CHAPTER 2
LITERATURE REVIEW

2.1 GENERAL

In this chapter, a comprehensive review of latest works in the areas of wave data analysis and modelling, wave transformation, estimation of sediment transport rates and coastal dynamics, are presented. Critical observations based on the above, especially with respect to National scenario (i.e, Indian) is summarized at the end of the chapter.

2.2 REVIEW OF EARLIER WORKS

2.2.1 Wave Data Acquisition, Analysis, Modelling and Forecasting

Vijayakumar et al. (2004) have compared wave characteristics obtained from wave float gauge developed for obtaining field wave data of Pondicherry coast and the wave measurements using a commercially available system with a pressure transducer. It has been reported that the results compare very well and the developed instrument has exhibited long – term stability during the period of operation.

Kudale et al. (2004) have carried out extreme wave analysis using measured wave data, visually observed data and hindcast storm wave data. They have concluded that all the three types of data sets are required to determine the wave climate at any location and that the extreme wave conditions on the east coast are severe in comparison to the west coast of India.

Chandramohan et al. (2004) have estimated the design waves along a proposed submarine pipeline corridor in the Gulf of Kachchh, west coast of India, using hindcasting procedure and wave transformation by the software TARANGAM. It has been concluded that extreme significant wave height along the pipe line corridor is expected to occur around 3.59; 4.19 and 4.59 m for $T_R = 10, 25$ and $50$ years, respectively.

Sudheesh et al. (2004) compared the results of wave modelling with measured and TOPEX altimeter waves for a summer monsoon season at Goa and Kochi located in the west coast of India. They have concluded that the wave parameters of model, altimeter and buoy agree with one another very closely and that wave modelling can be used for any practical application, especially, whenever measurements are not possible.
Praveen et al. (2004) attempted to predict the design wave heights and operational conditions off Alleppey during rough monsoon seasons using the parametric relations derived from Weibull model. It has been concluded that the parametric relations derived from the modified Weibull model for maximum wave height distribution after accommodating a depth factor to include shallow water wave transformation effects, could be used for its estimation in shallow water.

Jagadesh Kumar et al. (2004) attempted to validate the expression for estimating various significant wave periods and the model derived for the conventional significant wave period ($T_s$) distribution. It has been concluded that (i) the Gamma distribution simulates the zero up–crossing wave period satisfactorily; (ii) among the Erlang model and Gamma model for conventional significant wave period distribution, Gamma distribution gives an empirical support of 100% at 0.05 level of significance by chi–square test for conventional significant wave heights, using 10 years of visually estimated wave period data of deep waters of Arabian Sea, India.

Mulagaleti et al. (2004) developed models for probability of breaking and distribution of estimated dissipated wave energy, using the daily maximum significant wave height data obtained by CERC (Coastal Engineering Research Centre) at Duck, North Carolina, USA, and NIOT (National Institute of Ocean Technology, Madras, India) and the maximum wave heights off Valiathura located on the western coast of India. It has been concluded that the modified Weibull model seem to simulate both the deep and shallow water breaking wave height distribution and also useful for estimating the dissipation rate of breaking wave energy.

Sundar et al. (2004) have studied the wave characteristics and littoral drift among other things in connection with the proposed fishing harbour at Mahe, located on the western coast of India. It has been reported that the mean breaker height is about 0.9 – 1.9 m and that the net drift of sediment is $0.944 \times 10^6$ m$^3$ towards the south.

Sundar et al. (2004) have studied the shoreline evolution, among other aspects, in connection with the proposed fishing harbour in Rameswaram, located near the end of east coast of India. Monthly sediment rates were calculated from CERC expression and it has
been reported that the net drift of $0.35 \times 10^6$ m$^3$ towards north will get interrupted and the sediments will bypass the breakwater after 30 years.

Rajkumar et al. (2004) have used 10 years of TOPEX radar altimeter data and have estimated 50 and 100 years of return values of wave height and wave speed over the North India ocean. Gumbel's distribution has been found to fit the satellite wave data (in each bin). It is found that the extreme wave height are found to be higher in the western Arabian sea with values of order 8 – 9 m. whereas, the extreme values in the Bay of Bengal region are approximately 5 – 6 m.

Kaira et al. (2004) used satellite data of significant wave height, average wave period and wind speed to obtain significant wave heights at a coastal location along the west coast of India, using ANN (artificial neural network).

Mandal et al. (2004) have shown that ANN can be used to estimate ocean wave parameters from Pierson – Moskowitz (PM) spectra as well as from field data. It has been stated that even if there exists some missing data for a particular location and time, then also ocean wave parameters or spectral energy can be generated using trained neural network.

Bharatkumar et al. (1989) studied the wave and wave statistics off the west coast of India using SEASAT altimeter data. It has been concluded that wave data interpreted from altimeter observations show a general correlation with wave data obtained from ship's observation with a strong tendency for the altimeter to be on the higher side. Further it has been observed that correlation between wind speeds and wave heights obtained from remote sensed data shows good agreement with correlations obtained from measured data.

Panvalkar et al. (1982) have highlighted the features of a software package for wave data retrieval and analysis, developed in QUICK BASIC and which can run on IBM – PC/XT computer system. The software consists of six interactive programs for on-line retrieval, storage, time and frequency domain analysis and plotting of results. It has been stated that the package has been extensively used for retrieval and analysis of wave data collected at various important cities in India.
Gaikwad and Phadke (1989) have presented the details of an on-line analysis system with software for real time data acquisition and analysis. The system developed had been used for data acquisition on a number of sites on the west coast of India, such as, Karwar and Maldeev.

Muraleedharan et al. (1989) have analysed the long-term visual observation data on wave heights off Mangalore against four theoretical distributions (Weibull, Rayleigh, Gumbel, Log-normal and Exponential). It has been reported that the best fit is obtained for the 'Weibull' distribution.

Shahul Hameed and Baba (1989) attempted to parameterize the PMK (Perison - Moskowitz - Kitaigorodskii) using the year round data collected from a shallow water location at Alleppey, located on the west coast of India. Results from the above were compared with the TMA and Wallops spectral models. It has been concluded that the PMK model is in agreement with the field data collected and that the above 2-parameter model found to be as good as the 5-parameter TMA model to simulate shallow water spectra.

Dattatri and Venkata Rami Reddy (1989) analysed the wave data obtained off Karnataka coast (west coast of India) to obtain the wave groups (i.e., a sequence of high waves) statistics by two theories, namely, by Goda and Kimura. It has been concluded that Kimura's theory is found to explain satisfactorily the wave group statistics and that the correlation coefficient is found to be an important parameter to describe the wave group statistics.

Swaminathan and Mahadevan (1989) have described the salient features of the computer software developed for the analysis of ocean surfaces wave data collected along Tamil nadu coast (located on east coast of India). The computer software eliminates the effects of noise in the final wave statistics using the definition and the classification of waves suggested by the 'Wave Committee' appointed by the Royal Norwegian Council for Scientific and Industrial Research (RNCSIK). It has been emphasized to adopt a uniform procedure for the computation. Further, it is seen that only an ensemble averaged value of spectral density function with a finite variance and not the true value of the spectra, is obtained.
Kiran Kumar et al. (1989) have examined the nature as well as the extent of discrepancies, if any, in predicted wave height data with the help of wind data collected for one year in the Bombay high region, India. It is found that the variations noted in the case of short-term predictions are not found to be identically reflected in the corresponding long-term predictions. It is seem that the Weibull distribution emerged as the best fit long-term model for the site.

Usha and Subramanian (1989) analyzed 10 year visually observed data of Kanyakumari coast (located at the far end of east coast), India and also studied the berm oscillation. $H_s$ of 0.51m and $T_s$ of 12.8 sec have been obtained and it has been concluded that the coastline is a 'prograding' coastline.

Mathur and Sarma (1989) studied the wave, tide and current variations off Ennore coast (located north of Madras port, on the east coast of India) for a short period (3 weeks) to obtain basic parameters for planning the port. It has been concluded that currents are strong in deeper water when compared to the shallower regions and that the influence of the discharge from the Kortaliyar river is changing the flow and associated sediment distribution in the near-zone region.

Schlenkar et al. (1997) have validated CGWAVE—an advanced wave prediction model against all known controlled test cases for which sufficient data are available. It has been shown that the comparisons between the model output and laboratory data are good.

Kudale et al. (1997) compared the properties of regular waves in shallow water depths on sloping bottom obtained from a wave flume, with the theoretical properties of Cnoidal and Stokes (II order) waves. Random wave series with PM-spectrum were also generated in a flume. It was observed that the wave heights as well as crest heights (maximum water surface elevation reached by the wave above still water level — SWL). It has been concluded that the crest heights of random waves could be estimated by applying Cnoidal wave profile for the particular design wave height for shallow water condition.

Swain (1997) attempted simulation of wave climate of Arabian sea and Bay of Bengal over a desired grid resolution, using the third generation wave model developed by WAMDI group, with estimated mean climatic year of winds as input to the model.
Significant wave height parameter (monthly, seasonal and annual distributions) were obtained as model outputs. It has been observed that the simulated values have been validated qualitatively and can be utilized for various applications.

Varma et al. (1997) have described the details of transformation of ERS – 1 SAR (European Remote Sensing Satellite-1 Synthetic Aperature Radar) wave spectrum into wave height spectrum, for an area off west coast of India. It has been concluded that at any instant of time the ocean wave spectrum remain almost unchanged over a large area. However, with time, possibly with change in wind speed, it does change.

Panchang et al. (1997) have estimated significant wave heights of 50 year return period using GEOSAT measurements for several regions around North America. The study was based on the assumption that the extreme wave statistics can be described by the Gumbel distribution. It has been concluded that the technique can be used for estimating wave heights associated with any specified return intervals in regions, where buoy data are not readily available.

Ragesh et al. (1997) used Weibull model to predict various wave height parameters (mean wave height, significant wave height - $H_s$, one – tenth of the highest wave height $H_{1/10}$, max. wave height, most probable max. wave height), for Cochin coast (western coast of India) using both swell data and combined sea and swell data. It has been confirmed that the long – term wave height distribution pattern follows a Weibull model.

Shahul Hameed et al. (1997) have compared measured wave data from the Lakshadeep sea (India) for a period of one year using a directional wave rider buoy with IDWR (Indian Daily Weather Report) ship data of 7 years to ascertain the reliability of ship – reported data. It is found that the ship data always under – estimates the wave heights during rough weather and that the periods reported by the ships are always less than those particularly during fair weather season. Hence, it has been concluded that the ship data can be used only for obtaining first hand information on wave climate when no measurements are available. Further, the wave power for rough weather condition obtained from ship data will be gross under estimates.
Thomas et al. (1997) investigated the long-term wave climatology along the Trivandrum coast (west coast), India, based on recorded wave data for a period of 10 years. Waves were recorded using a pressure transducer and the wave direction using a Brenton compass. It has been observed that $H_s$ is between 1 and 4 m (during June – Aug.), whereas, the majority of waves are less than 1 m (during Dec. – Apr.); ii) waves with periods < 10 sec dominate the wave climate; iii) waves of this coast are largely influenced by swells rather than seas.

Balas et al. (2004) developed a multi-layer feed forward (MFF) and recurrent (Elman type) neural networks trained by steepest descent and momentum (SDM) and conjugate gradient (CG) learning algorithms to simultaneously predict the missing wave data (height, period, and direction predictions at the same time). The model was tested with various test cases to ascertain the validity. Further, the predictions were compared with (i) continuous artificial data generated; (ii) stochastic auto-regressive (ARX) models and (iii) third generation wind wave model (METU-3 Ozhan and Abdalla, 1993) and it was found that the predictions are in good agreement.

Babovic et al. (2004) have presented an alternate approach of combining observations and numerical model results to produce an accurate forecast. Third-generation wave model, WAM (The WAMDI group, 1988) was the numerical model used and embedding theorem which is the basis for local models was used for analysis and updating of numerical model output variables to forecast and correct the errors created by the numerical model. The efficiency of the local model as an error correction tool (by combining the model predictions with the observations) compared with the predictions of linear auto regressive models, have been highlighted.

Shi et al. (2003) used an improved curvilinear grid model on fully non-linear Boussinesq equations to simulate wave propagation in Ponce de Leon inlet, Fla. Simulations of 18 cases with monochromatic input waves and Texel – Marsden – Arsloe spectral waves were carried out on the same scale as in the 1:100 scale physical model and the results compared. It is shown that for the computations of non-linear wave transformation over irregular bathymetry, the Boussinesq model is able to predict non-linear wave features and is thus a more accurate model than some conventional models in shallow water.
Marghany et al. (2002) modelled the significant wave height based on the azimuth cut-off model (for three ERS – 1 images), along the coastal waters of Kuala Terengganu, Malaysia. It is found that the significant wave height modeled from azimuth cut-off is in good relation with ground wave conditions.

Oliveira (2002) applied a verified accurate numerical model (Copeland, 1985-a time dependent form of mild – slope equation) for wave propagation in near - shore regions to study wave transformation and to predict the wave climate in the coastal area south of Rio de Janeiro, Brazil, consisting of several islands. The numerical results have been verified against experimental and analytical results. The effects of the islands in the process of wave propagation and the resulting variation of exposure to wave action along the beach have been highlighted.

Allard et al. (2002) have described the various features and capabilities of a wave - tide surf modeling system called integrated ocean prediction system (IOPS) which was developed to support naval operations in littoral waters. The ultimate aim of providing situational awareness of the littoral and surf environmental conditions to the war fighter on demand through a host of such integrated systems have been highlighted.

Nerzic and Prevosto (1998) have developed a model for the distribution of wave and crest heights, which combines a Rayleigh or Weibull distribution (describing wave and crest heights as a first - order Gaussian process) and third order Stokes non - linear wave expansion (called Rayleigh – Stokes or Weibull – Stokes model). The model was validated by fitting the model distributions to North sea measured data and it provided much better predictions of maximum crest and wave heights than standard models.

Makarynskyy et al. used ANN (artificial neural network) to predict significant wave heights, wave periods and peak wave period with leading times of 3,6,12, and 24 hours. The simulations were compared with time series of these wave parameters estimated offshore off the west coast of Portugal. The results showed different levels of performance of each of the neural networks in terms of RMS error, correlation coefficient and scatter index.

Guedes Soares and Carvalho (2001) analysed the measured two – peaked sea spectra from a deep – water location at the Portuguese coast and the probability distributions of wave
height and period were determined and compared with several theoretical models. It is reported that the Rayleigh distribution gives rise to a systematic overprediction of the observed wave heights.

Chiswell and Kibblewhite (1980) analysed one year ocean wave records from Maui A site (39°33' S, 173° 27' E, New Zealand ) and obtained the general spectral properties of the wave field on the west coast of New Zealand. Joint height/ period distributions have been presented to characterize the wave climate of the Maui region.

Subha Rao et al. (2001) used neural networks with better update algorithms, namely, rprop (resilient propagation), quickprop (quick propagation) and Super SAB (based on the idea of sign - dependent learning rate adaptation) for wave forecasting (3.6 and 12 hourly wave heights). Wave data collected off Marmagoa during Feb. 96 – Jan. 97 (three hourly Hₙ over the above period) was used for training the algorithm. It is found that the ‘rprop’ algorithm has yielded very good results.

Wolfram et al. (2001) have presented the analysis of storm data collected over the last six years in the northern North sea from three wave height altimeters mounted on a fixed platform. The focus of the study was on the temporal changes in the characteristics of the individual waves and the wave spectra as the storm builds up to its peak and then decays. The variations in the characteristics of wave crest elevation, wave height and wave steepness during the passage of storms were studied. It is concluded that multi - directional analyses for storm wave particle kinematics, long - crestedness and other directionally sensitive quantities should use data collected from peak periods of storms to avoid bias, in related estimates of maxima.

Swain et al. (2001) have attempted to validate ‘3g – WAM’ simulated data with ship measurements and buoy measurements for an year. The study has revealed that the hindcast wave field for the period of model execution is quite encouraging and agrees with the field data. The study further indicated that the measured data have better agreement with the hindcast wave parameters than the visual wave data.

Londhe and Deo (2001) have used a feed forward neural network to estimate the attenuations of wave heights along the approach channel to a harbour from seaward to the
harbour entrance. It has been reported that the trained network was found to follow the expected trend of wave height attenuation along the harbour channel and the effect of variation in the wave period as well as that of angle of wave attack was also properly simulated by the network.

Ashok Kumar et al. (2001) have discussed and summarized the problem associated with wave measurements carried out along the east and west coasts of India @ 13 locations, using the directional wave rider buoys (supplied by M/S Datawell B.V., The Netherlands).

Tetsuya Hiraishi (2001) has described a model study to estimate the wave height and periods in water areas surrounded with atoll reefs in a isolated island located in a deep sea of northern pacific ocean. Modified Boussinesq type wave transformation model was applied to estimate wave heights and wave induced current velocities on reef.

2.2.2 Wave Transformation, Breaking

John et al. (1989) have studied the effect of refraction at the locations of a few existing major ports and the results were represented in the form of diagrams showing the most critical refraction functions and refraction coefficients, considering the most probable periods and all predominant directions of wave approach. The refraction diagrams were prepared by the wave orthogonal method (graphically). The results of the study has revealed that the location of Madras port is a region of high waves approaching from deep water along south and south-east directions.

Kurien and Shahul Hameed (1989) studied the effects of shallow water transformation on the distribution of wave heights and periods, by making use of synchronized deep and shallow water wave data from two different coastal environments (Trivandrum and Alleppey, west coast of India). A wave transformation model [Kurien (1987)] which has been field tested in different conditions [Bryant (1979); Kurien et al. (1985); Kurien and Baba (1988)] have been used to compute shallow water wave parameters in cases where no appropriate shallow water data is available. It has been shown that the distribution modes were incorrectly simulated by Rayleigh, CNEXO and Longuet – Higgins models. The distributions appear to be controlled by spectral width with the cases where its values are less than 0.45 following Longuet – Higgins and higher than that following CNEXO.
Gadre and Kanetkar (1989) carried out refraction analysis by wave ray method for the wave data recorded at Mirya bay, Ratnagiri, for one year. It has been reported that the 'groupiness factor' reduces due to shoaling effects and the spectral shape in shallow coastal waters gets skewed to the high frequency side indicating transfer of wave energy from low to high frequency. Also, the peakedness of the spectrum increases due to refraction and diffraction effects.

Nagendra Kumar et al. (1989) have reviewed the wave breaking on a beach highlighting the knowledge of breaking of steady water waves on prismatic beach and those aspects to be relevant to wave induced motions in the surf zone. It has been observed that the internal motions in a wave shortly after breaking are still poorly understood and that the quantitative modelling of large-scale vortices, which are an important element in the wave transformation, has not yet been developed. It seems that the motions in the bore regions are well understood both qualitatively and quantitatively.

Liiv (1997) investigated the turbulent characteristics inside the 2-D breaking wave in the surf-zone through laboratory experiments using LDA (laser doppler anemometry), flush mounted constant temperature anemometers (CTA) etc. It has been observed (based on experimental data on the physical model covered with rough and smooth bottom) that the bottom roughness affects strongly the wave propagation velocities and turbulent characteristics, not only inside boundary layer of the breaking wave, but also the entire height.

Shi et al. (2001) derived the equations in generalized coordinates based on the fully non-linear Boussinesq equation in cartesian coordinates to adapt computations to irregularly shaped shorelines (such as: harbours, bays, tidal inlets) and to make computations more efficient in large near-shore regions. The model was applied to five examples involving curvilinear coordinate systems. It is found that the results are in good agreement with analytical results, experimental data, and results from uniform grid model, which shows that the model has good accuracy and efficiency in dealing with the computations of non-linear surface gravity waves in domains with complicated geometrics.
Chen et al. (2005) have developed techniques for simulating the effects of ambient currents on wave transformation in coastal areas with arbitrary geometry using the finite element method (FEM). The model has been validated against three test cases and the results were found to be consistent with those of other published models.

Tsai et al. (2001) have applied the time-dependent mild-slope equation given by Watanabe and Dibajnia (1988) to compute the wave transformation in the surf zone, using the empirical non-linear shoaling equations proposed by Shuto (1974) for improving the accuracy of the numerical calculations. Wave deformation over three typical beach profiles (including uniform slope, bar and step profiles) have been calculated and compared with the experimental results available and the results are comparable.

Bayram and Larson (2000) investigated the possibility of simulating wave transformation in shallow water using Boussinesq equations with special emphasis on depth-limited wave breaking. Predictions made with the numerical model were compared with field measurements from the US Army Field Research facility in DUCK, NC. From an overall assessment it was found that the model failed to accurately reproduce the strong non-linear shoaling that occurred prior to breaking. However, improvements are needed before the predictions can be used for calculating the sediment transport rate in intra-wave models and the natural next step in the model would be to include non-linear dispersive terms in accordance with Sorenson et al. (1998).

Skotner and Apelt (1999) included the effect of spilling wave breaking into an existing set of Boussinesq-type equations with improved linear dispersion characteristics in deeper waters. The model has been calibrated for the case of regular waves breaking on a plane and gently sloping beach [i.e., experimental data by Hansen and Svendsen (1979)] and subsequently verified with two existing wave flume experiments of Hansen and Svendsen (1979). The results are found to be accurate with respect to mean water level and wave-induced flow, but, the wave height during shoaling is overestimated, which, it is suggested can be overcome by employing fully non-linear Boussinesq equations.

Work and Rogers (1997) considered four alternatives for description of wave transformation for on-line modeling applications for beach nourishment projects. A new governing equation and analytical solution for beach nourishment projects has been
presented which accounts for project-induced wave refraction using a 'two - line' approach. The usefulness of the analytical solutions for preliminary design has been highlighted. It has been shown that for engineering situations, the CERC formula yields the best result, among the three methods considered, namely, CERC formula, GENESIS [Hansen and Kraus, 1989] and Kamphuis (1991), for estimating longshore sediment transport rates.

Hamm et al. (1993) have presented a comprehensive review of works related to near shore wave propagation with an emphasis on several aspects related to coastal morpho-dynamic modeling including randomness and directionality of waves, energy transfer and dissipation in the surf zone, shallow water non-linearities and long period motions.

Blankinsopp and Black (2003) reviewed the studies on the effect of abrupt steps in bathymetry on the nature of wave breaking and a basis for the specification of construction tolerances for artificial surfing reefs was evolved. It was found that reflections from the face of sudden, unwanted vertical steps in bathymetry lead to a "mussy" surf zone and interfere with the breaking characteristics of incoming waves. In addition, abrupt steps can "trip" waves that are close to breaking, causing them to break prematurely and with a modified breaker type.

Chen et al. (2004) have reported the results of a new mathematical derivation for the transformation of a progressive wave propagating obliquely on a gentle slope. It is stated that the analytic solution derived enable the description of the features of wave shoaling and refraction in the direction of wave propagation from deep to shallow water, particularly, the process of successive deformation of a wave profile.

Lachaume et al. (2003) studied the shoaling, breaking and post - breaking of waves in two dimensions using a model, i.e. a numerical wave tank, based on coupling a BEM (boundary element method), solving potential flow equations, to a volume of fluid model solving Navier - Stokes (N - S) equations. The model was applied for calculating the transformation of solitary waves over plane slopes and the results were compared with existing laboratory experiments. It is reported that the agreement is quite good between the computations and measurements.
Andrew (1999) reviewed the different types of nearshore wave models available (at that time) and their attributes (i.e., equations and assumptions utilized and validation exercises performed and their findings). The wave models were placed under two classes namely, those could be applied in the field, either by small calculations, whilst, the second were computer-based. Krylov Strekalov and Tsyplukhin (1976) model and Thornton and Guza (1983) model under the first type and SWAN and REF: DIF: S models under the second type, have been identified and recommended for use.

Hilmer (2005) has presented a method for remotely measuring breaking wave heights over a range of environmental conditions using video, and its on-going application in a high energy nearshore environment. A 640 X 480 pixel analog surveillance camera with a view of 0.04 Km² (app) and a mean horizontal resolution of 0.5 m was used in the shallow region near Ipan, Guam. Initial comparisons between video measurements of breaking wave height have shown a strong correspondence with in-situ pressure sensor data.

Sanilkumar et al. (2001) have measured and studied the various parameters in the surf zone (monthly beach profiles, breaking wave characteristics and along-shore currents) for one year along the coast between Kanwar and Bhatkal. It is reported that i) beaches were stable during annual processes along the stretch of the coastline; ii) waves approach the coast more obliquely; iii) the annual net sediment transport was 0.069 X 10⁶ m³/year towards north at Arge beach and 0.040 X 10⁶ m³/year at Kasarkod and it was 0.142 X 10⁶ m³/year towards south at Gangavalli.

2.2.3 Sediment Transport

Chandramohan and Nayak (1989) and Chandramohan (1988) estimated the longshore sediment transport based on longshore energy flux equation with the assumption that the coast consists of a long open beach with adequate supply of sand, for almost the entire stretch of Indian coast, using VOS data. It is found that the results have inherent limitation for the west coast due to the presence of numerous headlands and estuaries intersecting the littoral zone. Regions of high transport rate and the directions have been identified.

Dixit et al. (1989) have highlighted the limitations of three methods generally used for the estimation of littoral drift, when used for several locations on the west coast of India. They
have stated that the radiation stress method was found to be useful in estimating the longshore current field at three locations on the west coast of India.

Malleswara Rao et al. (1989) carried out studies for determining the sediment transport rate off Visakapatnam coast using Galvin’s equation and CERC formula. It has been reported that large variations in the computed values were observed between the two methods and that the peak rate of sediment transport for the above coast was found to occur at a wave period of 9.0 seconds.

Jose and others (1997) have estimated the longshore transport at three different locations along the SW coast of India using the wave energy flux method of US Army Corps, 1984. It has been observed that the huge quantum of sediment transport (2.95 Mm$^3$) obtained for the southern coast is partly due to the higher breaker angle at these shorelines for the predominant westerly waves during the SW monsoon.

Jena and Chandramohan (1997) estimated the longshore sediment transport rate using the equation proposed by Walton (Jr) and Bruno (1989) and using (monthly) field measurements for one year for Kolachel on the western side of the peninsular tip of India. The study showed that the wave activity was high throughout the year and that the annual net transport rate was 0.3 X $10^6$ m$^3$/year towards west.

Kosyan et al. (1997) discussed the results of field investigations on the contribution of short and long waves and time mean flow on the cross-shore net suspended sand flux in southern North sea and its comparison with energetic model predictions. It has been concluded that theoretical estimations weakly predicts the direction of suspended sand fluxes by short and long waves and in many cases, the calculated fluxes were directed offshore, in contrary to measured fluxes.

Mallik et al. (1997) carried out an integrated study to understand the sediment mobility and wave climate in a harbour area (Vizhinjam) of Keral state (west coast) India, to throw light on siltation problems faced due to construction of breakwater. It has been concluded that the depletion rates vary from 0.09 to 2.46 kg/min and the major transport direction between 316° - 340° towards offshore in the pre and post monsoon periods. Waves of monsoon season were found to be in the range of 3-3.5 m, with periods of 7-8.5 seconds.
Sundar and Raju (1997) have investigated the nearshore dynamics and sediment transport induced by the construction of harbour breakwaters at Visakhapatnam port on the east coast of India. It has been concluded that the northerly sediment transport is maximum during June (2 lakh m³), while the southerly transport is maximum during the months of Nov. and Dec. (1.2 lakh m³).

Davies et al. (1997) have compared the predictions of four sediment transport models (turbulence - diffusion models) with detailed data sets obtained in the bottom boundary layer beneath regular waves, asymmetrical waves, and regular waves, superimposed co-linearly on a current. It has been concluded that each of the models agrees with the measured values within a factor of 2. Further, certain limitations of the above (predictive) models like: (i) the models do not represent conditions in the high sheet flow, (ii) none of the models is able to represent the phenomenon of convective entrainment at flow reversal have been highlighted. The need for new experimental research schemes has been emphasized.

White (1998) has given a comprehensive description of various known methods of measuring coastal sediment transport in the field along with their limitations. He has identified the three glaring gaps in the ability to measure; i) suspension of mixed sediment sizes; ii) suspension close to the sea bed; iii) bed load and has highlighted the efforts of CERC in closing these gaps through the project STILE (Sediment Transport Instrumentation for the Littoral Environment).

Li and Johns (1998) developed a 3-D numerical model for the propagation of shallow-water short-period surface waves in the surf zone and longshore current generation over a plane beach topography. It has been concluded that the location of the breaker line may be inferred from the position of maximum turbulent energy in the model solutions, which compares with most existing models where the prescription of such a breaking position is necessarily 'apriori'. Further, a continuous description of wave motions from an offshore region (h/L, where L-local wave length) through initial breaking to after breaking where they propagate in the form of 'bores' towards a shoreline, has been enabled by the use of turbulence closure scheme adopted by the investigators in the above study.
Perlin and Kit (1999) estimated sediment transport rates employing an analytic expression based on CERC formula for the Israeli coast and compared with the results of numerical simulations using the LITPACK model. The importance of accounting for wave directional shift for different ranges of wave heights and its influence on sediment transport calculations have been brought out.

Wang and Kraus (1999) measured the total longshore sediment rate in the surf zone at a temporary groin installed at Indian Rocks beach, west central Florida, USA. It has been concluded that the short-term impoundment (at a temporary groin) was found to be a promising method for measuring the total longshore sediment transport rate under low-wave energy conditions. Further, it is concluded that $K$ (in the CERC formula) is not a constant and that other factors may enter, such as the breaker type, turbulence intensity, and threshold for sediment transport.

Cuadrado et al. (2005) investigated how a coastal structure can alter the dynamics of the zone (Bahia Blanca Estuary, Argentina), which includes the estimation of the tidal and littoral transport in the area. Wind data was used to predict wave parameters. It has been inferred that different modes of transport occur on either sides of the breakwater, i.e., on the east side, longshore transport is the principal mode, and on the west side, tidal transport is predominant.

Wai and Lu (2000) developed a 3-D parallel model for simulation of sediment–water transport processes in coastal regions with main focus on parallel architecture of the model. Two real-life applications i.e., to Rusi bay located in Jingsu province, China and Pearl river estuary located in Guangdong province, Hong Kong, (China). It has been reported that the results of the simulation model agree well with the available field observations and that the implementation of parallel processing algorithm has greatly improved the computational speed by five-fold per additional processor.

Schoonees (2000) has investigated the net longshore sediment transport rates at three South African and at one North African site. Kamphuis formula (calibrated) was used to predict the longshore transport rate for each wave condition at three beaches. Based on the study, it has been recommended that an accurate assessment of the long-term mean net longshore transport rate at a site can best be made cost-effectively by doing limited site-
specific measurements, calibrating the best longshore transport formula for the particular site, and predicting the transport site using a representative wave climate.

Ruggiero and Mc Dougal (2001) developed an analytic model to predict the time and depth-averaged cross-shore and longshore sediment transport on a planar beach backed by a seawall. It has been shown that (i) on steep beaches, the total sediment transport is less than that for a natural beach; ii) on milder sloped beaches, the modulations due to partial standing waves become significant and the transport may be more or less than that for a beach with no wall, depending on the location of the seawall.

Bayram et al. (2001) evaluated the ability of six well-known formulae [(Bijker (1967); Engelund – Hansen (1967); Ackers – White (1973); Bailard – Inman (1981); Van Rijn (1984); Watanabe (1992)] developed for calculating the longshore sediment transport rate and compared with the high quality data on hydrodynamics and sediment transport from DUCK, DUCK 85, SUPERDUCK, and SANDYDUCK collected during field collection projects. It has been concluded that Van Rijn formula was found to yield the most reliable predictions over the range of swell and storm conditions covered by the field data set. It is expected that a re-calibration of the coefficient values with reference to field data from the surf zone is expected to improve their predictive capability.

Kaczmarek and Ostrowski (2002) have presented a focused study on sand transport in combined wave–current flow (at any angle between them) in the intensive flow regime. In the model proposed the wave–current interaction and sediment–flow effects are coupled. The results obtained were compared with laboratory and field results and it is found the agreement to be good.

Davies and Villaret (2002) compared the predictions of a sand transport research model and Bijker’s (1971) engineering model with data obtained in wave–current conditions at three field sites (two from UK and one from the Netherlands). The comparisons between suspended sand concentrations and transport rates show that a considerable amount of uncertainty (factor ± 5 or more) arises when individual predictions are compared with the measurements.

Tonk et al. (2002) investigated the applicability of conventional equations to predict littoral drift rates on a site (coastline of Perth, western Australia) characterized by steep beach morphology, low-wave energy conditions and a bi-modal wave climate. Littoral drift
rates measured by an impoundment study (with a permanent shore - normal groyne) were compared with three different predictions based on wave data and littoral drift equations [CERC and Inman and Bagnold (1963)]. It is concluded that the longshore sediment transport is predicted well using the CERC equation when only considering the contribution of the wind waves. The sea breeze generated littoral drift is estimated as 40,000 - 60,000 m³, confirming the important role played by the sea breeze system in determining the sediment budget of the region.

Sanilkumar et al. (2003) measured the lateral and vertical distributions of the sediment transport rate with traps deployed on a line spanning central west coast of India for a 4-month period. Measured values were compared with three empirical formulae, namely, (i) Komar and Inman (1970); ii) CERC formula (iii) TRANSPOR (Van. Rijn, 1989). It was found that LSTR (longshore sediment transport rate) calculated using the Van Rijn formula was close to the measured values with a correlation coefficient of 0.74 and an RMS error of 0.47. The probable reasons for the difference has been identified and listed.

Nordstrom et al. (2003) estimated the long shore sediment transport rates on a micro tidal estuarine beach in Great South Bay, New York (USA) during two dyed sand tracer experiments using a temporal sampling method. It is reported that the rates were 3.1 to 6.5 times greater than predicted by the three formulae, namely: (i) CERC formula; (ii) Bagnold equation (Inman and Bagnold,1963) and (iii) Kamphuis (1991) equation, using standard coefficients. Greater rates are attributed to the concentration of sediment transport in the energetic swash zone under plunging breakwaters.

Kuhrs et al. (2004) have attempted to study the transport of sedimentary material in parts of Baltic sea using a numerical model system which consists of four coupled components: a 3-D circulation model, a wave model, a bottom boundary layer and a sedimentary transport model. Using the model transport and deposition patterns of different materials under varying forcing conditions were studied. It is found that there are significant seasonal variations of calculated transport rates and that the material accumulates at the slopes of the basins within a few weeks under winter conditions.

Aagaard et al. (2004) have documented the linkages between long-term (decadal) shore face profile development and event-scale process measurements using a set of bathymetric
profiles spanning a period of 30 years (from a barrier on the Danish north sea coast) and measurements on hydrodynamics and sediment transport obtained during a number of week-long field experiments. Further they have also attempted to document and tentatively quantify the transport linkages between two different geomorphological units, i.e., the shore-face and the dunes. The study has shown that the near shore bars at Skallingen have migrated consistently onshore at rates of 20-30m/year over the past 30 years.

Celikoglu et al. (2004) aimed to create a method to predict the longshore sediment rates for non-uniform grain size distribution of sea bed material by considering sorting mechanism. Eighteen sets of experiments were performed in longshore sorting mechanism using two different sand beds. It has been found that the non-uniformity of the grain size and hence sorting of the beaches play a very important role in the transport due to wave motion in a similar way to the case of steady flow in alluvial channels.

Mani et al. (1997) carried out a numerical study involving sediment transport and combined wave refraction-diffraction to predict the shoreline behaviour due to a proposed satellite port about 15 km north of the existing Madras port on the east coast of India. Based on the analysis, (i) extent of general shoreline advancement, (ii) extent of coastal region that will be affected owing to recession of shoreline and its impact have been predicted and corrective measures suggested. It has been concluded that with corrective measures would help to keep Ennore creek alive, and about 800-1200 m$^3$/day of sand need to be by-passed from the southern part to the northern part for stabilizing the shoreline and the tidal inlet.

Sanilkumar (2002) estimated the longshore sediment transport rate considering the sea and swell waves separately using CERC formula along Nagapattinam coast (East coast) of India for one year. It was found that the difference between the estimated values of sediment transport rate by CERC and Walton & Bruno's formula differ by 3.5%. It has been estimated that the average annual net transport (towards south) was 0.098 X 10$^6$ m$^3$ and this contributes to the supply of sediment to the Palk bay.
2.2.4 Coastal Dynamics and Coastal Zone Management

Kumar et al. (1989) used Landsat, IRS and LISS – II remote sensed data along with extensive ground truth data for coastal geomorphology and Chilka environmental analysis of Orissa coast, India. The usefulness of the above approach has been brought and it has been indicated that the coastal region is under progradation. Localised coastal erosion has also been identified.

Dattatre et al. (1997) conducted studies to monitor the changes in beach profile due to the construction of sea walls, along some of the reaches of Dakshina Kannada coast (western coast) of India, based on extensive field data collected on the beach profile and underwater sea bed profile surveys. It has been concluded that the coast maintains a long – term dynamic equilibrium and that the properly located and constructed seawall does not accelerate the erosion either in front of it or in the adjoining areas.

Paravath and James (1997) have investigated the shoreline changes due to coastal protective measures implemented on three representative stretches along the Kerala coast (west coast, India) based on data on shoreline changes collected for a period of ten years. It has been observed that there is net loss of land even after the construction of protective measures, which may be due to isolated protection works which often disrupt the coastal equilibrium and the adjacent reaches are affected.

Chauhan (1997) investigated the wave climate, littoral current patterns, monthly and seasonal longshore drift rates, beach profile changes and sediment budget of the beach sediments along Machilipatnam (located in the east coast of India) during monsoon and non-monsoon seasons. Empirical relationship (as given in shore protection manual) was used to estimate sediment transport rates. It has been concluded that the jetties and other structures constructed at Machilipatnam will lead to accumulation of sediments to the south of such structures.

Jayakumar et al. (2004) studied the daily beach dynamics of open beach in Goa, India, by carrying out field investigations on beach profiles, breaking wave parameters, long – shore currents for one month each during pre and post – monsoon periods. The estimated long – shore sediment transport rate using Walton’s equation (SPM, 1984) has been reported as 0.013 X 10⁶ m³/year and 0.017 X 10⁶ m³/year during the above periods and in the southerly and northerly directions.
Ramanamurthy et al. (2004) have discussed the various methods and their limitations for analysing shoreline data and have suggested an improved method of combining remote sensing (RS), global positioning system (GPS) to evaluate shoreline changes, caused by construction of a port at Ennore, located north of Chennai port (Madras) in the east coast of India. The study also demonstrated the usefulness of the above new techniques in quantifying the impacts of port and various improved beach nourishment design.

Ghosh and Patel (1989) have presented an overview of an integrated numerical modeling system for coastal processes, comprising of several models such as: 2-D linear short-wave model, 2-D wave induced currents model and 2-D sediment transport model. The usefulness of the above has been demonstrated with its application to select coastal regions of India.

Ghosh and Singh (1989) developed a computer model for computation of distribution of longshore velocity and sediment transport for a major port along the east coast of India, using CERC formula and computing littoral current by using Komar's (1975) approach. It has been concluded that both the approaches compare very well. The zone of influence of littoral current (upto 400m) and average peak current (i.e. 0.6m/sec) have also been estimated and reported.

Ramanaiyan et al. (1997) have investigated the shoreline oscillation of Tamilnadu coast (east coast of India) using field data (monthly shoreline changes) collected from 30 sites (23 sites lie in the east coast and 7 sites on the west coast), for nearly 20 years. Based on average rate of erosion/ accretion per year, erosion sites, accretion sites, stable and oscillating sites, have been identified and reported.

Ramanamurthy et al. (2004) have described a very useful model that illustrates various steps to be followed while adopting a plan for shoreline management. The model has been applied to Chennai coast to demonstrate its usefulness.

Somayaji (1989) has highlighted the importance of coastal zone management in the Indian context. It has been stated that absence of coastal zone management in the country has resulted in haphazard growth of the activities which render the implementation of coastal zone management policy more and more difficult with passage of time.

Winterwarp (2005) has summarized a decade of research on siltation - reducing measures for harbour basins under a wide variety of environmental conditions. Such siltation -
reducing measures generally consist of a reduction in the exchange flow rates between the harbour basin and ambient water system and a reduction of the sediment carried by the exchange flow. Generic-type cost-efficient design of siltation reducing measures have been suggested, including the sophisticated siltation reducing measure - CDW (current deflecting wall).

Demir et al. (2004) have described a method for estimating both direct and indirect effects of dredging on shoreline changes and the proposed method was applied to a site on the Turkish Black Sea coast, using hindcast wave data. The influences of pit location and geometry were investigated systematically and recommendations regarding optimum pit dimensions and locations have been made.

Balakrishna and Dhilipkumar (2001) have used a system of computer modules (LITPACK) for simulating coastal processes along the Ennore expressway in Madras (Chennai), for a year based on the study the coastline changes have been predicted. Further, the impact of structures on coastline have been simulated and based on the results, the 'groyn system' which can restore the coastline has been suggested.

Baskaran and Neelamani (2001) have addressed the problem of estimating the most probable quantity of sediment for the safe and conservative design of groyn field, to prevent sediment deposition at the entrance channel of New Ennore port, Madras. Based on three methods, namely, i) fillet volume calculation of actual accretion after construction of southern breakwater; ii) CERC formula; iii) estimate based on deep water wave data, as reported by Chandramohan (1988). Based on the above, the conservative estimate (method III) has been selected and the total quantity of sediment that is expected to be trapped inside the groyn field at the end of 25 years (25 yrs X 343,000 m³/ year = 85,75,000m³) has been computed.

Ganesh and Sundar (2001) have used a numerical model based on the elliptical form of the mild slope equation developed by Berkhoff (1972) to predict the wave climate as waves encounter any obstruction like breakwater or groynes. The model was validated with experimental data and finite element model results of Berkhoff (1982) and then the model was applied to study the wave tranquility basin of Veerapandipattinam (Lat: 8° 30'N Long: 78° 7' E) in south India. The results have been used to obtain the proper alignment of breakwater.
2.3 CONCLUDING REMARKS

Based on the comprehensive review of latest works carried out, following critical observations are made:

(A) International Scenerio

(i) Tremendous progress have been made in the instrumentation used for data acquisition, modeling and forecasting of waves, sediment transport, during the last two to three decades.

(ii) Focus has also been on improving the earlier models and the solution approaches of wave transformation, breaking etc.

(iii) Efforts were also directed in tackling and solving numerous field problems (real life problems) in coastal engineering through collaborative efforts and in developing integrated software models.

(B) National (Indian) Scenario

(iv) Efforts have been made by National Research organizations like NPOL, NIO to publish wave climate data of Indian seas, based widely on scattered visual estimates reported by ships. In spite of such initiatives and best efforts, the amount of data on Indian seas is still found to be limited, particularly in the nearshore region, for the establishment of a reliable wave climate.

(vi) Comprehensive studies on wave climate data, coastal processes etc., have to be initiated along the Indian seas, especially, at locations having the potential for establishing minor ports, like, Pondicherry, Karaikal (on the east coast of India).

The above observations, especially, with respect to the Indian Scenario, led to the initiation of the present study and setting up of objectives, as outlined in Chapter 1.