referred to as **infra-gravity waves**. If the waves approach a beach obliquely the long waves can modify the longshore currents and also form **edge waves** that travel along the beach and are often *trapped* within the nearshore zone. Long waves also produce variations in both the set-up and the run-up in the surf zone caused by the primary waves. The long-period oscillations in these effects can cause both greater damage to, and overtopping of coastal structures.

An order of magnitude of the surf-beat amplitude in shallow water and in the surf zone can be obtained by using Equation 4.23, an empirical formula derived by Goda (2000):

$$\frac{\varsigma_{rms}}{H'_0} = 0.01\left[\frac{H'_0}{L_o}\left(1+\frac{h}{H'_0}\right)\right]^{-1/2} \tag{4.23}$$

where ς_{rms} = root-mean-square amplitude of the surf-beat profile (m). It is a function of the equivalent deep-water (significant) wave height H'_o defined in Section 4.2.2.5 (m), the deep-water wavelength L_o (m) computed from the significant wave period T_s (see Section 4.2.4.4) as $L_o = g(T_s)^2/(2\pi)$, and the local water depth, h (m).

Bowers (1993) also provides formulae to estimate the amplitude of bound long waves for intermediate depths and also for surf beat significant wave height. For the case of coastal structures exposed to long waves, Kamphuis (2001) proposed the use of Equation 4.24 to estimate the zero moment wave height of the long waves, H_{m0LW}, at the structure as a function of the breaking significant wave height $H_{s,b}$ and the peak wave period T_p (see Section 4.2.4.5).

$$\frac{(H_{m0})_{LW}}{H_{s,b}} = 0.11\left[\frac{H_{s,b}}{gT_p^2}\right]^{-0.24} \tag{4.24}$$

Equation 4.24 can be approximated as a rule of thumb by $(H_{m0})_{LW} = 0.4H_{s,b}$. Kamphuis (2001) also addresses the problem of reflection of these long waves on coastal structures, showing that the long wave profile (with distance offshore) may be described as the sum of an absorbed wave and a standing wave. The long wave reflection coefficient was about 22 per cent during the set of experiments.

4.2.2.8 Tsunamis

Tsunamis are seismically induced gravity waves characterised by wave periods that are in the order of minutes rather than seconds (typically 10–60 minutes). They often originate from earthquakes below the ocean, where water depths can be more than 1000 m, and may travel long distances without reaching any noticeable wave height. However, when approaching coastlines their height may increase considerably. Because of their large wavelength, these waves are subject to strong shoaling and refraction effects. Approaching from quite large water depths, they can be calculated using shallow-water theory. Wave reflection from the relatively deep slopes of continental shelves may also be an important consideration.

Some theoretical work is available (eg Wilson, 1963), as well as numerical models to describe tsunami generation, propagation and run-up over land areas (eg Shuto, 1991; Yeh *et al*, 1994; Tadepalli and Synolakis, 1996) and also some large-scale experiments (eg Liu *et al*, 1995). More information on tsunamis can be obtained from the Internet, for example at <www.pmel.noaa.gov/tsunami>.

Tsunamis are as unpredictable as earthquakes. Figure 4.15 presents observations for height and period of tsunamis from Japanese sources observed at coasts within a range of about 750 km from the epicentre of sub-ocean earthquakes.