CHAPTER 13 — SEA WAVES AND SURGES

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13.1 Sea waves and swell

Terminology is in section 13.3.

13.1.1 Forecasting wind-wave heights and periods

13.1.1.1 Waves in deep water (WMO nomogram)

(i) **Fig. 13.1** is an adaptation of a WMO nomogram which is suitable for forecasting in the Atlantic and in the northern and central parts of the North Sea. For given values of wind speed and fetch, **Fig. 13.1(a)** may be used to forecast the Significant Wave Height and **Fig. 13.1(b)** the corresponding Wave Period.

(ii) The dashed lines indicate the duration in hours after which the waves will attain the computed state. If the duration is limited, the waves will not develop beyond the point given by the intersection of the wind speed and the duration on the graph.

Golding (1983) Holt (1994)

13.1.1.2 Waves in shallow waters (Darbyshire–Draper graphs)

Fig. 13.2 is suitable for forecasting waves in shallow coastal waters and in the southern North Sea. The layout and use of the graphs are the same as **Fig. 13.1**.

Darbyshire & Draper (1963)

13.1.2 Wave conditions at the shoreline; refraction

(a) Waves generally approach a beach with crests parallel to it. The angle between wave crests and the beach is reduced through the effect of wave refraction as the wave moves into shallower water, so that waves approach the beach with their crests more nearly aligned parallel to the depth contours (**Fig. 13.3**). The wave height increases and the wave breaks, how and when depending on the beach steepness, wind and other factors.

(b) Wave period is similar to that in the open sea, but can be significantly altered on passing through a zone of breaking waves (e.g. over an offshore sand-bar). Longer-period waves, which may seem insignificant off shore, may become the most prominent waves on breaking, as the effect of shoaling will increase the wave height relative to the shorter-wavelength/shorter-period waves.

(c) Waves may be refracted by variations in water depth and by current gradients; the process is important for several reasons:
   - (i) Refraction (and shoaling) determines wave height and hence distribution of wave energy along the coast.
   - (ii) Change in wave direction along wave front results in convergence or divergence of wave energy and thus on forces exerted on structures.
   - (iii) Refraction affects bottom topography through the erosion and deposition of material.

There are PC-based techniques for transferring near-shore model forecasts to the beach zone. Details of forecasting the effects of tides and currents and surf etc. are in the DNOM Memorandum referenced.

DNOM (1984) Shore Protection Manual (1984)
Sanderson (1982)

13.1.3 Forecasting swell heights and periods

(a) The difficult task of forecasting in detail the range of wave heights and periods spreading out from a distant storm (which is both moving and developing in strength) is reduced by the practical limitations of the known data. These normally comprise little more than the distance of the storm, the maximum wave period generated in the storm area and the duration of wave generation in the direction from the storm to the forecast location.

(b) The information that is required includes:
   - (i) the arrival time of the first swell from the direction of the storm;
   - (ii) the height of the swell;
   - (iii) the range of wave periods and wavelengths at any given time.

(c) **Fig. 13.4** may be used for estimating some of the properties of the swell from a distant storm. The initial data are entered on the horizontal and vertical axes, and from their point of intersection estimates of the swell travel time, the ratio of the swell height to the initial wave-height, and the swell period can be read off.

The height of the total sea generated by a combination of wind waves and swell is:

$= \sqrt{[(\text{significant wave height})^2 + (\text{swell height})^2]}$

Bretschneider (1973)

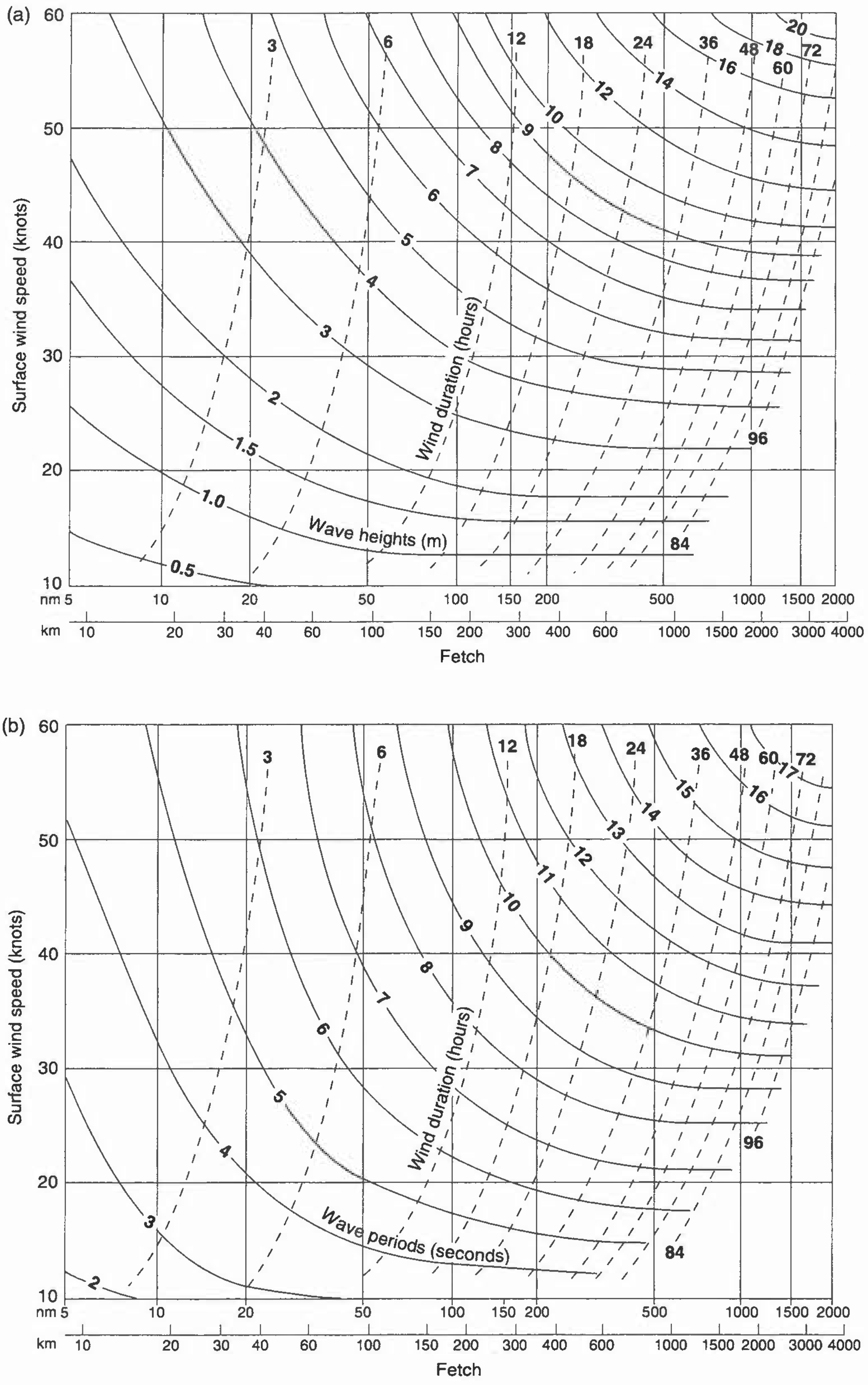

Figure 13.1. (a) Significant heights, and (b) periods, of deep-water waves (adapted from WMO nomograms).

13.1.4 Forecasting maximum waves

13.1.4.1 Wind waves

The most likely maximum wave height is 1.67 × the significant wave height. **Fig. 13.5** gives the maximum wave height corresponding to a given value of the significant wave height.

13.1.4.2 Swell waves

Swell height only varies a little, and for practical forecasting it may be considered as constant.

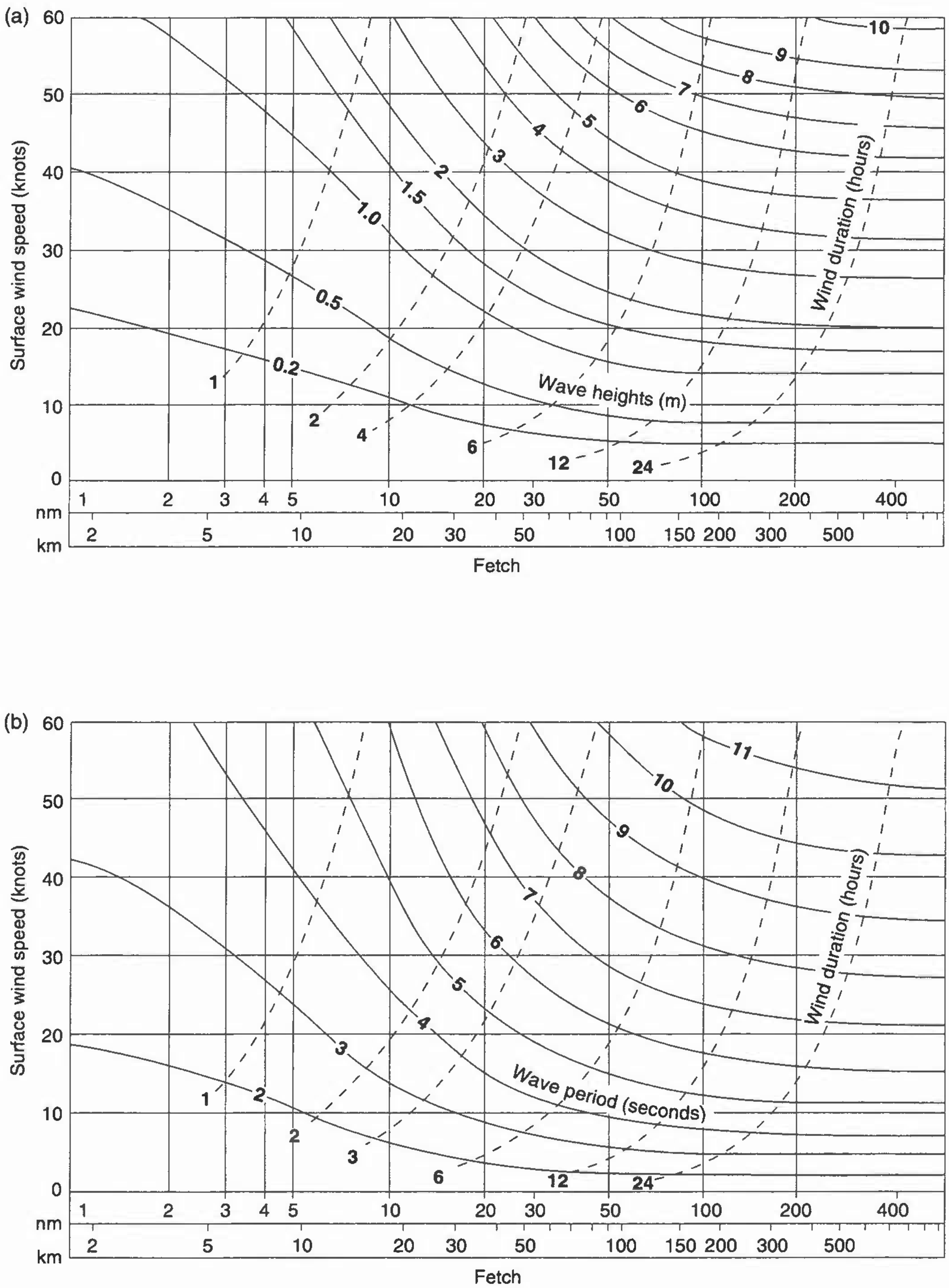

Figure 13.2. (a) Significant heights, and (b) periods, of shallow-water waves.

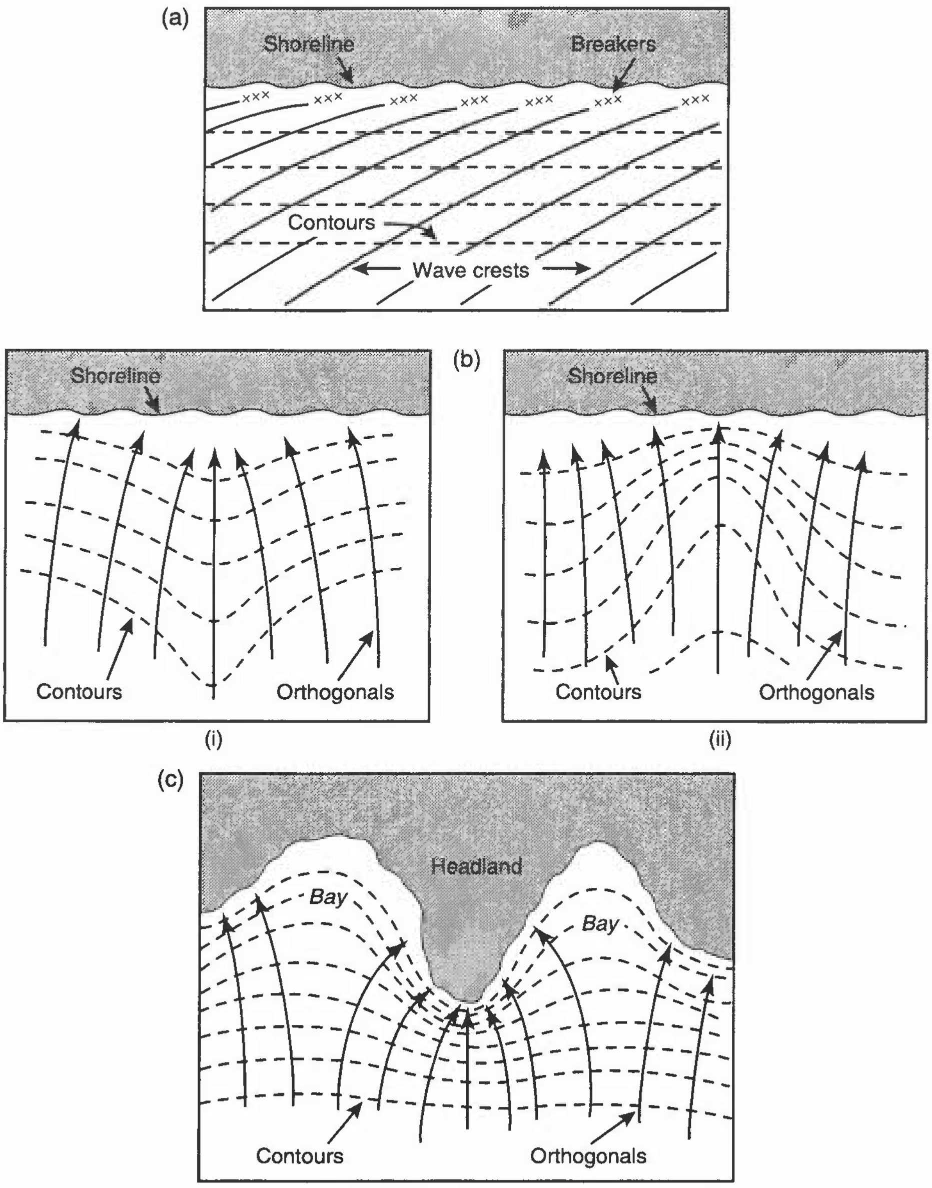

Figure 13.3. (a) Refraction along a straight beach with parallel bottom contours. (b) Refraction, (i) by a submarine ridge, and (ii) by a submarine canyon. (c) Refraction along an irregular shoreline.

13.1.4.3 Wind waves and swell waves combined

The maximum wave in a combined sea with wind waves and swell is:

$$\sqrt{[(\text{maximum wind wave})^2 + (\text{swell})^2]}$$

13.1.4.4 Extreme waves

When gales persist for long periods and the fetch is long, the 'maximum' wave height may be exceeded. **Fig. 13.5** gives an estimate of the 'extreme' waves which may be generated under these conditions.

DNOM (1984)
Open University (1991)

13.1.5 Tidal currents and waves

It is basic knowledge to mariners that waves become steeper and more of a hazard to shipping when the tide sets against the wind. Waves, generated in the sea before the tide has changed, have to reduce wavelength in order to conserve energy and must therefore increase amplitude.

Suthows (1945)

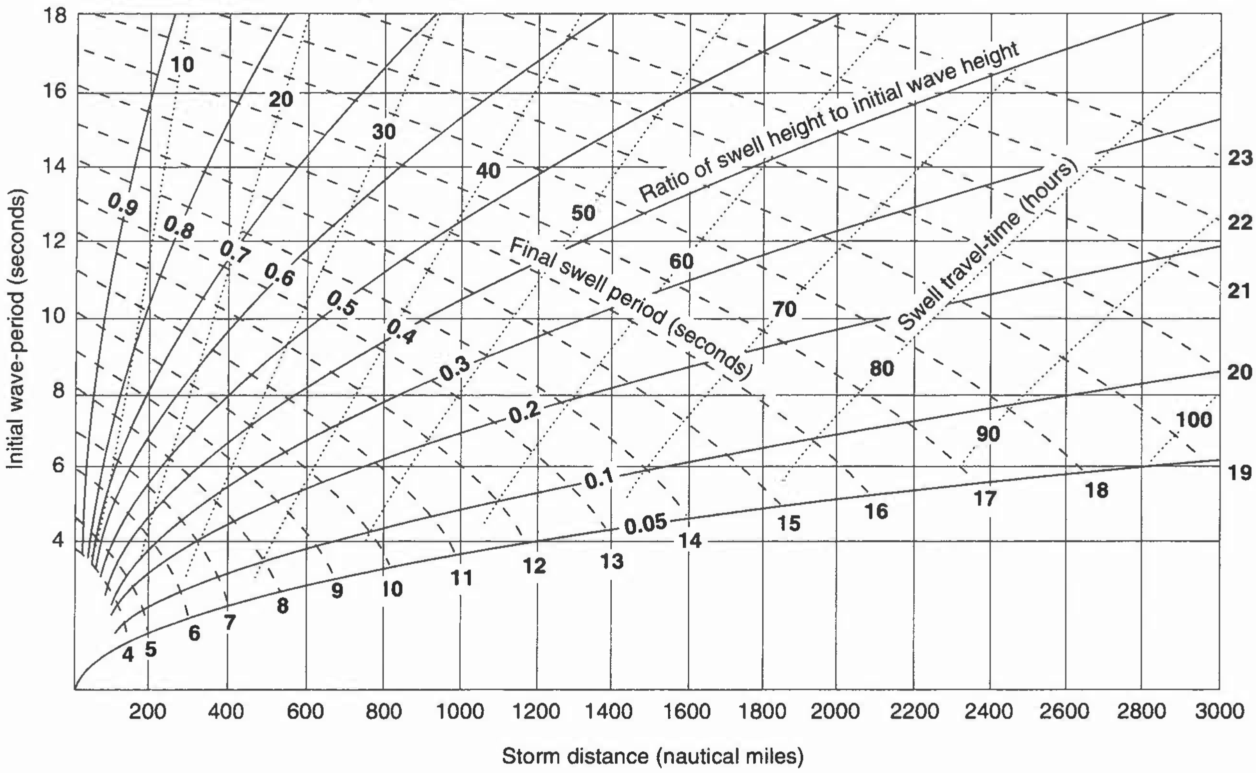

Figure 13.4. Forecasting swell height.

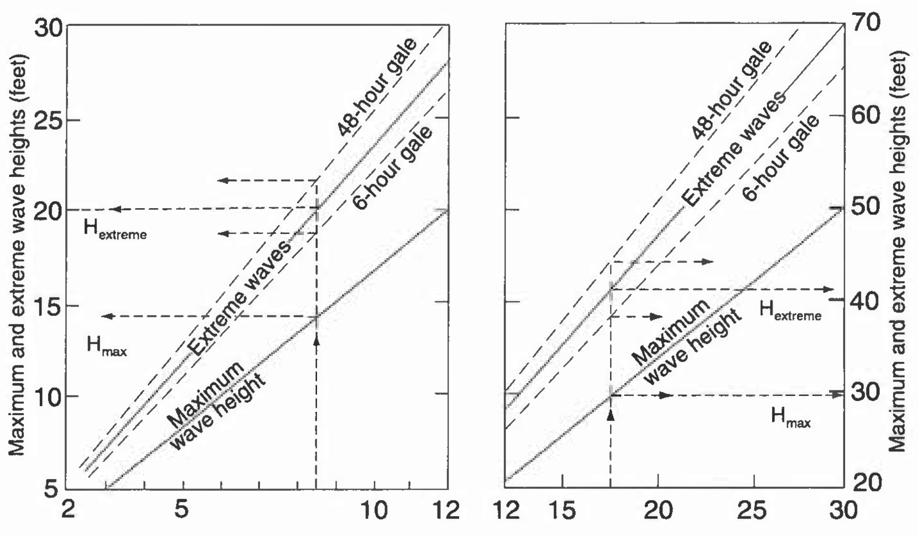

Figure 13.5. Forecasting maximum wave heights and extreme waves.

13.2 Storm surges

Storm surges are caused by particular combinations of wind, atmospheric pressure, waves and tides; the wind stress effects associated with a mobile low-pressure system dominate the surge effect due to any change in sea level due to the pressure system alone. This effect can be important along the south coast during prolonged periods of low pressure. Large anticyclones may depress tidal levels by up to 0.3 m.

Thus, levels in the Thames Estuary will comprise an element of the surge experienced in northern Scotland 12 hours earlier plus any surge generated within the North Sea; on occasion there may also be an element of surge that has propagated from the English Channel and through the Strait of Dover.

13.2.1 *Causes and effects of storm surges*

13.2.1.1 *Atmospheric pressure*

A change in atmospheric pressure of 1 hPa has the potential to cause a change in sea level of 1 cm. The response is not instantaneous but can be clearly observed when the UK is under the influence of an anticyclone, and coastal wind strengths are light. Tidal levels may then be depressed by as much as 0.3 m; areas of low pressure, similarly, has a tendency to raise tidal levels, although the transient nature of these systems means that the full response is not often seen.

13.2.1.2 *Wind stress*

The drag on the sea surface is assumed to be a function of the (10 m) wind speed and air density:

stress = Drag coefficient $\times$ air density $\times$ (wind velocity)^2.

Typically the drag coefficient = 0.63.

13.2.1.3 *Wind set-up*

The effect of the wind on the slope of the sea surface in a narrow channel of constant depth is dependent on the water depth and density:

Surge elevation = stress/[g $\times$ water density $\times$ depth]

The effect is thus greater in shallow water. For a force 9 wind (22 m s^{-1}) blowing for 200 km over water of 30 m depth the rise in the level would be 0.85 m; an increase to force 11 (30 m s^{-1}) would result in a surge residual of 1.6 m.

13.2.1.4 *Coriolis effect*

The currents resulting from wind stress increase with depth as the current speed decreases so that the current profile describes an Ekman spiral.

Pugh (1987) WMO (1988)

13.2.2 *Types and effects*

13.2.2.1 *North Sea surges*

In a typical surge a 'positive' phase is preceded by a lowering of tidal levels at the southern end of the North Sea, due to the influence of southerly winds and to the Strait of Dover restricting flow into and out of this area. The strongest surges often result from depression on a south-easterly track crossing northern England or Scotland; the surge then can be wholly generated in the North Sea. Such surges will affect the eastern end of the English Channel.

13.2.2.2 *'Negative' surges*

Strong southerly winds in the North Sea may result in tidal levels much lower than tidal table predictions in the southern end of the North Sea, the Strait of Dover and the Thames Estuary (levels of over 2 m below predictions have been recorded). Such reductions in tidal levels pose a risk of grounding to deep-draught shipping with low under-keel clearance approaching port.

13.2.2.3 *Frequency and extremes*

(i) On east and west coasts there are about 20 events each winter with surge levels exceeding 0.6 m; negative surges in the Thames Estuary number about 15.
(ii) The 50-year return period surge is 1 m in the Hebrides, 3 m in the Thames Estuary, 1 m at Land's End.
(iii) Surge peaks only infrequently coincide with high water.

13.2.2.4 *Areas at risk*

(i) Low-lying southern and eastern areas are at greatest risk from tidal flooding. The east coast experiences an average of 19 surges with amplitudes exceeding 0.6 m each winter.
(ii) Flooding of susceptible areas of western Britain are generally associated with strong south-westerly winds ahead of depressions approaching from the west of Ireland. The surges may also affect the western end of the Channel.
(iii) Storm surges around the Scottish coast are usually <1 metre and will generally only cause concern when combined with periods of extreme river flow. Local conditions in areas such as the Clyde may result in larger surges and associated flooding.

Pugh (1987)

13.2.3 Forecasting surge levels

(i) The Meteorological Office's Storm Tide Warning Service monitors the National Tide Gauge Network, comprising over 40 gauges around the coasts of the British Isles. It makes use of data from the European Wave Model and uses NWP data to force surge models that are routinely run twice-daily.

(ii) Empirical techniques are available for key locations on the east coast (no similar methods are available for the west coast, although the 'Lennon' criteria give an indication of a major event in the Bristol Channel or Liverpool areas).

(iii) 2-D modelling of the shelf area surrounding the UK on a 12 km mesh gives output in the form of port tables of surge residuals (effects due to meteorological influences) for 36 hours ahead.

(iv) Data can be provided for offshore locations, together with wind-induced currents and *tidal stream velocities* (periodic, generally horizontal, movements due to periodic forces).

(v) Customer demand has resulted in fine-mesh local-area models: a model of the Bristol Channel uses a 4 km grid and runs in concert with a Severn Estuary model with a 1.3 km grid.

13.3 Terminology

Amplitude. The vertical distance between mean water level and wave crest.

Currents. Non-periodic movements of water, generally horizontally.

Duration (D). The time during which a given wind persists. Waves take time to build but, for a given wind speed, D is not a relevant factor once a mature wave system is established.

Fetch. The length of the traverse of an airstream across a sea or ocean. Fetch limits the height which waves can attain.

Maximum wave height (H_{max}). The highest wave to be expected in every 100 consecutive waves. For wind waves it has been found that $H_{max} = 1.67\ H_{sig}$.

Meteorological residual. Deviations from astronomically predicted tidal levels resulting from meteorological influences.

Neap tides. The semi-diurnal tides of smallest range in a semi-lunar cycle of 15 days.

Period. The time between successive wave crests (or troughs).

Significant wave height (H_{sig}). The mean of the highest third of the waves in a wave train, over a period of 10–20 minutes. This happens to correspond to what is normally reported as the mean wave height.

Spring tides. The greatest semi-diurnal tide in a semi-lunar cycle of 15 days.

Storm surge. Large change in sea level resulting from a major meteorological event.

Swell. represents wind waves (sea) which have travelled out of the area in which they were generated, or can no longer be sustained by the winds in the generating area.

Tide. Periodic movement in the level of sea or ocean surfaces due to periodic astronomical forcing.

Tidal streams. Periodic movements of water, generally horizontal, due to periodic forcing.

Wave height (*H*). The vertical distance between a wave crest and the following trough.

Wavelength. The distance between successive wave crests (or troughs).

Wind waves. are the waves caused by the local wind system (the 'wind-sea').

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