Field studies – technology & significance for coastal engineering projects

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Abstract - Ocean environment is generally dynamic in nature with rise and fall of tides, density driven current and surface waves. The interface where the ocean meets the lands mass is broadly termed as the coast and the physical transition between the land and sea is the shoreline. The shoreline is subjected to continuous changes with wave actions and which in turn causing the littoral drift. [1] The coast is influenced with various anthropogenic activities and development project like ports & harbour development, construction of jetties, laying of intake and outfall pipeline for desalination plants & power plants etc. Any unplanned execution of work in this dynamic environment will leads to shoreline erosion loss of available land. Unlike conducting terrain survey on land, conducting hydrographical survey or oceanographic investigations need detailed understanding of the environment with associated sea state. Collection of oceanographic data plays a vital role in design and development of any infrastructural project along the coast. It has often been observed that design based on insufficient data result in infrastructure failure which often leads to difficulties during the construction and operation stages of the infrastructure. Typical examples are damage to groyne structures due to monsoon waves, siltation of ports & harbours leading to expensive dredging. Hence, the importance of field studies is very crucial in capturing the inputs and data required for proper design. One must thoroughly study the dynamic of waves, tides, currents, seabed stratification, seafloor classification and more importantly the nearshore bathymetry for understanding the dynamic coastal environment. It can be achieved by adopting sophisticated instruments like echosounders for measuring depth, acoustic based devices like seismic for seabed studies and sidescan to capture seafloor image operating with certain frequencies, tide recorder and current meter to record the time series variations of tides and currents in any coastal region [2]. Very few organizations in India have the capability to plan and execute such marine related studies. Among them the leading institutions to name a few are Ocean Engineering Department of IIT Madras, CWPRS-Pune, NIO-Goa, NIOT and NCCR-Chennai. Organizations like Indomer who have been in this field for the past 23 years have matched such infrastructure and have been able to navigate the requirements of conducting studies in the east and west coast of India. Coastal infrastructures projects are also subjected to catastrophic events like tsunami, cyclone, and storm surges etc. It is imperative that such effects can be predicted through modelling studies. The data collected from field studies are in turn used to calibrate numerical model and further scenarios are then simulated using established numerical modelling tools to understand these events. It is now possible to simulate conditions for tide, current, sediment transport, oil spill, shoreline changes etc. through modelling suites such as MIKE21, Delft3D, SWAN etc. [3]. This approach of conducting field studies supplemented with mathematical modelling will help design coastal infrastructure in a safe efficient and cost-effective manner. This paper describes in detail the various field surveys, field equipments, methodology adopted, and typical mathematical modelling studies carried out for coastal infrastructure project with Indian perspective in mind.

Keywords - anthropogenic, dynamic environment, erosion, oceanography, numerical modelling.

I. INTRODUCTION

Coastal and estuary or creek waters are the parts of the sea that have the most influence on our daily lives. The physical transition between the land and water is termed as the shoreline The processes that take place in shallow water are largely related with our expanding usage of the ocean, increasing excursion upon it, and admission into it. Coastal projects like construction of ports & harbours, laying intake & outfall pipelines, trestle jetties, shore protection structures etc. needs detailed engineering and oceanographic approach. Monitoring the coastal environment, plays a vital role in design and development of any infrastructural project along the coast. One must thoroughly study the ocean dynamics of waves, tides, currents, seabed stratification, seafloor classification and more importantly the nearshore bathymetry for any coastal projects. In addition, the shoreline and its morphological behaviour due to the implementation of such coastal developments projects needs to be monitored. Oceanographic investigation is the broad name which describes the various aspects of monitoring the coastal and oceanographic elements like wind, waves, tides, currents etc. With the advancement in technology, sophisticated instruments (calibrated and validated) are available to monitor coastal environment. For instance, any port development project requires prior understanding of the hydrodynamic in terms of wind, waves, tides & currents existing in the coastal process for the safe passage and navigation for vessels and thorough understanding of the seabed in terms of bathymetry, water quality & seafloor classification. The perception of this hydrodynamic regime can be achieved by conducting oceanographic measurements using instruments with scientific background. Oceanographic measurements can be taken up with site specific conditions to understand the existing baseline in the coastal environment. The field data thus collected can be an effective input for the prediction of anticipated changes due to the proposed development in the dynamic environment. All coastal infrastructure project like ports & harbours needs to be identified with field measurements. Any port development or offshore engineering project need at least one year met-oceanographic parameters study to design offshore and coastal structures. Only a few organizations in India are capable of planning and executing such marine related investigations. Ocean Engineering department of IIT Madras, CWPRS-Pune, NIO - Goa, NIOT and NCCR-Chennai are few of the major institutions serving the purpose. Indomer which has been in this industry for 23 years, has matched such infrastructure and has been able to negotiate the requirements of conducting investigations along east and west coast of India. Tsunamis, cyclones and storm surges, among other disasters, threaten coastal infrastructure project. The data acquired from field research is utilized to calibrate a numerical model and additional scenarios are subsequently simulated using numerical modelling methods. This method of performing field surveys combined with mathematical modelling will aid in the design of safe, efficient, and cost-effective coastal infrastructure.

II. COASTAL ENGINEERING

Coastal engineering is concerned with the coasts of oceans, seas, marginal seas, estuaries, and large lakes, where the coast is the physical transition between land and sea, and the shoreline is the interface where the water meets the land mass. The hydrodynamic influence of waves, tides, storm surges, and tsunamis, as well as the harsh environment of seawater, are common issues for coastal engineers and the morphodynamical changes in the coastal topography, which are induced by both natural and man-made changes. Coastal engineers are frequently involved in integrated coastal zone management, in addition to the design, construction, and maintenance of coastal structures, due to their specialized knowledge of the coastal system. Coastal zone is engraved with exquisite morphological forms such as beaches, cliffs, fjords, bays, estuaries, river mouths, inlets, gulfs, creeks, sand bars, offshore islands, tidal flats, marshy lands, mangrove forests and coral reefs. Coastal engineering has wide varying application globally, with enormous number of coastal cities having more than 10,00,000 population. In fact, out of 17 large cities in the world, 14 of them are located along coast. The major coastal cities across the globe are Edinburgh, New Orleans, Venice, Bangkok, Honolulu, Miami, Istanbul etc. In India, major coastal cities are Mumbai, Chennai, Kolkata, Visakhapatnam and Cochin. The application of coastal engineering in Indian scenario are design and construction of Ports, Fishing harbours, Desalination plants, Shore protection structures like breakwater, groyne, artificial reef, beach memorials & monuments, Rocket launch pads, Navy & Coast guard command centre and Offshore Terminals such as SPMs and Trestle Jetties.

III. FIELD MEASUREMENTS

To ensure a reliable design and construction of coastal structure, the factor playing key role in deciding the efficiency of the design are the field measurements which are to be done prior to the execution of work. Tides, Currents, Wind and Waves are the three important factors influencing any coastal development. To understand the dynamic rise and fall of tides, density driven current, waves and to understand the regional sea level rise and high flood level, field measurement is very essential. Inclusive of that, the water depth required for routing navigational channel, identifying the seafloor and subsea stratum for laying pipelines, calibration of mathematical models and to arrive the Design Water Level (DWL), field measurements play a major role in deciding the coastal developments. Field measurements are categorized into various types depending on the nature of work. Major categories of field measurements are Oceanographic measurements, Seabed Investigations, Marine Sampling, Shoreline Monitoring and Terrestrial Survey. The classification of field studies involved in any of the coastal engineering projects is shown in Fig. 1.

1. Oceanographic measurements

The dynamic properties of ocean process namely tide, current, wind and wave are critical oceanographic parameters deciding the design and development of any coastal engineering projects.

Tide: It is defined as the rise and fall of sea level due to the gravitational force exerted by sun and the moon, and the rotation of earth. In the past, the water level measuring systems mostly relied on a recorder operated by a float in "Silting Well". After the advancements in technology Tide Measurements are being carried out using digital instruments. Aanderaa WTR9 Tide Recorder is one such instrument which measures tide at required intervals. In general, the Tide recorder is moored using a rope at the top of the jetty. The tide sensor is placed in such a way that the level of the sensor is always below the Chart Datum (CD), so that the water level will not go below CD, thereby measuring the rise and fall of water over a long period of time. Measurement of Tide is very important factor in deciding the Design Water Level of any coastal structure. **Current:** A continuous, directed movement of sea water caused by various forces, such as wind, waves, Coriolis effect, temperature and salinity differences is known as ocean current. During earlier days, Dropsondes are used to measure the ocean currents. The dropsonde measures the temperature, conductivity, pressure and average current velocity in a vertical water column. The instrument is lowered into the ocean at a predetermined depth. It drops at a consistent rate to the bottom, where the weight is released on bottom contact, and the instruments lifts to the surface. The vertically accumulated drift during the rise and fall is represented by the distance between the drop point and the point where the instrument first surfaces. Later, Point sensors are commonly used for measuring ocean currents at a particular point of depth. The results obtained from Point sensors are uncertain. Nowadays, "Acoustic Doppler Current Profiler" (ADCP) is used for measuring ocean currents at a greater frequency. The ADCP works on the principle of Doppler effect. The instrument is tied in the deck of the ship and set into operation. The ADCP use piezoelectric transducers to transmit and receive signals. The distance is calculated based on the time of travel taken by sound waves. The shift in frequency is proportional to the velocity of water along the acoustic path. We can anticipate sediment movement, estimate contaminant drift, comprehend mixing and transport processes, and report wave conditions by measuring water velocity. **Wind:** The changes in air pressure caused by the temperature difference in the atmosphere, generates wind. surface waves and entire current systems are affected by wind, which is the main source of momentum for the ocean surface. Wind must be factored into our measurements when viewing and studying ocean process. Wind is major factor in determining the alignment of breakwater, which includes the identification of predominant direction in which the wind blows, thereby the wave action is progressed in that direction, results in breaching of breakwater section. The wind speed is measured using anemometer. **Wave:** Wind is the most prevalent cause of waves. The friction between the wind and the surface water produces wind driven waves, also known as surface waves. A wave crest is created when the wind blows across the surface of ocean, causing continuous disruption. These types of waves are prevailing globally across the open ocean and along the coast. Despite this, the sun and moon's gravitational pull on the earth causes waves, which are known as tidal waves. Pressure sensors are set in place underwater, and they measure the height of water column that passes above them. The height of the water column rises as wave crests passes by, when the troughs approach, the fall in height of the water column is observed. A record of sea surface elevations can be created by subtracting the sensors depth from the water column height. Wave Rider Buoys are used for measuring wave characteristics namely, significant wave height, zero crossing wave period, peak wave direction, wave energy spectrum etc.

2. Seabed Investigation Surveys

Seabed investigations are concerned with the development of maps or charts of the seafloor and the geological structure underneath the seabed. This mapping is carried out with various instruments operated on both near shore and offshore depending upon the type of coastal development. We Indomer use the following methods for conducting seabed investigations and to extract the data required for carrying out any coastal developments both on and offshore, such as Bathymetry survey, Shallow seismic survey, Sidescan sonar survey and Marine Magnetometer survey.

Bathymetry Survey: For any offshore development, such as installing SPMs, laying pipeline, constructing jetties, berthing structures and so on, the most important phenomena which decides the existence of facility at that location is the water depth available in that region. Bathymetry is the study of water depth in oceans, rivers or lakes. Based on the data collected from bathymetry survey one can determine the choice of platforms to be developed. History reveals that, Scientist do bathymetric surveys by means of suspending heavy rope over one side of the ship and recording the length of the rope it took to touch the seabed. Later, due to the advancements in technologies, Echosounders are used globally for doing bathymetry survey, categorized into two as Single Beam and Multibeam Echosounder. Single Beam Echosounder which is used to measure the depth directly under the boat. This survey is generally used for smaller water bodies. Multibeam Echosounder sends wide array of beams across the water column. The data is collected and processed as the beams reflect from the seafloor. The data can be visually observed on the boat during the survey. This survey is generally done in deeper oceans. The bathymetry data collected are processed using suitable software like "HYPACK" and the soundings are exported as CAD file and prepared in the form of charts in a suitable scale. The applications of bathymetry in research are wide varying. Flood Inundation, Stream and Reservoir contours, scour and stabilization, water quality studies and so on. **Shallow Seismic Survey:** Once the choice of platform is concluded based on the water depth available, the seabed exploration must be done to find the stratigraphic condition prevailing in the project region. Shallow Seismic Survey is one of the methods of seabed exploration, thereby involving the measurement of seismic waves transmitted from and reflect to the surface at interfaces between different geological layers. In situ geotechnical investigation of rock masses have traditionally relied on destructive bore hole drilling. It provides unambiguous and credible evaluation of parameters needed for geotechnical investigation, but they also take large amount of money and manpower. One more thing to be noted is that the boreholes are typically drilled vertically, thus the subvertical discontinuities parallel to the borehole axis remain undetected, resulting in uncertainty of results. By using "Sub bottom Profilers" we can conduct shallow seismic survey at a greater accuracy. It can detect the soft layers under seabed, thereby greatly reducing the investigation costs. In addition to this, the bedrock quality, profile and depth can also be found using the shallow seismic survey. Most of the undersea seismic data are usually captured using vessels. The nearshore environment is shallower than offshore. Under such circumstances, seismic equipment is placed in floats and deployed on beach to obtain the data we need to assess changes in shore geomorphology. Once after deployment, the seismic equipment is towed behind a research vessel and the seismic survey is done for the required area. The surveyed data is processed with relevant software like "CODA Octopus Survey Engine". The thickness of each layer detected is obtained by eliminating the penetration of acoustic bed from seabed, thereby maximum penetration of each layer is found. These data are plotted in terms of vertical profiles using drafting softwares and the "Isopach Map" is prepared. This Isopach gives the detailed description of layers having equal thickness, which is very useful in identifying the predominant strata existing in the project region. **Sidescan Sonar Survey:** Side scan sonar survey is done to ensure that the study area is free from all the obstacles which influence the coastal development works above the seafloor. "Benthos Chirp Side Scan Sonar" and "Ping DSP" are some of the side scan imaging instruments. The data obtained from this can be used for variety of purposes, such as identification of seafloor objects highlighting their shape, orientation and dimensions of the entity. Any feature above the seabed casts a shadow in the sonar image, thereby interpolation of size of the shadow is processed on boat, resulting in accurate dimensions of the object. The position of the data obtained is recorded automatically as coordinates, allowing completely a georeferenced tiff image to be produced. Debris and other impediments on the seafloor, such as oil and gas pipelines, outfalls, cable routes, oil & gas platform positions, and marine industry development works, are detected using side-scan sonar imaging. For an instance, rock outcrops reflect more acoustics and provide a stronger return signal than the soft environments like sand or mud. Segments with higher returns are typically depicted on the plan in a deeper color than the areas with lower returns. The backscatter returns can be used to represent the geomorphology. The data collected is processed using "HYSWEEP" and the seabed sediments and shallow structure is arrived as tiff imagery. The tiff imagery can be manually drafted as a map depicting the original features of seabed. **Marine Magnetometer Survey:** The magnetometer survey is performed to discover the magnetic anomalies based on principle of variation in magnetic field, thereby detecting the anthropogenic features on the seabed, buried on land, or assist in mapping of geological features. By identifying specific rock types and geological features, a magnetic map can aid in the discovery of mining reserves. Early magnetometers are like compass in that they use a magnetized needle whose orientation changes in response to the ambient magnetic field to estimate the field's direction. The frequency of oscillation of a magnetized needle is proportional to the square-root of the strength of the ambient magnetic field. In nearshore and offshore scenarios, it is particularly adapted for detecting and mapping of all ferrous objects such as anchors, chains, cables, pipelines, ballast and other distributed shipwreck debris, crashed aircraft fragments and other objects processing magnetic properties. During survey the real time display, data acquisition is done using appropriate software like "MagLog" and the magnetic anomalies can be visually seen on boat during the survey. High volumes of magnetic data are successfully converted into modelled grids, and target positions, depths, size, and apparent weight calculations are calculated. The tiff imagery obtained, and the post-processing takes place in proprietary software like "MagPick" that allows data to be examined and confirmed, as well as processed in profile form. Based on the data obtained during survey a magnetic "Anomaly Map" is prepared in a suitable scale which depicts the existence of magnetic particles in the study area.

IV. MARINE SAMPLING

Though coastal projects provide financial, social and environmental benefits depending on the projects, development of such projects in the marine environment is crucial. Other than oceanographic measurement and seabed investigations the quality of seawater and seabed sediment plays a vital role in planning coastal engineering projects. It has wide impact such as leaching, swelling, deterioration and corrosion on the concrete or steel structures located close to coastal region. Similarly, the sediment size distribution in the seabed determines the type and methodology of foundation in the seabed. Thus, seawater and seabed sediment analysis are important to establish a feasible infrastructure in the marine environment.

1. Seawater sampling

Seawater sampling is the collection of seawater at various location in the project region at different water depths to determine the quality of the seawater in that region. To analyze the physio-chemical parameters of the seawater, samples are collected using Van Dorn Water sampler at the different depths. A rope is tied to the sampler and lowered in the seawater till the desired depth of the water column with the lid of the sampler in open position. The messenger is released so that it strikes the sampler and closes the lid. The sampler is retrieved with the sample. The collected samples are transferred in 1 liter bottle by connecting a Teflon tube from the nozzle of the sampler and preserved as per requirements. The most important parameters in the seawater which may affect the quality of the concrete or steel over a period time in the marine environment are sodium, magnesium, chloride, sulphate and TDS. The characteristics of cement, admixtures, steel, coating material and adequate cover to be provided for coastal projects can be established by determining the values of these parameters.

2. Seabed sampling and marine borehole

The texture of sediment in sea are determined by collecting seabed samples and marine bore holes. The seabed sediment samples are collected using Van Veen Grab. Similar to seawater sampling the sampler is tied to rope and lowered to the seabed with the jaws open using catch. The sampler is lowered slowly and steadily to prevent the jaws closing before reaching the seabed. Once the sampler touches the seabed the catch is released and while retrieving, the jaws grab the sediment and closes itself due to the lever effect. The collected samples are spooned out and stored in a container. Marine boreholes are drilled beneath the seabed to identify the soil profile at various depths. Jack up barge with hydrostatic drilling rigs is used to penetrate layers of soil. The soil samples were observed, and the N value is calculated. This provides the depth of each layer at sampling location. From the geo investigation involved in Development of fishing harbour at Vellapallam the soil profiles are too weak, and it is recommended to dredge the soil along the alignment of the breakwater for a minimum depth of 3 m below seabed. This aided in working out detailed design and cost of the breakwater.

V. SHORELINE MONITORING

The existing dynamic nature of coastal boundaries, it is critical to understand the rate of long-term and short-term shoreline changes from the perspective of coastal vulnerabilities. Any coastal development will have its very own impact on the shoreline, thereby subjecting the coast to Erosion and Accretion which result in alteration of coastal geomorphology. Some important aspects of shoreline monitoring consist of the demarcation of High Tide Line (HTL) & Low Tide Line (LTL), Beach profile marking and Water level connection. In general, the methodology adopted for shoreline monitoring is same as that of topography survey. In general, optical instruments like dumpy level is used for demarcation. Due to the advancements in technology, Real Time Kinematic instruments are being utilized. Beach profile marking is used to identify the quantum of sediment deposition across various seasons. With high intensity wind and wave action, storms can cause severe beach erosion, thereby carrying the sand over dunes and to the flood tidal areas. In some areas storms could be able to amplify the beach profile’s seasonal cycle of accretion and erosion. Investigations should be made by combining historic measurements of beach profile and numerical modelling for the change in coastal morphology induced by storm and other factors. The field data collection can be an input for the prediction of anticipated changes due to the proposed development.

VI. MATHEMATICAL MODELLING STUDIES

To further comprehend the ocean process, the data acquired from field studies is utilized to calibrate a numerical model, and additional scenarios are subsequently simulated using numerical modelling methods. Modelling studies play a vital role in the design aspects of breakwater and other marine facilities. The layout planning, design and construction of ports & harbours for solving many coastal engineering related problems for which investigations through modelling studies will be required. Investigations by means of physical models can be useful whenever confirmation of a design aspect of a coastal structure or the suitability of a site is required. Besides, models can provide a typical scenario of a site or other useful information to deal with any kind of coastal situation. Mathematical modelling and associated tools offer prediction of changes due to development along the coast. The accuracy of field data collection leads to construction of input parameters to build a model setup. The design of any coastal structures is primarily dependent on design water level, high flood level, design waves and design currents. Any port projects along the coast requires prior understanding of nearshore coastal process, hydrodynamics, wave transformation, wave tranquility sediment transport and shoreline evolution studies. This study describes the details of field measurements to be taken up and associated mathematical modelling for the design and analysis of an optimum layout. And port & harbour developmental activity will have to meet the following requirements. **i)** Adequate length of coastline to provide all marine facilities such as breakwaters, jetties, berthing wharf, navigational channel, turning circle etc., **ii)** Required breakwaters to break the offshore waves and keep the harbour basin calm and to have a sheltered basin for cargo operation, **iii)** Design depth in the navigational channel, harbour basin, berthing area & turning circle and **iv)** Adequate shorefront and backup area to provide offshore & onshore facilities. Similarly, to design and develop any coastal structure, field measurement plays a vital role in analyzing the baseline condition and model calibration. With the calibrated and validated model, the changes in morphology and coastal hydrodynamics changes were studied. Apart from the factors listed, the global concern which is currently in trend is the Sea Level Rise (SLR). SLR is now being considered as a essential factor in all designs of coastal structures. However, field measurements are restricted to predict and forecast SLR. The SLR in terms of global and regional model can be anticipated through modelling scenarios and using available empirical relations. However, to predict the exact rise in sea level can be achieved through historical observation on tides.

VII. CONCLUSION

There are many consequences of using inappropriate data which lead to improper design, which is vulnerable to coastal hazards like cyclones, floods, tsunami, storm surge etc. Unplanned execution leads to loss of human, property, economy and ecosystem. In addition to this structural collapse and infrastructure damage like siltation in harbour basin and navigational channel of ports, breaching and sinkage of breakwater etc. Thus, to avoid these discrepancies we should do field studies in an effective manner, followed by modelling studies to provide efficient, safe and cost-effective coastal infrastructure. The Typical oceanographic instruments, modelling and seabed figs are shown in Figs. 2,3 and 4 respectively.

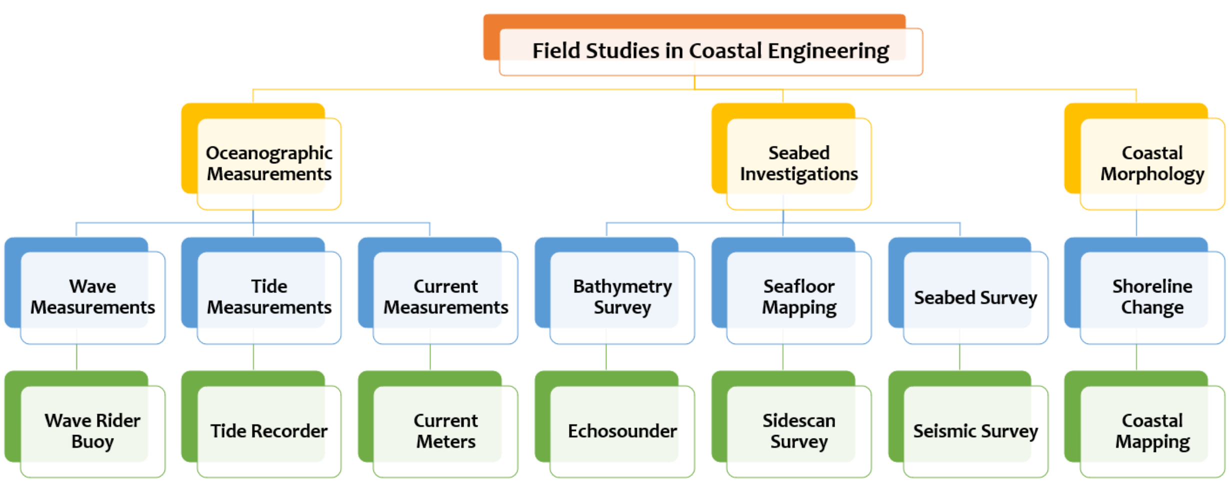

Fig. 1 – Classification of field studies in coastal engineering

Fig. 2 – Oceanographic instruments

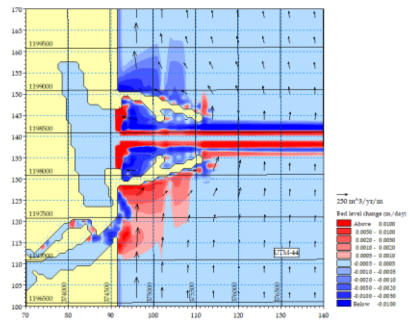

Fig. 3 – Typical modelling result

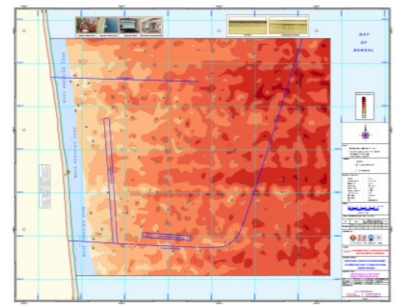

Fig. 4 – Typical seabed map

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