# Introduction to Bridges

Ch-1



3/12/21

## * Components of A Bridge :-

Broadly a bridge can be divided into two major parts:-
(i) Superstructure, (ii) Substructure.

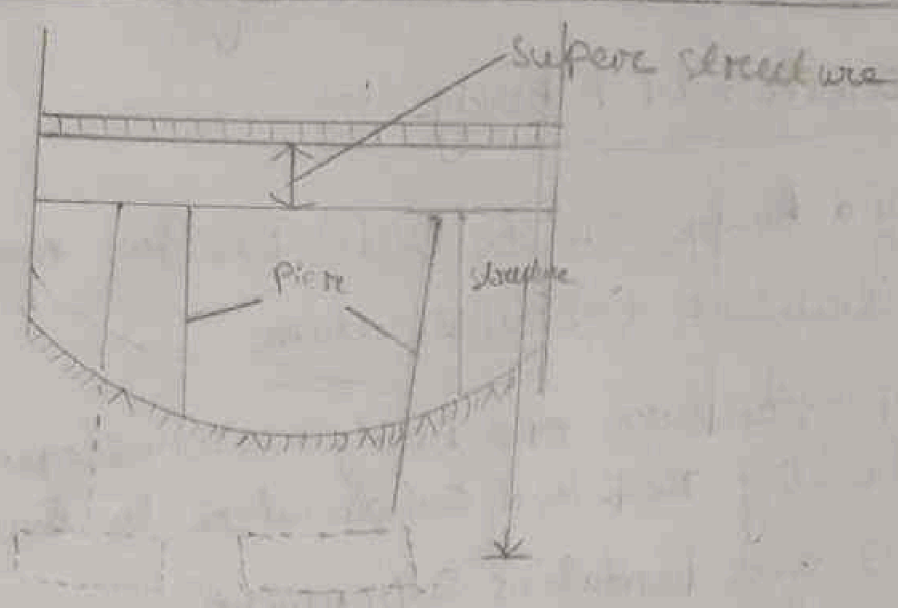
The superstructure of a bridge is annalogous to a single story building roof and substructure to that of walls, columns and fandations supporting it.

Superstructure consists of structural member carrying a communication route. Thus, handrails, guard stones & flooring supported by any structural system such as beams, girders, arches and cables above the level of bearings constitues the Superstructure.

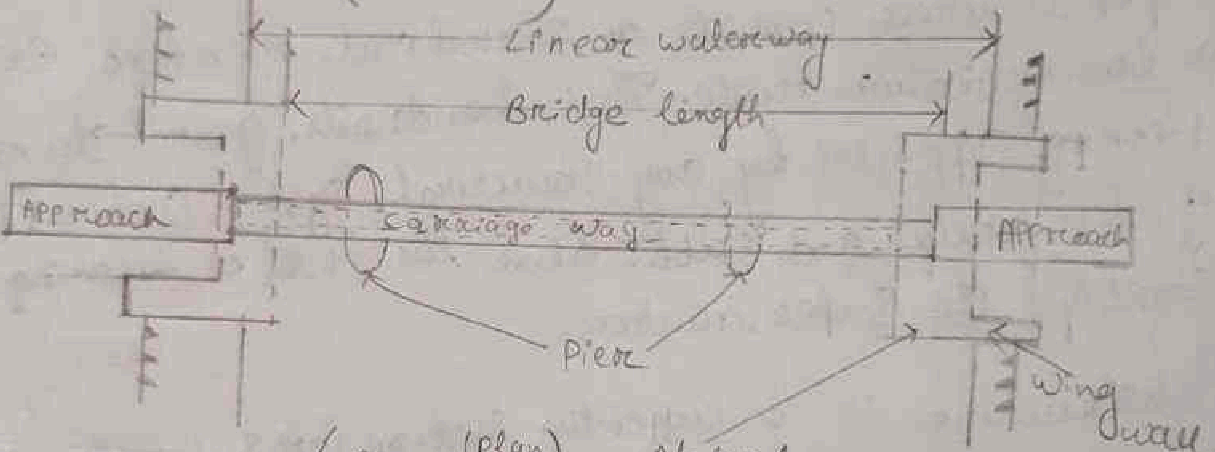
Substructure is a supporting system for superstructure. It consists of the following.

(i) Abutments
(ii) piers and Abutments piers
(iii) wing walls, and
(iv) foundations for the piers and abutments.

The other main parts of bridge structure are approaches, bearings and river training works, like aprons, revetment for slopes at abutments, etc.




(elevation)




(plan)
(Components of a bridge)

* **Afflux:-** Due to Construction of the bridge there is a Contraction in waterway. This results in ~~known as~~ rise of water level above its normal level while

* **Abutments:-** They are the end Support of the superstructure.

* **Apron:-** It is a layer of Concrete, masonry Stone, etc. placed like flooring at the entrance or outlet of a Culvert to prevent Scour.

* **Causeway:-** It is a pucca Submersible bridge which allows floods to pass over it. It is provided on less important routes in order to reduce the

construction cost of cross drainage structures. It may have vents for low water flow.

* **Culvert:-**

when a small stream crosses a road with linear water way less than about 6 metres, the cross drainage structure so provided is called culvert.

* **Cantilever Bridges :-**

Bridges which are more or less fixed at one end and free at the other. It can be used for spans varying from $8_m$ to $20_m$.

* **Continuous Bridges :-**

Bridges which continue over two or more spans. They are used for large spans and where unyielding fondations are available.

* **Effective span:-**

The Centre to Centre distance between any two adjacent Support is called as the effective span of a bridge.

* **Free Board :-**

Free board at any Point is the difference between the highest flood level after allowing afflux, if any, and the formation level of road embankment on the approaches or top level of guide bunds at the point.

* **Foot Bridge :-**

The foot bridge is a bridge exclusively used for carrying Pedestrains, cycles & animals.

* Highest Flood level (H.F.L) :-

It is the level of the highest flood every recorded or the calculated level for the highest Possible flood.

* Low water level (L.w.L) :-

The low water level is the level of water Surface obtained generally in the dry season.

* Ordinary Flood level (O.F.L)

It is the average level of a high flood which is expected to occur normally every year.

* piers :-

They are the intermediate supports of a bridge Superstructure and may be of Solid or open type.

* Simple Bridge:-

They include all beam, girder or truss bridges supported at both ends only. It is suitable for spans up to 8 metres.

* Arch bridges:-

These are the bridges which Produce inclined Pressures on support under vertical loads. These bridges Can be economically used up to Spans of about 20 metres. The arches may be in the barrel form or in the form of ribs.

# * CLASSIFICATION OF BRIDGES

Bridge can be classified into various types depending upon the following factors:-

(i) **Materials used for construction:-**
under this category, bridges may be classified as timber bridges.

(ii) **Alignment:-**

under this the bridge can be classified as straight or a skew bridge.

(iii) **Location of Bridge Floor:-**
under this category, bridge can be classified as deck, semi-through or through bridges.

(iv) **Purpose:-**
under this the bridge can be classified as an aqueduct, viaduct, highway bridge, railway bridge and foot bridge, etc

(v) **Nature of Superstructure Action:-**
under this the bridges may be classified as portal frame bridges, truss bridges, balanced cantilever bridges and suspension bridges.

(vi) **Position of High Flood level:-**

under this the bridges may be classified as submersible and non-submersible bridges.

(viii) Life:-

under this the bridges may be classified as permanent and temporary bridges. These permanent and temporary types of bridges are further classified.

(viii) Loadings:-

Road bridges and culvert have been classified by Indian Roads congress into class AA, class A and class B bridges according to the loadings they are designed to carry.

(ix) Fixed or Movable:-

For navigable channels where permanent and sufficient clear waterway cannot be provided, the following movable bridges are used.

(a) Swinging bridges, (b) Bascule bridges (c) Lift bridges.

(x) Span length:-

under this category the bridges can be classified as culverts (span less than 8m) minor bridges (span between 8 to 30 m) major bridges (span above 30m) and long span bridges (span above 120m)

(xi) Degree of Redundancy:-

under this the bridges can be classified as determinate bridges and indeterminate bridges.

(xii) Type of connection:-

under this category the steel bridges can be classified as pinned connected, riveted or welded bridges.

## * REQUIREMENTS OF AN IDEAL BRIDGE :-

An ideal bridge meets the following requirements to fulfil the three criteria of efficiency, effectiveness and equity.

(i) It serves the intended function with ulmost safety and convenience.

(ii) It is aesthically sound.

(iii) It is economical.

The requirements of traffic, aesthetics and economy for highway bridges shall be discussed in subsequent chapters. For the guidance of the designer and for ensuring uniformity of Practice Indian Roads Congress has envolved following comprehensive and exhaustive codes.

1) IRC " Standard specifications and code of Practice for road bridges".
Section I - General features of design (Fourth revision). 1998.

2) IRC - "Standard specifications and code of practice for road bridges" Section II - load and stresses, IRC : 6-1997

3) IRC " Standard and specification and code of practise for road bridges" Section III - Cement Concrete (Plain and reinforced) IRC : 21-1997.

4) IRC " Standard and specification and code of practice for road bridges" Section IV - Bricks, stone and block masonry" IRC : 40-1995.

5) IRC " Standard and specifications and code of Practice for road bridges" Section V - Steel road bridges IRC : 24-1984.

6) IRC "Standard and Specification and code of practice for road Bridges" Section VI - Composite construction for road Culverts and medium span bridges IRC: 22-1991

A comprehensive draft code for fondation and Substructure (Section VII) has been finalised by Bridge committee of IRC in 1995. A few more codes are on the preparation or finalisation or drafts for defining the scopes of various Sections, bearings in 1982, river training works (1997) Centering for bridges, etc. A code for prestressed concrete road bridges based on the limit state approach is also under finalisation. These codes incorporate the latest trends in bridge design practice. In order to plan and coordinate the research work in the country, a separate Cell headed by a chief engineer has been created in the roads wing for standards and research Co-ordination in bridges.

Highway Research Board of IRC has set up a Committee for collecting information on bridges and disseminating knowledge through the preparation of State-of-art reports on selected bridges topics of importance. Highway Research Board has also identified areas of research on which there has been no unanimity of thinking and no uniformity in design methods. These areas cover the subject like rational Methods for evaluating scour depths, Vibration in bridge decks, behaviour of concrete in seawater and Marine atmosphere, effects of live load

Surcharge on abutments, structural function of bottom plug in wells, different types of expansion joints and wearing coats, river training works, stability of well founded on hard strata, transverse moments in box type bridge decks, use of flyash in concrete, and so on. A monitoring committee has also been set up to ensure that the research is proceeding on the right lines and as per targets in advance.

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# Bridge Site Investigation Hydrology and Planning

## Selection of Bridge site :-

Detailed ground reconnaissance, collection of adequate hydraulic/ground data and subsoil investigation form an essential part of engineering survey for deciding the best possible location and type of bridge. The site for a bridge ~~the best possible~~ is usually governed by engineering economic, social and aesthetic considerations. In case of old alignments, the bridge sit may be governed by existing roadway or railway alignments. on the other hand, in case of new alignment, the bridge site is so chosen as to give the maximum commercial and social benefits keeping in view the three criteria of efficiency, effectiveness and equity. The planning process containing the various stages of goal formulation, studies and surveys, analysis of data, forecasting of future requirements, design alternative, choice of strategy and implementation including management should be strengthened with in built review, monitoring and evaluation at each and every stage with necessary feedback into the system for improved performance tending towards the optimal after a number of successive reviews. In order to select a least objectionable bridge site one must know the following characteristics of an ideal site.

* <u>Ideal Bridge site Characteristics :-</u>

(i) Suitable, unyielding and non-erodable material for foundation should be available at a short depth for the abutments and piers of a bridge. The bearing strata should be free from the tendency to slip or slide or sink under loads and away from fault zone. In other words, it should be geologically suitable.

(ii) The stream at the bridge side should be well defined and as narrow as possible.

(iii) There should be a straight reach of stream at bridge site.

(iv) The flow of water in the stream at the bridge site should be in steady regime condition. It should be free from whirls and cross currents.

(v) There should be minimum obstruction of natural waterway so as to have minimum afflux.

(vi) In order to have minimum fandation cost, the bridge site should be such that no excessive work is to be carried inside the water.

(vii) There should be no adverse environmental input.

* **Bridge Alignment:-**

Depending upon the angle which the bridge makes with the axis of the river, the alignment can be of two types.

(a) **Square Alignment:-**

In this the bridge is at right angle to the axis of the river.

(b) **Skew Alignment:-**

In this the bridge is at some angle to the axis of river which is not a right angle.

* As far as possible, it is always desirable to provide the square alignment. The skew alignment suffers from the following disadvantages:-

(i) A great skill is required for the construction of skew bridges. Maintenance of such type of bridges is also difficult.

(ii) The water-pressure on piers in case of skew alignment is also excessive because of non-uniform flow of water underneath the bridge superstructure.

(iii) The foundation of a skew bridge is more susceptible to scour action.

At certain locations to avoid costly and unsafe approaches it becomes essential to provide skew alignment. In such locations, the following points are kept in mind.

(i) There should be smooth entry and exit of water underneath the skew bridge.

(ii) The skew alignment should not be curved. It is difficult to construct and maintain the curved bridge. The curved bridge has to resist an additional force due to centrifugal action. It is always desirable to arrange piers parallel to the axis of river.

* Determination of flood Discharge:-

One of the essential data for the bridge design is fair assessment of the maximum flow which could be expected to occur at the bridge site during the design period of the bridge. The conventional practice in India for determination of flood discharge is to use a few convenient formula or past records. This faulty determination of flood discharge has led to failure of many hydraulic structures. The Indian Roads congress has recommended that the maximum discharge which a bridge on a natural stream should be designed to pass should be determined by a consideration of at least two of the following methods.

(a) From the rainfall and other characteristics of the catchment.

(i) By use of an empirical formula applied to that region,

(ii) By a rational method, provided it is possible to evaluate for the region concerned the various factors employed in the method.

(b) From the hydraulic characteristics of the stream such as cross-sectional area, and slope of the stream allowing for velocity of flow.

(c) From the records available, if any, of discharges observed on the stream at the site of the bridge, or at any other site in its vicinity.

* Empirical Methods :-

Following are some of the most commonly used empirical method for flood estimation in India.

(i) Dicken's formula
(ii) Ryve's formula
(iii) Inglis formula
(iv) Navab Jang Bahadur's formula
(v) Creager's formula
(vi) Khosla's formula, and
(vii) Besson's Formula

In these methods area of a basin or a catchment is considered mainly.
All other factor which influence peak flow are merged in a constant. A general equation may be written, in the form.

$$Q = C \cdot M^n$$

Here, Q = peak flow or rate of maximum discharge,
C = a constant for the catchment,
M = area of the catchment and $n$ is an index.

The constant for a catchment is arrived at, after taking the following factors into account:

(a) Basin characteristics,
(i) Area
(ii) Shape
(iii) Slope
(b) Storm characteristics,
(i) intensity
(ii) duration
(iii) distribution.

* Limitations :-

(i) These methods do not take frequency of flood into consideration.
(ii) These methods cannot be applied universally.
(iii) Fixing of constant is very difficult and exact theory cannot be put forth for its selection.

However, they give fairly accurate idea about the peak flow for the catchment they represent.

(i) Dicken's formula:-

It was formerly adopted only in Northern India but now it Can be used in most of the states in India after proper modification of the constant.

$$Q = C \cdot M^{3/4}$$

Here, Q = discharge in $m^3/sec$
M = area of Catchment in sq.km
c = constant.

According to the area Catchment and amount of rainfall c varies from 11.02 to 22.04.

| Region | Value of C |
|---|---|
| Northern India | 11.37 |
| Central India | 13.77 – 19.28 |
| Western India | 22.04 |

(ii) Ryve's formula:-

This formula is used only in Southern India.

$$Q = C \cdot M^{2/3}$$

Here, C = 6.74 for area within 24 km from coast.
= 8.45 for areas within 24-161 km from coast.
= 10.1 for limited hilly areas.

In worst cases it is found that value of c goes upto 40.5

(iii) **Inglis formula :-**

This formula is used only in the state of Maharashtra. Here three different cases are taken into consideration.

(a) For small areas only. (It is also applicable for fan-shaped catchment).

$$Q = 123.2\sqrt{M}$$

(b) For areas between 160 to 1000 square km.

$$Q = 123.2\sqrt{M} - 2.62\,(M - 259$$

(c) For all types of catchments.

$$Q = \frac{123.2\,M}{\sqrt{M + 10.36}}$$

In all equations M is area in sq. km.

(iv) **Nawab Jang Bahadur's formula :-**

$$Q = C\left(\frac{M}{2.59}\right)(a - b\log A)$$

Here a, b, and c are constant.

(a) = 0.993 and (b) = 1/14

(c) = 59.5 for North India

= 48.1 for South India.

(v) Creager's formula:-

This method was given formerly by creager, Justin and Hinds in U.S.A from the past records a graph is plotted between peak flow per square km of the basin and the basin area for various values. The points obtained on the graph are joined by an envelope curve. The equation to the curve is of the type:

$$q = C \cdot M^{n}$$

Here q = the peak flow per sq. km of a basin.
M = the catchment area in sq.km.
n = Some index.

By multiplying both sides of the above equation area of the basin M, we get

$$Q = C \cdot M^{n+1}$$

, where Q is peak flow.

Equation given by creager, Justin and Hinds is

$$Q = 46 \cdot CM^{(0.894M - 0.048)}$$

(vi) Khosla's formula:-

It is a rational formula. It is based on the equation

$P = R + L$

$R = P - L$

Here, R is runoff, P is rainfall and L is losses.

According to Mr. Khosla Main factor influencing losses is temperature. He expressed losses in mean temperature, $T_m$ in Fahrenheit. The formula in C.G.S System is given below.

$\mathcal{L} = 4.82\,T_m$, where $\mathcal{L}$ is in Mm and $T_m$ in Centigrade

$$R = P - 4.82\,T_m$$

The above mentioned formula of losses cannot be used for the values of temperature less than 40°F. For lower temperature he gave the following table:-

| | | | | | |
|---|---|---|---|---|---|
| $T_m$ °F | 40 | 30 | 20 | 10 | 0 |
| $\mathcal{L}$ inches | 0.84 | 0.70 | 0.60 | 0.50 | 0.40 |

Khosla formula is useful in assessing water potential for a basin in river valley project.

(vii) <u>Besson's formula</u>:-

This formula is very rational and can be used in any case

$$Q_m = \frac{P_m \times Q_r}{P_r}$$

$Q_m$ = peak flow expected.
$Q_r$ = Some observed peak flow.
$P_r$ = observed rainfall
$P_m$ = expected rainfall

* **Rational Method :-**

This method is applicable for determination of flood discharge for small culverts only. In order to arrive at a rational approach, a relationship has been established between rainfall and runoff under various circumstances. The size of the flood depends upon the following factors:-

(i) Climate or Rainfall factors. This includes:
(a) intensity
(b) distribution, and
(c) duration of rainfall.

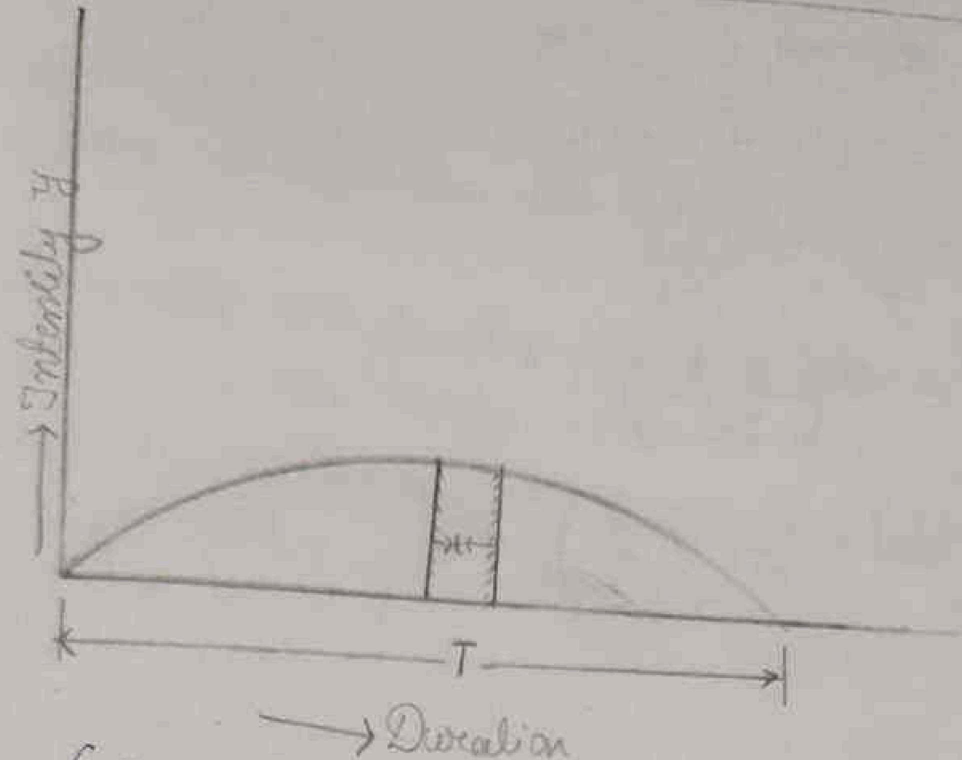
(ii) Catchment Area factors. This includes:-
(a) Catchment area (b) its shape
(c) its slope (d) Porosity of the soil
(e) vegetable cover and (f) initial state of wetness.

In order to establish a relationship between the intensity and duration of a storm, a curve has been plotted as shown in (fig 3.1.1)

Let, in an individual stream:-
F = total rainfall in cm.
T = duration of rainfall in hours.
I = Mean intensity of rainfall in cm/hour taken over the total duration of the storm.

Then, $I = F/T$

If, $i$ = Intensity of rainfall in cm per hour, obtain for sma
time interval '$t$' as shown in (fig 3.1.1)




(Rainfall intensity duration curve).

Since the intensity is not uniform throughout, the mean intensity obtained over the time interval 't' will be higher than the mean intensity 'I' taken over the whole period 'T'. The intensity of a storm is some inverse function of its durations. It has been reasonably well established that:-

$$\frac{i}{I} = \frac{T+c}{t+c}$$

$$i = \frac{F}{T}\left(\frac{T+c}{t+c}\right)$$

Here c = a constant
F = total rainfall

Analysis of rainfall statistics has shown that for all but extreme cases, C=1.

$$i = \frac{F}{T}\left(\frac{T+1}{t+1}\right)$$

Let, the time interval $t = 1$ hour.

Then Correrresponding $i = I_0$ (say)

$$\frac{I_0}{I} = \frac{T+1}{1+1}$$

$$I_0 = 1\left(\frac{T+1}{1+1}\right)$$

$$I_0 = \frac{F}{T}\left(\frac{T+1}{2}\right) = \frac{F}{2}\left(1+\frac{1}{T}\right)$$

* Waterway :-

The area through which the water flows under a bridge Superstructure is known as the waterway of the bridge. The linear measurement of this area along the bridge is known as the linear waterway. This linear waterway is equal to the Sum of all the clear spans. This may be called as artificial linear waterway. The natural waterway is the unobstructed area of the river or steam through which the water flows at the bridge site.

Due to the construction of a bridge the natural waterway gets contracted there by increasing the velocity of flow under a bridge. This increased velocity results into heading up of water on the upstream of the river or stream, known as afflux.

While fixing the waterway of a bridge the following guiding principles must be kept in mind to ensure the Safety of the structure.

(i) The increased velocity due to afflux should not exceed the permissible velocity under the bridge. Indicates the range of permissible velocities for the different fondation materials.

(ii) There should not be too much heading up of water surface above the bridge, when it is necessary to restrict the waterway to such an extent that the resultant afflux will cause the stream to discharge at erosive velocities, Protection against damage by ~~Sco~~ Scour should be afforded by deep fondation, Curtain or cut of walls, rip rap, steam bed pavement bearing piles, sheet piles or other suitable means. Likewise embankment slopes adjacent to all structures subject to erosion should be adequately protected by pitching, rivetment walls or other suitable construction.

(iii) The freeboard for high level bridges should not be less then 600mm.

(iv) Clearance should be allowed according to navigational requirements. The minimum clearance for opening of high level bridges which are approximately rectangular should be in accordance.

* The principles for fixing the waterway mainly depend upon the type of the stream to be bridged. The following are some of the recommendation for fixing the waterway:-

(i) **waterway for stream with Rigid Boundaries:-**

The artificial irrigation, navigation and drainage channels, whose boundaries remain the same during and after the flood, the effective linear waterway should generally be equal to the width of Channel at mid-depth.

(ii) **waterway for Quasi-Alluvial stream:-**

for non-meandering natural Streams not wider than 30m in alluvial beds but with well defined banks and for all natural Channels in beds with rigid inerodible boundaries, the liner-waterway should be the distance between banks at the high flood level water Surface.

(iii) **waterway for Alluvial streams:-**

for large natural Streams in alluvial beds and having undefined banks, the linear waterway should be determined from the designed discharge using the following formula Proposed by Lacey for Regime Conditions:

$$L = C\sqrt{Q}$$

Here L = The linear waterway in metres or Regime surface width in metres.

Q = The design maximum discharge in $m^3/sec$.

C = A constant usually taken as 4.8 for Regime channel but it may very from 4.5 to 6.3 according to local conditions.

(iv) waterway for streams with shallow sub-sections:-

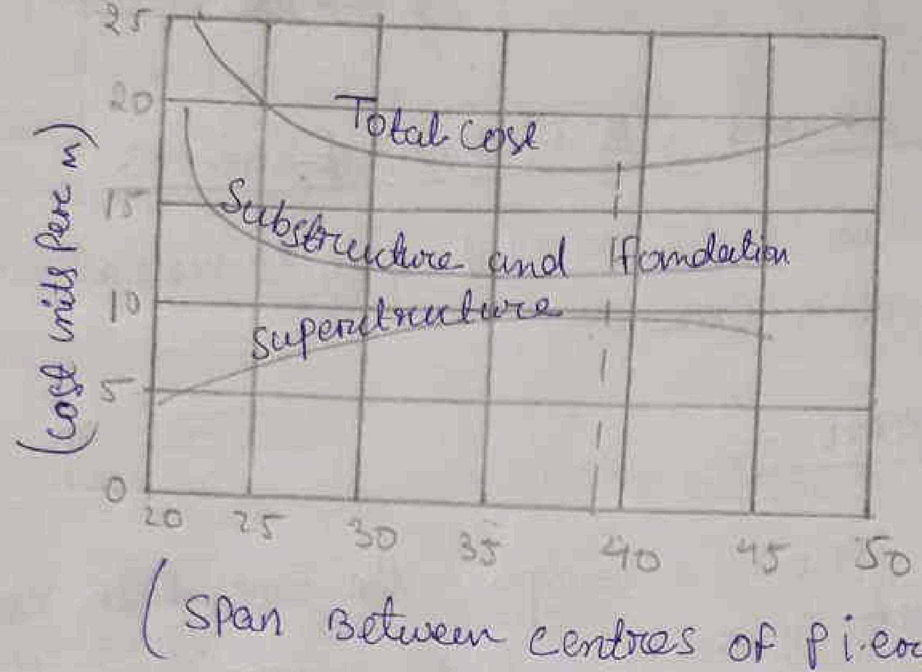
The waterway should be provided equal to actual surface width of the active channel.

* Economic span:-

The economic span of a bridge is the one which reduces the overall cost of a bridge to be a minimum. The overall cost of a bridge depends upon the following factors:-

(i) Cost of material and its nature.
(ii) Availability of skilled labour.
(iii) Span length
(iv) Nature of stream to be bridged
(v) Climatic and other conditions.

Typical cost components for prestressed concrete road bridges in the span range 20 to 50m are shown. The 5 are based on computation of alternative design with varied spans for a major bridge across Betwa River, adopting a two-girder prestressed concrete - reinforced concrete composite deck of two lane.




It is not in the hands of engineers to bring down the cost of living index or the price of the materials like Cement, steel, timber, etc. but they can help in bringing down the cost of bridges by evolving economical designs.

Considering only the variable items, the cost of Superstructure increases and that of the Sub-structure decreases with an increase in the span length. Thus most economic span length is that which Satisfies the following (i.e)

The cost of the Super-structure = The cost of the sub-Structure.

The derivation for the economic span can be established on the basis of the following assumptions:

(i) The bridge has equal span lengths. In practice, generally equal spans are kept.

(ii) The cost of the supporting system of super-structure varies as the square of the span length. This assumption is nearly justified, because the design of supporting system sections of super-structure depends upon the bending moment, which in turn varies as square of span length.

(iii) Cost of flooring and parapets varies directly as the span. This assumption is justified because as the span increases, the quantity of material also increases.

(iv) Cost of one pier and its fondation is constant. This is more or less only approximately true, as the depth of fondation is decided by scour considerations, which is constant at a bridge site.

(v) Cost of the abutments and their fondations is also constant. As the end span length increases the load on the abutment also correspondingly increases requiring costly design. The variation is negligible.

$L$ = Total length of the bridge.
$l$ = span length
$n$ = The total number of spans.
$= L/l$
$P$ = Cost of one pier with its foundation.
$A_1$ = Cost of one abutment and its fondation.
$A_2$ = Cost of one approach.

T = Total bridge cost.

Cost of one span of super-structure = $(a_1 l^2 + a_2 l)$

Here, $a_1$ and $a_2$ are constants of variations.

There are $(n-1)$ number of piers, and two abutments.

The total cost of bridge = Cost of supporting system of Super structure + cost of two abutments + Cost of $(n-1)$ piers + Cost of approaches, railings and Parapets.

$$T = n(a_1 l^2 + a_2 l^2) + 2A_1 + 2A_2 + (n-1)P$$

Replacing $n = \frac{L}{l}$

$$T = \frac{L}{l}(a_1 l^2 + a_2 l) + \left(\frac{L}{l} - 1\right)P + 2A_1 + 2A_2$$

$$= La_1 l + a_2 L + \frac{PL}{l} - P + 2A_1 + 2A_2$$

$$\frac{dT}{dl} = a_1 L + 0 - \frac{PL}{l^2}$$

For T to be minimum,

$$\frac{dT}{dl} = 0$$

$$a_1 L - \frac{PL}{l^2} = 0$$

$$a_1 = \frac{P}{l^2}$$

$$P = a_1 l^2$$

economic span $= l = \sqrt{\frac{P}{a_1}}$

cost of supporting system of one span is equal to cost of one pier.

As a rule, the number of spans should be kept minimum, as piers cause obstruction to water flow.

* **AFFLUX :-**

When a bridge is constructed, the structures such as abutment and piers cause the reduction of the natural waterway area. The contraction of the stream is desirable because it leads to tangible saving in the cost specially for alluvial streams whose natural surface width is too large than required for stability. Therefore, to carry the maximum flood discharge, the velocity under a bridge increases. This increased velocity gives rise to a sudden heading up of water on the upstream side of the stream is known as afflux. Greater the afflux greater will be the depth of scour and consequently greater will be the depth of foundations required. The top levels and lengths of guide bunds and flood protection bunds are fixed based upon the amount of afflux. It also determines the formation levels, free board and headroom.

(a) Marriman's formula:-

$$h_a = \frac{v^2}{2g}\left\{(A/C_a)^2 - (A/A_1)\right\}$$

Here,

$h_a$ = Afflux in metres

$v$ = Velocity of approach in metres per second

A = Natural waterway area at the site

a = contracted area in square metres

$A_1$ = The enlarged area upstream of the bridge square metres
C = Coefficient of discharge
$= 0.75 + 0.35(a/A) - 0.1(a/A)^2$ (approximately).

(b) Molesworth's Formula:-

$$h_a = \left[\frac{v^2}{17.9} + 0.015\right]\left\{(A/a)^2 - 1\right\}$$

Here, v, A and a have the same meaning as in the Marriman's formula.

Q) A bridge has a linear waterway of 150 metres constructed across a stream whose natural linear waterway is 220 metres. If the average flood discharge is 1200 metres$^3$/sec and average flood depth is 3 metres, calculate the afflux under the bridge.

=> Solution

The natural waterway area at the site $= A = 220 \times 3 = 660 m^2$
Contracted waterway area $= a = 150 \times 3 = 450 m^2$
The velocity of approach $= v = Q/A$
Here, Q = Flood discharge $= 1200 m^2/sec$.

$v = 1200/660 = 1.83$ m/sec.

using molesworth formula, the afflux can be given by

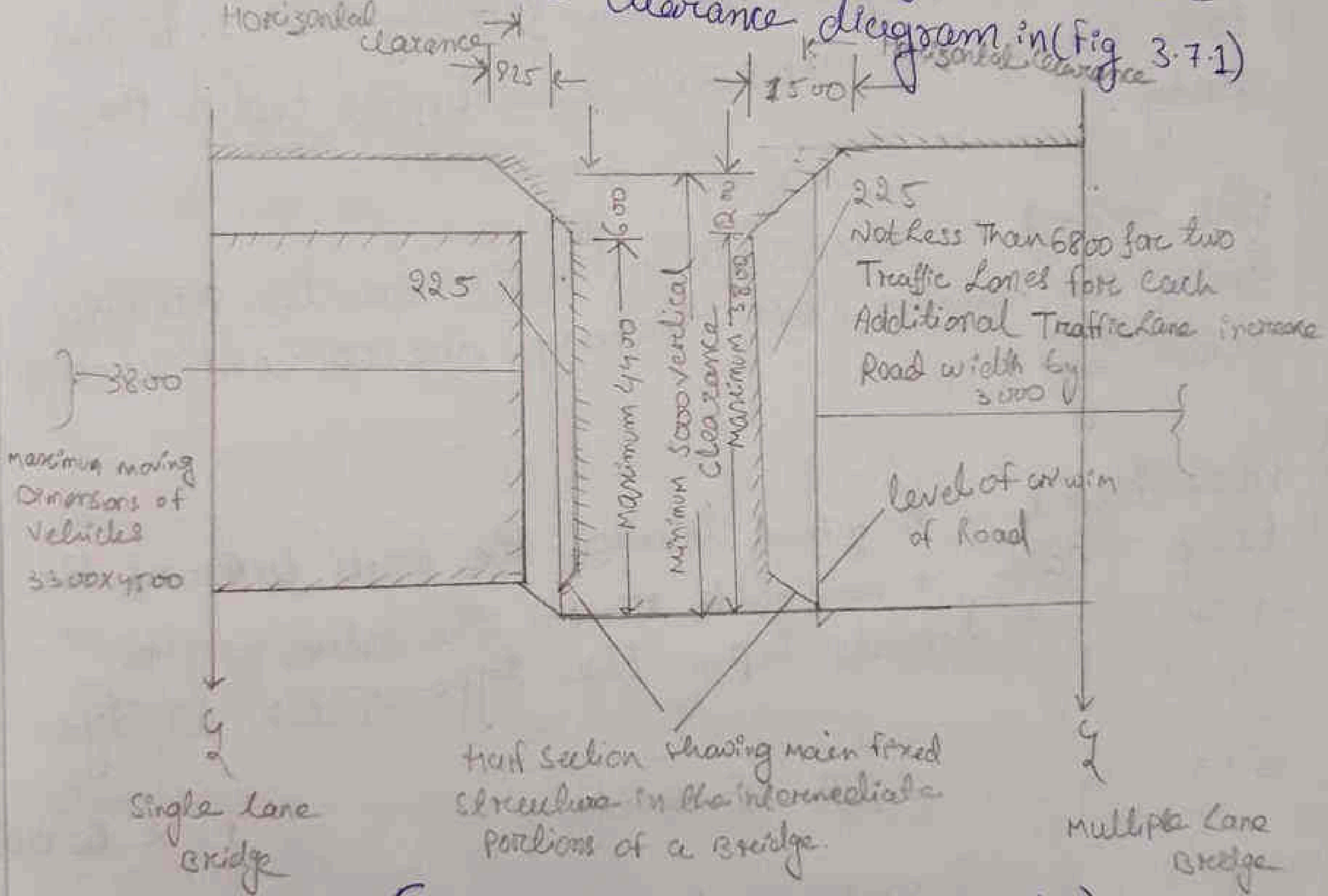
$$h_a = \left(\frac{v^2}{17.9} + 0.015\right)\left\{(A/a)^2 - 1\right\}$$

$$= (0.187 + 0.015)\left\{(660/450)^2 - 1\right\}$$

$= 0.202 \times 1.15 = 0.232m$

## Clearances :-

To avoid any possibility of traffic striking any structural part clearance diagrams are specified. The horizontal clearance should be the clear width and the vertical clearance the clear height, available for the passage of vehicular traffic as shown in the clearance diagram in (Fig 3.7.1)




(Clearance Diagram for Road Bridges)

For a bridge constructed on a horizontal curve with superelevated road surface, the horizontal clearance should be increased on the side of the inner kerb by an amount equal to 5m multiplied by the superelevation. The minimum vertical clearance should be measured from the superelevated level of the roadway.

## * Free Board :-

Free board is the vertical distance between the designed high flood level allowing for afflux, if any, and the level of the crown of the bridge at its lowest point.

It is essential to provide the free board in all types of bridges for the following reasons:

(i) Free board is required to allow floating debris, fallen tree trunks and approach waves to pass under the bridge.

(ii) Free board is also required to allow for the afflux during the maximum flood discharge due to contraction of waterway.

(iii) Free board is required to allow the vessels to cross the bridge in case of navigable rivers. The value of the free-board depends upon the type of the bridge.

| Sl.No | Type of Bridge | Free board |
|---|---|---|
| 1 | High level bridges | 600 mm |
| 2 | Arch bridges | 300 mm |
| 3 | Girder bridges | 600 to 900 mm |
| 4 | Navigational streams | 2400 to 3000 mm |

# Bridge Foundation

16|12|21



## * SCOUR DEPTH :-

when the velocity of stream exceeds the limiting velocity which the erodable particle of bed material can stand, the Scour occurs. The normal Scour depth is the depth of water in the middle of the stream when it is carrying the peak flood discharge. This can be easily ascertained by actual Soundings at or near the site proposed for the bridge during or immediately after a flood before the scour holes have had time to silt up appreciably. Due allowance should be made in the observed depth for increase in scour resulting from:

(i) The designed discharge being greater than flood discharge during which the scour was observed.

(ii) The increase in velocity due to the obstruction in flow caused by construction of the bridge.

The scour pattern at a bridge depends upon factors like flood discharge, bed slope, direction of flow, bed material alignment of pier, pier geometry i.e its shape and size, etc.

for a safe and sound design of a bridge it is important to estimate the correct scour depth. where the practical method of determining a scour is not possible, the following theoretical methods may be used to different types of streams.

* DEPTH OF FOUNDATION :-

The depth of bridge fandation is determined by consideration of the safe bearing capacity of the soil after taking into accont the effect of scour. In all doubtfull cases, the bearing capacity of the foundation soil is ascertained by actual field load tests. The bore holes are driven to determine the adequacy of thickness of the fandation bearing layer of the soil. The minimum depth of foundation can be approximately calculated by the following relationship.

$$h = \frac{P}{w}\left(\frac{1-\sin\phi}{1+\sin\phi}\right)^2$$

Here,

h = The depth of fandation in metres
P = The bearing capacity of soil in $kg/m^2$
w = The specific weight of earth in $kg/m^2$
$\phi$ = The angle of internal friction of the soil.

given the bearing capacity of various soil according to (IS: 1904-1961)

## * Type of Bridge Fandations

• In case of bridges the design of fandation mostly depends on the depth required for properly fanding it. when the fandations have to be Carried down to a considerable depth, The number of the Piers should be limited for the sake of economy. This Means the adoption of longer spans, in which case, the pier is to withstand more weight than of a shorter span.

If for the fondation and at the banks also, rock is available at shallow depths, and the valley is narrow and deep, a single span bridge is economical. If on the other hand, the valley is narrow and shallow it will be less costly, as the fandations are at a small depth. In this case short piers may be adopted.

If the valley is wide and deep then an arch bridge is Preferred. Due to the height, the sub-structure and its foundation may be costly. In order to achieve economy, the number of span may be reduced and a maximum rise may be Provided to the arches.

The selection of the fondation type Suitable for a particular site depends on the following considerations:

(i) Nature of subsoil

(ii) Nature and extent of difficulties, e.g. Presence of boulder, buried tree, etc., likely to be met with, and

(iii) Availability of expertise and equipment.

In case of fandations laid on rock, the rock should be benched by chiselling. In order to anchore the foundation to the rock, a number of dowel bars 38 mm diameter at about 80 cm spacing are provided. On this a levelling course with lean concrete is laid to serve as a base for fandation.

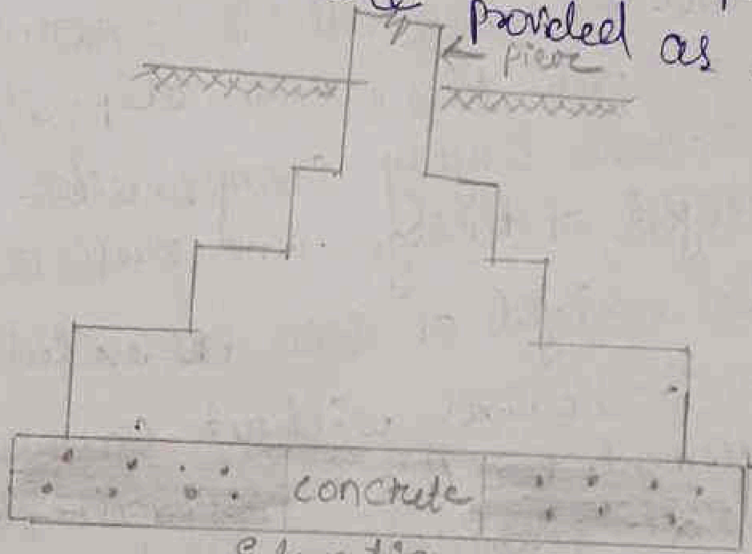
Depending upon their nature and depth, bridge foundations can be categorised as follows:

(i) Open fandations, (ii) Raft foundation, (iii) pile fondations (iv) well foundations.

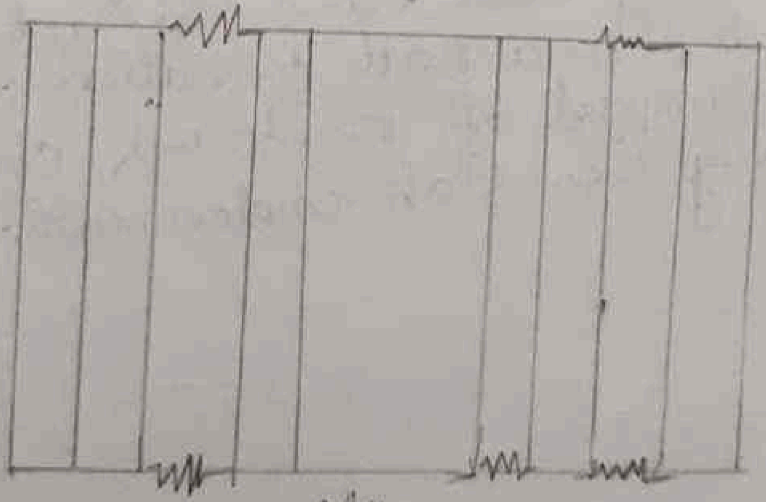
## (i) Open fandations

An open fandation or a spread foundation is a type of shallow fondation. This is the most common type of foundation and can be laid using open excavation by allowing natural slopes on all sides. This type of foundation is practicable for a depth of about 5 m and is normally convenient above the water table. The base of the pier or abutment is enlarged or spread to provide individual support. Since spread fondations are constructed in open excavations, therefore, they are termed as open fandations. This type of fondation is provided for bridges of moderate height built on sufficiently firm dry ground. The piers in such cases are usually made with a slight batter and are provided with footings widened at the bottom. Where the ground is not stiff the bearing surface is further extended by a wide layer of Concrete at the bottom.

If the fondation Soil is not stiff and there is plenty of water with springs, the sides are protected by Shoring. The water is removed by pumping to provide working Space. The Purpose of Shoring is to permit excavation with minimum extra width over the fondation width. Of facilitates working on the fondation in the dry. In shoring, sheathing with timber planks supported by wales and struts are provided as the excavation proceeds.




Elevation



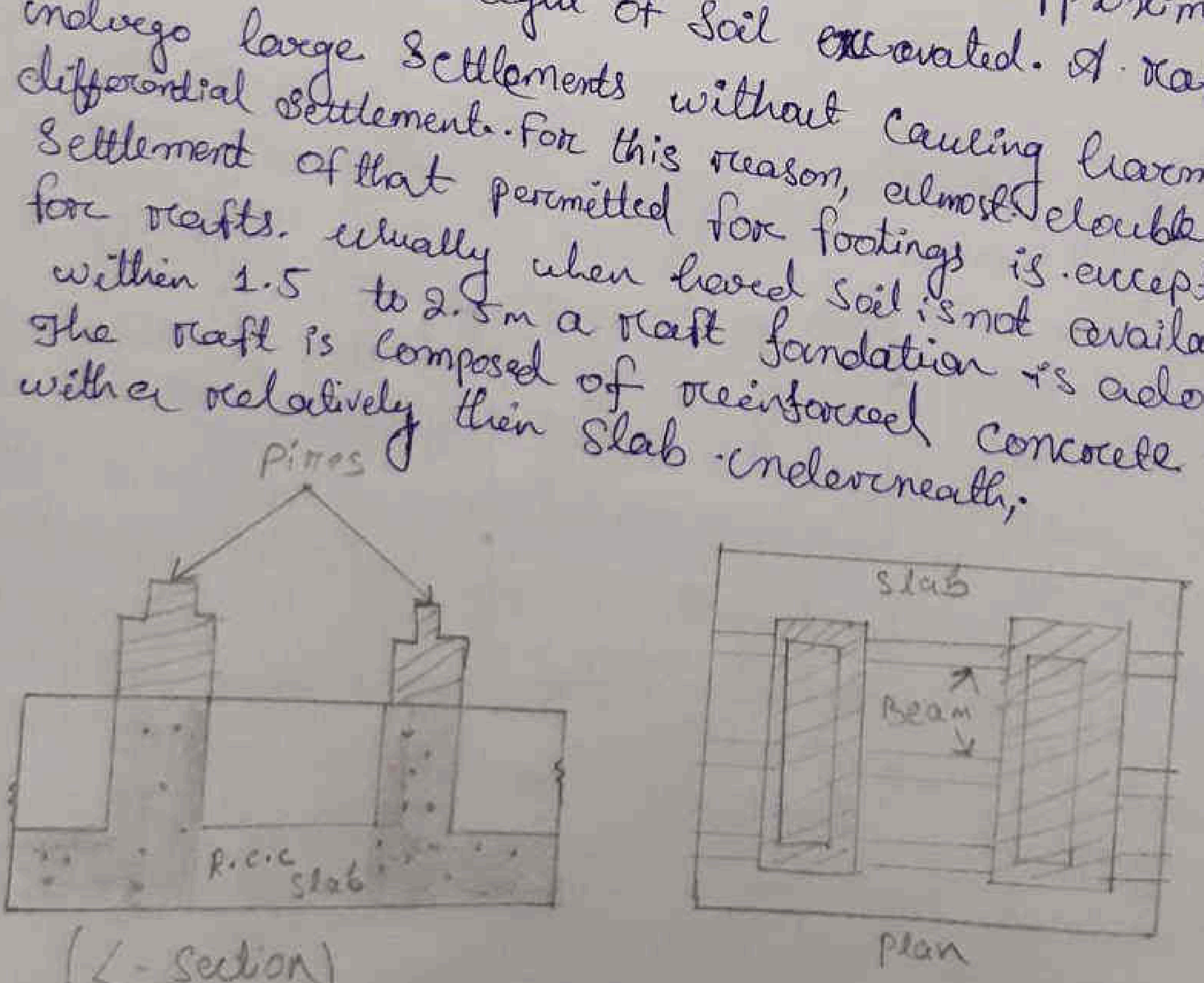
plan

(fig 9.5 12)

(ii)

## Raft Fandations in Bridges

A raft or mat is a combined footing that covers the entire area ~~because~~ beneath a bridge and supports all the piers and abutments. when the allowable soil pressure is low, or bridge loads are heavy, the use of spread footing would cover more than one-half of the area and it may prove more economical to use raft fandation. They are also used where the soil mass contains compressible lenses so that the differential settlement would be difficult to control. The raft tends to bridge over the erratic deposits and eliminate the settlement above highly compressible soils by making the weight of bridge and raft approximately equal to the weight of soil excavated. A raft may undergo large settlements without causing harmful differential settlement. For this reason, almost double the settlement of that permitted for footings is acceptable for rafts. usually when hard soil is not available within 1.5 to 2.5m a raft fandation is adopted. The raft is composed of reinforced concrete beams with a relatively thin slab underneath.




(Fig 9.5.13)

(iii) Pile foundations in Bridges :-

The pile foundation is a construction for the fandation of a bridge pier or abutment supported on the piles. A pile is an element of construction composed of timber, concrete or steel or a combination of them. pile foundation may be defined as a column. The piles may be placed separately or they may be placed in the form of a cluster throughout the length of the pier or abutment. This type of construction is adopted when the loose soil extends to great depth. The load of the bridge is transmitted by the piles to hard stratum below or it is resisted by the friction developed on the sides of piles.

* Classification of piles :-

Piles are broadly classified into two categories:-

(i) Classification based on the function.

(ii) classification based on material and composition.

(1) Classification Based on function:-

(i) Bearing pile.

(ii) friction pile

(iii) Screw pile

(iv) Compaction pile.

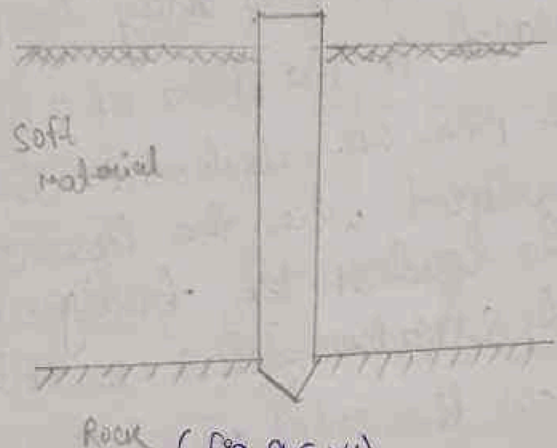
(v) uplift pile.

(vi) Batter pile.

(vii) Sheet pile.

(i) Bearing piles :-

These piles penetrate through the soft soil and their bottoms rest on a hard stratum. The soft ground through which the piles pass also gives some lateral support and this increases the load carrying capacity of the bearing piles. See These piles act as columns.

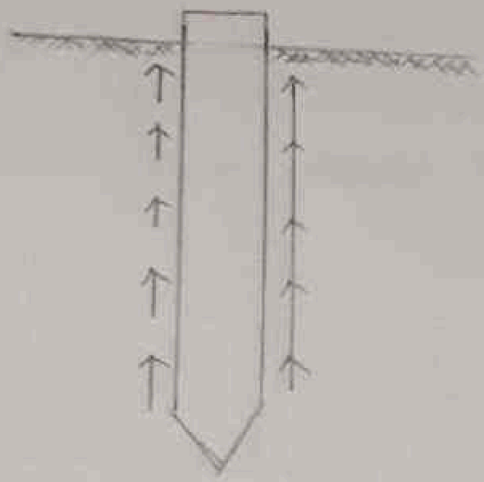



(fig 9.5.14)

(ii) Friction piles :-

when loose soil extends to a great depth, piles are driven up to such a depth that frictional resistance developed at the sides of the piles equals the load coming on the piles. The total frictional resistance of piles is obtained by multiplying frictional a resistance of soil with the area of pile in contact with the soil. The total frictional resistance can be increased in the following ways:-

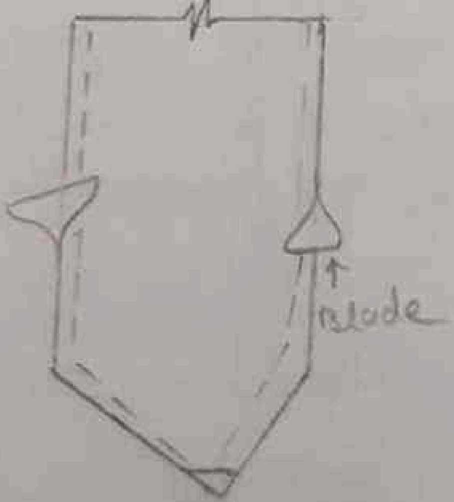
(a) By increasing the diameter of the pile.
(b) By driving the pile to a greater depth.
(c) By making the surface of the pile rough.
(d) By placing the piles closely.
(e) By grouping the piles.



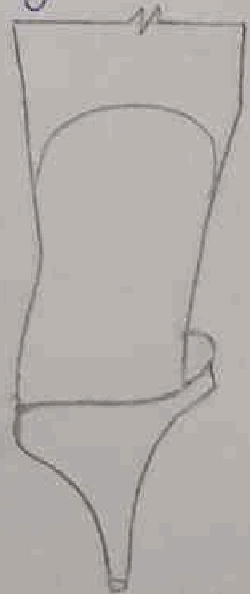
(fig 9.5.15)

(iii) Screw piles:-

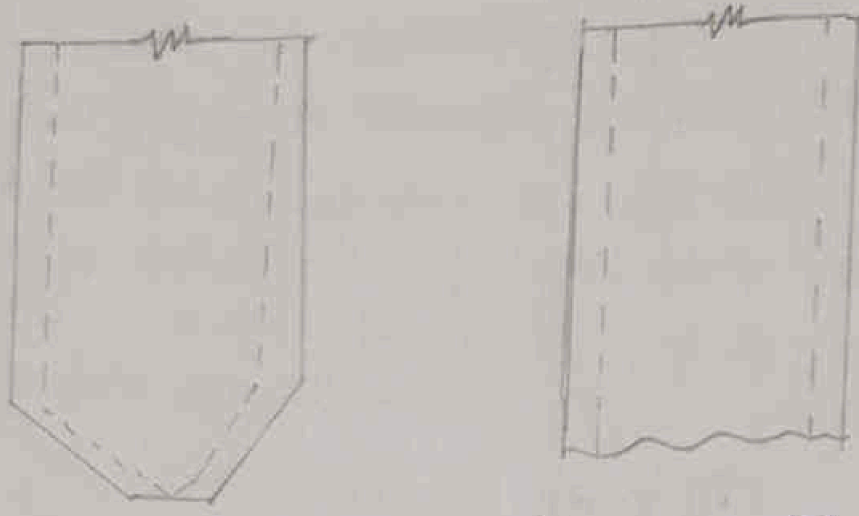
A screw piles consists of a hollow cast-iron or steel cylinder with one or more blades at the bottom. The blades are generally made of cast-iron. The bottom end of the screw pile with blunt point is useful when ground to be penetrated consists of sand and clay. Screw piles when provided with gimlet point, hollow conical point and serrated point are used for gravelly ground, sand mixed gravel ground and soft rock respectively.




(screw pile with blunt point)



(screw pile with gimlet point)



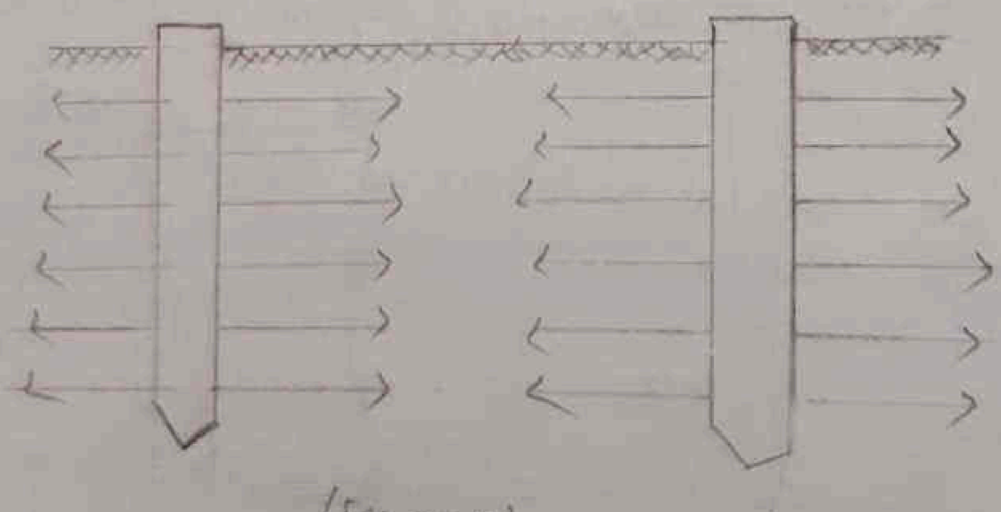
(Screw pile with hollow conical point)

(Screw pile with serrated point)

(fig 9.5.16)

## (iv) Compaction piles:-

They are used to compact loose granular soils in order to increase their bearing capacity. These piles themselves do not carry any load.



(Fig 9.5.17)

## (v) Uplift piles:-

These piles anchor down the structure subjected to uplift due to hydrostatic pressure or due to overturning moment.

(vi) Batter piles:-

They are used to resist large horizontal or inclined forces.

(vii) Sheet pile :-

They are used as bulk heads or as impervious cut off to reduce seepage and uplift.

* Classification Based on material and Composition:-

Following are the most Common types in this Category:-

(i) Cement Concrete piles.
(ii) Timber piles
(iii) Steel piles.
(iv) Sand piles.
(v) Composite piles.

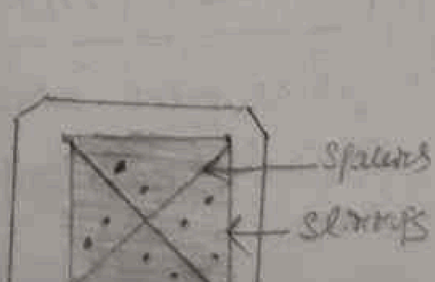
(i) Cement Concrete piles:-

Cement concrete piles possess excellent Compressive strength. These piles can be reinforced or prestressed. They can be divided into following two groups:-

(a) Pre-cast Concrete piles
(b) Cast - in-situ Concrete piles.

(a) Pre-cast concrete piles:-

These piles manufactured in factory. They may be tapered or parallel sided. They may be square, octagonal or round in shape. The precast concrete piles are generally used for a maximum design load of about 80 tonnes. They may be reinforced to withstand handling stresses. They require space for casting and storage, more time to set and cure before installation and heavy equipment for handling and driving. They also incur large cost in cutting off extra length or adding more length. These piles can be driven under water. It is possible to have a proper control over the composition and design of these piles as they are manufactured in a workshop. Any defect of casting such as hollows, etc., can be found out repaired before driving the pile. These piles possess high resistance to biological and chemical actions of the ground. The concrete in the piles should be controlled concrete and should correspond to M200 grade. Usually lifting points are specified at 0.207 of its length from either end, so that the magnitude of the maximum bending moment due to handling is kept at the lowest possible value.


(fig 9.5.18)

## (b) Cast in-situ concrete piles:-

In this type a bore is dug into the ground by inserting a casing. This bore is then filled with cement concrete after placing reinforcement, if any. They may be either called cast in-situ concrete piles or uncased cast in-situ concrete piles depending upon whether the casing is kept in position or is withdrawn.

A variety of patented processes have been developed under both of the above categories. The most common amongst them are Raymond piles, mac-Arthur piles, monotube piles, BSF bore-driven piles, Button bottom piles, Simplex piles, franki piles, etc.

Cast in-situ concrete piles are easy to handle and to drive in the ground. They do not require any extra reinforcement to resist the stresses developed during handling or driving operations. There is no wastage of material as the pile of required length is only constructed. The extra cost of transporting pile is eliminated. The disadvantages of these piles are:-

(i) It is difficult to maintain the reinforcement in correct position during construction of pile.

(ii) These piles cannot be constructed under water.

(iii) It is not possible to have a proper control over the composition and design of these piles.

(2) Timber piles :-

Timber piles are prepared from trunks of trees. They may be circular or square. They are 30 to 50cm in diameter with a length not exceeding 20 times its top width. At the bottom, a cast-iron shoe is provided and at the top, a steel plate is fixed. If a group of timber piles is driven, the top of each member of the ground is brought at the same level and then a concrete cap is provided to have a common platform. They have small bearing capacity, and are not permanent unless treated. It is very difficult or even impossible to drive these piles into hard stratum or boulders. Where timber is available easily these piles prove to be economical.

(3) Steel piles :-

Steel piles are used in following three different forms
(i) H piles, (ii) Box piles, and (iii) Tube piles.

(i) H piles :-

These piles are usually of wide flang section. They are suitable for trestle type piers in which the piles extend above ground level and serve as columns. Since they have small cross-sectional area, therefore, they can be easily driven in soil in which it will be difficult to drive ordinary displacement piles. They are used as long piles with high bearing capacity.

(ii) Box piles:-

They are rectangular or octagonal in form filled with concrete. These piles and used when it is not possible to drive H piles up to hard strata.

(iii) Tube piles:-

In this type tubes or pipes of steel are driven into the grand. Concrete is filled inside the tube piles. Because of their circular, cross-section, these piles are easy to handle and easy to drive.

* The advantages of steel piles can be listed below:-

(i) These piles can easily withstand the stresses due to driving.
(ii) These piles can be easily lengthened by welding and also can be cut off easily.
(iii) These piles can resist lateral forces in better way.
(iv) The bearing capacity of these piles is comparatively high.

The only disadvantage of steel piles is their corrosion. To prevent corrosion they should be coated with paints or may be encased with cement concrete.

4) Sand piles:-

These piles are formed by making holes in the ground and then filling them by sand. the top of the sand piles is filled with concrete to prevent the sand to come upwards due to lateral pressure. Sand piles are spaced at 2 to 3 m. Its length is kept about 12 times its diameter.

They are easy to construct and can be used irrespective of any position of water table. They are not suitable for loose or wet soils or where is a danger or scour. They are also not suitable in regions subjected to frequent earth - quakes.

5) <u>Composite piles:-</u>

A composite pile is formed when it is a combination either of a bored pile and a driven pile or of driven piles of two different materials. They are suitable where the upper part of pile is to project above the water table. They are economical and easy to construct.

(iv) <u>well fondations in Bridges:-</u>

The Caisson is a structure used for the purpose of placing a foundation in correct position under water. The term Caisson is derived from the French word 'caisse' meaning a box. It is a member with hollow portion which after installing in place by any means is filled with concrete or other material. Caissons are preferred in sandy soils. The Caissons can be divided in the following three groups:-

(i) Box Caissons.
(ii) open Caissons or wells
(iii) Pneumatic Caissons.

(i) Box Caissons:-

A box caisson is a strong watertight vessel open at top and close at the bottom. They are generally built of timber, reinforced concrete and steel. This type of caisson is suitable where bearing stratum is available at shallow depth, and where loads are not very heavy. To place the caisson in position, it is launched and floated to pier site where it is sunk in position.

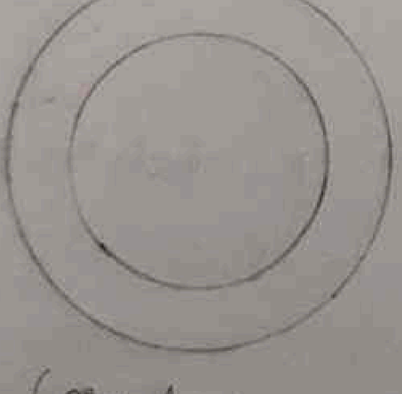
(ii) Open Caissons or wells:-

The open caissons are open both at the top and the bottom. They are used on sandy or soft bearing stratum liable to scour and where no firm bed is available for large depth below the surface.

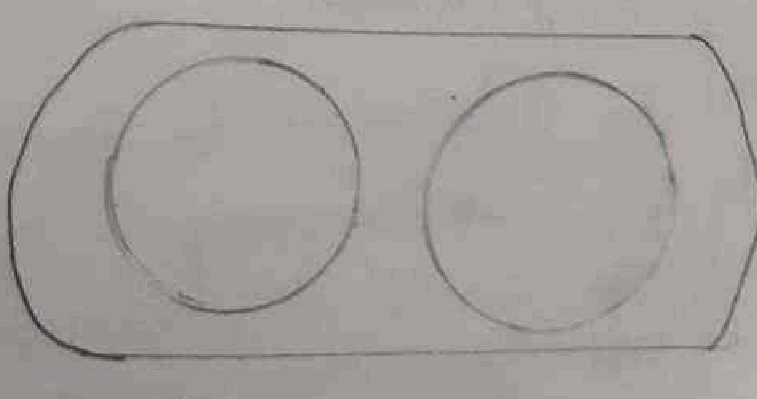
They are generally built of timber, metal, reinforced concrete or masonry. They form the most common type of deep foundations for bridges in India.

Shape of wells:-

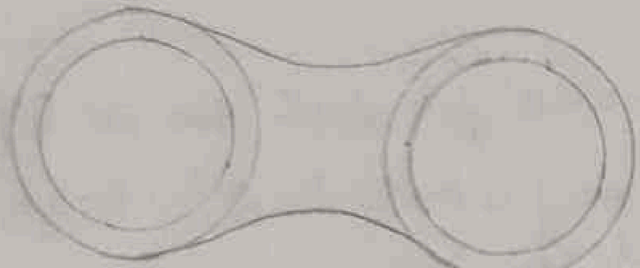
The shapes of wells may be circular, rectangular, Double-D rectangular with D-shaped ends, twin hexagonal and twin octagonal.



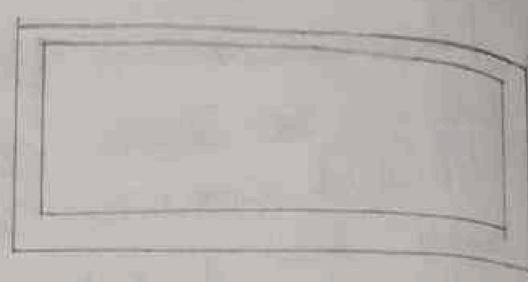
(Circular)



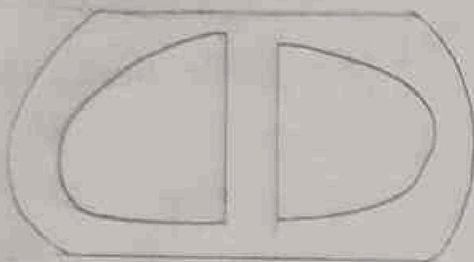
(Twin-circular)



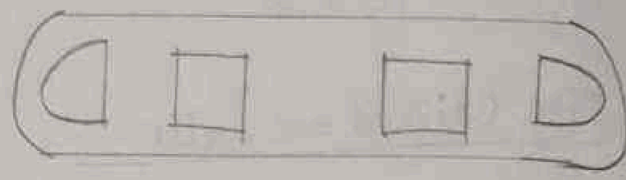
(Dumb-well)



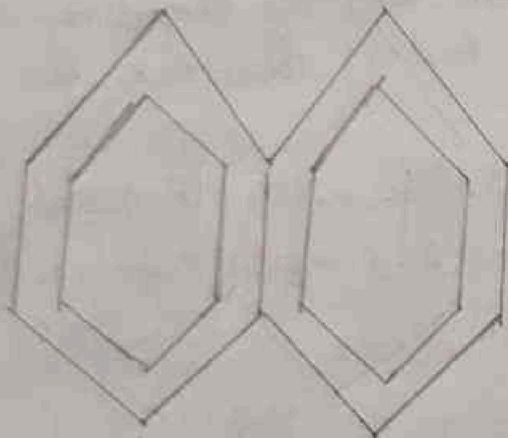
(Rectangular)



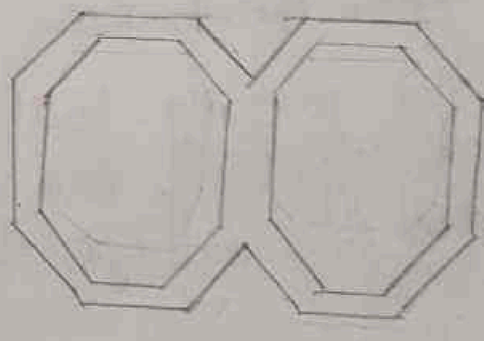
(Double-D)



(Rectangular with D-shaped Ends)



(Twin Hexagonal)



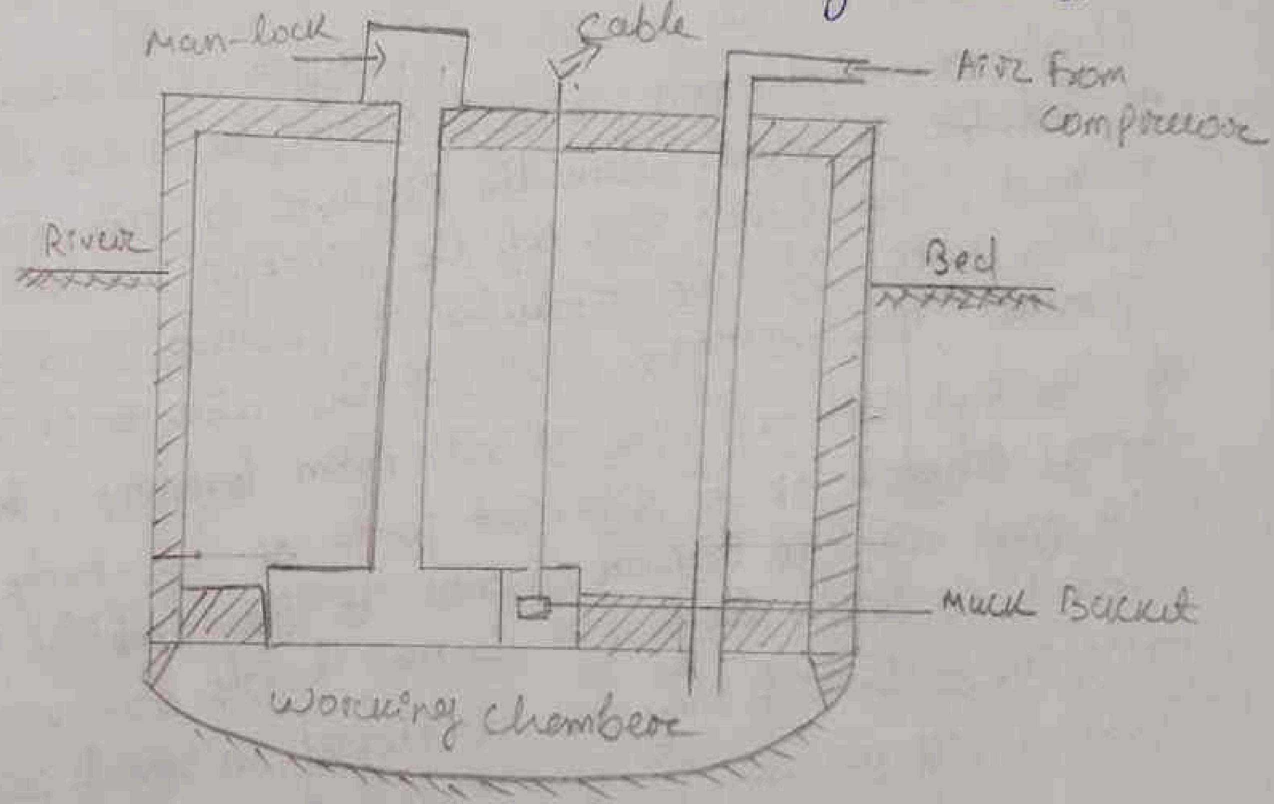
(Twin octangonal)

* The Choice of a particular shape depends upon the following factors:-

(a) The dimention of the base of the pier or abutment.
(b) The ease of sinking
(c) The cost of sinking and shuttering.
(d) The vertical and horizontal forces acting on the well.
(e) The Consideration of tilt and shift during sinking.

* (iii) pneumatic Caisson :-

A pneumatic Caisson is open at bottom and closed at top. this is useful at locations where it is not possible to adopt wells. They are Suitable when the depth of water is more than12m. The maximum depth of water up to which Pneumatic caissons can be used is limited from the consideration of health of the workers. In this the compressed air is used to remove water from the working, chamber and the foundation work is carried out in dry conditions.




(fig 9.5.33)

Shows the details of a pneumatic caisson. They can be made of timber, steel, or concrete, They are sunk to the desired depth by excavating in the working chamber. The working chamber is about 2m high. Two vertical shafts for the passage of men and material are constructed over opening in the roof of this chamber.

Caisson Disease:-

The workers working under compressed air suffer a certain type of disease when they return to atmospheric pressure. This disease is known as Caisson disease. The main symptoms of the disease are dizziness, double vision, headache, trouble in speaking, pain in legs. etc. The disease results in loss of consciousness, paralysis or even death.

When a person is subjected to compressed air, nitrogen is also absorbed along with oxygen by tissue-fluids of the person. The oxygen is dissolved by blood while nitrogen is kept in suspension as it is not st soluble in blood. when the pressure of air is reduced, tissue fluids give up the nitrogen content at a certain rate. If the reduction of pressure is not gradual, the nitrogen will not be able to come out in the form of gas. But it will form bubbles while being caught up in different parts of the body and will give rise to Caisson sickness. If the bubbles are blocked in joints, they will cause bends or violent pains in joints. If they are developed in spinal cord or heart, it will result in paralysis or death respectively.

* The following precautions should be taken to avoid the happening of Caisson disease.

(i) No person should work for more than one shift in a day and the duration of shift should not exceed 12 hours.

(ii) The temperature of the working chamber should be maintained at 25°C.

(iii) Persons with strong hearts, relatively low blood pressure and good circulation should be employed on the work.

(iv) The rate of compression and decompression should be properly controlled.

(v) The man locks should be well ventilated and adequately provided with suitable sanitary arrangements.

(vi) A stand-by air-compressing plant should be kept ready for use in case of emergency.

(vii) A medical chamber must be provided just near the site of work.

## * COFFERDAMS :-

A Cofferdams a temporary structure which is built to remove water from an area and make it possible to carry on the construction work under reasonably dry conditions. Cofferdams are usually required for project such as dams, locks and construction of bridge piers and abutments.

## * Requirements of a Cofferdam:-

(i) The cofferdam should be reasonably water tight,

(ii) The design and layout of a cofferdam should be such that the total cost of construction, maintenance and pumping is minimum.

(iii) It should be sufficiently stable against bursting, over turning and sliding, under the floods, waves and anticipated loads.

(iv) It should be generally constructed at site of work, and

(v) It should be so planned as to facilitate easy dismantling and reuse of materials.

* **Types of cofferdam :-**

following are some of the common types of cofferdams:

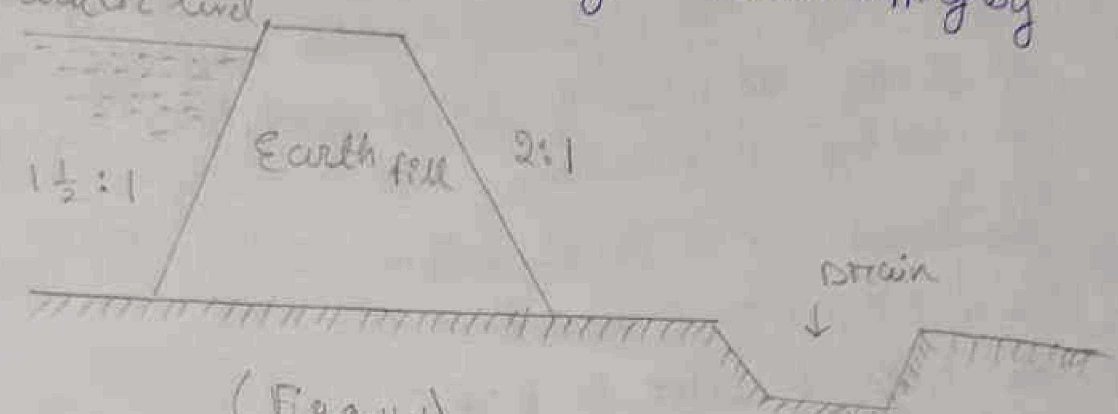
(i) Earth fill cofferdam
(ii) Rock fill cofferdam
(iii) Rock fill Crib Cofferdam
(iv) single wall cofferdam
(v) Double wall cofferdam
(vi) Cellular cofferdam.

* The selection of a type of cofferdam depends upon the following factors:-

(i) The extent of an area to be protected by a cofferdam,
(ii) The depth of water to be dealt with,
(iii) The possibility of overtopping by floods, tides, etc.
(iv) velocity of flowing water,
(v) The nature of bed on which the cofferdam is to rest,
(vi) The possibility of scour due to reduction of waterway caused by construction of cofferdam.
(vii) The availability of construction materials in the vicinity of site of work,
(viii) transportation facilities available.

## (i) Earth Fill Cofferdam:-

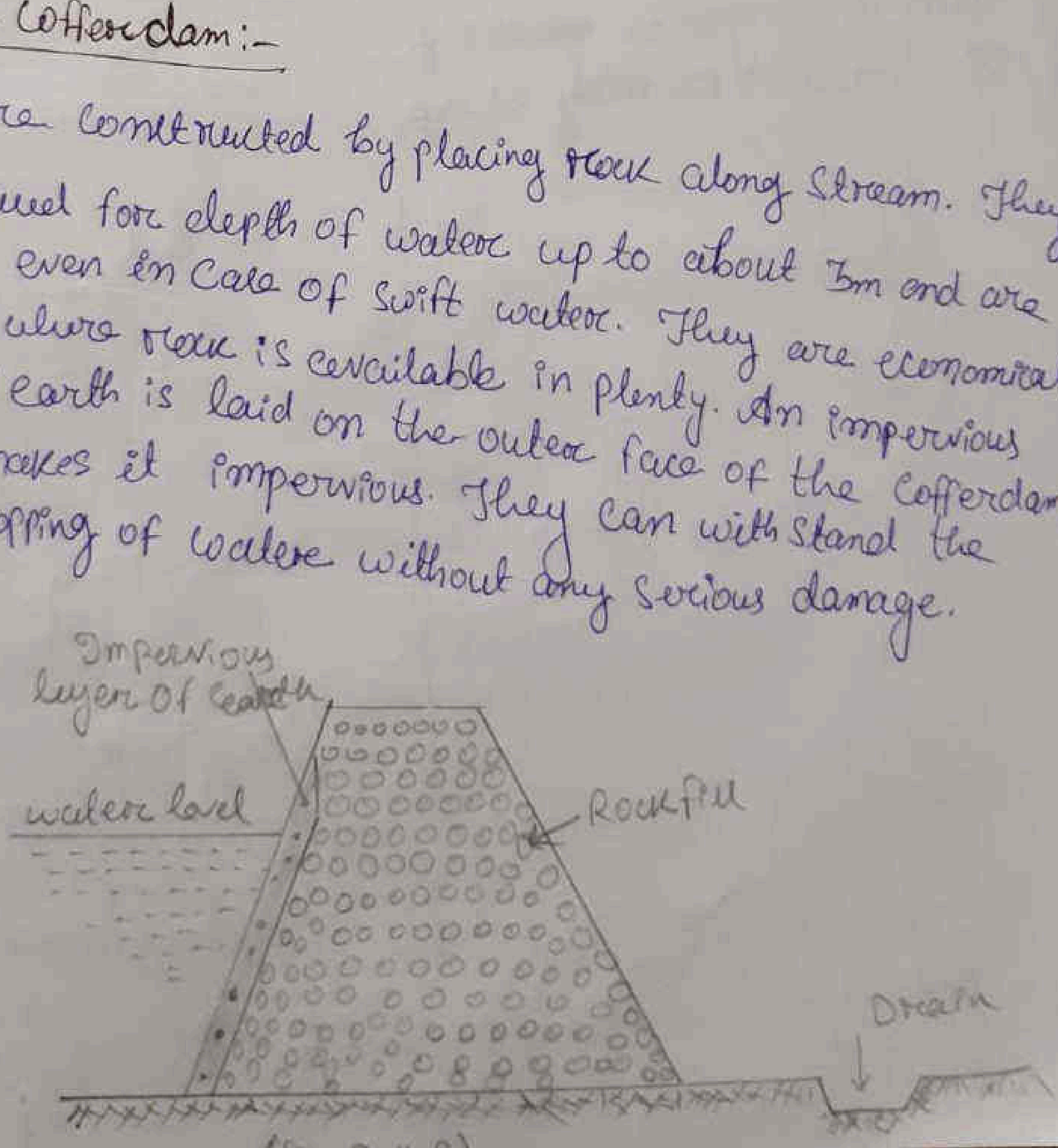
This is the simplest form of cofferdam. Its use is limited in the vicinity where impervious earth is available and water depth is shallow with low velocity of flow. It should never be used where there is danger of over-topping by water.




(Fig 9.11.1)

## (ii) Rock fill Cofferdam:-

They are constructed by placing rock along stream. They are suitable even in case of swift water. They can be used for depth of water up to about 3m and are economical in place where rock is available in plenty. An impervious layer of earth is laid on the outer face of the cofferdam, which makes it impervious. They can withstand the over-topping of water without any serious damage.

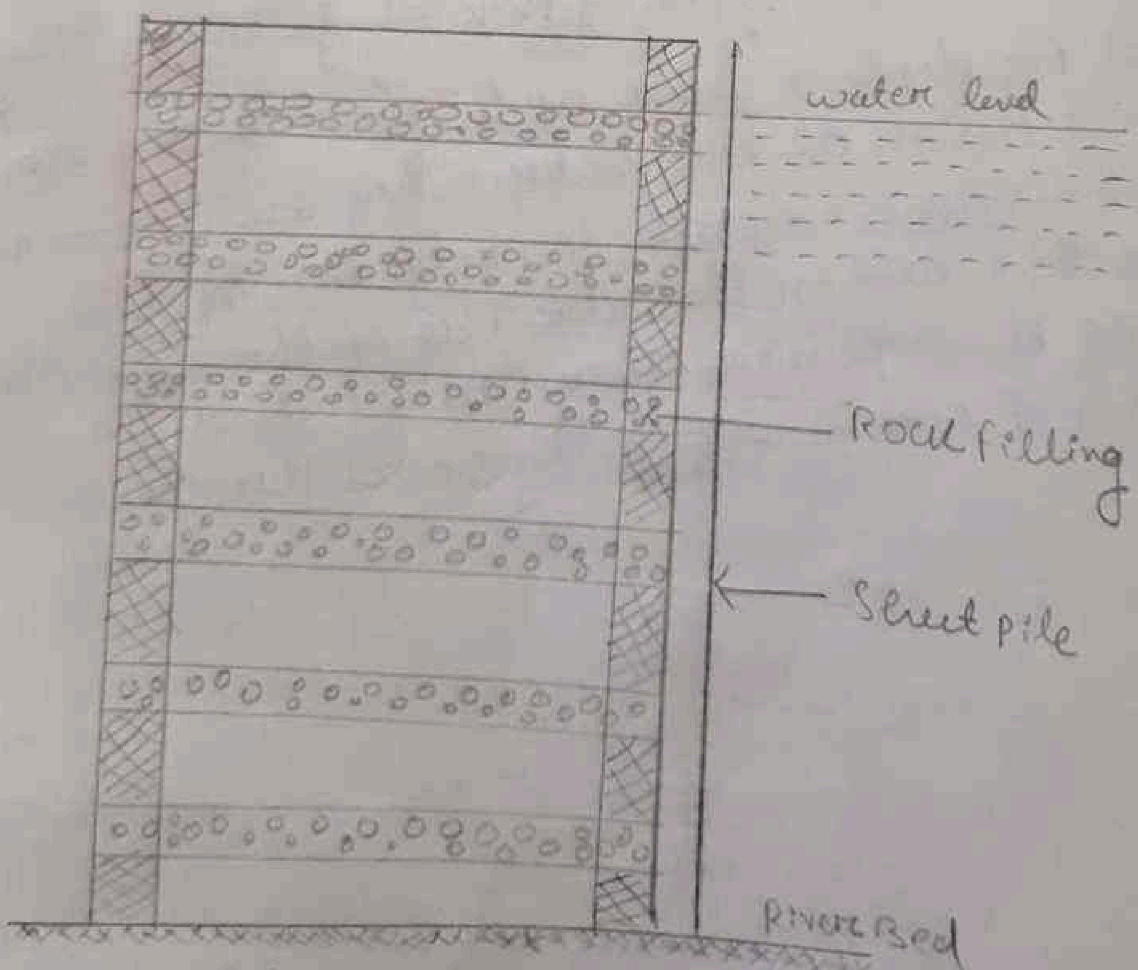



(fig 9.11 2)

(iii) Rock fill crib cofferdam:-

A rock fill crib cofferdam is comprised of timber cribs. A crib is a framework of wooden horizontal and cross beams laid in alternate courses. The cribs are open at the bottom and area filled with rock or gravel or earth. This gives stability to the crib against overturning or sliding. The following set of conditions are favourable for this type of cofferdam.

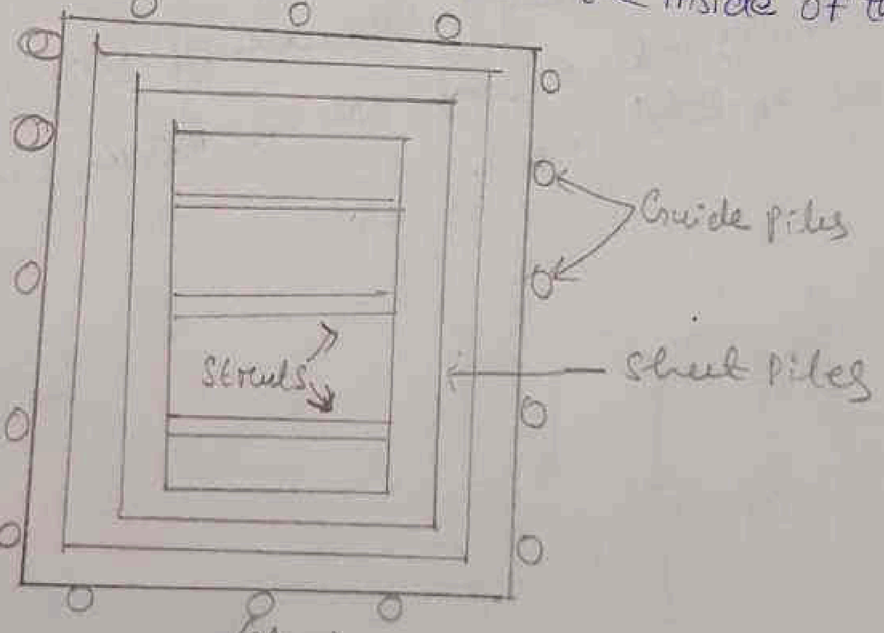
(i) The stream has a hard bottom,
(ii) The working space is limited,
(iii) The depth of water is high,
(iv) The current of water is swift,
(v) There is danger of overtopping,
(vi) The timber is relatively cheap.




(Fig 9.11.3)

(iv) Single wall Cofferdam:-

This type of Cofferdam is suitable when available working space is limited and area to be enclosed is small. It may be used to the maximum depth of water of 25m. The walls of a cofferdam are normally made up of steel sheet pile commercially available to a maximum length of 22m. Reinforced and prestressed concrete sheet piles have also been used. They are braced when used for bridges across perennial rivers. The crane operated grabs are utilized to carry out the excavation inside the enclosed space. Great care is taken to see the grab does not collide with any strut during its travel to and from the inside of the trench.




(Plan)

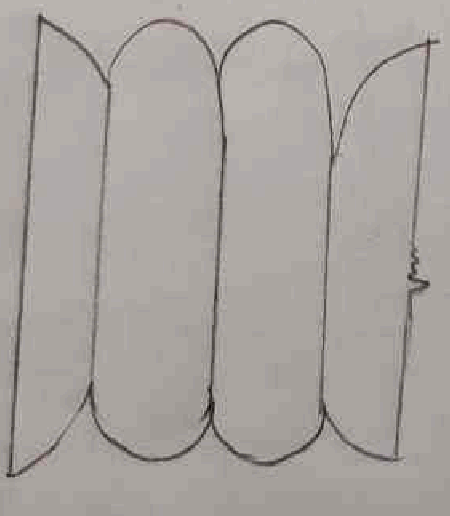
(Fig 9.11.4)

(v) Double wall Cofferdam:-

Double wall cofferdam are provided to enclosed a large area. The double wall gives stability to the cofferdam. This type is useful where scour problems and space limitations are prevalent.

(vi) Cellular coffer dam:-

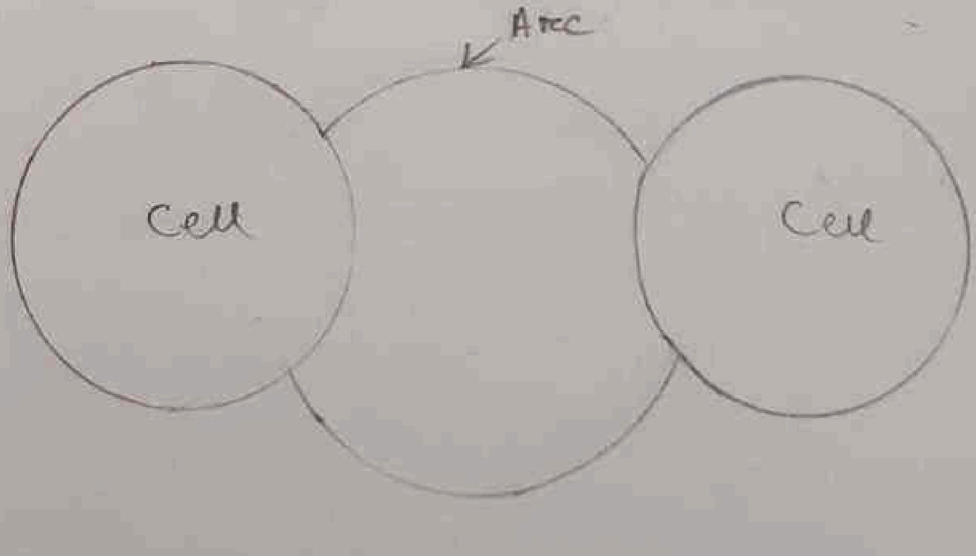
They are made of steel sheet piles and are suitable for dewatering large areas. They are comprised of diaphragm cells or circular cells or modified circular cells. In case of Cellular Cofferdams with diaphragm cell series of arcs are connected to straight cross walls. It can withstand overtopping of water. It is necessary to fill adjacent cells at the same rate with earth or sand otherwise the fill will distort the diaphragm. These types of cofferdams are quite expensive and should be used only in the case of long span bridge piers across wide rivers or in back water areas subjected to tidal waves.



(fig 9.11.5)

The circular cellular cofferdam is comprised of series of complete ~~circules~~ circles connected by short arcs. This type of cofferdam requires more material than the diaphragm. In this case each cell may be filled independently without any danger or distortion of cells. This means that the construction work for cells can be started simultaneously from several points. The cells are designed for.

(i) Stability against over-turning.
(ii) Sliding.
(iii) Circumferential tension in the film.




(Fig 9.11.6)