Catalog

4.1 INTRODUCTION

Photogrammetry

- Introduction
- Terrestial and aerial Photographs
- Stereoscopy
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PHOTOGRAMMETRIC SURVEYING

Photogrammetric surveying or photogrammetry is the science and art of obtaining accurate measurements by use of photographs, for various purposes such as the construction of planimetric and topographic maps, classification of soils, interpretation of geology, acquisition of military intelligence and the preparation of composite pictures of the ground.

PRINCIPLES BEHIND TERRESTRIAL PHOTOGRAMMETRY.

The principle of terrestrial photogrammetry was improved upon and perfected by Capt. Deville, then Surveyor General of Canada in 1888. In terrestrial photogrammetry, photographs are taken with the camera supported on the ground. The photographs are taken by means of a photo theodolite which is a combination of a camera and a theodolite. Maps are then compiled from the photographs.

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of the ground. The photographs are taken either from the air or from station on the ground. Terrestrial photogrammetry is that Brach of photogrammetry wherein photographs are taken from a fixed position on or near the ground. Aerial photogrammetry is that branch of photogrammetry wherein the photographs are taken by a camera mounted in an aircraft flying over the area. Mapping from aerial photographs is the best mapping procedures yet developed for large projects, and are invaluable for military intelligence. The major users of aerial mapping methods are the civilian and military mapping agencies of the Government.

The conception of using photographs for purposes of measurement appears to have originated with the experiments of Aime Laussedat of the Corps of the French Army, who in 1851 produced the first measuring camera. He developed the mathematical analysis of photographs as perspective projections, thereby increasing their application to topography. Aerial photography from balloons probably began about 1858. Almost concurrently (1858), but independently of Laussedat, Meydenbauer in Germany carried out the first experiments in making critical measurements of architectural details by the intersection method in the basis of two photographs of the building. The ground photography was perfected in Canada by Capt. Deville, then Surveyor General of Canada in 1888. In Germany, most of the progress on the theoretical side was due to Hauck.

In 1901, Pulfrich in Jena introduced the stereoscopic principle of measurement and designed the stereo comparator. The stereoaitograph was designed (1909) at the Zeiss workshops in Jena, and this opened a wide field of practical application. Scheimpflug, an Australian captain, developed the idea of double projector in 1898. He originated the theory of perspective transformation and incorporated its principles in the photoperspecto graph. He also gave the idea of radial triangulation. His work paved the way for the development of aerial surveying and aerial photogrammetry.

In 1875, Oscar Messter built the first aerial camera in Germany and J.W. Bagloy and A. Brock produced the first aerial cameras in U.S.A. In 1923, Bauersfeld designed the Zeiss stereoplanigraph. The optical industries of Germany, Switzerland, Italy and France, and later also those of the U.S.A and U.S.S.R. took up the manufacture and constant further development of the cameras and plotting instruments. In World War II, both the sides made extensive use of aerial photographs for their military operations.

World War II gave rise to new developments of aerial photography techniques, such as the application of radio control to photo flight navigation, the new wide-angle lenses and devices to achieve true vertical photographs.

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The principle underlying the method of terrestrial photogrammetry is exactly similar to that of plane table surveying, i.e. if the directions of same objects photographed from two extremities of measured base are known, their position can be located by the intersection of two rays to the same object. However, the difference between this and plane tabling is that more details are at once obtained from the photographs and their subsequent plotting etc. is done by the office while in plane tabling all the detailing is done in the field itself.

Thus in Fig , A and B are the two stations at the ends of base AB. The arrows indicate the directions of horizontal pointing (in plan) of the camera. For each pair of pictures taken from the two ends, the camera axis is kept parallel to each other. From economy and speed point of view, minimum number of photographs should be used to cover the whole area and to achieve this, it is essential to select the best positions of the camera stations. A thorough study of the area should be done from the existing maps, and a ground reconnaissance should be made. The selection of actual stations depends upon the size and ruggedness of the area to be Surveyed. The camera should be directed downward rather than upward, and the stations should be at the higher points on the area. The terrestrial photogrammetry can be divided into two branches:

(i) Plane-table photogrammetry.

(ii) Terrestrial stereo photogrammetry

The **plane table photogrammetry** consists essentially in taking a photograph of the area to be mapped from each of the two or three stations. The photograph perpendiculars may be oriented at any angle to the base, but usually from an acute angle with the latter. The main difficulty arises in the identifications of image points in a pair of photographs. In the case of homogeneous areas of sand or grass, identification becomes impossible. The principles of stereo photogrammetry, however, produced the remedy.

In **terrestrial stereo photogrammetry**, due to considerable improvement of accuracy obtained by the stereoscopic measurement of pairs of photographs, the camera base and the angles of intersection of the datum rays to the points to be measured can be considerably reduced since the camera axes at the two stations exhibit great similarity to each other. The image points which are parallactically displaced relative to each other in the two photographs are fused to a single spatial image by the stereoscopic measurement.

4.2 Hydrographic Surveying

- Tides
- MSL
- Sounding methods
- Location of soundings and methods
- Three-point problem
- Strength of fix
- Sextants and station pointer
- River surveys
- Measurement of current and discharge

The shore line surveys consist of:

(i) Determination or delineation of shore lines,

(ii) Location of shore details and prominent features to which soundings may be connected,

(iii) Determination of low and high water lines for average spring tides,

The determination or delineation of shore lines is done by traversing along the shore and taking offsets to the water edge by tape, or stadia or plane table. If the river is narrow, both the banks may be located by running a single line of traverse on one bank. For wide rivers, however, transverse may be run along both the banks. The traverse should be Connected at convenient intervals to check the work. Thus, the Fig. two traverses XY and X

- Y-- along the two opposite shores may be checked by taking observations from A and B to the points C and D. When the instrument is at B, angles ABC and ABD can be measured. From the measured length of AB and the four angles, the length CD can be calculated. If this agrees with the measured length of CD, the work is checked. Sometimes, a triangulation net is run along a wide river. In sea shore survey, buoys anchored off the shore and light houses are used as reference points and are located by triangulation.

In the case of tidal water, it is necessary to locate the high and low water lines. The position of high water line may be determined roughly from shore deposits and marks on rocks. To determine the high water line accurately, the elevation of mean high water of ordinary spring tide is determined and the points are located on the shore at that elevation as in direct method of contouring. The low water line can also be determined similarly. However, since the limited time is available for the survey of low water line, it is usually located by interpolation from soundings.

Sounding and the methods employed in sounding.

The measurement of depth below the water surface is called sounding. This corresponds to the ordinary spirit leveling in land surveying where depths are measured below a horizontal line established by a level. Here, the horizontal line or the datum is the surface of water, the level of which continuously goes on changing with time. The object of making soundings is thus to determine the configuration of the sub aqueous source. As stated earlier, soundings are required for:

(i) Making nautical charts for navigation;

(ii) Measurement of areas subject to scour or silting and to ascertain the quantities of dredged material;

(iii) Making sub-aqueous investigations to secure information needed for the construction, development and improvement of port facilities.

For most of the engineering works, soundings are taken form a small boat. The equipment needed for soundings are:

(i) Sounding boat

(ii) Sounding rods or poles

(iii) Lead lines

(iv) Sounding machine

(iv) Fathometer.

Sounding boat

A row-boat for sounding should be sufficiently roomy and stable. For quiet water, a flat bottom boat is more suitable, but for rough water round-bottomed boat is more suitable. For regular soundings, a row boat may be provided with a well through which sounds are taken. A sounding platform should be built for use in smaller boat. It should be extended far enough over the side to prevent the line from striking the boat. If the currents are strong, a motor or stream launch may be used with advantage.

Sounding rods or poles

A sounding rod is a pole of a sound straight-grained well-seasoned tough timber usually 5 to 8 cm in diameter and 5 to 8 metres long. They are suitable for shallow and quiet waters. An arrow or lead shoe of sufficient weights fitted at the end. This helps in holding them upright in water. The lead or weight should be of sufficient area so that it may not sink in mud or sand. Between soundings it is turned end for end without removing it from the water. A pole of 6 m can be used to depths unto 4 meters.

Lead lines

A lead line or a sounding line is usually a length of a cord, or tiller rope of Indian hemp or braided flax or a brass chain with a sounding lead attached to the end. Due to prolonged use, a line of hemp or cotton is liable to get stretched. To graduate such a line, it is necessary to stretch it thoroughly when wet before it is graduated. The line should be kept dry when not in use. It should be soaked in water for about one hour before it is used for taking soundings. The length of the line should be tested frequently with a tape. For regular sounding, a chain of brass, steel or iron is preferred. Lead lines are usually used for depths over about 6 meters.

Sounding lead is a weight (made of lead) attached to the line. The weight is conical in shape and varies from 4 to 12 kg depending upon the depth of water and the strength of the current. The weight should be somewhat streamlined and should have an eye at the top for attaching the cord. It often has cup-shaped cavity at the bottom so that it may be armed with land or tallow to pick up samples from the bottom. Where the bottom surface is soft, lead- filled pipe with a board at the top is used with the lead weight. The weight penetrates in the mud and stops where the board strikes the mud surface.

Suggested system of marking poles and lead lines

The U.S. Coast and Geodetic survey recommends the following system of marking the poles and the lead lines:

Poles:

Make a small permanent notch at each half foot. Paint the entire pole white and the spaces between the 2- and 3-, the 7- and 8-and the 12- and 13-ft marks black. Point red bands at the 5- and 10-ft marks, in black band at each of the other foot marks and bands at the half foot marks. These bands are black where the pole is white and vice versa.

Lead Lines: A lead line is marked in feet as follow: Feet Marks

2, 12, 22 etc	Red bunting
4, 14, 24 etc	White bunting
6, 16, 26 etc	Blue bunting
8, 18, 28 etc	Yellow bunting
10, 60, 110 etc	One strip of leather
20, 70, 120 etc	Two strips of leather
30, 80, 130 etc	Leather with two holes
40, 90, 140 etc	Leather with one holes
50	Star-shaped leather
100	Star-shaped leather with one hole

The intermediate odd feet (1,3,5,7,9 etc.) are marked by white seizing.

Sounding Machine

Where much of sounding is to done, a sounding machine as very useful. The sounding machine may either be hand driven or automatic. Fig.4.3. show a typical hand driven Weddele's sounding machine.

The lead weight is carried at the end of a flexible wire cord attached to the barrel and can lowered at any desired rate, the speed of the drum being controlled by means of a break.

The readings are indicated in two dials-the outer dial showing the depth in feet and the inner showing tenths of a foot. A handle is used to raise the level which can be suspended at any height by means of a paul and ratchet. The sounding machine is mounted in a sounding boat and can be used up to a maximum depth of 100 ft.

Fathometer: Echo-sounding

A Fathometer is used in ocean sounding where the depth of water is too much, and to make a continuous and accurate record of the depth of water below the boat or ship at which it is installed. It is an *echo-sounding* instrument in which water depths are obtained be determining the time required for the sound waves to travel from a point near the surface of the water to the bottom and back. It is adjusted to read depth on accordance with the velocity of sound in the type of water in which it is being used. A fathometer may indicate the depth visually or indicate graphically on a roll which continuously goes on revolving and provide a virtual profile of the lake or sea.

The main parts of an echo-sounding apparatus are:

1. Transmitting and receiving oscillators.
2. Recorder unit.
3. Transmitter / Power unit.

Figure illustrates the principal of echo-sounding. It consists in recording the interval of time between the emission of a sound impulse direct to the bottom of the sea and the reception of the wave or echo, reflected from the bottom. If the speed of sound in that water is v and the time interval between the transmitter and receiver is t, the depth h is given by

$$h = 1/2\ vt$$

Due to the small distance between the receiver and the transmitter, a slight correction is necessary in shallow waters. The error between the true depth and the recorded depth can be calculated very easily by simple geometry. If the error is plotted against the recorded depth, the true depth can be easily known. The recording of the sounding is produced by the action of a small current passing through chemically impregnated paper from a rotating stylus to an anode plate. The stylus is fixed at one end of a radial arm which revolves at constant speed. The stylus makes a record on the paper at the instants when the sound impulse is transmitted and when the echo returns to the receiver.

Advantage of echo-sounding

Echo-sounding has the following advantages over the older method of lead line and rod:

1. It is more accurate as a truly vertical sounding is obtained. The speed of the vessel does deviate it appreciably from the vertical. Under normal water conditions, in ports and harbors an accuracy of 7.5 cm may be obtained.
2. It can be used when a strong current is running and when the weather is unsuitable for the soundings to be taken with the lead line.
3. It is more sensitive than the lead line.
4. A record of the depth is plotted immediately and provides a continuous record of the bottom as the vessel moves forward.
5. The speed of sounding and plotting is increased.
6. The error due to estimation of water level in a choppy sea is reduced owing to the instability of the boat.
7. Rock underlying softer material is recorded and this valuable information is obtained more cheaply than would be the case where sub-marine borings are taken.

Making the soundings

If the depth is less than 25 m, the soundings can be taken when the boat is in motion. In the case of soundings with rod the leadsman stands in the bow and plunges the rod at a forward angle, depending on the speed of the boat, such that the rod is vertical when the boat reaches the point at which soundings is being recorded. The rod should be read very quickly. The nature of the bottom should also be recorded at intervals in the note-book.

If the sounding is taken with a lead, the leadsman stands in the bow of the boat and casts the lead forward at such a distances that the line will become vertical and will reach the bottom at a point where sounding is required. The lead is withdrawn from the water after the reading is taken. If the depth is great, the lead is not withdrawn from the water, but is lifted between the soundings.

The water surface, which is also the reference datum, changes continuously. It is, therefore, essential to take the readings of the tide gauges at regular interval so that the soundings can be reduced to a fixed datum. To co-relate each sounding with the gauge reading, it is essential to record the time at which each sounding is made.

Methods employed in locating soundings

The soundings are located with reference to the shore traverse by observations made

(i) entirely from the boat,

(ii) entirely from the shore or from both.

The following are the methods of location

1. By cross rope.
2. By range and time intervals.
3. By range and one angle from the shore.
4. By range and one angle from the boat.
5. By two angles from the shore.
6. By two angles from the boat.
7. By one angle from shore and one from boat.
8. By intersecting ranges.
9. By tacheometry.

Range.

A range or range line is the line on which soundings are taken. They are, in general, laid perpendicular to the shore line and parallel to each other if the shore is straight or are arranged radiating from a prominent object when the shore line is very irregular.

Shore signals.

Each range line is marked by means of signals erected at two points on it at a considerable distance apart. Signals can be constructed in a variety of ways. They should be readily seen and easily distinguished from each other. The most satisfactory and economic type of signal is a wooden tripod structure dressed with white and colored signal of cloth. The position of the signals should be located very accurately since all the soundings are to be located with reference to these signals.

Location by Cross-Rope

This is the most accurate method of locating the soundings and may be used for rivers, narrow lakes and for harbours. It is also used to determine the quantity of materials removed by dredging the soundings being taken before and after the dredging work is done. A single wire or rope is stretched across the channel etc. as shown in Fig.4.6 and is marked by metal tags at appropriate known distance along the wire from a reference point or zero station on shore. The soundings are then taken by a weighted pole. The position of the pole during a sounding is given by the graduated rope or line.

In another method, specially used for harbours etc., a reel boat is used to stretch the rope. The zero end of the rope is attached to a spike or any other attachment on one shore. The rope is would on a drum on the reel boat. The reel boat is then rowed across the line of sounding, thus unwinding the rope as it proceeds. When the reel boat reaches the other shore, its anchor is taken ashore and the rope is wound as tightly as possible. If anchoring is not possible, the reel is taken ashore and spiked down. Another boat, known as the sounding boat, then starts from the previous shore and soundings are taken against each tag of the rope. At the end of the soundings along that line, the reel boat is rowed back along the line thus winding in the rope. The work thus proceeds.

Location by Range and Time Intervals

In this method, the boat is kept in range with the two signals on the shore and is rowed along it at constant speed. Soundings are taken at different time intervals. Knowing the constant speed and the total time elapsed at the instant of sounding, the distance of the total point can be known along the range. The method is used when the width of channel is small and when great degree of accuracy is not required. However, the method is used in conjunction with other methods, in which case the first and the last soundings along a range are located by angles from the shore and the intermediate soundings are located by interpolation according to time intervals.

Location by Range and One Angle from the Shore

In this method, the boat is ranged in line with the two shore signals and rowed along the ranges. The point where sounding is taken is fixed on the range by observation of the angle from the shore. As the boat proceeds along the shore, other soundings are also fixed by the observations of angles from the shore. Thus B is the instrument station, A1 A2 is the range along which the boat is rowed and ϴ1, ϴ 2, ϴ 3 etc., are the angles measured at B from points 1, 2, 3 etc. The method is very accurate and very convenient for plotting. However, if the angle at the sounding point (say angle ϴ) is less than 30 o , the fix becomes poor. The nearer the intersection angle (ϴ) is to a right angle, the better. If the angle diminishes to about 30 ^{o} a new instrument station must be chosen. The only defect of the method is that the surveyor does not have an immediate control in all the observation. If all the points are to be fixed by angular observations from the shore, a note-keeper will also be required along with the instrument man at shore since the observations and the recordings are to be done rapidly. Generally, the first and last soundings and every tenth sounding are fixed by angular observations and the intermediate points are fixed by time intervals. Thus the points with round mark are fixed by angular observations from the shore and the points with cross marks are fixed by time intervals. The arrows show the course of the boat, seaward and shoreward on alternate sections.

To fix a point by observations from the shore, the instrument man at B orients his line of sight towards a shore signal or any other prominent point (known on the plan) when the reading is zero. He then directs the telescope towards the leadsman or the bow of the boat, and is kept continually pointing towards the boat as it moves. The surveyor on the boat holds a flag for a few seconds and on the fall of the flag, the sounding and the angle are observed simultaneously.

The angles are generally observed to the nearest 5 minutes. The time at which the flag falls is also recorded both by the instrument man as well as on the boat. In order to avoid acute intersections, the lines of soundings are previously drawn on the plan and suitable instrument stations are selected.

Location by Range and One Angle from the Boat.

The method is exactly similar to the previous one except that the angular fix is made by angular observation from the boat. The boat is kept in range with the two shore signals and is rowed along it. At the instant the sounding is taken, the angle, subtended at the point between the range and some prominent point B on the sore is measured with the help of sextant. The telescope is directed on the range signals, and the side object is brought into coincidence at the instant the sounding is taken. The accuracy and ease of plotting is the same as obtained in the previous method. Generally, the first and the last soundings, and some of the intermediate soundings are located by angular observations and the rest of the soundings are located by time intervals.

As compared to the previous methods, this method has the following advantages:

1. Since all the observations are taken from the boat, the surveyor has better control over the operations.
2. The mistakes in booking are reduced since the recorder books the readings directly as they are measured.
3. On important fixes, check may be obtained by measuring a second angle towards some other signal on the shore.
4. The obtain good intersections throughout, different shore objects may be used for reference to measure the angles.

Location by Two Angles from the Shore

In this method, a point is fixed independent of the range by angular observations from two points on the shore. The method is generally used to locate some isolated points. If this method is used on an extensive survey, the boat should be run on a series of approximate ranges. Two instruments and two instrument men are required. The position of instrument is selected in such a way that a strong fix is obtained. New instrument stations should be chosen when the intersection angle (?) falls below 30^{o}. Thus

A and B are the two instrument stations. The distance d between them is very accurately measured. The instrument stations A and B are precisely connected to the ground traverse or triangulation, and their positions on plan are known. With both the plates clamped to zero, the instrument man at A bisects B; similarly, with both the plates clamped to zero, the instrument man at B bisects A. Both the instrument men then direct the line of sight of the telescope towards the leadsman and continuously follow it as the boat moves. The surveyor on the boat holds a flag for a few seconds, and on the fall of the flag the sounding and the angles are observed simultaneously. The co-ordinates of the position P of the sounding may be computed from the relations:

The method has got the following advantages:

1. The preliminary work of setting out and erecting range signals is eliminated.
2. It is useful when there are strong currents due to which it is difficult to row the boat along the range line.

The method is, however, laborious and requires two instruments and two instrument.

Location by Two Angles from the Boat

In this method, the position of the boat can be located by the solution of the three-point problem by observing the two angles subtended at the boat by three suitable shore objects of known position. The three-shore points should be well-defined and clearly visible. Prominent natural objects such as church spire, lighthouse, flagstaff, buoys etc., are selected for this purpose. If such points are not available, range poles or shore signals may be taken. Thus A, B and C are the shore objects and P is the position of the boat from which the angles ϴ1 and ϴ 2 are measured. Both the angles should be observed simultaneously with the help of two sextants, at the instant the sounding is taken. If both the angles are observed by surveyor alone, very little time should be lost in taking the observation. The angles on the circle are read afterwards. The method is used to take the soundings at isolated points. The surveyor has better control on the operations since the survey party is concentrated in one boat. If sufficient number of prominent points are available on the shore, preliminary work O setting out and erecting range signals is eliminated. The position of the boat is located by the solution of the three-point problem either analytically or graphically.

Location by One Angle from the Shore and the other from the Boat

This method is the combination of methods 5 and 6 described above and is used to locate the isolated points where soundings are taken. Two points A and B are chosen on the shore, one of the points (say A) is the instrument station where a theodolite is set up, and the other (say B) is a shore signal or any other prominent object. At the instant the sounding is taken at P, the angle Ɵ at A is measured with the help of a sextant. Knowing the distance d between the two points A and B by ground survey, the position of P can be located by calculating the two co-ordinates x and y.

Location by Intersecting Ranges

This method is used when it is required to determine by periodical sounding at the same points, the rate at which silting or scouring is taking place. This is very essential on the harbors and reservoirs. The position of sounding is located by the intersection of two ranges, thus completely avoiding the angular observations. Suitable signals are erected at the shore. The boat is rowed along a range perpendicular to the shore and soundings are taken at the points in which inclined ranges intersect the range. However, in order to avoid the confusion, a definite system of flagging the range poles is necessary. The position of the range poles is determined very accurately by ground survey.

Location by Tacheometric Observations

The method is very much useful in smooth waters. The position of the boat is located by tacheometric observations from the shore on a staff kept vertically on the boat. Observing the staff intercept s at the instant the sounding is taken, the horizontal distance between the instrument stations and the boat is calculated by The direction of the boat (P) is established by observing the angle (Ɵ) at the instrument station B with reference to any prominent object A The transit station should be near the water level so that there will be no need to read vertical angles. The method is unsuitable when soundings are taken far from shore.

Reduction of soundings with an example

The reduced soundings are the reduced levels of the sub-marine surface in terms of the adopted datum. When the soundings are taken, the depth of water is measured with reference to the existing water level at that time. If the gauge readings are also taken at the same time, the soundings can be reduced to a common unvarying datum. The datum most commonly adopted is the 'mean level of low water of spring tides' and is written either as

L.W.O.S.T. (low water, ordinary spring tides) or M.L.W.S. (mean low water springs).

For reducing the soundings, a correction equal to the difference of level between the actual water level (read by gauges) and the datum is applied to the observed soundings, as illustrated in the table given below:

Time	Gauge (m)	Distance	Soluction (m)	Correction	Reduced sounding (m)	Remarks
8.00 A.M.	3.5	10	2.5	-0.5	2.00	
		20	3.2		2.7	
		30	3.9		3.4	
		40	4.6		4.1	
8.10 A.M.	3.5	50	5.3	-0.5	4.8	
		60	5.4		4.9	
		70	5.1		4.6	
		80	4.7		4.2	
		90	3.6		3.1	
8.10 A.M.	3.5	100	2.1	-0.5	1.6	

Gauge Reading at L.W.O.S.T. = 3.0 m.

Given the three shore signals A, B and C, and the angles α and β subtended by AP, BP and CP at the boat P, it is required to plot the position of P

1. Mechanical Solution

2. By Tracing Paper

Protract angles α and β between three radiating lines from any point on a piece of tracing paper. Plot the positions of signals A, B, C on the plan. Applying the tracing paper to the plan, move it about until all the three rays simultaneously pass through A, B and C. The apex of the angles is then the position of P which can be pricked through.

(i) By Station Pointer :

The station pointer is a three-armed protractor and consists of a graduated circle with fixed arm and two movable arms to the either side of the fixed arm. All the three arms have beveled or fiducial edges. The fiducial edge of the central fixed arm corresponds to the zero of the circle. The fiducial edges of the two moving arms can be set to any desired reading and can be clamped in position. They are also provided with verniers and slow motion screws to set the angle very precisely. To plot position of P, the movable arms are clamped to read the angles α and β very precisely. The station pointer is then moved on the plan till the three fiducial edges simultaneously touch A, B and C. The centre of the pointer then represents the position of P which can be recorded by a prick mark.

3. Graphical Solutions

(a) First Method :

Let a, b and c be the plotted positions of the shore signals A, B and C respectively and let α and β be the angles subtended at the boat. The point p of the boat position p can be obtained as under :

1. Join a and c.
2. At a, draw ad making an angle α with ac. At c, draw cd making an angle β with ca. Let both these lines meet at d.
3. Draw a circle passing through the points a, d and c.

4. Join d and b, and prolong it to meet the circle at the point p which is the required position of the boat.

Proof. From the properties of a circle,

apd = acd = α and cpd = cad = β

which is the required condition for the solution.

(b) Second Method:

Join ab and bc.

1. From a and b, draw lines ao1 and bo1 each making an angle (90 º - θ) with ab on the side towards p. Let them intersect at 0_1.

2. Similarly, from b and c, draw lines each making an angle (90 º - θ) with ab on the side towards p. Let them intersect at --.

With - as the centre, draw a circle to pass through a and b. Similarly, with - as the centre draw a circle to pass through b and c. Let both the circles intersect each other at a point p. p is then the required position of the boat.

Proof. ao1b = 180 º - 2 (90 º - θ)

Similarly, bo2c = 180 º - 2 (90 º - θ)

The above method is sometimes known as the method of two intersecting circles.

(c) Third Method :

1. Join ab and bc.
2. At a and c, erect perpendiculars ad and ce.
3. At b, draw a line bd subtending angle (90 º - θ) with ba, to meet the perpendicular through a in d.
4. Similarly, draw a line be subtending an angle (90 º -θ) with bc, to meet the perpendicular through c in e.
5. Join d and e.
6. Drop a perpendicular on de from b. The foot of the perpendicular (i.e. p) is then the required position of the boat.

Tides and its types and formation

All celestial bodies exert a gravitational force on each other. These forces of attraction between earth and other celestial bodies (mainly moon and sun) cause periodical variations in the level of a water surface, commonly known as tides. There are several theories about the tides but none adequately explains all the phenomenon of tides. However, the commonly used theory is after Newton, and is known as the equilibrium theory. According to this theory, a force of attraction exists between two celestial bodies, acting in the straight line joining the centre of masses of the two bodies, and the magnitude of this force is proportional to the product of the masses of the bodies and is inversely proportional to the square of the distance between them. We shall apply this theory to the tides produced on earth due to the force of attraction between earth and moon. However, the following assumptions are made in the equilibrium theory:

1. The earth is covered all round by an ocean of uniform depth.

The ocean is capable of assuming instantaneously the equilibrium, required by the tide producing forces. This is possible if we neglect

(i) inertia of water,

(ii) viscosity of water, and

(iii) force of attraction between parts of itself.

1. The Lunar Tides

shows the earth and the moon, with their centres of masses *O*1 and *O*2 respectively. Since moon is very near to the earth, it is the major tide producing force. To start with, we will ignore the daily rotation of the earth on its axis. Both earth and moon attract each other, and the force of attraction would act along *O*1*O*2. Let *O* be the common centre of gravity of earth and moon. The earth and moon revolve monthly about *O*, and due to this revolution their separate positions are maintained. The distribution of force is not uniform, but it is more for the points facing the moon and less for remote points. Due to the revolution of earth about the common centre of gravity *O*, centrifugal force of uniform intensity is exerted on all the particles of the earth. The direction of this centrifugal force is parallel to O_1O_2 and acts outward. Thus, the total force of attraction due to moon is counter-balanced by the total centrifugal force, and the earth maintains its position relative to the moon. However, since the fore of attraction is not uniform, the resultant force will very all along. The resultant forces are the tide producing forces. Assuming that water has no inertia and viscosity, the ocean enveloping the earth's surface will adjust itself to the unbalanced resultant forces, giving rise to the equilibrium. Thus, there are two lunar tides at A and B, and two low water positions at C and D. The tide at A is called the superior lunar tide or tide of moon's upper transit, while tide at B is called inferior or anti lunar tide.

Now let us consider the earth's rotation on its axis. Assuming the moon to remain stationary, the major axis of lunar tidal equilibrium figure would maintain a constant position. Due to rotation of earth about its axis from west to east, once in 24 hours, point A would occupy successive position C, B and D at intervals of 6 h. Thus, point A would experience regular variation in the level of water. It will experience high water (tide) at intervals of 12 h and low water midway between. This interval of 6 h variation is true only if moon is assumed stationary. However, in a lunation of 29.53 days the moon makes one revolution relative to sun from the new moon to new moon. This revolution is in the same direction as the diurnal rotation of earth, and hence there are 29.53 transits of moon across a meridian in 29.53 mean solar days. This is on the assumption that the moon does this revolution in a plane passing through the equator. Thus, the interval between successive transits of moon or any meridian will be 24 h, 50.5 m. Thus, the average interval between successive high waters would be about 12 h 25 m. The interval of 24 h 50.5 m between two successive transits of moon over a meridian is called the tidal day.

2. The Solar Tides

The phenomenon of production of tides due to force of attraction between earth and sun is similar to the lunar tides. Thus, there will be superior solar tide and an inferior or anti-solar tide. However, sun is at a large distance from the earth and hence the tide producing force due to sun is much less.

Solar tide = 0.458 Lunar tide.

Combined effect : Spring and neap tides

Solar tide = 0.458 Lunar tide.

Above equation shows that the solar tide force is less than half the lunar tide force. However, their combined effect is important, especially at the new moon when both the sun and moon have the same celestial longitude, they cross a meridian at the same instant.

Assuming that both the sun and moon lie in the same horizontal plane passing through the equator, the effects of both the tides are added, giving rise to maximum or spring tide of new moon. The term 'spring' does not refer to the season, but to the springing or waxing of the moon. After the new moon, the moon falls behind the sun and crosses each meridian 50 minutes later each day. In after 7 days, the difference between longitude of the moon and that of sun becomes 90 ^{o} , and the moon is in quadrature. The crest of moon tide coincides with the trough of the solar tide, giving rise to the neap tide of the first quarter. During the neap tide, the high water level is below the average while the low water level is above the average. After about 15 days of the start of lunation, when full moon occurs, the difference between moon's longitude and of sun's longitude is 180 ^{o} , and the moon is in opposition.

However, the crests of both the tides coincide, giving rise to spring tide of full moon. In about 22 days after the start of lunation, the difference in longitudes of the moon and the sun becomes 270 ^{o} and neap tide of third quarter is formed. Finally, when the moon reaches to its new moon position, after about 29 days of the previous new moon, both of them have the same celestial longitude and the spring tide of new moon is again formed making the beginning of another cycle of spring and neap tides.

4. **Other Effects**

The length of the tidal day, assumed to be 24 hours and 50.5 minutes is not constant because of (i) varying relative positions of the sun and moon,

(ii) relative attraction of the sun and moon,

(iii) elasticity of the orbit of the moon (assumed circular earlier) and earth,

(iv) declination (or deviation from the plane of equator) of the sun and the moon,

(v) effects of the land masses and

(vi) deviation of the shape of the earth from the spheroid.

Due to these, the high water at a place may not occur exactly at the moon's upper or lower transit. The effect of varying relative positions of the sun and moon gives rise to what are known as priming of tide and lagging of tide.

At the new moon position, the crest of the composite tide is under the moon and normal tide is formed. For the positions of the moon between new moon and first quarter, the high water at any place occurs before the moon's transit, the interval between successive high Water is less than the average of 12 hours 25 minutes and the tide is said to prime. For positions of moon between the first quarter and the full moon, the high water at any place occurs after the moon transits, the interval between successive high water is more than the average, and tide is said to lag. Similarly, between full moon and 3rd quarter position, the tide primes while between the 3rd quarter and full moon position, the tide lags. At first quarter, full moon and third quarter position of moon, normal tide occurs.

Due to the several assumptions made in the equilibrium theory, and due to several other factors affecting the magnitude and period of tides, close agreement between the results of the theory, and the actual field observations is not available. Due to obstruction of land masses, tide may be heaped up at some places. Due to inertia and viscosity of sea water, equilibrium figure is not achieved instantaneously. Hence prediction of the tides at a place must be based largely on observations.

MEAN SEA LEVEL AND ITS USED AS DATUM

For all important surveys, the datum selected is the mean sea level at a certain place. The mean sea level may be defined as the mean level of the sea, obtained by taking the mean of all the height of the tide, as measured at hourly intervals over some stated period covering a whole number of complete tides, the mean sea level, defined above shows appreciable variations from day to day, from month to month and from year to year. Hence the period for which observations should be taken depends upon the purpose for which levels are required. The daily changes in the level of sea may be more. The monthly changes are more or less periodic. The mean sea level in particular month may be low while it may be high in some other moths. Mean sea level may also show appreciable variations in its annual values. Due to variations in the annual values and due to greater accuracy needed in modern geodetic levelling, it is essential to base the mean sea level on observations extending over a period of about 19 years. During this period, the moon's nodes complete one entire revolution. The height of mean sea level so determined is referred to the datum of tide gauge at which the observations are taken. The point or place at which these observations are taken is known as a tidal station. If the observations are taken on two stations, situated say at a distance of 200 to 500 kms on an open coast, one of the station is called primary tidal station while the other is called secondary tidal station. Both the stations may then be connected by a line of levels.

4.3 ASTRONOMICAL SURVEYING

Celestial Sphere.

The millions of stars that we see in the sky on a clear cloudless night are all at varying distances from us. Since we are concerned with their relative distance rather than their actual distance from the observer. It is exceedingly convenient to picture the stars as distributed over the surface of an imaginary spherical sky having its center at the position of the observer. This imaginary sphere on which the star appears to lie or to be studded is known as the celestial sphere. The radius of the celestial sphere may be of any value - from a few thousand metres to a few thousand kilometers. Since the stars are very distant from us, the center of the earth may be taken as the center of the celestial sphere.

Zenith, Nadir and Celestial Horizon.

The Zenith (Z) is the point on the upper portion of the celestial sphere marked by plumb line above the observer. It is thus the point on the celestial sphere immediately above the observer's station.

The Nadir (Z') is the point on the lower portion of the celestial sphere marked by the plum line below the observer. It is thus the point on the celestial sphere vertically below the observer's station. Celestial Horizon. (True or Rational horizon or geocentric horizon): It is the great circle traced upon the celestial sphere by that plane which is perpendicular to the Zenith-Nadir line, and which passes through the center of the earth. (Great circle is a section of a sphere when the cutting plane passes through the center of the sphere).

Terrestrial Poles and Equator, Celestial Poles and Equator.

The terrestrial poles are the two points in which the earth's axis of rotation meets the earth's sphere. The terrestrial equator is the great circle of the earth, the plane of which is at right angles to the axis of rotation. The two poles are equidistant from it. If the earth's axis of rotation is produced indefinitely, it will meet the celestial sphere in two points called the north and south celestial poles (P and P'). The celestial equator is the great circle of the celestial sphere in which it is intersected by the plane of terrestrial equator.

1 CO-ALTITUDE OR ZENITH DISTANCE (Z) AND AZIMUTH (A).

It is the angular distance of heavenly body from the zenith. It is the complement or the altitude, i.e. $z = (90^o - \theta)$.

The azimuth of a heavenly body is the angle between the observer's meridian and the vertical circle passing through the body.

Determine the hour angle and declination of a star from the following data:

(i) **Altitude of the star = 22 º 36'**

(ii) **Azimuth of the star = 42 º W**

(iii) **Latitude of the place of observation = 40 º N.**

Solution.

Since the azimuth of the star is 42 º W, the star is in the western hemi-sphere.

In the astronomical DPZM, we have

PZ = co-latitude = 90 º - 40 º = 50 º

ZM = co-altitude = 90 º - 22 º 36' = 67º 24' ; angle A = 42 º

Knowing the two sides and the included angle, the third side can be calculated from the cosine formula

Thus, cos PM = cos PZ . cos ZM + sin PZ. Sin ZM. cos A

= cos 50 º . cos 67 º 24' + sin 50 º . sin 67 º 24'. cos 42 º

= 0.24702 + 0.52556 = 0.77258

PM = 39 º 25'

Declination of the star = d= 90 º - PM = 90 º - 39 º 25' = **50 º 35' N.**

Similarly, knowing all the three sides, the hour angle H can be calculated from Eq. 1.2

$$\cos H = \frac{\cos ZM - \cos PZ . \cos PM}{\sin PZ . \sin PM} = \frac{\cos 67°24' - \cos 50° . \cos 39°25'}{\sin 50° . \sin 39°25'}$$

$$= \quad = \frac{0.38430 - 0.49659}{0.48640} = -0.23086$$

cos (180 º - H) = 0.23086

180 º - H = 76 º 39'

H = 103 º 21'.