4. ARCHES

Arches are structural members used in a building to bridge across the opening of doors, windows, or cupboards etc. to support the weight of the superimposed masonry by arch action.

Arch action;-It consist of small wedge shaped units joint together by mortar.

But arches made of steel and Rcc are builtinsingle unit without the use of wedge shaped units and are used for bridge constructions.

Terms;-

***Intrados*:**-the inner curve of arches

***Soffit*-** Inner surface of arch

***Extrados*-** Externalcurve of arch

Voussoirs-wedge shaped unit forming courses of an arch

Skewback- inclined surface of abutment.it is prepared to receive the arch

Springer - first voussoirs at springing level on either side of arch which is adjacent to skewback

Crown - highest point of extrados

Key - wedge shaped unit at crown of arch. It is made prominent by making it of larger section nad projected above and below the outline of arch.

Abutment - the end support of arch

Piers - intermediate support of an arcade.

Springing point- point from which curve of arch springs

Springing line- imaginary horizontal line joining 2 springing points

Span - clear horizontal distance between supports

Rise - clear vertical distance between highest point on intrados and springing line

Centre- geometrical centre of arch curve

Ring- circular course forming on arch

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Depth or height- perpendicular distance between intrados and extrados

Spandril- irregular triangular shape formed between extrados and horizontal line drawn tangent to crown

Haunch- the lower half portion of arch between crown and skewback

Arched - row of arches supporting a wall above and supported by piers

Thickness of soffit- horizontal distance measured perpendicular to the front and back face of an arch

Impost - projecting course at upper part of a pier and abutment to stress the springing line.

The arch may be defined as a mechanical arrangements of wedge shaped blocks of stone or bricks which mutually support each other and entire arch is supported at ends by piers or abutments. The wedge shaped units are so arranged together along a curve line that they balance their own weight by mutual pressure and exert a vertical pressure only which can be sustained by support below.

Stability consideration

- Stability of arches depends on friction between surfaces of voussoirs and cohesion of mortar.
- Stability of arches is endangered by
  - (i) Crushing of arch material
  - (ii) Sliding of voussoirs
  - (iii) Rotation / overturning about an edge
  - (iv) Differential settlement of supports

To maintain the stability or equilibrium of arches, points to be noted

(I) **<u>Crushing of arch</u>** ;-

To prevent crushing of arch material which occurs when thrust at some point of arch creates the safe crushing strength of material, points considered are:-

(a) Size of voussoirs should be adequate to resist anticipated thrust.

(b) For small spans , thickness at arch ring is kept uniform from crown to springing.

Thickness of ring = $\frac{1}{12}$ * span Or

thickness = 20 cm for span upto 1.5 m

= 30 cm for span between 1.5m to 4m

= 40 cm for span between 4m to 7.5 m

(c) For large spans (> 7 cm) , thickness of arch ring may be increased at springing by about 20% to thickness at crown.

(d) Only first class blocks should be used and for large spans arches may be strengthened by steel reinforced so that safe crushing strength is not exceeded.

(II) Sliding of voussoirs :- To prevent sliding of one over after-**:**

(a) All bed joints should be perpendicular to the line of the least resistance, normally they are made normal to the curve of arch, where they are nearly perpendicular to the line of least resistance.

(b) Depth of the voussoirs should be adequate to resist the tendency of joints to open and slide upon one after other.

(III) Rotation about wedge -: To prevent this

(a) Line of resistance/thrust at any section should be within middle third of arch height.

(b) Thickness of arch and its curve are so designed that time of thrust atleast fall within the section and crosses each joint away from edge.

(IV) To safeguard against **differential settlement** :-

(a) Abutments should be sufficiently strong to resist the thrust of arch due to self-weight and superimposed loads.

For abutments of ample size – segment arch is strongest

For smaller size of supports- semi-circular / pointed arch is used

Semi-circular arch is strongest and exerts no thrust on abutments and piers.

(b) Whatever may be the shape of arch, it should be symmetrical to avoid differential settlement of support.

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Types of arches

(I)Classification according to no. of centres -: Outline of intrados / soffit may be formed by a single arc / combination of arcs of various radii and centres and so named as one centre, two centred, 3 centred arcs

*** One centred arch-** They have only one centre .The types are semi-circle, segmental arch(less than a semi-circle), horse shoe arch (more than a semi-circle),

Stilted arch (semi-circular with 2 verticals portions at springing's), bulls eye arch (complete circular arch)

* **Two centred arch-** They are

(a) Blunt arch- Both centres are within the arch itself.

(b) Gothic/Equilateral/pointed arch-Radii of arches are equal to span and centres are on springing points.

(c) Acute/laneet arch-both the centres lie on the springing line but outside the springing points.

* **Three centred arch-**

(a) Elliptical arch-It is the form of semi ellipse, Two centres are used for making up the ends and the third is used to draw the central position.

(b)3 centred drop arch-procedure here is reversed. Ends of the arch formed by arc, central portion is drawn by the other 2 centres.

***Four centred arch-**Two arch are on the springing line and two are

Below the springing line.

***five centred arch-**It looks like semi-elliptical arch. Its procedure is as following

(i) first draw the springing line and divide into 5 parts.

(ii)With centres as A and B draw arches of radius equal to span intersecting at point C_5. Join C_5 with 2 and 3.and produce indefinitely.

(iii)With centres as C_1 and C_2 and radius 3 divisions(i/e 1-4) draw arches intersecting at 4.

(iv)Join OC_1 and OC_2 intersecting lines C_5-2 and C_5-3 and C_3 and C_4.

(v)points C_1, C_2, C_3, C_4, C_5 are the centre of the arch.

CLASSIFICATION ACCORDING TO SHAPE FORMED BY SOFFIT/INTRADOS-:

(I)**FLAT ARCH** (straight/ square / camber arch)-:

The extrados is horizontal and intrados is given a slight rise/camber of about 10 to 15mm/metre width of span so as to allow for slight settlement of it. The angle of skewback with horizontal is usually 60 degree. The depth of the arch is generally kept 3 or 4 courses of brick.

They are limited to span upto 1.5m unless strengthened by steel reinforcement.

(II)**French / Dutch arch**-: Similar in design with flat arch but differs in method of construction. This is not so sound in construction and so used for small inside opening or narrow spans only.

(III)**Semi-circular arch**-: The shape of the arch soffit is a semi-circle. The centre of the arch lies on the springing line.

(IV)**Segmental arch**-:The centre lies below the springing line. The bed joint of voussoirs radiate from the centre of arch. Depth may be 20cm, 30cm or multiple of half brick. Commonly used for arch.

(VI)**Relieving arch**-:Generallyconstructed over a wooden lintel or over a flat arch. It relieves the load of lintel or flat arch. The ends should be kept inside the solid wall. These days lintels restrict the use of relieving arch.

(VII)**Pointed arch / Gatchic –**It is formed intersection of curves at crown.Ther are 5 forms of these types of rches.i/e drop , equilateral , tudor, larcet and venetin.

(VIII)**Venetin arch**-: This one form of pointed arch which has a deper depth at crown other than arch springing line. It has 4 centres on springing line.

(IX) **Floreutine arch**-: Similar to venetian arch except that the intrados consist of a semi circular curve. It has three centres of springing line.

(X)**Semi-circular arch**-:It is formed by more than one centre usually 3 or 5 centres.

(XI)**Horse shoe arch**-:It has a horse shoe like.

(XII)**Stilted arch**-: (a) 2 cusped arch -:This arch with 2 cups has centres at different level. This arch can be made in various forms and used for decorative purposes. This is not structurally efficient.

(c) Corbel arch-: It shape justifies its name it does not have arch action. Here each course is cantilevered out over the course below until the two sides meet. This is the oldest form of arch and not used in modern buildings.

CLASSIFICATION ACCORDING TO MATERIALS AND WORKMANSHIP INVOLVED IN CONSTRUCTION

Stone Arch-

Rubble Arch-

*They are made of roughly dressed stones arranged and fitted into a definite arch shape by cement.

*All the stones used may not be of same size and so joints are thicker.

*They are relatively weak and so used for interior types of works.

*Their use is limited to span of 1 m.

*Up to a thickness of 40 cm stones are laid in one ring for full depth .

*for greater thickness than 40 cm two rings alternative courses of harder and stretcher.

Ashler Arch-

*Here strong are properly cut and dressed to true wedge shape (i. e voussoirs)

*Up to a depth of 60 cm, voussiors are made of full thickness of arch and are set in time (cement mortar)

*To known the no. and size of voussoirs and the key stove of arch, a full size arch is first set out on platform level and then sizes of stones are marked on platform after leaving a gap for joints. Templates are made for voussoirs and key stone of required shape, finally stones are out and dressed to wedge shapes of templates and arch is laid.

*They have good appearance and used for superior work.

*They have laid as heading and stretcher alternatively. When thickness is large, only the stone is made of full thickness of arch ring.

Brick Arch

Rough Brick Arch-

*Made with ordinary bricks, which are net wedges shaped and so joints are wider at extrados than the intrados.

*Generally they are constructed with half brick rings.

*They are cheap, poor in strength and appearance (suitable for consealed work)

Rough Cut Brick Arch-

*Ordinary bricks are roughly cut with a brick laying are to form wedge shaped voussoirs. So joints are not appealing to eyes.

*They are considered not appealing to eyes and so unsuitable for exposed work

*Used where facing brick work is finished with plaster coat.

Gauged Brick Arches

GAUGED BRICK-

*Bricks prepared to exact size and shape of voussoirs by cutting and dressing.

*Joints are very fine, thin and radially.

*Hard bricks can not be used due to difficulty in cutting to true wedge shape.

*So special bricks called rubber bricks are which can be cut and dressed easily to required shape.

*They are cut by saw and finished by rubbing with stone.

*To get thin and fine joint, lime purely is used to bind voussoirs.

PURPOSE MADE BRICKWORK-

*Superior type arch work to get fine and thickness.

*putty lime is used for binding blocks.

Concrete Archery

Precast Concrete Block Archery-

*For small building opening, precast concrete blocks are used in cement mortar for arch construction.

*Concrete blocks for voussoirs, key blocks, skewbacks of required dimension is prepared from concrete mix and cured for 2-weeks. They are without steel reinforcement. They are successful in India for important building and bridges.

Monolithic Concrete Arches-

*They are constructed from cast in-situ concrete with / without reinforcement depending on span and force frequently used for roofing of building, culvert and bridges.

*The construction for small spans and ordinary loads can be made with plane concrete. For large span RCC arches are used.

*For roofing arches, rise of 5 cm for every 30cm of span is allowed when lime concrete is used in arch work.

*Normally arch thickness greater than 15cm up to span of 3m and beyond this 4 cm should be added for each additional 30 cm more.

*Proper frame work and centering is provided to support fresh concrete during construction. Entire work should be kept for at least two weeks.

THRUST LINE

METHOD OF ANALYSIS OF MASONRY ARCHES

Static Approach-

The line containing all the points where the stress resulted at every section of the arch is called thrust line.

*The arch is safe when line of thrust is found to total inside the thickness of the masonry.A classic analysis method using this result involves the use of funicular polygon. This is a graphic method to construct the line of thrust for arches. If the arch is subjected only to vertical loads, then the horizontal component of thrust is constant throughout the whole arch. Nevertheless, the value of this component and its position at the start / end of the element are unknown. Thus the method must be iterative.

Maximum Thrust-

The maximum thrust case is thrust line, or zone of thrust, which takes the intrados once near the crown and the extrados near each springing. This pattern is the response the arch makes to abutments which squeeze together.

Linear Arch / Theoretical Arch / Line Of Thrust

When arch is subjected to given system of loading, the arch shape which follows the shape of the BM diagram for a beam of some span as that of the acrh and subjected to some loading as that in the arch is known as linear arch.

*The line of thrust of a portable arch is funicular polygon.

Eddy's Theorem-

In an arch, BM at any point = horizontal thrust * vertical distance between line of thrust and centre line of arch

(BM at any section of an arch is proportional to the ordinate/intercept between the given arch and the linear arch.)

* Under revision