio of wave height to length). Almost all hurricane-induced erosion is limited because the time scale of the erosion process is shorter than the duration of the near-peak storm tides. Therefore, only a percent of the potential erosion actually may be realized.

2.2.5 Trends of Shoreline Change

The long-term trends of shoreline change depend on a number of factors and all the causative processes cannot be quantified at present. Relevant factors include the antecedent topography (geo-morphology) and the geologic rise of sea level, which has caused the shoreline to shift landward across the present-day continental shelf during the last 15,000 years. In some areas submerged sand on the inner shelf still is being transported shoreward and thus contributes to overall shoreline stability or accretion (Williams and Meisburger, 1987). In other areas there are no offshore sources of sand, and the slowly rising sea level induces beach erosion. Local land subsidence caused by natural or human-induced processes also can cause shoreline recession. Finally, the equilibrium beach profile is not well established along some (particularly glaciated) coasts, and sand is transported seaward for this reason alone even if there are no other causes.

Beach stability also must be considered in terms of alongshore discontinuities, which can cause areas of long-term erosion (e.g., headlands) to be in close proximity to areas of long-term accretion (e.g., sand spits). Because of these complexities, the only reliable basis at present for determining long-term shoreline changes or stability is through analysis of site-specific data.

In general, the coastal processes of interest are:

- Hydrodynamics processes (winds, waves, water level fluctuations, and currents).
- Seasonal meteorological trends (cyclones, winter storms).
- Sediment processes (sources, transport paths, sinks, and characteristics).
- Geological processes (soil and strata characteristics, stable and migrating sub-aerial and sub-aqueous features, rebounding or subsiding surfaces).
- Long-term environmental trends (sea level rise).
- Environmental processes (chemical, ecological).

- Social and political conditions (land use, development trends, regulatory laws, social trends, public safety and economics).

Harbor works, navigation channel improvements, shore protection, flood damage reduction, and environmental preservation and restoration are the primary areas of endeavor.

It is concluded that the most common design requirement for coastal engineers is the need for good wave information, particularly directional information. Adequate knowledge of waves in deep water is necessary to forecast the impact of waves in shallow water (NRC, 1989)

Processes in the open ocean show a broad uniformity over large (kilometers and more) space scales. The coastal zone, on the other hand, exhibits non uniformity in the cross-shore direction because of wave shoaling, in the long shore direction because of changes in shoreline orientation and shoreline structures, and in every direction because of distributed shoals, bars, and irregular bottom bathymetry. The diversity of scales makes this environment unique, as does the overall high- energy characteristic of the coastal region (NRC, 1989).

The combination of shallow water, high sediment mobility, eroding shorelines, and poor predictability—not to mention constantly changing wave conditions, currents, and bottom forms (small-scale topography features)—all make this environment a difficult one to monitor (NRC, 1989).

The important driving forces in the coastal zone include winds, waves, currents, and tides. While local winds generate local waves and create higher water levels during storms, pressure systems thousands of kilometers from the coast create winds that ultimately may have a severe impact on the shoreline. Waves are perhaps the outstanding characteristic of the inner shelf-near shore zone. Waves change from their relatively predictable deep-water form once they encounter the shallow water of the shelf (NRC, 1989).

Complexities of bottom topography, currents (such as the Gulf Stream), and local winds mould these deep-water waves into forms that are poorly predictable in many important circumstances, such as during storms. The constant change in waves as they move into shallow water and interact with each other and the sea bottom or seabed combines with the time variation in wave conditions to make description and prediction elusive. Winds drive and modify surface currents. Waves, as they break and run up on beaches, drive currents that parallel the shore (NRC, 1989).

Tides also contribute to the complexity of the near shore environment. Near the many coastal inlets characteristic of the Atlantic and Gulf coasts of the United States, tides alter wave height and direction and coastal currents in an intricate fashion. Varying tidal elevations (in some areas exceeding 10 meters) cause the waves to act on different parts of a beach during low tide and high tide; sometimes the high-tide position can reach inland several kilometers (NRC, 1989).

A wave may alter the bottom topography in an area, and that change in bottom topography can in turn change the characteristics of the wave. A common example is the near shore sandbar. Under certain wave conditions, a near shore bar is formed by moving sediments from the beach out to deeper water, forming a local shoal. The presence of this shoal in turn changes the breaking characteristics of the incoming waves, causing them to break over the bar first instead of on the beach. This interaction or feedback is a limiting factor in our understanding of coastal processes. One cannot study waves by themselves or bed forms by themselves, neglecting the other processes. Instead, this feedback requires the engineer to model or measure both the bed and the driving forces, a difficult theoretical and observational problem (NRC, 1989).

2.2.6 Sediment Transport

Currents associated with nearshore cell circulation generally act to produce only a local rearrangement of beach sediments. The rip currents of the circulation are important in the cross-shore transport of sand, but there is minimal net displacement of beach sediments along the coast. Waves breaking obliquely to the coast and the longshore currents they generate are more important to the longshore movement of sediments. The resulting movement of beach sediment along the coast is referred to as littoral transport or longshore sediment transport, whereas the actual volumes of sand involved in the transport are termed the littoral drift.

This long-shore movement of beach sediments is of particular importance in that the transport can either be interrupted by the construction of structures which block all or a portion of the longshore sediment transport like jetties and breakwaters, or can be captured by inlets and submarine canyons. In the case of a jetty, the result is a buildup of the beach along the updrift side of the structure and an erosion of the beach downdrift of the structure. The impacts pose problems to the adjacent beach communities, as well as threaten the usefulness of the adjacent navigable waterways (CEM, 2006).

The waves and currents transport the sediments in the ocean. Bailard (1982) considered the energetic approach with empirical coefficients which is now being applied in numerous implementations for various local conditions of survey, both in-situ and in laboratory. The global sediment transport in response to waves is shown in Fig.2.2.

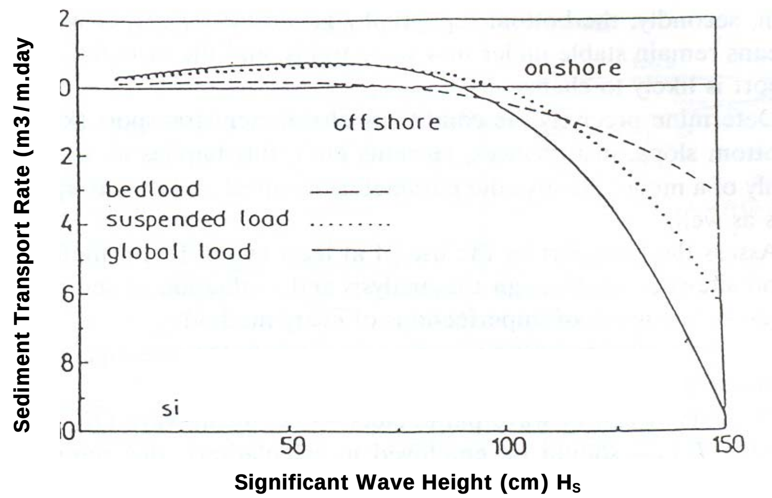


Fig. 2.2 Global Sediment Transport rate as a function of wave height *(Bailard 1982)*

It should be noted that sediment moves on shore if the significant wave height is H_S < 90 cm and off shore if waves are greater. The maximum onshore transport appears for $H_S=60$ cm. Under storms with H_S > 100 cm the predicted transport is offshore, which can be true as shore erosion is often observed for such waves, which may indicate the removal of sediment towards sea.

2.2.7 Coastal Process Categories

Taken in the broadest sense, four categories of coastal processes act on the coastal areas (NRC, 1989). Two of these categories may be considered primary and the other two, interactive.

Primary processes consist of:

- Kinematics and dynamics of high-frequency coastal water motions (periods of 0.1-5 minutes) and
- Kinematics and dynamics of low-frequency coastal water motions (periods greater than 5 minutes).

Interactive processes consist of:

- Fluid/sediment interaction and
- Fluid/structure interaction.

In general, the short-period, high-frequency phenomena are related to wind- wave generated water motions; long-wave period, low-frequency phenomena are generated, for example, by pressure effect, tidal motions, and such catastrophic events as slides, slumps, or earthquakes. The categories were specified because of the need to recognize spatial and temporal differences in the coastal measurement systems and instrumentation required for each category.

2.3 Coastal Problems

The concentration of the World's population in a fairly narrow coastal belt seems to be an inevitable feature of the mankind's growth. Various estimates project that about 67% of world's population will be living in the coastal zone spread over 80 to 200 km from the shoreline. Human activities in the coastal zone are widespread and have risen to enormous economic proportions.

Great attention to the stability and sustainable development of the coastal zone is therefore paid by governmental authorities, coastal managers, owners of hotels and estates, and many other users. Some coastal environments may be regarded as rather stable (rock and reef coasts) while other are more vulnerable (sand and mud). Hence coastal users and managers all over the world are frequently faced with serious erosion of their sandy coasts.

The primary causes of coastal erosion in any given region are generally the following.

1. Tides
2. Sea level changes
3. Interception of littoral drift
4. Sand mining

5. River mouth changes
6. Direct wave action

Erosion counter measures depend, interalia, on local conditions of shore and beach, coastal oceanology and sediment transport. Continuous maintenance and improvement of the coastline, together with monitoring and studies of coastal processes have yielded considerable experience at various coastal institutions and laboratories worldwide.

All the shores may not be in equilibrium with the present littoral processes. Shores with a character inherited from previous non-littoral processes (i.e., glacial or river deposited materials) maybe doomed to significant rates of erosion under present conditions, such as the Mississippi delta of Louisiana and portions of the Great Lakes. Some of the shores also exhibit short-term seasonal or episodic event-driven cyclic patterns of erosion and accretion (e.g., the southern U.S. Atlantic coast). Other shores demonstrate long-term stability due to balanced sediment supply and little relative sea level rise influence, such as the west coast of Florida. For some shores, very little beach-building material is available, and what little is available may be prone to rapid transport, either alongshore or offshore (e.g., the Great Lakes). Shores that have been heavily modified by man's activities usually require a continuing commitment to retain the status quo. Prime examples are New Jersey, which was extensively modified during the 20th century and is now undergoing several major beach fills, and numerous urban areas around the country (Los Angeles, New York, Galveston, Chicago, Miami, Palm Beach). In India, naturally occurring coastal erosion is limited to Kerala and Karnataka states on the south west coast (CEM, 2006).

In order for one shore to accrete, often some other shore must erode. Erosion is a natural response to the water and wind processes at the shore, but erosion is only a problem when human development is at risk. Sometimes, man-made alterations to the littoral system, including modifications to sediment sources or sinks, may contribute to the eroded condition. The National Shoreline Study (DOA 1971) found that 24 percent of the entire United States shore of 135,000 km (84,000 miles) is undergoing significant erosion where human development was threatened. If Alaska, with its 24,800 km. (15,400 miles) of shore is removed from the statistic, 42 percent of the United States shore is experiencing significant erosion (CEM, 2006).

The reworking and often eroding the margins of the land leads the seas wearing down the continents. Sediments derived from the land are often transient along the coasts, temporarily forming beaches, bars or islands before coming to rest on the sea floor.

There is a greater natural diversity in shore types throughout the world. Consequently, engineering, development, and policy strategies need to be tailored for each unique region and need to be flexible to changes in the local condition. Coastal engineers, managers, and planners need to be aware of coastal diversity for a number of reasons:

1. The coast is dynamic and constantly evolving to a new condition.
2. The balance and interaction of processes are different in different areas - understanding diversity provides clues to the critical factors that may affect a particular study site.
3. Different settings imply different erosion and accretion sediment patterns.
4. Analytical tools and procedures may be suitable for a particular setting but totally inappropriate for another.
5. Similarly, engineering solutions may only be appropriate for certain settings where they will function properly, i.e; solutions are site specific and can't be generalised.

Shorelines are subjected to a broad range of processes, geology, morphology and land usages. Although winds, waves, water levels, tides, and currents affect all coasts, they vary in intensity and relative significance from one location to another. Variations in sediment supply and geological setting add to this coastal diversity.

Erosion and flooding threaten an estimated $3 trillion of development along the coast, with 80 to 90 percent of the nation's sandy beaches eroding (Hillyer, 1996). The cost of shore protection and restoration throughout the developed areas of the coast will increase, especially if the growing value of coastal property and recreation benefits are factored into the cost benefit calculations (CEM, 2006).

2.3.1 Classification of Coastal Problems

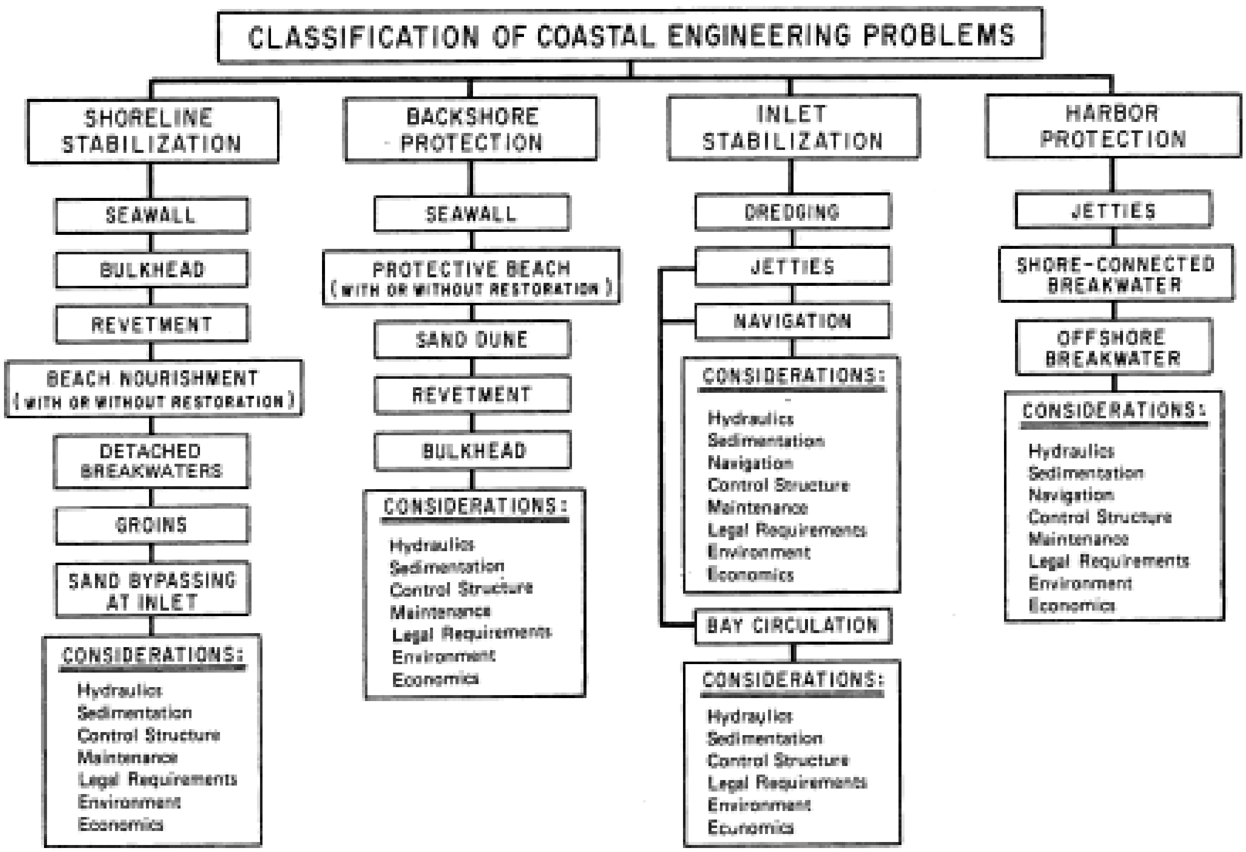
The problems in the coastal region can crop up in different ways like beach erosion/accretion, bank erosion of an estuary, silting up of river mouths, shoreline retreat etc. These problems have been broadly classified and the possible solutions are listed according to priority as given in table 2.1 (SPM, 1984).

The following paragraphs provide a brief overview of each feature or area of engineering application and emphasize a few perceived measurement goals.

2.3.1.1 Shore

Shore stabilization is a primary engineering goal along large sections of the U.S. coastline. Achieving this goal requires understanding the behavior of the shore or shoreline and effects adjacent to both hard engineering structures (e.g., seawalls, revetments, groins) and soft structures (e.g., beach nourishment). Basic to the knowledge required is an understanding of shore response to wave action and currents. Because present modeling capability to predict shoreline response is inadequate, measurements of the sediment transport rate, concentration, and distribution are necessary in both longshore and cross-shore directions. It is important to make these measurements under conditions of moderate-to-high-wave energy. Likewise, the ability to rapidly and accurately measure beach and near-shore profile changes under a broad range of wave-energy conditions is essential to verification of prediction models. An essential consideration for all of these measurements is the ability to carry them out successfully under high- energy episodic conditions associated with storms, because these energetic conditions result in maximum sediment transport.

Table 2.1 Classification of Coastal Engineering Problems



The need for understanding shore processes is illustrated by the erosion of the shore at the Cape Hatteras Lighthouse on the Outer Banks of North Carolina. The 110-year-old historic tower is endangered by changes in the shoreline that have brought the high-water line to within 100 feet of the structure. A series of studies has sought to ascertain the reasons for past variations in the position of the shore, in order to forecast the future. But the basic understanding of shore processes is inadequate for reliable prediction of the rate of shoreline change during high-energy wave conditions (NRC, 1987).

Another factor in shoreline processes is relative sea-level change. Rising relative sea level exerts an inexorable pressure on most sections of the world's shoreline (but not all). For instance, many high latitude shoreline segments in Canada and Europe are emergent, contrasting with the U.S. shoreline which is primarily submergent. Whereas past relative sea-level rise in the United States has averaged about 30 cm per 100 years, this value exhibits considerable spatial variability.

Relative sea-level rise presents a future challenge to coastal engineers, but it can be anticipated in engineering planning. If projections of increases in relative sea-level rise are correct, engineering projects designed for 25-50 year time scales will have to incorporate rising sea levels more directly into their design phase. Meanwhile, existing facilities and structures may have to be shored up to account for this long-ignored factor in the design equation (NRC, 1987).

Nevertheless, unpredictable changes caused by coastal storms and hurricanes pose a greater concern than does the effect of sea-level rise.

2.3.1.2 Backshores

Much like shore stabilization, backshore protection requires an understanding of processes that vary in nature and importance from one location to another. Knowledge of dune, bluff, and beach response to extreme wind and wave events is essential to this understanding. Measurements of run-up and setup under high-energy wave conditions and knowledge of storm surge histories are necessary. Measurement problems involving immersion, burial, and exposure of sensors may be more pronounced and problematic in these locations.

Unusually high lake levels along many shores of the Great Lakes during the mid-1980s provided an example of where backshore protection was paramount. When lake levels rise, backshores are likely to suffer damage from wave and current erosion during storms, especially when low-pressure systems combined with wind setup accentuate the already high water levels. Then, severe bluff and beach damage often result in significant environmental impact and property damage. The ability to measure wave direction and runup would support more reliable predictions of areas of greatest impact and how to safeguard them.

2.3.1.3 Entrances

Entrances include both natural inlets and constructed harbor mouths and channels. Stabilization of entrances is a primary engineering goal in certain natural and almost all constructed channels. The annual cost of maintenance dredging of inlets and harbors by the Corps of Engineers alone is rapidly approaching $400 million. A major measurement problem related to maintenance dredging of inlets and channels is the determination of transport and deposition of sediment during high-energy wind and wave events that frequently close navigation passages. This fact reinforces the need for measurements of sediment transport and concentration during high-energy tidal flows.

A good example of this problem is the entrance of the Columbia River leading to the major ports of Portland, Oregon, and Vancouver, Washington. At this entrance, a large curving sandbar often produces serious depth restrictions to the passage of ships as Pacific swells interact with strong river currents. The severity of navigation problems requires a specialized pilot for bar passage, separate from the river navigation pilot. Extensive studies of the pitching motion of ships crossing that bar under varying wave, tide, and current conditions (Wang and Noble, 1982) have verified the critical need to predict the movement of the shifting bar in order to avoid grounding or broaching.

Systems for diverting sand are being constructed to keep entrances open and to maintain sand nourishment to downdrift beaches. These systems require prediction of sand transport volumes that are dependent on local wave and current conditions. Presently, the use of sand diversion systems is severely limited by inadequate capability to predict sediment transport, largely owing to the lack of coastal engineering measurement systems.

2.3.1.4 Harbours

Design of safe, effective harbors with low operation and maintenance costs is another primary coastal engineering goal. Essential to achievement of this goal is an understanding of the stability of breakwaters formed from mounds of rock, the failure of concrete elements used to increase this stability, the leakage of wave energy through the breakwater, and scouring away by the waves of the sediments that form the breakwater's foundation. The cost of these structures is very large. Therefore, there is a strong economic pressure to improve prediction capabilities, thereby eliminating over-design. Measurement of wave forces on and within breakwater structures is required, as well as measurement of wave and current forces adjacent to and along the breakwaters. This is a particularly complex area of engineering, where theoretical development is sparse and empirical determinations are often based on indirect relations between wave forcing and structural response. Few measurements have been made of the forces and structural interactions on actual structures. Only recently have measurements been undertaken on the external structural elements. To the best of our knowledge no measurements internal to the structures have been made. This is an engineering area that requires development of specialized measurement systems.

A well-known example of this need is the failure of the harbor at Sines, Portugal. A massive breakwater constructed on the Atlantic coast was designed to provide a vast port and industrial complex. Before the structure was completed, a period of violent Atlantic storms produced waves that severely damaged the breakwater, destroying much of the capwall and roadway and preventing completion of ship berths planned for the lee side. Extensive investigation of the wave conditions that led to the Sines failure did not lead to a consensus judgment; rather, it resulted in 13 different opinions as to the principal cause of the breakwater damage.

2.3.2 Coastal Inlets

Coastal inlets play an important role in nearshore processes around the world. *Inlets* are the openings in coastal barriers through which water, sediments, nutrients, planktonic organisms, and pollutants are exchanged between the open sea and the protected embayments behind the barriers.

Lakes, many river mouths are considered to be inlets, while in the Gulf of Mexico, the wide openings between the barriers, locally known as passes, are also inlets. Inlets can be cut through unconsolidated shoals or emergent barriers as well as through clay, rock, or organic reefs (Price 1968). There is no simple, restrictive definition of inlet; based on the geologic literature and on regional terminology, almost any opening in the coast, ranging from a few meters to several kilometers wide, can be called an inlet. Inlets are important economically to many coastal nations because harbors are often located in the back bays, requiring that the inlets be maintained for commercial navigation. At many inlets, the greatest maintenance cost is incurred by repetitive dredging of the navigation channel. Because inlets are hydrodynamically very complex, predictions of shoaling and sedimentation have often been unsatisfactory. A better understanding of inlet sedimentation patterns and their relationship to tidal and other hydraulic processes can hopefully contribute to better management and engineering design.

Tidal inlets are analogous to river mouths in that sediment transport and deposition patterns in both cases reflect the interaction of outflow inertia and associated turbulence, bottom friction, buoyancy caused by density stratification, and the energy regime of the receiving body of water (Wright and Sonu 1975). However, two major differences usually distinguish lagoonal inlets from river mouths, sometimes known as fluvial or riverine inlets (Oertel 1982).

a. Lagoonal tidal inlets experience diurnal or semidiurnal flow reversals.

b. Lagoonal inlets have two opposite-facing mouths, one seaward and the other lagoonward. The sedimentary structures which form at the two openings differ because of differing energy, water density, and geometric factors.

The term *lagoon* refers to the coastal pond or embayment that is connected to the open sea by a tidal inlet. The *throat* of the inlet is the zone of smallest cross section, which, accordingly, has the highest flow velocities. The *gorge* is the deepest part of an inlet and may extend seaward and landward of the throat (Oertel 1988). *Shoal* and *delta* are often used interchangeably to describe the ebb-tidal sand body located at the seaward mouth of an inlet.

2.3.2.1 Current-channel Interaction

As flow converges on an inlet entrance, the angle at which flow approaches a dredged channel can be important with regard to change in current direction and can ultimately relate to channel shoaling. The direction of current approach will depend on bottom configuration and structure(s) location. Boer (1985) developed a mathematical model to study currents in a dredged channel.

He found that a current approaching obliquely to a channel is refracted within the channel and the streamlines contract within the channel causing a velocity increase. This effect becomes relatively small for angles larger than 60°E (angle between channel axis and current direction). This effect is largest near the bed and smallest near the surface. Due to continuity, depending on the relative depth of the channel to the surrounding depths, there is a decrease factor because of increased depth in the channel.

2.3.2.2 Classification of inlets and geographic distribution

Tidal inlets are found around the world in a broad range of sizes and shapes. Because of their diversity, it has been difficult to develop a suitable classification scheme. The dynamics of estuaries are therefore much more difficult to analyse than the dynamics of the open ocean. This inherent difficulty has led to a number of attempts to bring order into the range of possible estuarine circulations and group estuaries of similar characteristics together. A number of classification schemes for estuaries resulted from this approach.

Pritchard (1952) introduced a classification of estuaries based on topography, which distinguishes coastal plain estuaries (drowned river valleys), fjords and bar-built estuaries.

1. Coastal plain estuaries

   These were formed by the flooding of river valleys following a rise in sea level over geological time. They show little sedimentation, so that the ancient river valley still determines the estuarine topography. These estuaries are shallow, with depths rarely exceeding 30 m or so, and mostly located in the temperate climate zones.

2. Fjords

   These are river valleys deepened by glaciers during the last ice age. The scouring of the valley floor results in very deep estuaries, sometimes exceeding 800 m. The characteristic feature of fjords is the existence of a shallow sill at the mouth formed by accumulated rock at the glacier front. These sills can be as shallow as 4 m, but sill depths of between 40 m and 150 m are more common. True fjords are found only in the temperate zones; but fjord-like estuaries can occur elsewhere as well.

3. Bar-built estuaries

   These are drowned river valleys with a high sedimentation rate. They are thus mostly very shallow, with depths of a few metres, and often branch out towards the mouth into a system of shallow waterways (lagoons). The sediment accumulates near the mouth of the estuary and forms a bar, where the water depth decreases even further. Bar-built estuaries are common in the subtropics and tropics but can occur wherever the coastal zone is characterised by deposition of sediment.

Regional geological setting can be a limiting factor restricting barrier and in turn, inlet development. Most inlets are on trailing-edge coasts with wide coastal plains and shallow continental shelves (e.g., the Atlantic and Gulf of Mexico shores of the United States). High relief, leading-edge coastlines have little room for sediment to accumulate either above or below sea level. Sediment tends to collect in pockets between headlands, few lagoons are formed, and inlets are usually restricted to river mouths. The Pacific coast of North America, in addition to being steep, is subject to high wave energy and has far fewer inlets than the Atlantic.

Based on studies of the German and Georgia bights, Nummedal and Fischer (1978) concluded that three factors, i.e.; Tide range, Nearshore wave energy and Bathymetry of the back-barrier bay were critical in determining the geometry of the inlet entrance and the associated sand shoals.

For the German and Georgia bights, the latter factor controls velocity asymmetry through the inlet gorge, resulting in greater seaward-directed sediment transport through the inlet than landward transport. This factor has aided the development of large ebb shoals along these coasts, even though the German coast is subject to high wave energy. Back bay area and geometry are likely crucial factors that need to be incorporated in a comprehensive inlet classification scheme.

Davies (1964) applied an energy-based classification to coastal morphology by subdividing the world's shores according to tide range. Hayes (1979) expanded this classification, defining five tidal categories for coastlines:

1. Microtidal, < 1 m.
2. Low-mesotidal, 1-2 m.

3. High-mesotidal, 2-3.5 m.
4. Low-macrotidal, 3.5-5 m.
5. Macrotidal, > 5 m.

Hayes (1979) classification was based primarily on shores with low to moderate wave power and was intended to be applied to trailing edge, depositional coasts. In the attempt to incorporate wave energy as a significant factor modifying shoreline morphology, five shoreline categories were identified based on the relative influence of tide range versus mean wave height (Fig. 2.3)

1. Tide-dominated (high).
2. Tide-dominated (low).
3. Mixed-energy (tide-dominated).
4. Mixed energy (wave-dominated).
5. Wave-dominated.

The problems at the coastal inlet can be beach erosion, tidal inlet shoaling, navigability, channel reliability, and quantify the sediment-sharing interactions between inlets and adjacent beaches. The increasing sea levels and periodic tides can flood the inlets with marine sediments which may block the estuary by building bars at mouth, shoaling of estuary or silting in the channel.

Natural channel entrances have a substantial capacity to modify sediment transport in their vicinity. However, artificially dredged channel entrances, structurally modified for navigational purposes, have a much greater potential for affecting the adjacent shores. These impacts can have a different magnitude depending on the characteristics of the particular entrance. Effects can extend miles from the entrance and are greatest where there is substantial net long-shore sediment transport.

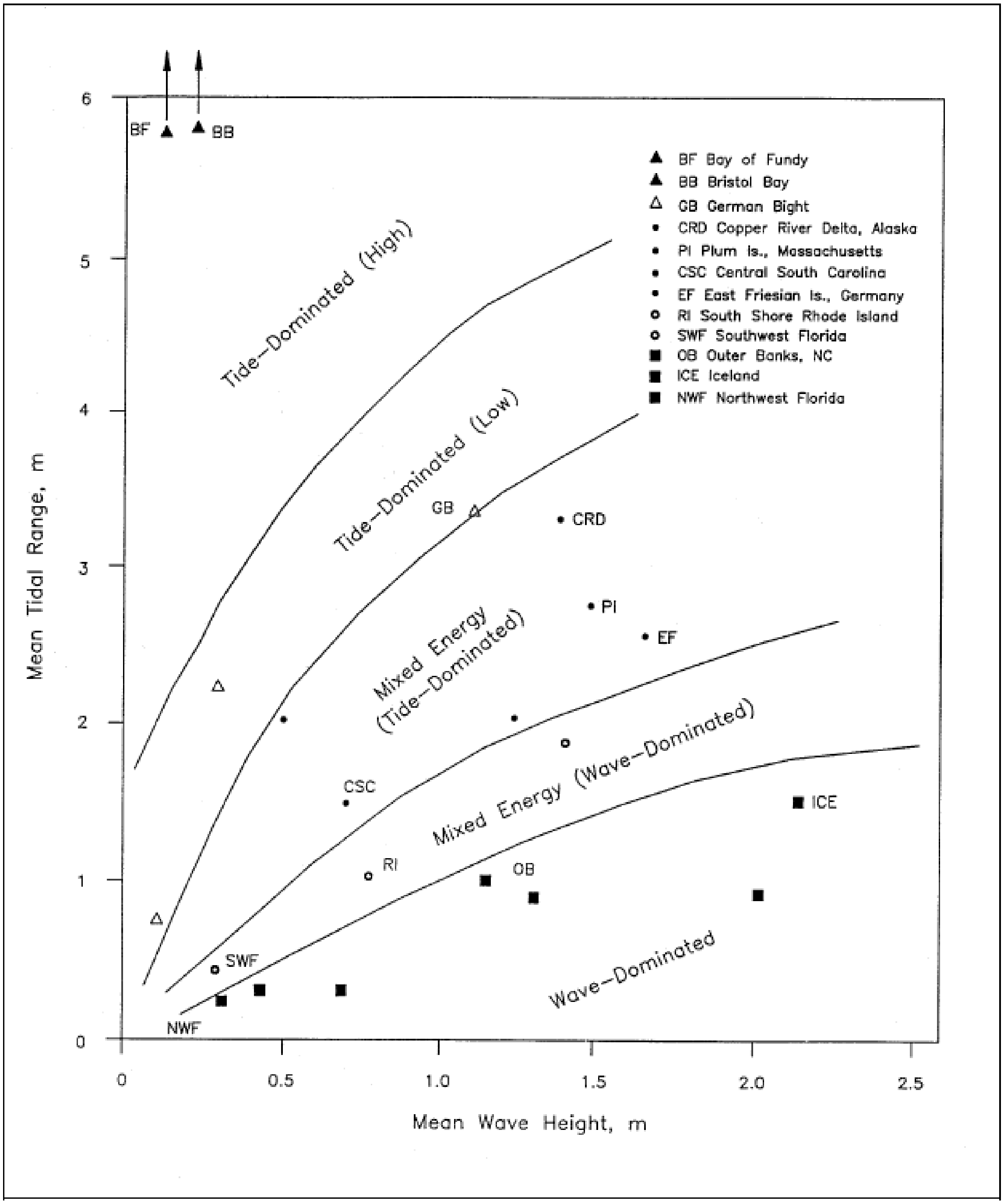


Fig. 2.3 Energy based classification of Inlets (from Hayes (1979))

Underlying geology may also control inlet location and stability. Price and Parker (1979) reported that certain areas along the Texas coast were always characterized by inlets, although the passes tended to migrate back and forth along a limited stretch of the shore. The positions of these permanent inlets were tectonically controlled, but the openings were maintained by tidal harmonics and hydraulics. If storm inlets across barriers were not located at the established stable pass areas, the inlets usually closed quickly. Some inlets in New England are anchored by bedrock outcrops and therefore cannot move freely.

Estuaries are typically classified by their existing geology or their geologic origins (in other words, how they were formed). In geologic time, which is often measured on scales of hundreds of thousands to millions of years, estuaries are often fleeting features of the landscape. In fact, most estuaries are less than 10,000 years old (Levinton, 1995). The five major types of estuaries classified by their geology are coastal plain, bar-built, deltas, tectonic and fjords.

1. Coastal plain estuaries, or drowned river valleys, are formed when rising sea levels flood existing river valleys.
2. Bar-built estuaries are characterized by barrier beaches or islands that form parallel to the coastline and separate the estuary from the ocean. Barrier beaches and islands are formed by the accumulation of sand or sediments deposited by ocean waves.
3. Delta, characterized by large, flat, fan-shaped deposits of sediment at the mouth of a river, occurs when sediments accumulate more rapidly than ocean currents can carry them away.
4. When the Earth's tectonic plates run into or fold up underneath each other, they create depressions that form tectonic estuaries.
5. Fjords are steep-walled river valleys created by advancing glaciers, which later became flooded with seawater as the glaciers retreated.

In addition to classifying estuaries based on their geology, scientists also classify estuaries based on their water circulation. Water movements in estuaries transport organisms, circulate nutrients and oxygen, and transport sediments and wastes. Once or twice a day, high tides create saltwater currents that move seawater up into the estuary. Low tides, also once or twice a day, reverse these currents. In some estuaries, the mixing of fresh water from rivers and saltwater from the sea is extensive; in others it is not. The five major types of estuaries classified according to their water circulation are as follows (USEPA, 1993 and Levinton, 1995;).

1. Salt-wedge,
2. Fjord,
3. Slightly stratified,
4. Vertically mixed, and
5. Freshwater

The daily mixing of fresh water and saltwater in estuaries leads to variable and dynamic chemical conditions, especially salinity. When fresh water and saltwater meet in an estuary, they do not always mix very readily. Because fresh water flowing into the estuary is less salty and less dense than water from the ocean, it often floats on top of the heavier seawater. The amount of mixing between fresh water and seawater depends on the direction and speed of the wind, the tidal range (the difference between the average low tide and the average high tide), the estuary's shape, and the volume and flow rate of river water entering the estuary. These factors are different in each estuary, and often change seasonally within the same estuary.

2.3.2.3 Problems of Coastal Inlets

Two longstanding coastal problems are beach erosion and inlet shoaling and are interrelated. Dredging of tidal inlet passes and construction of river training jetties/breakwaters to improve boat navigation may cause down drift beach erosion by interrupting the normal sediment movement and near-shore circulation patterns. Coastal inlet systems can be dynamic and hazardous, requiring dredging of coastal channels to prevent excessive shoaling.

2.3.3 Forcing Factors influencing Coastal Problems

The main reasons for coastal problems are wave climate, sea level rise, morphology, geology, and land usages. Although winds, waves, water levels, tides, and currents affect all coasts, they vary in intensity and relative significance from one location to another.

The ground water table variations aid and abet the coastal erosion. Similarly sea level rise can worsen coastal problems with increase in waves, tides, currents and coastal flooding. The discharge of sediments and water and their variations together with geological setting add to this. The existing coastal structures if constructed without regard to coastal dynamics may prove to be another factor in increasing the coastal woes.

2.4 Alternative coastal problem mitigation measures – Concepts

The coastal engineer operates in a dynamic, intricate, and multifaceted environment. Application of coastal engineering knowledge to the solution of problems is complicated by a host of physical and environmental factors. For example, in order to design and build a structure, engineers need a firm understanding of coastal water movements, sedimentation rates, stresses of the wave and water motion, and other forces on the shoreline and on the structure. Extreme events like breaking storm waves, storm surges, tides, and tsunamis add to the already complex nature of the coastal engineering discipline.

To perform the job properly requires detailed and accurate information on the conditions under which a structure must perform and survive. Measurements and measurement systems are required to determine the range of influence, strength and timing of the forces of nature in the coastal zone.

For this study, the committee (NRC, 1989) first identified those issues or problem areas recognized as important to the engineering community; some issues are more urgent and must be given greater priority. Then it was necessary to identify and evaluate the state of knowledge of coastal processes related to each engineering issue. This evaluation in turn considered the state of theoretical development and analytical and numerical modeling in each coastal process area.

The various strategies for fighting shoreline problems are relocation, structural intervention and soft technologies. These have been shown in the following flow chart.

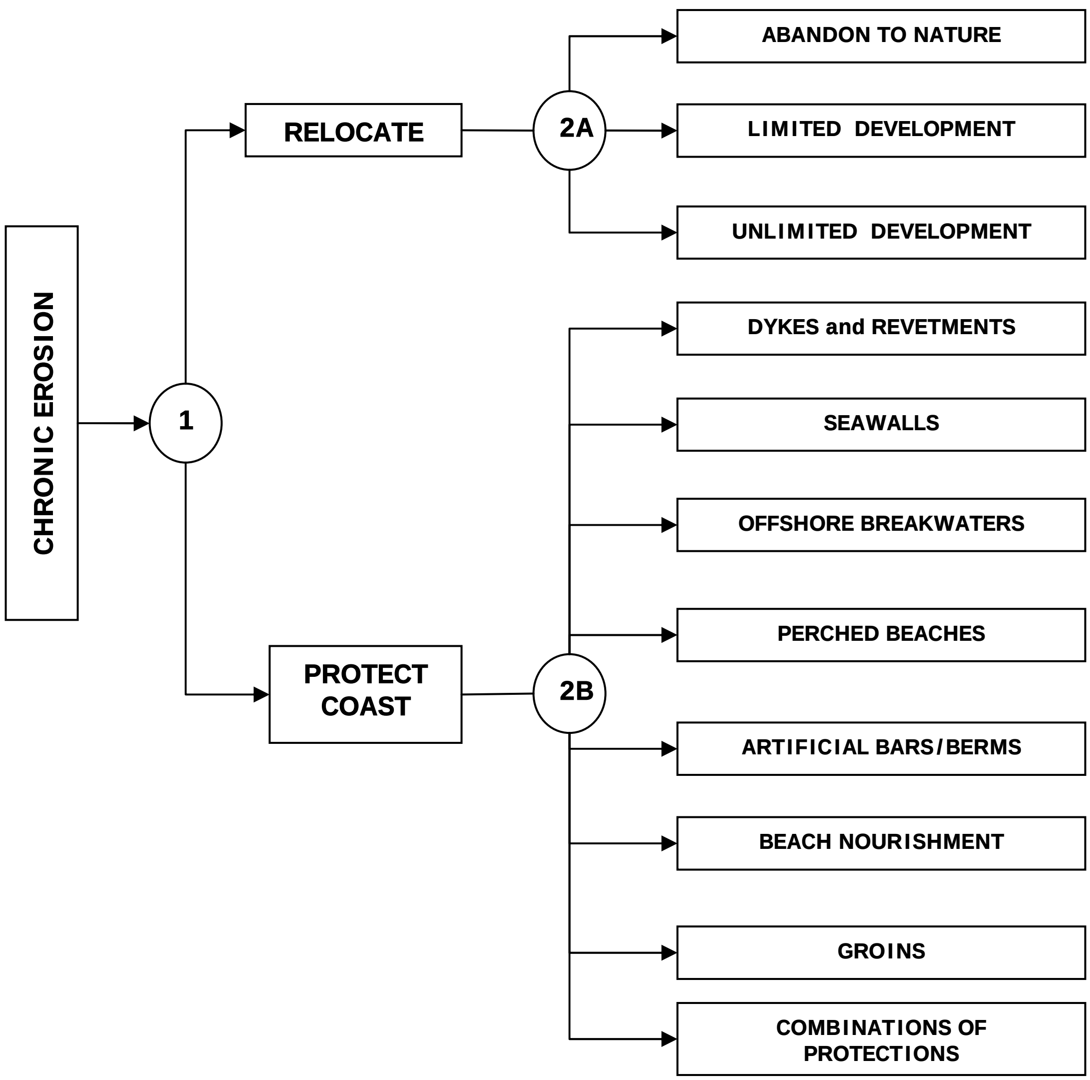


Fig. 2.4 Strategies for dealing with Coastal Erosion (Kraus, 1989)

2.4.1 Relocation

Relocation of existing structures from eroding and/or flood-prone shorelines has long been a neglected mechanism for responding to shoreline retreat. The technical feasibility of moving small or medium-size structures has been established. Relocation as a widespread adjustment to shore erosion is most likely to be cost effective for smaller structures, particularly one-and two-story residential buildings.

Relocation encounters a number of institutional and economic impediments. Structures on deep lots may gain sufficient protection by relocating landward on the same lot. However, if sufficient space is not available on the same lot, an alternative site must be acquired and prepared. This increases the cost of relocation substantially. It also may incur problems of zoning; mortgage refinancing; and provision of sewer, water, and road access. The alternative site may lack the view and/or direct shoreline access that are often the reason for waterfront property ownership.

However, a structure threatened by imminent collapse essentially is valueless and poses substantial potential costs to the community in terms of lost tax revenue, deterioration related to disinvestment/abandonment, clearance of wreckage, casualty loss deductions from income tax liability, disaster relief payments, and flood insurance loss payments. Relocation therefore may be a desirable public goal. Relocation involving any public subsidy of support should involve a landward distance at least equal to established setbacks for new construction.

2.4.2 Soft Technologies

Two new "soft" technologies are now available to help solve these problems. Fluidization -- the process of adding excess water to a sandy sediment in place to convert it to a pumpable fluid -- is a long-term solution that keeps sand out of the inlet boat channel and puts it on the downdrift beach. The other method is beachface dewatering (a procedure that is essentially the reverse of fluidization, i.e.; removing water from the sandy sediment to lower the local ground water table), creates a wider and usable recreational beach and provides storm protection by stabilizing the beach (Jim Parks, -).

Experience shows that the presence of mangrove ecosystems on coastline contains loss of life and property during such calamities. This has been found true even in the case of Tsunami attack on Tamilnadu coast during December 2004. These ecosystems are known for their economic importance. They are breeding, feeding and are nursery grounds for many estuarine and marine organisms. These areas are used for captive and culture fisheries. Primarily the Kandla or Mangroves work as mini ecosystem (Raghuram, 2007).

The distribution of mangrove ecosystem on Indian coastlines indicates that the Sundarban mangroves occupy a large area followed by Andaman-Nicobar Islands and Gulf of Kutch in Gujarat. Rest of the mangrove ecosystems are comparatively smaller.

2.4.3 Erosion Control through Coastal Structures

There are many examples of properly planned, designed, constructed, and maintained seawalls and revetments that have prevented further retreat of the shoreline, but beaches sometimes have been lost as a result. There are also examples of properly planned, designed, constructed, and maintained detached breakwaters and groin fields that have been effective in the local control of coastal erosion; however, impacts on downdrift beaches must be considered. Beach nourishment is now the method of choice for beach preservation in many coastal communities.

Sometimes the solutions require the use of “hard” static structures built of rock, steel, or concrete, and sometimes the solutions involve “soft” dynamic approaches, such as adding littoral material or modifying the vegetation.

The basic tools of the coastal engineer are still fairly limited and comprise cross shore structures (such as groins, jetties, spurs), shore-parallel structures (offshore breakwaters, seawalls, revetments (generally close to shoreline) and dikes), headland structures and artificial beach nourishment. The solutions to the coastal problems are briefly introduced in the paragraph below.

2.4.4 Impacts of structural intervention on shore stability

Jettied entrances and breakwaters forming harbors along sandy coasts often cause accretion updrift and erosion downdrift of the project. Up-river deforestation can cause erosion of banks and deposition at the river estuary and along the coast. Additionally, when rivers that deliver sand and sediment to the coast are dammed for flood control and other purposes, beach erosion can result over the long-term.

Groins generate considerable changes in wave and circulation patterns but their basic function, to slow down the rate of littoral drift, is sometimes overlooked. In the absence of beach nourishment, groins can redistribute the existing supply and, in a continuous littoral system, may be expected to create a deficiency at the down drift end where the uncontrolled drift rate is reestablished. Without an adequate supply of beach material, groins are of limited value.

In addition to controlling the rate of drift, groins are also used extensively to control the distribution of material along a frontage and to limit the temporary effects of drift reversal. There are unfortunately many examples where either bad design or failure to provide for the down drift consequences has resulted in an adverse effect on the coastline. In other instances, failure to maintain groin systems might be worser than having no groins at all.

Offshore breakwaters are usually provided either to reduce wave energy at shoreline structures or to modify the wave climate and enhance sediment transport patterns so as to improve beach levels and create desirable beach features, such as salients.

Offshore breakwaters can be shore-connected or detached, submerged or emerging, longshore or oblique, etc. Eg. USA, Japan, Srilanka.

Perched beach is a system consisting of a submerged breakwater (sill or reef), usually located not far away from shoreline, and artificial beach nourishment providing sand to the area extending between sub-aerial beach and the sill crest.

Seawall (wording sometimes used interchangeably with bulkhead) is either a retaining wall intended to hold or prevent sliding of the soil behind it or a massive structure whose primary purpose is to protect the backshore from heavy wave action. Sometimes one speaks of 'beach wall' or 'shore wall'.

Revetment is placed on a slope to shelter the adjacent uplands from erosion, with no defence of the neighbouring areas. Wave reflection, a serious disadvantage of vertical-wall bulkheads (seawalls), does not accelerate toe erosion as strongly at revetments as it does at seawalls. Eg. Seawalls in India and Japan.

Dikes are generally intended as means of flood prevention. The crest of a dike is elevated high enough to counteract or confine overtopping in rare storm surge events. Eg. Dikes in Netherlands.

Beach nourishment or fill (or recharge), consists of import of granular material to beach from an external source. It is not new, and has been used in some countries for decades, but is now being applied to an increasing extent and in a greater variety of ways. The resulting beach provides some protection to the area behind it and also serves as a valuable recreational resource. The beach fill functions as an eroding buffer zone, and its useful life will depend on how quickly it erodes. One must be prepared to' periodically renourish (add more fill) if erosion continues.

Headland control has been devised by analogy to the Nature's efforts to keep in equilibrium a certain crenulate shape of erosion bays sculptured for thousands or so years (Silvester & Hsu 1993). The crenulate shaped bays can be kept in equilibrium by use of a system of headlands. The headland system is claimed to be in feedback with coast and to combine the advantages of groins and detached breakwaters (shore-parallel or oblique).

Conventional hard solutions like sea walls, jetties, groins and breakwaters and other methods such as dredge and fill beach nourishment, and repeated maintenance channel dredging either (a) contribute more to the problem than to the solution,(b) are short term solutions needing frequent and costly repetition, (c) are damaging to the environment, or (d) are quite expensive with inadequate benefit/cost ratios.

The various strategies of fighting coastal problems discussed above have to be critically analysed before finalizing the preferred one for implementation. The different stages of such an analysis is illustrated in the flow chart shown below.

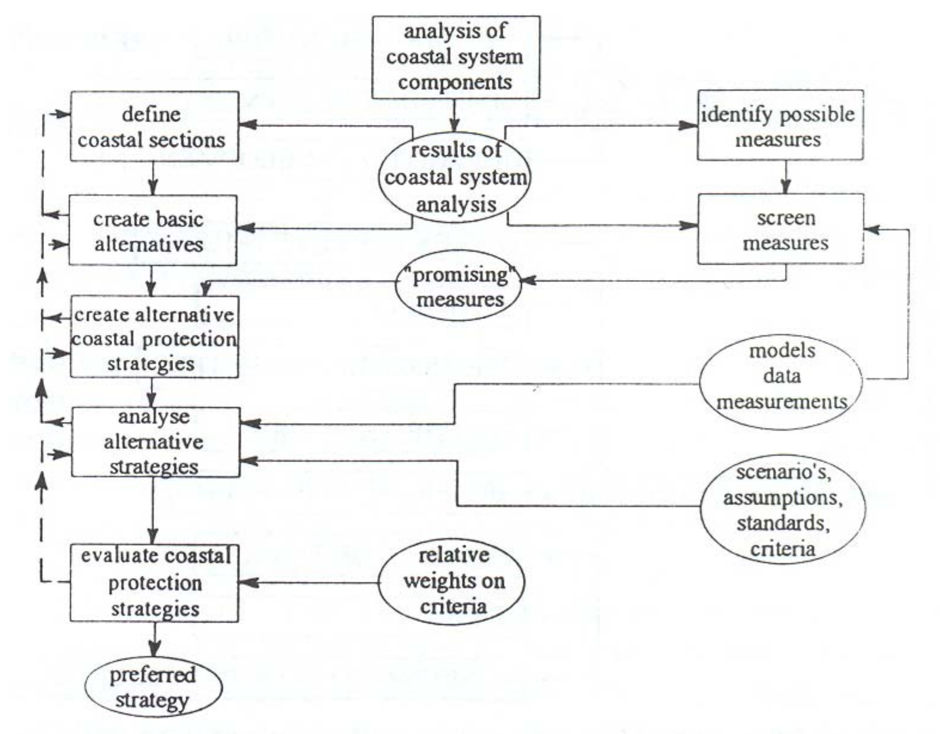


Fig.2.5 Analysis of Coastal Strategies *(Source: Pilarczyk and Zeidler, 1996)*

2.4.5 Design of Solutions to Coastal Problems

Basically the coastal problems have been classified into four categories such as shore stabilization, backshore protection, inlet stabilization and harbour protection. The solutions to these problems are listed priority wise in section 3.3.1. The data requirements to find the solutions for various coastal problems are listed in the following table.

Table 2.2 Data requirements to find the solutions for various coastal problems

Shore Stabilization	**Inlet Stabilization**	**Backshore Protection**	**Harbor Protection**
Sediment Characteristics	Sediment Characteristics	Sediment Characteristics	Sediment Characteristics
Grain size distribution	Grain size distribution	Grain size distribution	Grain size distribution
Concentration of suspended fraction	Packing density	Beach Characteristics	Harbor Characteristics
Inlet Characteristics		Beach profiles	Bathymetry
Near-bed transport rates	Bathymetry	Longshore sediment transport	Shoreline changes
Beach Characteristics	Net sediment flux	Cross-shore sediment transport	Protective structures
Beach profiles	Patterns of erosion and deposition	Patterns of erosion and deposition	
Local areas of deposition or erosion	Protective structures	Hydrodynamic Characteristics	
Stabilizing structures	Hydrodynamic Characteristics	Wave direction	Hydrodynamic Characteristics
Hydrodynamic Characteristics	Wave height and steepness	Wave height and steepness	Wave height and steepness
Incident wave heights and steepness	Wave direction	Wave runup	Wave direction
Current velocities		Storm surge Current velocities	
Wave direction	Bottom shear stress (wave/current interaction)	Tsunami runup	Bottom shear stress
Velocities of wave-driven currents			
Velocities of other currents			
Bottom shear stress			
Turbulence characterization			

The various factors influencing the selection of shoreline protection measures among the various alternatives are listed in the table below and in the figure.

Table 2.3 Factors influencing the selection of shoreline protection system alternatives

Category of Factor	Components of screening factors
Technical	• The capability of reducing the longshore transport gradient. • The capability of reducing the offshore transport gradient • Durability of (components of) the system • Risks of failure of (components of) the systems • Execution risks • Maintenance considerations • Sensitivity to large scale external morphological changes
Economic	• Investment costs • Monitoring and maintenance costs • Repair and rehabilitation cost • Total lifetime costs, expressed in presen t value
Environmental	• Impact on adjacent beaches and properties • Impact on water quality
Aesthetic and social	• Aesthetically pleasing • Socially acceptable

In the case of coastal structures the following major events can be distinguished:

1. Overflow or overtopping of the structure (i.e; instability of the superstructure);
2. Erosion or instability of slopes;
3. Instability of inner sections leading to progressive failure;
4. Scour and instability of toe-protection;
5. Instability of the foundation and internal erosion (i.e; piping)
6. Instability of the whole structure.

All these failure modes must be taken into account in the stage of structural design, by which the undesirable 'by-effects' are prevented or eliminated. Some of the criteria for selection of shore protection measures are shown in fig.3.4.

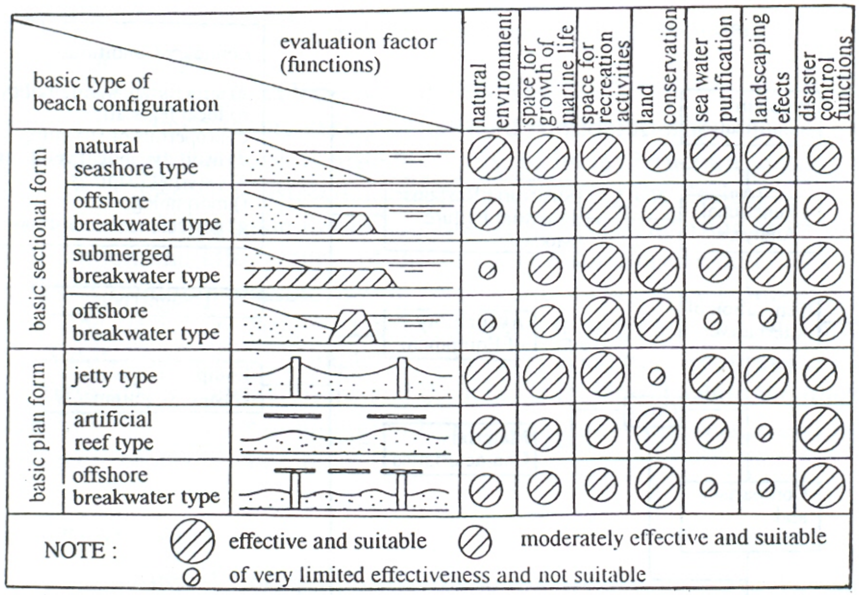


Fig.2.6 Criteria for selection of shore protection measures

2.4.6 Design considerations and methodology

As in many other engineering activities, the design of coastal structures should encompass the following considerations.

1. Specification of the structure's function(s)
2. Description of the physical environment (boundary conditions)
3. Selection of envisaged construction technologies
4. Inclusion into design of the structure's operation and maintenance
5. Conceptual design
6. Preliminary design and selection of alternatives;
7. Geometrical dimensioning based on far-field considerations;
8. Detailed design based on near-field factors, including structural design;
9. Inclusion of possible construction constraints affecting the design;
10. Inclusion into design some flexibility allowing for redesign basing on monitoring of the operation and effectiveness of the structure after construction.

The essence of design methodology and functional requirements of different coastal engineering problem mitigation measures is shown in the fig.2.7. It is seen that the design in various stages is verified through the use of simulation models at different levels of complexity. Boundary conditions (bottom) constitute input to both design considerations and the models employed, while the functional requirements (top) ensure evaluation of the suitability of the design and provide design objectives at the same time.

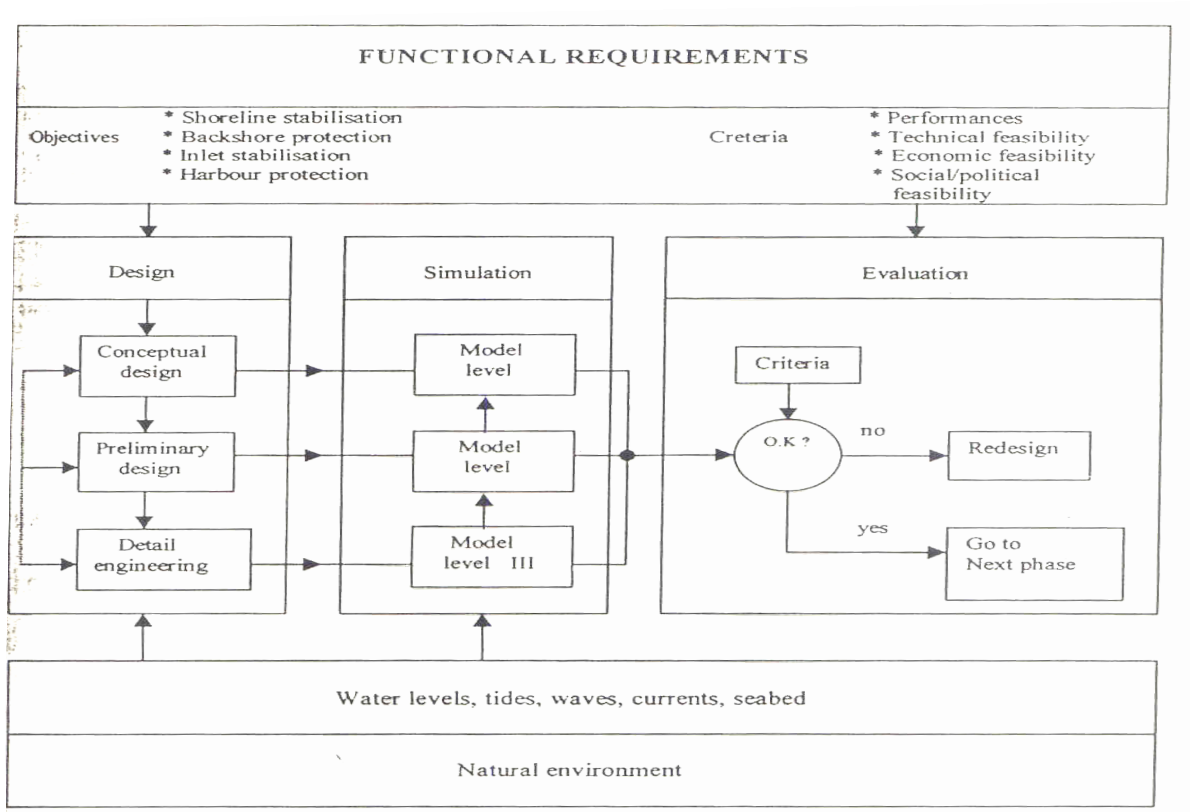
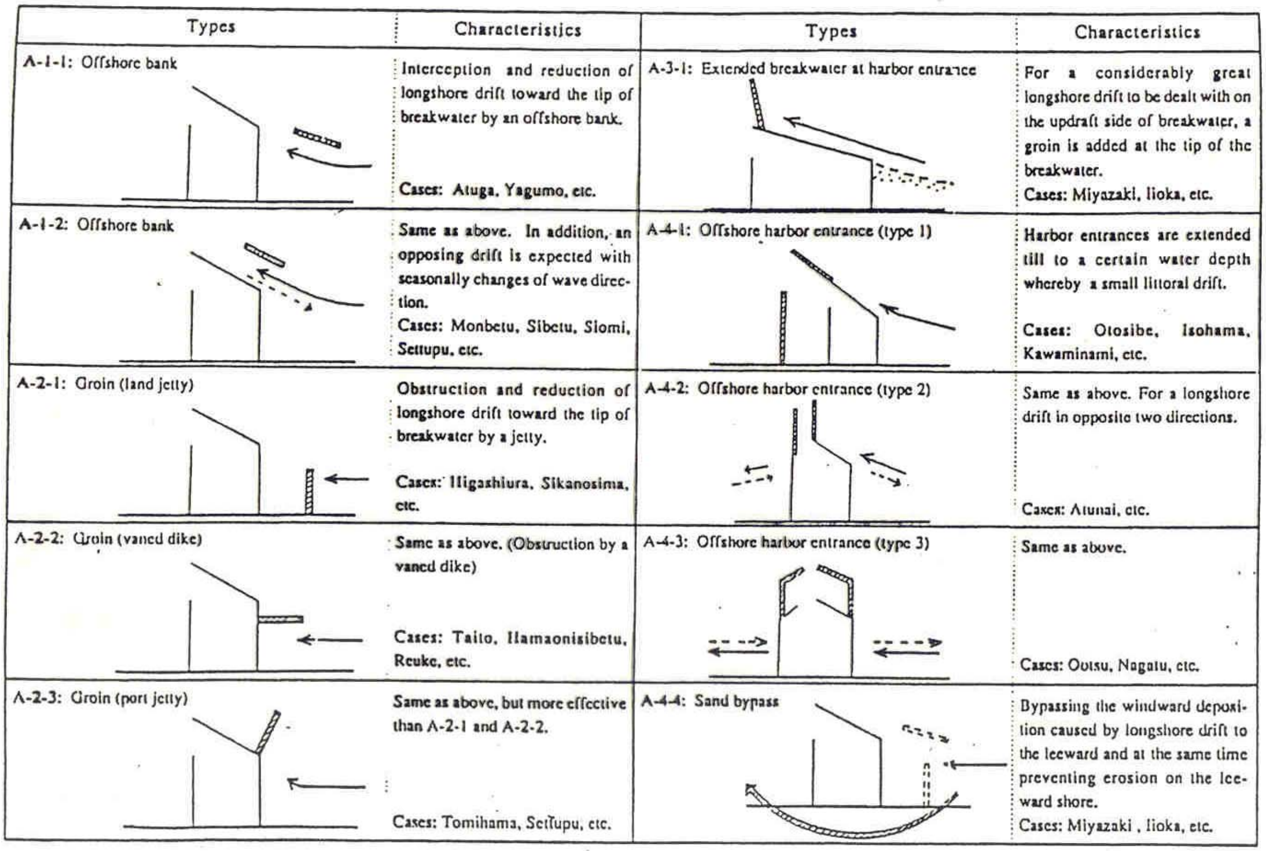


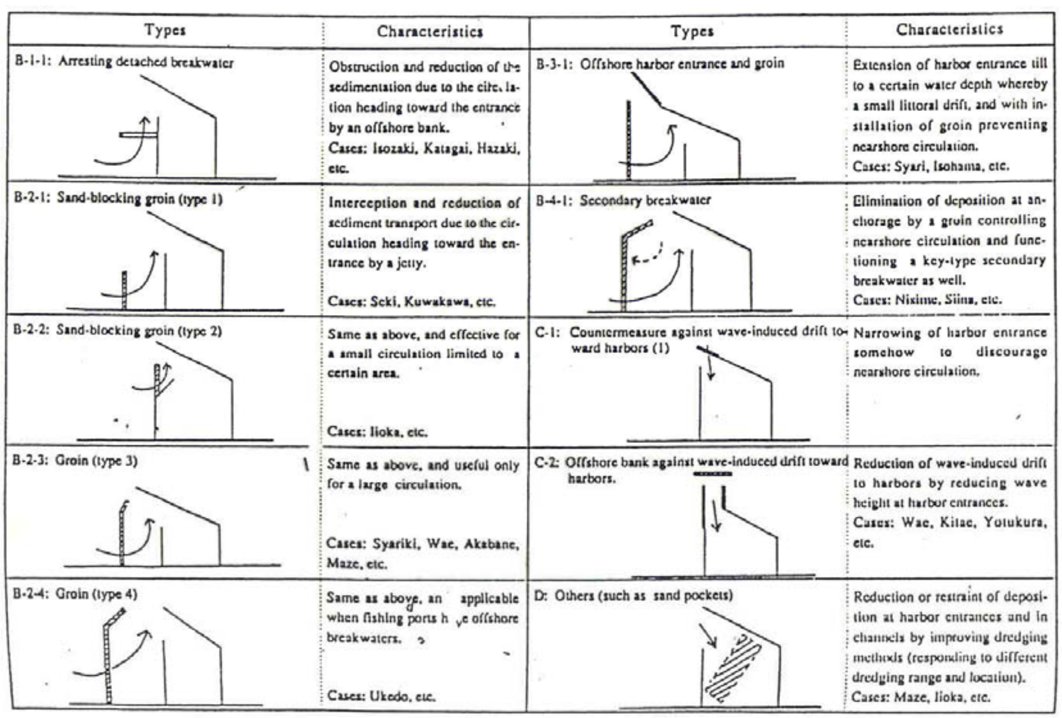
Fig.2.7 Design methodology of different coastal engineering problems

Typical solutions for mitigating the dangers of littoral drift towards harbour entrance channel are shown in the fig. 2.8 and 2.9.



Types	Characteristics	Types	Characteristics
A-1-1: Offshore bank	Interception and reduction of longshore drift toward the tip of breakwater by an offshore bank. Cases: Atuga, Yagumo, etc.	A-3-1: Extended breakwater at harbor entrance	For a considerably great longshore drift to be dealt with on the updraft side of breakwater, a groin is added at the tip of the breakwater. Cases: Miyazaki, Iioka, etc.
A-1-2: Offshore bank	Same as above. In addition, an opposing drift is expected with seasonally changes of wave direction. Cases: Monbetu, Sibetu, Siomi, Settupu, etc.	A-4-1: Offshore harbor entrance (type 1)	Harbor entrances are extended till to a certain water depth whereby a small littoral drift. Cases: Otosibe, Isohama, Kawaminami, etc.
A-2-1: Groin (land jetty)	Obstruction and reduction of longshore drift toward the tip of breakwater by a jetty. Cases: Higashiura, Sikanosima, etc.	A-4-2: Offshore harbor entrance (type 2)	Same as above. For a longshore drift in opposite two directions. Cases: Atunai, etc.
A-2-2: Groin (vaned dike)	Same as above. (Obstruction by a vaned dike) Cases: Taito, Hamaonisibetu, Reuke, etc.	A-4-3: Offshore harbor entrance (type 3)	Same as above. Cases: Ootsu, Nagatu, etc.
A-2-3: Groin (port jetty)	Same as above, but more effective than A-2-1 and A-2-2. Cases: Tomihama, Settupu, etc.	A-4-4: Sand bypass	Bypassing the windward deposition caused by longshore drift to the leeward and at the same time preventing erosion on the leeward shore. Cases: Miyazaki, Iioka, etc.

Fig.2.8 Types of improvement work for the prevention of littoral drift



Types	Characteristics	Types	Characteristics
B-1-1: Arresting detached breakwater	Obstruction and reduction of the sedimentation due to the circulation heading toward the entrance by an offshore bank. Cases: Isozaki, Katagai, Hazaki, etc.	B-3-1: Offshore harbor entrance and groin	Extension of harbor entrance till to a certain water depth whereby a small littoral drift, and with installation of groin preventing nearshore circulation. Cases: Syari, Isohama, etc.
B-2-1: Sand-blocking groin (type 1)	Interception and reduction of sediment transport due to the circulation heading toward the entrance by a jetty. Cases: Seki, Kuwakawa, etc.	B-4-1: Secondary breakwater	Elimination of deposition at anchorage by a groin controlling nearshore circulation and functioning a key-type secondary breakwater as well. Cases: Nisime, Siina, etc.
B-2-2: Sand-blocking groin (type 2)	Same as above, and effective for a small circulation limited to a certain area. Cases: Iioka, etc.	C-1: Countermeasure against wave-induced drift toward harbors (1)	Narrowing of harbor entrance somehow to discourage nearshore circulation.
B-2-3: Groin (type 3)	Same as above, and useful only for a large circulation. Cases: Syariki, Wae, Akabane, Maze, etc.	C-2: Offshore bank against wave-induced drift toward harbors.	Reduction of wave-induced drift to harbors by reducing wave height at harbor entrances. Cases: Wae, Kitae, Yotukura, etc.
B-2-4: Groin (type 4)	Same as above, and applicable when fishing ports have offshore breakwaters. Cases: Ukedo, etc.	D: Others (such as sand pockets)	Reduction or restraint of deposition at harbor entrances and in channels by improving dredging methods (responding to different dredging range and location). Cases: Maze, Iioka, etc.

Fig.2.9 Types of improvement work for the prevention of littoral drift due to nearshore circulation and wave induced towards harbours

2.4.3 Design procedures

Figure 2.10 illustrates the design procedures in a more specific way. The starting point consists of the identification of the beach erosion problem, followed by the selection of the type of protection measure; the final design can incorporate the risk analysis. Attention is drawn to the proper choice of the shore protection measure. The selection is usually affected by the cost.

Aside from the cost, many other aspects must also be taken into account upon selection of the shore protection measure. Some of them are legal restrictions, regional constraints and priorities, construction, operation, maintenance aspects and risk aspect etc.

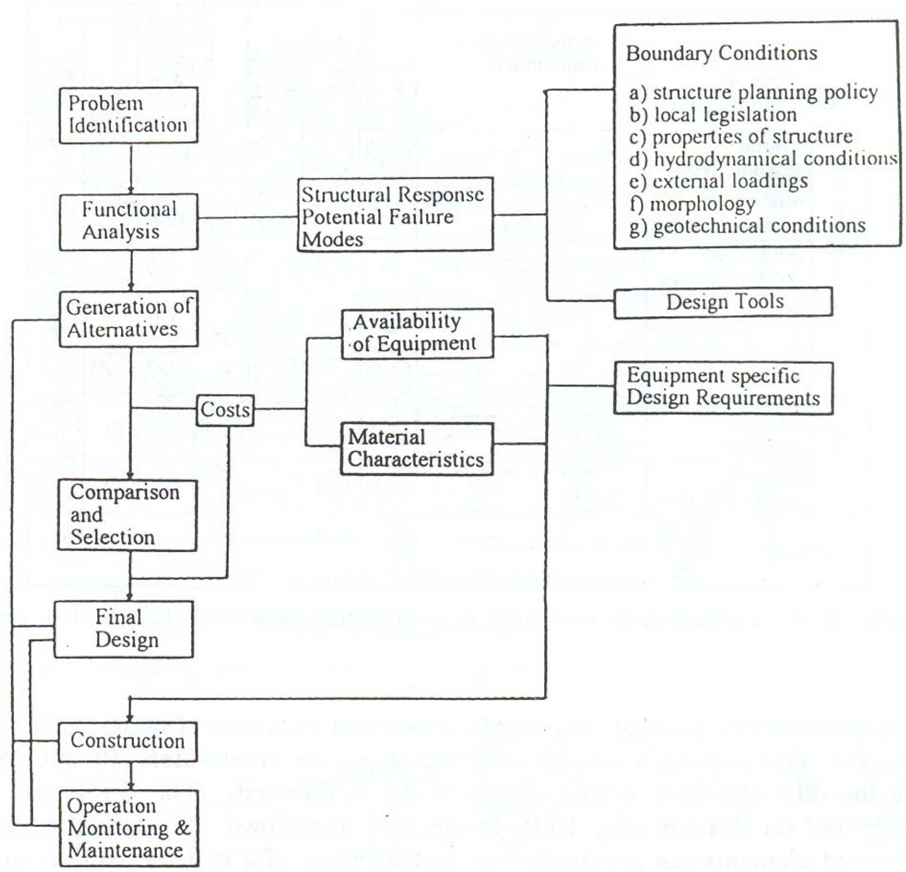


Fig.2.10 Flowchart highlighting the various design procedures

2.4.4 Note of Caution

Coastal engineering problems are unique and site specific due to variety of reasons. Therefore, a generalised scheme of solutions can't be evolved and every problem has to be separately studied and best suitable mitigation measure has to be searched. To implement this concept, all possible causes and outcomes of failure have to be analysed.

Various coastal strategies are adopted to protect life and property against storm surges, to combat erosion and/or to create (often artificial) beaches for recreational purposes, and to preserve the natural environment. There are no absolute rules, nor absolute solutions to the problem of coastal erosion given the dynamic and the diverse character of the shoreline. No single set of regulations, or single land use management philosophy, is appropriate for all coastal situations or settings. The diversity of the coasts requires consideration of a variety of solutions when addressing problems in a particular area.

It should be realised that the effectiveness of coastal structures is verifiable in scales of decades, not years. Various structures have been constructed all over the world without proper examination of their applicability to the coastal conditions at the site, often by unreserved adaptation of earlier solutions. The latter had usually been operated and looked at in time spans shorter than decades (lives of coastal engineers and managers passing their experience to their successors). Although likely to be wrong or ineffective, they might have appeared as successful in short time scales. As such they have been attractive to more designers and contractors, thus displaying the unfortunate property of 'uncontrollable reproduction'.

Hence a word of warning seems appropriate to prevent the designer from repeating the solutions without a careful analysis of the background, site conditions, and evidence of the structure's effectiveness.

2.5 Case Studies

Different hard solutions are adopted in different countries depending up on their individual problems. These vary from beach nourishment and sand filled geotextile tubes to groins and offshore breakwaters. Brief case studies of typical coastal problems and their solutions designed in some of the developed and developing countries are presented in this section.

There are at least 4,000 detached breakwater segments along Japan's 9,000 km coast (Seiji et al. 1987; Japanese Ministry of Construction JMC 1986). Fifteen segments provide protection to the 300 km of Israeli Mediterranean shoreline (Goldsmith & Sofer 1983); and 80 breakwater segments were constructed on the Danish North Sea coast by mid-eighties (Laustrup 1988). Shore-parallel structures for shore protection have been used in Spain (Berenguer & Enriqez 1988) and Singapore (Silvester & Ho 1972, Chew et al. 1974) and are being evaluated for a major coast protection scheme in Negombo, Sri Lanka (Danish Hydraulic Institute 1988). Many other countries are joining the club of offshore breakwater users.

At Massachusetts USA, sand filled Nylon fabric bag protective structure, supports the perched beach at Bay Road; Dead Nuk Island and Morris Island and Sunken Meadow Beach (Gutman 1979). Yet the importance of this form of shore protection is felt to be underestimated in United States (Chasten et al. 1993). Seventeen detached breakwater projects (46 breakwater segments) exist along 9,200 km of the continental US and Hawaiian shorelines. Seventy-one additional segments either are in the early stages of construction or are planned for construction within the next few years by the US Army Corps of Engineers.

The documented performance of offshore breakwaters, in particular in Japan and Israel, demonstrates that this type of shore protection is both effective and versatile, successfully performing in low to moderate wave energy environments with sediment ranging from fine sand to pebbles (Pilarczyyk and Zeidler, 1996).

The coastal problems and the different solutions adopted in various countries are illustrated in this chapter which can be very valuable in providing guidance to solve our own problems in India.

2.5.1 Nigata Coast, Japan

For Nigata Coast, several types of breakwaters, all permeable in nature were considered and were tested by many people. From the previous experimental studies, it was found that if the height of the submerged breakwater (h) is less than 70% to 80% of the water depth, where the structure is located, the damping action against the incoming waves is not significant. Observations were made at two stations namely Ojoin beach and Kosoda beach. The height of waves damped by submerged breakwater was found to be 30% to 70% of that of the original waves. The steepness ratio of waves damped by breakwater was 10% to 70% of that of the original waves. The wave steepness was ranging from 0.02 to 0.08 and in both beaches they have studied the variation of beach profiles due to the presence of submerged breakwater by field observations and by experimental work. The laboratory experiments consist of models of hollow block and 'L' type submersible breakwaters, which were constructed at Nigata west coast. It was found that the scour around the breakwater was considerable when the structure is located in the breaker zone. It depends on the observed h/d. As h/d ratio reduces the scouring will increase where the structure is placed in surf zone. It was also observed that the scouring action would increase as h_s/d increases, when the structure is placed in off shore zone.

2.5.2 Norfolk Happisburgh, Winterton (UK)

A case study as quoted by Pilarczyk and Zeidler (1996) of the Sea Defence work. The aim of the scheme is to build up salients or headland-shaped features behind the reefs rather than complete tombolos (spits of sand connecting the beach to the offshore reefs) which would intercept longshore transport (by Pilarczyk and Zeidler

1996).

In summary of the key design points it should be stated that the primary requirement imposed on the reefs is to reduce and control wave energy in the nearshore zone. The design criteria are to limit wave transmission to 60% during extreme storm conditions, whilst allowing on average at least 40% under normal conditions to avoid excessive interruption of alongshore sediment transport. The philosophy adopted is to provide low crested porous structures which would also be high enough to break larger storm waves, thereby reducing beach volatility. The final design has been to use 20-tonne Accropodes and 8 to 16-tonne rock with the armouring which will overlay a wide berm of graded rock. This will prevent scouring and assist with the overall structural stability. A bed protection incorporating a geotextile is also placed beneath the rock. An overall crest elevation of + 3.0 m CD is required to ensure transmitted waves are sufficiently reduced during the most extreme design conditions.

2.5.3 Negombo project, Srilanka

Negombo Project area is situated on the west coast of the island extending from the Negombo Lagoon outlet in the south to Porutota in the North. The coast in this area is subject to high level of development pressure arising from fishery, tourism and residential requirements.

The breakwater scheme described by Mangor et al. (1992) covers a coastal stretch of 4 kilometres. Together with a groin scheme at the lagoon entrance the project coastline is about 7 km long and it is partially protected by existing stone revetments and groins.

The erosion experienced in this area is reported as 2-3 m/year over the last 25 years. Because of the development pressure and the heavy erosion rate, this area was considered at high national priority for providing protection. Major tourist hotels spread along 2.5 km of the beach were threatened, along with a 2.5km long stretch with low cost housing and existing fishery facilities. The Master Plan estimates an annual net loss of 40,000 m^3 of coastal sediments from the project area. The littoral drift is indicated to be less than 50,000 m^3/year with a neutral area in Ettukala, front which net drift is towards the south as well as to the north.

The concept for the Negombo Coast Conservation Scheme has been formulated as beach nourishment stabilized by four offshore breakwaters. Four breakwaters have been arranged in a stretch of 4 kilometres. They are located approximately 140 m from the coastline at 3 m water depth. The length of the breakwaters varies from 168 m to 182 m and the distance between breakwaters (center to center) varies from 906 m to 1026 m. The breakwaters are turned 6 to 8° from the bearing of the coastline.

The breakwaters have been located in such a manner that breakwaters do not directly cover any of the major tourist hotels but will result in development of beaches in front of them, breakwaters have least interference with previously demarcated beach fishing grounds and erosion of coast in lee of breakwaters does not proceed beyond the original shoreline.

2.5.4 Belgium

The Belgian coastline is characterized by a 65 km long stretch of sandy beach/dune barrier. The coastal barrier is a dynamic system in equilibrium with the prevailing hydro-meteorological conditions (sea-level, waves, tides, winds) and is thus subjected to fluctuations in location and height of the beaches and dunes. Since the early 1900's, several constructions along this coastline aimed to provide coastal protection for the polder hinterland or to allow tourist resorts and urban developments. These infrastructures for coastal protection or coastline fixation are essentially combinations of sloped sea-walls, groin-fields and beach profiling/replenishment works (Helewaut & Malherbe 1993).

The growing urban development and touristic exploitation of the coastal area, together with the assessment of eroding coastal sections, create the need for integrated and flexible coastal protection actions. Therefore several beach nourishment projects have been designed and/or executed for the last 15 years, some of them in combination with offshore breakwaters.

2.5.5 Bulgaria

The Bulgarian Black Sea coast has a variable relief, complex geological structure, and a combination of different types of cliffs and depositional and erosional forms. The coastal zone is intensively developed for industrial and recreational purposes.

The main problems of coastal protection against erosion are related to the type and development of the geodynamic processes. They also depend on the distribution of the dominant types of coasts: abrasional, landslide, accretional, and abrasional-accretional. Each of these types of coasts offers specific problems regarding coastal protection (Nikolov et al. 1988b).

2.5.6 Italy

Franco (1985) collected information on about 700 rubble-mound detached breakwaters built along Italian coasts and derived relationships linking geometrical parameters of the breakwaters, despite their dissimilarities and scatter. Typical length is 100 m, gap width 30 m, water depth 3.5 m, distance from shoreline 100 m, crest width 4 m at + 1 m above SWL, seaward slope 1:2 to 1:3, and shoreward slope 1:1. The direct effect of submerged breakwaters is seen by Franco (1990) in the limitation of wave transmission due to the breaking of the largest waves on the breakwaters.

An outline of Italian coastal structures, including offshore breakwaters, for the Veneto coast, has been given by Liberatore et al. (1991). The Veneto coast extends along the Northern Adriatic from the mouth of the Tagliamento to that of Po di Goro (a southern branch of the Po River) for about 130 kilometres. It consists entirely of sandy beaches, fed by the sediments of many large Italian rivers (first of all the Po). The coast is interrupted by a number of rivers and tidal inlets, the most important of which are those connecting the Venice Lagoon to the sea.

Most of the Veneto beaches are intensively exploited as seaside resorts, and many of the rivers and tidal inlets are used for navigation (generally by pleasure and fishing craft, whereas commercial or industrial shipping is limited to the larger inlets, such as those leading to the Venice Lagoon and some major branches of the Po).

As a consequence of intensive coast exploitation, a number of structures were built: some inlets were stabilised with jetties (the oldest ones dating back to 1840, when improvement at Malamocco was started), and a number of protective structures were built along the beaches to combat erosion. Some of the protective structures were built centuries ago.

Selection of structures built to protect beaches from erosion has also been questionable in some cases, limited attention being paid to understanding coastal processes and interferences with new structures. For some beaches this also resulted in redundant protective structures, greatly altering natural features.

Very limited recourse to nourishment and sand bypassing works is also observed, contrary to the more general trend in the world, which is to avoid the use of rigid structures on the beaches as much as possible.

2.5.7 Japan

The amount of offshore breakwaters is increasing at a remarkable pace since they are believed to effectively reduce and absorb incident wave energy (CEM, 2006). However, detached breakwaters, as well as the wave absorbing block mounds in front of seawalls, detract from the coastal landscape and prevent the effective utilization of many coastal regions. Recently, with the increasing concern for the preservation of coastal environments and easier access to the shoreline, and with demands for pro-water front, new forms of coastal protection works have been devised in Japan:

(1) Gentle slope sea dikes with permeable surfaces,

(2) Submerged breakwater with wide crown widths or artificial reef,

(3) Beach nourishment,

(4) Headland defense works.

2.5.8 Spain

Berenguer & Tamayo (1988) discuss beach restoration at Malaga urban area (Pedregalejo case study) using pocket beaches. The study was based on the assumption that the existence of a beach is a primary factor for the development of the adjacent urban areas.

Berenguer and Enriquez (1988) take for granted that pocket beach is a usual method to restore an eroded or regressive coast without natural sand supply. Some forty beaches of this kind are claimed to be found on the Spanish coast. They consider the design parameters of pocket beaches, based on the analysis of data collected from 24 existing beaches on the Mediterranean coast of Spain. Fourteen of these beaches have been studied in detail; nine of them located on the Alboran Sea and the other five on the Catalan coast. Data from 10 additional beaches have also been considered. Different parameters such as structural design, location of breakwaters, beach planform, beach profile, wave conditions at the site and sediment conditions have been analyzed. A mathematical model has been used for the study of the shoreline equilibrium planform. Practical coastal criteria in design considerations have been drawn from the observed behaviour of the studied beaches.

Pedregalejo is one of the coastal districts of the city of Malaga, 4 km away from the city center and the commercial port. At the beginning of this century Pedregalejo beach, 1,200 m long, was nearly 50 m wide. Uncontrolled growth of low-standard houses invading the back part of the beach, and gradual beach erosion due to wave action induced the disappearance of the emerged beach in 1977. These negative processes together with a total absence of urban services (sewerage, cleaning, etc) were the reasons for degradation of the beach area.

Several kinds of protective works were discussed. The solution of a longitudinal defence was discarded due to its inability for generating a wider beach. The variability and relative weakness of littoral transport, together with the steep slope of the submerged beach (2-4%) advised against the use of straight groins if they were not accompanied by artificial nourishment. The inclusion of a maritime promenade, more than 8 m wide, between the houses and the beach forced to advance the shoreline more than 40 m seaward. There was not too much sand available, and the nearest quarries were more than 20 km far from site, at the other side of Malaga. So it was decided that this solution, as well as the option of simple artificial nourishement, would require too high quantities of sand, as inferred from the volumes used in the restoration of other beaches.

The solution finally adopted was to build a system of groins, detached breakwaters and platform-islands which, besides reducing wave energy reaching the build-up area, minimized the necessary contribution of new sand and decreased its maintenance, as far as possible. In addition, the curved shape of beach caused by wave diffraction, would increase the length of the resulting shoreline as compared with the existing one.

The maximum size of the quarry-stones for the detached breakwater and groins has been 5-6 Ton placed on two layers on a 1 on 2 slope. On the inner side of the breakwaters, 3 Ton rubble mound has been used. The platorm-islands and the first segment of the groins have a concrete pavement, 25 cm thick, which allows them to be used as a promenade or a solarium.

2.5.9 Rome

Ferrante et al. (1993) provide a description of a new large project of artificial beach nourishment protected by a submerged sill carried out at Lido di Ostia near Rome in 1989-1991.

The sandy beaches of Lido di Ostia stretch along the southern delta cusp of the Tiber River, some 25 km from Rome on the Tyrrhenian Sea and represent a very popular holliday resort for the Roman community. The cuspated delta was formed by alluvial sediments carried by the river, producing a progressive coastline advance of more than 4 km from the Roman age until this century. Then, particularly in the last 25 years, a severe erosion process has been taking place reverting the evolution trend to a recession rate of 1.7 m/year. The main cause has been the strong reduction of river sediment supply (due to upstream dams and extraction of building material from the river bed) with a subsequent deficit in the coastal sand budget and a trend towards the cusp straightening and smoothing out.

The local tidal range is very small (below 0.5 m), but deep water waves may exceed a significant height of 5 m and a period of 10 s. Recent coastal protection works have been partially successful, such as the system of detached breakwaters constructed near the river mouth erosion was shifted down drift, mainly affecting the southern beach between the Vittoria Pier and the Pescatori Canal, causing damage to the beach clubs and even to the littoral road during storm periods.

The project was to recreate a wide protective beach with an efficient technical defence solution complying with the economical, managing, political and environmental requirements.

Given the existing high deficit of the littoral sand budget, the proposed beach nourishment needed to be protected by some coastal structure able to dissipate part of the wave energy and reduce the littoral transport, and to retain the new fill material. The most suitable solution then included an offshore underwater rock barrier 'fixing' the natural dynamic sandy bar, as a 'perched beach' scheme.

The protection scheme covers a beach length of 3 km and basically consists of a sill made with a submerged rubble mound parallel to the shoreline at a distance of some 150 m, with toe level at MSL -4.0/-5.0 m, a 15 m wide crest berm at -1.5 m, seaward slope of 1:5, a multilayer rock mound (maximum stone weight of 1 t) placed above a geotextile and a 5 m wide rock toe protection in a 1m deep trench.

2.5.10 South Korea

Shore erosion is currently causing millions of dollars worth of damage to shorelines and public properties along the east coast of Korea.

Young In Oh and Eun Chul Shin (2006) present the various issues related to the geotextile tube construction for shore protection at Young-Jin beach on the east coast of Korea. A new approach to a stability analysis by 2-dimensional limit equilibrium theory is highlighted and the hydraulic model test results and case history of Young-Jin beach projects are described. Based on the results of stability analysis and hydraulic model tests, a two line geotextile tube installed with zero water depth above crest was found to be more stable and effective for wave absorption than other design plans. Also, the shoreline at Young-Jin beach was extended by about 2.4–7.6 m seaward and seabed sand was gradually accumulated around areas covered by the geotextile tube.

2.5.11 Kerteh Bay, Malaysia

Kerteh Bay is located on the embayed east coast of peninsular Malaysia, located within the Terengganu State. The Rantau Petronas Complex, which consists of housing facilities, a school complex and a golf course, is situated within the Kerteh Bay.

Much of the coast consists of a series of large and small hook-shaped bays. In recent decades the Kerteh Bay suffers from accelerated severe coastal erosion. The bay is widely exposed to direct wave attack. During the annual north-east monsoons blowing from the South-East China Sea, storm period the erosion attack on the Rantau Petronas Complex is of such a severity that the sea encroaches the beach up to the very limits of the Complex. The acceptable risk level has been exceeded so that in near future an immense damage to the Complex facilities will occur. In order to prevent that substantial loss of investment, the Petronas authorities decided to implement protective measures in order to restore and preserve a safe beach width in front of the Complex.

The stretch of the beach to be restored and preserved was approximately 2100 m. Generally, the site is blanketed with coarse to fine sand. A typical cross-sectional bathymetry shows that the sandy beach gradually declines at a slope of 1:10 above ACD (Admiralty Chart Datum), a slope of 1 :50 between ACD and 3.0 m - ACD, and a slope of 1:100 deeper than 3.0 m - ACD.

The coastal landscape of Terengganu State is dominated by low elevation coastal plains of variable width, interrupted by numerous headlands and river outlets. The coastal plain is locally covered by a number of beach ridges and backed by a fluvially dissected, hilly terrain. Along the entire stretch of coastline, sandy beaches dominate. Sand spits and tidal swamps are, furthermore, commonly developed at and within the larger river mouths.

The highest astronomical tides (2.7 m + ACD) usually coincide with the northeast monsoon period, which is between December and March.

The design surge, having a recurrence period of 40 years, is 0.8 m. The resulting DWL is 3.5 m + ACD and highest tide was +2.7. With respect to extreme design waves, having the return period of 30 years, the following figures resulted:

(a) 600N direction: H. = 4.0 m, T = 9.0 s;

(b) 300N direction: H. = 6.4 m, T = 10.0 s.

The littoral drift rate, associated with the dynamically stable configuration of Kerteh Bay, was assessed about 210,000 m^3/year, of which more than 80% is transported during the NE monsoon period. The upcoast sediment supply from Paka Bay is largely transferred into Kerteh Bay via offshore bar bypassing at the northern end of the bay. The 'supply point' on to the coast of Kerteh Bay is located immediately updrift form Rantau Petronas Complex, which makes this coastal stretch particularly vulnerable to any disruption of the equilibrium situation. The observed erosion over this period would indicate an average deficit in the upcoast sediment supply of some 40,000 m^3/yr. The cause and persistency of this deficit is unknown, but quite likely they originate from shore developments within the upcoast Paka Bay. The deficit in upcoast sediment supply yields a gradient in the longshore transport along the shore front of Rantau Petronas Complex, which is believed to constitute the main cause of erosion in the area. The offshore losses might be a possible sediment sink. It appears, however, that the cross-shore mode of transport in the present, unstable situation at Rantau Petronas Complex shows a predominant onshore component; in other words, nature acts as to replenish part of the material which is lost in alongshore direction. Obviously, some erosion and consequent retreat of the upper beach face may still occur during storm events.

The design philosophy with respect to generation, evaluation and selection of basic concepts of adequate measures against the coastal erosion were pointed out. Four possible basic concepts generated were: a beach nourishment, a revetment, a groin system and a detached breakwater scheme (Lindo et al. 1993 and Tilmans et al. 1992).

Groins and beach nourishment were concluded to be technically better than the other alternatives. One of the disadvantages of the system is that sand losses can still occur due to offshore transport during severe storms.

However, offshore breakwaters with beach nourishment are found to be the most adequate system in technical terms. The concept with offshore breakwaters offers protection to the beach by reducing the incoming wave energy. In this way, if properly designed, not only the longshore transport gradient is reduced but also the risk of offshore sand transport is considerably diminished. Moreover, the amount of beach nourishment required is limited, also compared to the groins alternative. Due to the anticipated stability of the breakwaters itself as well as the shelter against wave attack offered to the beach, this system is considered the most durable of the alternatives considered and maintenance requirements will be minimal.

Comparison of the initial capital investments shows that the protection system consisting of groins and a beach nourishment is the least expensive one. However, taking into account the capitalized maintenance costs, the picture changes radically. Because the breakwater system only requires a relatively small amount of maintenance and renourishment of the beach is not required, this option turns out to be the cheapest solution in time.

2.5.12 Swaminarayan Mandir in Valsad-Gujarat

The Swaminarayan Mandir in Valsad-Gujarat is situated at a distance of around 200-250 m from the seashore. The shore suffers extensive erosion due to strong wave action and the formation of eddies contributed by the adjacent river and high velocity winds. Seabed erosion had almost reached to the walkway of the temple and posed a threat to the structure in the long run. The problem of erosion is so tremendous that roughly 6-7 m of the shore are lost per year.

The help of CWPRS was taken to restrict the erosion and have a full proof solution in the long run. After studying the problem CWPRS suggested the use of Polymer Rope Gabion for construction of Anti Erosion Sea wall and using Woven Geotextile as a filter media below the gabions.

After completion of the job, washed out land of about 30m x 330m was reclaimed and beautified by the temple authorities for pilgrimage purposes. The gabion wall is performing very well and about 3m deep silting has taken place at the wall. The sea wall after 4 years is absolutely in sound condition even after being subjected to severe cyclonic winds and rainfall. No major maintenance cost has been incurred during the last 4 years (Venkatraman M., 2004).

2.5.13 Kanyakumari Coast

The various stretches along the coastal line in Kanyakumari district were facing a problem of severe bank erosion due to the tidal actions. This was causing a threat to the nearby fishermen villages and some of the villagers needed to shift their structures away from the coast.

It was proposed to construct parallel sea walls along the 28 stretches wherever the severity of the problem was more. Use of polymer rope gabions was proposed taking into view the effect of wave action and usefulness of gabions.

The project is completed and these walls have reduced the erosion to considerable proportions. Its performance is much better than the old seawalls constructed by just dumping stones without using gabion and geotextiles (Venkatraman M., 2004).

2.5.14 Theronda coast, Alibaug, Maharashtra

The Theronda coast suffered bank erosion due to the tidal actions. The severity of the problem was major, as large portions of the land was getting affected due to this.

It was proposed to construct a parallel sea wall along the coast of Theronda. For the construction of the sea wall the use of polymer rope gabions was proposed taking into view the effect of wave action and usefulness of gabions (Venkatraman M., 2004).

The project is still in the construction phase and the completed portion of the wall has reduced the erosion to a considerable proportion.

2.5.15 Ponnani Estuary, Kerala

Ponnani (10°47' N latitude and 75°55' E longitude) is a major fishing and landing centre in Malappuram district of Kerala state is facing a similar beach erosion problem as in the vicinity of Netravathi-Gurupur estuary. Ponnani is situated on the southern side of Malappuram district. Two rivers namely, Bharathapuzha and Tirurpuzha join together in the confluence and their discharge passes through a common river inlet at Ponnani. Ponnani has been functioning as an estuarine port for a long time. The importance of this port started dwindling since the last two decades due to the formation of shoals in front of port wharf and shallow outer bars at the river mouth. The two rivers joining at Ponnani were rather shallow and the bathymetry at the entrance was complicated due to shallow water depths causing shift in the natural channel and frequent modifications in the adjoining beaches connecting the shallow bars. The inlet had very limited area of cross section. Due to the complicated bathymetry and inlet shifting, the fishermen were facing considerable difficulties in manoeuvring their vessels. From the model studies conducted in CWPRS, Pune, it was suggested that two rubble mound breakwaters, one 780m at the north and the other 570m at the south, be constructed at the inlet for maintaining a safe navigational channel.

As per the recommendation of model studies and design, the construction of breakwaters, the major component of the harbour was officially commenced in May 2002. It has been noticed that there are tremendous impact/coastal changes after the commencement of breakwater construction in the estuary. The construction of the breakwaters has advanced up to 595m on the northern side and 250m on the southern side. The work is now stopped due to some contractual and local issues. The issue is being sorted out to resume and complete the work.

It has been found that during post monsoon season there is considerable erosion to the north of north breakwater and marginal deposition on the south of south breakwater. This situation is reversed during the monsoon and pre monsoon seasons. It is concluded that there is net accretion on the north and net erosion on the south of the breakwaters. These changes have been attributed to the trapping of reversing littoral drift occurring naturally off the Ponnani coast (Paravath and Pareeth, 2006).

2.6 SUMMARY

The coastal problems such as beach erosion, inlet stabilization etc are commonly found in all maritime countries. However, they are unique and site specific due to variety of reasons.

Various coastal strategies are adopted to protect life and property against storms, high waves and to combat erosion and/or to create artificial beaches and to preserve the natural environment.

Different solutions are adopted in different countries depending upon their individual problems. These vary from beach nourishment and sand filled geotextile tubes to groins and offshore breakwaters.

No single set of regulations, or single land use management philosophy, is appropriate for all coastal situations or settings. The diversity of the coasts requires consideration of a variety of solutions when addressing problems in a particular area. To implement this concept, all possible causes and outcomes of failure have to be analysed.

3

BEACH EROSION AROUND NETRAVATHI-GURUPUR ESTUARY

3

BEACH EROSION AROUND NETRAVATHI-GURUPUR ESTUARY

3.1 Introduction

Large scale coastal erosion in the last couple of decades has raised doubts as to whether the erosion is a recent phenomenon. Dynamic changes have occurred in this fragile boundary between the land and the sea, ever since this interface was formed. But the changes have attained public attention only now because of heightened human interference.

Severe coastal erosion was highlighted in 1996 during the monsoons along the coastal stretches of Kotepura in Ullal town of Mangalore Taluk of Dakshina Kannada (D.K.) District in Karnataka State. Most of the changes on the D.K. coast are of a cyclic nature maintaining a long term dynamic equilibrium (Dattatri et. al., 1997). The site of erosion is a barrier spit over a length of 1.4 Km connected to main land at one end. The other end of this spit was free to migrate as a part of changes in shoreline around the mouth of River Netravathi. Similarly, in the north, known as Bengre spit exists running parallel to the mainland. Gurupur River also joins this mouth running from north adjacent to Bengre Spit. The migrations of both the spits have been contained with the help of breakwaters since 1994 and the navigability of the fishing vessels have been improved. Subsequently wide scale erosion and accretion have been reported in Ullal and Bengre respectively.

Another site of similar problem exists near the estuary of Sharavathi and Badagane rivers at Honnavar in Uttara Kannada (U.K.) District in Karnataka. Honnavara Town is situated on the northern bank of River Sharavathi. The river Sharavati joins the sea on the eastern side of Honnavara. A small river Badagane also joins river Sharavathi and these two rivers together form an estuary to join the Arabian Sea. Similar to Netravathi river mouth, this river mouth also has two narrow sand spits on either side. These spits are locally known as Kasarkod sand spit on the southern side and

Pavinakurve sand spit on the northern side of the river mouth. Pavinkurve spit is experiencing severe erosion since 1995 resulting in northward migration of the river mouth.

The erosion in the vicinity of these river mouths may be due to the interplay of wave onslaught during the monsoon, the monsoon water discharges through this inlet, the combined flow patterns due to these discharges, tides, waves, decreased sediment load from the land and ground water discharge. Subba Rao (1999a, 2002a) observes that there are significant natural changes occurring in the river mouths of D.K. district and assumes importance when these areas are encroached by population. Solutions including rubble mound revetments have not yielded useful results for shore protection. Hence, there is a need for detailed investigations. However, the study of coastal erosion presented in this chapter is limited to erosion around the Netravathi-Gurupur river estuary.

3.2 Study Area

The Western Ghats or the Sahyadris, the westfacing scarp nearly paralleling the west coast of India, the host of the tropical evergreen forest, plays an important role in the precipitation of the south-west monsoon. Geologically, the Ghats comprise, granulite in the south, granite-greenstone in the middle and the Deccan traps in the north. This is the region where the largest river of Dakshina Kannada, i.e.; the river Nethravathi originates. The area enjoys a humid tropical climate and receives an average annual rainfall of about 3930 mm (KREC Study Team, 1994). The main rock types are peninsular gneisses and schistose rocks. Wadia (1975), Subrahmanya (1987), Ravindra and Krishna Rao (1987) argue that landslides too can be a factor for the retreat of the Ghat scrap. Large scale mass movement is generally ascribed to the tectonic activity and the presence of less resistant rock mass which are easily susceptible for denudational processes. Sissakian (1982) opines that rocks loose their cohesion due to weathering, especially mechanical weathering which increase the possibilities of water penetration. This leads to an increase of the pore pressure and consequently decreases the cohesion and internal friction angle which in turn will trigger the sediment movement on slopes.

A striking feature of districts of D.K. and Udupi (the erstwhile D.K. district) is the coast-parallel river bends and the confluence of two or more rivers before they join the sea. Because of these features the shoreline of the area can be classified into two main categories : a) barrier-beach shoreline and b) strand plain shoreline. The barrier beach shorelines are those adjoining coast parallel rivers as at Bengre near Mangalore, and Hangarakatta in Udupi District.

The study area for the present project consists of Netravathi-Gurupur river mouth and the areas in its vicinity which are situated in D.K. District at the south west corner of Karnataka State. The coastline is dotted with open coastal stretches and river mouths/estuaries. The southern part of Karnataka Coast is categorised as "rocky coast with barriers" and is transitional in character from the cliffed Konkan coast to the north and alluvial plain coast of Malabar to the south. Netravathi and Gurupur rivers have the catchment areas of about 3432.8 km^2 and 824 km^2 respectively with maximum discharges of 8170 m^3/sec and 1140 m^3/sec respectively (Lakshman & KREC Study Team, 1994). The sea water intrusion is up to a distance of 20km in the Netravathi river and up to 15km in Gurupur river during summer (Subrahmanya and Jayappa, 1987). The river borne sediments are of size 2.8mm while the sea borne sediments at Bengre varies from 0.17 to 0.87 mm and 0.24 to 2.83mm at Ullal beach.

The D.K. District experiences tropical and monsoon climate, with constantly high humidity with alternate wet and dry seasons. Besides the regular monsoon, the Arabian sea and the West Coast of India is also exposed to occasional cyclones, but the effect of cyclones are minimal for this coast. The temperature in the coast is generally equable with temperature ranging between 20 to 36°C.

The climate of this region is marked by heavy rainfall, high humidity and oppressive weather conditions in summer. SW monsoon months are the coolest (mean daily temperature is < 29° C) and April-May are the hottest months of the year. The air is highly humid all through the year. Winds are strong and mainly westerly or southwesterly during SW monsoon months. During the rest of the year, winds blow mainly from directions between north and east in the mornings and westerly or northwesterly in the afternoons (Jayappa et. al., 2003).

Rainfall controls coastal processes of this area and determines fresh water discharges into the Arabian Sea through various river systems. The detritus from the Western Ghats, isolated hilltops in the midland and lowlands collected and transported to coastal areas through the river systems, nourish the adjoining beaches to some extent. This is a process associated with heavy rainfall, which is concentrated during SW monsoon months.

The SW monsoon generally reaches Kerala by 1st June and Mangalore around 1st week of June and withdraws by about end of August or mid September. The winds become W/SW increasing in strength reaching its peak value by July. After August, a reverse series of change in the predominant wind direction accompanied by a decrease in the strength leads to the NE monsoon with October and November being quiet. By mid November the NE monsoon blows regularly in the North and by mid December in the South also (KREC Study Team, 1994).

The D. K. coast is subjected to very strong sea breezes during the non-monsoon months. The sea breezes in the afternoons predominate over the land breezes in the early mornings.

Deep-water waves approach this coast from the directions between W, SW and NW. The maximum significant wave height (H_s) is about 3.44 m with the average zero-crossing period of 10.4 sec. The largest single wave recorded is about 5.4 m and typical SW monsoon waves are of height about 4 m. Tides are semidiurnal with a mean tidal range of 1.2 m. and spring tidal range of 1.8 m. (KREC Study Team, 1994).

The ocean waves are high along coast in the months from June to September. Wave periods range from 9 to 10 seconds in monsoon. Maximum wave height recorded is 6.5 m while the wave heights are less than 1m during non-monsoon season and the wave periods show wide variation with the presence of long period waves. Predominant deepwater wave direction in monsoon is SW, W and NW. These waves become almost parallel to coast due to refraction as they near to shoreline (KREC Study Team, 1994).

The Ocean currents along the D.K. coast during the months of February to September is generally towards the South with velocities ranging from 0.11 to 0.41 m/sec. During the months November to January, the current in general is towards the North with velocities of 0.11 to 0.31 m/sec.

The sediments brought by the rivers are primarily suspended load which consists of the clays and the silts and this is dispersed by the ocean currents. The sand fractions are deposited in the beaches adjacent to the river mouths.

Studies carried out along the West Coast have shown that there are a number of beach ridges alternating with swales indicating progradation of land. The progradation of the land is also confirmed by the configuration of the shoreline which is convex towards the sea. When the entire stretch of 25 km from Ullal to Mulki is taken into consideration, there is a greater volume of sand accreted than eroded indicating widening of the beaches in most of the areas. The erosion of the coast here occurs in isolated pockets in the open coast as well as in the vicinity of estuaries. Further, the erosion is of a temporary nature in the sense that eroded beach would be almost recovered in the post monsoon season. Beach width variations of the order of 100 m between monsoon seasons and post monsoon seasons have been measured but the beach has been almost restored to its original position in most of the cases of erosion in open coasts. The only reports of permanent loss of land due to erosion on the D.K Coast have been at the river mouths and the beaches adjacent to it (KREC Study Team, 1994).

During the course of detailed beach profile studies, it became clear that though some pockets are undergoing erosion taken as a whole, the south Karnataka beaches are accreting (Subrahmanya, 1996) while according to KREC Study Team (1994); the beaches are in dynamic equilibrium.

Investigation of the Netravathi River channel reveals that even in areas where the gradient in river terraces with stratified sediments gently in the down stream direction are present. A valley deepening coastal region has a rugged topography as evident by flat topped lateritic mesas cut by deep parts. Geological mapping of Mangalore area have two linear bands of pebble beds which are north of and nearly parallel to the present day channel of Netravathi. The pebble beds indicate paleochannels of Netravathi suggesting that the river course has migrated southwards. A similar southward migration of river is revealed by the study of aerial photographs and satellite images. Comparison of offshore bathymetric records with the present data indicates that there is seaward uplift.

South of Mulki, near Surathkal, an oyster, which is now dead, is seen fringing a gneiss outcrop. This colony is above the inter-tidal zone indicating a relative fall in sea-level. The spreading of the sea floor in the Indian Ocean which was responsible for the rapid migration of India northward and subsequent collision with the Asian mainland, resulting in the Himalayan mountain range, is still active. The newly created sea-floor is being accommodated in part at the collision boundary. The remaining part results in high compressive stress within the Indian plate. The intraplate stresses here should result in relative sea level changes along the continental margins. Thus apparent sea-level changes should occur along the Indian continental margins given the high predicted stresses. The relative fall in sea-level at Chennai and Mangalore can be interpreted as indicators of the present day stress regime which is resulting in deformation of the crust.

The study area for the present project consists of areas around Netravathi-Gurupur river mouth. This extends in the north up to 1.6km along Bengre Coast, in the south up to 4 km along the Ullal Coast, in the east up to about 8 km in Gurupur and Netravathi rivers from the mouth and in the west up to a depth of 10m from the high tide line as shown in Fig. 3.1.

The river bed mostly consists of fine sand, silt and clay and is influenced by tides and heavy fresh water flow takes place during southwest monsoon. The increase in flow velocity during monsoon would disturb the stability of the dredged section and is expected to increase the siltation in the dredged channel (Chandramohan and Panchatcharam, 2001).

Beaches after being subjected to erosional phase during southwest monsoon season, were found to regain their profiles by January or February. The erosion observed at the river mouths can be attributed to the readjustment of the river mouths during monsoon season when the river flow was highest (Chandramohan et. al., 1994).

Fig. 3.1 Map of the Study Area

The average slopes of the bed contours off Ullal and Bengre coasts observed during our bathymetric survey in November 2006 are listed in the table below. It can be seen that the slopes of the foreshore and up to 6m contour off Ullal are twice that off Bengre Coast. While the slopes for 6m contour and beyond are comparable.

Sl. No.	Contour Depth (m)	Off Ullal Coast	Off Bengre Coast
1	0.0 - 6	1:20 to 1:30	1:50 to 1:65
2	6 - 12	1:400 to 1:500	1:420 to 1:520
3	12 - 20	1:780 to 1:900	1:800 to 1:910

Subba Rao et. al. (2000a, 2001a) and Subba Rao and N.B.S.Rao (2000a) observed that the foreshore slopes were steeper in monsoon when compared with other seasons and also the foreshore slope along D.K. coast is steeper than that of all other coasts considered for their study.

3.3 Beach Erosion and their Forcing Factors

Dattatri et. al. (1997) observes that the erosion experienced along Karnataka coast is only limited to the isolated regions during monsoon season and do not cause any net retreat of the shoreline as the beach fully recovers in the post-monsoon season. But where the active zone of the beach is encroached, the erosions cause loss to property and there is public demand that these areas be protected.

The coastal stretches where the erosion takes place in the districts of D.K. and Udupi (the erstwhile D.K District) are divided into 3 classes (KREC Study Team, 1994):

A : OPEN BEACHES

1. Thannirbavi
2. Doddakopla, Guddakopla, Hosabettu & Kulai
3. Mulur
4. Kaup-Polipu
5. Thonse, Kemmannu Hoode and Vadabhandeswar
6. Gujjadi and Mannur

B : BEACHES ADJACENT TO SHORE PARALLEL RIVERS

1. Sasihitlu (Pavanje river)
2. Uliaragoli- Udyavar – Padukere (Udyavar River)

C: BEACHES ADJACENT TO RIVER MOUTHS

1. Bengre and Ullal
2. Hejamadi Kodi near Mulki
3. Kodi Bengre at Hangarakatta
4. Kasaba Kodi at Kundapur

The studies carried out by Karnataka Engineering Research Station, (1989), regarding the beach erosion problem at Ullal concludes that the material from the deeper zones are removed and deposited on the fore-shore thereby forming a berm during pre-monsoon and post-monsoon period, then, during monsoons, the same material is eroded and deposited in deeper zones. The beach slopes are generally steeper during monsoon and flatter during non-monsoons which leads to a definite conclusion that the beach width is oscillating during a year. The grain size during monsoon was coarser while it was generally finer during non-monsoon periods.

The coast has been in existence over a geological time scale, moulded, eroded and remoulded by nature. A glance through this geological history tells us that the recession of the sea went beyond today's shoreline and was about 50km west, about 11,000 years ago and gradually the sea has transgressed and extended landwards (KREC Study Team, 1994). There are also evidences that the shoreline might have been close to the present Western Ghats at some geological age. What is now D.K. district might have been part of the Continental shelf. These geological evidences confirm that the shoreline is not a permanent feature but is subject to changes both on a short term basis and on a long term basis. What we are concerned here is the changes on a short term basis, on a year to year basis.

In the opinion of the KREC study team (1994), the erosion on the open coasts must be due to direct wave action. Although the deep water wave characteristics may be the same along the areas in the districts of D.K. and Udupi (the erstwhile D.K District), there are local variations due to wave refraction. Coastal reaches where convergence of wave orthogonals takes place due to wave refraction are more vulnerable to erosion. Such places identified on the basis of wave refraction analysis are the following: Thannirbavi, Hosabettu-Kulai, Mukka, Sasihitlu; Hejamadi, Mulur, Kaup-Polipu, Vadabhandeswar, Kemmannu Hoode, Gujjadi and Mannur (John, 1988).

It should also be noted that river mouth changes are natural and cyclic in nature. The periodicity of these cyclic changes varies from a few years to a few decades, and varies from one location to another. The sand spits on either side of the river mouths are in continuous movements and this would result in a deposition and growth of one sand spit and corresponding erosion on the opposite sand spit. The beaches adjacent to the coast parallel rivers are more susceptible to erosion due to higher pore pressures and higher exit gradients. (KREC Study Team, 1994).

Such places on the D. K. Coast are at Bengre, Sasihitlu, Uliaragoli-Padukere, Kodi Bengre, Kasaba Kodi and Maravanthe.

From the data obtained from sea sled survey conducted along the D.K. Coast during 1995 and 1996, it was evident that the pre-monsoon and post-monsoon profiles were almost same. This indicated that the pre-monsoon profiles have regained their profiles during post-monsoon i.e., the pre-monsoon and post-monsoon profiles closely follow each other. The material eroded during monsoon is recovered during post-monsoon period. From this one can conclude that although there are changes during monsoon, there is no net erosion or deposition. Hence one can say that the portion of the beach considered in the present study is in a state of Dynamic Equilibrium (Dattari, 1997 and Subba Rao, 1999b).

Erosion of beaches on the one hand and siltation of navigable estuaries and harbours on the other, are some of the major problems of this coast. Problems associated with erosion include loss of valuable beaches, agricultural lands and palm trees, damage of houses and infrastructure, hindrance to fishing activities and hardship to the people living in the coastal areas who are mostly on the socio-economic weaker side of society. The problems associated with siltation of navigable estuaries and harbours are capsizing of fishing boats and loss of fishermen's lives.

While conducting the present field study from 2004 to 2006, it has been observed that legal and illegal mining of sand from beaches, estuaries and upstream rivers was going on continuously in the study area for various industrial, construction and commercial purposes. This may result in deficit of material on the beaches in long term and lead to accelerated erosion of the coast. This, being a direct loss of material, affects the dynamic equilibrium of beaches.

KREC Study Team (1994) studied the beach profile data collected in different sets at various beaches of southern Karnataka up to 1994. From these profiles, different profile configurations as well as onshore-offshore movement of sediment have been inferred. The changes obtained from the first and the last set of monthly profiles reveal that in a period of one year, generally beaches attain their original width and slope. One can observe from SW monsoon profiles (August) that the beaches become narrower and steeper compared to profiles taken during April. Beaches get accreted during December-February over the eroded surfaces of SW monsoon. This trend continues until the end of pre-monsoon (March-May). Hence, changes in beach morphology are more prominent between pre-monsoon and SW monsoon seasons of the same year than the annual profiles of any particular season.

Annual changes in sediment volume indicate accretion both on backshore and foreshore. It has been estimated that on an average of about 1 m^3/m and 6 m^3/m of beach sand have been deposited on backshore and foreshore respectively. This estimation reveals that about 71900 m^3 of sediment has accumulated between Ullal and Thannirbhavi beaches. Estimation from seasonal superimposed profiles reveals that on an average about 107 m^3/m of sand is eroded during SW monsoon. It has been estimated that during this season about 1.073 X 10^6 m^3 of sediment is eroded from Ullal to Thannirbhavi beaches (Jayappa et. al., 2003). This indicates a small quantity of sand loss in the areas considered. However on a large scale it can be said that these changes are seasonal and almost all the open beaches regain the lost sand during fair weather season indicating that the beaches are dynamic equilibrium (Chandramohan et. al., 1994, KREC Study Team, 1994 and Jayappa et. al., 2003). Associated with beach topographical changes, mean grain-size of beach sediment also shows slight changes with relatively coarser material during erosive periods and finer material during accretive periods (Subba Rao et. al., 2000a). The sediments are well sorted during monsoon period and moderately sorted during post-monsoon period in the study area consisting of NITK beach and Mukka. The sorting values of sand range from 0.318 to 1.201 (Subba Rao and N.B.S. Rao, 2000a)

The primary causes of coastal erosion in any given region are generally the following (KREC Study Team, 1994).

1. Direct wave action
2. Tides
3. Currents
4. Sea level changes
5. Interception of littoral drift
6. Sand mining
7. River mouth changes
8. Ground Water Table fluctuations

3.3.1 Direct Wave Action

Wind waves affect beaches in two ways,

1. Steep waves cause the beach erosion by taking away the material (Subba Rao, 2002).

2. Waves when travelling from deep to shallow waters, the phenomenon of refraction occurs. Due to this wave orthogonals may converge or diverge on the beach. At places of divergence, relatively calm water exists and gradual deposition takes place. At places of convergence, energy gets concentrated and erosion occurs (Shetty and Subba Rao, 2002 and Subba Rao, 2002).

The steep monsoon waves cause off-shore movement of sand while long-low swell waves in the non-monsoon months cause on-shore movement of sand. If over a period of time, the off-shore movement predominates then coastal erosion takes place and if on-shore movement predominates, beach will buildup. The wave heights which are likely to cause predominant, off-shore movement will be a function of beach slope, beach sediment size and wave period. As a rough approximation, one can say on the present coast, waves with heights more than 1 m would cause off-shore movement. In the non-monsoon months, the wave heights are generally less than one meter and beach buildup will take place in these months. It is only during monsoon months that steep waves act and the vulnerability of the beaches for erosion very high (KREC Study Team, 1994).

Analysis of the causes of erosion along West coast of India by John and Nayak (1985) and John (1989) leads to conclusion that concentration of wave energy at certain locations due to the existing bathymetric conditions seems to be the primary factor.

Dattatri and Renukaradhya (1970) studied the applicability of the general wave forecasting methods like SMB and PNJ to the Indian coast during the south-west monsoon period of 1968. Wave recorder was of pressure type and was deployed at a depth between 6.0 m to 7.5m. The winds of around 15 – 25 knots were recorded in the wave generating areas for the Mangalore coast which generally lie between 10° and 18° latitude N and 64° to 74° E longitude. The study consisted of analysis of weather maps (synoptic charts), wave hind-casting, analysis of wave records and comparison of recorded waves with hind-cast waves.

They concluded that SMB method appears to be closer to the recorded wave heights than PNJ method, the fetch length in the monsoon period lies between 200 to 600 NM, general direction off wave travel is between S 35° W and N 65°W since the range of wind direction is found to be between these limits. The predominant direction is from west.

Dattatri (1981) studied the long-term wave height distributions for west coast of India from the data obtained from sub-surface type wave recorder buoy off NMP for 18 months during 1968-69. The maximum wave height recorded during the 12 months for which the data was analysed, was 5.4 m with a zero-crossing period of 8.9 sec. This can be considered to be the annual wave with a probability of occurrence of 1/365 = 0.00274.

He concluded that none of the probability distribution laws that are used for the external wave predictions seem to fit the Mangalore wave data to make extrapolation based on the entire data possible and stratification of data into monsoon season and non-monsoon season did not yield significantly different results.

Dattatri and Reddy (1991) studied the wave group statistics for waves off west coast of India. They concluded that the highest wave in a wave train rarely appears as an isolated wave, but is invariably accompanied by several other high waves. The wave group formation is more pronounced than that predicted by Goda’s theory. Kimura’s theory which takes into account the correlation coefficient between successive waves is found to describe the wave data better. They found that the groupiness parameter is found to have significant influence and shows strong tendencies of correlation with peakedness parameter and correlation coefficient.

Sujatha (1991) studied the statistics of wave parameters and wave groups for the data recorded off Mangalore coast at a depth of about 14 m between 30 June and 17

August 1990 (total of 43) which was made use for calculation of spectral estimates and groupiness parameters.

She concluded that:

1. Short term distribution of wave heights is well described by Rayleigh distribution and this distribution holds good even beyond the narrow band assumption.
2. Most of the wave spectra exhibited multiple peaks and these can be explained to be due to inherent in the generating mechanism.
3. The wave group formation is more pronounced than that predicted by Goda's Theory, which assumes that successive waves are independent.
4. The correlation coefficient is considered to be very important parameter which influences the wave group statistics.
5. Wave grouping is more pronounced during wave growth stage (increase in wave height) than during wave decay stage (decrease in wave height).

Sumathy (1992) analysed of waves off Mangalore harbour on the west coast. Data off Mangalore are from subsurface pressure type recorder at -10m for 12 months. This data have been used for the prediction of the design wave height for coastal and harbour structures off Mangalore coast. The analysis show that in the depths analysed, the depth does not seem to have a significant influence on the wave height distribution. She reports that Rayleigh distribution is reasonably satisfactory for all water depths analysed.

She concluded that a study of joint distribution of wave heights and periods shows that highest wave does not occur with the longest period but with an intermediate period while the data follows a skewed distribution and an extreme design wave height of 7.5 m with a return period of 10 years is suggested for structures placed off Mangalore coast

Based on initial studies carried out (KREC Study Team, 1994) it was understood that the effects of breakwaters on the wave onslaught, the monsoon water discharge through the space between the breakwaters, the combined flow patterns of these discharges, tides, waves, decreased sediment load from the land and ground water discharge might be playing major roles to result massive scale erosion and breach of Ullal Spit. Some solutions including rubble mound revetments and Gabion Revetments have not yielded useful results for shore protection.

Subba Rao et. al. (2006a, 2006b) by comparing the seasonal spectra found that the wave energy for pre-monsoon season is more than that for the post-monsoon season. They also found that Scott theoretical spectrum provided reasonably good fit with the observed data.

3.3.2 Tides

Tides increase the zone over which destructive waves can erode the beach. High tides prevent the premature breaking of the waves on the off-shore sand bars which dissipate some of their energy at that location. So the waves break closer to the shore which is responsible for eroding the beach material. Hence, places with high tidal range are more susceptible to erosion. High tides also cause deep penetration of a large tidal prism into the estuary bringing in sea-borne sediments. Depending upon the river discharge and the channel geometry, the ebb currents may influence the sediment discharge differently (Subba Rao, 2001).

In the present area of study, the Netravathi-Gurupur estuary is a bar built estuary where the currents have cut open the sand spits to communicate with the sea. Along Mangalore coast, the tidal range is of the order of 1.5 to 1.8m. The ebb currents also flush the river borne sediments along with other sediments into the sea which may further distributed by ocean waves and currents. It can be said that the tides are of little significance in the context of the beach erosion in the study area.

Reddy et. al. (1979) have reported the measurements of flood and ebb tide currents at the Netravathi-Gurupur river mouth. The maximum speeds of surface and bottom currents during monsoon season during flood tide were about 0.98 and 1.04 m/sec. respectively, and the same during ebb tide were about 1.3 and 1.08 m/sec. Ebb currents were stronger than the flood currents primarily due to fresh water discharge in the rivers. During post-monsoon season, the maximum current speeds were during the ebb tide and they were 0.7 m/sec. at the surface and 0.52 m/sec. near bottom. The corresponding values during flood tide were less than 0.3 m/sec. There is therefore a strong tendency of the ebb currents dominating over the flood currents for most of the year.

3.3.3 Currents

Currents are driven mainly by tides and winds, but temperature and salinity gradients, Coriolis effect, river discharges, and organized current systems (such as the Gulf Stream) can also be important. Currents can vary greatly between the surface and bottom.

Surf zone currents are the driving force transporting sediments in both the longshore and cross-shore directions. As such, they are the key factor in beach erosion and accretion. They may also be important relative to scour and stability of breakwaters and revetments. These are driven by breaking waves and nearshore winds. Currents are very sensitive to wave direction and the magnitude of longshore transport can vary greatly over a time period of days, months, and even from year to year in response to natural variations in wind and wave climate. At many sites, even the dominant direction during a single year (upcoast or downcoast) can deviate from the normal pattern. Thus an adequate sample of years is necessary for stable design estimates (CEM, 2006).

Currents through inlets are the primary process affecting exchange of water and sediments between the bay and ocean. They impact water quality, erosion and shoaling patterns. They can impede navigation by creating steepened, breaking waves when strong ebb current opposes energetic ocean waves. They may cause scour along jetties and other inlet structures and affect structure stability (CEM, 2006).

The observations of currents along the D.K. coast during monsoon season have shown that the fresh water discharges from the rivers in D.K. district are carried southwards once they join the sea and for a considerable distance, these freshwater are concentrated near-shore in the southern directions (KREC Study Team, 1994).

Dange and Ghosh, (2001), are of the opinion that long-shore current is an important parameter for predicting rate of sediment transport along a shoreline. On west coast, the beach slopes are generally flat and there is no distinct breaker zone. The sediment size being fine, affects the height of ripples formed on the sea bed and it is difficult to assess the bed friction parameter which is needed to compute the long-shore current velocity, based on the equation of conservation of mass or momentum.

They have measured various ocean parameters off the coast of Old Mangalore Port during January 1988 and their ranges are presented in the table below.

Parameter	**Range of parameter**	
	From	**To**
Breaker Wave height (H_b)	0.60 m	1.6 m
Wave Period (T)	7.5 sec	13 sec
Angle of wave crest (α_b)	6^0	17^0
Beach slope (tan β)	0.018	0.04
Measured velocity (v_1)	0.11 m/sec	0.6 m/sec.

They concluded that the Longuet – Higgins equation (SPM, 1984) is most suitable for estimating long-shore current velocity along west coast of India with an accuracy of 20%.

Subba Rao et. al. (2006d) comment on the MIKE-21 modeling results that the current direction during fair weather season is towards south and that during monsoon season towards north which are in good agreement with the field observations.

3.3.4 Sea level rise

A sea level rise would directly result in a corresponding higher shift to the zone of wave action on the beach. This would be reflected in a shoreline recession which will be larger on milder slopes. According to Per Bruun's Theory, every millimeter rise of sea level on the Karnataka coast must result in a shoreline retreat of about one meter (KREC Study Team, 1994).

The sea level at present on a global scale is rising at the rate of 1.0 to 1.5 mm / year. The greenhouse effect may slightly increase the rate of sea level rise. It is reported based on the tide-gauge data for Mangalore, that there is a relative fall in the sea level of the order of 1.38 mm/year in sharp contrast to a global sea level rise, due to an upward rise of land along the 13^0 N latitude at a faster rate than the rise of global sea level (Mulki – Pulicat axis). Oyster beds, which are about 0.50 m above the high water line, may also be seen near to Surathkal. Hence, this supports the conclusion that near the coast line there is a relative fall in sea level. Hence, the sea level rise can't be a reason foe erosion along this coast.

Beach profile observations over a long period such as 10 years or more are required before definite conclusion of retreat or advance of shoreline can be made. Over the past 50 years no net retreat or advance has been observed on the beaches adjoining N.I.T.K, at Surathkal. This particular stretch of beach does not have any special local characteristics such as river mouth close by for any adverse effect. There have been minor changes from year to year but on a long term basis, the beach has maintained a dynamic equilibrium.

As per the KREC Study Team (1994), on the D.K. Coast, with the negligible littoral drift, the erosions reported particularly in the open coasts can be attributed to other factors. The geological evidences and the tide gauge data indicate a relative sea level fall have discounted the erosion due to sea level changes. Subba Rao (2002a) also observes that sea level rise does not pose any problem in the coasts of D.K. district.

3.3.5 Interception of littoral drift

The breaking waves and water movements in the near-shore combine with various horizontal and vertical patterns of nearshore currents to transport beach sediments. Sometimes this transport results only in a local rearrangement of sand into bars and troughs, or into a series of rhythmic embayments cut into the beach. At other times there are extensive longshore displacements of sediments, moving large quantities of sand. This transport is among the most important near-shore processes that control the beach morphology, and determines in large part whether shores erode, accrete, or remain stable (CEM, 2006).

Subba Rao et. al. (2000a) observed that there is a direct correlation between the median grain size and the foreshore slope found that the foreshore slope increases as the median grain size increases.

Long-shore sediment transport rates were calculated (Chandramohan et. al., 1994) from the analysis of the sediment samples collected at various stations close to the mid tide line every month from June 1989 to May 1990. The long-shore sediment transport rate was computed using Walton's equation.

$$Q = \frac{1290 \rho g H_b W v C_f}{0.78(5\pi/2)(v/v_o)}$$

Where Q is annual long-shore sediment transport rate in m^3/year, ρ=1025 kg/m^3, g=9.81 m/sec^2, C_f=0.01, H_b= Breaking wave height in m., W=Surf zone width in m., v=long-shore current velocity in m/sec. and (v/v_o)=Theoretical dimensionless long-shore current velocity.

The studies carried out by Chandramohan et. al., (1994) showed low rate of long-shore sediment transport at Ullal, highest being about 0.12×10^5 m^3/month (i.e; 1.44×10^5 m^3/year) towards south during June and August. Sediment transport was southward from December to September and Northward in October and November. Annual net transport rate was 0.36×10^5 m^3/month (i.e. 4.32×10^5 m^3/year) towards south and annual gross transport was relatively low at 0.38×10^5 m^3/month (i.e; 4.56×10^5 m^3/year). This leads to the conclusion that the sediment carried through long-shore transport is negligibly small and can be neglected. However, had there been a large scale littoral drift, there would have been maximum accretion of sea borne sediments on the north of the northern NMPT breakwater and matching erosion on the south of the southern NMPT breakwater which is not visible. Also, the analysis of the siltation at the entrance channel of NMPT and the changes in the coast line adjacent to the breakwaters at NMPT and Malpe indicates that the sediment deposited on either side of the breakwaters are mostly coarse sediments brought by the rivers and not the fine or medium sand of open beaches (sea borne sediments) moved by littoral drift. This confirms that the littoral drift in the study area is negligibly small. This is also confirmed considering the changes in the river mouth in the area. Therefore interception of littoral drift may not be a cause for coastal erosion at certain pockets on the coast. The littoral drift, even if it is present along the coast, is negligibly small and that there are no significant coastal erosion problems on this coast caused by interception of littoral drift (KREC Study Team, 1994 and Habeeb Khan, 2000).

Based on the beach profile and sediment trend matrix investigations done by Subba Rao et. al. (2000, 2001a, 2002a, 2003a, 2003b, 2004a) to identify the sediment movement paths, they have concluded that the sediment movement along D. K. coast is seasonal and there is no net littoral drift along it.

Further, studies carried out by Subba Rao et. al. (2002, 2006c) reveals that the direction of sediment movement gets reversed along D.K. coast seasonally. Subba

Rao (2002a) also observes that littoral drift does not pose any problem in the coasts of D.K. district.

3.3.6 Sand Mining

Sand mining is the removal of beach sand for land fills, plinth fillings, foundry material and other activities. It deprives the beach of valuable material in the active zone where waves act. Deficiency of material is accelerated by waves, picking the material from the coasts and results in severe erosion. Sand mining from the beaches is prohibited activity under the enactment of Ministry of Environment but is clandestinely practiced. At Ullal, near Somanatheshwar Temple, sand mining is done on a regular basis and needs to be prevented. This may be one of the causes of localised erosion there. In Udupi District too, sand mining for silicon has been reported from Brahmavar area.

On the D.K. Coast, the sand mining is not significant and can not be a reason for the erosion. Therefore the erosion reported on the D.K. Coast must be due to direct wave action and that due to changes at the river mouths (KREC Study Team, 1994).

3.3.7 River Mouth Changes

The river mouths along Karnataka coast, particularly the sand spits on either side show strong tendencies of migration. These movements do not follow any regular patterns. Some of these sand spits of unconsolidated sand extend for long distances with river on one side and the sea on the other side. The typical examples are Bengre sand spit on Gurpur river, Sasihithlu sand spit on Pavanje river, the Uliyaragoli Padukere sand spit on Udiyavara river, Kasaba Kodi sand spit on Haladi Kollur river near Kundapura etc.

The problem associated with the river mouth on the coast are as follows:

1. The migration of the sand spits would involve erosion at one end and deposition at opposite end. Human encroachment has taken place on these

fragile sand spits (sand bars) which are highly vulnerable. To protect the land and property, costly protection works are required. More often, adequate space is not available for the proper construction of these works, making them more vulnerable to failure.

2. The long and narrow sand spits are highly vulnerable areas since they consist of sand which can be easily worked out by waters of both the sea and the river. The sand spit at Uliyaragoli Padukere adjoining the Udyavara river near Malpe is about 10 km long and at places it is only 50 m wide with a vital link road running in the middle. At some locations on the spit, the coastal erosion threatens to cut off the road. So it becomes necessary to provide protection to maintain the only link roads.

The NITK Expert Team was of the opinion that the beaches in these places are more vulnerable to erosion due to the high water table caused by the flood flows in the adjoining rivers. Even smaller waves in these cases can cause significant erosion.

3.3.8 Ground water table fluctuations

Ground water table fluctuations have the potential either to encourage erosion or to hold on the beach sand. Grant (1946, 1948) observed that an elevated beach water table promotes beach face erosion, in contrast to a lower water table promoting deposition. Most of the studies conducted by Horn (2002) also suggest that beaches with a low water table tend to accrete and those with high water table tend to erode. Beaches adjacent to the coast parallel rivers are more vulnerable to erosion due to higher water tables that exist when the rivers flow full in monsoon.

The higher ground water table with a hydraulic gradient towards sea can induce erosion as it may lead to quick sand phenomenon and may cause erosion. Such a condition may generally be observed during the monsoons. In the post-monsoon seasons, the ground water table may dip due to excess withdrawal for consumption and reduced recharge. This leads to a hydraulic gradient from sea towards land. Now this causes a stabilising force which discourages erosion of beach sand. This phenomenon is generally observed in the study area. The erosion-accretion patterns at specified areas may differ due to various other factors and their relative interactions.

3.4 Solutions adopted till date

There are three basic types of protective structures adopted on the D.K. Coast. They are:

- Seawalls
- River bank protection in the tidal reaches
- Spurs across river banks in tidal reaches.
- Breakwaters as river training jetties
- Mangrove plantation

Seawalls are found to be very popular as a shore protection work on the Indian coast. However, a significant length of the seawalls have been found damaged either partially or fully. A critical study of their failure leads to two possible reasons: (a) inadequacy in design; (b) scour at toe and consequent loss of support resulting in collapse of seawalls. Seawalls have been extensively used in at Ullal, Bengre, Sasihitlu in D.K District and Padu and Moolur near Kapu in Udupi District of Karnataka state and many coastal stretches in Kerala state to arrest the retreat of shorelines and protect the beaches from erosion.

River bank protection works have been adopted at the river mouths to hold the migratory sand spits in position. These have been provided at D.K. and Udupi Districts such as at Bengre along the Gurupur river banks, Kolchikambla along Shambavi river bank near Mulki, Hejamadi Kodi near Mulki, Seethanadi river bank near Hangarakatta, Haladi river bank at Kasaba Kodi near Kundapur.

The major construction of the spurs is at Bengre across the Gurupur river bank. The primary purpose of these spurs is to divert the Gurupur river flood flows away from the river bank with a view to concentrate the river flows in the middle of the river channel. It was anticipated that the increased velocities will remove the shoals that had formed in the middle of the river opposite to the fishing harbour. This has not happened, probably because the lengths of these spurs have not been sufficient to cause the required increase in velocity (KREC Study Team, 1994).

Breakwaters have been constructed at Malpe and at Mangalore with the primary purpose of confining the river flows such that the higher velocities will flush out the deposited sediment and keep the channel open for safe navigation of fishing boats. Fortunately on the D.K. coast, the littoral drift is negligibly small. Otherwise these breakwaters would have caused severe erosion on the downdrift coasts (KREC Study Team, 1994). Still the effect of the breakwater on the Ullal beach needs to be watched with caution. There has been deposition of river sediment on the Bengre and Ullal sides of the breakwaters in June 1994. There has been deposition noticed at Ullal where severe erosion was earlier observed. This may be attributed to the breakwaters constructed on either side of the river mouth (KREC Study Team, 1994).

The Forest Department has started raising mangrove plantations in the estuaries of coastal Karnataka, particularly in Dakshina Kannada, which is prone to natural calamities during monsoon (Raghuram, 2007).

In Karnataka, there are only isolated areas covered with mangroves and over the decades these ecosystems have vanished because of denudation. The Forest Department now has taken up extensive cultivation of mangroves in the estuaries of Gurupur and Nethravathi rivers. The department has planted saplings in 200 hectares in the estuaries.

The plantations are coming up in the river estuaries of Nethravathi, Gurupura, Mulky, Sasihithlu, Pavanje, Thanneerbavi, Kuloor, Panjimogaru, Adamkudru and Ullal in

Mangalore taluk. The main species that have been planted includes rhizophora mucronata, avcicennia alba, Kandelia Candel and Brugueira gymnothiza. It is decided to bring more areas under mangroves in the estuaries comes as part of the Centre's plan to increase the buffer zones on the sea coastal ecosystems.

Efforts were made to form Village Forest Committees in these areas and at Sasihitlu one such committee was already in place. These committees would oversee the protection of these plants and their management with the people of their respective villages. Sensing the opportunity it presents to them, the fishermen are helping the Forest Department in organising mangrove planting programmes.

3.4.1 Performance of protection measures

The spurs at Bengre have slightly settled at their tips in the deep water portions and this is normal and not of any serious magnitude to affect the satisfact6ry performance of these structures.

River bank protection works at D.K. and Udupi Districts have been performing satisfactorily and do not seem to have suffered any damage except minor settlements.

The breakwaters at Malpe have been functioning fairly satisfactorily and no maintenance dredging is required at Malpe fishing harbour. The breakwaters as river training jetties at Netravathi-Gurupur river mouth have been completed in 1994 and their performance has been quite satisfactory with navigational channel at Old Mangalore Port being maintained by it self without dredging. There has been deposition of river sediment on the Bengre and Ullal sides of the breakwaters in June 1994. There has been deposition noticed at Ullal where severe erosion was earlier observed. But very recently at Ullal, the southern breakwater has suffered extensive damage.

3.4.2 Performance of seawalls

The KREC Study Team (1994) felt that the best solution for protection of property which is threatened by coastal erosion on the D.K. Coast, would be the seawalls and minor irrigation department has adopted seawalls all along coast for protection. The availability of good quality rock in sufficient quantities at distances fairly close by is also one reason for adopting seawalls with natural rock as the main armour. But the seawalls have completely sunk at Padu and Moolur near Kapu in Udupi District where wave energy concentration occurs due to wave refraction. At other places partial settlement is observed. Mention is also made that at a number of places, the seawalls are in good condition and performing satisfactorily (KREC Study Team, 1994).

The seawalls at Sasihitlu in D.K. District have suffered damage. These failures start initially as toe failure and progressively leads to settlement of the wall and finally total failure due to over topping. The armour used is 570 Kg, which is inadequate and the seawall failed due to the toe failure occuring because of scour and subsequent collapse of the armour.

One of the most critical factors controlling the impact of seawall on beach is its position on the beach profile relative to the surf zone. The best place for a seawall is at the back of beach where it provides a protection against the largest storms. It is found that a properly located and constructed seawall does not accelerate the erosion either in front of it or in the adjoining areas (KREC Study Team, 1994, Dattatri et. al., 1997, Subba Rao and Pramod, 2003). By contrast, a seawall built out to the mean high water line due to scarcity of space which in turn is due to beach encroachment may constantly create problems related to frontal and end scour as well as up-coast sand impoundments, and this is the case at many locations along D.K. and Udupi coasts.

Single layer armouring of sea walls adopted in some places has necessarily resulted in the armour stones laid to smooth finish with their largest surface on the beach face. This results in increased wave runup, uplift forces on the stones and very low void ratio, which are not desirable from stability and performance considerations. Two layers of armour stones dumped are condusive to dissipation of incident wave energy. The presence of two layers also prevents the secondary layer from being exposed easily.

Subba Rao et. al. (2003c) observe that certain lengths of seawalls adopted along Karnataka coast to contain the erosion have been either partially or fully damaged due to scouring at the toe of the structures. Hence it is necessary to recognise the need for proper maintenance after the coastal protection works are in place and the administrative bodies make necessary provisions for the same.

3.4.3 Performance of emergency works

To meet the ever increasing public demand for immediate protection against erosion during severe monsoon periods, emergency works are carried out. They are the sand bag protection and stone revetments at Ullal and Surathkal areas of D.K. District. These constructions are invariably from the top down in these adverse situations and the specifications regarding the weight of stones, the different graded layers cannot be followed. Whatever stones that are available are used for the emergency protection. These constructions are not only in the active zone of the beach but to upgrade them later to the standard cross-section is also very difficult. These sections will be the ones to be damaged first in the subsequent monsoons. However, during the south west monsoons these works have stood the test of the time.

However, the problems of areas around Netravathi-Gurupur river mouth still persist due to failure of various solutions. Hence, there is a need for detailed investigations into the problem and proper design of the relevant solutions.

3.5 Summary

The study area around Netravathi-Gurupur river mouth is being modified due to the influence of various marine and non-marine agencies since decades. The river mouth was found shifting and beaches at Ullal and Bengre were found eroding. A number of mitigation measures such as spurs, seawalls and breakwaters as river training jetties have been tried to arrest the migration of river mouth and stop the beach erosion. However, the problems of areas around Netravathi-Gurupur river mouth still persist due to failure/improper functioning of mitigation measures. Hence, there is a need for detailed investigations into the causes of the problem and proper design and implementation of the solutions.

4

SCOPE AND METHODOLOGY OF INVESTIGATIONS

4
SCOPE AND METHODOLOGY OF INVESTIGATIONS

4.1 Background

Severe coastal erosion is taking place during the monsoons along the coastal stretches of Kotepura in Ullal town of Mangalore Taluk of Dakshina Kannada District in Karnataka State. The site of erosion is a barrier spit over a length of 1.4 Km connected to main land at southern end. The northern end of this spit is free to migrate as a part of changes in shoreline around the mouth of River Netravathi. Similarly, the northern spit, known as Bengre spit exists running parallel to the mainland with northern end connected to land and the southern end is free to migrate as a part of river mouth. Gurupur River also joins this mouth running from north adjacent to Bengre Spit.

Historically, this river mouth was found to migrate with oscillating positions. When siltation at the mouth was disrupting the navigability of fishing boats, two rubble mound breakwaters (river training jetties) were built on either side of river mouth. Subsequent to these constructions, the following observations have been made.

1. These structures have stalled the migration of river mouth.
2. Heavy accretion on the North of Northern Breakwater along the Bengre spit. This accretion has taken place till the tip of the northern breakwater.
3. Along the Ullal Spit on the south side of southern breakwater, severe erosion has been taking place. This erosion has shown greater proportions and threatening to open another mouth to river Nethravathi along the stretch of Ullal spit in the months of July/August, 2000 during South West Monsoon.

Based on initial studies, it was understood that the effects of breakwaters, monsoon river discharge and tidal prism through the estuary, the combined flow patterns of these discharges, tides, waves, decreased sediment load from the land and ground water discharge might be playing major roles to result massive scale erosion and breach of Ullal Spit. Some solutions including rubble mound revetments and Gabion Revetments have not yielded useful results for shore protection. Hence, there was a need for detailed investigations including field measurements on bathymetry, waves, tides, discharges, ground water discharge and other relevant measurements and mathematical modeling of flow conditions for various proposed alternate solution schemes. Numerical model studies to evaluate the alternate scheme of solutions to this problem including submerged breakwater, T-Groins and simple groin system are carried out to study their efficacies. This chapter explains how the project was conceived and scope of the project and methodology adopted for solving the problem.

4.2 Project Formulation and Execution

Integrated Coastal and Marine Area Management – Project Directorate (ICMAM-PD), Chennai and National Institute of Technology Karnataka (NITK), Surathkal planned to execute this work in 2003 and strive for getting the local stakeholders like PWD of Karnataka State Government for implementing the results of the present work. ICMAM-PD acts as a nodal coordinating institute for planning, making available the state-of-art equipments, software, computing facilities, technical support and implementation of project results. The Department of Applied Mechanics and Hydraulics, NITK acts as a regional center to carryout various components of investigations like bathymetric survey, field measurements on waves, tides, currents, river discharges, sediment samples, ground water levels and flows, etc. and numerical modeling and interacting with local stakeholders for implementing the project results. Required infrastructure consisting simple equipments and human resource for carrying out this project will be developed at the Department of Applied Mechanics and Hydraulics, NITK without any duplication. The available expertise in term of coordinators and advisors in the field of coastal engineering will also be pooled for the execution of this project. The expertise of Integrated Coastal and

Marine Area Management Project Directorate, Chennai (ICMAM-PD) is solicited in case of field measurements using costly and complicated measurements.

4.3 Scope of the project

The project is planned and executed based on the broad scopes listed hereunder.

1. Analysis of Historical and present available information on coastal erosion along the stretches of shorelines adjacent to the Netravathi-Gurupur River Mouth.
2. Identification of forcing factors of coastal erosion along the stretches of this river mouth.
3. Developing suitable long-term alternative measures for effective shore protection measures for the stretches around this river mouth.
4. Zeroing on the optimal solution to the problem.
5. Development of shoreline management for sustainability of shorelines around this river mouth in order to avoid damages due to erosion in the pre & post scenarios of implementation of project results.

4.4 Methodology of Investigations

The methodologies formulated to execute the project are broadly summarised below.

1. Data collection from local residents suffering from coastal erosion and Government departments handling the present crisis.
2. Collection of any relevant data from toposheets, NHO charts and local district Survey of India maps and literature regarding bathymetry, shoreline and river mouth positions.
3. Determining the changes in the shoreline position from the synoptic satellite data.
4. Delimiting the exact area of interest and detailed planning of physical measurements on waves, currents, sediments and flushing discharges and other physical parameters.

5. Bathymetric data collection, land survey to get the existing salient features present around the shoreline and existing shoreline position.
6. Field Measurement of Waves, Currents, Sediments, Tides, Groundwater level and flows at sand spits and flushing discharges and sediment.
7. Estimation of varying sediment load and flushing discharges over a year with the details on catchments of river mouth.
8. Analysis of measured field data.
9. Numerical modelling of existing coastal processes.
10. Analysis of various shore protection measures and planning for alternate solution schemes.
11. Numerical modelling of coastal process in the presence of suitable protection measures and evaluation of efficacy of different alternatives of shore protection.
12. Selection of suitable protection measures and suggestions for implementation.
13. Development of Shoreline Management for pre and post implementation of project results in concurrence with stakeholders like PWD.

4.5 Field Measurements

The following field measurements constitute part of the present investigations.

1. Topography and bathymetry survey in the areas covering the stretches adjacent to the mouth of rivers Netravathi and Gurupur over an approximate shore length of about 6 km. This survey includes levels on the land up to nearest property boundary if the houses are built from the Highest High Tide Level and levels in the surf zone are to be integrated with bathymetric levels with a common reference level. All the boundaries of rock outcrops within the area of survey have to be marked with the levels. Land features like rock boundaries, sandy stretches, house, road, mosque, church, rivulets, any existing structures like groynes, sand dunes and canal will be identified and marked on the topographic and bathymetric chart.

2. Continuous measurement of near shore currents for 2-3 weeks covering one neap and one spring tide in two seasons at six locations around the river mouth.
3. Wave and Tide measurement for 2-3 weeks covering one neap and one spring tide in three times in a year at one location around the river mouth.
4. Fortnightly measurement of beach profiles, foreshore sediments and ground water levels on the two spits on either side of two river mouths.
5. Measurement of river discharges and sediment source at the river mouth through direct or indirect measurements.

4.6 Instruments used in ocean data collection

A variety of state-of-art equipments are used to collect the data regarding waves, tides, currents, bathymetry, shoreline mapping etc. It includes wave/tide gauges, current meters, GPS instruments, echosounders have been extensively used apart from Acoustic Doppler Current Profilers (ADCP), Advanced Doppler Profiler (ADP) etc. A brief description of some of the instruments are given in the following sections.

4.6.1 Wave and tide gauges

The Valeport Model 730 and MIDAS range of instruments have been used to collect a comprehensive wave and tide data which comprise the following features. Valeport directional Wave/tide gauge has with it the directional wave recorder, providing tide height, a variety of wave statistics, frequency energy spectrum and directional spectrum whereas non- directional wave/tide gauge comprises only wave recorder, providing tide height, wave statistics and frequency energy spectrum. Fig. 4.1 shows Valeport Directional and Non-directional wave/tide gauge.

Fig. 4.1 Valeport Directional and Non-directional wave/tide gauge

All the above models are fitted with onboard memory for use as self recording instruments. They also have real time output of tide and wave data (where appropriate), through hardware or radio link to PC. The instrument has an internal battery pack, or can be supplied with either an internal or separate battery pack. In all cases, power can be supplied externally. The software provided by the manufacturer allows setting up of the sampling regime, with variable frequency, number of samples and cycle time, as well as storm trigger levels and data saving options. The software also performs data extraction, and basic data displays. The versatility of the sampling regime, together with the real time data output option make the instrument the most complete range of Wave and Tide Recorders currently available and ideal for all shallow water applications.

The above instruments use linear wave theory to measure and recreate wave data from oscillations in hydrostatic pressure. This instrument is fitted with an electromagnetic current sensor as well as a pressure sensor. By sampling current oscillations at the same time as pressure variations, it is therefore possible to deduce the wave direction spectrum. It is important to note that as depth increases, both pressure and current oscillations are attenuated, and whilst the algorithms contain filter functions to account for this, it is possible to measure wave action if the instrument is deployed up to a depth of 20 m below the water surface.

Tidal Data

The instrument records mean pressure over tidal burst, standard deviation of burst, temperature and conductivity

Wave Data (Model 730D)

The instrument is set such that it records data each hour for about 5 minutes with a burst duration which is set as a number of scans i.e., 1024. From the 5 minutes recorded data, maximum wave height is recorded and significant wave height is calculated for each hour.

Wave Statistics: Unit records following parameters for each wave burst.

Mean Level (h), Tidal Slope over burst (hts), Significant Wave Height (H_S), Maximum Elevation from mean (η_{max}), Minimum Elevation from mean (η_{min}), Mean Period (T_1), Mean Zero Up-Crossing Period (T_z), Peak Period (T_p), Significant Wave Period ($T_{1/3}$), Maximum Wave Height (H_{max}), Total Energy (E).

Spectral Analysis Data: Calculated on board. Scale and resolution defined by sampling regime.

Raw Pressure Data: All data in burst saved as absolute value.

4.6.2 Aanderaa Recording Current meters (RCM)

The recording current meters (RCM) utilize the well-known Doppler Shift principle as basis for its measurements. Four transducers transmit short pulses (pings) of acoustic energy along narrow beams. The same transducers receive backscattered signals from scatters that are present in the beams, which are used for calculation of the current speed and direction. The scattering particles are normally plankton, gas bubbles, organisms and particles stemming from man-made activity.

The most common way to use the RCM is in an in-line mooring configuration. As it operates under a tilt up to 35° from vertical, it has a variety of in-line mooring applications by use of surface buoy or sub surface buoy. The instrument is installed in a mooring frame that allows easy installation and removal of the instrument without disassembly of the mooring line. Direct Reading is conveniently done due to its compact design, low drag force and easy handling. The instrument can be lowered into the sea from a small boat using a simple winch. In this application a small vane plate should be fastened to the instrument to avoid spin during operation. Data can be stored internally and read after retrieval or be read in real time on deck by use of the profiling cable. RCM can also be used in a bottom frame mooring (non-magnetic). A software program is used to download the stored data to a Personal Computer. Fig. 4.2 shows Aanderaa recording current meter and the mode of deployment.

4.6.3 Echosounder

Echosounder, shown in Fig. 4.3, is used to measure water depth by sending acoustic pulses via a transducer. This consists of a transducer and a transceiver. The transceiver contains a transmitter, which controls pulse length and provides electrical power at a given frequency. The acoustic pulses are reflected at the sea floor and the reflected echoes are received at the transducer. The elapsed time between the outgoing pulse and the return echo is a measure of the depth. These systems generally achieve 10 - 50 meters of penetration, depending upon sediment type. The data obtained are then filtered and a bathymetry chart of the area is prepared using relevant softwares.

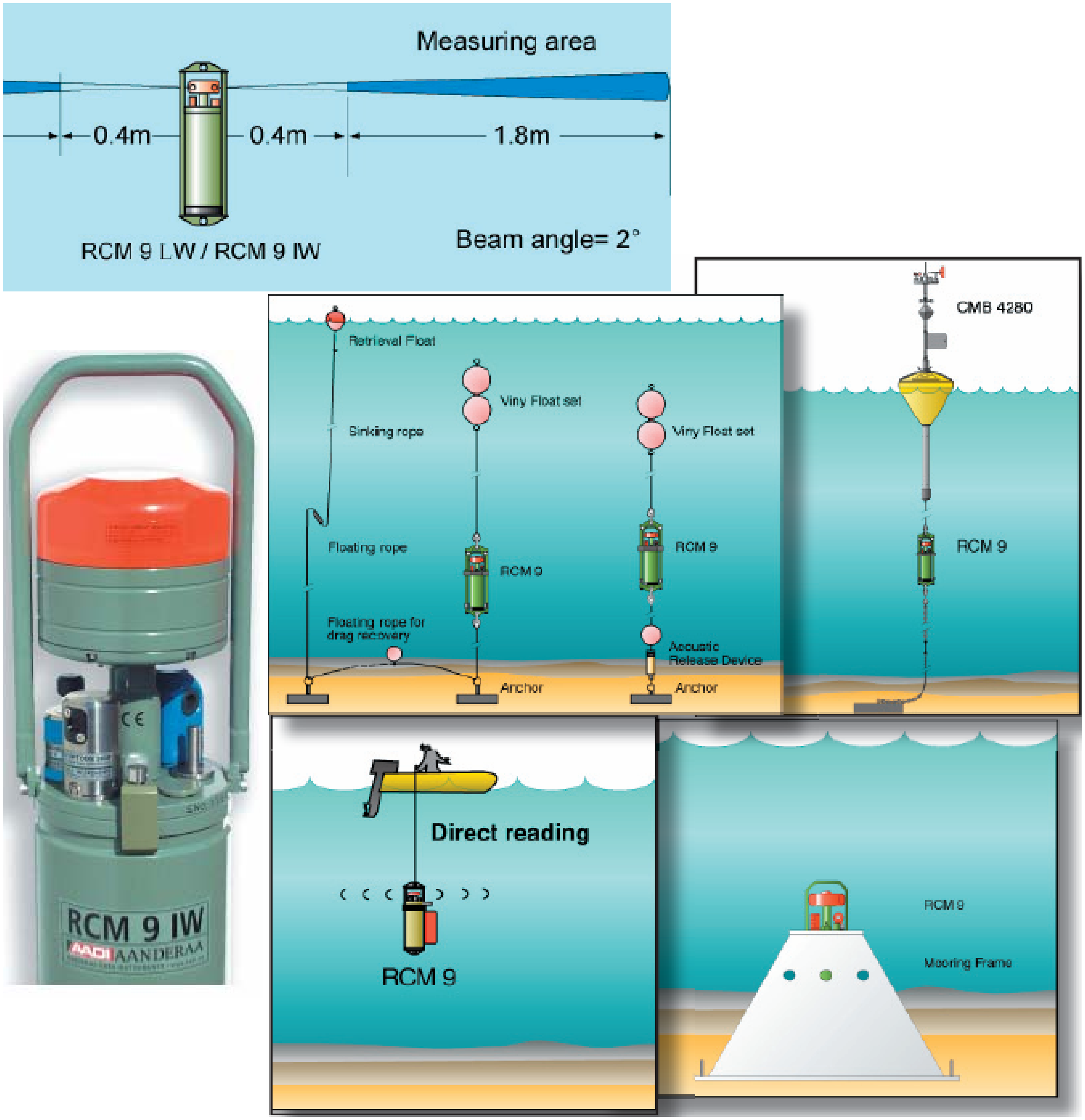


Fig. 4.2 Schematic figure showing the Aanderaa Recording Current Meter and the mode of deployment

Fig. 4.3 Display of Odom Hydrotrac Single Beam echosounder and a schematic connection details.

4.6.4 Global Positioning Systems (GPS)

GPS instruments are used to collect the data regarding the shoreline changes taking place in the study area. It is also used to collect ground control points (GCP) for georeferencing the satellite imageries. Leica SR 530 Real Time Kinematic GPS has been used to collect the precise shoreline data seasonally and Leica GS 5+ Arc Pad GPS has been used to trace the shoreline every fortnight whenever possible.

4.6.5 Levelling instruments

Conventional telescopic leveling instruments and Leica NA 730 Auto level were used to measure the beach profiles every fortnight.

4.7 Field and oceanographic measurements

The data required as identified in the methodology and the same which is proposed in the field measurements have been carried out in a phase-wise scheme seasonally. Data regarding beach profiles, ground water table variations, foreshore sand sample and shoreline change were collected every fortnight when and where possible. The oceanographic data has been collected in six phases from 2004 to 2006 and the details have been given hereunder. However, the periods considered for data collection depend entirely on the existing environmental/meteorological conditions. For all the phases of measurements, state-of-art equipments like Aanderaa current meters and Valeport directional and non-directional wave/tide gauges with technical support and expertise were provided by ICMAM-PD, Chennai. All the data collected is published in Volume-II of this report. The different measurements undertaken and the equipments used are described hereunder.

4.7.1 I Phase measurements

The first phase measurements for the pre-monsoon period of the year 2004 project commenced on 20th April and continued till 6th May. One set of current meter, directional wave and tide gauge was deployed at water depth of -10m and another set of current meter and non-directional wave and tide gauge were deployed at -6m water depth off Ullal coast respectively.

1. Water samples were collected every 3 hours at about 2m depth for 15 days to measure the daily variation of suspended sediment concentration.
2. A few samples of sea bottom sediments were also collected for analysis.
3. Tide pole readings were recorded for every 15 minutes throughout the day at Old Port, Mangalore in the Gurupur river and also at Hoige Bazar in Netravathi river.

4.7.2 II Phase Measurements

The post-monsoon data collection for the year 2004 was carried out in the second phase measurements which commenced on 18th October and continued till 2nd November. The same scheme of measurements as in the first phase was used during this phase also except for river discharge measurements and bathymetric survey.

The flows through rivers were computed indirectly by measuring the flow velocity with the help of floats and by taking the cross-sections across the river. The task of carrying out the bathymetric survey in the study area was entrusted to the Port and Fisheries Department of the Govt. of Karnataka, as they were familiar with the study area and well equipped with state-of-art hydrographic survey team.

4.7.3 III Phase Measurements

Data collection schemes used in the previous measurements was used to collect the pre-monsoon data for the year 2005. The third phase of data collection was commenced on 1st March and ended on 16th March.

4.7.4 IV Phase Measurements

The post-monsoon ocean data collection for the year 2005 was conducted during 8th to 22nd October. One additional set of directional wave/tide gauge along with a current meter was deployed at various places like Bolar in Gurupur river, and Bengre in Gurupur river for about 3 days each and at 6m depth to the north of northern breakwater off Bengre coast for the remaining period.

4.7.5 V Phase Measurements

The pre-monsoon data for the year 2006 was collected from 3rd May to 18th May 2006. Three sets of current meter and directional wave/tide gauge were deployed each at 6m and 10m water depth to the south of Ullal breakwater and at a water depth of 6m at Bengre to the north of northern breakwater. Two more sets of non-directional wave/tide gauge and current meter were deployed each at Gurupur river near Bengre and near Bolar in Netravathi river.

Acoustic Doppler Current Profiler (ADCP) was used to record the river discharges for a tidal cycle both at Adyar Kadavu in Netravathi river and Kulur in Gurupur river and also in between the northern and southern breakwaters. Two sediment traps were fabricated and deployed for a period of 10 days each at Bengre and Ullal at a depth of 6m. All other measurements were done as per the previous schemes except that the tide pole readings were not recorded manually.

4.7.6 VI Phase Measurements

It was felt that one more set of measurements was required to calibrate the numerical model to simulate the coastal processes. Hence sixth and last phase of measurements for the post-monsoon season of 2006 were carried out from 31st October to 15th November.

Four sets of current meter and directional wave/tide gauge were deployed each at 6m and 10m water depth to the south of Ullal breakwater, at a water depth of 6m at Bengre to the north of northern breakwater and in the river mouth at a depth of 11m. Two more sets of non-directional wave/tide gauge and current meter were deployed each at Gurupur river near Bengre and at Netravathi river near Bolar.

Current profiling was done using Acoustic Doppler Profiler (ADP) which was deployed at -11m off Ullal coast. Bathymetry survey was done up to a distance of 2.5 kms to north of northern breakwater at Bengre and up to 5 kms to the south of southern break water at Ullal to a depth of 15m. and also in both the rivers.

ADCP instrument was used to record the river discharges for about 12 hours in a day both at Adyar Kadavu in Netravathi river and Kulur in Gurupur river. River discharge measurements were also done by conducting the float studies at the above mentioned places. Sediment traps were deployed at -6m,-8m,-11 off Ullal coasts and one at Bengre -8m. Rest of the data was collected according to previous measurement schemes.

4.8 Modelling

The software package MIKE 21 developed by the Danish Hydraulic Institute (DHI) has been used for modeling the hydrodynamics, waves and sediment transport phenomena in the study area. This software package is well documented, widely distributed and recognized as a modeling tool for the purpose of study of coastal processes.

MIKE 21 is a professional engineering tool for modelling two dimensional free surface flows. It can be used for simulating hydrodynamic circulation, wave transformations and sediment transport related phenomena in near-shore areas and ports. It has got various modules required to study various coastal processes and only the modules related to hydrodynamics (HD), waves (PMS) and sediment transport (ST) have been used here.

4.9 Schedule of work

The following chart shows the various activities planned and executed under the project.

Details of Work	Time in Months (From Oct, 2003 to Jun, 2007)														
	2003	2004				2005				2006				2007	
	03	06	09	12	15	18	21	24	27	30	33	36	39	42	45
Recruitment of project staff															
Literature survey															
Field survey															
Analysis of the data															
Developing numerical models															
Development of management plan															
Preparation of report															

4.10 Summary

The various coastal processes affecting the areas around Netravathi-Gurupur river mouth from decades together have to be identified and contained in a most efficient and economic way. Hence, the need aroused for detailed field measurements and mathematical modeling for various proposed alternative solution schemes. This project was conceived and executed to achieve the same within the limitations.

5

MODELLING OF COASTAL PROCESSES AND EROSION PREVENTION MEASURES

5
MODELLING OF COASTAL PROCESSES AND EROSION PREVENTION MEASURES

The previous chapters dealt in detail with the existing problems, the data collection exercises, various equipments used for data collection, methodologies followed in finding a suitable solution to the problem etc. The present chapter discusses in detail the modelling part wherein the data collected regarding the waves, tides, currents, sediments etc. have been analysed and incorporated.

5.1 Wave Model

MIKE 21 PMS can be applied to the study of wave disturbance in open coastal areas, and for computing wave fields in coastal areas with structures (e.g. Groins, detached breakwaters) when back scatter (reflection into the incoming waves) can be neglected and diffraction is predominantly perpendicular to the main wave direction. The assessment of wave conditions and wave-induced currents are essential for the calculation of sediment transport and erosion/deposition patterns in the coastal zone. MIKE 21 PMS is based on the parabolic approximation to the mild-slope equation and accounts for the effects of wave shoaling, refraction, diffraction, breaking, direction spreading, forward scattering and bed friction on the incident waves.

The boundary conditions at the offshore are the incoming wave conditions like wave height, period and direction. The symmetrical boundary condition which ensures that the gradient of the wave conditions across the boundary (d/dy) is zero is adopted for the present model study. The basic output data from the model is the wave climate involving significant wave height, mean wave period and mean wave direction. Other output data that can be obtained from the model are radiation stresses and instantaneous surface elevations.

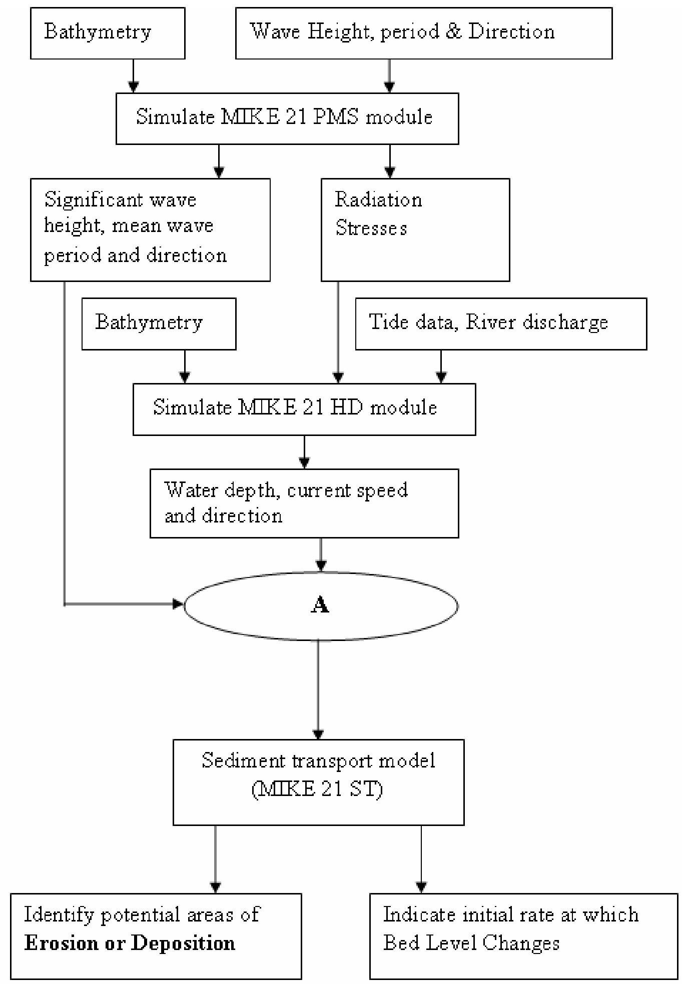


Fig. 5.1 Methodology of Modelling

5.1.1 Output

The model output consists of significant wave height, mean wave period and mean wave direction which are later fed as an input for the Non cohesive Sediment Transport Model.

5.1.2 Calibration of Model

Data collected at Ullal 8m water depth (U8), Bengre 8m water depth (B8), Gurupur River and Netravathi River data are used as a boundary condition for the simulation of Hydro-dyne model. Calibration of the model was done by using the data collected at River Mouth 11m water depth (M11) and Ullal 6m water depth (U6). The calibrated results for location B8 and U8 are given in figures 5.2 and 5.3 respectively.

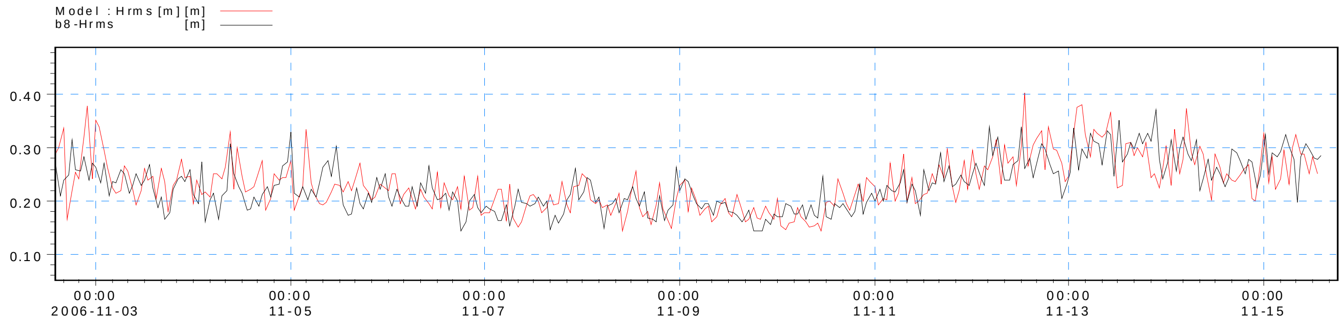


Fig: 5.2 Calibrated wave height at B8 location

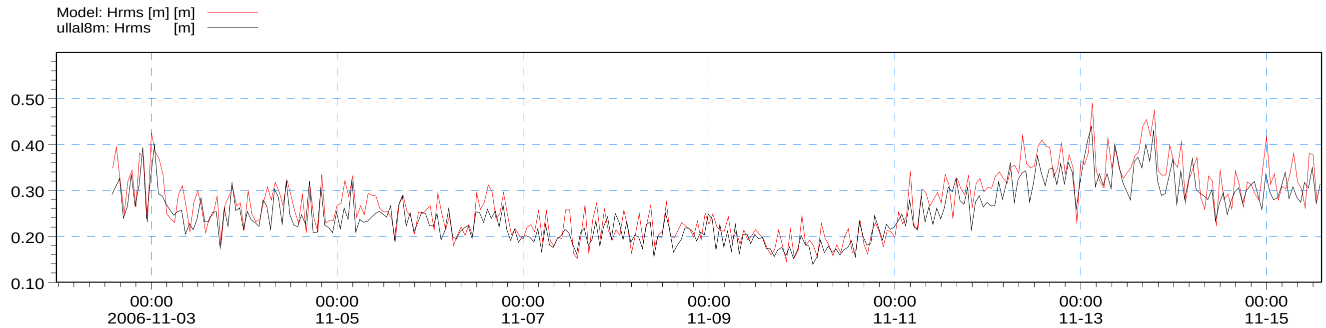


Fig: 5.3 Calibrated wave height at U8 location

5.2 Hydrodynamic Model

The hydrodynamic (HD) module is the basic module in the MIKE 21 Flow Model. MIKE 21 HD is a hydrodynamic model, which calculates the flow field from the solution of the depth-integrated continuity and momentum equations. Input values include bathymetry, bed resistance coefficients, wind field, hydrodynamic boundary conditions and eddy viscosity. The model includes the capability to allow periodic flooding and drying in inter tidal areas. In addition to wind and tide, the forcing terms may include the gradients in the radiation stress field as calculated by the wave module. The outputs of the simulations are water levels and fluxes (velocities) in the computational domain due to tide. The bathymetry considered for the model simulation is shown in fig. 5.4. For the present study, the seaward boundary is extended up to 20m depth contour and landward boundary considered is up to the shoreline. Five open boundaries were considered in the simulation in which the north and south boundaries are provided with water levels, the river boundaries are provided with their respective discharges and the western boundary is fed with zero flux.

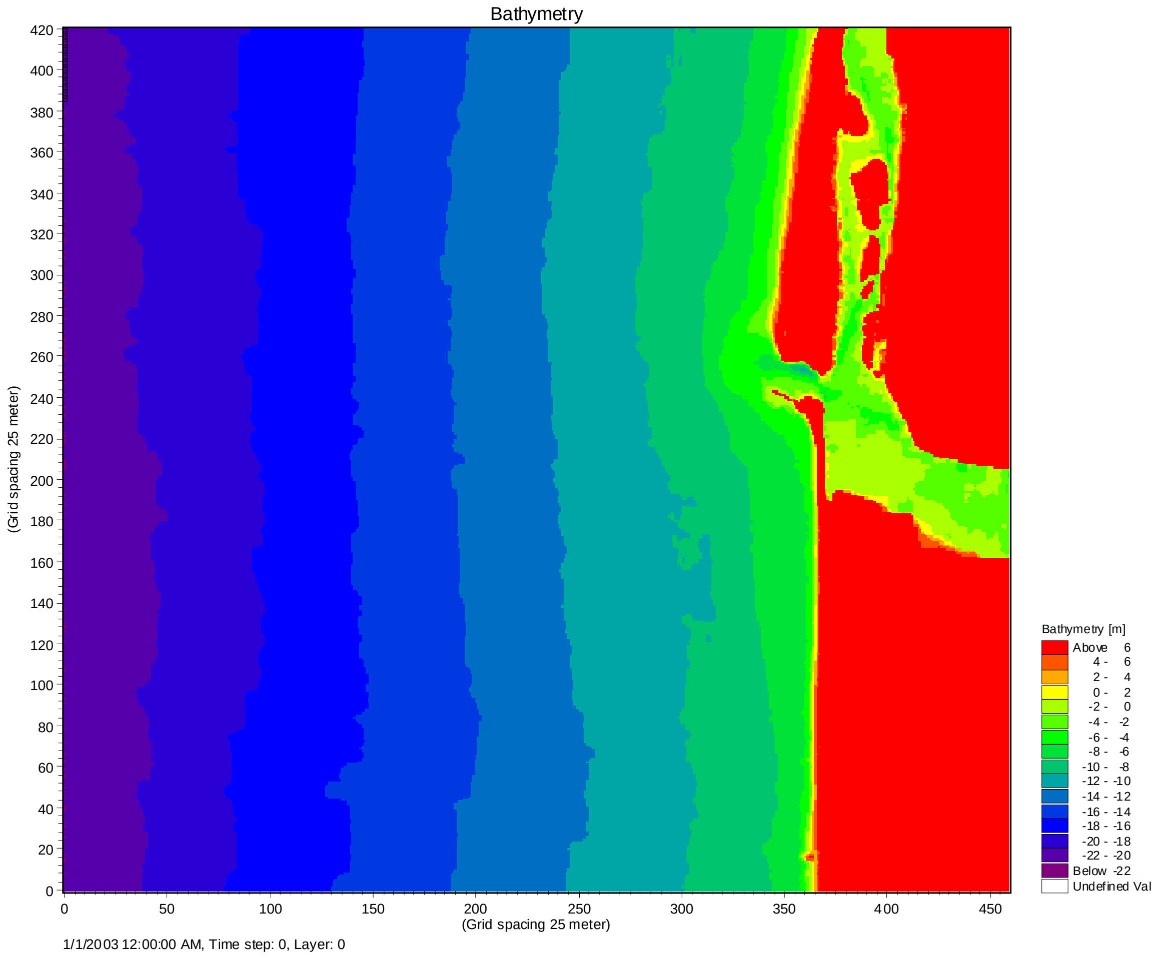


Fig. 5.4 Bathymetry of the study area

5.2.1 Output

The results obtained from HD model are the tidal height and current.

5.2.2 Calibration of Model

The results obtained from the model are compared with the field data. The water level comparision at locations U6 and M11 are shown in figures 5.5 and 5.6 whereas the current comparisons at locations B8, M11 and U6 are shown in figures 5.7, 5.8 and 5.9 respectively.

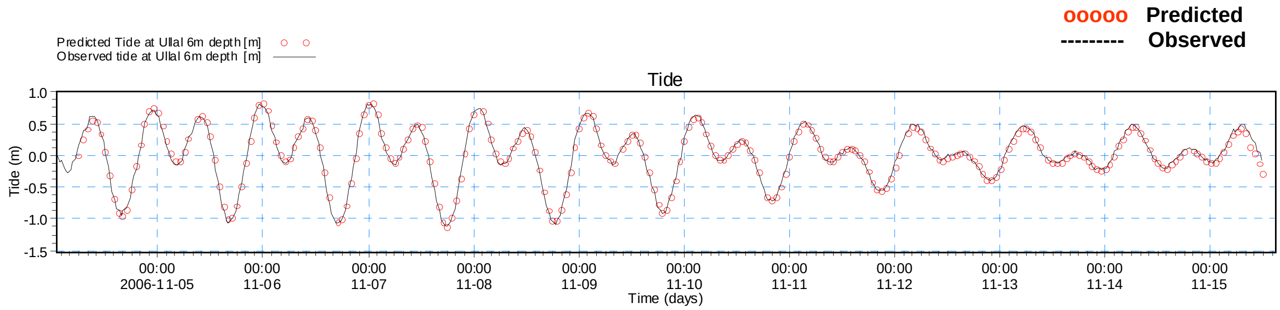


Fig. 5.5 Water level comparision at U6 location

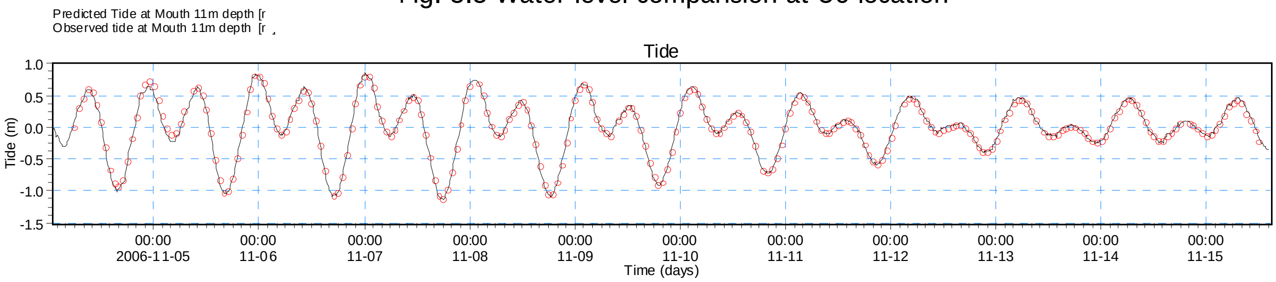


Fig. 5.6 Water level comparision at M11 location

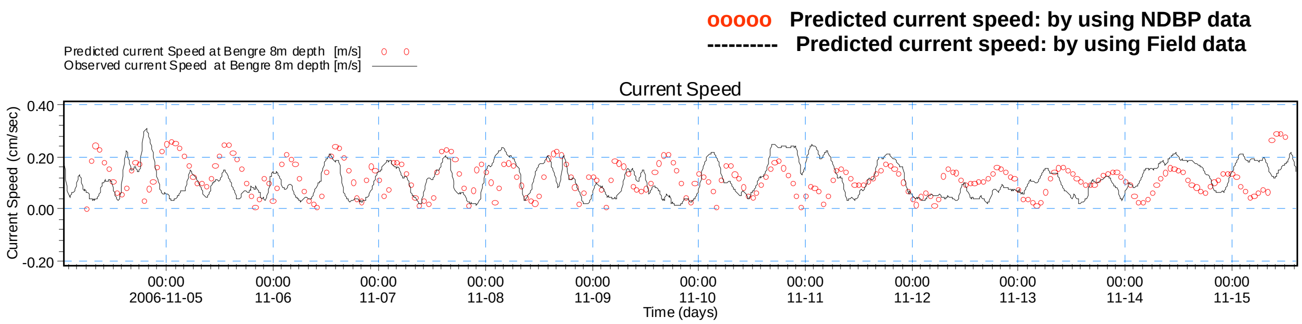


Fig. 5.7 Current comparision at B8 location

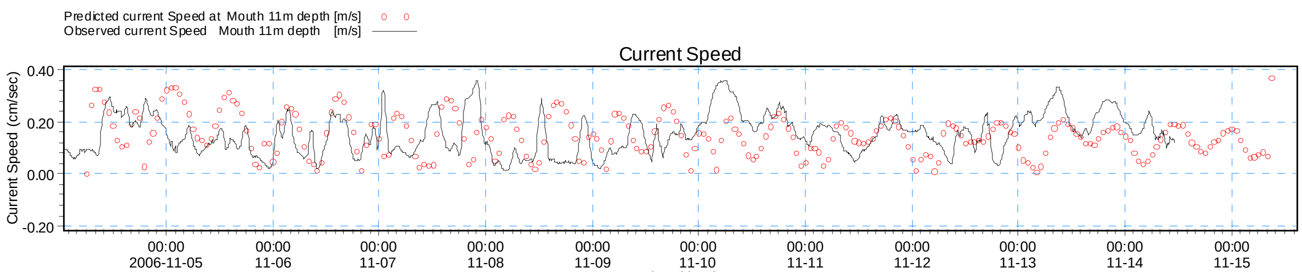


Fig. 5.8 Current comparision at M11 location

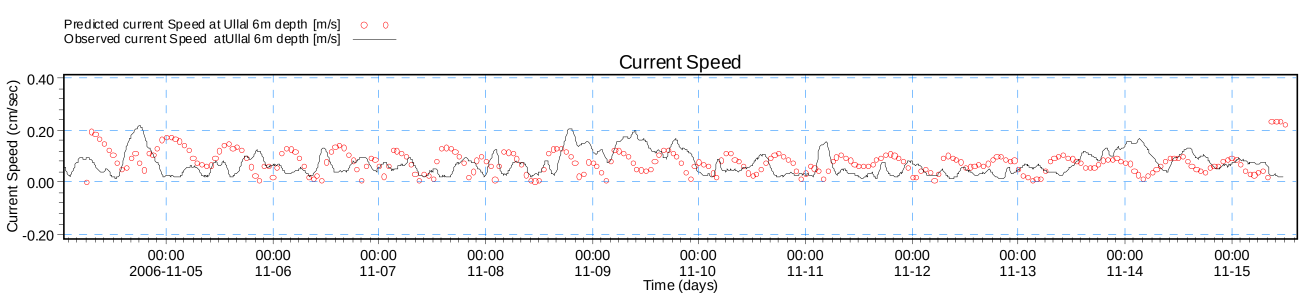


Fig. 5.9 Current comparision at U6 location

The predicted water levels compare perfectly with observed values while current speeds do not.

5.3 Modeling of Pre-Monsoon, Monsoon and Post-Monsoon seasons

Since the collected data regarding tide, water level and currents is for a limited duration, 1 year data collected by NDBP at NMPT was used to simulate Pre-monsoon and Monsoon seasons is shown in the fig. 5.10.

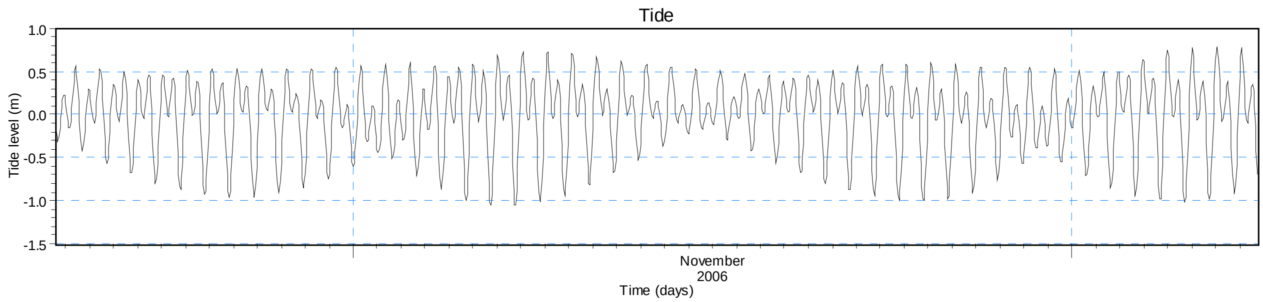


Fig: 5.10 One year tide data collected by NDBP Buoy at NMPT

Before the NDBP data was used for the simulation the model has been validated. The validation was done for the Post-monsoon season by using the observed boundary data. Validated results for water levels at locations U6 and M11 are shown in the figures 5.11 and 5.12. respectively.

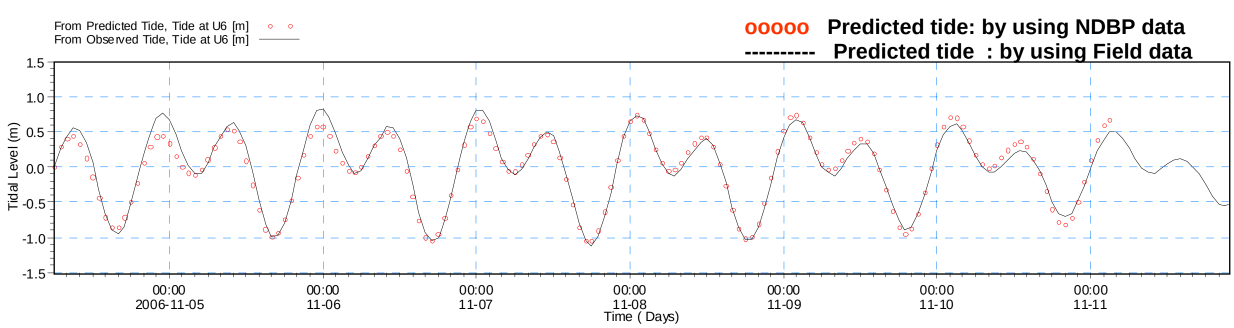


Fig. 5.11 Water level comparision at U6 location

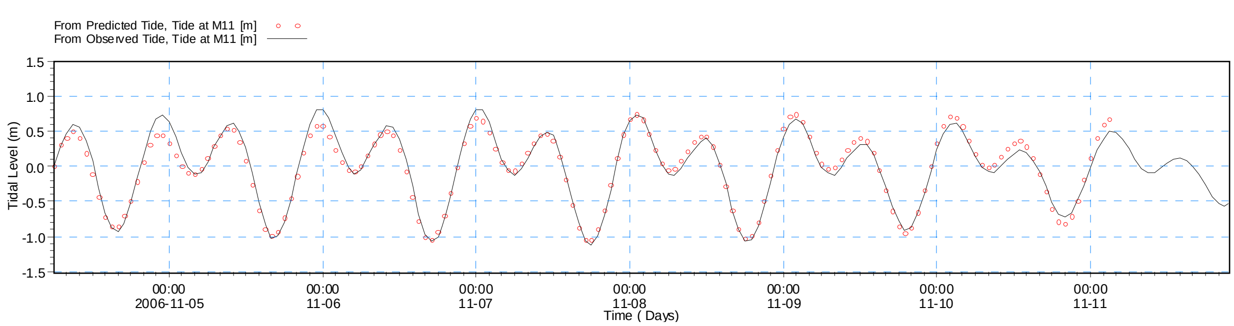


Fig. 5.12 Water level comparision at M11 location

The comparisons of currents at locations U6 and M11 are shown in figures 5.13 and 5.14 respectively.

ooooo Predicted current speed: by using NDBP data

---------- Predicted current speed: by using Field data

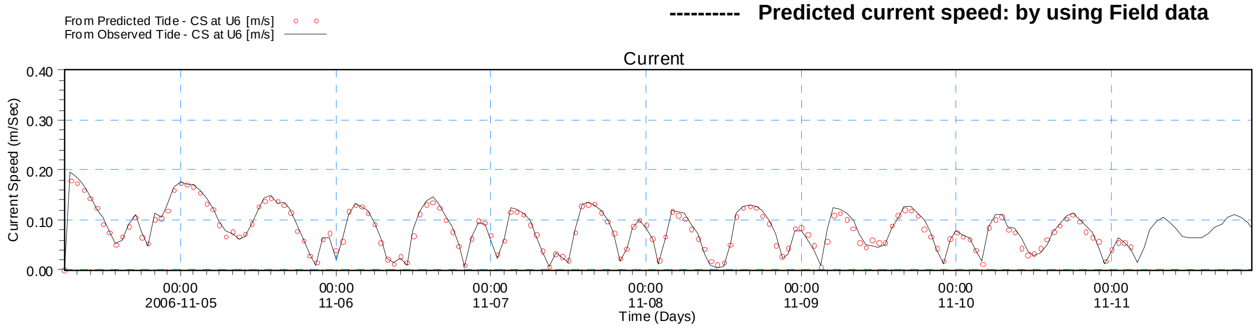


Fig. 5.13 Current comparision at U6 location

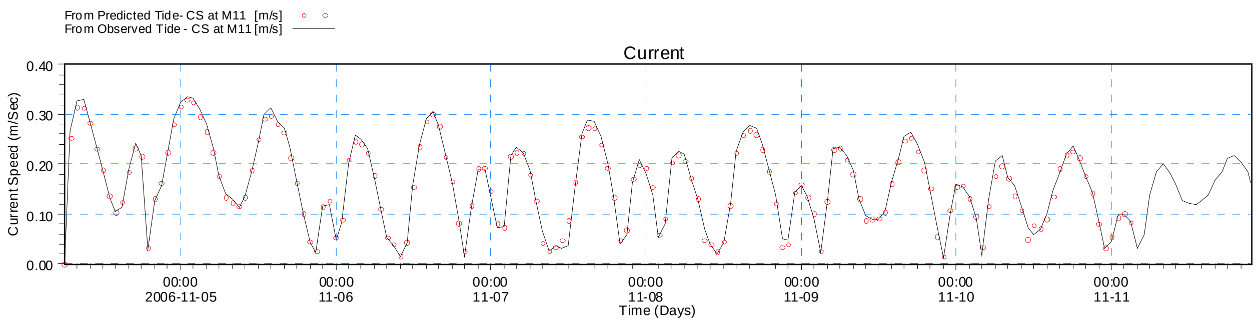


Fig.5.14 Current comparision at M11 location

The figures 5.11 to 5.14 show good agreement between predicted and observed data, 1 year NDBP data was used for the model simulation of monsoon and Pre-monsoon seasons. In order to understand the effect and importance of the southern breakwater (BW), Model was run without BW too for which the results are shown in the fig. 5.15.

These figures represent the Flood and Ebb conditions during Monsoon season with southern Breakwater and without Breakwater. It can be inferred that during this season the current magnitude is about 0.5m/sec. In the absence of the southern breakwater the current concentration is high near the spit indicating that increased erosion may occur.

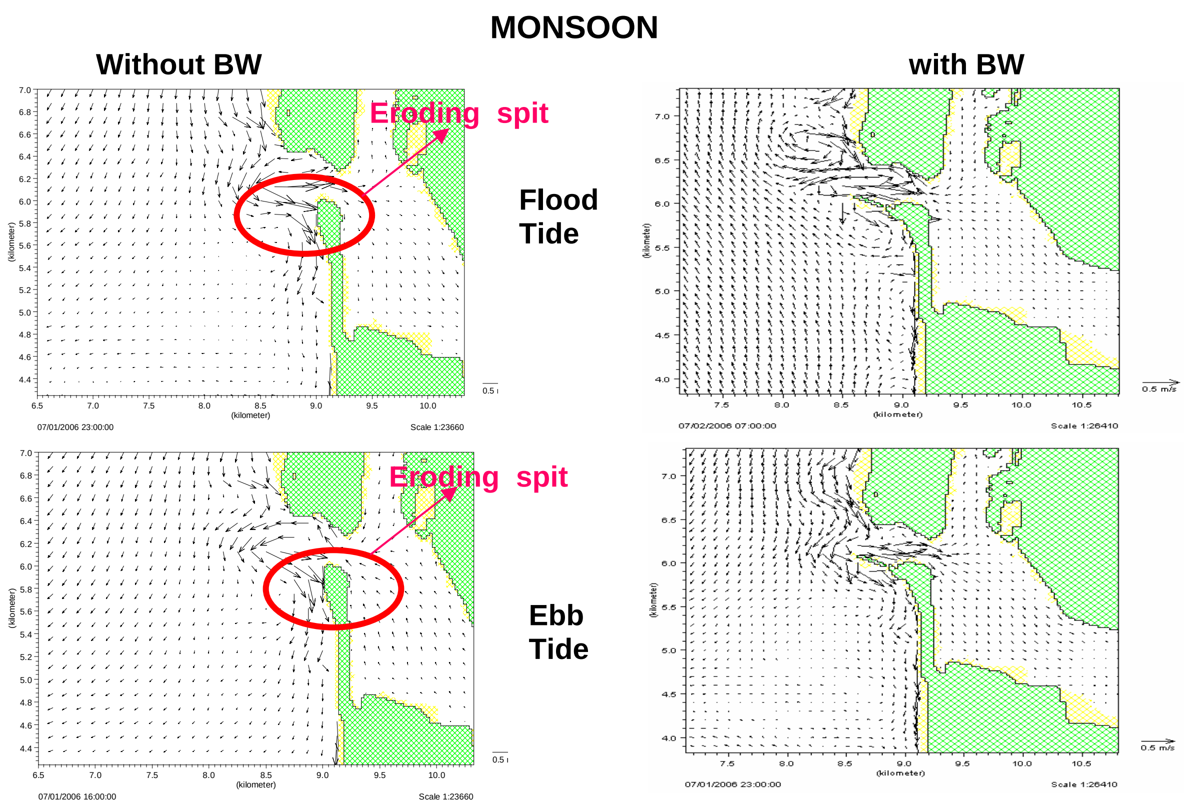


Fig. 5.15 Current pattern during Monsoon season

The Flood and Ebb conditions during pre-Monsoon season with southern BW and without it are shown in fig. 5.16. It can be inferred that during this season the current magnitude is about 0.35m/sec. In the absence of the southern breakwater the current concentration is towards Bengre spit is high.

Fig.5.17 represents the Flood and Ebb conditions during Post-Monsoon season with southern BW and without it. It can be inferred that during this season the current magnitude is about 0.25m/sec. It appears that the influence of BW on currents during post-monsoon season is not very significant.

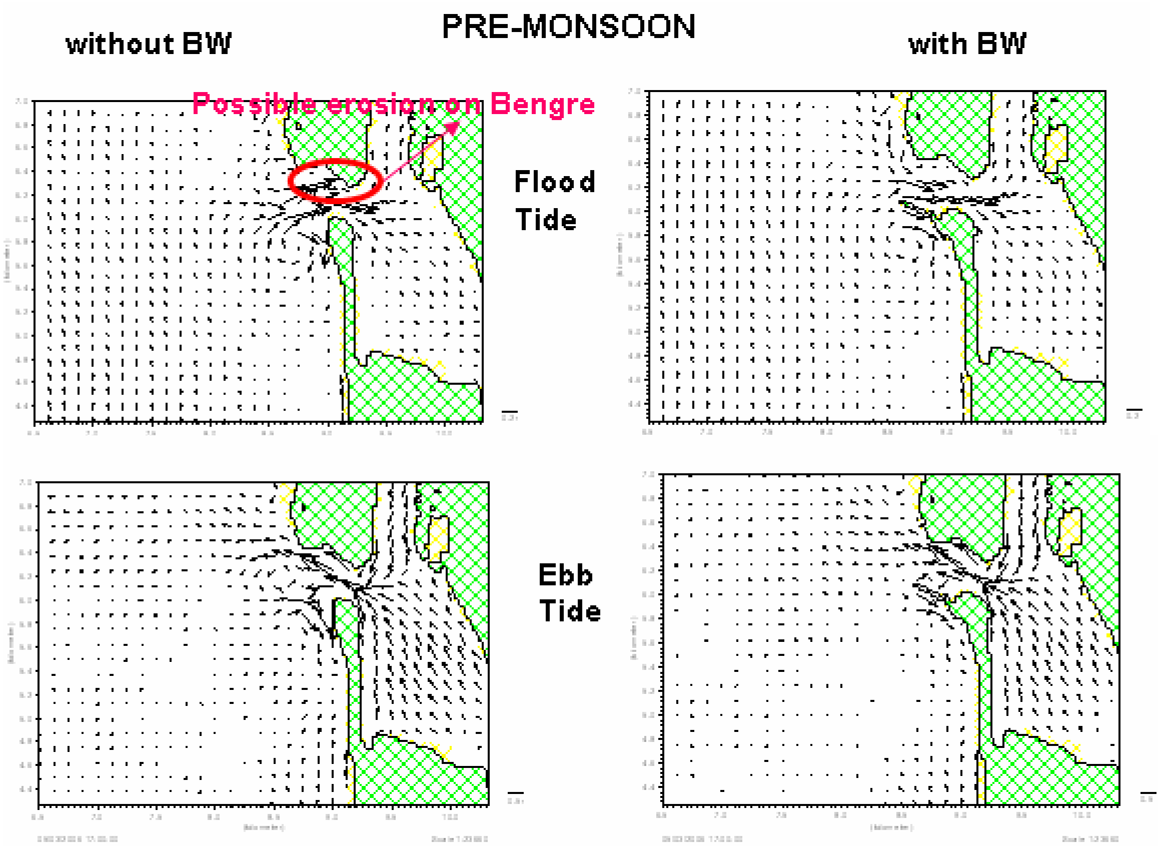


Fig. 5.16 Current pattern during pre-monsoon season

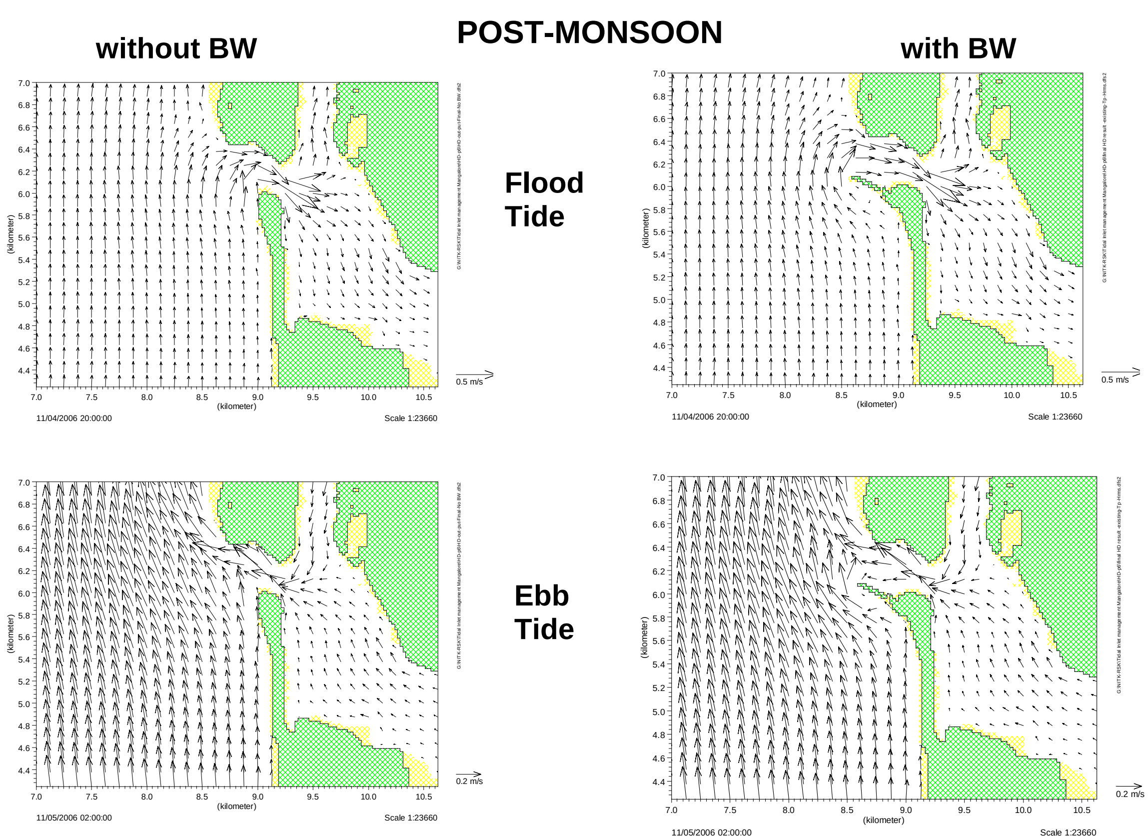


Fig. 5.17 Current pattern during post-monsoon season

5.3.1 Circulation pattern observed during Monsoon season

It has been observed that the circulation is not constant through out the coast it is varying depending on the river discharge and offshore wind and wave conditions. The figures from 5.18 a through 5.18e represents the circulation pattern at different time steps during monsoon season where a clear rip current circulation can be observed.

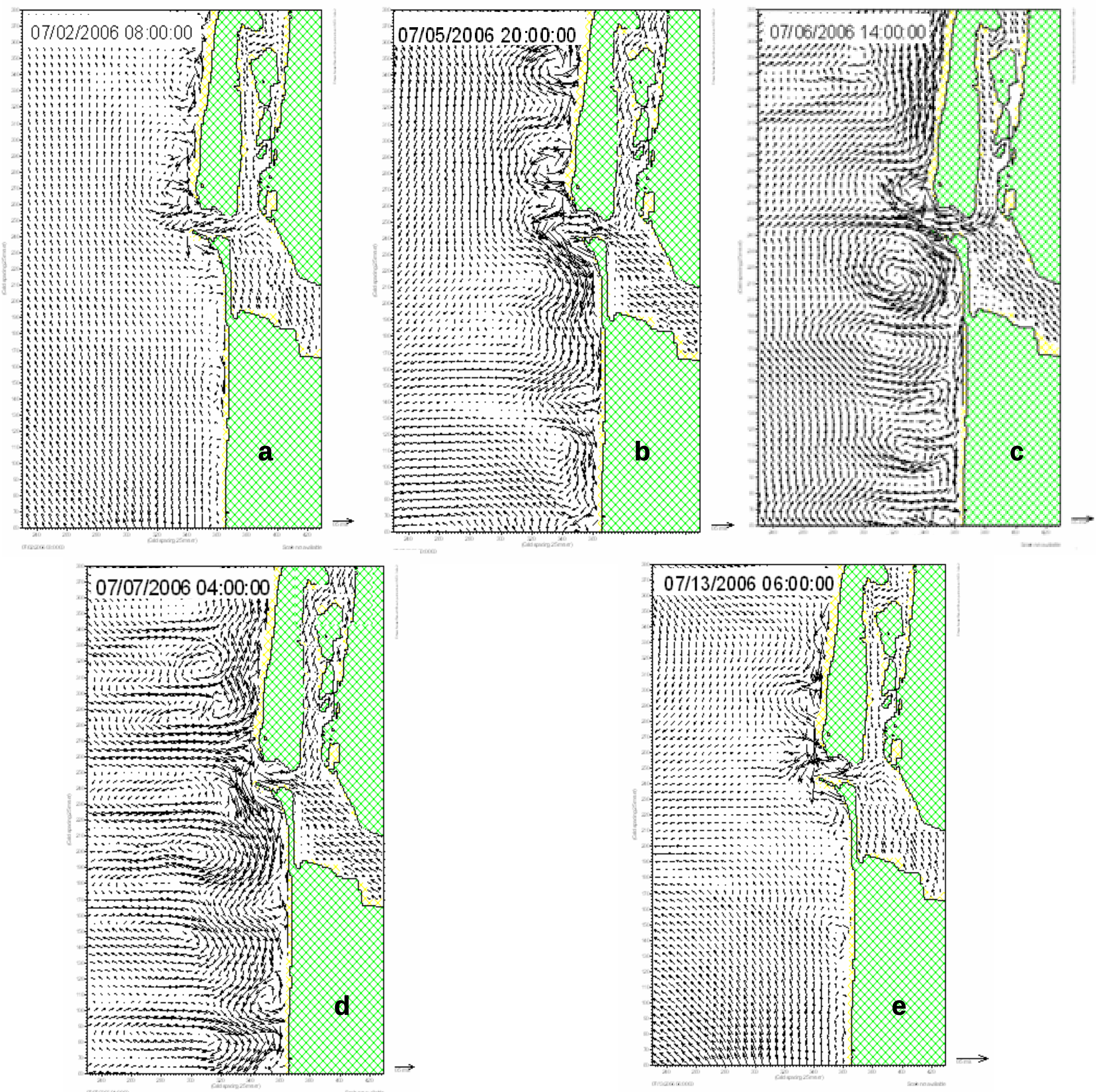


Fig. 5.18 Circulation during monsoon for Ullal coast

However, it is felt that the data considered for the study is not exhaustive and any future studies considering the output of this study should take note of this.

5.4 Non Cohesive Sediment Transport Model

MIKE 21 ST is the module of the MIKE 21 modeling system calculates the rates of non-cohesive sediment (sand) transport for both pure current and combined waves and current situations. The results provided by MIKE 21 ST can be used to identify potential areas of erosion or deposition and to get an idea of the initial rate at which bed level changes will take place, but not to determine an updated bathymetry at the end of the simulation period.

5.4.1 Output

From the results obtained, it can be inferred that during monsoon season, net sediment movement is towards south, during post-monsoon season it is towards North and during Pre-monsoon season it is towards south. Schematic sketches of sediment movement during pre-monsoon, monsoon and post-monsoon are shown in fig. 5.19a through 5.19c respectively.

5.5 Sediment trend matrix

The sediment trend matrix analysis was carried out for the year 2005. During pre monsoon season net sediment movement is towards South, during post-monsoon season it is towards North. The paths traced by sediments during movements are in good agreement with the MIKE 21 ST model results, as shown in the fig. 5.20.

5.6 Design of erosion prevention structures through modelling

Modeling has been carried out over 3 alternative structures which include Groin, Submerged Reef and T-Groin for monsoon condition during which high energy concentration was observed.

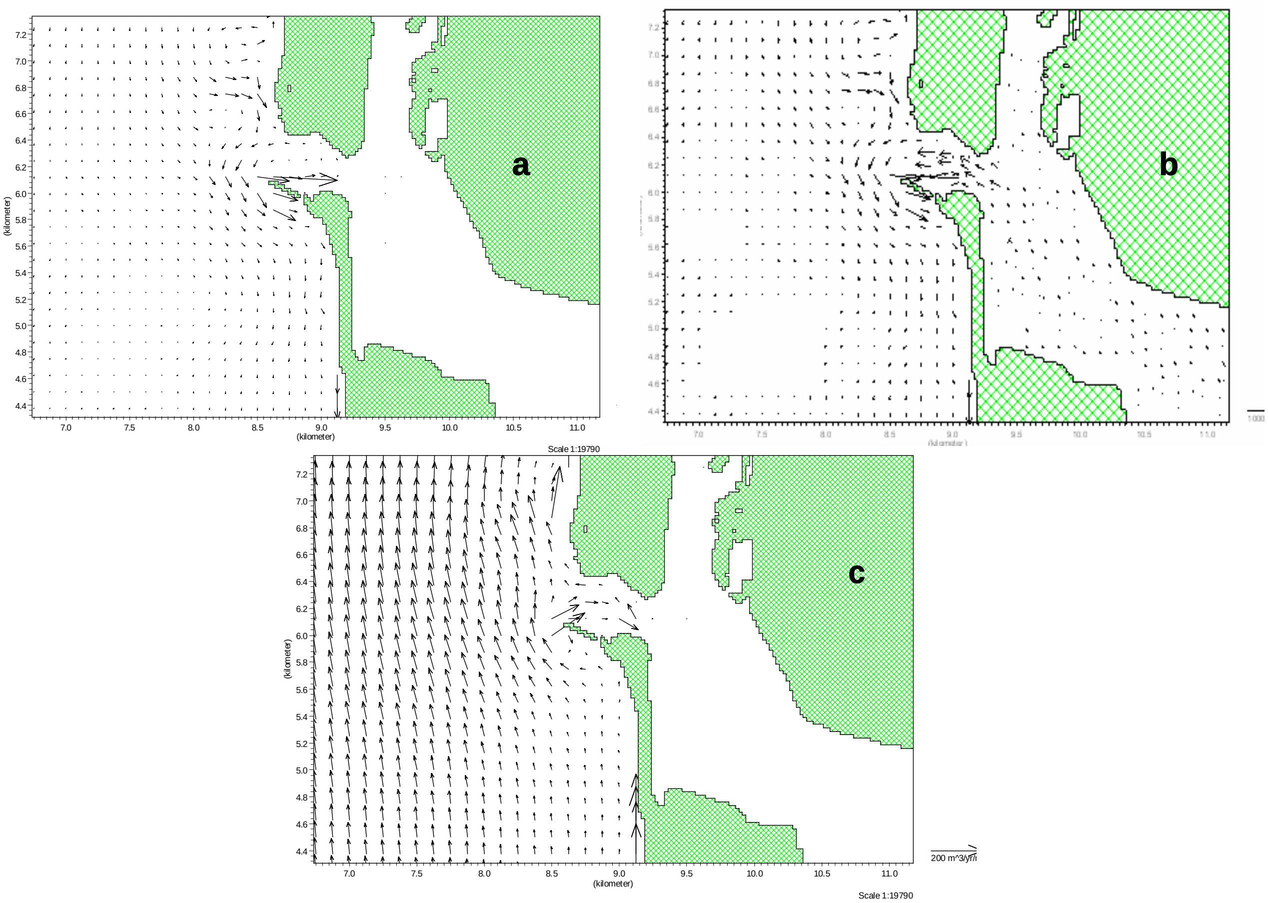


Fig. 5.19 Sediment pattern during various seasons

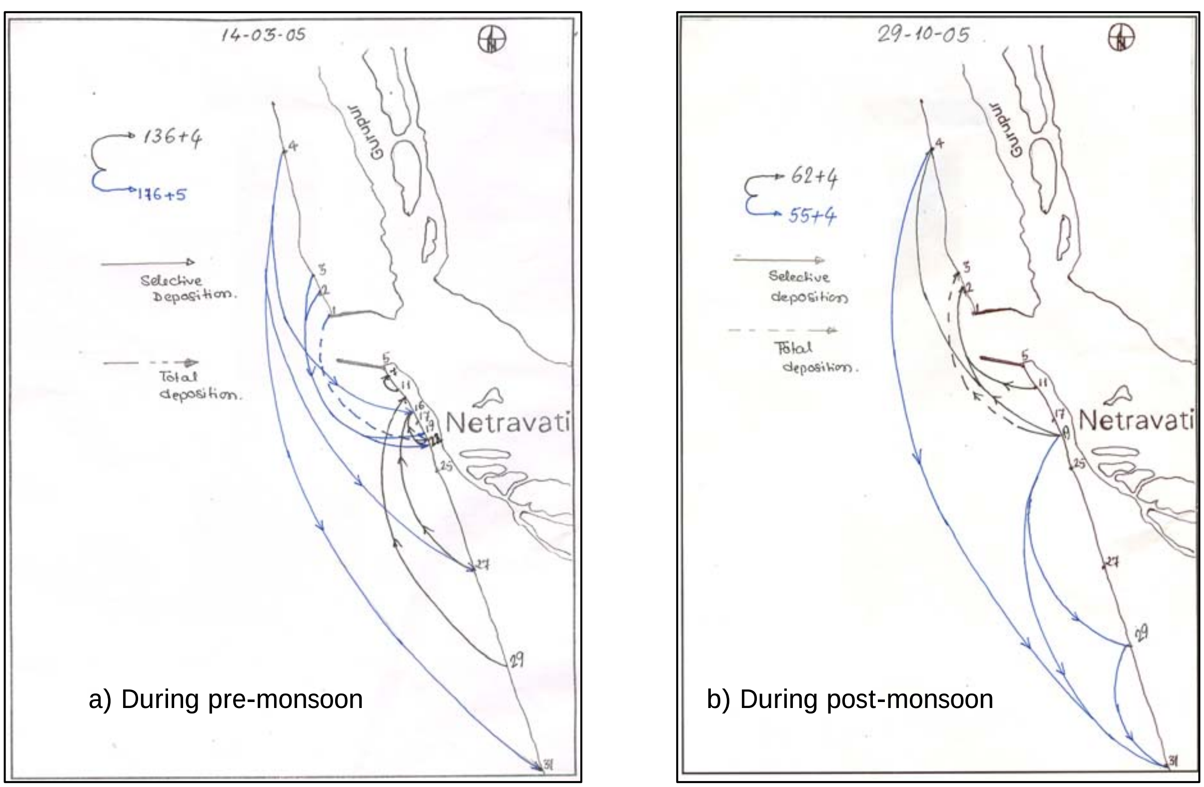


Fig. 5.20 Sediment movement trends

In a groin field, the ratio of Groin length to distance between groins can vary from 1:1.5 up to 1:4 (Sorensen, 1978). If spacing to length ratio is less than 1.5 there is a chance of rip currents formation in between the groin field. In the present study the length of the Groin is considered is 60m from the shore and the spacing between the Groins is 90m. The structure is an emergent one.

Shoreline response to a T-head groin is similar to that of a detached breakwater (Pope and Dean 1986). The main difference between them is that the beach plan shape behind the T-head structure is controlled by waves arriving at one side of the structure, with no opposing waves and currents possible as in the case of the reef. As a consequence, the salient behind a detached breakwater is expected to grow more slowly than a salient behind a T-head groin, other conditions being equal. The shoreline grows until a salient or tombolo is fully formed, after which further functioning of the two structures should be the same. Thus, shoreline response to a T-head groin is more analogous to a headland than to a detached breakwater. In the present study the length of the flange section adopted is 60m, the web section is 60m and the spacing provided is 30m and the structure is an emergent one with crest 2.0m above MSL.

As a rough guideline, the submerged breakwater/Reef length to distance from shoreline, L_B/Y_B can be taken in between 1 and 2, the gap ratio G_B/L_B should be between 0.5 and 1 for a submerged reef. If $G_B/Y_B<0.8$, no erosion takes place in front of the gap (Pilarczyk and Zeidler, 1996). Keeping this in view, the length ratio L_B/Y_B is taken as 1 and gap ratio G_B/L_B is taken as 0.5 for optimization. An increase in L_B/Y_B ratio leads to salient formation at the lee of the breakwater and decrease in the L_B/Y_B ratio leads to the formation of tombolo at the lee of the Breakwater. It has been identified that for Mangalore region the deep water wave steepness is $Ho/Lo>0.03$, (after E.J. John) which indicates the formation of an offshore bar. For this condition submerged structures proves to be viable. In the present study the length of the submerged reef considered is 60m, distance from the shore is 60m which is located at a depth of 3.5m and the spacing between them is 30m.

From the bathymetry survey it has been found that the bed slope in Ullal region is 1:20 up to contour 6m water depth. The results obtained shows that the effect of Groin is insignificant in dissipating the wave energy and its functional ability constraints to mobilize current movement and sediment movement alongshore. T-Groin and submerged reef are proven to be better in dissipating the wave energy because of this functional ability they were considered for the further analysis. The model been run for the criteria mentioned above. The wave results pertaining to the same are shown in fig. 5.21.

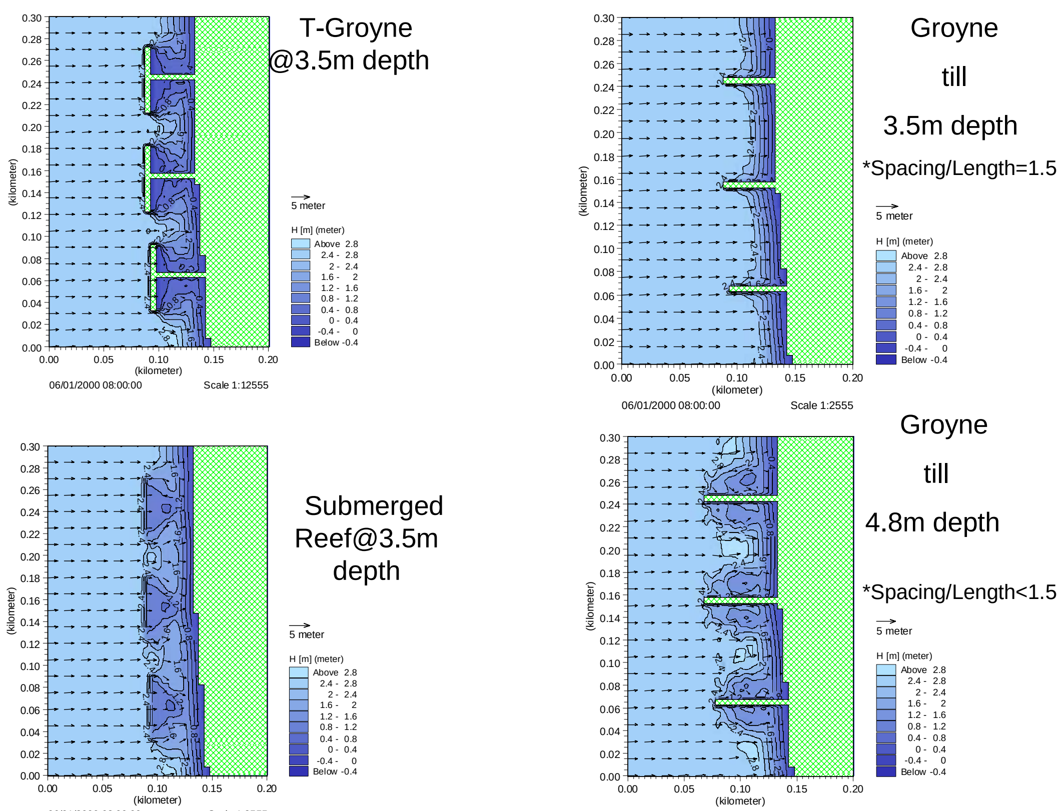


Fig. 5.21 Wave interaction with structures

The results obtained shows that the T-Groin and the submerged reef are effective in reducing the wave action than that of Groins.

5.6.1 Methodology adopted for Structural Optimization

Care is required both to optimize the benefits of the structures and to minimize or eliminate any negative impacts on the shoreline. Keeping this in view submerged reef has been chosen as the best alternative to dissipate the wave energy for the major portion of the Ullal coast while T-Groin has been considered at the tail of the southern breakwater in order to protect the shore (refer to Fig. 5.22) and the optimization has been done for submerged reef to arrive at its dimensions as shown below.

Length of the break water (L_B) =60m

Gap between the breakwater (G_B) =30m

Incident wave height (Hi) =2.6m at the structure (offshore wave height given is 4.5m, Tp=8sec)

Crest width (B) =5, 10, 15,20m respectively

Crest depth (C) =0, 0.5, 1, 1.5, 2, 2.5 m respectively

Wave length (L) =50m (site condition)

Average depth at the structure (d) = 4.2m

Wave Direction (D) = 251(perpendicular to the coast)

For the above particulars the following plot has been depicted from the statistical values obtained after running the model with parametric random wave criteria.

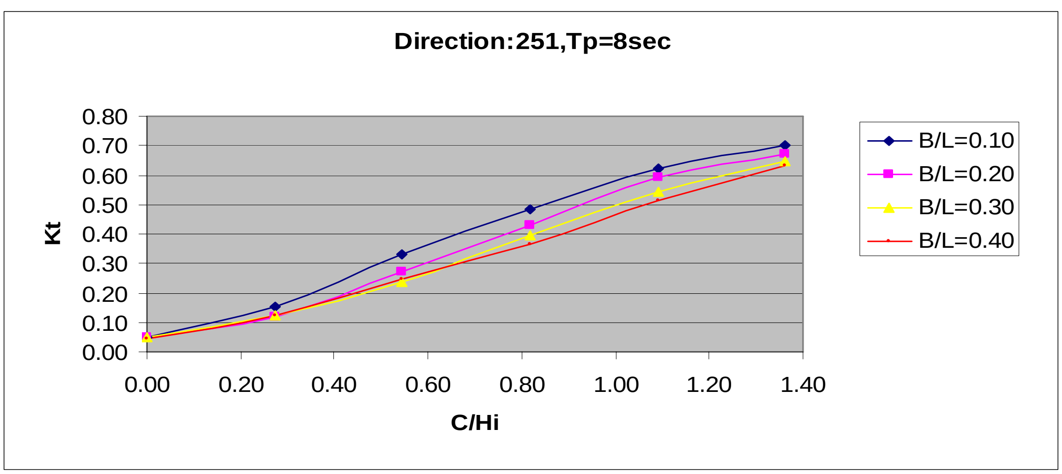


Fig. 5.22 Transmission coefficient in relation to the relative crest depth

It can be inferred that for the increase in crest width there is a considerable reduction in the transmission coefficient. Comparing the variation of K_t for varying B/L, it is found that B/L of 0.2 (i.e. B = 10m) seems to be optimum.

5.6.2 Structural interaction during monsoon season

The fig. 5.24 represents the current interaction with Ullal coast without and with structures. Fig 5.24.a shows that the current movement is very close to the coast which may lead to erosion and beach width loss whereas the fig 5.24.b shows that the current has moved offshore in the presence of structures resulting in a calm region near the coast which may contribute to the beach stability.

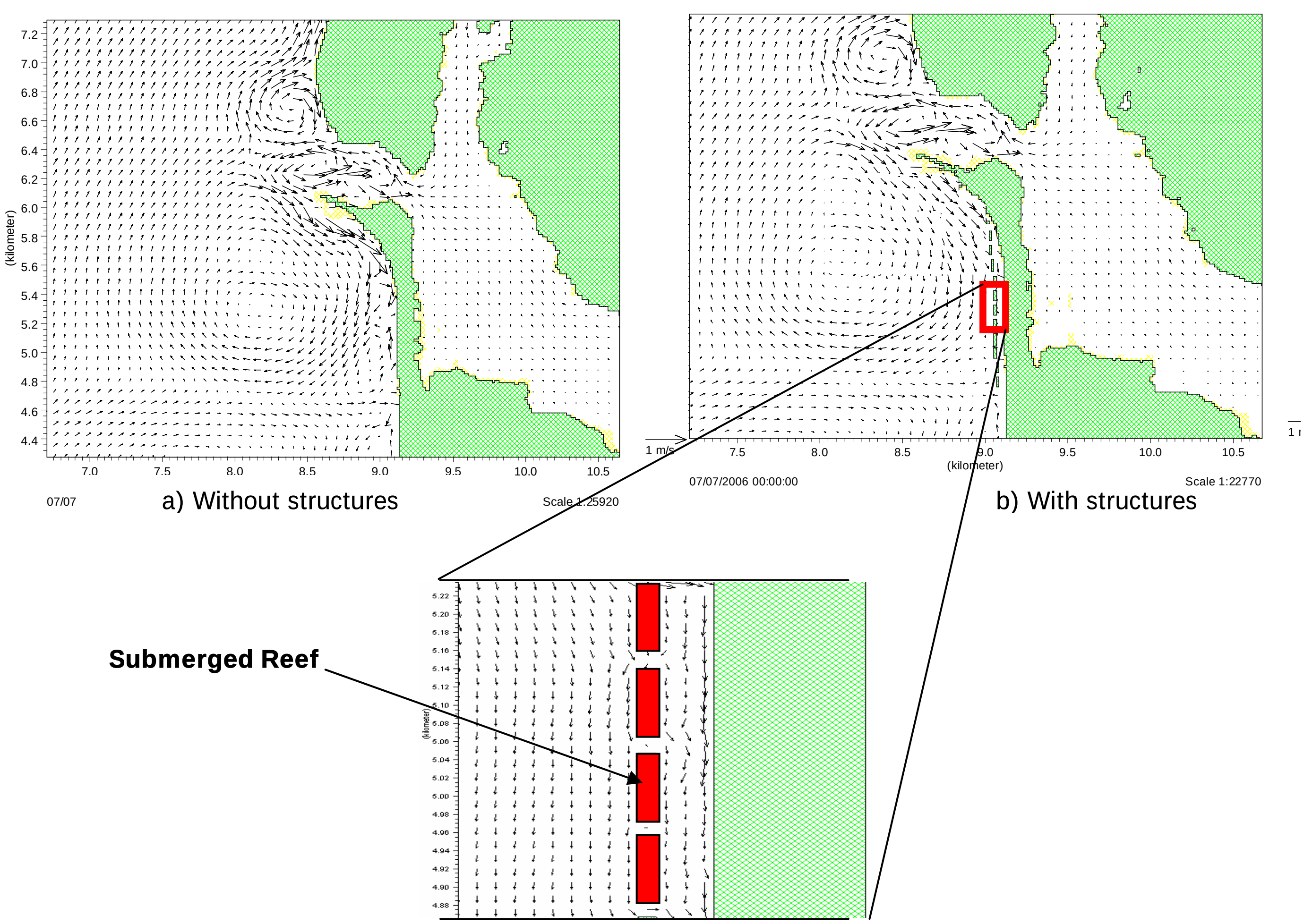


Fig. 5.23 Current interaction with Ullal coast

Fig. 5.24 shows the sediment movement pattern in Ullal after placing the structures. It is clearly visible that the impact of the structure on the sediment transport conditions is much less significant for the case of the submerged reef structure than for the surface-piercing one. General analogy is that, if a structure obstructs the sediment movement, there are chances that, either it may lead to sediment deposition or erosion. But a Submerged Reef structure will not effect the sediment movement much.

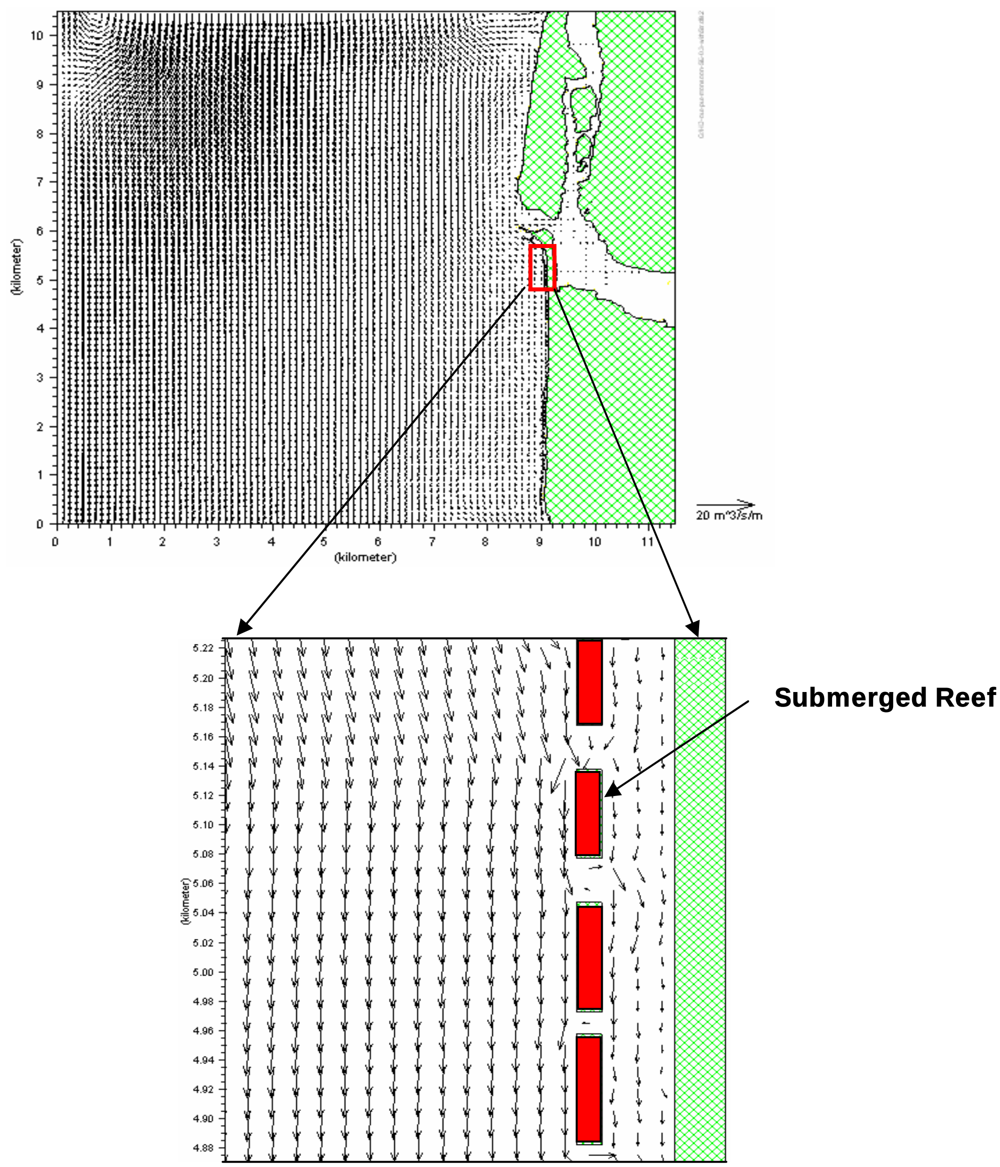


Fig. 5.24 Sediment movement pattern with structures

5.7 Management of Tidal Inlets

The management of tidal inlets requires the understanding of existing coastal processes in and around the study area. It is also important to for the decision makers to take suitable corrective steps in order to prevent any erosion of beach and regression of the shoreline around the tidal inlets.

Severe coastal erosion is taking place since 1996 during the monsoons along the coastal stretches of Kotepura in Ullal town of Mangalore Taluk of Dakshina Kannada District in Karnataka State. The river mouth is enclosed by two land connected spits in the North and South. The site of erosion is the southern spit over a length of 1.5 Km.

Historically, this river mouth was found to migrate with oscillating positions. When siltation at the mouth was disrupting the navigability of fishing boats, two rubble mound breakwaters (river training jetties) were built on either side of the mouth of the rivers in 1994. Subsequent to these constructions, the erosion at Ullal and accretion at Bengre has been observed.

The preliminary enquiry regarding the erosion problems at Ullal revealed that the forcing factors for beach erosion at Ullal essentially consisted of waves, currents, discharge of river water and sediments, ground water table variation together forming a complex system resulting in a nearshore cell circulation patterns which dislodged the sand from the beach. The beach encroachment and sand mining are the other factors which contributed to beach erosion in their own way. The present encroachment may be encouraged to relocate themselves far from the beach. Serious efforts to prevent future sand mining and beach encroachment have to be contemplated and efforts may be made to implement the existing CRZ regulations. The existing river training jetties (breakwaters) have undergone settlement and failure over the period of time due to lack of maintenance and repair. All these factors have complicated the beach erosion at Ullal. This has necessitated a detailed and exhaustive investigation into the problem.

The present study is concerned about finding a lasting solution to the erosion at Ullal beach. In the course of project duration, good amount of data has been collected regarding environmental and oceanographic data like ground water table variations, beach profiles, wave climate, currents, bathymetry and sediments in and around Netravathi-Gurupur river mouth.

MIKE 21 modules like HD, PMS and ST have been brought into use to simulate the relevant parameters like tides, wave heights, currents and sediment movement using the data collected. This simulation has been then utilised to model the probable conceptual beach protection structures like simple groins, T-Groins and submerged reef. The model results with the structures in place are compared with those without structures. This comparison clearly illustrated the superiority of the submerged reef as a beach protection measure in safeguarding Ullal shoreline.

The management plan of Netravathi-Gurupur river mouth and adjoining Ullal beach should necessarily consist of building a series of detached submerged reefs from the south of southern breakwater up to a chainage of 4000m southwards. These submerged reefs may be of slope 1:2 and length 60m placed at a distance of 60m from the shore and located at a depth of 3.5m with a gap of 30m between them. These submerged reefs are highly advantageous regarding environmental conservation and sediment dynamics. The reefs fully allow the exchange of waters between the nearshore and offshore. They also prevent onshore offshore sediment movement considerably leading to retention of sediments on the lee side. In addition to these advantages, they list high on aesthetics as they do not block the view of the horizon and boost the tourist potential of Ullal by being helpful in developing water sports.

6

OBSERVATIONS AND CONCLUSIONS

6
OBSERVATIONS AND CONCLUSIONS

Based on the studies carried out till date following typical observations have been made and conclusions inferred thereof.

Typical Observations

- Wave Direction - NW, W and SW during pre-monsoon, monsoon and post-monsoon seasons respectively.
- Estuarial flood current faster than ebb current.
- Coastal current/Sediment movement towards south during pre-monsoon and get reversed during post-monsoon.
- Tides are classified as mixed with predominant semidiurnal component.
- GWT observations show that the stretches where the hydraulic gradient is towards the sea are prone to erosion.
- During monsoon season, erosion occurs at Ullal and accretion at Bengre region and gets reversed during fair weather season.
- Sediment movement paths traced matches well with results of model.
- The sediment budget for the study area is evolved.
- The model results are generally in fairly good agreement with the observed data.

Conclusions

- The coastal problem in the study area has been recognized and its various forcing factors have been successfully identified.
- The data collected from the study area has been successfully used to model the coastal processes of the area.

- Developing suitable long-term alternative measures such as simple groin system, T-Groin field and submerged breakwater for effective shore protection off Ullal coast have been attempted.
- Submerged breakwater has been zeroed in as the best solution to the present erosion problem at Ullal.
- However for increased confidence in evolving accurate design of the recommended solution, it is advised to conduct the physical model feasibility of the same.

REFERENCES

REFERENCES

1. Ahrens, J. P., 1984, “Reef type breakwaters”, Proc., *Conf. on Coastal Engg.*, pp. 2648 – 2662.
2. Armono, H. D., and Hall, K. R. (2002). “Wave transmission on submerged breakwaters made of hollow hemispherical shape artificial reef”, *Proc., Canadian Coastal Engg. Conf.,* Army Corps of Engineers, Alexandria, VA (prepared for the Office of Management and Budget, Washington, DC.)
3. Baba, M., (1986). “Computation of wave transmission over a shore protecting submerged breakwater”, J. *of Ocean Engg.,* 13(3), 227 – 237.
4. Baba. (1985). “Design of submerged breakwater for coastal protection and estimation of wave transmission coefficient”, *Proc., 1st Nat. Conf. on Dock and Harbour Engg*., I.I.T., Bombay, Dec, B-13 – B-26.
5. Baeteman, C. 1994. “Subsidence in Coastal Lowlands Due to Groundwater Withdrawal: The Geological Approach; Coastal Hazards, Perception, Susceptibility and Mitigation,” C. W. Finkl, Jr., ed., Journal of Coastal Research Special Issue No. 12, pp 61-75.
6. Bailard J.A. 1982, Modeling on-offshore sediment transport in the surf zone. Proceed. Intern Conf. Coastal Eng. Vol.II. Cape Town, Republic of South Africa.
7. Baird, W. F., and Hall, K. R. (1984). “The design of breakwaters using quarried stones”, *Proc., 19th Conf. on Coastal Engg.,* 3, pp 2580 – 2591.
8. Bakker, W. T. 1968. “The Dynamics of a Coast with a Groyne System,” *Proceedings, 11th International Coastal Engineering Conference*, ASCE, NY, pp 492-517.
9. Balsillie, J. H., and Berg, D. W. 1972. “State of Groin Design and Effectiveness,” *Proceedings, 13th International Conference on Coastal Engineering*, ASCE, NY, pp 1367-1383.

10. Balsillie, J. H., and Bruno, R. O. 1972. “Groynes: An Annotated Bibliography,” Miscellaneous Paper 1-72, U.S. Army Corps of Engineers, Coastal Engineering Research Center, Springfield, VA.

11. Barnett, T. P. 1984. “The Estimation of 'Global' Sea Level: A Problem of Uniqueness,” Journal of Geophysical Research, Vol 89, No C5, pp 7980-7988.

12. Berenguer J. & e. Thmayo 1988. Beach restoration at Malaga urban area: Pedregalejo case study. *Proceed. 21st lCCE 1-15.*

13. Berenguer J.M. & J. Enriquez Fernandez 1988. Design of pocket beaches. The Spanish case. *Proceed. 21st ICCE* 1411-1425. Malaga, Spain.

14. Bierawski, L. G., and Maeno, S. (2002). “Water pressure fluctuations around a submerged breakwater”, *Proc., Symposium on Dynamic Water Pressure and Bed response in water, DPRI,* Kyoto University, Japan, Dec., 45 -54.

15. Boer, S. 1985. “The Flow Across Trenches at Oblique Angles to the Flow,” Report 5490 Delft Hydraulics Laboratory, Delft, The Netherlands.

16. Bowen, A. J., and Inman, D. L. 1966. “Budget of Littoral Sands in the Vicinity of Point Arguello, California,” Technical Memorandum, Coastal Engineering Research Center, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

17. Bruun, P. 1952. “Measures Against Erosion at Groins and Jetties,” *Proceedings, 3rd International Conference on Coastal Engineering*, ASCE, NY.

18. Carter, R. W. G. 1988. Coastal Environments: An Introduction to the Physical, Ecological, and Cultural Systems of Coastlines, Academic Press, London, UK.

19. Chandramohan, P. and Panchatcharam, K., 2001, “Siltation in the Dredged Channel in Gurupur River”, Proc. Intl. Conf. in Ocean Engineering, pp. 487-492.

20. Chandramohan, P., Sa nil Kumar, V., Nayak, B. U. and Raju, N. S. N., 1994, “Surf zone dynamics along the south Karnataka coast between Bhatkal and Ullal, West coast of India”, Indian Journal of Marine Sciences, Vol. 23, pp. 189-194.

21. Chasten M., J.D. Rosati, J. Mc Cormick and R.E. Randall, 1993, Engineering Design Guidance for Detached Breakwaters as Shoreline Stabilisation Structures, US Army Corps of Engineers, WES, CERC-93-19.

22. Cheng RT, Burau J.R and GARTNER N.R, 1991. Interfacing data analysis and numerical modeling for tidal hydrodynamics phenomena. In PARKER. B,B(ed), Tidal Hydrodynamics. John Wily, New York, pp. 201-219.
23. CHENG RT, CASULLI. V. and GARTNER N.R, 1993. Tidal, residual. Intertidal mudflat (TRIM) model and its application to San Francisco Bay, California. Estuarine, Coastal and self science. 36, pp. 235-280.
24. Chew S.Y., P.P.Wong and K.K. Chin, 1974, Beach development between headland breakwaters, Proceed. 14th Intern. Conf. Coastal Eng. 1399-1418.
25. Coleman, J. M. 1988. "Dynamic Changes and Processes in the Mississippi River Delta," Bulletin of the Geological Society of America, Vol 100, pp 999-1015.
26. Dange, A. P. and Ghosh, L. K. (2001). Longshore current velocities along west coast of India. Intl Conf. in Ocean Engineering, Dec 11-14, 2001, pp. 473-479
27. Danish Hydraulic Institute, 1988
28. Dattatri, J. (1981) Wave climatology for west coast of India: Log-term wave height distributions. INCOE 81, pp. L 62- 65.
29. Dattatri, J. and Baba, M. (1987) Average spectra for waves off the west coast of India. Second national conference on dock and harbour engineering, 9-12, December 1987, Madras, pp.130-133.
30. Dattatri, J. and Renukaradhya, P. S. (1970) Wave forecasting for the west coast of India. Coastal Engineering, Washington, Vol. I, pp. 203-215.
31. Dattatri, J. and Venkata Rami Reddy, p. (1991) Wave group statistics for waves off west coast of India. INCOE – 91, Goa, pp. 9-18.
32. Dattatri, J., Raman, H., and Jothi Shankar, N. (1978). "Performance characteristics of submerged breakwater", *Proc., 16th Coastal Engg. Conf.,* Hamburg, 2153 – 2171.
33. Dattatri, J., Rao, N.B.S., Rao, Subba, Dwarakish, G.S. and Kumar, Nagendra B., 1997, "Beach profile studies along D.K. Coast of Karnataka State"-Second Indian national conference on harbour and ocean engineering (INCHOE-97), Centre for earth science studies (CESS), Thiruvananthapuram., pp. 1135 - 1144.

34. Davies, J. L. 1964. “A Morphogenic Approach to World Shorelines,” Zeitschrift für Geomorphology, Vol 8, pp 27-42.

35. Dean-Rosati J., 1990, Functional Design of Breakwaters for Shore Protection:Empirical Methods, US Army Corps of Engineers, CERC-90-15.

36. Dick Milne, T., and Brebner, A. (1968), “Solid and permeable submerged breakwater”, *Proc., 11th Conference on Costal Engg*., 1141 – 1158.

37. Diskin, M. H., Vajda, M. L., and Amir, I. (1970). “Piling up behind low and submerged permeable breakwaters”, *J. of Waterways and Harbour Division,* 96(2), 359 – 371.

38. DOA-Department of the Army, Corps of Engineers. 1971. *Report on the National Shoreline Study,* Washington, DC. 20314, August 1971, 59 p.

39. Edge, B. L., Housley, J. G., and Watts, G. M. (1976). “Low cost shoreline protection”, Proc., 15th Conf. on Coastal Engg., 3, 2888 – 2904.

40. Eduarodo Siegle, David A. Huntley and Mark A Davidson, 2002, Modelling Water Surface Topography at a Complex Inlet System, Teignmouth, UK, Journal of Coastal Research. 36, pp. 675-685.

41. EM 1110-2-1617 “Coastal Groins and Nearshore Breakwaters.”

42. Emery, K. O., and Aubrey, D. G. 1991. Sea Levels, Land Levels, and Tide Gauges, Springer-Verlag, New York, NY.

43. Ferrante A., L. Franco and S. Boer, 1993, Modelling and monitoring of a perched beach at Lido di Ostia (Rome)., Proceed. 23rd Intern. Conf. Coastal Eng. 252:3305-3318. Venice, ASCE.

44. Fleming, C. A. 1990. “Guide on the Users of Groynes in Coastal Engineering,” Report 119, Construction Industry Research and Information Assoc. (CIRIA), London, England.

45. Franco L., 1985, Behaviour of detached breakwaters, Proceedings European Workshop on Coastal Zones, as related to physical processes and coastal structures. Lautraki, Greece.

46. Franco, L., 1990, “Effect of Constructions on Coastal Morphology”, Proc. CEEC Course on Coastal Morphology, Delft.

47. Franco, L., 2001, “New Italian experience in the design of maritime structures”, Proc., Int. Conf. in Ocean Engg., COE, I.I.T. Madras, Chennai, Dec., K-81 – K-93.

48. Franco, Leopold. 1996. “History of Coastal Engineering in Italy,” *History and Heritage of Coastal Engineering,* American Society of Civil Engineers, New York, NY. pp 275-335.

49. Frihy, O. E. 1992. “Sea-Level Rise and Shoreline Retreat of the Nile Delta Promontories, Egypt,” Natural Hazards, Vol 5, pp 65-81.

50. Fullford, E. T. (1985). “Reef type breakwater for shoreline stabilization”, *Coastal Zone-‘85*, 1776 – 1795.

51. Galvin, C. J. and Eagleson, P. S., 1965, “Experimental study of long-shore currents on a plane beach, Technical Memorandum No. 10, C.E.R.S., U.S. Army Corps of Engineers, pp. 80.

52. Goda, Y. (1996). “Wave damping characteristics of longitudinal reef system”, *Advances in Coastal Structures and Breakwaters,* Thomas Telford, London, 192 – 207.

53. Goldsmith V. and S. Sofer, 1983, Wave Climatology of the Southeastern Mediterranean: An Integrated Approach, Israeli J. Earth Sci., 32:1-51.

54. Grant, U. S., 1946, Effect of ground water table on beach erosion (abstract), Bulletin Geological Society of America, 57, 1252

55. Grant, U. S., 1948, Influence of water table on beach aggradation and degradation, Journal Marine Research, 7, 655-660.

56. Habeeb Khan, P., 2000, “Sediment trend matrix analysis of beach sand along Dakshina Kannada coast”, M.Tech. Thesis, Dept. of Applied Mechanics and Hydraulics, KREC, Surathkal.

57. Hands, E. B. 1983. “The Great Lakes as a Test Model for Profile Response to Sea Level Changes,” Chapter 8 in Handbook of Coastal Processes and Erosion, P. D. Komar, ed., CRC Press, Inc., Boca Raton, FL. (Reprinted in Miscellaneous Paper CERC-84-14, Coastal Engineering Research Center, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.)

58. Harris, L. E. (2003). "Artificial reef structures for shoreline stabilization", *Proc., 3rd Int. Surfing Reef Symposium* Raglan, New-Zealand, June, pp 176 – 179.

59. Hayes, M. O., 1979. "Barrier Island Morphology as a Function of Tidal and Wave Regime," *Barrier Islands from the Gulf of St. Lawrence to the Gulf of Mexico*, S. P. Leatherman, ed., Academic Press, New York, NY, pp 1-29.

60. Helewaut M. and B. Malherbe, 1993, Design and Execution of beach nourishment in Belgium, Proceed. Coastal Zone '93 7(14b).

61. Hicks, S. D. 1972. "Changes in Tidal Characteristics and Tidal Datum Planes," The Great Alaska Earthquake of 1964, Oceanography and Coastal Engineering, National Academy of Sciences, Washington, DC, pp 310-314.

62. Hicks, S. D. 1978. "An Average Geopotential Sea Level Series for the United States," Journal of Geophysical Research, Vol 83, No. C3, pp 1377-1379.

63. Hill R.O., 1966, Changes in beach form at Sri Pantai Northeast Johore, Malaysia. Journal of Tropical Geography 23: 19-27.

64. Hillyer, T. M. 1996. *Shoreline Protection and Beach Erosion Control Study, Final Report: An Analysis of the U.S. Army Corps of Engineers Shore Protection Program.* IWR Report 96-PS-1, Shoreline Protection and Beach Erosion Control Task Force, Water Resources Support Center, Institute for Water Resources, U.S.

65. Hoffman, J. S., Keyes, D., and Titus, J. G. 1983. "Projecting Future Sea Level Rise; Methodology, Estimates to the Year 2100, and Research Needs," Report 230-09-007, U.S. Environmental Protection Agency, Washington, DC.

66. Homma Masashi and Horikawa Kiyoshi (1961) "A study on submerged breakwaters", Coastal Engineering *in Japan*, 4.

67. Homma Masashi, and Sakou Toshitsugu. (1959). "An experimental study on the submerged breakwater", *Coastal Engg. Conf. in Japan*, 11, 103 – 109.

68. Horikawa, K., and Kuo, C. T. (1966). "Study on wave transformation inside surf zone", *Proc., Conf. on Coastal Engg.* in Japan, 217 – 233.

69. Horn, D.P., (2002), "Beach ground water dynamics", Jl. of Geomorphology, Elsevier Publications, Vol. 48, pp. 121-146.

70. Houston, J. R. 1993. “Responding to Uncertainties in Sea Level Rise,” The State of Art of Beach Nourishment, Proceedings of the 1993 National Conference on Beach Preservation Technology, The Florida Shore & Beach Preservation Association, Tallahassee, FL, pp 358-372.
71. Houston, J. R. 1993. “Responding to Uncertainties in Sea Level Rise,” The State of Art of Beach Nourishment, Proceedings of the 1993 National Conference on Beach Preservation Technology, The Florida Shore & Beach Preservation Association, Tallahassee, FL, pp 358-372.
72. J. Dattatri, N.B.S. Rao, B. Nagendra Kumar, Subba Rao and G. S. Dwarakish, (1997), "Coastal erosion along Dakshina Kannada Coast, Karnataka, INDIA” Proc. National seminar on “Coastal zone environment management : An appraisal of the contemporary research and development”, Dept. of Marine Geology, Mangalore University, Mangalagangothri, pp 8-9.
73. Jayappa, K. S. and Subrahmanya, K. R., 1989, “Beach Morphological changes between Talapadi and Surathkal, Dakshina Kannada”, Proc. Recent Geoscientific Studies in the Arabian Sea off India, Geological Survey of India, Spec. Publ., 24, pp 299-306.
74. Jayappa, K. S., Vijaya Kumar, G. T. and Subrahmanya, K. R., 2003, “Influence of Coastal Structures on the beaches of southern Karnataka”, Jl. of Coastal Research, Vol. 19(2), pp. 389-408.
75. Jim Parks, -, “New "Soft" Technologies For Coastal Applications: Fluidization for Inlet Sand Bypassing, and Beach face Dewatering For Beach Widening and Stabilization”, DYNEQS Ltd., Florida Ave. (http://ieeexplore.ieee.org/iel2/4490/12734/00592824.pdf?arnumber=592824)
76. JMC-Japanese Ministry of Construction, 1986, Handbook of Offshore Breakwater Design, JMC-CERC.
77. John, E. J., (1988). "Coastal erosion and protection along the West coast of India." Technical Report, Dept. of Applied Mechanics and Hydraulics, K. R. E. C., Surathkal, submitted to the Ministry of Surface Transport, Govt. of India.

78. John, E.J. and Nayak, I. V. (1985) Study of coastal erosion and performance of coastal protection works on the west coast of India. First National conference on Docks and Harbour Engineering, IIT, Bombay. Vol. I, pp. b 27 – B 35.
79. Johnson, J. W., Fuchs, R. A., and Morison, J. R. (1951). "The damage action of submerged breakwater", *Transaction, Americal Geophysical Union* 2 (5), 704 – 718.
80. Kaldenhoff, H. (1996). "Recent developments in the construction of breakwaters", *Proc., of Int. Conf. in Ocean Engg., COE,* I.I.T. Madras, Chennai, Dec., 681 – 693.
81. Kaldenhoff, H. (1996). "Recent developments in the construction of breakwaters", *Proc., of Int. Conf. in Ocean Engg., COE,* I.I.T. Madras, Chennai, Dec., 681 – 693.
82. Kale, A. G., and Gadre, M. R. (1989). "Construction of offshore structures for beach protection", *Proc., 3rd Nat. Conf. on Dock and Harbour Engg*. Dec., K.R.E.C Surathkal, India, 577 – 582.
83. Karnataka Engineering Research Station, 1989, "Booklet on Sea Erosion studies conducted at Ullal Sea Erosion Site, Mangalore Taluk, D. K. District", KERS, Krishnarajasagara, Govt. of Karnataka, p 3.
84. Khader Abdul, M. H., and Rai, S. P. (1980). "A study of submerged breakwaters" *J. of Hydraulic Research,* 18(2).
85. Kobayashi Nobuhisa., and Wurjanto Andojo. (1989). "Wave transmission over submerged breakwater", *J. of Waterw., Port, Coastal and Ocean Engg*. 115(5), 662 – 680.
86. Komar, P. D. 1992. "Ocean Processes and Hazards Along the Oregon Coast," Oregon Geology, Vol 54, No. 1, pp 3-19.
87. Komar, P. D., and Enfield, D. B. 1987. "Short-Term Sea-Level Changes on Coastal Erosion," Sea-Level Fluctuations and Coastal Evolution, Special Publication No. 41, D. Nummedal, O. H. Pilkey, and J. D. Howard, eds., Society of Economic Paleontologists and Mineralogists, Tulsa, OK, pp 17-28.

88. Kraus, N. C., 1989, “Beach change modeling and the coastal planning process”, Proc. Coastal Zone, pp 553-567.

89. Kraus, N. C., and Bocamazo, L. M. 2000. “State of Understanding of Groin Functioning and Recent Promising Innovations,” *Proceedings, 3rd Annual Conference*, Northeast Shore and Beach Preservation Assoc.,

90. Kraus, N. C., Hanson, H., and Blomgren, S. H. 1994. “Modern Functional Design of Groin System,” *Proceedings, 24th International Conference on Coastal Engineering*, ASCE, NY, pp 1327-1342.

91. KREC Study Team, 1994, “Study on Coastal Erosion – Input to Environmental Master Plan Study, DANIDA-DEE-Mangalore”, Dept. of Applied Mechanics & Hydraulics, KREC, Surathkal.

92. Kuhn, G. G., and Shepard, F. P. 1984. Sea Cliffs, Beaches, and Coastal Valleys of San Diego County; Some Amazing Histories and Some Horrifying Implications, University of California Press, Berkeley, CA.

93. Kunhimammu Paravath and P.I. Sheik Pareeth, 2006, Coastal Changes Due to the Construction of Breakwaters at Ponnani Estuary, Proc. of 15th Congress of APD-IAHR, IIT Madras, Chennai, India, August 7-10, pp. 709-714.

94. Lakshman Nandagiri and KREC Study Team, 1994, “Baseline study on riverflow and groundwater replenishment”, Input to Environmental Master Plan Study, DANIDA-DEE-Mangalore, Dept. of Applied Mechanics & Hydraulics, KREC, Surathkal.

95. Laustrup C., 1988, Erosion Control with Breakwaters and Beach Nourishment, J. Coastal Research, 4(4):677-685.

96. Leveson, D. 1980. Geology and the Urban Environment, Oxford University Press, New York, NY.

97. Levinton, J. S., 1995, “Marine Biology: Function, Biodiversity, Ecology”, Oxford University Press, New York.

98. Liberatore, G., A. Muraca and F. Companale, 1991, “Effects of Coastal Structures on the beaches of the Veneto (Italy), Proc. 23rd Intern. Conf. Coastal Eng., ASCE, Venice, New York, pp. 237-251.

99. Lindo M.H., D. Heijboer and N.M.K.N. Hassan, 1993, "Coastal Erosion-the Kerteh case. Possible measures and selection of the most suitable concept", Van Oord-ACZ, Gorinchem, the Netherlands.

100. Losada, J., Silva, K., and Losada, M. A. (1996). "3D non breaking regular wave interaction with submerged breakwaters", *Coastal Engg., Elsevier Science*, 28, 229 -248.

101. Lundgren, H., and Jacobsen, H. C. L. (1987). "Breakwaters on weak soils", *Proc., Conf .on Coastal and Port Engg. in Developing Countries,* Indonesia, 1, 779 – 793.

102. Lyles, S. D., Hickman, L. E., Jr., and Debaugh, H. A., Jr. 1988. "Sea Level Variations for the United States, 1855-1986," U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Rockville, MD.

103. Madsen, O. S., and White, S. M. (1976). "Wave transmission through trapezoidal breakwaters", *Proc. of 15th Conf. on Coastal Engg.,*. 3, 2662 – 2676.

104. Mangor K., D. Godage, S. Amarasinghe and V. Anderskouv, 1992, Coast Conservation Scheme combining Beach Nourishment and Offshore Breakwaters – testing, design and performance, Proceed. Intnl. Confer. Coastal Eng. in Devel. Countries, 210-226.

105. Mani, J. S., Vijaykumar, S., and Mahadevan, R. (1991). "Diffraction of wanes by submerged breakwater", *Pro., 4th Indian Na. Conf. on Ocaen Engg.*, National Institute of Oceanography, Goa, Sept, 403-407

106. Mariolakos, I. 1990. "The Impact of Neotectonics with Regard to Canals, Pipelines, Dams, Open Reservoirs, etc. in Active Areas: The Case of the Hellenic Arc," Greenhouse Effect, Sea Level and Drought, Proceedings of the NATO Advanced Research Workshop on Geohydrological Management of Sea Level and Mitigation of Drought (1989), R. Paepe, R. W. Fairbridge, and S. Jelgersma, eds., Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 427-438.

107. MIKE-21 Scientific Document, 2005.

108. National Research Council (NRC), 1989, Report on "Measuring and Understanding Coastal Processes for Engineering Purposes", NATIONAL ACADEMY PRESS, Washington, D.C.

109. Nayak, U. B. 1976. "On the Functional Design and Effectiveness of Groins in Coastal Protection," Ph.D. diss., University of Hawaii, Honolulu, HI.

110. Nicholas M Grunnet, Dirk-Jan R Walstra and B.G. Ruessink, 2004. Process-based Modelling of a Shore face Nourishment.

111. Nikolov H., G. Simeonova and K. Marinov., 1988, "Coast reinforcement problems along the Bulgarian Black Sea coast", Jl. of Geology and Hydrogeology, Vol. 18, pp 34-43.

112. Nizam, and Yuwono, N. (1996). "Artificial reef as an alternative beach protection", *Proc., 10th Congress of Asian and Pacific Division of Int. Assn. for Hydraulic Research* I.A.H.R., Aug., Malaysia, 2, 422 – 430.

113. Nummedal, D., and Fischer, I. A., 1978, "Process-Response Models for Depositional Shorelines: The German and the Georgia Bights," Proceedings of the Sixteenth Conference on Coastal Engineering, American Society of Civil Engineers, New York, pp 1215-1231.

114. Oertel, G. F. 1982. "Inlets, Marine-Lagoonal and Marine Fluvial," *The Encyclopedia of Beaches and Coastal Environments*, M. L. Schwartz, ed., Hutchinson Ross Publishing Company, Straudsburg, PA, p 489.

115. Oertel, G. F. 1988. "Processes of Sediment Exchange Between Tidal Inlets, Ebb Deltas, and Barrier Islands,"*Hydrodynamics and Sediment Dynamics of Tidal Inlets*, Lecture Notes on Coastal and Estuarine Studies, Vol.29, D. G. Aubrey and L. Weishar, eds., Springer-Verlag, New York, pp 297-318.

116. Palmer, R. Q., and Walker, J. R. (1976). "Honolulu reef runway dike", *Proc., 15th Conf. on Coastal Engg.,* 3, 1629 – 1646.

117. Payton, C. E., ed. 1977. Seismic Stratigraphy - Applications to Hydrocarbon Exploration, Memoir 26, American Association of Petroleum Geologists, Tulsa, OK.

118. Pennant-Rea, R., ed. 1994. “Chainsaw Massacres,” The Economist, Vol 331, No. 7869, p 39.

119. PIANC WG21, 1992, Guidelines for the design and construction of flexible revetments incorporating geotextiles in marine environment, Suppl. Bull. 78/79.

120. Pilarczyyk, K. W., and Zeidler, R. B. (1996). “Offshore breakwater and shore evolution control”, *A. Balkema Rotterdam,* The Netherlands.

121. Plafker, G., and Kachadoorian, R. 1966. “Geologic Effects of the March 1964 Earthquake and Associated Seismic Sea Waves on Kodiak and Nearby Islands, Alaska,” Geological Survey Professional Paper 543-D, U.S. Government Printing Office, Washington, DC.

122. Pope, J., and Dean, J. (1986). “Development of design criteria for segmented breakwaters,” Proceedings 20th Coastal Engineering Conference, ASCE, 2144-2158.

123. Price, W. A. (1978). “Some ideas on breakwaters theme speech”, *Proc., Conf. on Coastal Engg.,* 1, 37 - 48.

124. Price, W. A. 1968. “Tidal Inlets,” *The Encyclopedia of Geomorphology*, Encyclopedia of Earth Sciences Series, Vol III, R. W. Fairbridge, ed., Reinhold Book Corp., NY, pp 1152-1155.

125. Price, W. A., and Parker, R. H. 1979. “Origins of Permanent Inlets Separating Barrier Islands and Influence of Drowned Valleys on Tidal Records Along the Gulf Coast of Texas,” Transactions Gulf Coast Association of Geological Societies, Vol. 29, pp 371-385.

126. Pritchard, D., 1952, Estuarine hydrography, Advances in Geophysics (1), pp. 243-280.

127. Raghuram, M., 2007, “Mangrove to protect coastline against floods”, Article in “The Hindu”, National Daily, Mangalore Edition dated 20th Feb, 2007, pp 5.

128. Ravindra, B.M. and Krishna Rao, B. (1987). Relation of Coastal faults and river morphology to sea erosion in Dakshina Kannada, Karnataka. Jour. Geol. Soc. India, V.29, pp. 424-432.

129. Reddy, M. P. M., Hariharan, V. and Kurian, N. P., 1979, “Seasonal variations of hydrographic conditions of estuarine and oceanic waters adjoining the old Mangalore port”, Jl. of Pure and Applied Geophysics, Birkhäuser Basel Pub., Vol. 117(5), pp. 935-942.

130. RojanaKamthorn, S., Isoke, M., and Watanabe, A. (1989). “A mathematical model of wave transformation over a submerged breakwater”, *J. of Coastal Engg. in Japan,* 32(2), 209 – 233.

131. Ross, G., and Pleskunas, S. (2003). “High density polyethylene pipe reef for surfing and shore protection”, *Proc., 3rd Int. Surfing Reef Symposium*, Raglan, New-Zealand, June, pp 371 – 373.

132. Sahagian, D. L., and Holland, S. M. 1991. Eustatic Sea-Level Curve Based on a Stable Frame of Reference: Preliminary Results, Geology, Vol 19, pp 1208-1212.

133. Sawargi T., 1992. Detached Breakwaters. Proc. Design and Reliability of Coastal Structures. Venice.

134. Sawargi T., I. Deguchi & S.K. Park 1988. Experimental Study on the function of submerged breakwater to control cross-shore sediment transport on artificially nourished beaches. Coastal Engineering in Japan 31(1): 121-130

135. Seiji M., T. Uda and S. Tanaka, 1987, Statistical Study on the effect and stability of detached breakwaters, Coastal Engineering in Japan 30(1).

136. Shetty, Umashankar Y. and Subba Rao, 2002, “Study of coastal erosion and performance of seawalls along Dakshina Kannada coast”, Proc. of National conference on Hydraulics, Water Resources & Ocean Engineering - HYDRO 2002, under ISH, Dept. of Civil Engg., IIT Bombay, pp. 287 – 291.

137. Silvester R. and J.R.C. Hsu, 1993, Coastal Stabilisation-Innovative Concepts. Prentice Hall Inc.

138. Silvester, R., and S. Ho, 1972, “Use of crenulate shaped bays to stabilize coasts”, Proc. 13th International Conference on Coastal Engineering, pp 1347-1365.

139. Sissakian, V., 1986, “The study of mass movement from aerial photographs”, Symposium on Remote Sensing for resources development and environmental management/Enschede/August 1986. pp. 675-678.

140. Smith, D. A. Y., Warner Sorensen, R..M., and Atherley. (1996). “Submerged crest breakwater design”, *Advances in Coastal Structures and Breakwaters*, Thomas Telford, London, 208 - 219.

141. Sollitt, C. K., and Cross, R. H. (1970). “Wave transmission through permeable breakwaters”, *Proc., 12th Conf. on Coastal Engg.,* 3, 1827 – 1840.

142. Sorensen, R. M. (1987). “Evaluation of perched beach concept for shore stabilization”, *Proc., Conf. on Coastal and Port Engg. in Developing Countries,* Indonesia, 1, 318 – 326.

143. Sorensen, R. M. 1978. Basic Coastal Engineering. New York: John Wiley & Sons.

144. SPM-Shore Protection Manual, 1984, 4th ed., 2 Vol, Coastal Engineering Research Center, U.S. Army Engineer Waterways Experiment Station, U.S. Government Printing Office, Washington, DC.

145. Srinivas Reddy, C. (1992) Satellite study of coastal processes along Mangalore coast. M. Tech thesis, Dept. of Applied mechanics, KREC, 1992. p. 71.

146. Stone, G. W., and Morgan, J. P. 1993. “Implications for a Constant Rate of Relative Sea-Level Rise During the Last Millennium Along the Northern Gulf of Mexico: Santa Rosa Island, Florida,” Shore and Beach, Vol 61, No. 4, pp 24-27.

147. Subba Rao and Kiran G. Shirlal, 2001, “Sediment movement in the vicinity of Netravathi-Gurupur river mouth” National seminar on four decades of marine geosciences in India – A retrospective SEAGEO-40, Geological Society of India, Mangalore, pp 24.

148. Subba Rao and N.B.S. Rao, (2000a), "Study on grain size statistics of beach sand along Dakshina Kannada Coast of Karnataka State", Proc. National Workshop on Coastal Hydrology, CBIP, New Delhi.

149. Subba Rao and Pramod, Ch., 2003a, “Beach profile studies along KREC beach of Karnataka Coast”, NITK Research Bulletin, National Institute of Technology Karnataka, Surathkal, Dec, Vol. 12, No. 2, pp 24 – 31.

150. Subba Rao, (2002a), “Study of Coastal Erosion along Karnataka Coast”, ISH Journal of Hydraulic Engineering, The Indian Society for Hydraulics, CWPRS, Pune, Vol. 8(2), pp 23 - 33.
151. Subba Rao, 1999a, "Shoreline modifications along D.K. coast of Karnataka state”, Workshop on Maritime Development along Karnataka Coast, conducted by Dept. of Applied Mechanics, KREC, Surathkal. pp 46-58.
152. Subba Rao, 1999b, “Studies on the performance of perforated pile breakwaters”, Ph.D. Thesis, Dept. of Applied Mechanics & Hydraulics, KREC, Surathkal.
153. Subba Rao, 2001, “Causes of erosion along Karnataka coast”, National Workshop on Coastal Erosion–Protection and Management, Dept. of Applied Mechanics and Hydraulics, KREC Surathkal.
154. Subba Rao, 2002, “Beach erosion along Dakshina Kannada coast of Karnataka State”, KREC Research bulletin, Karnataka Regional Engineering College, Surathkal, Vol.11 (1), pp 1 - 9.
155. Subba Rao, Kiran G Shirlal, Radheshyam B and Satyanand K, 2006a, “Spectral Analysis of Waves Off Mangalore Coast”, Proc. 15th Congress of Asia and Pacific Division of the International Association for Hydraulic Research and International Symposium on "Maritime Hydraulics" IIT Madras, Chennai., INDIA, pp. 1003-1013.
156. Subba Rao, Kiran G. Shirlal and Habeeb Khan P., 2002, “Sediment trend matrix analysis of beach sand along Dakshina Kannada coast”, KREC Research Bulletin, Karnataka Regional Engineering College, Surathkal, Vol.11(1), pp 17 - 23.
157. Subba Rao, Kiran G. Shirlal and N. B. S. Rao, 2002a, “Sediment trend matrix analysis of beach sand along Dakshina Kannada coast, Karnataka”, Proc. of International seminar on Sedimentation and Tectonics in Space and Time, Department of Civil Engineering, S.D.M. College of Engineering and Technology, Dharwad, pp 54.
158. Subba Rao, Kiran G. Shirlal and N. B. S. Rao, 2003b, “Sediment Trend Matrix Analysis Normal to Shore near Surathkal Beach, Karnataka”, Journal of Geological Society of India , Bangalore, Vol. 61, pp 215 – 219.

159. Subba Rao, Kiran G. Shirlal, Radheshyam B. and Mahaganesha K., 2004, "Studies on beach profile along Dakshina Kannada coasts and its importance on sediment budget", Proc. International Conference on Conservation, Restoration and Management of Lakes and Coastal Wetlands (LAKE -2004) held at Bhubaneswar, Orissa.

160. Subba Rao, Kiran G. Shirlal, Radheshyam B. and Mahaganesha K., 2004a, "Study of Littoral Transport along D.K. Coast, Karnataka", Third Indian National Conference on Harbour and Ocean Engineering (INCHOE-04), National Institute of Oceanography (NIO), GOA, held during December – 2004, Vol. 1, 89 - 95.

161. Subba Rao, Kiran G. Shirlal, Subrahmanya K. and Radheshyam B., 2006b, "Analysis of waves off Mangalore Coast-Spectral Approach", NITK Research Bulletin, National Institute of Technology Karnataka, Surathkal, June, Vol. 15, No. 1, pp 54 – 60.

162. Subba Rao, Kiran Shirlal, Kankara, R.S., Radheshyam B, Govindaraja K. R. and Madhubabu, 2006c, "On modelling the tides and currents using MIKE-21 HD for Gurupur-Netravathi river mouth", Proc. National Conference on Hydraulics and Water Resources (HYDRO-06), ISH & Bharati Vidyapeeth University, Pune, pp 475 - 486.

163. Subba Rao, Kiran Shirlal, Subramanian, B. R., Radheshyam B, Govindaraja K. R. and Praveen Suvarna, 2006d, "On modelling the sediment dynamics using MIKE-21 ST off Gurupur-Netravathi river mouth", Proc. National Conference on Hydraulics and Water Resources (HYDRO-06), ISH & Bharati Vidyapeeth University, Pune, pp 467 - 474.

164. Subba Rao, Kiran. G. Shirlal and Habeeb Khan P, 2001a, "An interpretation of sediment trends along D.K.Coast", ISH Journal of Hydraulic Engineering, The Indian Society for Hydraulics, CWPRS,Pune., Vol. 7(1), pp 33 - 39.

165. Subba Rao, N.B.S. Rao and Habeeb Khan, 2000a, "Grain size parameters of KREC beach sand, West coast of India", KREC Research Bulletin, Karnataka Regional Engineering College, Surathkal, Vol.9(1), pp 8 - 15.

166. Subba Rao, N.B.S. Rao and P. Raghavendra, (1999), "Granulometric studies of KREC beach sands, west coast of India", Proc. National Seminar on Coastal Zone Management, SDMCET Dharwad & IGCP – 367, Spl. Pub. Vol. No. 2, pp 79-82.

167. Subba Rao, Radheshyam B., Raju D. H. and Umashankar Shetty, 2003c, "Failure analysis of seawalls along Karnataka Coast", Proc. of National Seminar on Coastal Dynamics & use of Geoinformation with Special Reference to Indian Peninsula, Dept. of Marine Geology, Mangalore University, Mangalagangotri.

168. Subba Rao, Subrahmanya K, Manu & Radheshyam B., 2003, "Beach profile studies along NITK beach of Karnataka coast", Proc. of National Seminar on Coastal Dynamics & Use of Geoinformation with Special Reference to Indian Peninsula, Dept. of Marine Geology, Mangalore University, Mangalagangotri.

169. Subrahmanya, K. R. and Gangadhara Bhat, H., -, "Faults and Mass Movements in the Western Ghats Scarp of the Nethravathi River Basin", pp. 236-240.

170. Subrahmanya, K. R. and Jayappa K. S., (1987) Origin of Netravathi – Gurupur Estuarine System. Proc. Natn. Sem. Estuarine Management, Trivandrum, pp.70-72.

171. Subrahmanya, K. R., 1996, "Active Interplate Deformation in South India", Tectonophysics, Elsevier Science, Vol.262 (1996), pp. 231-241.

172. Subrahmanya, K.R. (1987). Evolution of the Western Ghats, India- A simple model. Jour. Geol. Soc. India, V.29, No, 4, pp. 446-449.

173. Sujatha Kumari, C. H. (1991) Statistics of wave parameters and wave groups: A study for Mangalore data. M. Tech thesis, Dept. of Applied mechanics, KREC, February 1991. p. 121.

174. Sumathy Ganapaty (1992) Waves off Karnataka coast: Height and period distributions. M. Tech thesis, Dept. of Applied mechanics, KREC, February 1992. p. 121.

175. Suter, J. R., and Berryhill, H. L., Jr. 1985. "Late Quaternary Shelf-Margin Deltas, Northwest Gulf of Mexico," Bulletin of the American Association of Petroleum Geologists, Vol 69, No. 1, pp 77-91.

176. Tanimoto, K, and Goda, Y. (1992). “Historical development of breakwater structures in the world”, Coastal Structures and Breakwaters, Thomas Telford Ltd., London, 193 – 206.

177. Tanner, W. F. 1989. “New Light on Mean Sea Level Change,” Coastal Research, Vol 8, No. 4, pp 12-16.

178. Thornton, E. B., and Schaeffer. (1978). “Probability density function of breaking waves”, *Proc., Conf. on Coastal Engg.,*. 1, 507.

179. Thornton, E. B., Galvin, J. J., But, F. L., and Richardson, D. P. (1976). “Kinamatics of breaking waves”, *Proc., 15th Conf. on Coastal Engg.,*. 1, 461 – 476.

180. Tilmans W.M.K., W.H.G. Klomp and H.H. de Vroeg, 1992, Coastal Ersoion – The Kerteh case, Analysis of causative factors and mitigative measures using dedicated mathematical modeling tools, Internat. Colloquium on Computer Applications in Coastal and Offshore Engineering, Kual Lampur, Malaysia; also:Delft Hydr. Publ. 477.

181. Tomlinson, J. H. 1980. “Groynes in Coastal Engineering: A Literature Survey and Summary of Recommended Practice,” Report No. IT 199, Hydraulics Research Station, Wallingford, England.

182. Toyoshima O., 1972, Coastal Engineering for Practicing Engineer, Detached Breakwaters (K.W. Pilarczyk, ed.). Ch.8, pp 118.

183. U. S. Army Corps of Engineers, 2006, “Coastal Engg. Manual (CEM)”, *Coastal Engg. Research Centre*, U.S. Govt. Printing Office, Washington, D.C.

184. U.S. Environmental Protection Agency (USEPA), Date unknown, National Estuary Program: Challenges Facing Our Estuaries—Key Management Issues. National Estuary Program, Accessed September 5, 2006 from: http://www.epa.gov/owow/estuaries/about3.htm#intro

185. Van de Graff, J. (1996). “Use of structures in coastal protection”, *Proc., Int. Conf. in Ocean Engg.,* COE-96,I.I.T. Madras, Chennai, Dec, 461-468.

186. Van der Meer, J. W., and Angremond, K. (1992). “Wave transformation at low crested structure”, *Coastal Structures and Breakwater*, Thomas Telford, London, 25 – 41.

187. Venkatraman M., 2004, Coastal Protection using Polymer Rope Gabions, Proce. Geosynthetics India 2004, geosynthetics-New Horizons, IIT Delhi.

188. Vishwanath, D. N. (1993) Study of coastal erosion and protection works along Dakshina Kannada Coast. M. Tech thesis, Dept. of Applied mechanics, KREC, March 1993. p. 127.

189. Vittal Hegde, A., Subba Rao and Kiran G. Shirlal, 2005, “Performance evaluation of coastal protection works”, Technical Report submitted to Govt. of Karnataka.

190. Wadia, D. N., 1975, Geology of India (4^{th} Edition), Tata McGraw Hill Publ. Co. Ltd., New Delhi, pp. 254.

191. Whitehill, W. M. 1968. Boston, A Topographical History, 2nd ed. (enlarged), The Belknap Press of Harvard University Press, Cambridge, MA.

192. Williams, S. J., and E. P. Meisburger. 1987. Sand Sources for the Transgressive Barrier Coast of Long Island, N.Y.: Evidence for Landward Transport of Shelf Sediments. Proceedings, ASCE Specialty Conference on Coastal Sediments '87, New Orleans, Louisiana.

193. Wright, L. D., and Sonu, C. J. 1975. “Processes of Sediment Transport and Tidal Delta Development in a Stratified Tidal Inlet,” *Estuarine Research*, Vol 2, L. E. Cronin, ed., Academic Press, New York, pp 63-76. www.reefball.com/submerged breakwater/Armono %20 and %20 Hall. pdf.

194. Wunsch, C. 1996. Doherty Lecture: “The Ocean and Climate - Separating Myth from Fact,” MarineTechnical Society Journal, Vol 30, No. 2, pp 65-68.

195. Young In Oh, and Eun Chul Shin, 2006, Using submerged Geotextile tubes in the protection of the E. Korean shore, Jl. Coastal Engineering, Coastal Engineering, Elsevier Publications, Vol. 53, pp. 879–895.

196. Young, C., and Hale, L., 1998, “Coastal Management: Insurance for the Coastal Zone,” Maritimes, Vol. 40, No. 1, pp 17-19.

ANNEXURE

Annexure-1

PROJECT USER MEETING AND RECOMMENDATIONS

The project user meeting was held at N.I.T.K, Surathkal on 5th January, 2004. The following dignitaries participated in the first user meeting.

1. Dr. B. R. Subramanian, Project Director, ICMAM, Chennai
2. Capt. Kudri, Port Officer, Old Mangalore Port, Mangalore
3. Prof. J. Dattatri, Advisor, Bangalore
4. Prof. N.B.S. Rao, Advisor, Mangalore
5. Sri M. M. Kamath, Advisor, Mangalore
6. Sri B. S. Prakash, CRO, Coastal Engg. Div, KERS, Mysore
7. Sri. Ramana Murthy, Scientist, ICMAM- PD, Chennai
8. Sri M. Puttaraju, ARO, C.E. Sub Div.,ICERS, Mangalore
9. Sri D. Bose, EE, NMPT, Mangalore
10. Sri Shankare Gowda, EE, P&F Div., Udupi
11. Sri R. S. Kankara, Sr. Scientific Officer, ICMAM-PD, Chennai
12. Sri T.T.S. Phayde, ARO, C.E. Sub Div., ICERS, Bhatkal
13. Dr. S. G. Mayya, Prof. & Head, Dept. of Applied Mechanics, NITK, Surathkal.
14. Dr. Subba Rao, Co-ordinator & PI, NITK, Surathkal.
15. Dr. Kiran G. Shirlal, Jt. Co-ordinator & Investigator, NITK, Surathkal
16. Dr. G. S. Dwarakish, Investigator, NITK, Surathkal
17. Sri Subrahmanya K, Investigator, NITK, Surathkal

Important Observations

The important observations of the user meeting are listed below.

1. Dr. Subba Rao presented the *proposed objectives, methodology & tentative year wise action plan of the various programmes those are to be undertaken for the completion of the project* and requested the delegates to deliberate on the same.

2. Dr. B.R. Subramanian requested the gathering to deliberate upon the sea erosion problem and its dynamic nature.

3. Sri Shankare Gowda opined that *coastal erosion occurred every year repeatedly and the Government Departments are helpless to restrict the development within CRZ* and they are forced to undertake emergency works to fight erosion and these protection works are of purely temporary nature, cannot withstand the large wave forces in monsoon season and get severely damaged.

4. Capt. Mohan Kudri observed that *earlier the Nethravathiravathi – Gurupur estuary was shifting and after the construction of breakwaters in 1994, the water depths are maintained even without dredging and additional sediments brought are removed naturally.*

5. Prof. J. Dattatri dealt elaborately on the known and unknowns of coastal processes, methods of coastal protection and their performance. He opined that *if constructed properly, the seawalls can protect the shoreline. However, the best solution was strict administration of CRZ act.* He also observed that before undertaking any other activity of the project, the near shore bathymetry and refraction studies should be conducted. Mathematical models must be calibrated with the field data at two or three points along the coast.

6. Prof. N. B. S. Rao endorsed Prof. J. Dattari's views and commented that *lot of historical data are available with the various Government Departments such as KERS, MID, PWD, P&F Div. etc., which can be used for the initial numerical model studies and to determine exactly which data are relevant and using these results, further data collection may be planned subsequently.*

7. Sri M. M. Kamath briefly dealt about the stage wise development of NMPT and highlighted the siltation problem. He suggested that *the data on ocean parameters are available with NIOT, Chennai which can be helpful for this project.* He also opined that, with the help of NMPT, the various oceanic

instruments of the project may be deployed in the coastal waters but, the project authorities may have to share the data with NMPT. Dr. B. R. Subramanian accepted the suggestion and agreed to share the oceanic data collected with all the user organisations/Government departments.

8. Sri D. Bose talked about Siltation problems in NMPT and opined that *onshore – offshore sediment transport is predominant compared to littoral drift.*
9. Sri B. S. Prakash enquired about the impact of Netravathi river diversion project on sea erosion at Ullal. Sri Kiran G. Shirlal replied that already *two vented dams are built across river Netravathi which are contributing to the loss of sediments to the estuary* and however, the impact of Netravathi river diversion project may not be significant.
10. Sri. Ramana Murthy opined that the *current distributions in estuary and sea are not fully understood and may have to be studied* in detail.
11. Sri. R. S. Kankara opined that *pre-monsoon bathymetry, shoreline profile and wave data have to be collected and the study area* have to be fixed. He also felt that sediment grain size analyses as well as sediment transport studies before and after monsoons have to be undertaken.

Outcome

The important outcomes of the user meeting are:

1. The delegates discussed the various points put forth and the coordinators agreed to consider the same in the implementation of the project.
2. Secondary data regarding bathymetry, flow and sediment discharge, core sample data, waves and their directional data, suspended sediment concentrations, tracer study data, beach profiles, dredging data, earlier remote sensing data etc. may be collected from MID, P&F Div., NMPT, Old Mangalore Port, KERS, NRSA etc. before middle of April.
3. Various equipments like Directional wave/tide recorder, current meters may be deployed for the phase wise measurements in the pre and post

monsoon seasons as per the project schedule taking into consideration the local and site conditions. Meanwhile shoreline data using RTK GPS, beach profiles, beach sediment samples and Ground water table fluctuation data may be periodically collected. Bathymetric survey data (echo sounder) and river discharge data also may be collected as and when required.

Annexure-2

LIST OF ACADEMIC WORKS

The following academic works have been carried out based on the study conducted under this project.

Ph.D. Thesis

- Study of Coastal Processes and Solution to Erosion Problems in the vicinity of Netravathi-Gurupur River Estuary- A modelling Approach

M.Tech. Dissertation

- Long term and Spectral Analysis of Waves off Mangalore Coast
- Hydrodynamic and Wave Modelling at Netravathi - Gurupur River Mouth
- Modeling of Coastal Protection Works at Ullal using MIKE-21
- Modelling of Coastal Processes around Gurupur-Netravathi River Mouth using MIKE-21