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PROFESSIONAL DEVELOPMENT PROGRAMME: COASTAL INFRASTRUCTURE DESIGN, CONSTRUCTION AND MAINTENANCE

A COURSE IN

COASTAL DEFENSE SYSTEMS I

CHAPTER 4

COASTAL PROCESSES: TIDES AND TIDAL FLOWS

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4.Coastal Processes: Tides and Tidal Flows

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4.1 Water Levels.

All coastal and offshore engineering requires a knowledge of water levels, for example, to determine the crest heights of coast protection systems or the deck elevation of an offshore platform. Water levels for design are based on **Mean Sea Level, MSL,** which must be related to a land-based datum, usually a national datum level.

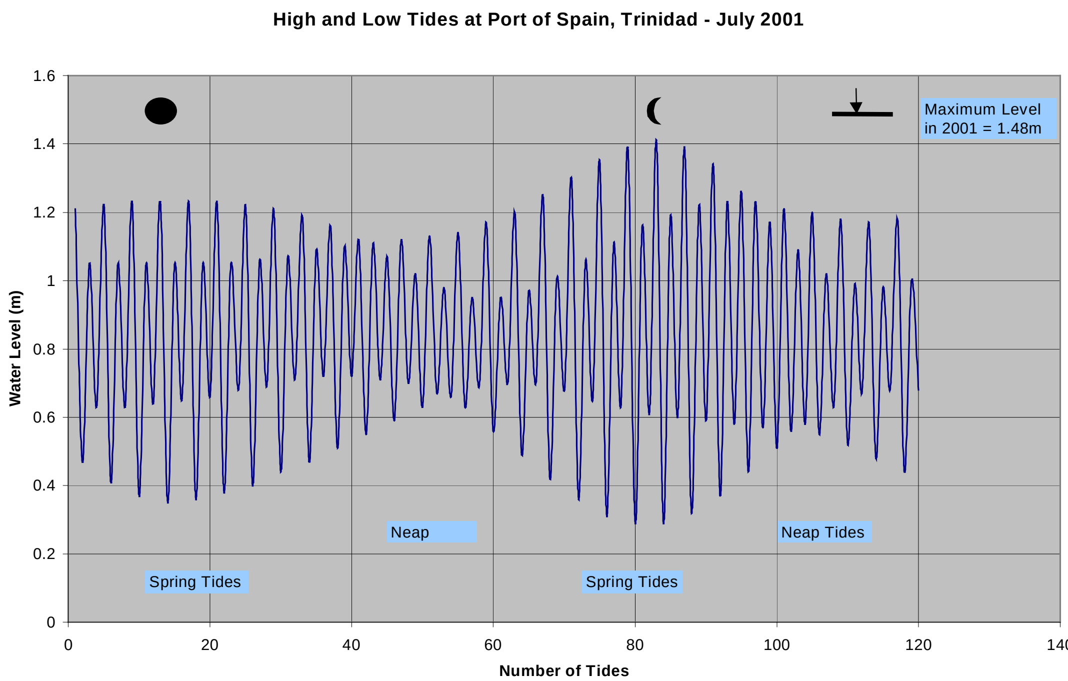
In some areas MSL varies regularly through the year due to thermal and mean atmospheric pressure variations, but such variations are predictable. It is widely recognised that MSL is increasing annually due to global warming and a rise of some 0.50m by the year 2050 is generally accepted. However, it may not be economic to design for such a rise in present day design but to arrange the design so that its effectiveness can more easily be enhanced at a later date when the rise in MSL is more accurately known. In relation to climate change there are other parameters required in design that are more important than a rise in MSL – see later in these notes.

4.2 Tidal Generation.

Tides are generated by the gravitational attraction of the Moon, the Sun and the Planets; thus they are entirely predictable. Essentially tides are long waves. **Tidal Ranges** (range being defined as the difference in elevation between high tide and low tide) in the open ocean are small, of the order of 1.0m, but they are increased due to the influence of water depths and geography. In some embayments the tidal range can be as high as 13.0m (Bay of Fundy, Canada). Therefore, the tidal data required for design is site-specific and must be based on the analysis of local records of water surface elevation.

The Moon and the Sun are the dominant tide generators, the Moon having about twice the influence of the Sun, being much closer to the Earth although of much smaller mass.

Since the Moon and the Sun dominate the generation process, the timing of the tides (termed phasing) is not 12 hours but nearer to 12 hours 24 minutes. Therefore the time of, for example, high tide is later by, typically, 48 minutes



each day.

Figure 1. Predicted Tide Levels for Port of Spain, Trinidad, for Six Weeks beginning 1st. July 2001.

Tidal predictions are published for **major ports** world-wide, with corrections in terms of tidal height and times for **secondary ports** relative to the nearest major port.
Figure 1 illustrates a typical tidal record in which the combination of individual components results in changes to the tidal amplitude and phase in time. **TIDAL RANGES** (maximum – minimum water level) reach a maximum with a minimum in the interval between; these are termed **SPRING** and **NEAP** tides respectively.

4.3 Tidal Parameters.

In offshore, coastal and harbour engineering it is necessary to define a number of tidal levels, as shown in Figure 2, below.

Highest Astronomical Tide	HAT
Mean High Water Springs	MHWS
Mean High Water Neaps	MHWN

Mean Sea Level	MSL
Mean Low Water Neaps	MLWN
Mean Low Water Springs	MLWS
Lowest Astronomical Tide	LAT

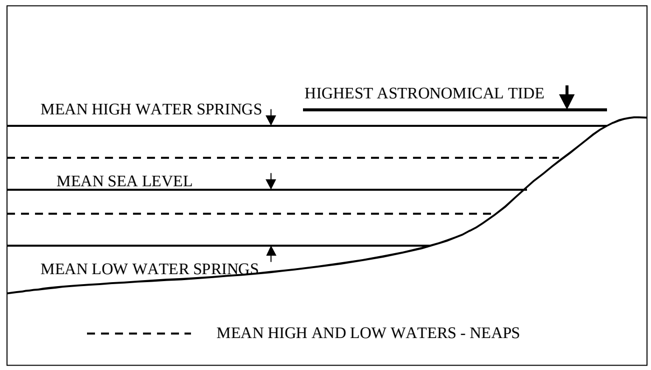


Figure 2. Tidal Levels for Design

HAT and LAT can be found by scanning published tide tables for one year and noting the highest and lowest predicted tidal levels. These will be within a few millimeters of the long-term HAT and LAT values and can be used for design purposes.
The **mean spring tidal range** (MHWS – MLWS) and **mean neap tidal range** (MHWN – MLWN) are often used in numerical modelling of tides as representative of general tidal conditions.

Most countries have a National Vertical Datum which is often MSL but note that Chart Datum as used on many nautical charts, e.g., British Admiralty charts, is often defined as equal to or near LAT. Its exact value is noted on each chart. It is essential that any monitoring of tidal levels is tied to the National Vertical Datum.

4.4 Tidal Currents.

In addition to changes in water level, tidal dynamics clearly generates currents which are oscillatory in nature. These currents are capable of transporting sediment, influencing navigation, imposing loads on structures exposed to the flow etc. Therefore it is important to determine the velocity field associated with tidal changes, generally using numerical models.

Figure 3 illustrates results from an advanced numerical model, in this case for a site in the Irish Sea, U.K. waters, in a mean water depth of some 100m. This example is output from the Proudman Oceanographic Laboratory, U.K., POL CS3 (three dimensional) large scale numerical model in which the grid size is typically 12km by 12km. Smaller scale models may need a grid size as small as 10m by 10m.

For a sinusoidal variation in water surface elevation one would expect a similar fluctuation in the associated velocity field, in phase with the surface elevation. However, land masses modify the tidal dynamics very considerably, for example, figure 2 shows that the maximum flow velocities are at mid-flood and mid-ebb. Numerical models have to be used to determine the flow field, verified by full-scale data, if possible. Records of water level and current speed and direction over a fourteen-day period, covering a springs/neaps cycle are normally sufficient for calibration but in complex areas more than one measuring site may be necessary.

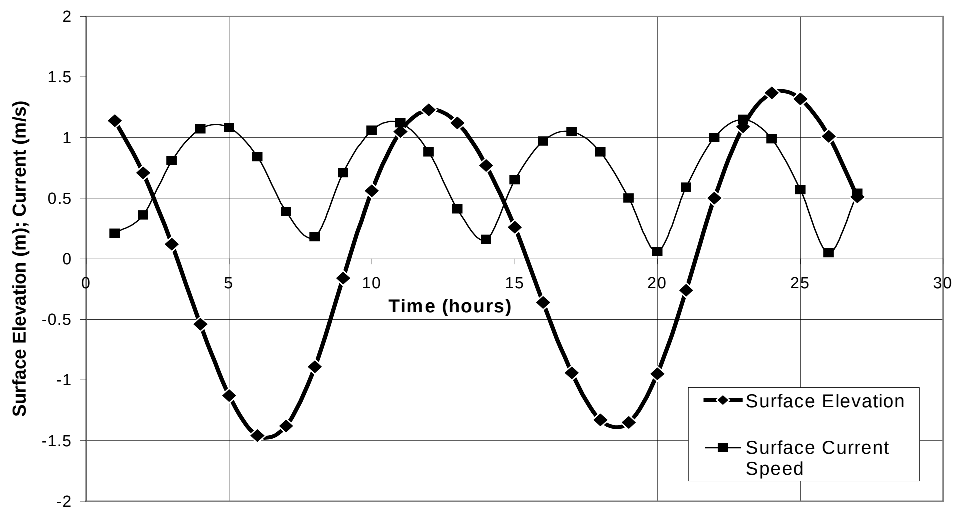


Figure 3. Numerically Predicted Tidal Elevations and Surface Current Speed.

(note that the flow velocities will change direction by 180 degrees between flood and ebb tides)

In many cases a simple calculation can indicate the order of magnitude of tidal velocities. Take an example of a lagoon connected to the open sea by a rectangular cross-sectioned channel. Assuming that the tidal range in the lagoon is the same as that at the entrance to the channel and dividing a tidal cycle into hourly increments, application of the mass continuity equation can give a good indication of the tidal flow speeds in the channel.

This simplified model is very much modified in shallower water when harmonics of the fundamental frequency are generated or when the tidal wave is reflected forming a standing wave and, of course, when influenced by lateral boundaries.

4.5 Velocity Profile in Uni-directional Flow.

In uni-directional flow the velocity profile as a function of elevation, z, above the bed level is given by:

$$u(z) = (u_*/\kappa) \ \ln (z/z_o) \quad 4.1$$

where κ is the von Karman constant, 0.4, z_o is the level at which the velocity is assumed to be zero, z being measured upwards from the sea or channel bed, and u_* is termed the **SHEAR VELOCITY.** This is a fictitious velocity – it actually relates to the shear stress exerted on the bed by the flow – but it provides the basis for calculations of velocity profiles.

$$u_* = g^{1/2}[\ \bar{u} /C] \qquad 4.2$$

where C is the Chezy friction coefficient and $\bar{u}$ is the mean flow velocity.
In uni-directional flows three types of flow regime are defined in terms of u_*, ν, the kinematic viscosity of the fluid, and k_s, the Nikuradse roughness scale (links to flow in pipes):

Hydraulically smooth flow	$u_*k_s/\nu < 5$	4.3
Transitional flow	$5 < u_* k_s/\nu < 70$	4.4
Hydraulically rough flow	$u_*k_s/\nu > 70$	4.5

The corresponding values of z_o are given by:

Hydraulically smooth flow	$z_o = 0.11\nu/u_*$	4.6
Transitional flow	$z_o = 0.11\nu/u_* + 0.033k_s$	4.7
Hydraulically rough flow	$z_o = 0.033k_s$	4.8

Integrating the velocity profile from z_o to h, where h is the depth of flow, gives:

$$\bar{u} = (u_*/\kappa) [(z_o/h) - 1 + \ln (h/z_o)] \qquad 4.9$$

where $\bar{u}$ is the mean velocity – which occurs at 0.37h, assuming z_o /h is small. The influence of the bed roughness on the flow arises through k_s and in sediment transport k_s is usually set equal to $2.5d_{90}$ to $3.0d_{90}$, the latter being the 90 percentile diameter of the bed material, or $3d_{50}$ for uniform sized sediments. However, it is also necessary to determine the Chezy friction coefficient or the D'arcy-Weisbach friction coefficient, f. [Careful with definitions of f – European and American definitions differ!] The following equations are relevant:
Laminar flow: f = 64/Re Re, the Reynolds Number = uh/ν
Hydraulically smooth flow:

$$C = 18 \log(12h/(3.3\nu/u_*)); \qquad (f/8)^{0.5} = 3 + 2.5 \ln(u_*h/\nu) \qquad 4.10$$

Transitional flow:

$$C = 18 \log(12h/(k_s + (3.3\nu/u_*))); \quad f/8)^{0.5} = 6 + 2.5 \ln(h/(k_s + (3.3\nu/u_*))) \quad 4.11$$

Hydraulically rough flow:

$$C = 18 \log(12h/k_s); \quad (f/8)^{0.5} = 6 + 2.5 \ln(h/k_s) \quad 4.12$$

Thus, knowing a bed roughness, a depth of flow and a mean velocity the velocity profile can be determined.
We note here that the "time-averaged bed shear-stress", $\overline{\tau}_o$, is given by:

$$\overline{\tau}_o = ghi = \rho g (\overline{u}^2/C^2) = \rho f (\overline{u}^2/8) \quad 4.13$$

where i is the energy gradient, $\overline{u}$ is the depth-averaged velocity, C = the Chezy friction coefficient and f is the D'Arcy-Weisbach friction coefficient.

4.6 Wind Effects.

In the general indication of the shallow water equations for tidal motion given above, mention was made of wind effects. When a wind blows over the ocean surface it, obviously, generates waves (see later in these notes). Additionally it applies a shear stress, τ_w, to the water surface:

$$\tau_w = C\rho_a U^2 \quad 4.14$$

where C is a friction coefficient for air flow over water, ρ_a is the density of air and U is the wind speed – usually measured at a height of 10m above the water surface.

The effect of this shear force is to create a surface slope which, at the downwind end of the "fetch" (the length of sea over which the wind blows) will result in a significant increase in water level. This increase is part of the **STORM SURGE** which will increase water levels at the coastline and **must be taken into account in design**.

Storm surge is a random process because wind speeds and direction are random in time and they are obviously site-specific. Data on storm surges is usually obtained from local tidal records by subtracting the predicted tide level from the recorded levels. The resulting data set of storm surge values is then extrapolated to predict surges with return period longer than the duration of the records analysed. (see later under "waves for design").
In a design context, a storm surge of a given magnitude is associated with a **"RETURN PERIOD"**. For example, if a surge of 2.5m has a return period of 25 years then it is expected that a surge of 2.5m or more will be experienced, on average, once every 25years, or, there is a 4% chance of experiencing the 25 year event in any one year. This chance is often referred to as **ENCOUNTER**

PROBABLILITY. The same concept arises again in relation to design waves, see later.
To define the maximum water level for coastal engineering design it is necessary to select a surge with a stated return period and **to add that surge to the Highest Astronomical Tide**. Selection of a return period has to be related to the risk involved and the consequences of an event in excess of the chosen value.

4.7 Atmospheric Pressure.

Mean atmospheric pressure at sea level is approximately 1013 millibars (mbar)
In storm conditions the atmospheric pressure may change considerably, increasing or decreasing. The corresponding change in MWL, η_p, is:

$$\eta_p = 0.01(1013 - p_a) \quad \text{(m)} \qquad 4.15$$

where p_a is the atmospheric pressure at sea level in mbar. This change must be added to the storm surge although if the latter is derived directly from records of water surface elevation it will be included in combination with the wind-induced set-up.

4.8 Summary.

Variations in water levels due to tidal action must be taken into account for coastal engineering design.

It is essential to establish Mean Sea Level at a site and to select a storm surge return period such that the magnitude of the surge can be added to the Highest Astronomical Tide to set the maximum water level for the design.

Tidal currents are also critical to some coastal design situations, e.g., for navigation, sediment transport and pollutant dynamics, and, of course, they dominate in estuarial locations. In such cases it is often necessary to apply a numerical model to determine the velocity field, usually in two horizontal dimensions.

Information on the variation of the velocity in the vertical can be obtained by the application of a logarithmic velocity profile provided information on the bed roughness is available. It is always desirable to calibrate any numerical model with full-scale data and methods to obtain the latter are now relatively routine.
The effects of wind-induced set-up and atmospheric pressure variations are combined in "storm surge" which is an important factor for coastal design. It is this surge coupled with very high wave conditions which results in coastal inundation and damage in extreme conditions.