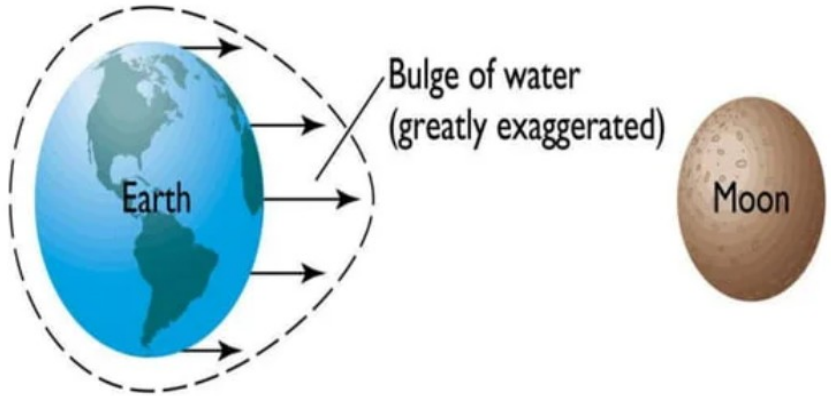


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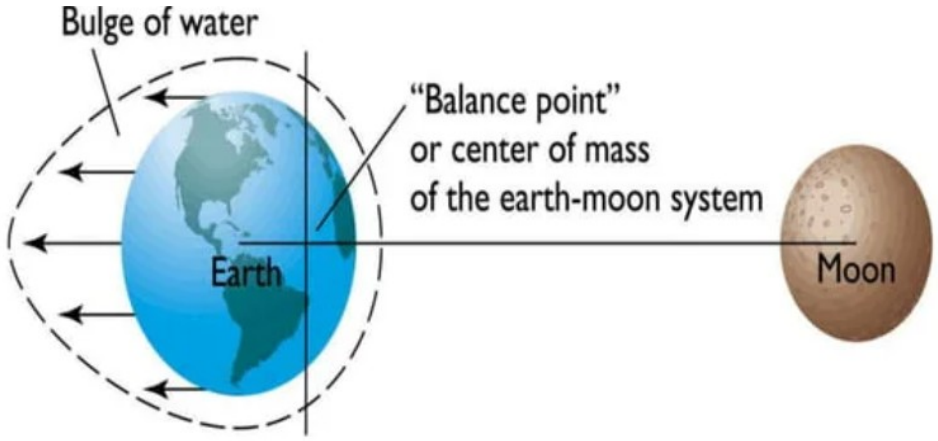
Lecture 13-14
Tidal Theories and Tide Prediction

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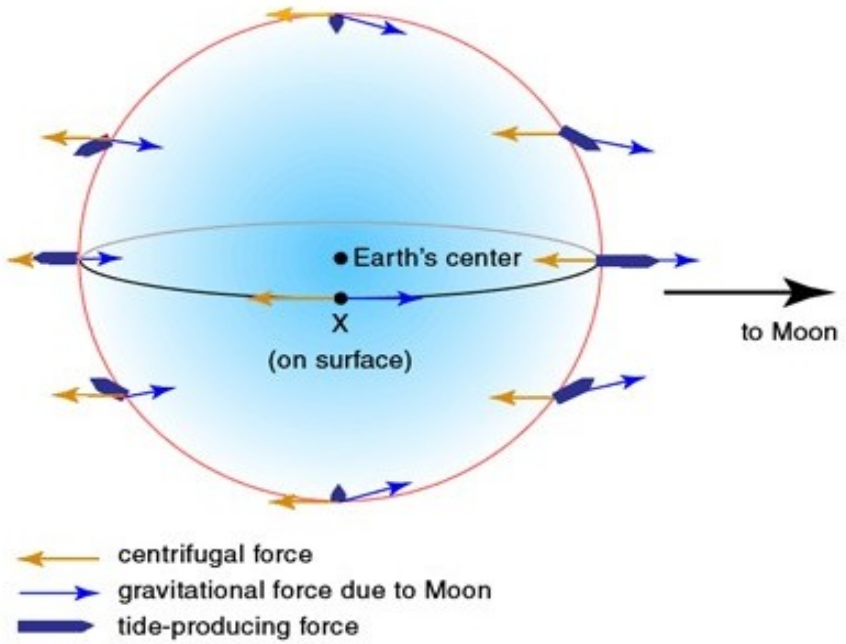
Tidal Theories



(a) GRAVITATIONAL FORCE



(b) CENTRIFUGAL FORCE



Tidal Theories

Newton's statical or equilibrium theory

⇨ The first theory that attempted to explain the tides in the ocean was the equilibrium theory developed by Newton (1687).

⇨ Newton showed that the attractive forces of the moon on the side of the Earth nearest to the moon would be greater than the average forces on the opposite side of the Earth. Therefore, the water would be pulled less than the average forces on the opposite side of the Earth, which results in the water moving away from the moon.

⇨ In an ocean completely covering the earth and of equal depth, the horizontal component of the tide-generating forces pulls the water towards the points nearest and farthest away from the moon, thus causing elevation of the water at these points, with a corresponding depression in the water level halfway between these two points on the earth's great circle.

Tidal Theories

Newton's statical or equilibrium theory

⇨ The sun also would tend to give similar effects related to itself.

⇨ Equilibrium theory can explain certain characteristics of ocean tides, especially the occurrence of semidiurnal tides.

⇨ This theory can also explain the formation of spring and neap tides.

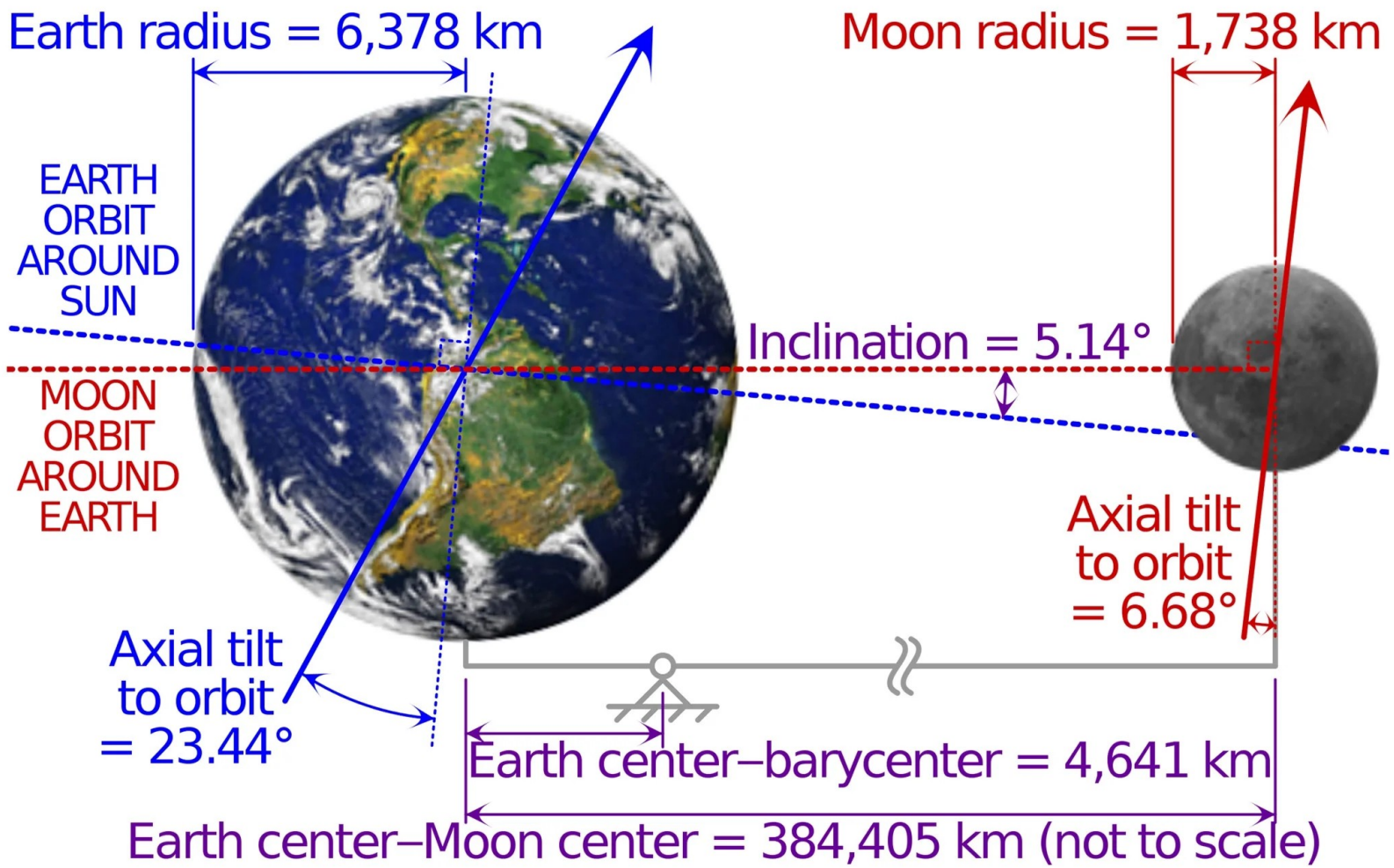
- When the sun and the moon are in line with respect to the earth (full moon and new moon) their tide-generating forces are added, producing the highest high tides known as spring tides.

- When the sun and the moon are perpendicular to one another with respect to the earth, their effects tend to cancel one another, producing the lowest low tides known as neap tides.

Tidal Theories

Limitations of Newton's statical or equilibrium theory

- In the equilibrium theory, the Earth is assumed to be enveloped with a sea of uniform depth. But this condition is fulfilled only in the Southern Ocean. Therefore, it is only in this portion of the ocean where the equilibrium figure may be developed.
- The theory was developed based on gravitational pull and assumed equilibrium of a particle at each instant
- If this assumption were correct, there would have been high tides exactly when the moon was passing over the meridian
- But this is not observed to be true, and there is a time lag or advance. The Newtonian explanation is thus incomplete.


Earth radius = 6,378 km
Moon radius = 1,738 km
EARTH ORBIT AROUND SUN
MOON ORBIT AROUND EARTH
Inclination = 5.14°
Axial tilt to orbit = 6.68°
Axial tilt to orbit = 23.44°
Earth center–barycenter = 4,641 km
Earth center–Moon center = 384,405 km (not to scale)

Tidal Theories

Laplace theory

⇨ Nearly a century after Newton put forward his equilibrium theory. Laplace (1775) formulated the dynamic theory of tides.

According to this theory, the tide-producing forces produce tide waves in the ocean whose period corresponds to the generating forces. The dynamical theory attempted to understand tides by considering the effect of the depth and width of the ocean basins, the earth's rotation, and friction on the behavior of fluids subjected to rhythmic forces.

⇨ Laplace went a step further, considering the disturbances due to earth rotation. His theory is known as the dynamical theory.

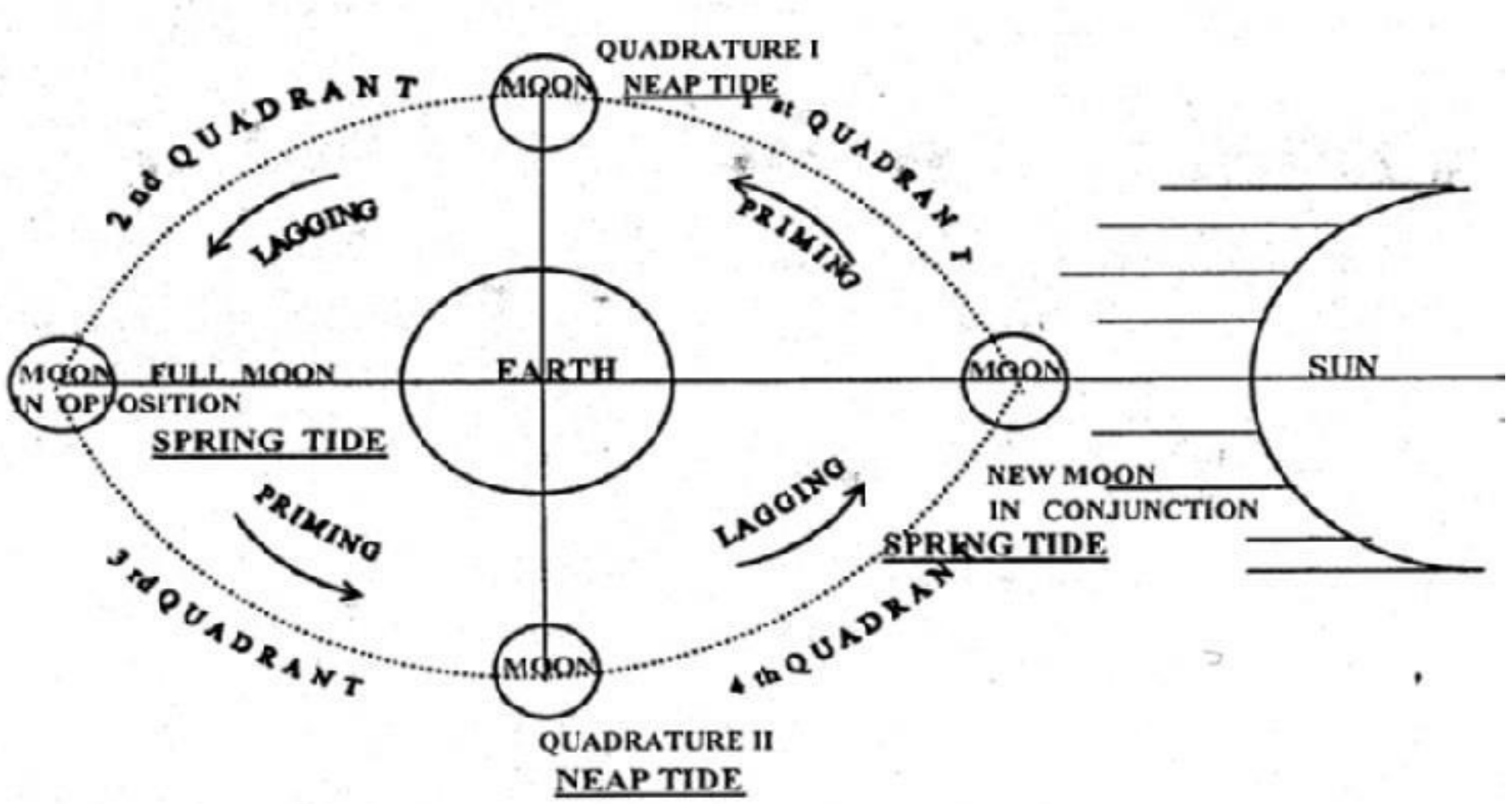
Priming of Tide

- The periodic acceleration in the time of occurrence of high and low waters changes due to the relative positions of the moon and the sun.
- Priming of tide is the initial rise in water level in a river, estuary, or canal caused by the incoming tidal wave before the main high tide arrives.
- Priming occurs when the moon is between the new moon and the first quarter and between the full moon and the third quarter.
- For these positions of the moon, the high water at any place can occur before the moon transits.
- The interval between successive high water would be less than the average (12 hr 25 mins) = prime of tide

Lagging of Tide

- Lagging of tide is the delay in the occurrence of high or low water at a particular location compared to the predicted time or compared to a reference location.
- The lagging of the tide occurs when the moon is in the second and fourth quarters.
- For these positions of the moon, the high water at any place can occur after the moon transits.
- The interval between successive high water would be more than the average (12 hr 25 mins) = lag of tide

Priming and Lagging of Tide



Tide Tables

- Tide tables, sometimes called tide charts, are used for tidal prediction and show the daily times and levels of high and low tides, usually for a particular location.

- The dates of spring tides and neap tides, approximately seven days apart, can be determined by the heights of the tides on the classic tide tables: a small range indicates neaps and a large range indicates springs.

Tide Tables

PHASES OF THE MOON 2019
(DAY: HOUR: MINUTE)

MONTH	NEW MOON	FULL MOON
January	06:07:28	21:11:16
Februaty	05:03:04	19:21:53
March	06:22:04	21:07:43
April	05:14:50	19:17:12
May	05:04:45	19:03:11
June	03:16:02	17:14:31
July	03:01:16	17:03:38
August	01:09:12	15:18:29
	30:16:37	
September	29:00:26	14:10:33
October	28:09:38	14:03:08
November	26:21:06	12:19:34
December	26:11:13	12:11:12

LIST OF CPA TIDE GAUGE STATION

SL	TIDE GAUGE STATION (AUTO)	POSITION(AP.)
01	KHAL NO- 18	Lat:22°13′33"N Long:91°48'18"E
02	KHAL NO- 10	Lat:22°16′1.5"N Long:91°49'27"E
03	KALURGHAT	Lat:22°23′51"N Long:91°53'17"E
04	KAPTAI	Lat:22°29'37.5"N Long:92°11'34.5"E
05	SADARGHAT	Lat:22°19′27"N Long:91°50'0.5"E
06	DOCK OFFICE	Lat:22°18′06.8"N Long:91°47'47.7"E

01 | JANUARY | 2019

	KALURGHAT Time	m	SADARGHAT Time	m	KHAL-10 Time	m	KHAL-18 Time	m	
1 TU	0450	0.14	0406	0.36	0349	0.72	0322	0.93	1 TU
	1030	2.59	1007	2.97	0941	3.22	0927	3.51	
	1705	-0.05	1627	0.29	1603	0.53	1543	0.80	
	2311	3.08	2242	3.42	2219	3.72	2203	3.97	
2 WE	0602	0.02	0519	0.29	0457	0.57	0434	0.80	2 WE
	1136	2.59	1114	2.99	1050	3.24	1035	3.55	
	1804	-0.05	1728	0.25	1702	0.49	1644	0.73	
			2334	3.48	2310	3.81	2255	4.08	
3 TH	0002	3.15	0616	0.21	0548	0.44	0528	0.66	3 TH
	0657	-0.07	1206	3.06	1143	3.31	1123	3.64	
	1228	2.65	1818	0.19	1749	0.42	1732	0.64	
	1853	-0.07			2351	3.89	2335	4.19	
4 FR	0044	3.22	0017	3.54	0632	0.37	0611	0.56	4 FR
	0743	-0.11	0702	0.16	1222	3.41	1200	3.73	
	1309	2.74	1246	3.14	1829	0.35	1813	0.55	
	1932	-0.10	1900	0.15					
5 SA	0119	3.28	0054	3.60	0026	3.97	0010	4.27	5 SA
	0822	-0.10	0741	0.15	0710	0.33	0649	0.52	
	1344	2.82	1320	3.21	1255	3.49	1233	3.81	
	2006	-0.12	1937	0.12	1904	0.30	1850	0.50	
6 SU ●	0151	3.32	0129	3.64	0059	4.01	0043	4.31	6 SU ●
	0855	-0.06	0815	0.16	0744	0.34	0722	0.51	
	1415	2.87	1352	3.25	1326	3.53	1305	3.85	
	2036	-0.13	2010	0.12	1935	0.28	1922	0.50	
7 MO	0221	3.33	0202	3.65	0131	4.01	0114	4.30	7 MO
	0923	-0.02	0844	0.17	0814	0.35	0753	0.52	
	1444	2.90	1422	3.25	1356	3.53	1335	3.85	
	2107	-0.12	2040	0.13	2005	0.28	1952	0.53	
8 TU	0252	3.32	0234	3.64	0201	3.98	0144	4.26	8 TU
	0950	-0.01	0913	0.16	0842	0.34	0822	0.53	
	1514	2.91	1452	3.24	1424	3.52	1404	3.83	
	2140	-0.10	2111	0.13	2036	0.29	2022	0.58	

Prediction of Tides

The two elements required in the prediction of the tide at a place are:

i. Time of occurrence of tide and
ii. Height of tide above datum

There are two principal methods of tide prediction:

i. Prediction by use of non-harmonic constants
ii. Prediction by use of harmonic constants

Prediction by use of Non-Harmonic Constants

- The various nonharmonic constants that are used for prediction of the tide at a place are:

a) Age of tide

b) Lunitidal interval

c) Mean establishment

d) Vulgar establishment

Age of tide

- The time that elapses between the generation of a spring tide and its arrival at the place is called the age of the tide at that place.

- The age of the tide (also known as the age of phase inequality, lunitidal interval) at a location is a term that denotes the interval between the time of a Full or New Moon (when the equilibrium semi-diurnal tide force is maximum) and the time of the local spring tide.

- The age of tide varies for different places up to a maximum 3 days.

- It is obtained as the mean of several observations.

Lunitidal Interval

- Lunitidal interval or high water lunitidal interval is the time interval that elapses between the moon’s transits and the occurrence of the next high water.

- The values of the lunitidal interval can be observed if they are plotted against the time of the moon’s transits.

- The interval may be taken from the local time of the moon's transit to the local time of high water, or it may be taken from the Greenwich time of the moon's transit to the standard time of high water.

Mean Establishment

- The average value of the lunitidal interval at a place is known as its mean establishment or mean lunitidal interval.

- Also referred to as the mean high water interval, this is the mean value of all the high water intervals throughout at least a lunation, which is approximately 29 days.

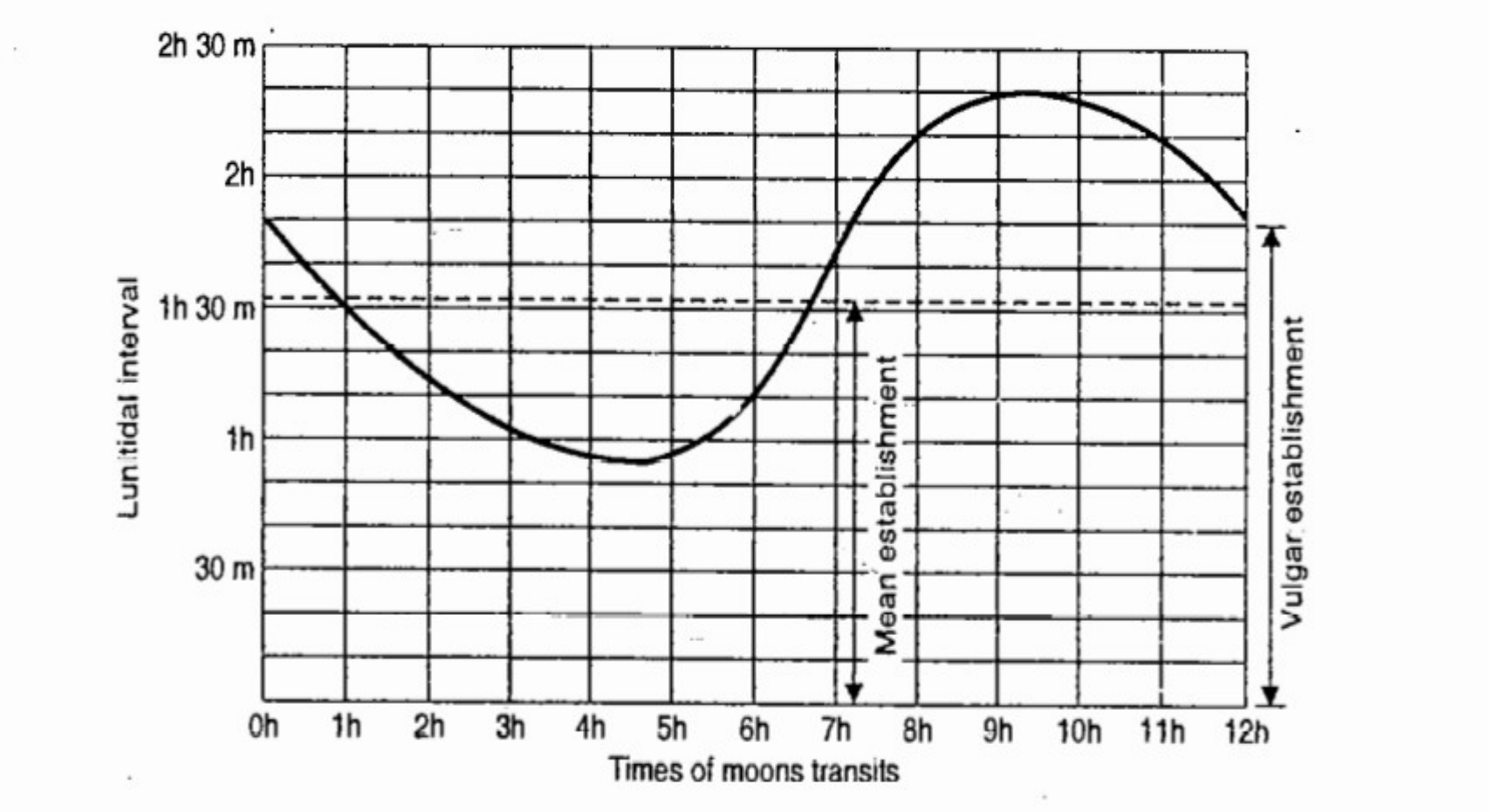
Vulgar Establishment

- Vulgar establishment is defined as the value of the lunitidal interval on the day of the full moon or change of moon.

- The value of vulgar establishment is approximately equal to the clock time at which high water occurs on the days of full moon or change of moon.

- Mean establishment = vulgar establishment – lagging correction.

Lunitidal Interval



Prediction of Time of High Water

To get the approximate time of the high water -

1. Find the age of tide and mean establishment for the place from the charts.
2. Knowing the hour of the moon's transit at the place, on the day in question, determine the time of the moon's transit on the day of generation of the tide.
3. Corresponding to the time of transit of moon on the day of generation of tide find out the amount of priming or lagging correction from the table given below

Hour of Moon's transit	0	1	2	3	4	5	6	7	8	9	10	11	12
Correction in minutes	0	-16	-31	-41	-44	-31	0	+31	+44	+41	+31	+16	0

Prediction of Time of High Water

4. Add algebraically the priming or lagging correction to the mean establishment to get the lunitidal interval for the day in question.

4. Add the lunitidal interval to the time of the moon's transit on the day in question, to get the approximate time of high water.

Prediction by use of Non-Harmonic Constants

Let us find the time of afternoon high water at a place with the following data:

a) Time of the moon's transit on that day = 4h 40 m
b) Mean establishment =3h 10 m
c) Age of tides = 2 days

We know that the moon falls behind the sun at the rate of 50 m per day. Hence, at the birth of the tide, 2 days earlier, the time of the moon's transit = 4h 40m – 2 × 50m = 3h 0m.

From the table, corresponding to the time of transit of 3h 0m,
the correction for priming= - 41m

Therefore, lunitidal interval= mean establishment + correction
= 3h 10m - 41m = 2h 29 m

Now, the time of high water = Time of moon's transit + Lunitidal Interval
=4h 40m + 2h 29 m = 7h 09 m = **7.09 PM**

Height of Tide

- Another item in the prediction of the tide is the estimation of the height of the rise of the tide, i.e, the vertical distance of the high water level above some suitable reference datum.
- A commonly adopted datum is the low water level of ordinary spring tides for the place.
- The approximate height of the tide of known rise or range, at any time between high and low water, can be ascertained from the following expression:

$$H = h + (1/2)\, r \cos\theta$$

Where,

H = required height of tide above datum

h = height of mean tide level above datum

r = range of the tide

θ = (interval from high water/interval between high and low water) $\times$ 180

Prediction by use of Harmonic Constants

- 36 tidal constituents of harmonic type.
- 09 important constituents are listed in the following table-

Symbol for constituent	Description or name	Period
M_2	Lunar semi-diurnal	$\frac{1}{2}$ Lunar day
S_2	Solar semi-diurnal	$\frac{1}{2}$ Solar day
N_2	Larger elliptic-semi-diurnal	-
K_2	Luni-solar semi-diurnal	$\frac{1}{2}$ Sideral day
K_1	Luni-solar diurnal	Sideral day
O_1	Larger diurnal (declinational)	-
P_1	Solar diurnal (declinational)	-
M_4	First overtake of semi-diurnal	$\frac{1}{4}$ Lunar day
MS_4	Compound luni-solar $\frac{1}{2}$ diurnal	-

Tide Gauges

- The height of high and low waters and their variations with time can be measured at the site with the help of tide gauges.
- The following are some of the common types of tide gauges used:

1. Non-registering type tide gauges: In which an attendant is required to take a reading from time to time
    i. Staff gauge
    ii. Float gauge
    iii. Weight gauge
2. Self-registering type tide gauges: No attendant is required.

Tide Gauges

1. Staff Gauge

- This is the simplest type of gauge, which is firmly fixed in a vertical position.
- The gauge consists of a board with a suitable height.
- The staff is read directly from some distance.

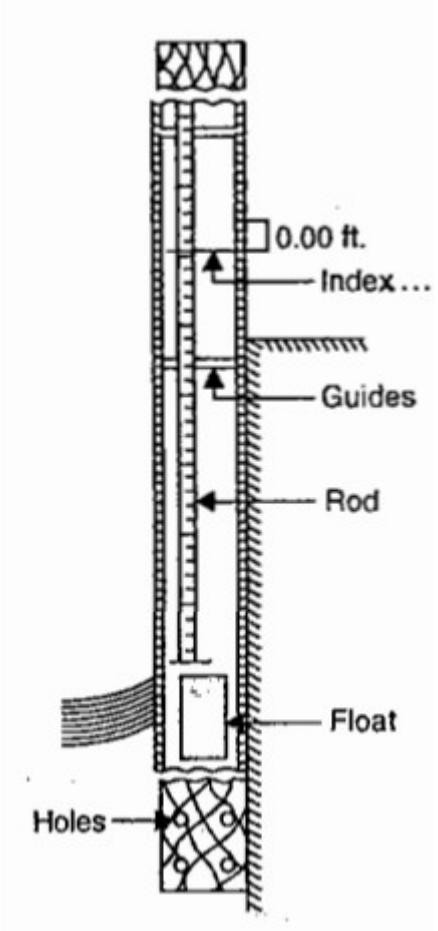


Tide Board or Tide Staff

Tide Gauges

2. Float Gauge

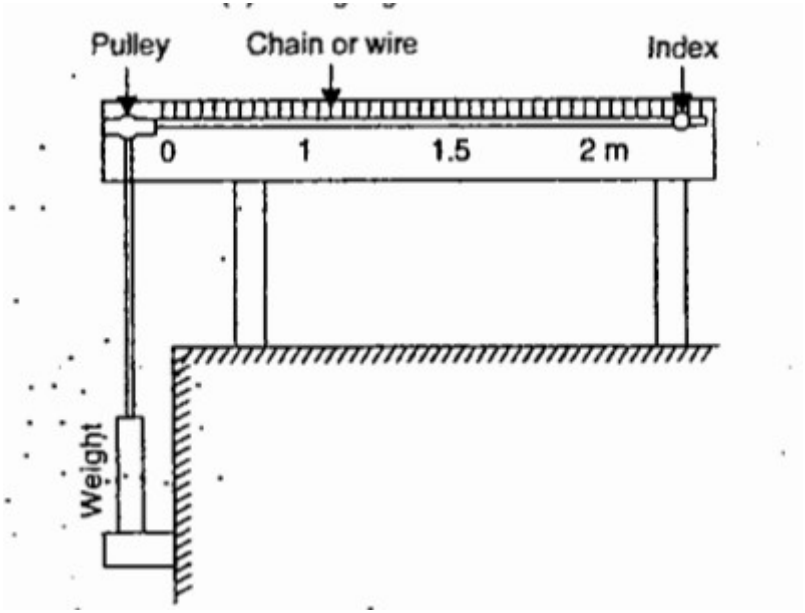
- On account of the wash of the sea, it may be difficult to read a staff gauge accurately. In that case, a float gauge may be used.
- It consists of a simple float with a graduated vertical rod, enclosed in a long wooden box of 30cm*30cm square section. The box has few holes at the bottom through which water may enter and lift the float.
- The readings are taken through a slit window against some suitable index.



Tide Gauges

3. Weight Gauge

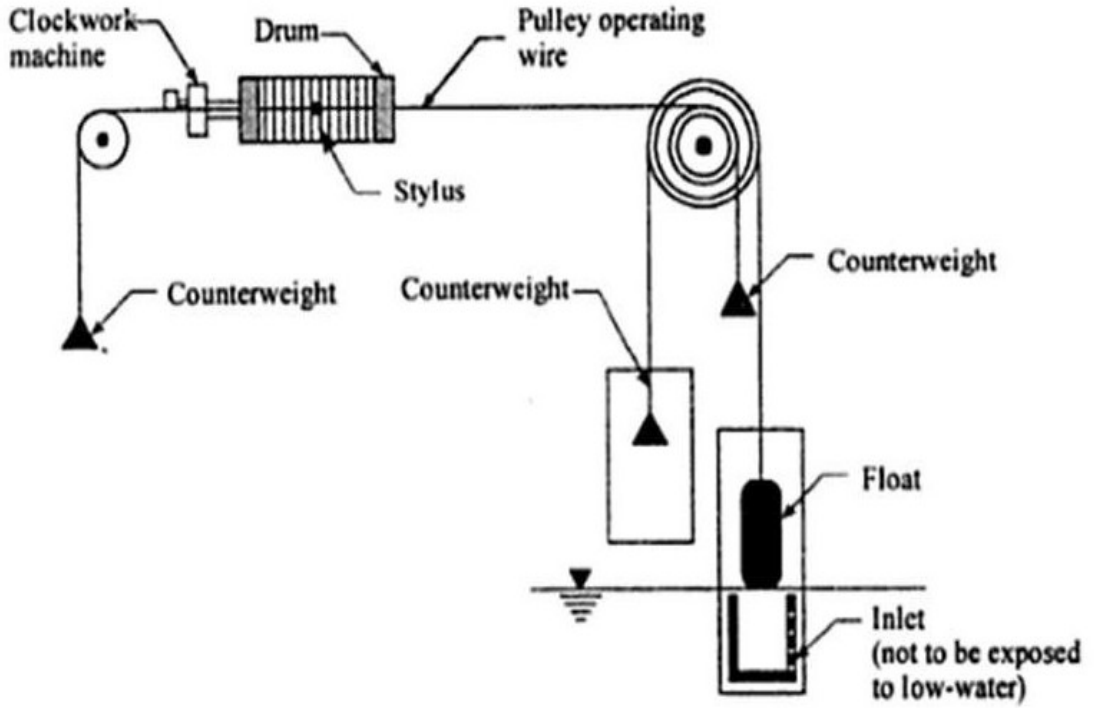
- The weight gauge consists of a weight attached to a wire or chain. The chain passes through a pulley, along the side of a graduated board.
- The weight is lowered to touch the water surface and the reading is taken against an index attached to the chain.



Tide Gauges

Self-registering Gauges:

- A self-registering gauge automatically registers the variation of water level with time.
- It essentially consists of a float protected from wind, waves etc. The float has attached to a wire or cord which passes over a wheel (called the float wheel) and is maintained at constant tension by some suitable arrangement.
- This type of gauge is usually housed in a well constructed under a building so that effect of wind and other disturbances is reduced.




THANK YOU