Chapter Outline

Coastal Water Level Fluctuations

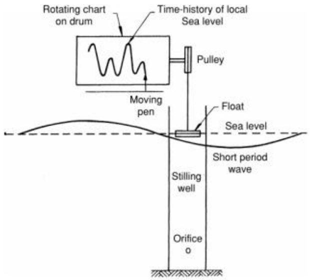
- Long Wave Equations
- Astronomical Tide Generation and Characteristics
- Tsunamis
- Long-Term Sea Level Change

Prof. Marta Cianferra e-mail: marta.cianferra@dia.units.it

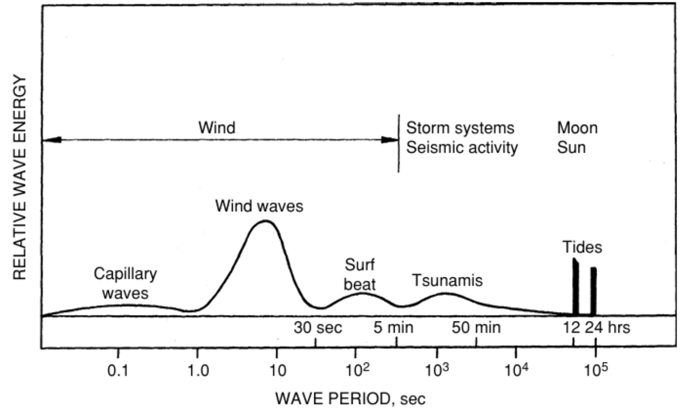
Long Wave Equations

Long-period waves may be classified as:

1. Astronomical tide - periodic fluctuations caused by the interaction of gravitational and centrifugal forces primarily between the earth, sun, and moon
2. Tsunamis - surface waves generated by underwater disturbances primarily of seismic origin
3. Basin oscillations - resonant response of water bodies to long period wave and non-wave excitations
4. Storm surge - setup and setdown of coastal water levels caused by meteorological forces
5. Climatological/geological effects - long-term changes in relative sea level owing to atmospheric warming coupled with coastal uplift or subsidence



Common type of gage that can be used to measure the coastal water level fluctuations classified above



From 1 to 30 s wind generated waves, the one typically sees when visiting the coast. Tsunami waves can have periods from 5 to 60 min. While the dominant tidal periods are around 12 and 24 hours.

Prof. Marta Cianferra e-mail: marta.cianferra@dia.units.it

Long Wave Equations

The waves considered here have relatively long periods and thus tend to have low d/L values so that they usually are shallow water waves even in the deeper ocean.

$$-g(d+\eta)\frac{\partial \eta}{\partial x}+fq_y+\frac{1}{\rho}(\tau_{sx}-\tau_{bx})=\frac{\partial}{\partial x}\left(\frac{q_x^2}{d+\eta}\right)+\frac{\partial}{\partial y}\left(\frac{q_xq_y}{d+\eta}\right)+\frac{\partial q_x}{\partial t}$$

$$\underbrace{-g(d+\eta)\frac{\partial \eta}{\partial y}}_{\substack{\text{gravitational force per}\\ \text{unit mass exerted}\\ \text{through the slope of the}\\ \text{water surface}}}+\underbrace{fq_x}_{\substack{\text{Coriolis}\\ \text{acceleration}\\ \text{component}}}+\underbrace{\frac{1}{\rho}(\tau_{sy}-\tau_{by})}_{\substack{\text{net}\\ \text{horizontal}\\ \text{stress per}\\ \text{unit mass}}}=\underbrace{\frac{\partial}{\partial x}\left(\frac{q_xq_y}{d+\eta}\right)+\frac{\partial}{\partial y}\left(\frac{q_y^2}{d+\eta}\right)+\frac{\partial q_x}{\partial t}}_{\substack{\text{resulting}\\ \text{convective and}\\ \text{local acceleration}\\ \text{components for}\\ \text{the water}}}$$

- q_x and q_y are volumetric flow rate per unit width of vertical section
- bottom stresses in the x and y directions (τ_{bx} and τ_{by})
- surface stresses in the x and y directions (τ_{sx} and τ_{sy})
- Coriolis parameter $f \;=\; 2\,\omega \sin \phi$

ω is the earth's rotational speed ($7.27\ 10^{-5}\ rad/s$) and ϕ is the latitude of the point on the earth's surface where the equations are being applied.
f times a horizontal component of the flow velocity yields the horizontal Coriolis force per unit mass

Astronomical Tide Generation and Characteristics

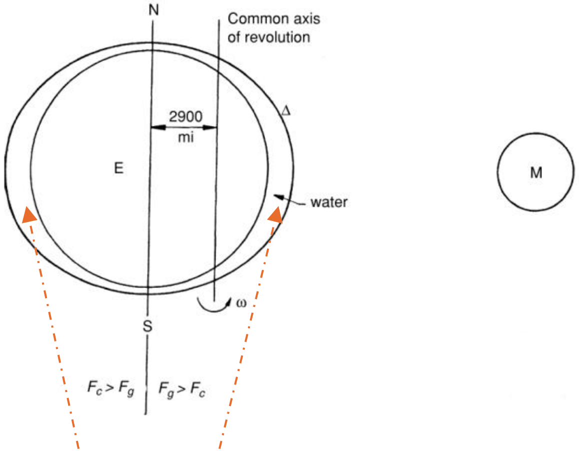
The gravitational attraction of the sun and moon on the oceans and the equal and opposite centrifugal forces owing to the rotation of the earth–sun–moon system are the primary tide generating forces. Although the sun's mass is approximately $2.7x10^{7}$ times that of the moon, the closer proximity of the moon to the earth results in the moon having about twice the sun's gravitational force on the oceans.

Moon tides

The Moon orbits around the Earth in about 27 days, 7 h and 43 m, a period known as the sidereal month. However, during this time, the Earth is also moving along its orbit around the Sun.
As a result, after completing one sidereal orbit, the Moon is not yet in the same position relative to the Sun. While the Earth completes one rotation relative to the Sun (one solar day), the Moon advances about 1/29.5 of its orbit. Therefore, **the Moon needs additional time to realign with the Sun-Earth system**.
This is why the full cycle of lunar phases - from one new moon to the next - takes about **29.5 days**, known as the synodic month.

Two effects act together: the **gravitational attraction of the moon** and the **centrifugal force** produced by the fact that the Earth and the Moon rotate around their **common center of mass**. This interaction creates two tidal bulges.

→ as a result, the **lunar tidal cycle** is about **12 hours and 25 minutes**
Principal lunar tidal period M2 = 12.0 (1 + 1/29.5) = 12.42 hours



These bulges are the tide waves that propagate as shallow water waves.

UNIVERSITÀ DEGLI STUDI DI TRIESTE
Dipartimento di Ingegneria e Architettura
Prof. Marta Cianferra e-mail: marta.cianferra@dia.units.it

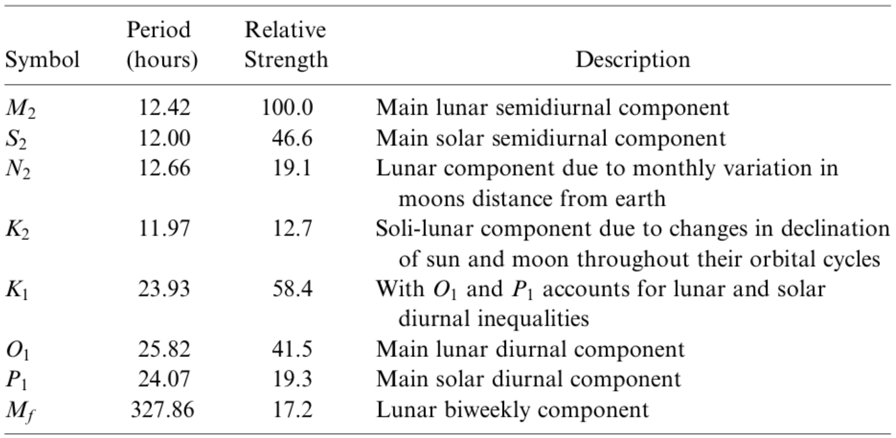
Astronomical Tide Generation and Characteristics

The planes of the moon’s and sun’s rotation relative to the earth are not in line and change with regard to each other as time passes.

Also, the orbits of the sun and moon are elliptical rather than circular. These plus other factors make the net tide generating force very complex.

Lunar phase	Geometry	Ocean effect
Full Moon	Sun - Earth - Moon aligned	strongest tides
New Moon	Sun - Moon on same side	strongest tides
Quarter Moon	Sun and Moon at 90°	weaker tides (neap tides)

The principal lunar and solar components are just two of over 390 active tidal components having periods ranging from about 8 hours to 18.6 years.
Each component has a period that has been determined from astronomical analysis and a phase angle and amplitude that depend on local conditions and are best determined empirically.
Most of the 390 components are quite small and can be neglected for practical tide prediction. Eight major components with their commons simbol, period, approximate relative strength (depending on location), and description are listed in this table



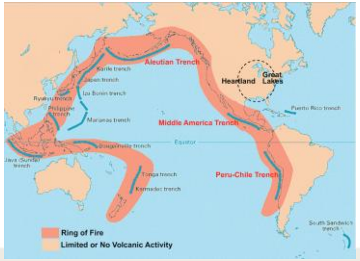
Symbol	Period (hours)	Relative Strength	Description
M_2	12.42	100.0	Main lunar semidiurnal component
S_2	12.00	46.6	Main solar semidiurnal component
N_2	12.66	19.1	Lunar component due to monthly variation in moons distance from earth
K_2	11.97	12.7	Soli-lunar component due to changes in declination of sun and moon throughout their orbital cycles
K_1	23.93	58.4	With O_1 and P_1 accounts for lunar and solar diurnal inequalities
O_1	25.82	41.5	Main lunar diurnal component
P_1	24.07	19.3	Main solar diurnal component
M_f	327.86	17.2	Lunar biweekly component

Tsunamis

The term ‘‘tsunami’’ means ‘‘harbor wave’’ in Japanese, is used to denote the relatively long period waves generated by a variety of underwater disturbances including earthquakes, landslides, and volcanic eruptions.

Although tsunami waves have a low amplitude at sea, shoaling, refraction, and resonance can greatly increase the nearshore amplitude and runup of these waves.

- In the open ocean, a tsunami is **a very long, low wave**, often less than 1 m high, but **extremely long (about 100-500 km)**.
- As it approaches the coast, **the water depth decreases**, shoaling causes a **gradual rise of water (**which appears as **a slow advance of the sea onto land**, rather than a steep breaking crest).
- This is why a tsunami can **appear slow and continuous, yet be devastating** when it floods the shoreline.



The 1964 Alaskan tsunami was generated by an earthquake of 8.4 to 8.6 magnitude and a 20- to 50 kilometer focal depth that resulted in vertical land movement over an 800 kilometer front in a period of 4 to 5 min.

The sea bed rotated around a hinge line with underwater uplift and subsidence in excess of +8m and -2m, respectively. Most tsunamis are generated in the active earthquake regions along the rim of the Pacific Ocean.

Prof. Marta Cianferra e-mail: marta.cianferra@dia.units.it

Tsunamis

Example

A tsunami wave with a period of 20 min and a height of 0.6 m at a point in the ocean where the depth is 3800 m (this is the mean depth of the earth's seas).

→ The celerity and length of this wave.

$$C = \sqrt{gd} = \sqrt{9.81(3800)} = 193\,\mathrm{m/s}(695\,\mathrm{km/h})$$

Assume shallow water condition

$$L = CT = 193(20)60 = 231,700\,\mathrm{m}$$

$$d/L = 3800/231,700 = 0.016$$

$$H/L = 2/231,700 = 8.6 \times 10^{-6}$$

→ Its celerity, length, and height in a nearshore depth of 10 m assuming no refraction, diffraction, or reflection effects.

$$\left(H^2\sqrt{d}\right)_{10} = \left(H^2\sqrt{d}\right)_{3800} \longrightarrow H = 0.6\left(\frac{3800}{10}\right)^{0.25} = 2.65\,\mathrm{m}$$

$$(H^2L)_{10} = (H^2L)_{3800}$$

$$C = \sqrt{9.81(10)} = 9.9\,\mathrm{m/s}$$

$$L = 9.9(20)60 = 11,900\,\mathrm{m}$$

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Tsunamis

Tsunami waves still have a very low steepness when they reach the shore.

Primary coastal damage is caused by the surge of water as the tsunami runs up the sloping coast.

Although run up elevations of tsunami waves will depend on the land slope and surface conditions as well as the actual tsunami wave steepness, as a rule of thumb the runup elevation will be equal to or slightly higher than the wave height at the coast.

The run-up may vary from a rapidly rising water surface to a wave that forms a bore that runs up the coastal slope. The former appears more likely for the longer period waves (e.g. 50 to 60 min) and the latter for the shorter period (e.g. 10 to 20 min) waves.

The run-up velocity can be significant for some tsunami waves. Calculations estimated the required flow velocity to overturn the engine to be about 7.5 m/s. Other damage comes from flooding and scour caused by the flowing water.

Long-Term Sea Level Change

When the mean sea level is measured at many coastal sites over a long period of time, it is observed that this level is changing relative to the land. The change is due to a general global eustatic rise in the mean sea level superimposed on a possible tectonic uplift or subsidence of the coast

The 25 U.S. Atlantic coast relative sea level change values range from +1.79 to +4.33 mm/year, whereas four stations in Alaska had mean sea level changes of 0.09 to 12.4 mm/year (updated to 2006). Asea level rise of 2 to 4 mm/year produces a rise of 0.2 to 0.4 m in a century.

Global eustatic sea level rises that have been observed during the past century are believed to be caused by atmospheric warming which causes sea water to expand and land ice in glaciers to melt, adding water to the seas. There have been a number of forecasts that this rise in global eustatic sea level will accelerate during the coming century

Recent findings show that over the past 30 years, the rate of global sea level rise doubled. This rate measures the average rise in sea level each year - most of it resulting from climate change. The study found that in 1993, the rate was about 0.08 inches (2.1 millimeters) per year but has since increased to about 0.18 inches (4.5 millimeters) per year in 2023.

→ Have a look on this Long-term global sea-level change due to dynamic topography since 410 Ma - ScienceDirect

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