1.6 Wave Forecasting 1.6.1 The Significant Wave

Forecasting of waves for operational or design purpose needs to be made by measuring and analyzing the actual wave observations at a given location. But considering the difficulties and costs involved in getting large scale wave data, many times, the readily available wind information is gathered and then converted into corresponding wave information although this procedure is less accurate than the actual wave analysis.

The wind information required to forecast the waves can be obtained by making direct observations at the specific ocean site or at a nearby land site. The latter observations require projection to the actual location by applying some overland observation corrections. Wind speed and its direction can be observed at regular intervals and hourly wind vectors can be recorded. Alternatively use of synoptic surface weather maps can also be made to extract the wind information. These maps may give Geostrophic or free air speed, which is defined as the one undisturbed by effects of the boundary layer prevalent at the interface of air and sea. Instead of this speed, which may exist at a very large height from the sea surface, the wind prediction formulae incorporate the wind speed value at a standard height of 10 m above the mean sea level (U_{10}) which can be obtained by multiplying the geostrophic speed by a varying correction factor. This value of U_{10} so deduced needs further corrections as below before it can be used as input in the wave prediction formulae.

(i) **Correction for overland observations:** This is necessary when wind is observed overland and not over water in which case the roughness of the sea surface is different. If wind speed overland (U_L) is greater than 1.85 m/sec, i.e., 41.5 mph, the correction factor $R_L = U_{10}/U_L$ may be taken as 0.9. If $U_L \sim 15$ m/sec, $R_L = 1.0$. If $U_L < 15$ m/sec, $R_L = 1.25$.

(ii) **Correction for the difference in air and sea temperature**: This difference affects the boundary layer. The correction factor can be substantial - varying from 1.21 for a temperature difference of -20 degrees to about 0.78 for the temperature difference of +20 degrees.

(iii) **Correction for shortness of observations duration:** Since the wind is observed for a very short duration of say 2 minutes at a time, its stable value over duration of an hour or so is required to be calculated. Empirical curves are available to obtain the corrections (i), (ii) and (iii) above. (SPM, 1984).

(iv) **Correction to account for the non-linear relation between the measured wind speed and its stress on the seawater:** This correction is given by,

$$U_{corrected} = (0.71)\, U_{10}^{\;1.23} \qquad 1.6.1$$

If the wind speed in a given region does not change by about ± 2.5 m/sec with corresponding direction changes of about ± 15 degrees then such a region can be regarded as fetch region. Its horizontal dimension expressed in distance scale, called Fetch, is required as another input in the wave prediction formulae. For coastal sites the upwind distance along the wind direction would give the required fetch value. Alignment (curvature or spreading) of the isobars in weather maps also yields the wind fetch.

Constant wind duration forms an additional input in the formulae of wave prediction. This is obtained by counting the time after allowing deviations of 5 percent in speed and 15 degrees in the directions.

The problem of wave forecasting aims at arriving at the values of the significant wave height (H_s) and the significant wave period (T_s) from given wind speed, duration and fetch distances over which the speed remains constant.

If we have a collection of pairs of individual wave heights and wave periods (or zero cross periods, meaning thereby that the crests should necessarily cross the mean zeroth line. (Fig 1.10), then an average height of the highest one third of all the waves (like H_1, H_2, H_3...of Fig 1.10) would give the significant height. (H_s) while an average of all wave periods (like T_1, T_2, T_3...of Fig 1.10) would yield significant wave periods (T_s). These definitions are empirical in origin.

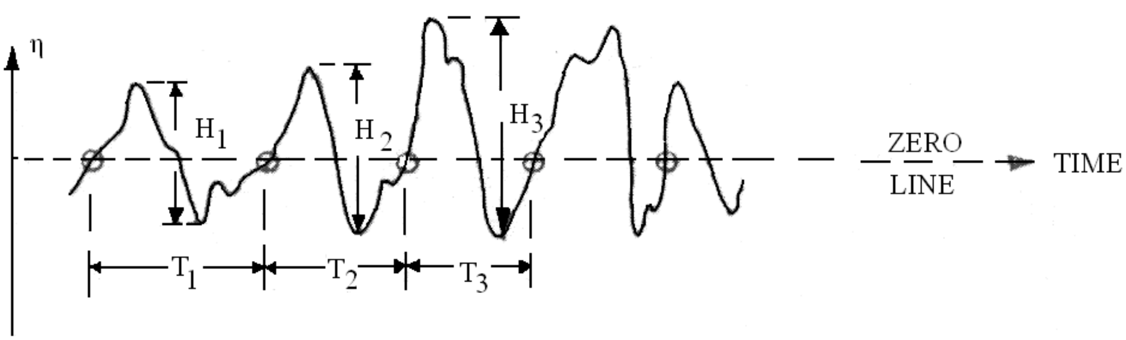

Fig 1.10 Individual Waves

1.6.2 Empirical versus numerical techniques

The wave forecasting techniques can be classified into two broad types viz., (i) empirical, simplified or parametric and (ii) numerical or elaborate. The former methods explicitly give wave height and period from the knowledge of wind-speed, fetch and duration while the later ones require numerical solution of the equation of wave growth. The numerical methods are far more accurate than the parametric and give information over a number of locations simultaneously. They however require a number of oceanographic and meteorological parameters. They are more justified when the wind speed varies considerably along with its direction in a given time duration and area.

When the wind field can be assumed to be fairly stationary and when accurate and elaborate wind data are not available, simplified parametric wind-wave relationships, involving an empirical treatment, could be a workable alternative to the elaborate techniques. Common methods under this category are Darbyshire, Pierson-Neumann-James, Sverdrup-Munk-Bretschneider and Hasselmann, methods of prediction of wave characteristics. The latter two techniques are more common and are described below:

1.6.3 Empirical Methods

SMB Method

The Sverdrup-Munk and Bretschneider (SMB) equations are based on dimensional analysis considerations. These equations are suggested for deep water (where depth may exceed about 90 m) are given below (SPM 1984). The wind of speed (u) blowing over fetch (F) will produce the Hs and Ts values according to following equation:

$$\frac{gH_s}{u^2} = 0.283\tanh\left[0.0125\left(\frac{gF}{u^2}\right)^{0.42}\right] \qquad 1.6.2$$

$$\frac{gT_s}{u} = 2.4\pi\,\tanh\left[0.077\left(\frac{gF}{u^2}\right)^{0.25}\right] \qquad 1.6.3$$

The above H_s, T_s values would occur only if the wind blows for a duration t_{min} given in terms of fetch 'F' as follows:

$$\frac{gt_{\min}}{u} = 68.8\left(\frac{gF}{u^2}\right)^{0.67} \qquad 1.6.4$$

If actual duration $t<t_{min}$, then find F from equation (1.6.4) for the given t and then substitute the new F value in equation (1.6.2) and (1.6.3). This is duration limited sea (with fetch controlled by duration). If $t \geq t_{min}$, the wave heights and periods are controlled by the given fetch. A graphical representation of the above equation is known as SMB curves (SPM, 1984). In shallower water of depth (d) the three equations equivalent to equation (1.6.2), (1.6.3) and (1.6.4) are, respectively

$$\frac{gH_s}{u^2} = 0.283\tanh\left[0.53\left(\frac{gd}{u^2}\right)^{0.75}\right]\tanh\left\{\frac{0.0125\left(\frac{gF}{u^2}\right)^{0.42}}{\tanh\left[0.53\left(\frac{gd}{u^2}\right)^{0.75}\right]}\right\} \qquad 1.6.5$$

$$\frac{gT_s}{u} = 7.54\tanh\left[0.833\left(\frac{gd}{u^2}\right)^{0.375}\right]\tanh\left[\frac{0.077\left(\frac{gF}{u^2}\right)^{0.25}}{\tanh\left[0.833\left(\frac{gd}{u^2}\right)^{0.375}\right]}\right] \qquad 1.6.6$$

$$\frac{gt_{\min}}{u} = 6.5882\exp\left\{\left[0.016\left(\ln\left(\frac{gF}{u^2}\right)\right)^2 - 0.3692\ln\left(\frac{gF}{u^2}\right) + 2.2024\right]^{0.5} + 0.8798\ln\left(\frac{gF}{u^2}\right)\right\}$$

1.6.7

The curves for the shallow water, these equations (each drawn for a separate water depth), are available in the graphical forms. Fig 1.12 shows an example corresponding to water of depth 10.5m.

Hasselmann Method

A group of investigators led by Hasselmann developed a simplified parametric model of wave growth to obtain the H_s and T_s values for given quantities of u and Fathers equations along with the one that gives the minimum duration necessary to produce these values of H_s and T_s are given below:

For Deep Water:

$$\frac{gH_s}{u^2} = 0.0016\sqrt{\frac{gF}{u^2}}$$

1.6.8

$$\frac{gT_s}{u} = 0.2857\left(\frac{gF}{u^2}\right)^{1/3}$$

1.6.9

$$\frac{gt_{\min}}{u} = 68.8\left(\frac{gF}{u^2}\right)^{2/3} \qquad 1.6.10$$

For Shallow water:

$$\frac{gH_s}{u^2} = 0.283\tanh\left[0.53\left(\frac{gd}{u^2}\right)^{0.75}\right]\tanh\left\{\frac{0.00565\sqrt{\frac{gF}{u^2}}}{\tanh\left[0.53\left(\frac{gd}{u^2}\right)^{0.75}\right]}\right\} \qquad 1.6.11$$

$$\frac{gT_s}{u} = 7.54\tanh\left[0.833\left(\frac{gd}{u^2}\right)^{0.375}\right]\tanh\left[\frac{0.0379\left(\frac{gF}{u^2}\right)^{0.33}}{\tanh\left[0.833\left(\frac{gd}{u^2}\right)^{0.375}\right]}\right] \qquad 1.6.12$$

$$\frac{gt_{\min}}{u} = 537\left(\frac{gF_s}{u}\right)^{7/3} \qquad 1.6.13$$

The graphical forms of these equations are also available.

Darbyshire and Draper's Technique:

Another widely used alternative wave prediction technique is that developed to Darbyshire and Draper (1963). This can be conveniently given in terms of the curves. (Brebbia and Walker, 1978).

1.6.4 Forecasting in Hurricanes:

Above referred simple parametric forecasting models fail when wind conditions like, its speed, direction and profile rapidly change with time as in case of the cyclones. It becomes difficult to forecast waves using simple equations in such situations. However, tropical cyclones, called hurricanes in U.S.A., exhibit relatively stable wind profile and hence they can be tackled by parametric modeling. For slowly moving hurricanes, waves in deep water can be predicted by knowing (i) forward speed of the hurricane, U_F, (ii) radial distance from the hurricane center to the point of maximum wind on isobar map & (iii) air pressure at the hurricane center. At the point of maximum wind, the H_s and T_s values are given by, (SPM 1984):

$$H_s = 5.03 \exp\left(R\Delta P / 4700\right)\left\{1 + \left[0.29\alpha U_F / (U_R)^{1/2}\right]\right\} \qquad 1.6.15$$

$$T_s = 8.60 \exp(R\Delta P / 9400)\left\{1 + \left[0.145\alpha U_F / (U_R)^{1/2}\right]\right\} \qquad 1.6.16$$

where R = radius of maximum wind (km)

Δ P = normal pressure (= 760 mm of mercury) at hurricane center (mm)

U_F = wind speed along hurricane forward direction

U_R = wind speed at radius R corresponding to maximum wind (at 10 m above MSL – sustained)

= 0.865 U_{max} (if hurricane is stationary)

= 0.865 U_{max} + 0.5 U_F (if hurricane is moving)

where

U_{max} = maximum gradient wind speed at 10 m above MSL

= $0.447[14.5(\Delta P)^{1/2} - R (0.31 f)]$ where

f = Coriolis parameter = 2 $\omega \sin\phi$ where

ω = angular speed of earth's rotation = (2 π)/ 24

α = 1 (if hurricane is slowly moving) or

= f (U_F, fetch) otherwise.

Above equations give the values of H_s and T_s at the point of maximum wind. To find the significant wave height value at any other point, say H_s', same H_s is required to be reduced by a reduction factor shown in Fig 1.17 while corresponding T_s' value is to be obtained by using,

$$T_s' = (H_s' / g)^{1/2} \qquad 1.6.17$$

1.6.5 Numerical Wave modeling

The numerical wave models deal with a spectrum of waves rather than unique wave height and period values of the above simplified schemes. They involve a detailed modeling of wave generation, propagation and dissipation mechanisms. They basically solve a differential wave energy balance equation given below in terms of a directional spectrum G_η :

$$\frac{\partial}{\partial t} G_\eta(f,\theta,\bar{x},t) + \bar{C}_g(f,\theta).\nabla G_\eta(f,\theta,\bar{x},t) = S \qquad 1.6.18$$

where

$G_\eta(f,\theta,\bar{x},t)$= Directional wave spectrum at wave frequency f and direction θ at given position $\bar{x}$ and time 't'. (Note: directional wave energy spectrum gives energy of a wave component of certain frequency along a certain direction)

$\bar{C}_g(f,\theta)$ = Group velocity vector for wave frequency (f) and direction (θ).

∇ = Operator; $\nabla = i\frac{\partial}{\partial x} + j\frac{\partial}{\partial y} + k\frac{\partial}{\partial z}$

S = Source function = S_{in} + S_{ds} +S_{nl}

S_{in} = Wind energy input

S_{ds} = Wave energy dissipation in bottom friction and wave breaking

S_{nl} = Wave energy input being transferred from one wave frequency component to the other in a non-linear way.

Many numerical models employ a net source function (S) rather than its separation into three parts as above. The source functions are based on some theoretical understanding and may require modifications based on measurements. The above governing differential equation, (1.6.18), is generally solved using finite difference schemes so as to obtain wave directional spectrum over a number of locations and over a series of time instants. This requires specification of initial temporal conditions and spatial boundary conditions. The directional spectrum may typically be resolved into finite number of frequencies and directions. Equation (1.6.18) is applicable for deep water and can be modified to account for shallow water effects life refraction and diffraction.

Resolution of the directional spectrum into discrete frequencies and directions is laborious and can be substituted by parametering it into assumed forms of wave spectrum and energy spreading function.

Actual waves at site may result from a combination of wind waves and swells arriving from a distant storm. In that case separate governing equations are required to be written.

There is a variety of numerical wave models used worldwide to obtain spatial wave forecasts with lead time of 1 to typically 72 hours. They can be classified as First Generation, Second Generation and Third Generation models- each indicating significant improvement in the wave modeling technique. The First Generation models, evolved in 1960s and 1970s,are the simplest. They assume growth of each wave spectral component independently. They are useful mainly in constant wind field. In the Second Generation model, the concept of a non-linear interaction between different wave components was introduced with simplified terms. These simplified terms are substituted by their exact solution in the Third Generation models. These can be usefully employed when the wind field is rapidly changing.