Ocean Tides

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IOGOOS-INCOIS Training

06 December, 2021

Outline of the Presentation

- **Ocean Tides - basics**
- **Equilibrium & dynamical theories, Tidal constituents**
- **Monitoring of Tides**
- **Tidal currents**
- **Tide producing forces**

Basics

- Tides are due to the gravitational attraction of moon and to a lesser extent, the sun on the Earth.
- Because the moon is closer to the Earth than the sun, it has a larger effect and causes the Earth to bulge toward the moon.
- At the same time, a bulge occurs on the opposite side of the Earth due to inertial forces.

Basics

- These bulges remain stationary while the Earth rotates.

- Tidal bulges result in a rhythmic rise and fall of ocean surface, not noticeable to someone on a boat at sea, but is magnified along the coasts.

- There ae two high/low tides each day of same/varying magnitudes.

Basics

- Tides are long waves, either progressing or standing.
- The dominant period usually is 12 hours 25 minutes, which is ½ of a lunar day.
- Tidal propagation and amplitude are influenced by friction, the Earth's rotation (Coriolis force), and resonance determined by shapes and depth of the ocean basins and marginal seas.

Equilibrium and dynamical theories

Theoretical explanation for nature of tides was attempted in 17th and 18th century with the work of Newton and Laplace → explain the nature of tides.

Simplest possible explanation → Earth's surface free of continental land mass → perfectly smooth sphere completely covered by water everywhere → prediction model coined as "equilibrium model" for tides.

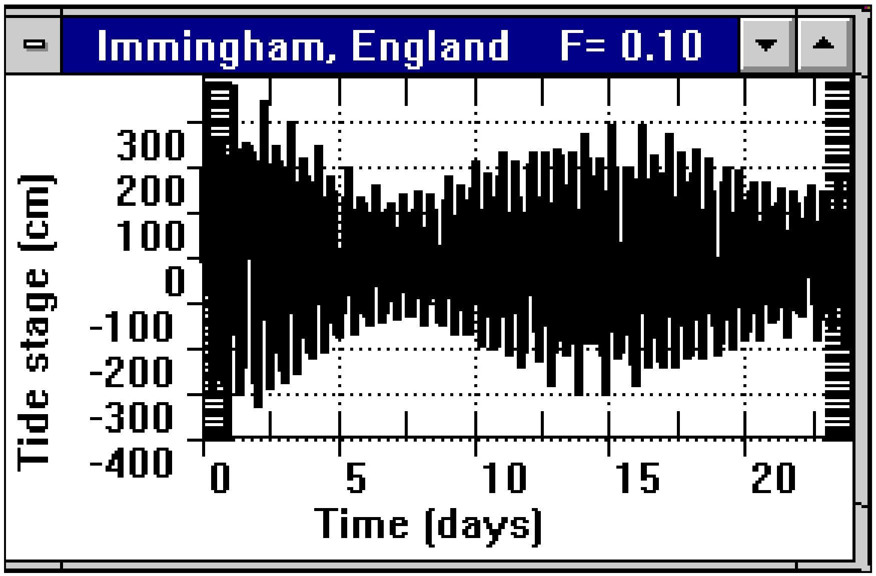
Equilibrium and dynamical theories

Equilibrium model of tides could not explain the varying amplitudes of tides as seen in open ocean.

Subsequently, improvements were made in tidal prediction considering tides in a dynamical way → "dynamical model" for tides.

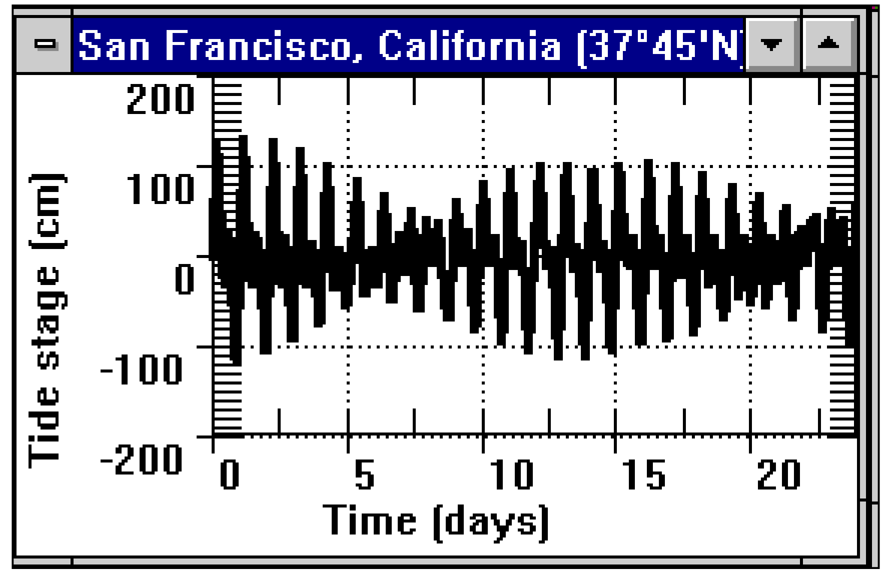
Tides can be predicted with sufficient accuracy using harmonic (fourier) analysis of long record of water level fluctuations.

Measured Sea Level at different Locations



Location: Immingham, England

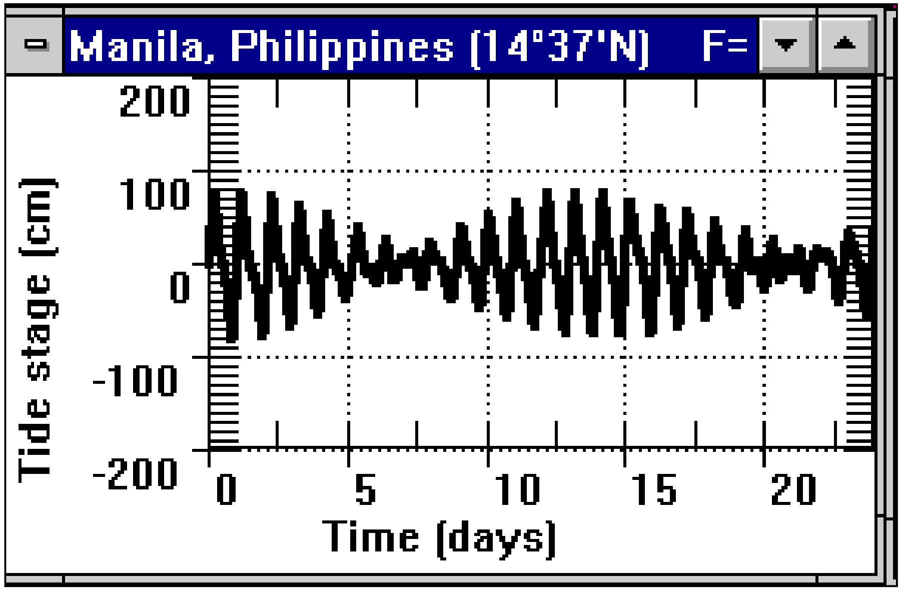
Semi-diurnal: Two high/low waters each day



Location: San Francisco, USA

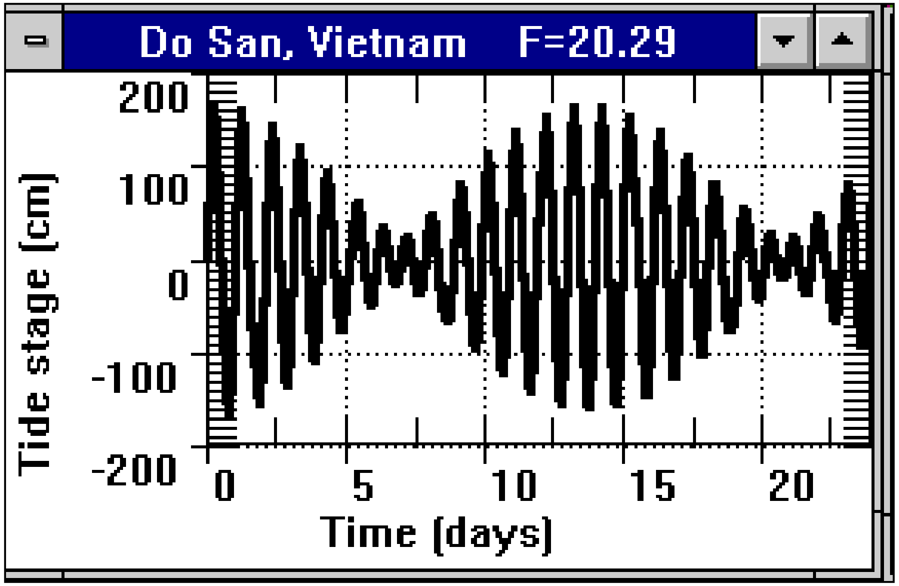
Mixed and mainly Semi-diurnal: Two high/low waters each day most of the time, ONLY one high/low water during neap tides

Measured Sea Level at different Locations



Location: Manila, Philippines

Mixed, mainly Diurnal: One dominant high/low water each day, two high/low water during spring tide



Location: Do San, Vietnam

One High/Low water each day

Monitoring of Tides & Tidal Currents

What affects Tides in addition to Sun and Moon

The relative distances and positions of the sun, moon and Earth all affect the size and magnitude of the Earth's two tidal bulges.

At a smaller scale, the magnitude of tides can be strongly influenced by the shape of the shoreline.

When tidal bulges hit wide continental margins, the height of the tides can be magnified. Conversely, mid-oceanic islands not near continental margins typically experience very small tides of 1 meter or less.

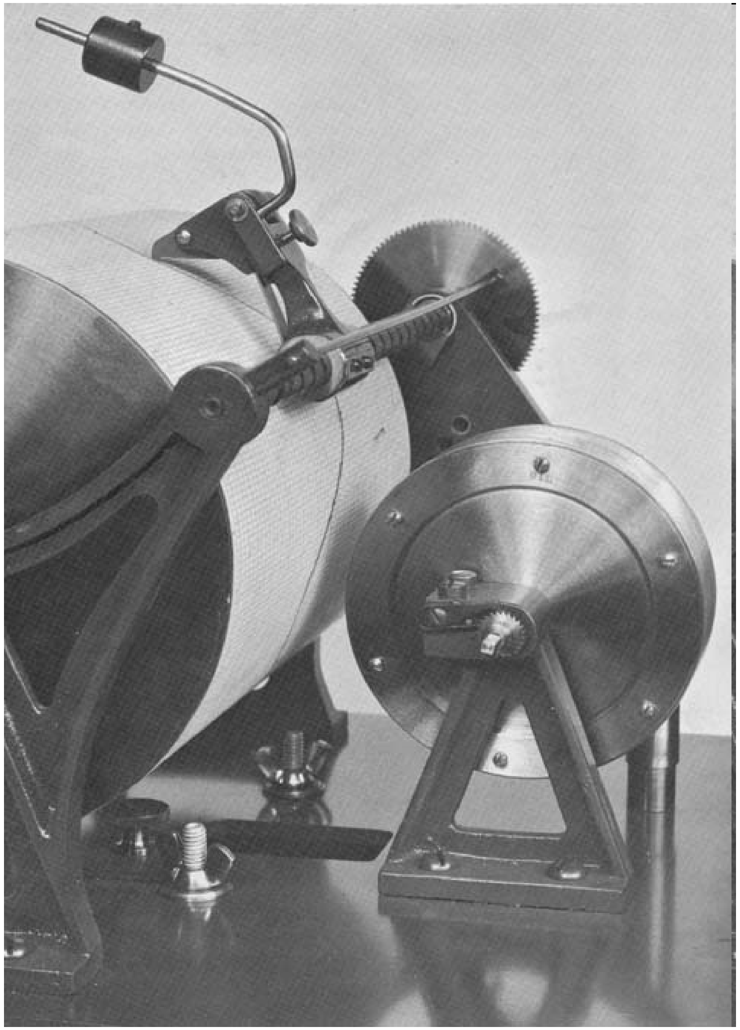
High Tide

Low Tide

What affects Tides in addition to Sun and Moon

- Local wind and weather patterns also can affect tides.
- Strong offshore winds can move water away from coastlines, exaggerating low tide exposures.
- Onshore winds may act to pile up water onto the shoreline, virtually eliminating low tide exposures.
- High-pressure systems can depress sea levels, leading to clear sunny days with exceptionally low tides.
- Conversely, low-pressure systems that contribute to cloudy, rainy conditions typically are associated with tides than are much higher than predicted.

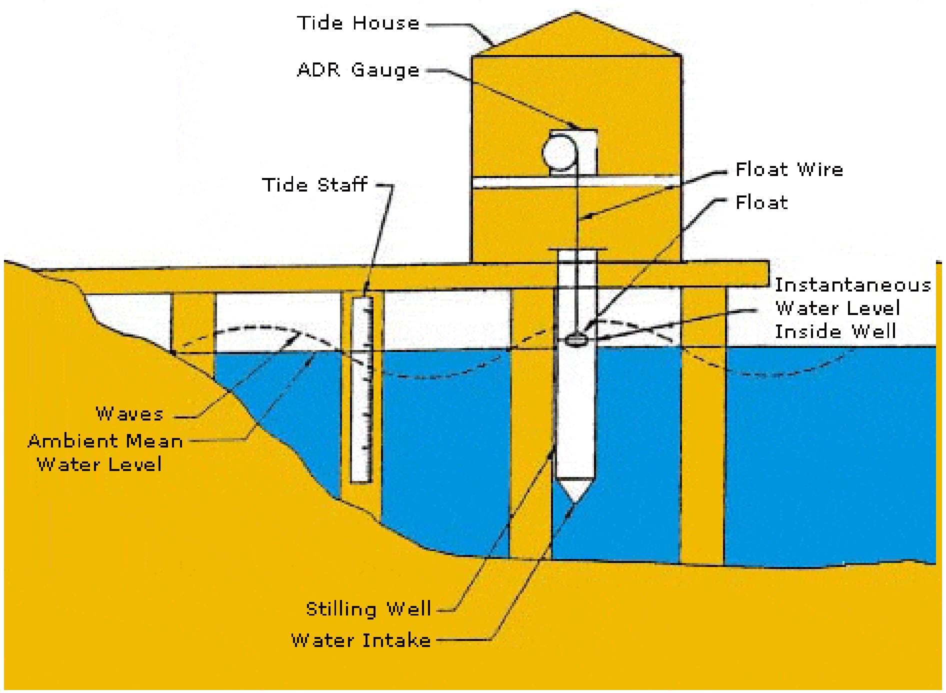
Recording Devices



The Figure on left is the earliest mechanical pen-and-ink strip recorders. In the upper left part of the image, we can see the stylus marking water level data onto the paper recording strip as it slowly rotates in time with an internal clock.

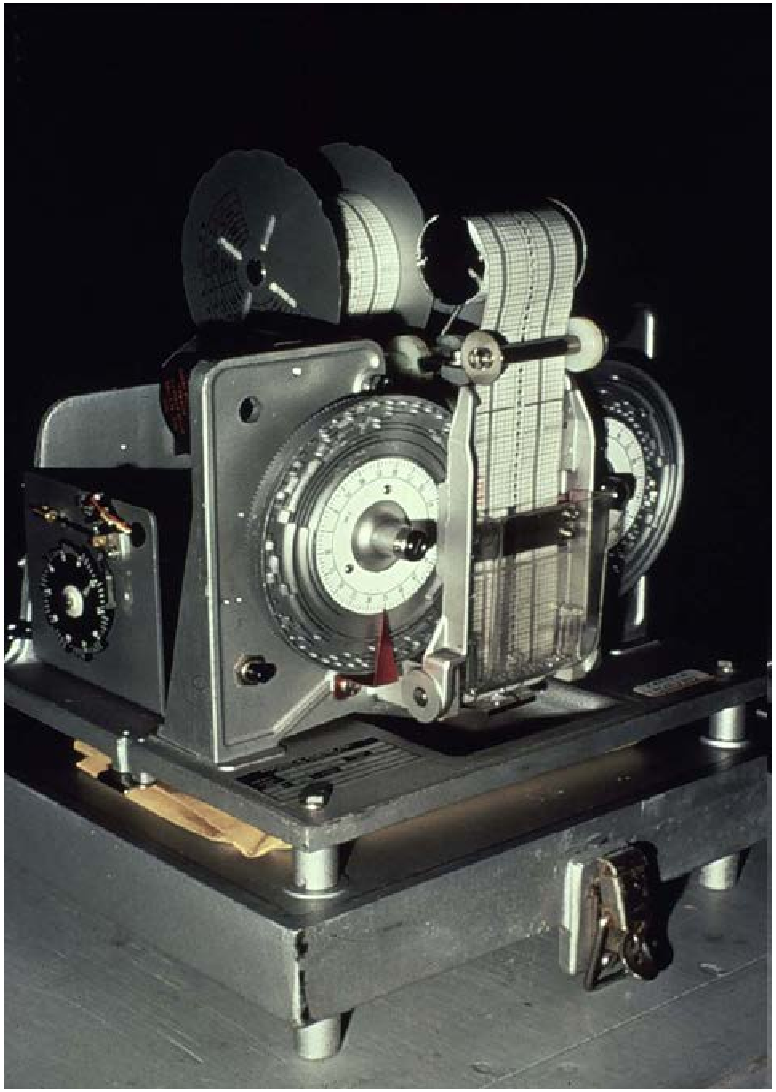
These innovative devices required continuous monitoring and maintenance. All of these mechanical recorders have been replaced with electronic devices that are much more accurate and require less maintenance.

Recording Devices



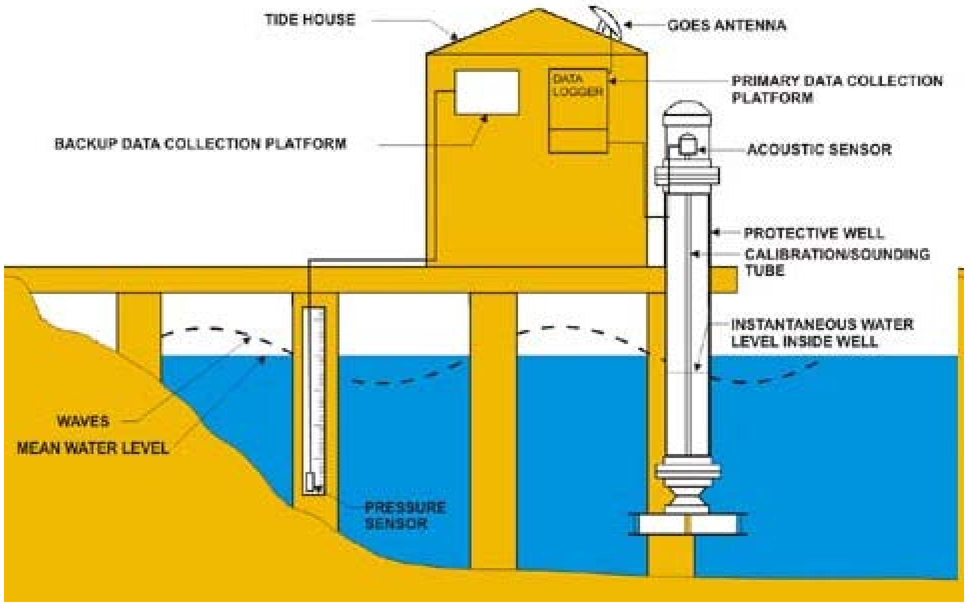
Special tide houses were constructed to shelter permanent water level recorders, protecting them from harsh environmental conditions. In this diagram, we can see how the analog data recorder (ADR) is situated inside the house with the float, and the stilling well located directly beneath it. Attached to one of the piers pilings is a tidal staff. Essentially a giant measuring stick, this device would allow scientists to manually observe the tidal level and then compare it to the readings taken by the analog recorder.

Recording Devices



A close-up view of the early analog to digital “punch” data recorders that replaced the earlier pen-and-ink strip recorders. These devices would punch a hole into a specially marked strip of paper every six minutes, recording the tidal level at that time. At regular intervals, the paper strips would be removed from the devices and fed into electronic computers. The punches from the strips would be analyzed and graphed. These devices were the pre-cursers to today's advanced electronic monitoring systems. Although more accurate than the older pen-and-ink recorders, they still required frequent maintenance and adjustments.

Modern Recording Devices



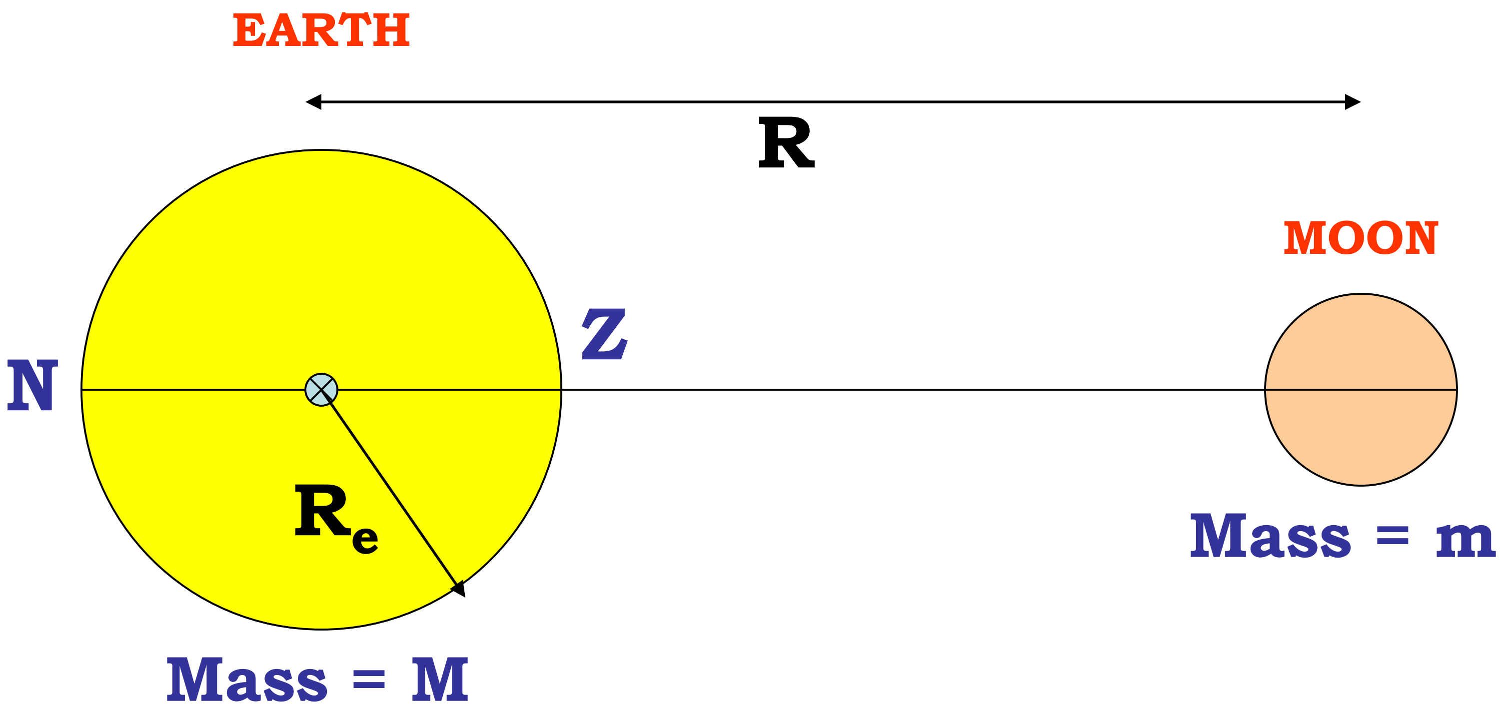
While similar in design to older tide houses, these newer enclosures are designed to protect sensitive electronics, transmitting equipment, and backup power and data storage devices. The older stilling well has been replaced with an acoustic sounding tube and the tidal staff with a pressure sensor. This new field equipment is designed to operate with the highest level of accuracy with a minimum of maintenance, transmitting data to land station for analysis and distribution.

Recording Devices

Not all monitoring stations are housed in protective enclosures. This water level and meteorological recorder is attached directly to a pier. On the left is the acoustic sounding tube and sensor. Rising up from the piling is a solar cell, and above that, a satellite transmitter. The recording electronics are housed in a small weather proof box

Tide producing forces

Effect of Tides



Gravitational Force between Earth and Moon is:

$$F_G = \frac{GMm}{R^2}$$

Effect of Tides

Gravitational Force (per unit mass) of fluid parcel is:

$$F_G = \frac{GM}{R^2}$$ ⇒ directed towards surface of the moon

Consider Earth-Moon system separated by distance $2R_e$ (R_e is radius of the earth and 'R' the distance between the centers of the two body).

Objective is to compute the anomalies at the points "Z" and at point "N" on the Earth surface.

Effect of Tides

$$\text{Now, } (R_e \pm R)^2 = R_e^2 \pm R^2 \pm 2R_eR$$

It is known that, $R_e \ll R$ (hence R_e^2 is negligible)

$$\Rightarrow (R_e \pm R)^2 = R^2 \pm 2R_eR$$

Gravitational force at the sub-lunar point "Z" is:

$$F = \frac{GM}{(R - R_e)^2} = \frac{GM}{(R^2 - 2R_eR)} = \frac{GM}{R^2\left(1 - \frac{2R_e}{R}\right)}$$

Effect of Tides

$$\Rightarrow F = \frac{GM}{R^2\left(1 - \frac{2R_e}{R}\right)}$$

Consider the term $\left[1 - \frac{2R_e}{R}\right]^{-1}$ of the denominator.

Multiplication with like terms : $\frac{1}{\left[1 - \frac{2R_e}{R}\right]} \frac{\left[1 + \frac{2R_e}{R}\right]}{\left[1 + \frac{2R_e}{R}\right]} = \frac{\left(1 + \frac{2R_e}{R}\right)}{\left(1 - \frac{4R_e^2}{R}\right)}$

As $\frac{R_e^2}{R} << 1 \Rightarrow$ the term $\left(1 - \frac{4R_e^2}{R}\right)$ can be dropped leaving behind $\left(1 + \frac{2R_e}{R}\right)$

$$\Rightarrow F = \frac{GM}{R^2}\left(1 + \frac{2R_e}{R}\right)$$

Effect of Tides

Assuming that $g_0 = \frac{GM}{R^2}$ (mean gravitational force)

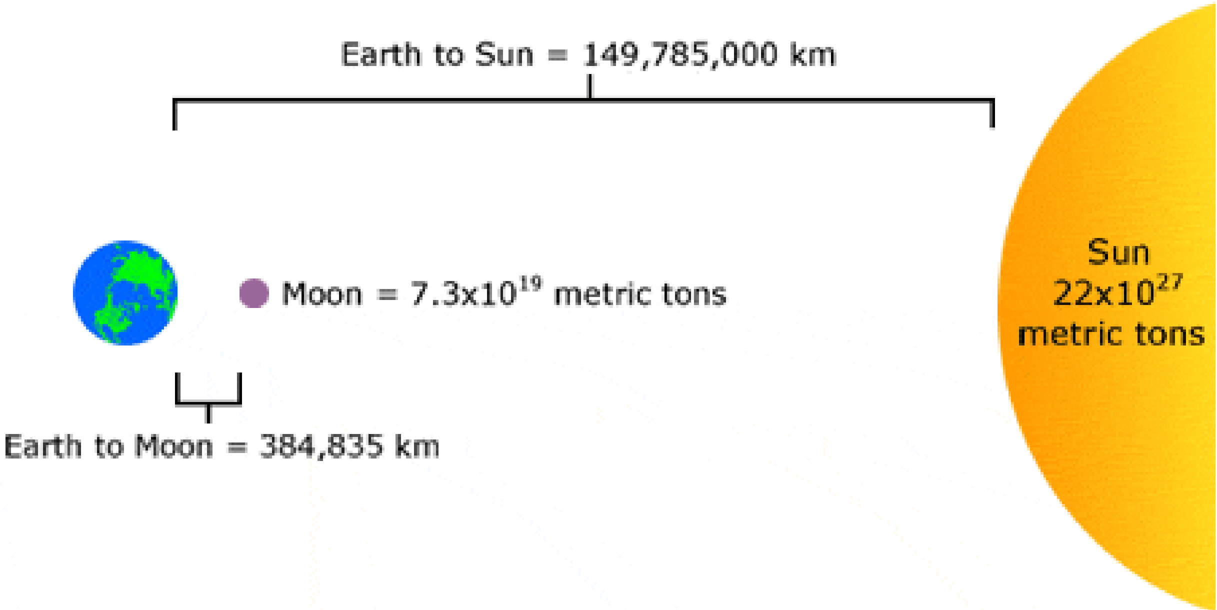
The tidal force corresponding to point "Z" is: $F = g_0\left[1 + \frac{2R_e}{R}\right]$

The tidal force corresponding to point "N" is: $F = g_0\left[1 - \frac{2R_e}{R}\right]$

Likewise at any point on Earth's surface the tidal force can be computed.

Tide producing forces

The Sun-Moon-Earth System



$$\text{Tide-Generating Force} = \propto \frac{\text{Mass}}{(\text{Distance})^3}$$

$$\text{Tide-Generating Force of the Sun} = \propto \frac{\text{Sun's Mass}}{(\text{Sun's Distance to Earth})^3}$$

*NOTE: The sun has 27 million times more mass than the moon and is 390 times farther away from the earth than the moon.

$(390)^3 = 59{,}000{,}000$ So... $\frac{27 \text{ million}}{59 \text{ million}} = 0.46$ or 46%

Therefore the Sun has 46% of the tide-generating force of the Moon.

Thank You