Lesson 10: Tides

- **Learning Objectives**:
  - Comprehend general causes and types of tides.
  - Understand tidal reference planes and their uses as depth and height references on nautical charts.
  - Apply correct procedures in the use of the Tide Tables to construct a complete tide table for a locality of interest and to find the expected tide for a particular time of interest.
  - Apply correct procedures in the use of the Tide Tables to determine the clearance under a bridge or overhanging obstruction, or depth of water over a shallow bottom at a particular time or period of interest.
  - Applicable reading: Hobbs pp 178-200.

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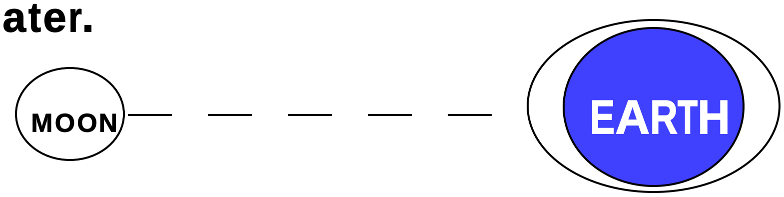
- ***Tide*** **- The vertical rise and fall of the surface of a body of water caused primarily by the differences in gravitational attraction of the moon, and to a lesser extent of the sun, upon different parts of the earth.**
  - **The moon is many times closer to the earth than the sun, so its gravitational pull is two-and-a-quarter times more pronounced, even though the sun's mass is thousands of times greater.**



  - **The strong gravitational pull of the moon on the side of the earth nearest the sun, together with the strong outward centrifugal force generated by the earth-moon system on the opposite side of the earth, cause the water on the earth's surface to bulge out in the form of high tides on both sides. The same phenomenon occurs between the sun and the earth but on a much smaller scale.**
  - **The moon revolves around the earth once each month. Since the earth rotates beneath it in the same direction, it takes 24 hrs and 50 min for the earth to complete one revolution with respect to the moon. This period is known as a tidal day.**
    - **Most locations on earth experience four tides per day; two high tides and two low tides. Each successive high and low tide constitutes one tide cycle.**
    - **At some locations, tide patterns are distorted from the normal 4-tide pattern because of the effects of land**

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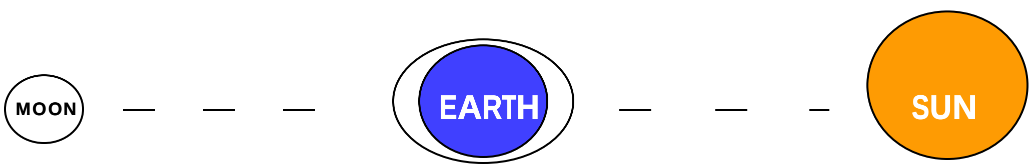
masses, constrained waterways, friction, the coriolis effect, and other effects.

– **Spring tides:** The tidal effects of the sun and the moon act in concert twice a month, once near the time of the new moon when the moon and sun are on the same side of the earth as the sun, and again near the time of the full moon, when it is at the opposite side of the earth from the sun. Tides at these times are unusually high or low.

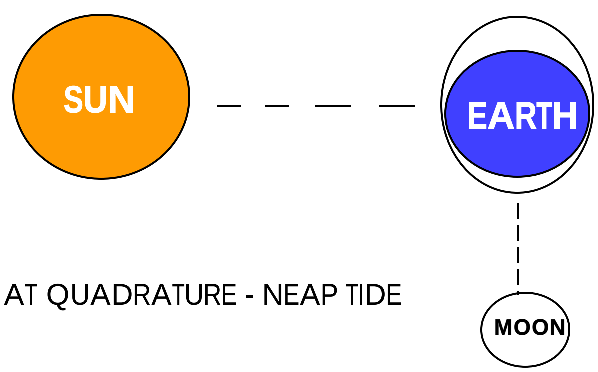
NEW MOON - SPRING TIDE



FULL MOON - SPRING TIDE

(Overhead 10-1)

– **Neap tides:** The tidal effects of the sun and the moon are in opposition to one another when the moon is at quadrature - the first and last quarter - at which times the moon is located at right angles to the earth-sun line. At these times, high tides are lower and low tides are higher than usual.



MOON AT QUADRATURE - NEAP TIDE

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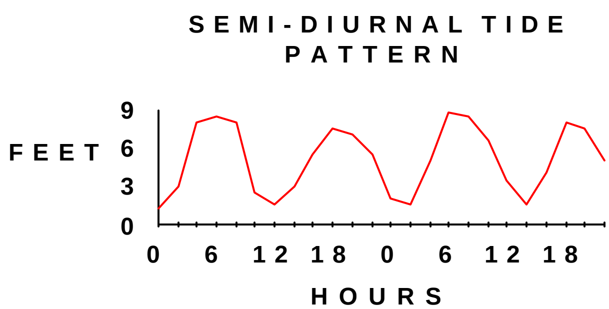
- **<u>Terms associated with tides:</u>**
  - **<u>Sounding datum</u> - An arbitrary reference plane to which both heights of tides and water depths expressed as soundings are referenced on a chart.**
  - **<u>High tide or high water</u> - The highest level normally attained by an ascending tide during a given tide cycle. Its height is expressed in feet or meters relative to the sounding datum.**
  - **<u>Low tide or low water</u> - The lowest level usually attained by a descending tide during a tide cycle. Its height is expressed in feet or meters relative to the sounding datum.**
  - **<u>Range of tide</u> - The vertical difference between the high and low tide water levels during any given tidal cycle. It is expressed in feet or meters.**
  - **<u>Stand</u> - The brief period during high and low tides when no change in the water level can be detected.**
- **<u>Types of Tides:</u>**
  - ***Semidiurnal tide*- This is the tide pattern observed over most of the world. There are *two high and two low tides each tidal day*. Usually there are only slight variations in the heights of any successive high or low waters. Tides at most locations on the U.S. Atlantic coast are representative of this pattern.**



(Overhead 10-2)

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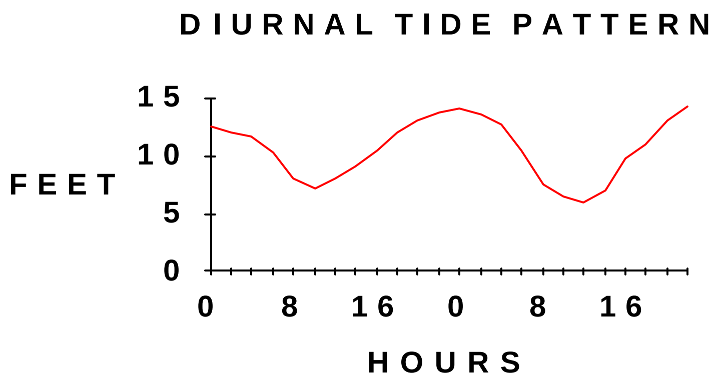
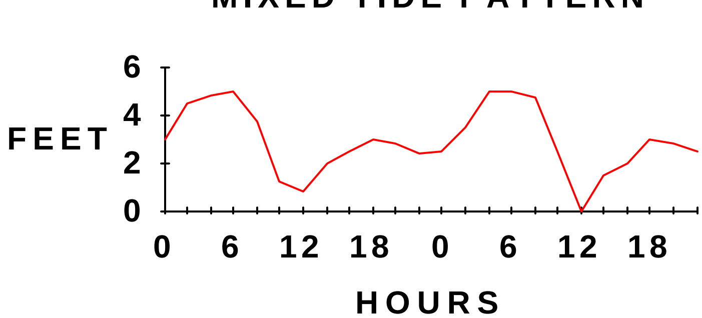
– **<u>Diurnal tide</u> - This tide pattern has only a single high and a single low water occur each tidal day; high and low tide levels on succeeding days usually do not vary a great deal. Tides of this type appear along the northern shore of the Gulf of Mexico, in the Java Sea, and in the Tonkin Gulf.**



– **<u>Mixed</u> - This tide pattern is characterized by wide variation in heights of successive high and low waters, and by longer tide cycles than those of the semi-diurnal tide. This tide pattern is prevalent on the U.S. Pacific Coast, and on many Pacific islands.**

MIXED TIDE PATTERN



- **<u>Tidal Reference Planes:</u> Standard reference planes are necessary in order to make measurements used by the navigator meaningful. In general, heights and elevations are given on a chart with reference to a standard *high-water reference plane,* and heights of tide and charted depths are**

given with respect to a standard *low-water reference plane.*

- Mean high-water springs (MHWS) - The highest of all high-water reference planes, is the average height of all spring tide high-water levels.
- Mean higher high water (MHHW) - The average of the higher of the high water levels occurring during each tidal day at a location, measured over a 19-year period.
- Mean high water (MHW) - The average of all high-tide water levels, measured over a 19-year period. It is the high-water reference plane used on most charts produced by the United States for the basis of the measurement of heights, elevations, and bridge clearances.
- Mean high-water neaps (MHWN)- The lowest of all high-water reference planes; it is the average recorded height of all neap tide high-water levels.
- Mean low water neaps (MLWN) - The highest of all common low-water reference planes; It is the average height of the all neap tide low-water water levels.
- Mean low water (MLW) - The average height of all low-tide water levels observed over a period of 19 years.
- Mean lower low water (MLLW) - The average of the lower of the low water levels experienced at a location over a 19-year period. It is the low-water reference plane used for charts of the U.S. Pacific, U.S. Atlantic, and Gulf coasts, as a basis for measurement of charted depth and height of tide.
- Mean low water springs (MLWS) -The lowest of all low-water reference planes; it is the average of all spring tide low-water levels. It is the sounding depth on which most

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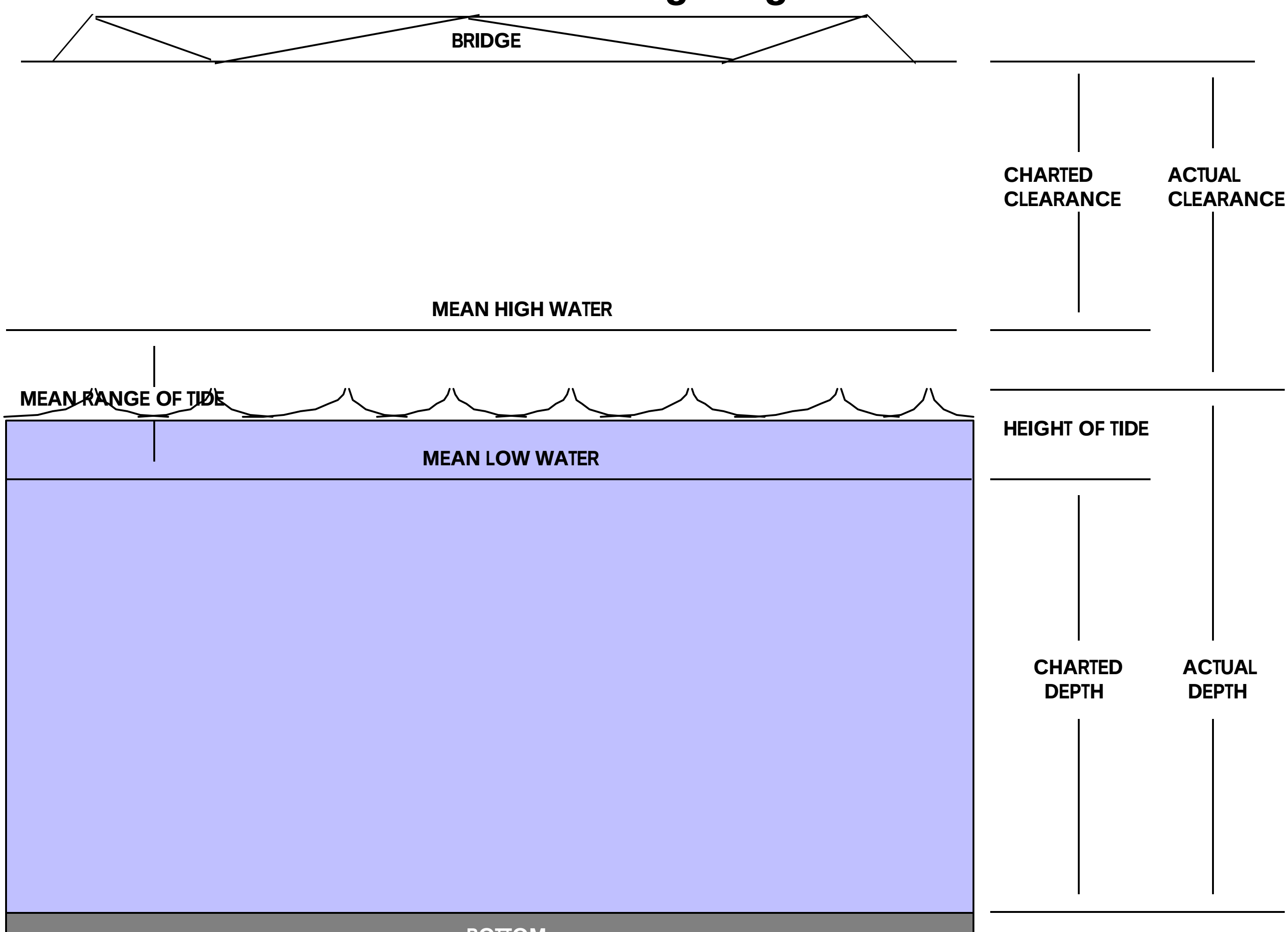
water depths of foreign charts are based.

– To help visualize the relationship between these reference planes, the charted depth, height of tide, and clearance under a bridge, suppose the navigator had a chart that used mean high water for the high water reference plane from which charted heights and bridge clearances were reckoned, and mean low water, for water depths and heights of tide. The physical relationships that would exist are illustrated in the following diagram:



(Overhead 10-3)

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- The mean high water and mean low water reference planes represent the average limits within which the water level would normally be located. The <u>mean range of tide</u> is the vertical distance between these two planes; it represents the average range of tide at this location.
  - The actual water level will occasionally fall below the mean low water plane, particularly around the time of spring tides. Height of tide in this situation is negative.
  - The actual vertical clearance will sometimes be smaller than indicated on a chart using mean high water as its reference plane for heights/clearances.

- <u>Predicting height of tide:</u> The exact depth of the water is a key factor when navigating over sandbars and shoals and underneath bridges. Moreover, the height of the tide will need to be calculated when going to anchorage, so the proper amount of anchor chain can be let out, or pierside, in order to allow for the proper amount of slack in the mooring lines.
  - In order to perform the necessary calculation for the height of the tide, the navigator refers to the Tide Tables.
  - The Tide Tables are arranged geographically with one volume covering each of the following areas: East Coast, North and South America; West coast, North and South America; Europe and West Coast of Africa; and Central and Western Pacific and Indian Oceans.
    - The *Tide Tables* contain daily predictions of the times of high and low tides at some 190 major reference ports throughout the world. They also list differences in times of tides from specific reference ports for an additional 5,000 locations referred to as subordinate stations.

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» **Each volume of the Tide Tables is made up of seven tables. The first three are of primary interest for making tide predictions:**

- **<u>Table 1</u> lists the times and heights of tide in both feet and meters at each high and low water, in chronological order for each day of the year at the reference stations used in that volume.**
  - **Normally there will be two high tides and two low tides on any given day, and there will be a high or low tide about every six hours.**
  - **A negative sign appearing before the height of tide figure indicates that this low tide falls below the tidal reference plane, which for this volume of the Tide Tables is mean low water.**
  - **If the port is keeping daylight savings time, each tide time prediction must be adjusted by adding one hour to the time listed.**
- **<u>Table 2</u> contains a listing of tide time and height difference data, as well as other useful information, for each of the *subordinate stations* located within the area of coverage of that volume*.***
- **<u>Table 3</u> is used primarily to find the height of tide at any given time, after daily tide predictions for a given location have been computed; it can also be used to find the time frame within which the tide will be either above or below a desired height.**

– **<u>Example:</u> Construct a Tide Table for Brooklyn Bridge for 4 November (NOTE: This example was worked using the <u>1984</u>**

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TIDE TABLES in order to allow students to follow along with their tables. It follows the same procedures described in Hobbs' text).

– The navigator uses the first three tables in the Tide Tables in conjunction with a standard tide form (Appendix A).
  - » The top part of the form is designed for construction of a daily tide table for a given reference or subordinate station, making use of tables 1 and 2.
  - » The bottom part of the form is used for computing the height of the tide at a given time at the designated location, using information from table.
  - » Step 1: Locate the subordinate reference station difference data by referring to the index for Table 2 in the back of the proper *Tide Table* volume. In this case the East Coast of North and South America (A portion of the the index appears in App. B). The subordinate station number of Brooklyn Bridge is found to be 1313.
  - » Step 2: Turn to the station number in Table 2 (illustrated in App. C) and record the Brooklyn Bridge time and height-difference data on the top of the tide form. Then, locate the reference station for the Brooklyn Bridge; the reference station appears in boldfaced type in the "Differences" column above the subordinate station data. In our example, the reference station is New York (at the Battery), located on page 56 of Table 1.
  - » Step 3: Turn to Table 1 (Appendix D)at the appropriate page and record the daily predictions for New York at the Battery for 4 November. The last tide event for the

preceding day is also recorded due to the fact that a time correction may cause this event to actually occur on 4 November.

» Step 4: Add the tide and time difference data to the daily prediction data for New York, with care being taken to use high-water difference figures for high water time and height conversions and low-water difference figures for low water conversions.

- At this time, it is noted that when the lower-water time difference, +10 minutes, is added to the last tide on the 3rd-a low tide at 2310-it does not result in this tide appearing at the bridge on the 4th; this entry is now dropped from consideration.
- It is important to note that the preceding day's last tide were recorded on the tide form. Conversely, If the subordinate station time differences were negative, then the first tide event on the following day at the reference station should be recorded because the addition of a negative time correction could result in a tide occurring on the day in question at the subordinate station.

» Step 5: The height of the tide at Brooklyn Bridge at 0900 is calculated using the bottom section of the tide form.

- First, the duration of the falling tide from the 0541 high water to the 1142 low water is computed (6 hrs and 01min).
- Second, the time from the nearest tide comprising the tide cycle, in this case the 1142 low, is computed (2 hrs and 42 min).

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- Third, Table 3 (Appendix E) is entered at the top left with the tabulated duration of rise or fall that is closest to the computed value; in this case the entering argument is 6 hrs and 00 min.
  - The tabulated time from the nearest high or low water closest to the computed value is found directly across to the right from the entering argument; for this problem, it is 2 hrs and 36 min. Since the time falls in between 2hrs and 36 min and 2 hrs and 48 min, the time further from the low water is taken in order to allow for a greater safety margin.
  - The correction sought is in the bottom half of the table, directly beneath this second argument, and opposite the tabulated range of tide that most closely matches the actual range of tide; the correction found is +1.4 feet.
  - This correction is applied to the 1142 low water to find the height of tide at 0900 of 1.9 feet.
  - NOTE: This example was worked under the assumption that the location of interest was observing standard zone time. If daylight savings were in effect, it would be necessary to convert all reference station daily predictions to daylight savings time by adding one hour.

- The bridge problem: When piloting in coastal waters, it may be necessary to pass underneath an overhanging obstruction such as a bridge or cable.

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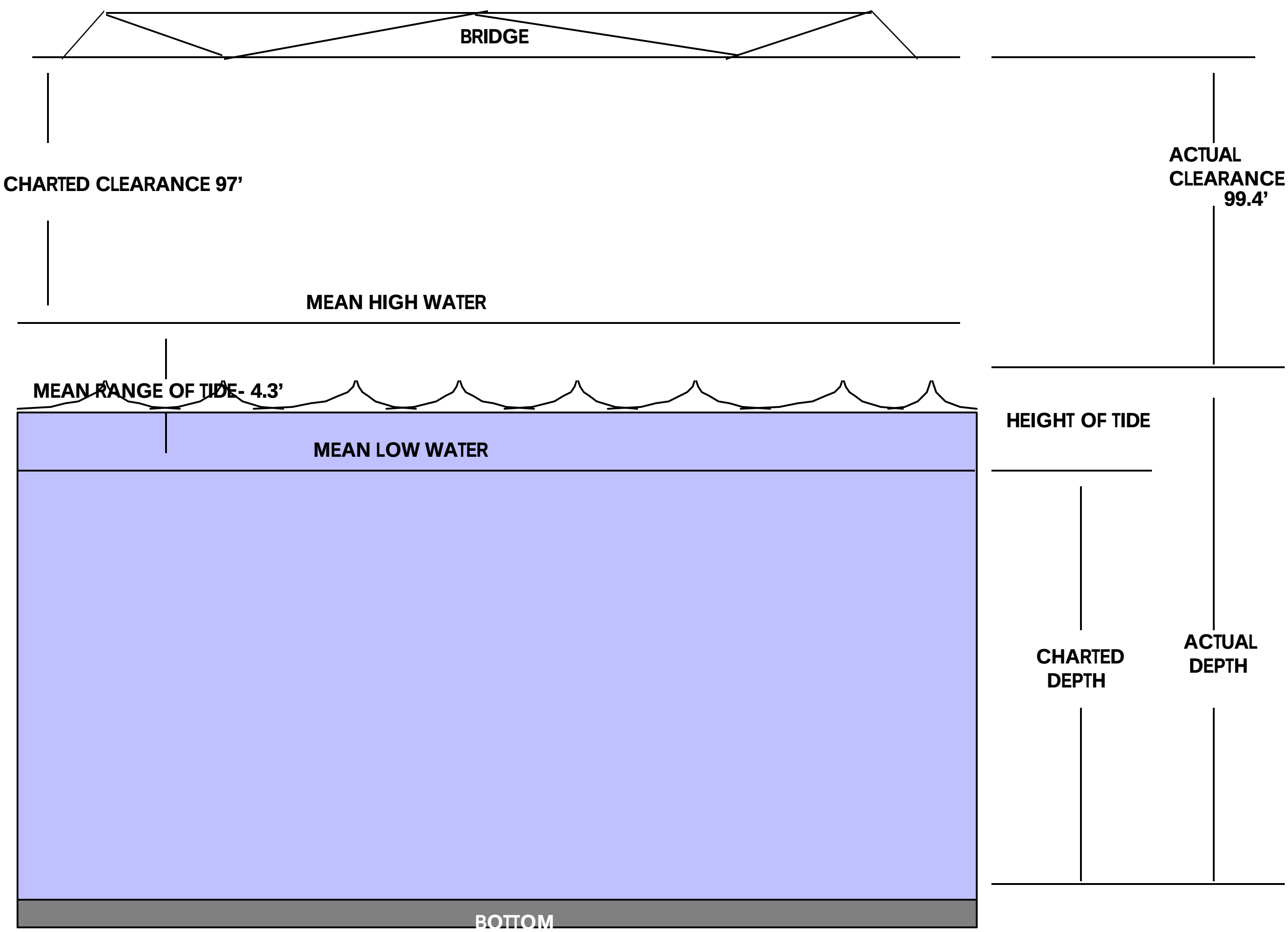
– The navigator must determine whether or not the ship can pass safely under the obstruction at the time it is scheduled to pass underneath it. If the ship cannot, a time frame must be determined within which the ship can safely pass.

– In the previous example, the charted clearance of the Brooklyn bridge was 97 ft, and the masthead height of the ship was 100 ft. The drawing below depicts the physical relationships that exist at 0900:



(Overhead 10-4)

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- **The height of the tide at 0900 was calculated to be +1.9 ft. The mean range of tide can be found by referring to table 2 of the *Tide Tables;* in this example it is 4.3 feet. The actual bridge clearance is given by the algebraic sum:**

  97 + (4.3 - 1.9) = 99.4 feet

  Charted Clearance + (Mean range - height of tide) = Actual clearance

- **The ship cannot pass beneath the bridge, so a time span when the ship can pass underneath safely must be calculated.**
- **The diagram on the following page shows that the actual vertical clearance under the bridge must be equal to or greater than 100 ft. The following equation expresses the quantity we are looking for:**

  100 <= 97+ (4.3-x)

  Required clearance <= Charted clearance + (Mean range - height of tide)

- **Solving the equation yields a value of 1.3 feet which indicates that the passage must be made beneath the bridge close to the time of low tide.**
- **Referring to the tide table in the previous calculation, it can be determined that the low tide nearest the desired 0900 time of passage is the low tide occurring at 1142, which is 0.5 feet. This height is .8 feet below the tide height at which the mast would strike the bridge.**
- **To find the time frame around the 1142 low tide within which the height of tide will be at or below 1.3 ft, we must work through Table 3 “in reverse”.**

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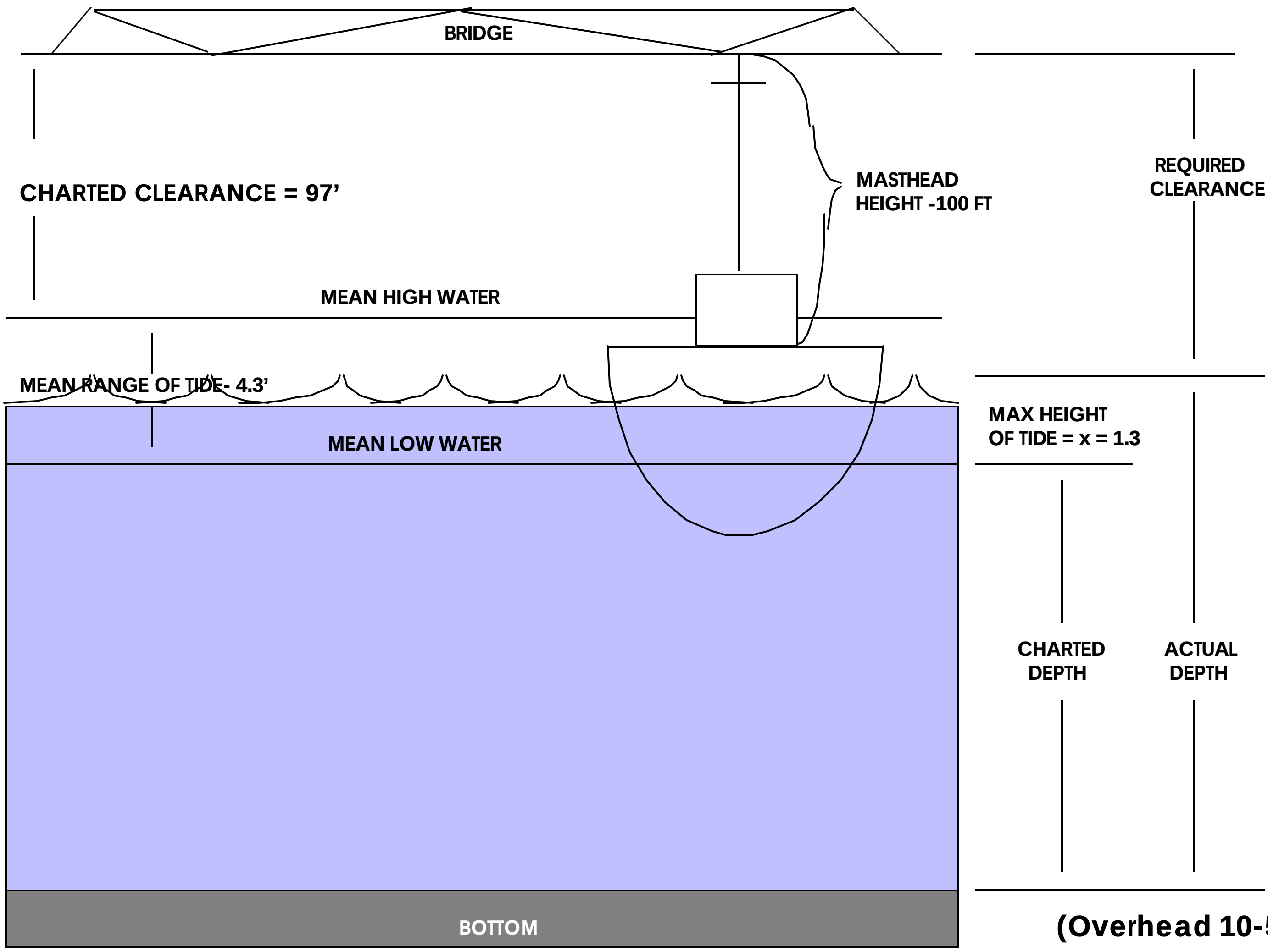

(Overhead 10-5)

- The entering arguments are the maximum acceptable correction to the height of the 1142 tide, and the ranges of tide and durations of rise or fall for the tide cycles on each side of the 1142 low tide. It will be necessary to work through the table twice - once to find the earlier time, and once to find the later.
- The height correction is the same in both cases,

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.8 feet [1.3-.5]. To find the earliest time, the period between 0541 and 1142 is considered. The range of the tide during this period is 3.4 feet, and the duration of the fall is 6 hrs and 01 min.

- <u>Step 1:</u> Enter the table (App F.) at 3.3 as it is the closest value to 3.4, then move across to find the value closest to our maximum correction of .8 feet. Since the max correction falls between two values, the lower value is taken as this allows for a greater safety margin (0.7ft).
- <u>Step 2:</u> Follow the column corresponding to .7 ft vertically to the row corresponding to the duration of fall closest to 6 hrs and 01 min. This value is 6 hrs and 00 min, and the corresponding time correction is 1 hr and 48 min.
- <u>Step 3:</u> Subtract this value from 1142 and arrive at an early time of 0954. To find the later time, the same procedure is followed with the tide cycle following the 1142 low (1142 to 1756) . The resultant later time is 1336.

- <u>The shoal problem:</u> This situation is analogous to the bridge clearance problem. It occurs when a ship must pass over a shoal or sandbar.
  - The same procedure as the bridge problem is applied with the exception that the times on each side of a high tide when the tide will be above a certain level is calculated.
    - » The actual depth of the water must be equal to or greater than the sum of the ship's draft, plus an appropriate safety factor.

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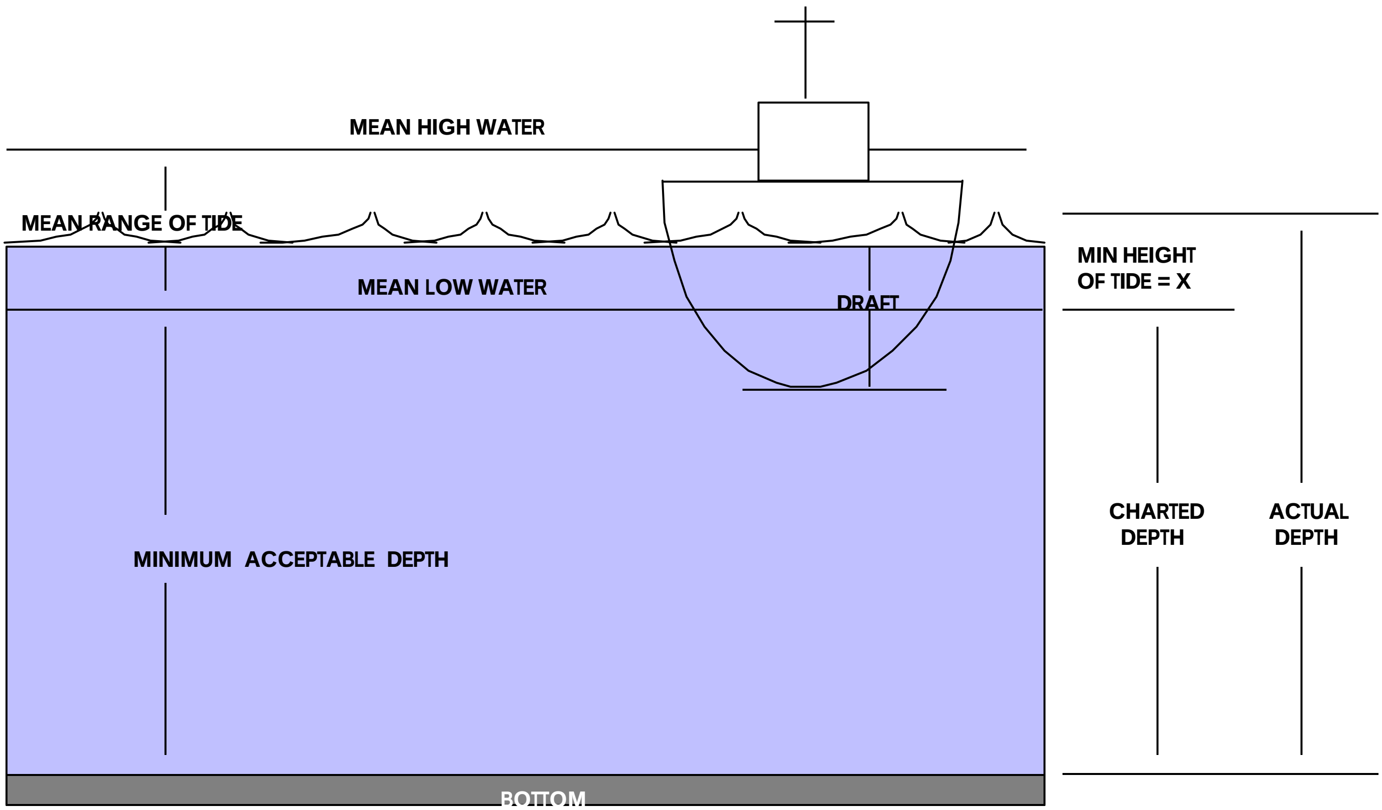
– **Once the minimum allowable height of tide is determined, the time frame is found using *Tide Table 3*.**



(Overhead 10-6)

– **<u>Effect of unusual Meteorological Conditions</u> - It is important to note that the time, tide and height predictions given in the *Tide Tables* are based on the assumption that normal weather conditions will prevail. Heights of tide, for example, are based on a normal barometric pressure of 29.92 inches of mercury. If the pressure falls by one inch, sea level in the area may rise by as much as a foot. The navigator, faced with a transit underneath a bridge or over a shoal, will schedule the transit as close to the time of a high or low tide in order to provide for the greatest possible safety margin.**

Tides

(Overhead 10-7)

Insert Tide Form
(given with original
draft)

Tides

(Overhead 10-8)

Insert Excerpt from 1984
Tide Tables Index to Stations
(page 271)

Tides

(Overhead 10-9)

Insert Excerpt from 1984
Tide Tables Table II
(page 211)

Appendix C - Table 2

Tides

(Overhead 10-10)

Insert Excerpt from 1984
Tide Tables Table I
(page 59)

Appendix D - Table 1

Tides

(Overhead 10-11)

Insert Excerpt from 1984
Tide Tables Table III
(page 239)

Appendix E - Table 3 (Normal Tide Calculation)

Tides

(Overhead 10-12)

Insert Excerpt from 1984
Tide Tables Table III
(page 239)

Appendix F - Table 3 (Bridge Problem)