CHAPTER 1

INTRODUCTION

1.1 Introduction

Knowledge of the magnitude and behaviour of waves at site is an essential prerequisite for almost all activities in the ocean including planning, design, construction and operation of harbour, offshore and coastal protection structures.

The waves of major concern to a harbour engineer are generated by the action of wind. The wind creates a disturbance in sea which is restored to its calm equilibrium position by the action of gravity and hence the resulting waves are called Wind Generated Gravity Waves. The height of a wave is the vertical distance between its crest and trough while the period of a wave is the time required to complete one cycle of its any oscillations. The height of waves (H), in practice varies from a few cm to over 30 m while the variation in corresponding wave period (T), is from 3 seconds to 25 seconds. The horizontal spread of one wave, i.e., wavelength (L), ranges from few meters to over a kilometer. Fig 1.1 defines the significant parameters of an oscillatory or periodic wave.

1.2 Generation

Continuous changes in the temperature over the rotating earth produce corresponding changes in the atmospheric pressure all over it. The wind produced by these pressure gradients blows with different energies at different places and at different times. The relatively higher energies contained by the wind are transferred to the calm water by pressure acting normal to sea surface as well as by shear exerted tangential to it.

Many investigators (like Helmholtz, Jeffery, Phillips, Miles, Hasselmann) in the past have attempted to explain the process of wind energy transfer through factors like pressure gradient across the wake (Fig 1.2), resonance of turbulent eddies in the atmosphere (Fig 1.3), shear forces based logarithmic wind profile (Fig 1.4) and resonant interactions between different wave components. However the exact nature of the process of wave generation still eludes the scientists owing to its complexity (Kinsman (1965)). The consequent formation and growth of waves is influenced by the wind pressure, its speed, fetch (the distance over which the wind, blowing over the sea surface, remains the same) and wind duration (the time over which the storm prevails) together with depth of water at the site.

In the initial stages of wave generation, high frequency and short length waves are formed (Stage 1 of Fig 1.5). These, being unstable, break and supply energies thereby to the lower frequency waves which in turn get developed (Stage 2 of Fig 1.5). The process continues till a 'fully developed sea' is formed (Stage 3 of Fig 1.5) where all wave component reach a saturation stage (Brebbia and Walker, 1979).

As the wave height and period increases from Stage 1, (Fig 1.5) waves start moving faster and faster, and when the increasing wave speed matches the speed of the generating wind the transfer of wind energy ceases and so also the growth of waves. This process requires availability of certain time duration as well as that of fetch distance. If either time or fetch is less, a 'partially developed sea' is formed.

1.3 Decay

After generation, waves travel along different directions and their energies get spent due to factors, like, the air or water turbulence, bottom friction, besides spreading over wider areas due to angular dispersion. This gives rise to the decay in the height of waves as they travel out of their area of generation.

Opposition to wave movement lowers its length and increases its height making it steep and unstable and when the ratio of the wave height (H), to its length (L), (called wave steepness) exceeds 1/7 or when the angle at the crest lowers to 120^0 (Fig 1.6), the crest particles separate out and the wave starts breaking. This is the case in deep water. In shallower water waves break when they arrive in water where the depth is anywhere in between about 0.8 to 1.4 times their height. The exact value of the water depth at breaking depends on the sea bed slope and wave steepness. Section 4.7 gives more details on wave breaking.

1.4 Classification

Depending on the repetition of wave form, the waves can be r*egular*, if the same wave form repeats in time as well as space or i*rregular* or r*andom*, if it does not repeat. These two types of waves are show in (Fig 1.7). Actual waves found in nature are basically random; but for the sake of analytical simplicity they are many times assumed to be regular.

With the wave period (or frequency) as basis the waves can be l*ong period*, g*ravity* or s*hort period* waves where the normal gravity waves correspond to periods ranging from 1 to 30 seconds. They are generated by wind and restored by gravity. Fig 1.8 shows energy content in waves of different periods.

The waves can be generated by *wind, tectonic activities, sun* and *moon's attraction* or *ship movements* while they are restored to their equilibrium position by *Surface Tension, Gravity* or *Coriolis force*.

As per the shape of their profile the waves can be *Sinusoidal, Trochoidal, Cnoidal, Solitary* and *Random* (Fig 1.7).

If the whole profile moves in the forward direction the wave is a *Progressive Wave*; otherwise, simple up and down oscillations of the water particles at fixed position constitute a *Standing* or a *Clapotis wave* (Fig 1.7).

If the water particles move in closed orbits, the wave is an *Oscillatory wave* otherwise it is a *Translatory wave* (Fig 1.7). Water particles may have both oscillatory and translatory or open orbit movements.

If wave steepness, which is the ratio of wave height to wavelength, is small (say less than 0.02) the wave is called *Small Amplitude* wave otherwise it is a *Finite Amplitude Wave*.

1.5 Measurement

Wave measurements can be made with different types of recorders kept either at the sea surface or over and below it. The airborne devices include the movie or lapse photographs of the sea surface elevation and satellite based sensing of the surface using a radar altimeter. The floating recorders could be either of electrical resistance gauges. Ship borne pressure sensors or wave rider buoys. The submerged category of the recorders involves the pressure gauges and the echo sounders.

Out of all above types the wave rider buoy (Fig. 1.9) is most commonly employed in routine wave data collection. It is in the form of a spherical buoy that is kept floating on the sea surface. It undergoes accelerations in accordance with the wave motion. The vertical accelerations are continuously recorded by an accelerometer located inside the buoy. These are further integrated twice electronically to obtain records of the sea surface elevations which in turn are sent to shore based receiving station. Commonly, a 20-minute record collected once in every 3 hours, as a true statistical sample during that period, is practiced to optimize the data collection.

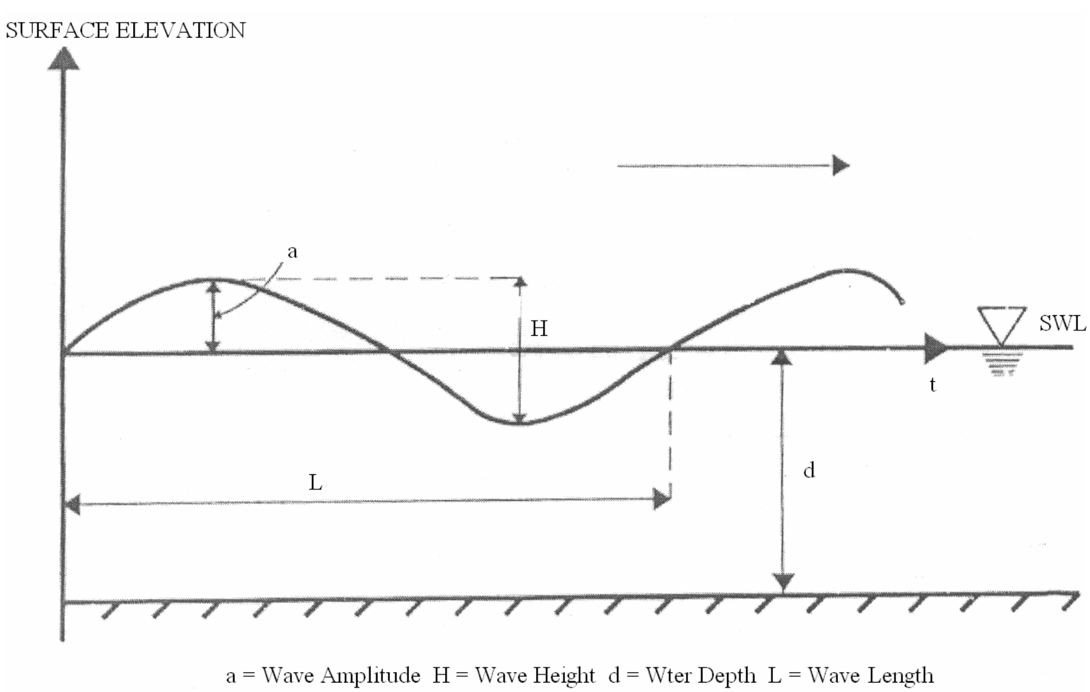

Fig 1.1 Definition Sketch Of a Propagating Wave

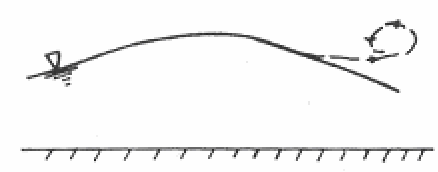

Fig 1.2 Flow Separation At Crest

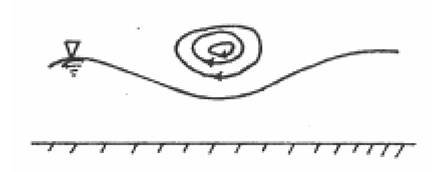

Fig 1.3 Turbulent Eddies

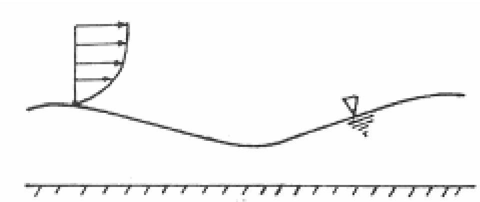

Fig 1.4 Logarithmic Wind Profile

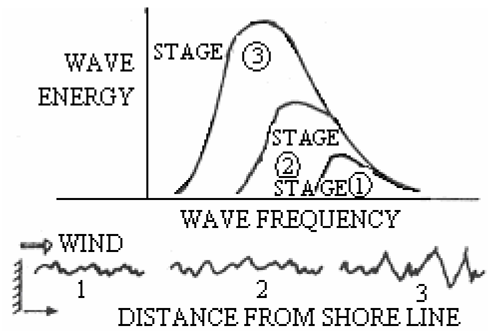

Fig 1.5 Wave Growth

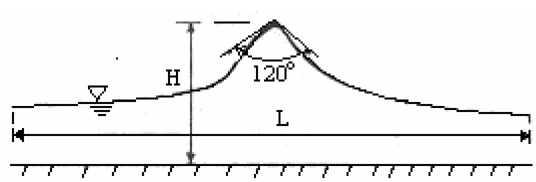

Fig 1.6 Wave Breaking

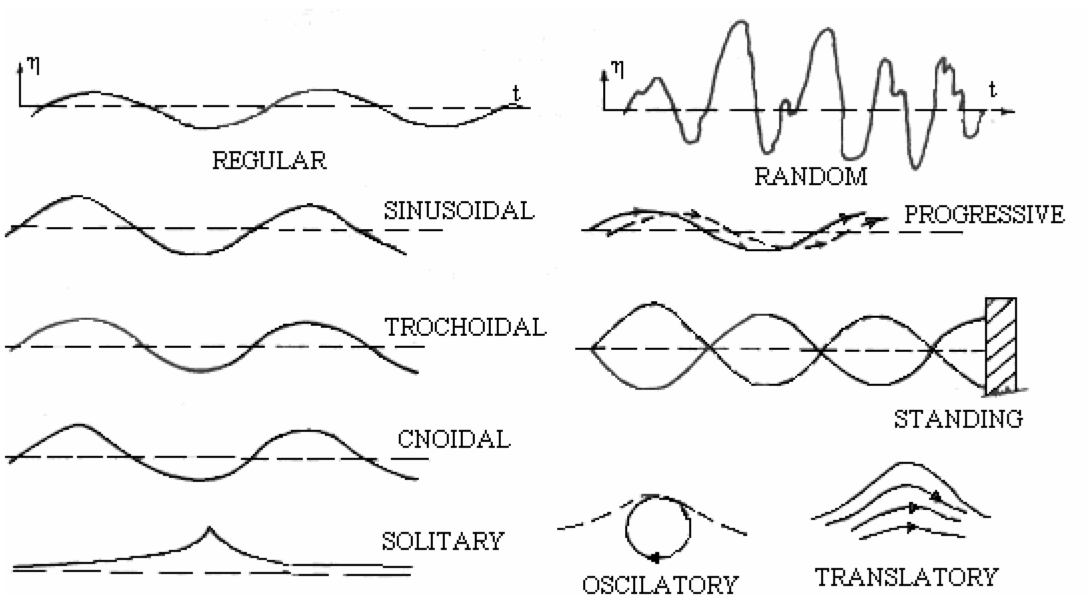

Fig 1.7 Wave Types

Legend:

1. Capillary waves
2. Ultra-gravity waves
3. Ordinary grav. waves
4. Infra-grav. waves
5. Long period waves
6. Ordinary tide waves
7. Trans-tidal waves

A. Wind
B. Wind + Ordinary grav. waves
C. Storm & earthquakes
D. Sun & Moon
E. Storm + Sun & Moon

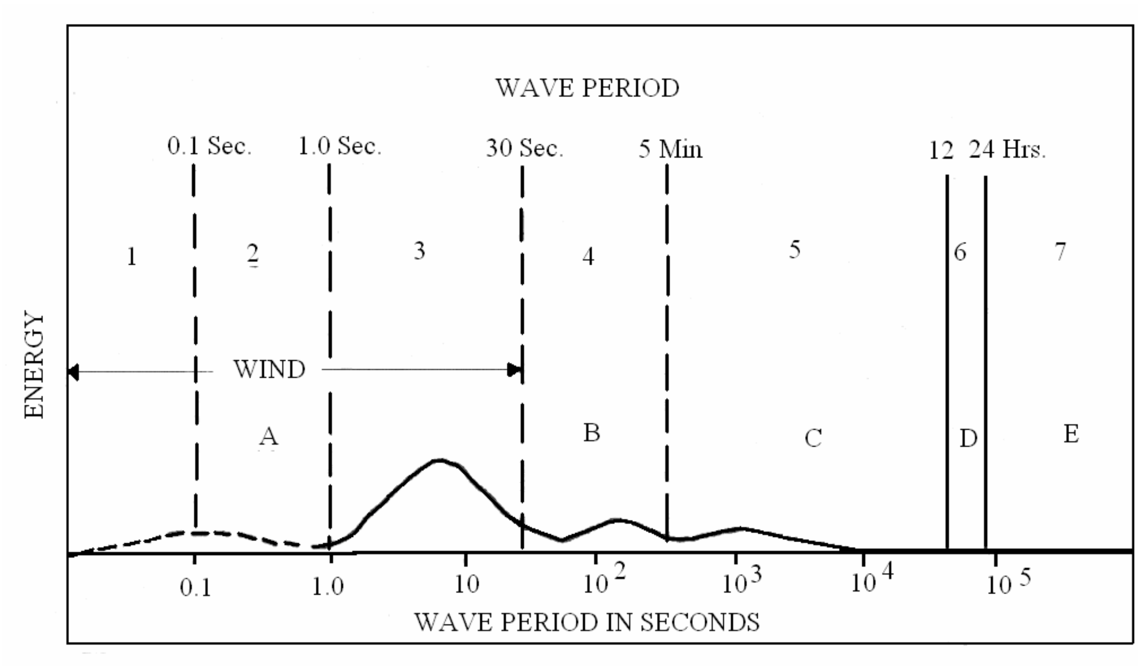

Fig. 1.8 Wave Energy Versus Period **(Ref.: Gaythwaite, 1981)**

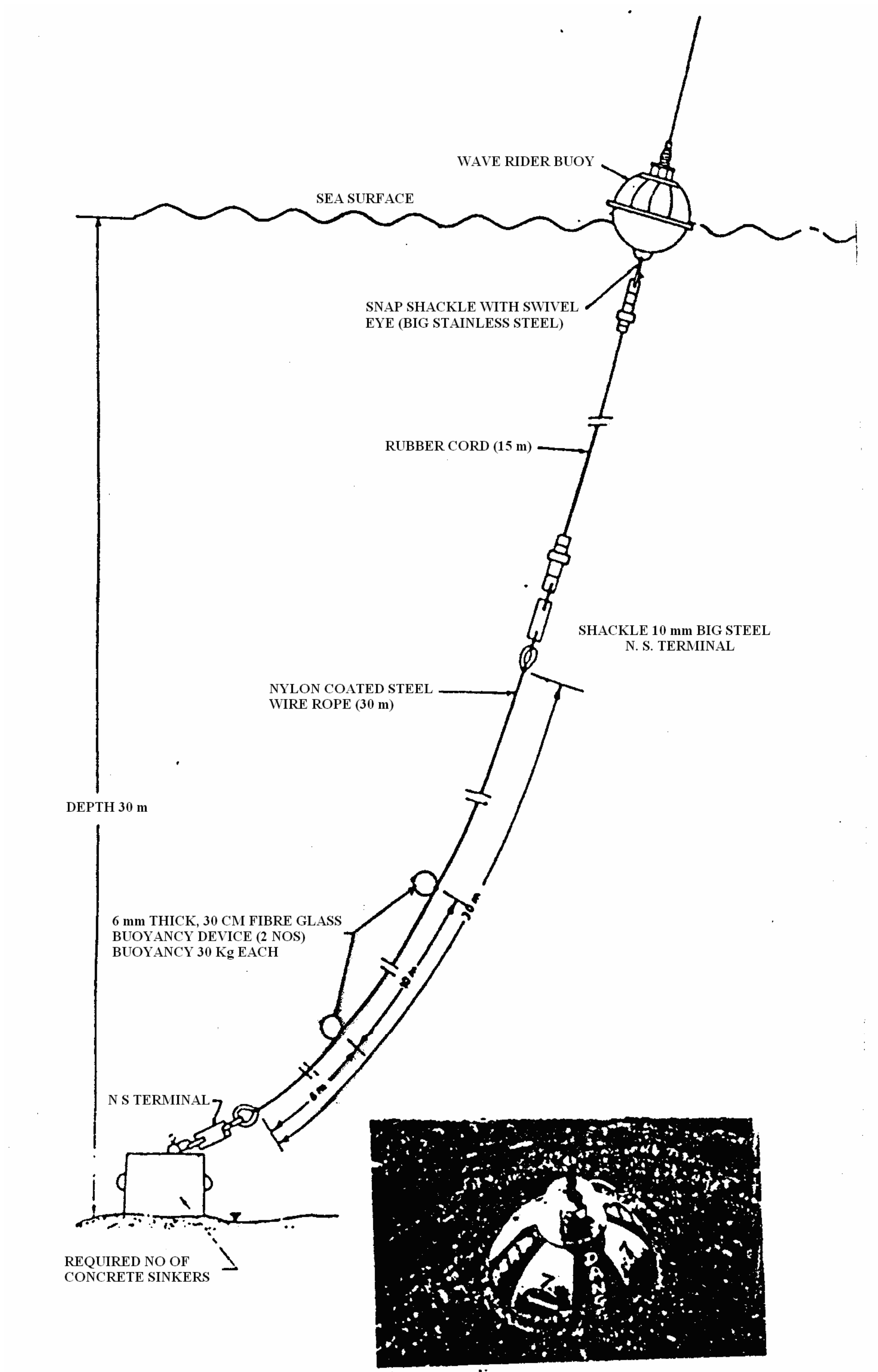

Fig 1.9 Wave Rider Buoy **(Ref.: CWPRS, 1993)**

1.6 Wave Forecasting

1.6.1 The Significant Wave

Forecasting of waves for operational or design purpose can be made by measuring and analyzing the actual wave data. But considering the difficulties and costs involved in gathering large scale wave data, many times, the readily available wind information is gathered and then converted into corresponding wave information; though this procedure is less accurate than the actual wave analysis.

The wind input to forecast waves can be obtained by making direct observations at the specific ocean site or at a nearby land site. The later observations require projection to the actual oceanic location by applying some overland observation corrections. Wind speed and its direction can be observed intermittently once in a few hours time. 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 the 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} 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 a 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 additional input in the formulae of wave prediction. The actual duration of wind observation can be taken as the required quantity, provided it is of few hours; otherwise a linear interpolation between the larger duration of observations may become necessary.

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).

1.6.2 Simplified versus Elaborate Techniques

The wave forecasting techniques can be classified into two broad types viz., (i) the simplified or parametric and (ii) the elaborate or numerical. 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 later two techniques are more common and are described below:

1.6.3 Simplified Method

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 for deep water. Fig 1.11 shows the same. In this figure 1.11 there are five sets of lines along which one parameter is kept constant. Horizontal lines represent constant (corrected or adjusted) wind speed, U_A, while the vertical ones show constant fetch length (F). These two belong to the input parameters along with the third one represented by the inclined set of lines for constant wind duration (t). The output of significant wave height (H_s) and associated wave period (T_s) can be seen in terms of corresponding isolines in the Figure 1.11. In order to use these curves proceed horizontally from the given U_A value and find intersection of this horizontal line (imagined, if necessary) with the vertical line coming up from the given F value. Then find out H_s and T_s values by interpolation. Similarly proceed horizontally from given U_A line and find its intersection with given duration line and get another set of H_s and T_s values. The smaller set of H_s and T_s values is required answer. If these values are obtained on the basis of given fetch then the sea is called fetch controlled. Otherwise it becomes duration controlled. Alternatively we can get the required significant height and period after stopping at those values wherever the given F or t is reached first.

Example 6.1: Obtain the values of the significant wave height and period in deep water generated by wind of (corrected) speed of 24.2 m/sec lasting for 3 hours over a fetch of 10 Km. State whether the sea is fetch or duration controlled?

Solution: By following the above procedure we get the final values as:

Significant wave height = 1.25m

Significant wave period = 3.9 sec.

The sea is fetch limited.

Example 6.2: Obtain the changed values of the significant height and period in the above example, if the same wind has a fetch of 100 km instead of 10 km.

Solution: Following the same procedure as above,

Significant wave height = 2.2 m

Significant wave period = 5.7 sec

The sea is duration limited.

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 waterdepth), are available in the graphical forms. Fig 1.12 shows an example corresponding to water of depth 10.5m.

Example 6.3: What values of the significant wave height and period will be generated if wind of corrected speed 22 m/sec acts on 10.5m deep water and if this wind speed remains same over a fetch distance of 24.4 km and a duration of 5 hours?

Solution: Significant wave height = 1.5m

Significant Wave period = 4.4 sec.

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 F.These 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. They are given in Fig 1.13 and 1.14. Following example illustrates their applications.

Example 6.4: For a wind of corrected speed 20 m/sec remaining constant over a fetch distance of 30 Km, obtain H_s and T_s values using Hasselmann technique, if (a) water is very deep and if (b) water depth is 2.86 m. Also obtain the minimum duration necessary to generate above values of H_s and T_s in deep water.

Solution: (a) Deep water case:

$(g F) / u^2 = (9.81 * 30{,}000) / 20^2 = 737.75$

In Fig 1.13,proceeding vertically from this value and noting the point of intersection of this vertical line with the inclined one corresponding to the 'Deep water wave, we get,

$(g H_s) / u^2 = 0.044$. This gives $H_s = 1.79$ m.

In Fig 1.14 following a similar procedure, we get,

$(g T_s)/ u = 2.6$. This gives $T_s = 5.4$ s.

(b) Shallow water case:

$(g d) / u^2 = (9.81 * 2.86) / 20^2 = 0.07$

From Fig 1.13 proceeding vertically from $(g F) / u^2 = 737.75$ and noting the point of intersection with the curve (imagined) corresponding to $(g d) / u^2 = 0.02$,

This gives $H_s = 0.82$ m.

Similarly from Fig. 1.14, $(g T_s)/u = 1.8$. This gives $T_s = 3.67$ s.

The minimum duration necessary to generate $H_s = 1.79$ m and $T_s = 5.5$ s in deep water is given by equation 1.6.4,i.e.,

$$g\, t_{min} / U = 68.8\, (g F/ u^2)^{2/3}$$

Hence, $t_{min} = 68.8\, (9.81 * 30{,}000/20^2)^{2/3}\, (20/9.81)$

$= 3.17$ expressed in hours.

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 as in Fig 1.15 and 1.16.These curves give the value of the maximum wave height in 10 minutes of the observation period, i.e., H_{10}, and corresponding wave period, separately for coastal waters (upto 45 m deep) and for deep ocean water. The significant wave height can be derived from this value of H_{10} by using the equation:

$$H_s = H_{10} / 1.6 \qquad 1.6.14$$

Given the value of wind speed, fetch and duration, Fig 1.15 is useful to know H_{10} and T_s in coastal water while Fig 1.16 helps to know the same in oceanic water. Application of these curves follow the same procedure as that for the SMB curves.

Above simplified wind-wave relationships are generally valid when the wind blows over a fetch area over which the friction factor is averaged and is taken around 0.01.When this is not the case, the actual wave height will be either lower (if the wave propagation is over more rough and vegetable area) or higher (if the waves move over smoother sea bed where the friction is less than the stress exerted by the wind). SPM (1984) gives a method to calculate the wave height at the end of such a different fetch characteristics. This method is based on using the same wind-wave relationships with an adjustment of the fetch value.

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 modelling. 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):

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

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

where R = radius of maximum wind (km)

ΔP = 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 = $(2\pi)/24$

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:

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

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)

$\overline{C}_g(f, \theta)$ = 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 6 to 72 hours. (WMO, 1988). 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. In India, a Second Generation Model code named 'Dolphin' has been applied to make single location forecasts (Mandal and Nayak, 1986).

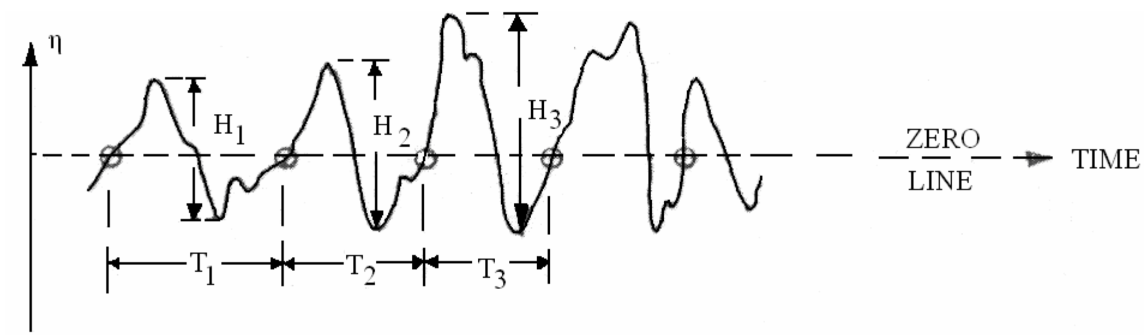

Fig 1.10 Individual Waves

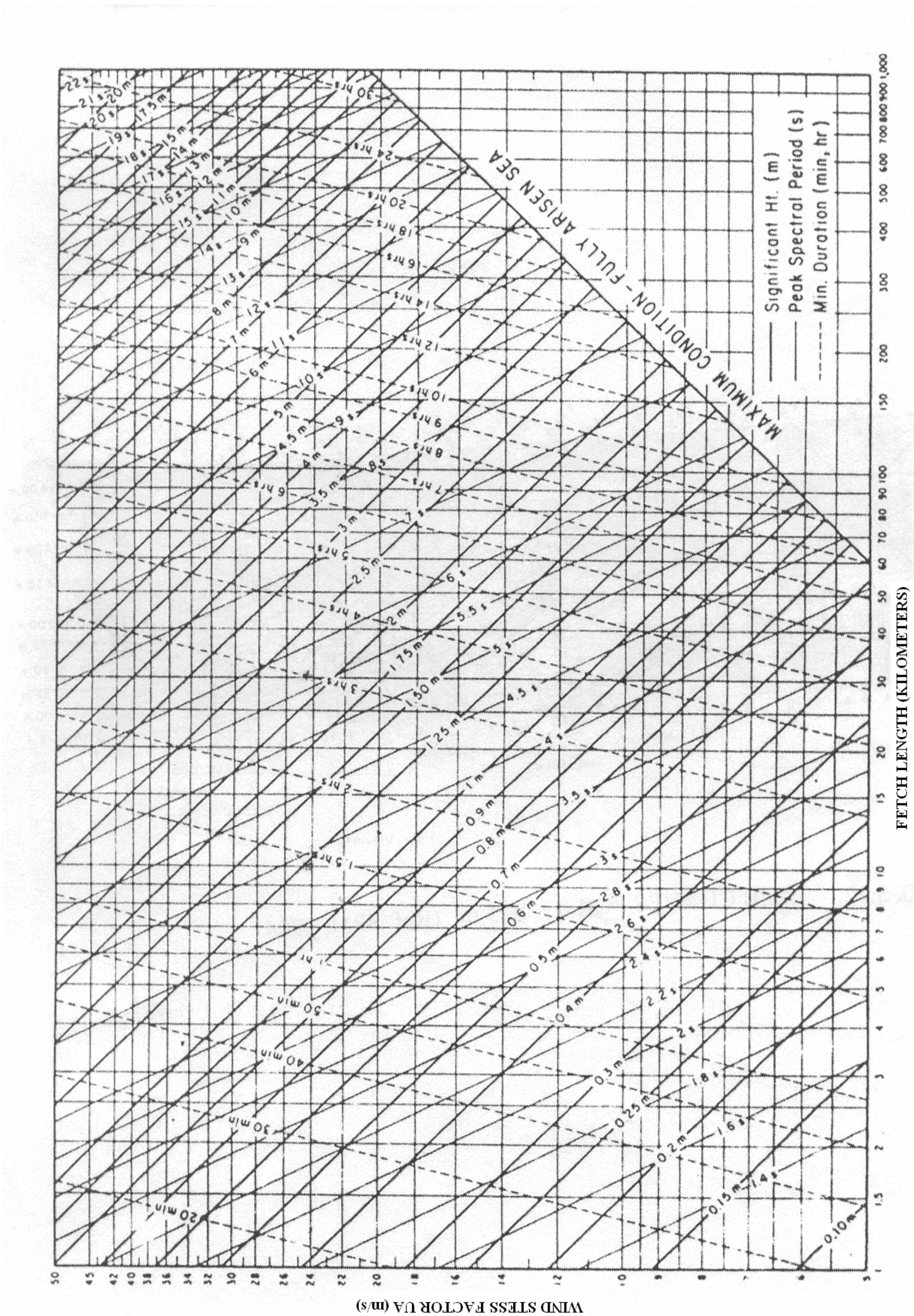

Fig 1.11 SMB Curves for Deep Water **(Ref.: SPM, 1984)**

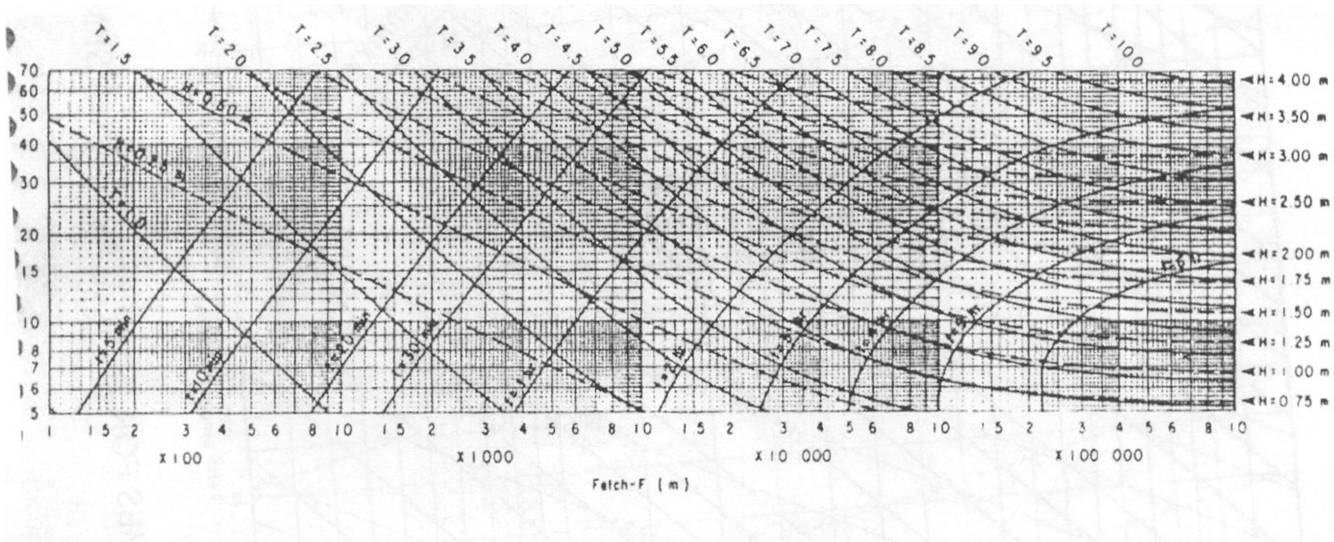

Fig 1.12 SMB Curves for d = 10.5m **(Ref.: SPM, 1984)**

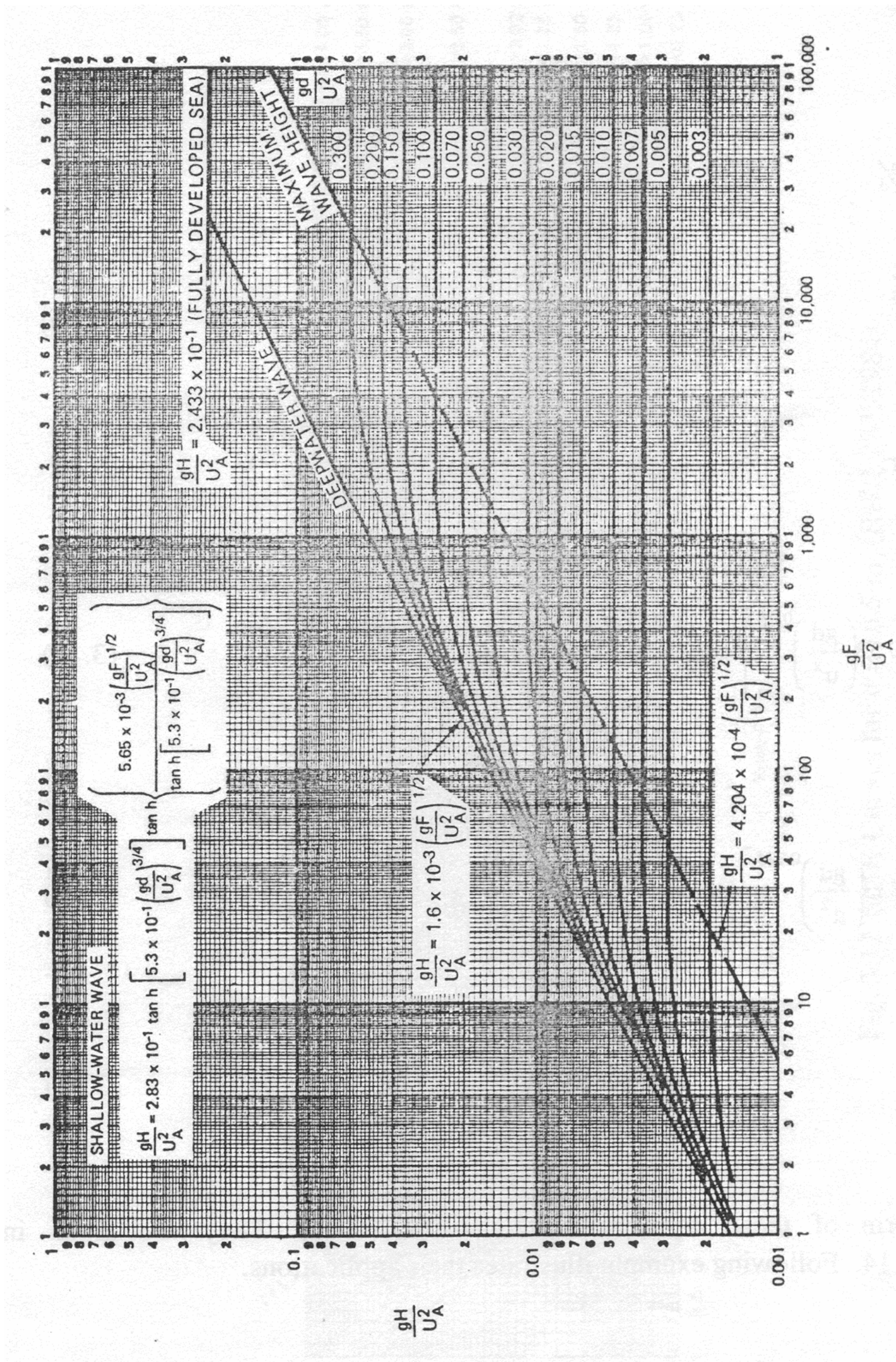

Fig 1.13 Hasselmann Curves for H **(Refer SPM 1984)**

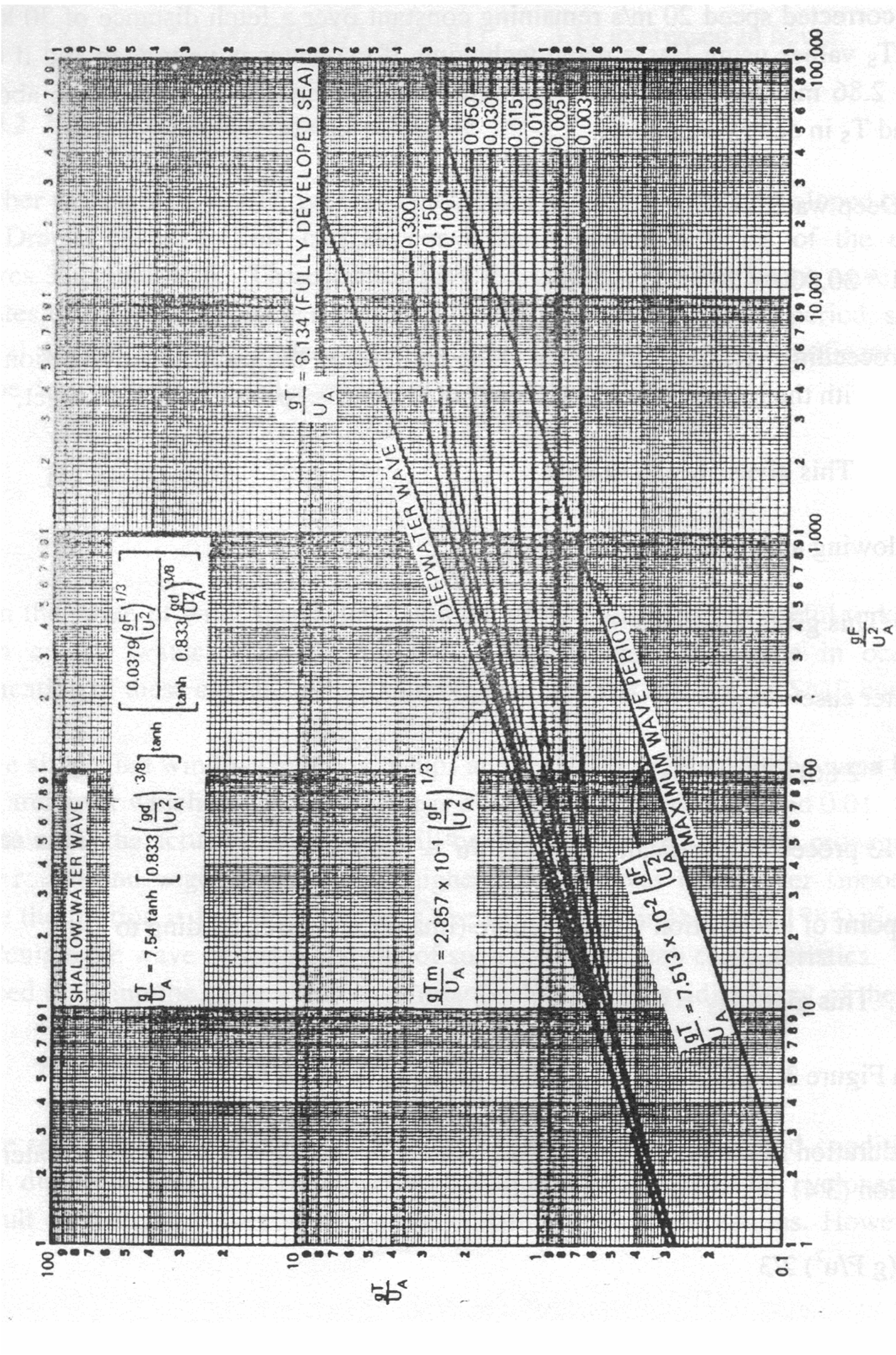

Fig 1.14 Hasselmann Curves for T **(Refer SPM 1984)**

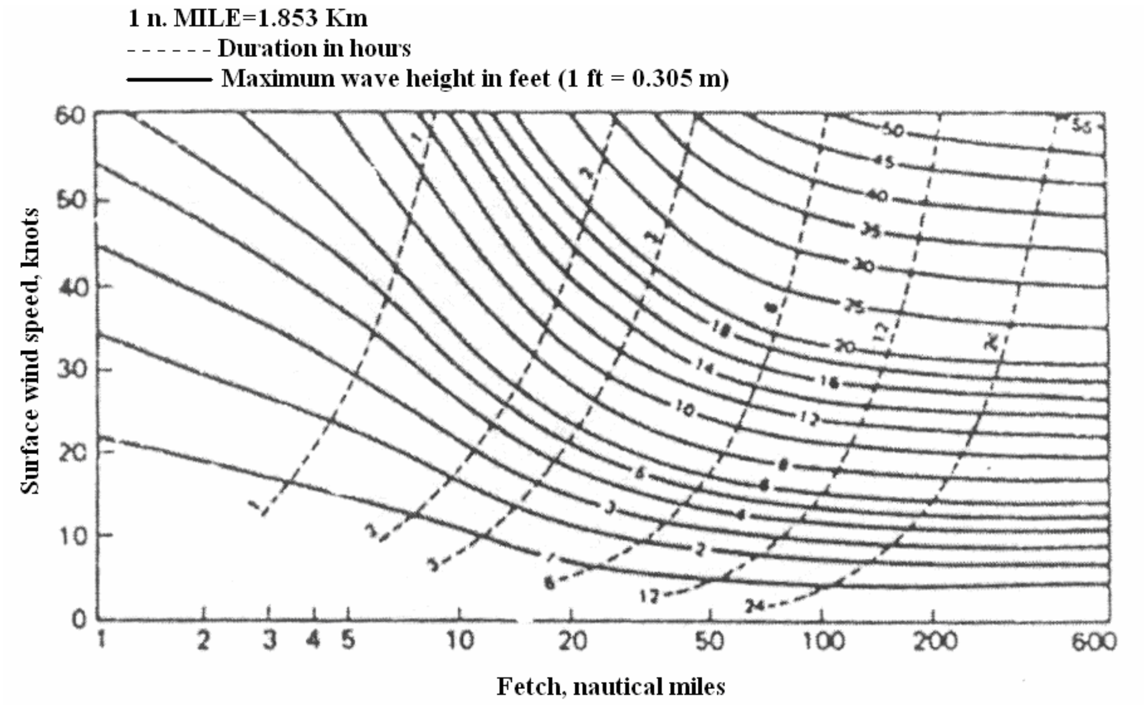

Fig 1.15 a H_{10} for coastal Waters

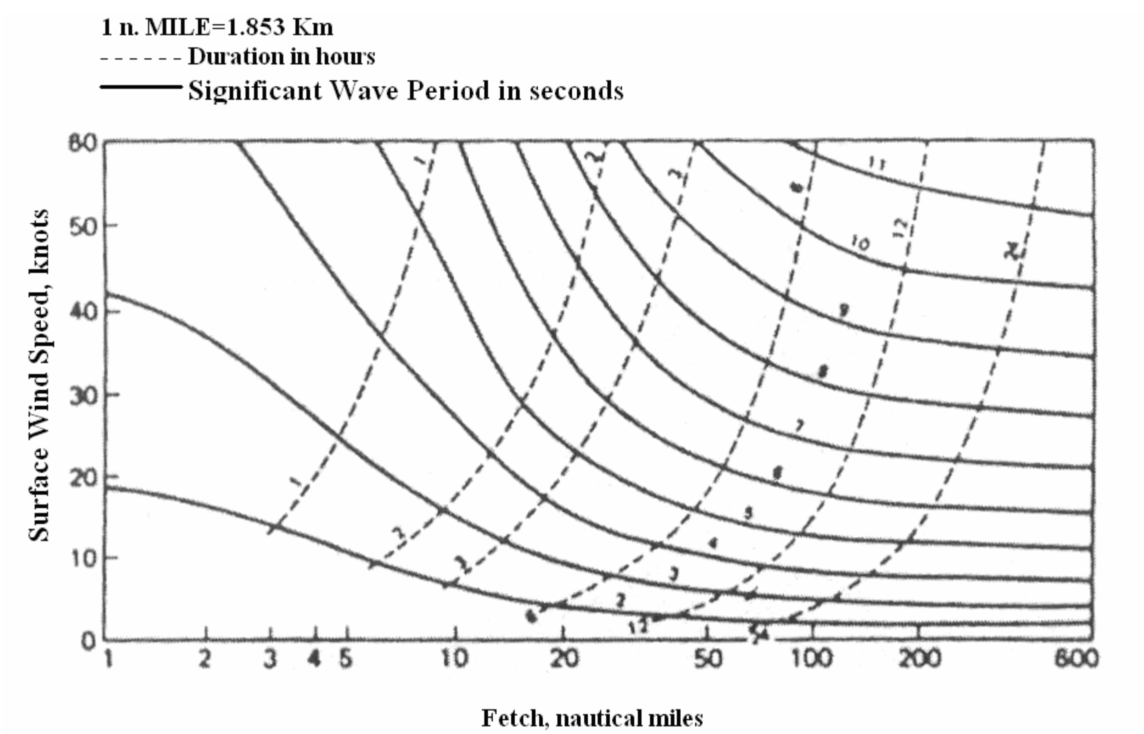

Fig 1.15 b T_S for Coastal Waters (**Ref. Brebbia and Walker, 1979**)

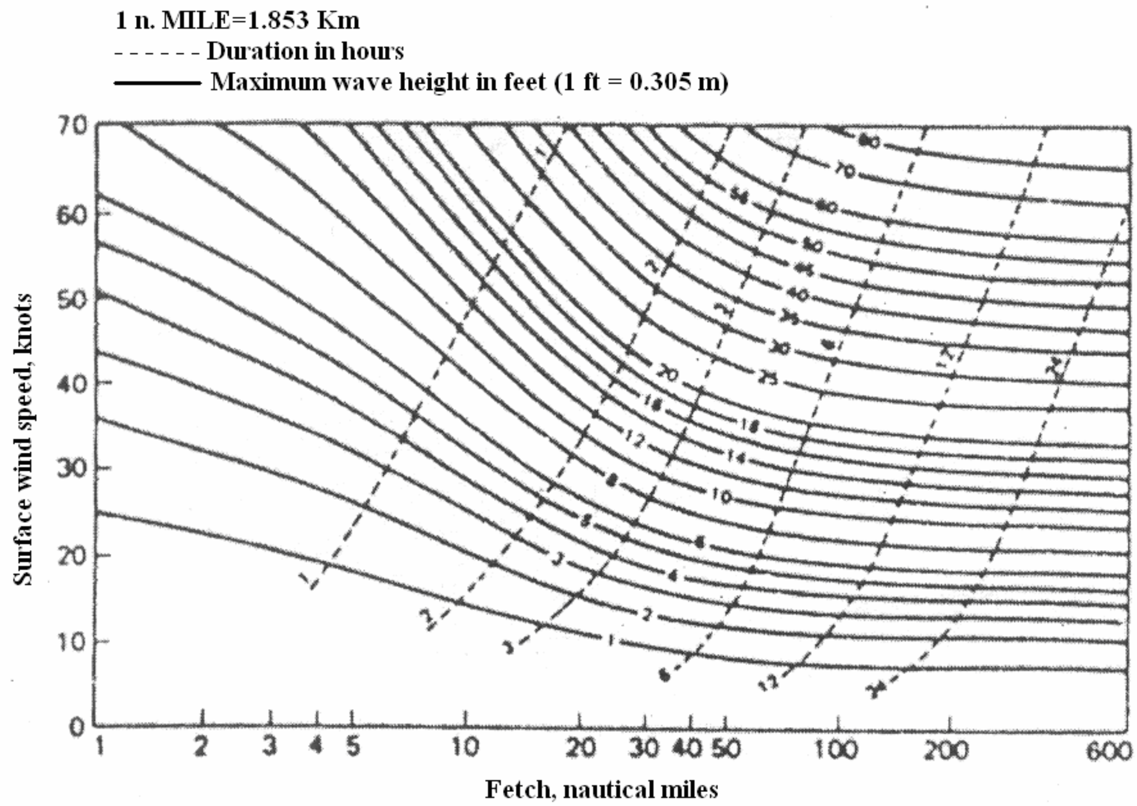

Fig 1.16 a H_{10} for Oceanic Waters

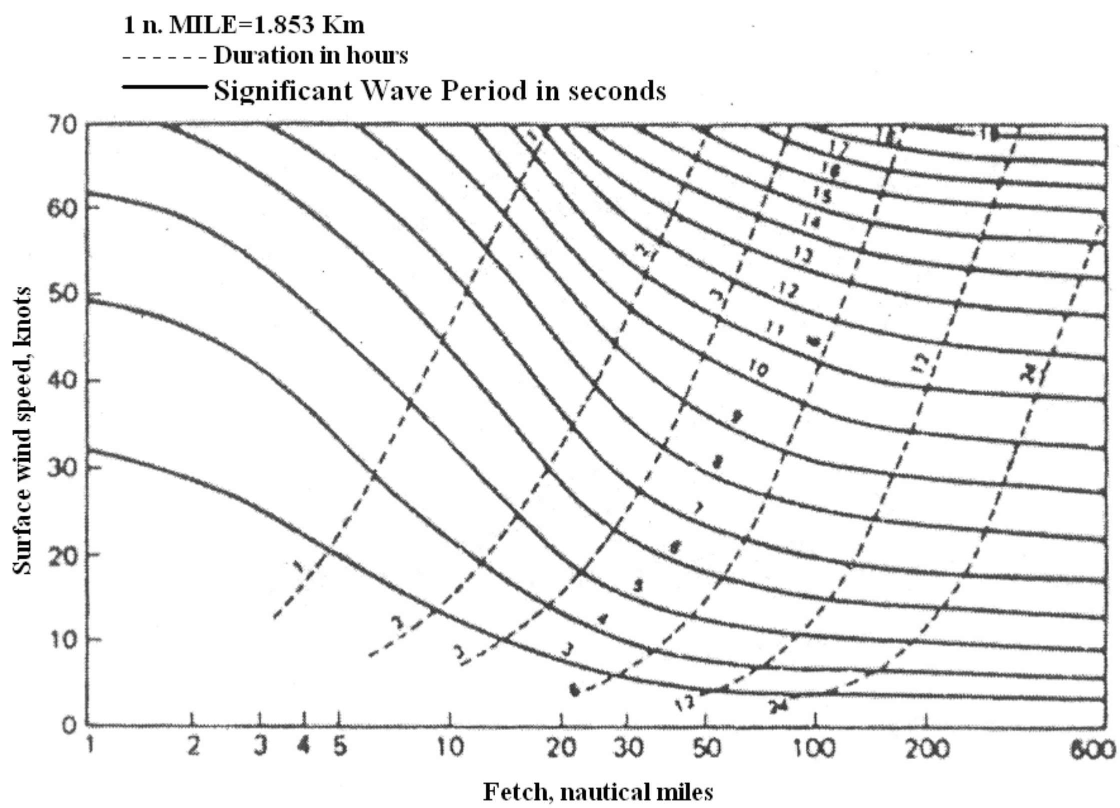

Fig 1.16 b T_S for Oceanic Waters (**Ref. Brebbia and Walker, 1979**)

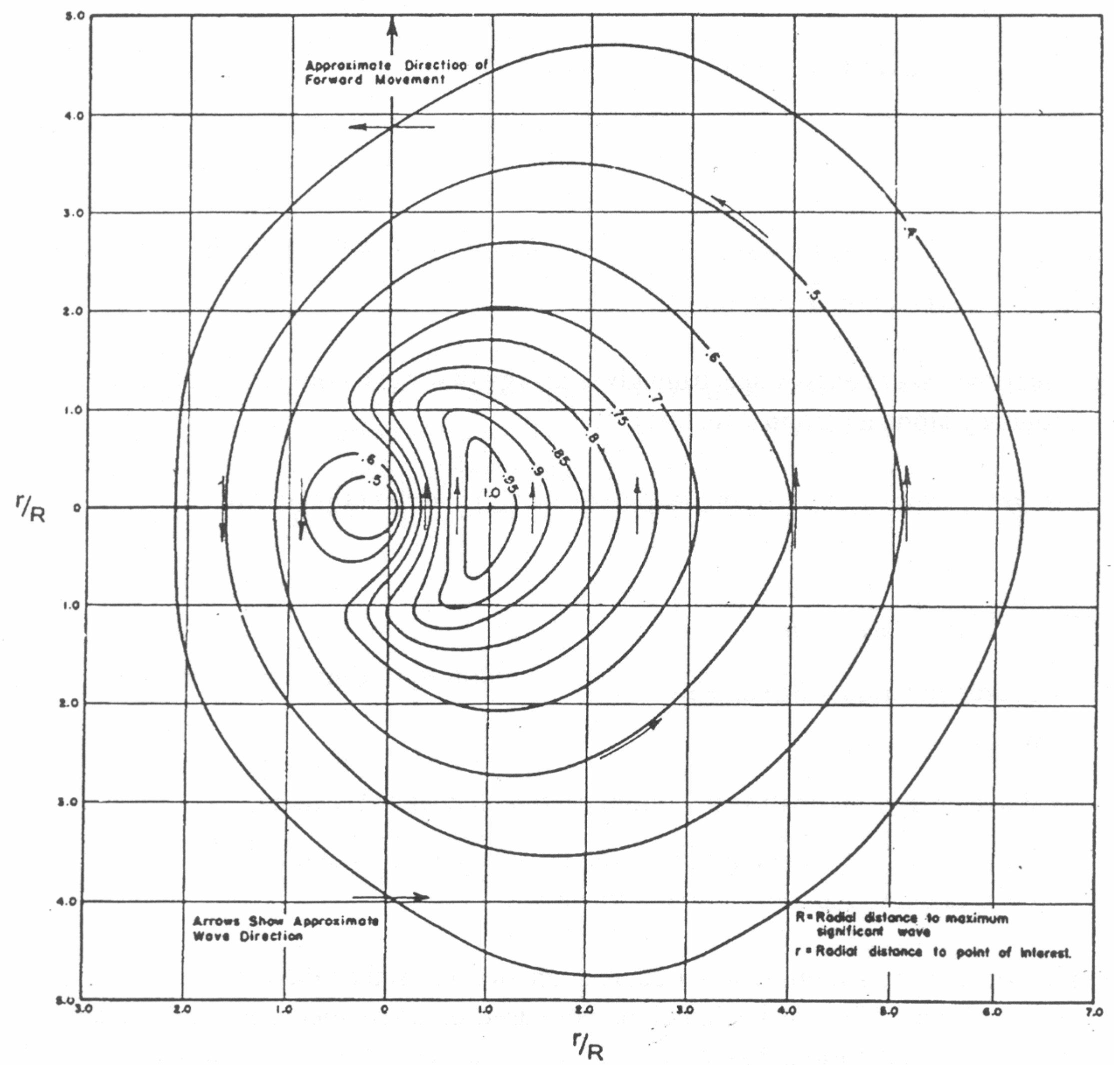

Fig 1.17 Reduction factor for Hs **(Ref. SPM, 1984)**