CHAPTER 2

REVIEW OF LITERATURE

2.1 GENERAL

Global values of wind speed and wave height can be obtained from satellite-based radar altimeters. Most present applications of wind wave research for coastal engineering and environmental purposes involve the use of numerical models that simulate the evolution of directional wave energy spectra in time or space or both. Studies on sediment transport and accumulation are of vital importance to projects involving the water to land interface. A number of studies have been conducted along the coasts on different aspects of sediment movement and coastal processes, but qualitative determination of littoral transport along the coasts of India have been made only at few localities.

2.2 WAVE HYDRODYNAMICS

2.2.1 1-D Methods

By matching surface displacement and mass flux normal to the change in bathymetry, Lamb (1932) was one of the first to develop a long wave approximation for the reflection and transmission of a normally incident wave at a finite depth step. Complete transmission was found for certain water depth and pit width combinations for an obstacle (trench or shoal) with arbitrary cross-section with the upwave and downwave depths uniform (Kreisel, 1949). Sretenskii (1950) investigated oblique waves over a step
between finite and infinite water depths assuming the wave length to be large compared to the finite depth. Bartholomeusz (1958) performed a more thorough analysis of the finite depth step problem and found that the Lamb solution provided correct results for the reflection and transmission coefficients for lowest order \((kh)\), where \(k\) is the incident wave number and \(h\) is the water depth upwave of the step. An extensive survey of early theoretical work on surface waves including obstacle problems was found by Wehausen and Laitone (1960). Jolas (1960) studied the reflection and transmission of water waves of arbitrary relative depth over a wide submerged rectangular parallelepiped (sill) and performed an experiment to document wave transformation. To solve the case of normal wave incidence and arbitrary relative depth over a sill or a fixed obstacle at the surface, Takano (1960) employed an eigen function expansion of the velocity potentials in each constant depth region and matched them at the region boundaries by solving a set of linear integral equations was solved for a truncated series. Dean (1964) investigated long wave modifications by linear transitions, which included both horizontal and vertical changes. The formulation allowed for many configurations including a step, either up or down, and converging or diverging linear transitions with a sloped wall.

Newman (1965a) studied wave transformation due to normally incident waves on a single step between regions of finite and infinite water depth with an integral equation approach. Newman (1965b) examined the propagation of water waves past wide obstacles. Miles (1967) developed a plane-wave solution for unrestricted \(kh\) values using a variational approach (Schwinger and Saxon, 1968), which for this case essentially solves a single equation instead of a series of equations (up to 80 in Newman’s solution) as in the integral equation approach. The variational approach was applied by Mei and Black (1969) to investigate the scattering of surface waves by rectangular obstacles. For a submerged obstacle, complete transmission was found for
certain $kd$ values where $d$ is the depth over the obstacle. Black and Mei (1970) applied the variational approach to examine the radiation caused by oscillating bodies and the disturbance caused by an object in a wave field. Black et al (1971) applied the variational formulation to study radiation due to the oscillation of small bodies and the scattering induced by fixed bodies. Lassiter (1972) used complementary variational integrals to solve the problem of normally incident waves on an infinite trench where the depth on the two sides of the trench may be different (the asymmetric case). The symmetric infinite trench problem was studied by Lee and Ayer (1981), who employed a transform method. The fluid domain was divided into two regions, one an infinite uniform depth domain and the other a rectangular region representing the trench below the uniform seabed level.

Lee et al (1981) proposed a boundary integral method for the propagation of waves over a prismatic trench of arbitrary shape, which was used for comparison to selected results in Lee and Ayer (1981). The solution was found by matching the unknown normal derivative of the potential at the boundary of the two regions. A comparison to previous results for trenches with vertical sidewalls was conducted with good agreement. Miles (1982) solved for the diffraction by an infinite trench for obliquely incident long waves.

The problem of obliquely incident waves over an asymmetric trench was solved by Kirby and Dalrymple (1983). An extension of this study was found in Kirby et al (1987), where the effects of currents flowing along the trench were included. The presence of an ambient current was found to significantly alter the reflection and transmission coefficients for waves over a trench compared to the no current case.
2.2.2 2-D Methods

Changes in bathymetry can cause changes in wave height and direction through the four wave transformation processes. Some of the two-dimensional models consider only wave transformation, while others use the modified wave field to determine the impact of a pit or shoal on the shoreline. Several models use only a few equations or matching conditions on the boundary of the pit or shoal to determine the wave field, and in some cases, the impact on the shoreline in a simple domain containing a pit or shoal. Other much more complex and complete models and program packages had been developed to solve numerically for the wave field over a complex bathymetry, which may contain pits and/or shoals.

Black and Mei (1970) studied wave transformation in a two-dimensional domain by solving for the radially symmetric case of a submerged or semi-immersed fixed circular cylinder in cylindrical coordinates. Williams (1990) developed a numerical solution for the modification of long waves by a rectangular pit using Green’s second identity and appropriate Green’s functions in each region that comprises the domain. This formulation accounts for the diffraction, refraction, and reflection caused by the pit. Williams and Vazquez (1991) removed the long wave restriction and applied the Green’s function solution method outside of the pit. This solution was compared to a Fourier expansion solution inside the pit with matching conditions at the pit boundary. McDougal et al (1996) applied the method of Williams (1990) to the case of a domain with multiple pits. The first part of the study reinvestigated the influence of a single pit on the wave field for various pit geometries.
2.2.3 Numerical methods

The previous two-dimensional solutions, while accounting for some of the wave transformation processes caused by a pit, are limited in their representation of the bathymetry and none account for wave energy dissipation or nonlinear effects. Numerical approaches allow much greater flexibilities. Berkhoff (1972) developed a formulation for the three-dimensional propagation of waves over an arbitrary bottom in a vertically integrated form that reduced the problem to two dimensions. This solution is known as the mild slope equation, and different forms of the solution had been developed into parabolic (Radder, 1979), hyperbolic, and elliptic (Berkhoff et al. 1982) models of wave propagation, which vary in their approximations and solution techniques.

Numerical methods allow solution for wave propagation over an arbitrary bathymetry. RCPWAVE (Ebersole et al. 1986), REF/DIF-1 (Kirby and Dalrymple, 1994), and the MIKE 21 EMS module (Danish Hydraulic Institute, 1998) are some of the examples of parabolic and elliptical models. Other models such as SWAN (Holthuijzen et al. 2000) and STWAVE (Resio, 1988; Smith et al. 2001) provide the capability to model wave transformation over complicated bathymetries and may include processes such as bottom friction, non-linear interaction, breaking, wave–current interaction, wind–wave growth and white capping to better simulate the nearshore zone.

The elliptic mild slope equation models use different solution techniques with the RDE model (Maa and Hwung, 1997; Maa et al. 1998a) applying a special Gaussian elimination method and the Preconditioned Bi-conjugate Gradient model (Maa et al. 1998b). Application of numerical models to the problem of potential impact on the shoreline caused by changes
to the offshore bathymetry was conducted by Maa and Hobbs (1998) and Maa et al. (2001).

2.3 SEDIMENT TRANSPORT

The longshore transport was calculated using the Scripps Equation as modified by Komar (1969):

\[ Q = 0.045 / \gamma_s \rho g H_b^2 C_g \sin(2\alpha_b) \]  

where

- \(Q\) - volume rate of longshore transport
- \(\gamma_s\) - submerged unit weight of the beach material
- \(\rho\) - density of the fluid
- \(g\) - gravity
- \(H_b\) - breaking wave height
- \(C_g\) - group velocity at breaking
- \(\alpha_b\) - breaking wave angle relative to the shoreline

This form of the Scripps Equation combines the transport and porosity coefficients into one term; the value used for either parameter was not stated and would only affect the time scale of evolution. This process was repeated to account for shoreline evolution with time. Motyka and Willis (1974) were among the first to apply a numerical model to predict shoreline changes due to altered offshore bathymetry. The model only included the effect of refraction caused by offshore pits for idealized sand beaches representative of those found on the English Channel or North Sea coast of England. A simplified version of the Abernethy and Gilbert (1975) wave refraction model was used to determine wave transformation of uniform deep water waves over the nearshore bathymetry. The breaking wave height and
direction was calculated and used to determine the sediment transport which was combined with the continuity equation to predict shoreline change. Researchers in several distinct disciplines had contributed to the study of the behaviors of beaches and coasts. Komar (1976) had given a systematic account of the beach processes and sediment dynamics. Longshore transport equations containing a transport term driven by the breaking wave angle and another driven by the longshore gradient in the wave height can be found in Ozasa and Brampton (1979), who cite the formulation of Bakker (1971) for the longshore current. Sediment transport was calculated using the formulation of Gourlay (1982), which contains two terms, one driven by the breaking wave angle and the other by the gradient in the breaking wave height in the longshore direction. The shore protection manual, brought out by the Coastal Engineering Research Centre (1984) and coastal sediment transport concepts and mechanisms brought out by United States Army Corps of Engineers (1991) still remain as valuable documents for the coastal engineers. Gravens and Rosati (1994) performed a numerical study of the salient and a set of offshore breakwaters at Grand Isle, Louisiana. Of particular interest was the analysis and interpretation of the impact on the wave field and the resulting influence on the shoreline of the ‘‘dumbbell’’ shaped platform borrow area located close to shore. The report employs two numerical models to determine the change in the shoreline caused by the presence of the offshore pits: a wave transformation numerical model (RCPWAVE) and a shoreline change model - GENESIS (Hanson, 1987) using the wave heights from the wave transformation model. Schoonees (2000) found that measurements of longshore transport rates should be conducted continuously for 5–8 years in order to obtain an accurate value within 10% of the true long-term mean net longshore transport rate. The seasonal closure of Wilson inlet was investigated by Ranasinghe and Pattiaratchi (1999). Wellen et al (2000) assessed the applicability of longshore sediment transport equations for coarse-grained beaches and identified 12 existing formulae as being
potentially applicable for coarse-grained sediments. Grain size distributions from the beach sediments were used to assess the effect of manmade and natural structures such as rivers, creeks, sea walls and groynes (Muzuka and Shaghude, 2000). But this method had failed to differentiate the effects of man made structures and natural distortions when they were located side by side. Bender (2001) extended the numerical solution of Williams (1990) for the transformation of long waves by a pit to determine the energy reflection and shoreline changes caused by offshore pits and shoals. The impact on the shoreline was modelled by determining the wave heights and directions along an initially straight shoreline. Haas and Chandramohan et al (2001) carried out numerous theoretical and field studies to quantify the volume and direction of littoral sediment transport along the Indian coast. Tang (2002) employed RCPWAVE and a shoreline modelling program to evaluate the shoreline evolution leeward of offshore pits including the Grand Isle, LA pit geometry and a range of idealized pit geometries. This indicated that wave reflection and/or dissipation is an important wave transformation processes that must be included when modelling shoreline evolution in areas with bathymetric anomalies. Measurements of the longshore sediment transport rate along the surf zone at a 4 km long beach on the central west coast of India were made over 4 months period by Sanil Kumar et al (2003). Haas and Hanes (2003) had concluded that model results were in close agreement with the total longshore transport of sand – longshore wave power correlation described by Komar and Inman (1970) and the Coastal Engineering Research Centre (CERC, 1984) formula.

2.4 SEDIMENT TREND MATRIX

Several methods using the grain size parameters of bottom sediments to establish their transport directions had been employed over the last three decades, including those of McCave (1978), McLaren (1981),
McLaren and Bowles (1985), Gao and Collins (1991, 1992) and Le Roux (1994). Pedreros et al (1996) had applied grain size trend analysis for the determination of sediment transport pathways in intertidal areas. A modified version of the CERC formula, which relates longshore sediment drift to deep water wave height and direction, had been used by Perlin and Kit (1999) to define the equivalent wave height. Studies on the aspects of sediment transport along the Indian coastline reported by Johnson (1957) and Sastry et al (1979) provide valuable information on the problem of wave-induced sediment transport along the Indian coast.

Perlin and Kit (1999) had used a modified version of CERC formula to determine the directional distribution of sediment along with LITPACK software. Muzuka and Shaghude (2000) had studied on grain size distribution along the Msasani beach, north of dar es salaam harbour. Rodriguez and Mehta (2000) had derived an approximate formula for the longshore transport of fine grained sediment due to waves. TRANSVEC provides a rapid method not only to analyse grain size parameters, but also to check the statistical validity of the resultant trends (Rouxa et al 2002). Rios et al (2002) had inferred the seasonal variations in net annual sediment transport path from the grain size parameters and concluded that the trend paths as proposed by Gao and Collins (1992) provided better results compared to the procedure laid by McLaren (1981).

Kumar et al (2003) and Nordstrom et al (2003) had used CERC formula to determine the sediment transport rate at central west coast of India and on a micro tidal estuarine beach respectively. Weber et al (2003) had used grain size parameters to infer sediment transport energy and to distinguish different environment along the 300 km long transport path from the delta platform to lower Bengal fan. The statistical parameters tend to change seasonally and hence net sediment transport pathways also changes (Rios et al
2003). The difference in grain size distribution in the geomorphologic units between two monsoon seasons were observed to be larger and was attributed to increased contribution to the beach from freshly immature river sands, which are generally coarser (Abuodha, 2003). Benedet et al (2004) had suggested a morphological classification of beaches on the basis of wave breaker height, wave period and sediment characteristics. Kudale et al (2004) had predicted the design wave along the coast of India.

2.5 REMOTE SENSING APPLICATIONS IN OCEAN STUDIES

The changes taking place in the coastal processes due to the constriction of groin, jetty and harbour were brought out by Bakker (1968), Komar et al (1976) and Narashima Rao (1983). Operational use of LANDSAT and SPOT images in monitoring ocean and coastal processes had been presented by Nayak and Sahai (1985); and Wadsworth and Piau (1987). Chelton et al (1986) had proved that four year average fields of the wind stress divergence and curl obtained from High-resolution measurements by the QuikSCAT scatterometer revealed a rich diversity of persistent small-scale features in the global wind stress field that cannot be detected by other means. Cotton and Carter (1994) had compared mean monthly altimeter values of significant wave height from GEOSAT, TOPEX and ERS1 with both buoy data and each other. Young (1994) and Young and Holland (1996) had shown that a period of 3 years was sufficiently long to form reliable global estimates of mean monthly values of wind speed, $U_{10}$ and significant wave height, $H_s$. An inter comparison of mean monthly measurements of wind speed and wave height obtained from GEOSAT, TOPEX and ERS1 with National Data Buoy Centre buoys was done by Young (1997). As a result of these comparisons, the following calibration relationships had been developed for each of the satellites:

$$H_s = 1.144H_{s\ (GEOSAT)} - 0.148$$

(2.2)
\[ H_s - 1.067 H_s^{(TOPEX)} - 0.079 \]  

(2.3)

\[ H_s - 1.243 H_s^{(ERS1)} + 0.040 \]  

(2.4)

\[ U_{10} - U_{10}^{(GEOSAT)} \]  

(2.5)

\[ U_{10} - 0.99 U_{10}^{(TOPEX)} + 1.61 \]  

(2.6)

\[ U_{10} - U_{10}^{(ESR1)} \]  

(2.7)

Marghamy (2002) had utilized Synthetic Aperture Radar data with L and C band to model the shoreline changes. Landuse / landcover changes were studied from Survey of India toposheet, Indian Remote sensing Satellites (IRS) 1A and 1C imagery in 1:50,000 (Ghosh et al 2001; Sanjeev and Subramanian, 2003; Thanikachalam et al 2003). Raj Kumar (2004) had used satellite data for modelling the deep and coastal ocean waves. For deep ocean region, third generation wave model WAM (wave model) was used. Surface wind field (1° x 1°) of QuikSCAT and National Centre for Medium-Range Weather Forecast (NCMRWF) winds were used was the primary input to WAM model provided by an atmospheric general circulation model. Rao et al (2004) used SWAN model with forced field data and WAM simulated results to evaluate the sensitivity of the nearshore wave propagation to the type of information used in the open sea boundary. WAM and SWAN are third generation wave models used to compute random short-crested wind-generated waves on Eulerian grids.

2.6 EARLIER WORKS ON THE STUDY AREA

Shoreline changes of Madras coast due to littoral drift had been studied by Raja Ganesh Ram (1987). Chandramohan et al 1990 suggested that the transport is towards the north from March to October and towards the
south from November to February. Northerly and southerly components of annual sediment transport along Madras coast were estimated to be of the order of $0.89 \times 10^6 \text{ m}^3$ and $0.60 \times 10^6 \text{ m}^3$ respectively with the net northerly drift of $0.3 \times 10^6 \text{ m}^3/\text{annum}$. Suresh et al (2004) had found that the coastline near Poompuhar and Tranquebar were earlier under severe erosion posing threat to the existing monuments. Ramanamurthy et al (2004) had used Remote sensing, Geographic Information System (GIS) and GPS techniques to analyze the impact of Ennore satellite port upto a distance of 2.5 km on either side of the port.

Some earlier studies on ocean waves in Bay of Bengal were those of Sathe et al (1979), Mukherjee and Sivaramakrishnan (1982), Varadarajulu et al (1982) and Sivaramakrishnan (1982, 1983 and 1986). Highest waves were reported during June in Bay of Bengal (Prasad Rao and Durga Prasad, 1984). Sundar (1986a) had described the wave spectra off Madras. He found that wave heights follow Rayleigh distribution and Scott spectrum had a closer agreement with the measured spectrum. Variations in the wave climatology off Madras due to monsoon had been analysed by Sundar (1986b). Though southwest monsoon winds were stronger in most parts of the Indian coast, wind speeds at Madras Harbour were the strongest during northeast monsoon (Sundar and Ananth 1988). Barstow et al (2003) had done an intercomparison of WAM, Topex/Poseidon and buoy data for two locations (DS 1 and DS 3) in Indian Ocean. Johnsen et al (2005) used Advanced Synthetic Aperture Radar (ASAR) and Radar Altimeter (RA-2) Instruments onboard ENVISAT for assimilation with original ESA ENVISAT products to derive wave height of Indian ocean using WAM model.
2.7 GAPS IDENTIFIED

From the literature reviewed on various aspects, following lacunae are observed:

- No single model had been used for offshore and nearshore wave transformation, and sediment transport. There is always a compromise when data format is changed between models depending on model uniqueness. The error due to format change can be avoided when single model is used.

- A holistic approach is missing; the studies attempted any one component only. Approach on integration of models to obtain offshore, nearshore and littoral transport had not been undertaken.

- Studies on modelling of nearshore wave climate along Chennai coast from the offshore wave transformation based on satellite data are absent.

Hence the present study aims to hindcast waves in offshore and nearshore areas with NCEP wind components and numerical modelling. Predicted nearshore wave climate were used to compute the littoral transport using LITDRIFT of MIKE 21.