27

Arch and Buttress Dams

ARCH DAMS

27.1. Definition and Types of Arch Dams

An arch dam may be defined as a solid wall, *curved in plan*, standing across the entire width of the river valley, in a single span*. This dam body is usually made of cement concrete, although rubble and stone masonry has also been used in the past.

This wall will structurally behave : partly as a *cantilever retaining wall standing up from its base, and partly, the load will be transferred to the two ends of the arch span by horizontal arch action*. The arch load will, thus, be transferred to the side walls of the canyon, which must be strong, stable and rocky.

The distribution of part of the load to the side walls of the canyon, reduces the load on the cantilever wall, thereby reducing its thickness, as compared to that in an ordinary gravity dam ; and that is the only benefit we derive from an arch dam in comparison to a gravity dam.

Evidently, the greater is the wall curvature (in plan), the greater will be the load that will be transferred to the sides of the canyon, and hence greater will be the economy in the dam thickness.

This economy in dam thickness can be further increased considerably by making the dam body not only curved in plan, but also curved in section. Such a non vertical dam is known as **double curvature arch dam** or a **shell-arch dam**, because such dams are designed as *shell-structures*. Such three dimensional designs are quite complex, and are taught only at M-Tech level in Structural Engineering.

Since the design and construction of an arch dam is very complicate, requiring extraordinary skill for erecting shuttering in the field, it is generally preferred in practical life to construct gravity dams. And that is why, we find only one arch dam in our country**, as against several hundreds of gravity dams. This arch dam too, is not a simple arch dam, but a shell-arch dam.

Simple arch dams, which transfer a large part of their loading by cantilever action, may also be of different types, since their faces may be either vertical or curvilinear. Depending upon the shape consideration, simple arch dams can be divided into three types, *viz :*

(*i*) *Constant radius arch dams*

* When multiple or a number of arches are used, supported between intermediate piers, the dam is known as a *buttress dam*.

** *Idukki dam*, across Periyar river in Kerala State ; Photoview shown in Fig. 27.1.

(ii) *Variable radius arch dams* ; and

(iii) *Constant angle arch dams.*

A constant radius arch dam is the simplest in design as well as construction, but uses the maximum concrete. A constant angle arch dam on the other hand, uses about 43% of the concrete used by a *constant radius arch dam*. The variable radius arch dam is an intermediate choice, using around 58% of the concrete used by *constant radius arch dam*.

The *shell arch dams* are much more economical than even the constant angle arch dams, as their sections can be quite thin. Say for example, the famous *Vajont dam* of Italy is only 22 m thick at its base, inspite of being 261.6 m in height. Similarly, the *Idduki dam* in India is only 45 m thick at its base, even with 170.7 m height. As compared to these thin sections, the famous *Hoover dam* of USA, which is a *constant radius arch dam (with upstream face vertical) is 201 m thick at its base, with only 222 m height. The difference between the three types of arch dams are explained below :*

27.1.1. Constant Radius Arch Dams. (Fig. 27.2). A constant radius arch dam is that, in which, the radii of the *outside** curved surface are equal at all elevations, from top to the bottom. The centres of all such circular arcs, called **extrodos**, will therefore, evidently lie on one vertical line. However, the **introdos** (*i.e.* inside** curved surface of the arch) has gradually decreasing radius from top to the bottom, so as provide increased concrete thickness towards the base for accounting the proportionally increasing hydrostatic water pressure of the reservoir. The dam body will, therefore, be triangular in cross-section with upstream face vertical, and a minimum thickness at the top.

Evidently, it is only the radii of the *introdos*, which decrease with depth ; while the centres of all such circular arcs continue to lie on the same vertical line, on which lie the centres of the *extrodos*. Hence, in such a dam, the centres of extrodos, introdos, as well as the centrelines of the horizontal arch rings. at various elevations, lie on a straight vertical line that passes through the centre of the horizontal arch ring at the crest. Such a dam is, therefore, sometimes called a **constant centre arch dam**, although strictly speaking, this centre is not at one point, but lies at different heights along one vertical line.

Evidently, the central angles of the arch rings of the introdos will vary at different elevations, due to the varying width of the river valley (see Fig. 27.2); the maximum being at the top of the dam, and the minimum at the bottom of the dam.

It has further been shown that the *best* or *most economical central angle* in an arch dam is the one whose value is equal to $133° - 34'$***. But in a constant radius arch dam, such an angle value can be adopted only at one place, since the angle varies with height considerably, due to narrow V-shape of the valley. It is therefore considered prudent to keep the economical angle of $133° - 34'$ at about mid height. The angle at the top will, therefore, be more than this value; but due to topographical considerations, the angle at the top can not be fixed greater than about 150°. *Hence, the angle at the top should be such as to give the best average angle, but restricted to about 150°.*

* Water side or upstream side.

** Downstream side.

*** This is derived in article 27.3.1.1, a little later.

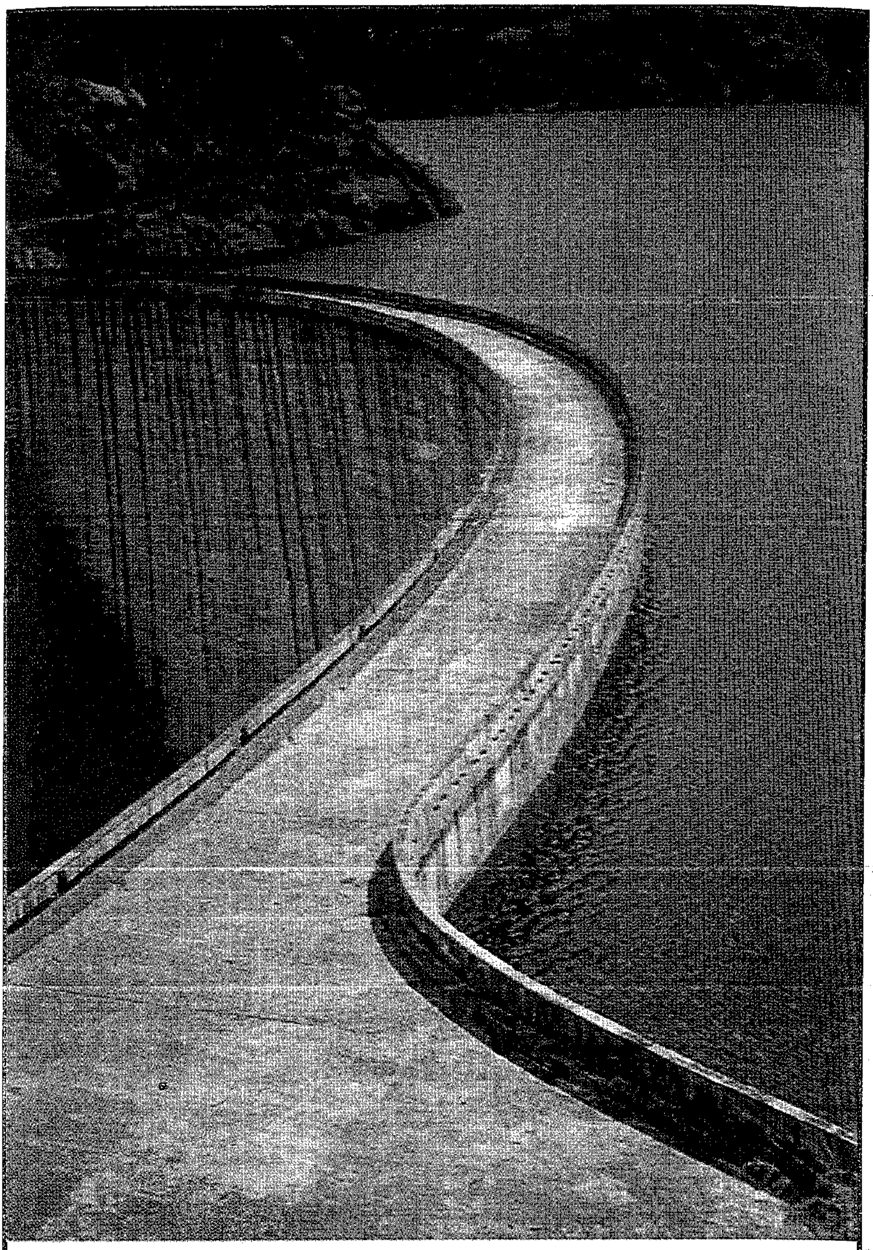


Fig. 27.1. Photoview of Idukki Dam.
A concrete arch dam, constructed across Pariyar river in Kerala State of India. The length of the dam at top is 366 m and maximum height above the lowest point of foundation is 169 m. The construction of the dam was completed during 1966-1974.

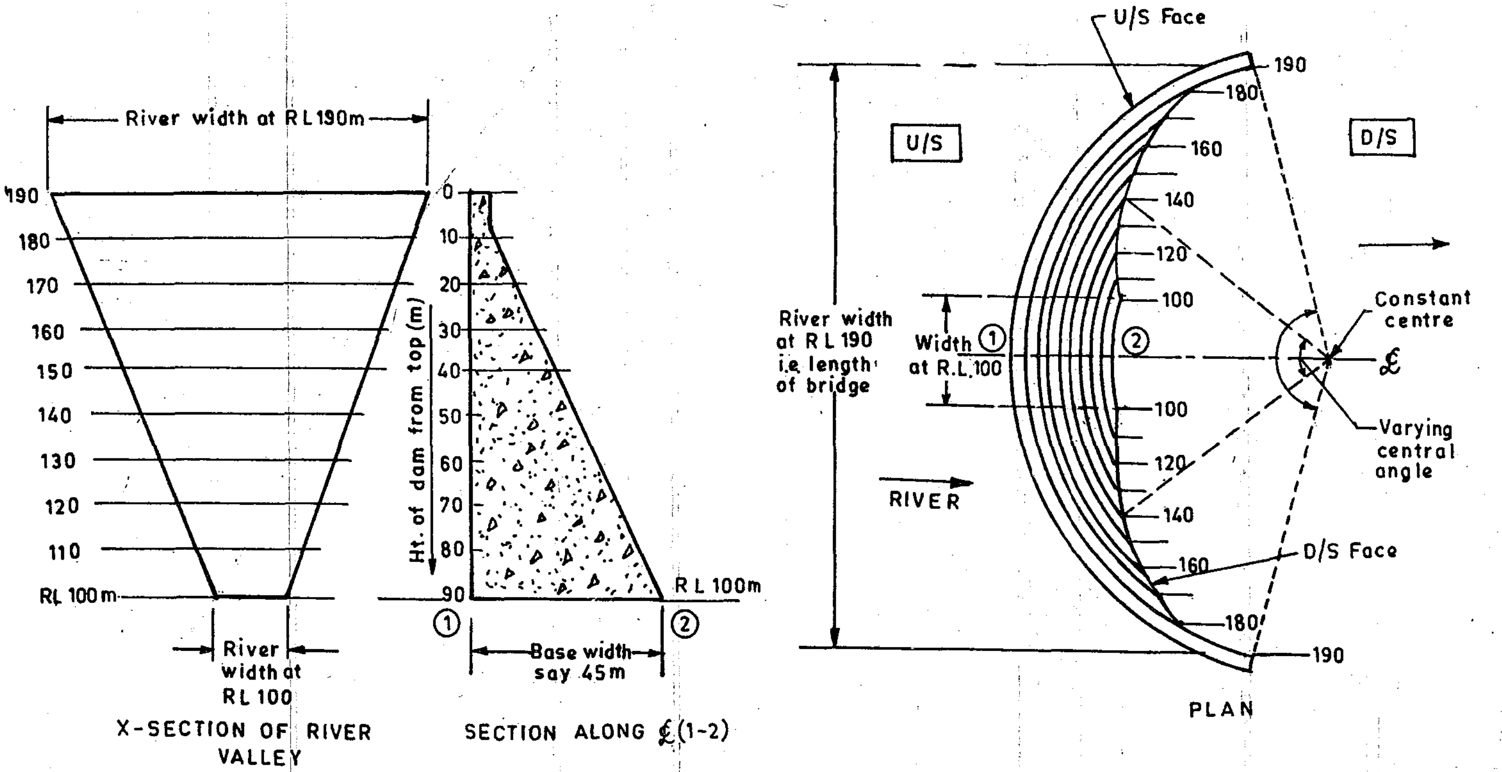


Fig. 27.2. Constant radius arch dam.

27.1.2. Variable Radius Arch Dams. (Fig. 27.3). A variable radius arch dam is the one in which the radii of the extrodos curves* and of *introdos curves*** vary at various

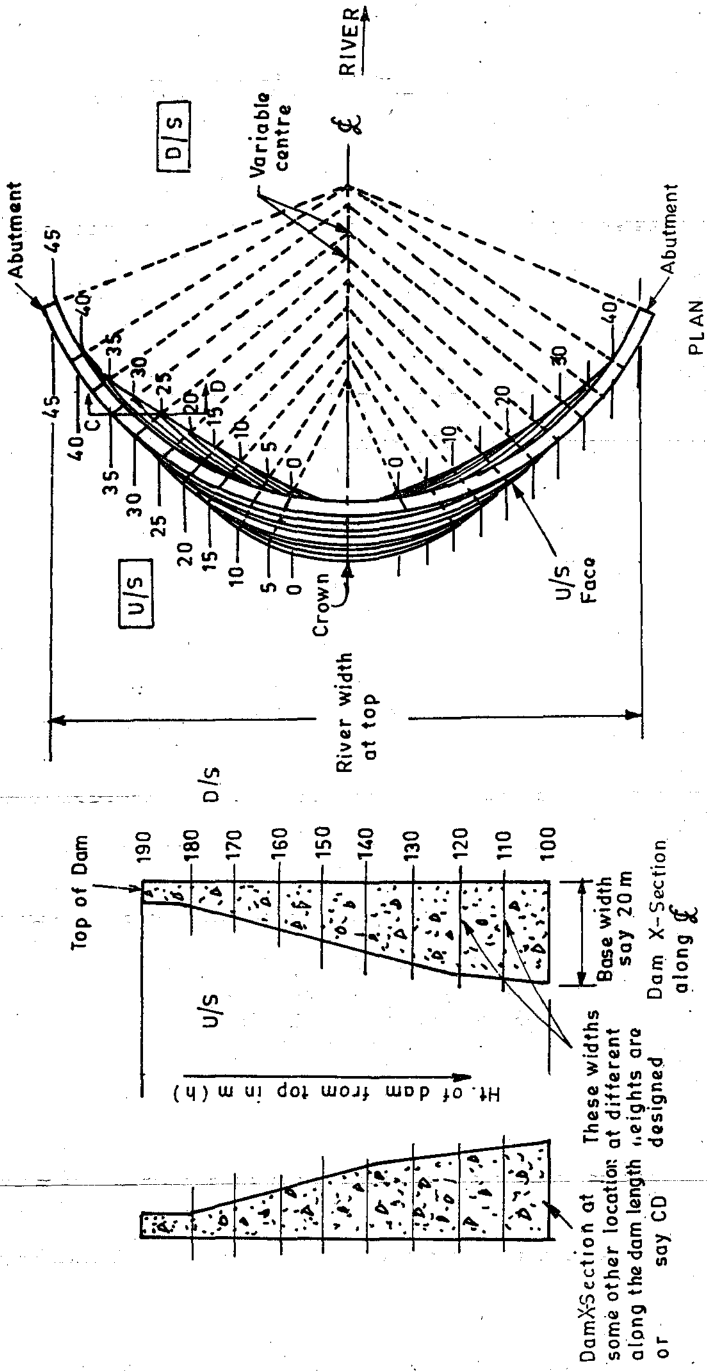


Fig. 27.3. Variable radius arch dam.

* arch rings corresponding to upsteam face.

** arch rings corresponding to downstream face.

elevations, being maximum at the top, and a certain minimum at its bottom. This makes the central angles as large as possible, so that the maximum arch efficiency may be obtained at all elevations.

In a typical design of such a dam, the downstream face of the dam at the central line (crown) is vertical ; while at all other locations, there is a batter on both the sides except at the abutments, where again, the upstream side becomes vertical. If overhangs are permitted, due to availability of stronger foundations, then the faces at the crown as well as abutments, may be provided with overhangs, affecting saving in the designed thicknesses.

Evidently, since in such an arch dam, the centres of the various arch rings at different elevations, do not lie on the same vertical line, it is also known as **variable centre arch dam.** Such dams are preferred for V-shaped valleys as compared to constant radius arch dams which may be preferred for comparatively wider U-shaped valleys.

27.1.3. Constant Angle Arch Dams. The constant angle arch dam is a special type of variable radius arch dam, in which the central angles of the horizontal arch rings are of the same magnitude at all elevations, as shown in Fig. 27.4. The design of such a dam can, thus, be made by adopting the best central angle of $133° - 34'$; and hence such a dam proves to be the most economical, out of the three types of ordinary arch dams, as pointed out earlier also.

However, the design of such a dam usually involves providing *overhangs at abutments*, which require stronger foundations, and hence such a type cannot be used if the foundations are weak.

27.2. Forces Acting on Arch Dams

Generally, the same forces act on an arch dam, which do act on a gravity dam. These forces are : (*i*) *water pressure* ; (*ii*) *uplift pressure* ; (*iii*) *earthquake forces* ; (*iv*) *silt pressure* ; (*v*) *wave pressure* (*vi*) *ice pressure* ; as discussed in article 19.3. However, the relative importance of the forces is different in an arch dam, as compared to that in a gravity dam. Say for example, the uplift pressure in an arch dam is small and is generally neglected, because of the narrow base width of its body. On the other hand, the stresses caused by *ice, temperature changes*, and *yield of supports (i.e. abutments)*, generally become quite important in arch dams, and hence must be thoroughly examined.

Whereas, the ice pressure, applicable in cold countries, causes a continuous concentrated load along the arch element at the elevation of the ice ; the internal stresses caused by the temperature changes move the dam upstream during the summer, and downstream during the winter. Hence, the **low water temperatures** become quite important in stress analysis, since these stresses act additive to the reservoir water pressure. Moreover, even the slight **yield of abutments** due to transfer of load by arch action, may also cause high internal stresses in the arch, and should therefore, be prudently accounted for.

27.3. Design of Arch Dams

Arch dams can be designed on the basis of any one of the following three methods:

(1) *Thin cylinder theory* ;

(2) *Theory of Elastic arches ; and*

(3) *The Trial load method.*

radius r, angle subtended at the centre of the arch equal to 2α, and thickness t. Intensity of *hydrostatic pressure* p at any depth h, is given by :

$$p = \gamma_w h \qquad ...(i)$$

where γ_w = unit weight of water.

This horizontal pressure acts in the radial direction. The total downstream component of the horizontal force (P_H), acting along the axis of the river, is then given by

$$P_H = \text{Intensity of pressure} \times \text{Projected area} = \gamma_w \cdot h \times 2r \sin\alpha$$

$$= 2\gamma_w h \, r \sin\alpha \qquad ...(ii)$$

If R is the reaction at each abutment, its upward component is equal to $2R \sin\alpha$. Equating this to P_H for equilibrium, we get

$$2\gamma_w \cdot h \cdot r \sin\alpha = 2R \sin\alpha$$

or $$\gamma_w \cdot h\, r = R \qquad ...(iii)$$

This equation gives an expression for the abutment reaction, which is equal to the maximum compressive force induced in the arch.

If σ is the compressive stress induced in the arch at the abutments, then

$$\sigma = \frac{R}{t} = \frac{\gamma_w \cdot h \cdot r}{t} \qquad ...(iv)$$

If f_c is the allowable compressive stress for the arch material, then

$$f_c \gg \frac{\gamma_w \cdot h \cdot r}{t}; \text{ or } t \gg \frac{\gamma_w \cdot h \cdot r}{f_c}$$

Under Limits, $$\boxed{t = \frac{\gamma_w \cdot h \cdot r}{f_c}} \qquad ...(27.1)$$

The above equation indicates that the thickness of the arch (t) should increase linearly with the depth below the water surface, and that at a given elevation, the required thickness of the arch ring is proportional to the radius of the arch (r) at that elevation.

27.3.1.1. Central angle for minimum concrete. Considering the arch ring as shown in Fig. 27.5, we have

the volume of concrete per unit height of the arch ring (V)

$$= r\,(2\alpha) \cdot A$$

where A is the cross-sectional area of the arch ring $= (t \times 1)$

Since $A = t \times 1$, we have

$$V = r\,(2\alpha) \cdot t$$

Substituting the value of t from Eq. (27.1), we get

$$V = r \cdot (2\alpha) \cdot \frac{\gamma_w \cdot h \cdot r}{f_c}$$

or $$V = \frac{\gamma_w \cdot h}{f_c} \cdot r^2 \cdot (2\alpha) \qquad ...(i)$$

Now, if L is the span of the arch ring, then from Fig. 27.5, we observe that

$$\sin \alpha = \frac{L}{2r}$$

or
$$r = \frac{L}{2 \sin \alpha} \qquad \text{...(ii)}$$

Substituting this in Eq. (*i*) above, we get

$$V = \frac{\gamma_w \cdot h}{f_c} \left(\frac{L}{2 \sin \alpha} \right)^2 (2\alpha)$$

$$= \frac{\gamma_w \cdot h}{f_c} \cdot \frac{L^2}{2} \left[\frac{\alpha}{\sin^2 \alpha} \right] \qquad \text{...(iii)}$$

where $\frac{\gamma_w \cdot h}{f_c} \cdot \frac{L^2}{2}$ is a constant $= K$ (say)

$\therefore$
$$V = K \cdot \left[\frac{\alpha}{\sin^2 \alpha} \right]$$

or
$$\frac{\partial V}{\partial \alpha} = K \left[\frac{\sin^2 \alpha - 2\,\alpha \cdot \sin \alpha \cos \alpha}{\sin^4 \alpha} \right]$$

For minimum volume of concrete (V)

$$\frac{\partial V}{\partial \alpha} = 0$$

$\therefore$
$$\sin^2 \alpha = 2\alpha \cdot \sin \alpha \cdot \cos \alpha$$

or
$$\sin \alpha = 2\alpha \cdot \cos \alpha$$

or
$$\frac{\sin \alpha}{\cos \alpha} = 2\alpha$$

or
$$\tan \alpha = 2\alpha$$

or
$$2\alpha = \tan \alpha$$

$\therefore$
$$2\alpha = 133° - 34'$$

This shows that the most economical central angle is $133° - 34'$, as was stated by us earlier.

27.3.1.2. Limitations of thin cylinder theory. The various limitations of this theory are :

(*i*) The arch sections are not thin cylinders. They are also not free at abutments, as assumed in this theory.

(*ii*) The theory does not consider shear and bending stresses in the arch.

(*iii*) The analysis is based on only the hydrostatic water pressure. *Temperature stresses and ice pressures, which are quite important in arch dams, get ignored in this theory.*

(*iv*) Stresses due to yielding of abutments and those due to rib shortening have not been accounted in this theory.

(*v*) plastic flow of concrete and shrinkage in concrete have not been accounted for.

27.3.2. The Elastic Theory for Design of Arch Dams. As pointed out earlier, the archs are subjected to additional forces, such as :

(*i*) *temperature stresses*, due to temperature changes ;

(*ii*) *shrinkage stresses*, due to setting of concrete ;

(*iii*) stresses due to yielding of abutments ; and

(*iv*) stresses due to rib shortening.

The stresses at (*i*) and (*ii*) are quite evident, and need no explanation. It may however, be added that the effect of rise in temperature, as in summer season, produces opposite stresses, whereas, the stresses due to fall in temperature are additive, and hence, only need be accounted. The stress at (*iii*) above is also understood, since no abutment is rigid, and yields to an extent depending upon the nature of the rock. This yield increases the span of the arch, inducing additional stresses. The stress at (*iv*) above, can be explained as below :

In case of a cylinder, the pressure acts from all sides, and the entire ring is compressed so that the diameter of the cylinder decreases by a small amount, but *there* is no deformation. While in the case of an arch, *which is a part of a cylinder*, the ends being fixed, the distance between them (*i.e.* the span) does not change. This restriction of the change in span, causes additional stresses, known as *rib-shortening stresses. In a long thin arch, these stresses are small ; but in the case of a thick arch of small angle, they are appreciable, and need to be accounted for.*

All the above stresses are taken into consideration by the theory of elastic arches.

27.3.3. General formulas. The formulas for elastic arches, usually given in the books on "Theory of Structures" or "Applied Mechanics" are reproduced here for the benefit of students, intending to solve arch dams by elastic theory.

With reference to Fig. 27.7.

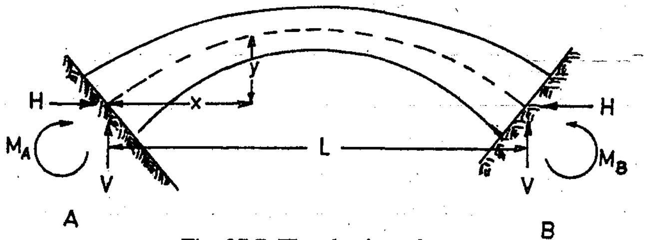


Fig. 27.7. The elastic arch.

$$M = \mu + M_A + (M_B - M_A)\frac{x}{L} + H \cdot y \qquad ...(27.2)$$

$$\int \frac{M}{E \cdot I} y ds = \int \frac{\mu \cdot y}{EI} \cdot ds + M_A \int \frac{y \cdot ds}{EI} + \frac{M_B - M_A}{L} \int \frac{xyds}{EI} + H \int \frac{y^2}{EI} ds = 0 \qquad ...(27.3)$$

$$\int \frac{Mx}{EI} ds = \int \frac{\mu \cdot x}{EI} \cdot ds + M_A \int \frac{x \cdot ds}{EI} + \frac{M_B - M_A}{L} \int \frac{x^2 \cdot ds}{EI} + H \int \frac{xy}{EI} ds = 0 \qquad ...(27.4)$$

and $$\int \frac{M}{E \cdot I} ds = \int \frac{\mu}{EI} \cdot ds + M_A \int \frac{ds}{EI} + \frac{M_B - M_A}{L} \int \frac{x \cdot ds}{EI} + H \int \frac{yds}{EI} = 0 \qquad ...(27.5)$$

where μ = the bending moment on a straight horizontal freely supported beam

M = the bending moment at any point on the arch

M_A and M_b = fixed end bending moments at both the ends of the arch

H = horizontal thrust at the abutments

For **symmetrical arch**, $M_A = M_B$; and the Eq. (27.4) vanishes ; while Eqs. (27.3) and (27.5) get simplified to :

$$\int \frac{M}{EI} \cdot y \cdot ds = \int \frac{\mu \cdot y}{EI} \cdot ds + M_A \int \frac{yds}{EI} + H \int \frac{y^2 \cdot ds}{EI} = 0 \quad \text{...[27.3 (a)]}$$

and $$\int \frac{M}{EI} \cdot ds = \int \frac{\mu}{EI} ds + M_A \int \frac{ds}{EI} + H \int \frac{y \cdot ds}{EI} = 0 \quad \text{...[27.5 (a)]}$$

As the *contraction* due to temperature effect and *rib- shortening* due to thrust, is prevented by the abutments, these effects modify the above Eqs. (27.3), (27.4) and (27.5) as

$$\alpha \cdot TL - \int \frac{M}{EI} \cdot y \cdot ds = 0 \quad \text{...[27.3 (b)]}$$

where α = Coefficient of thermal expansion

T = Fall in temperature in °C

$$\int \frac{M}{EI} ds = 0 \quad \text{...[27.4 (b)]}$$

$$\int \frac{M \cdot x}{EI} ds = 0 \quad \text{...27.5 (b)]}$$

and $$M = M_A - V_x + H \cdot y \quad \text{...(27.6)}$$

in which the additional term V stands for the vertical thrust of opposite nature at the two abutments, and is reckoned positive upwards.

For a symmetrical arch, $V = 0$; so that the Eq. (27.6) simplifies to

$$M = M_A + H \cdot y \quad \text{...[27.6 (a)]}$$

and Eqs. [27.4 (*b*)] and [27.5 (*b*)] become

$$M_A \int \frac{y}{EI} \cdot ds + H \cdot \int \frac{y^2}{EI} ds - L \cdot \alpha T = 0 \quad \text{...[27.4 (c)]}$$

and $$M_A \int \frac{ds}{EI} + H \int \frac{y}{EI} ds = 0 \quad \text{...[27.5 (c)]}$$

By solving these equations, the values of M_A, H and V are obtained.

Rib-shortening effect can be reckoned along with the other loads by adding its effect to the left side of Eq. (27.3).

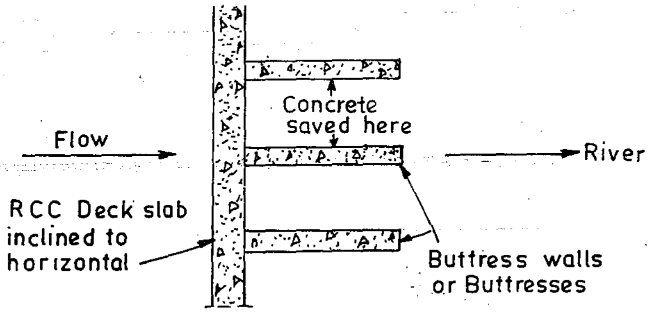
BUTTRESS DAMS

27.4. Definition and Types of Buttress Dams

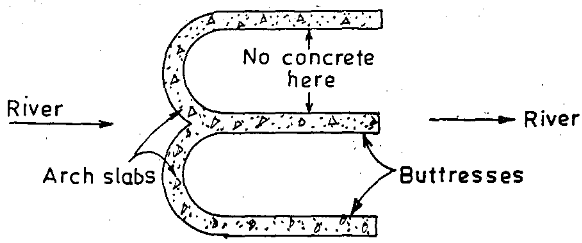
An ordinary concrete gravity dam, as we know, is a solid body of mass concrete, somewhat triangular in section, running across the entire width of the river valley. Such a solid wall requires huge amount of concrete, which partly remains *unstressed to full extent*, thereby leading to wastage of concrete. The uplift pressure also acts on the entire width of the dam body, from its bottom, which further increases its size, without giving any additional benefit as a dam.

Efforts have, therefore, been made from time to time, to innovate methods for affecting economy in the use of concrete, by cutting down the concrete from those dam portions where it remains unstressed. Attempts have, therefore been made to provide *hollow gravity dams*. **Buttress dams**, are an improvement innovation over the hollow concrete gravity dams.

In such an innovated dam, therefore, *solid walls of specified thickness and section*, are constructed parallel to the flow, at some suitable intervals. These walls are called **buttresses.** *Inclined slabs* or *arch slabs* are then supported on upstream side on these buttresses, as shown in Fig. 27.8.



(*a*) Deck type



(*b*) Multiple arch type

Fig. 27.8. Simplified line sketches of buttress dams.

Although, several types of buttress dams have been devised, but the most common types, are :

1. *Deck slab type ; and*
2. *Multiple arch type.*

Both these types of dams have been shown in their simplified line diagrams, in Figs. 27.7 (*a*) and (*b*) respectively.

Slab type dams are generally preferred for smaller heights, say from 20 to 50 m, or so. The highest such dam in the world is *Rodriguez dam* in Mexico, having a height of 73.2 m. Such dams are virtually referred to as buttress dams, or **Amberson dams** (based upon the name of their inventor).

The multiple arch dams, on the other hand, are used for higher dam heights, say from 50 m onward, and the highest such dam of the world is *Manicougan-5 dam* in Canada, having a height of 210 m.

Detailed views of both these types of dams are shown in Figs. 27.9 and 27.11, respectively ; and are discussed below :

27.4.1. Simply Supported Slab Type of Buttress Dams. (Fig. 27.9). In such a type of dam, the R.C.C. deck slab is freely supported on the buttresses, which have corbels for the slab to rest on. The deck slab is inclined to horizontal by about 40° to 55°, so as to support the dead load of a portion of reservoir water, and thus, to provide the stabilising force, in addition to the 'self' weight of the dam, to avoid its sliding.

Design considerations. The loading and safety criteria for buttress dams or buttresses, is the same as that for a gravity dam section, except that the provided *buttress thickness* 't' will take the load coming from the dam length $= x + t$; where x is the clear

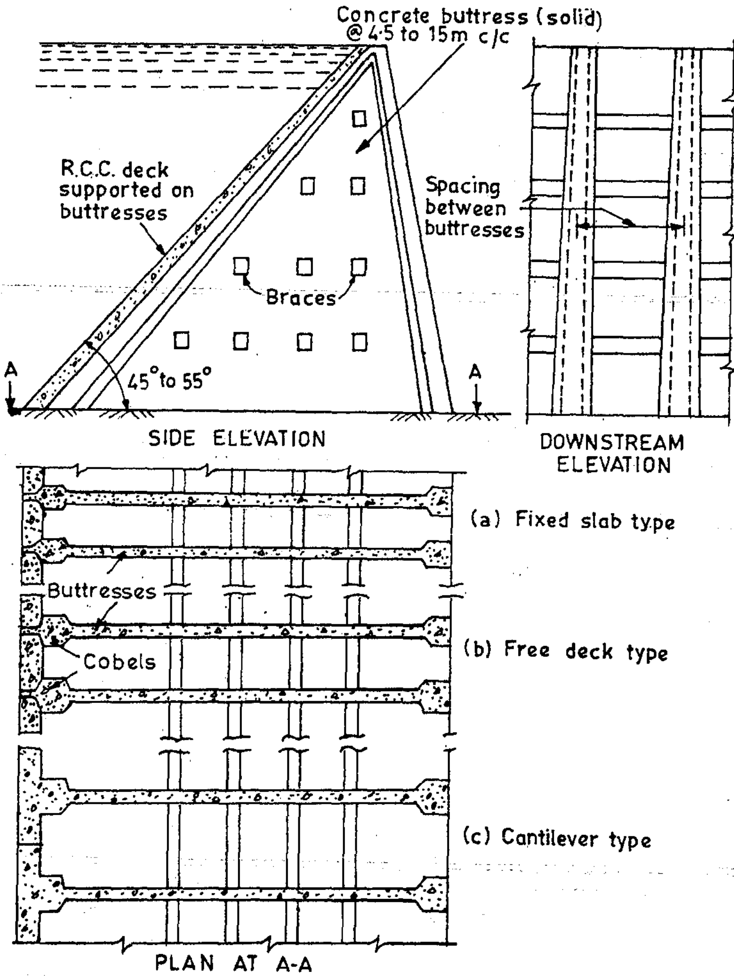


Fig. 27.9. Detailed views of a free deck type of a buttress dam.

spacing between the two consecutive buttresses. Hence, t metre length of buttress section, will take the loads coming from $(x + t)$ metre length of dam, as against the unit metre length of gravity dam section taking load from the unit metre dam length. The resultant impact can be considered by increasing the unit weight of water by multiplying its actual value by a *surcharge factor* (S), defined as :

$$S = \frac{x+t}{t} \qquad \text{...(27.7)}$$

Hence, the effective unit wight of water can be considered as $\gamma_w \left(\frac{x+t}{t}\right)$, and the section of the buttresses can be designed, exactly in the same manner, as a gravity dam section is designed, considering unit length and a continuous section.

The deck slabs can be designed as simply supported R.C.C. decks, each spanning over two adjacent buttresses, and each having a span $= x + t$.

Buttress spacing and Deck slope

(*i*) The **most economical spacing of buttresses** is the one, in which *the minimum thickness of concrete is fully utilised.* This spacing is governed to a very large extent by the values of the upstream slope of the dam (ϕ). For economy, it is also necessary that the buttress spacing be changed for dams of different heights. The suggested spacings for different dam heights, are shown in table 27.1.

Table 27.1. Suggested Economic Buttress Spacings

Mean Dam height in m	*Economic buttress spacing suggested in m, for a normal ϕ value of 40° to 50°*
Less than 15	4.5
15—30	4.5 to 7.5
30—45	7.5 to 12
above 45	12 to 15

(*ii*) The *height, thickness*, and *spacing of buttresses*, can further be controlled by :

$$\textbf{Slenderness ratio} = \frac{\text{Height of buttress}}{\text{Thickness of buttress}} = 12 \text{ to } 15 \qquad \text{...(27.8)}$$

$$\textbf{Massiveness factor} = \frac{\text{Spacing of buttresses}}{\text{Thickness of buttress}} = 2.5 \text{ to } 3 \qquad \text{...(27.9)}$$

(*iii*) For constant buttress spacing, variation of few degrees in the u/s slope may result in an appreciable change in the quantity of concrete. This concrete quantity required per metre length of dam (V_c) is, infact, related to *u/s* deck slope (ϕ), dam height (H), and the sliding factor $\left(F_s \text{ } i.e. \frac{\Sigma H}{V}\right)$ by the equation :

$$V_c = 0.208\, H^2 \left[\frac{1}{F_s} - \cot\phi\right] \qquad \text{...(27.10)}$$

This equation clearly shows that for a fixed dam height (H) and a given value of F_s, the concrete quantity depends solely on ϕ. Hence, for different values of ϕ, at fixed values of H and F_s, concrete quantities can be worked out. *Vertical lines*, like those shown in Fig. 27.10, are, thus, drawn for each value of the concrete quantity corresponding to each value of ϕ.

Concrete quantities are also worked out for various angles of u/s slope (ϕ) and different buttress spacings, for fixed decided dam height (H) ; and plotted to get a curve for each angle. A **master curve** is then drawn through the junctions of the curves and the vertical lines corresponding to each angle.

The master curve gives the **absolute economic value of buttress spacing** for different *u/s* slope (ϕ) for the decided dam eight.

Say for example, from the plotted curves of Fig. 27.10, we find that for a $\phi = 48°$, buttress spacing is about 8.8 m ; for a $\phi = 49°$, buttress spacing is about 10 m. *This reflects that by increasing the upstream slope, we can increase the buttress spacing.* This figure also reflects that lower values of ϕ (lesser than 47°) are not available on this particular master curve ; which shows that such lower values will not prove economical

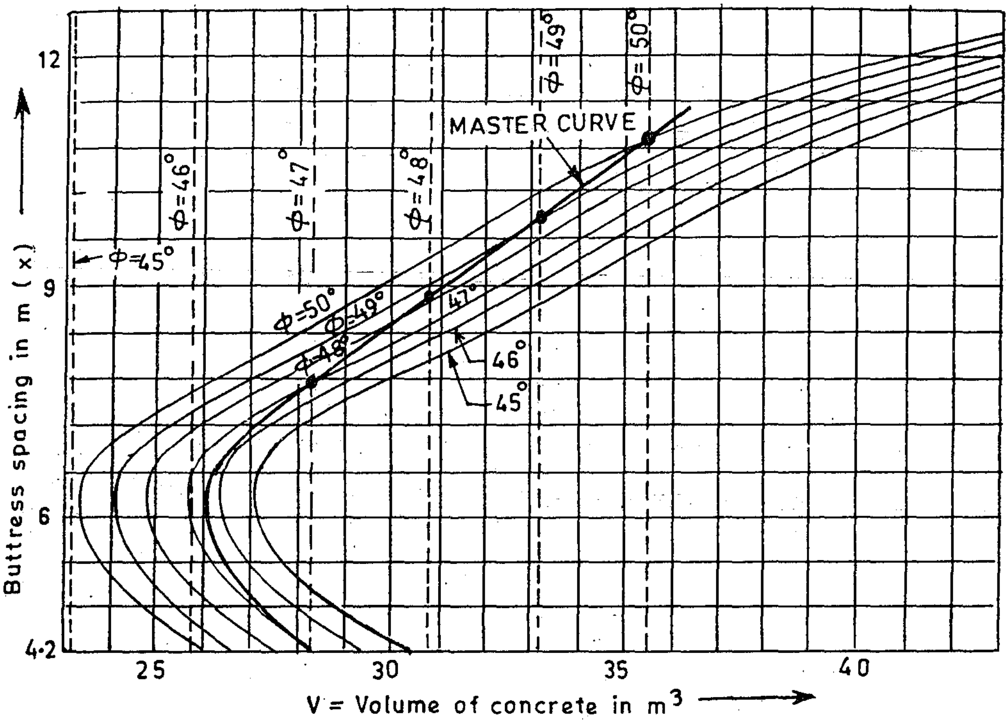


Fig. 27.10. Master curve for absolute economic value of buttress spacing.

for this project. Hence, each individual project (or dam) has, thus, to be analysed for decided dam height, to determine the permissible economical values of ϕ, and their corresponding values of buttress spacing, and thus finally to choose any one set of them.

27.4.2. Multiple Arch Type of Buttres Dams. As stated earlier, in this type of dams, arch slabs are constructed for *u/s* face of the dam, to be supported on buttresses, as shown in Fig. 27.11 and 27.12. Each buttress may be in the form of a single stiffened wall, as shown in Fig. 27.13 (*a*) ; or a double hollow wall, as shown in Fig. 27.13 (*b*).

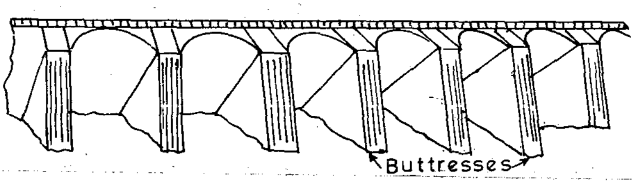


Fig. 27.11. Perspective view of a multi-arch buttress dam.

Meer Alam dam in India, built in about 1800 A.D., is the earliest recorded example of such a type of dam. As stated earlier, such dams are preferred for larger heights, as they prove more stable and flexible, as compared to the ordinary buttress dams (*i.e.* slab type).

The stability of any unit of a multiple arch dam depends on the adjacent units, so that any settlement in one would affect the others. Hence, such a dam would require

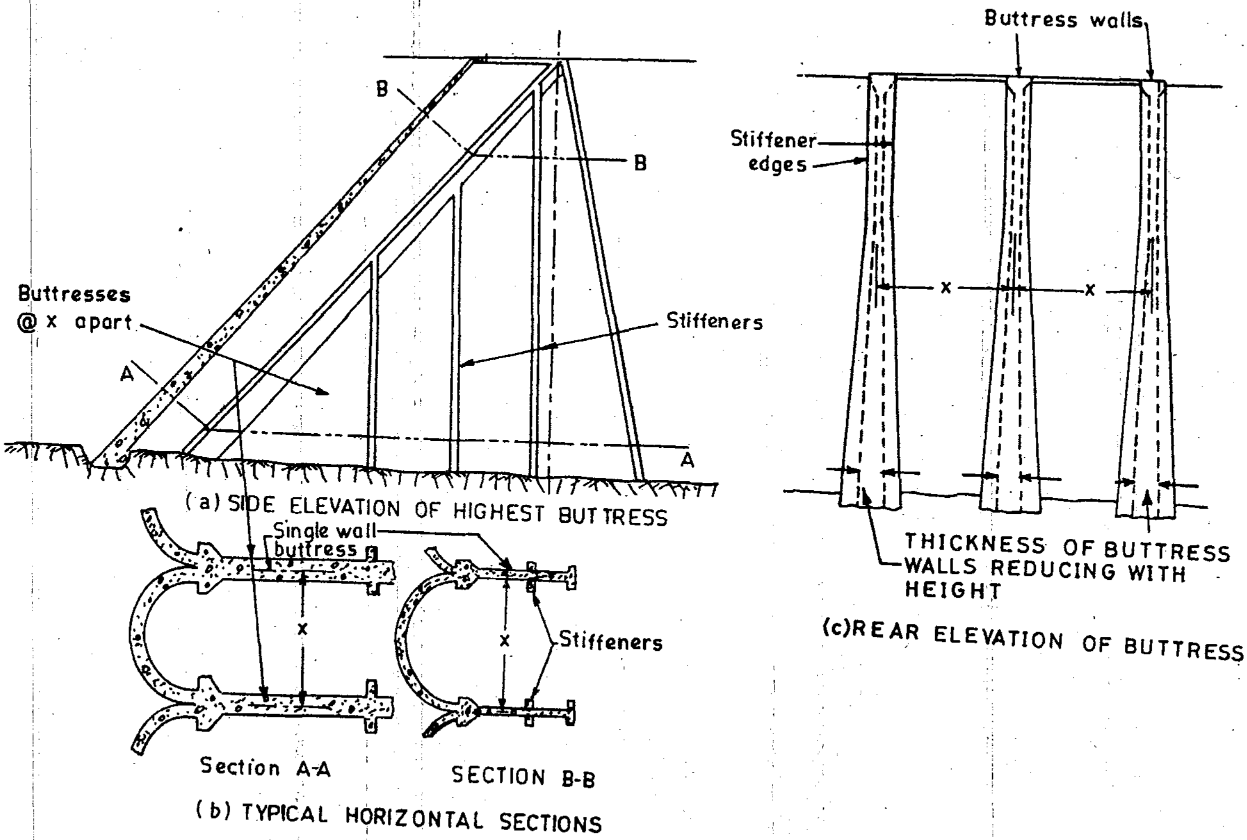
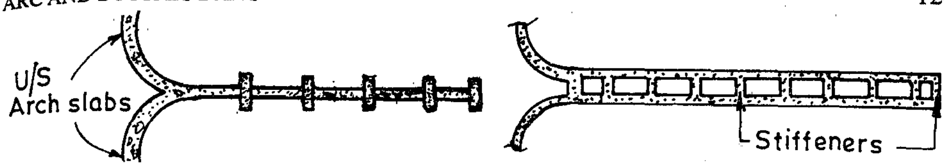


Fig. 27.12. Detailed views of a multiple arch dam.



(*a*) Single wall buttress (*b*) Double wall or hollow buttress

Fig. 27.13. Single and Double walled buttress.

better foundations, as compared to an ordinary buttress dam, where deck slabs on two adjacent buttresses, behave as independent units.

For short spans (10 to 15 m), circular arches of uniform thickness prove economical; whereas, for larger spans, arches of variable thickness are provided. If the central angle of each arch is kept between 180° to 150°, with semi circular or nearly semi circular arches, the horizontal thrust between adjoining arches gets eliminated.

For arched buttress dams, the range of buttress spacing generally adopted, is between 15 to 21 m, although as high a value as 42 m has been permitted in *Webber Greek dam* in California, USA ; a site plan of which is reflected in Fig. 27.14.

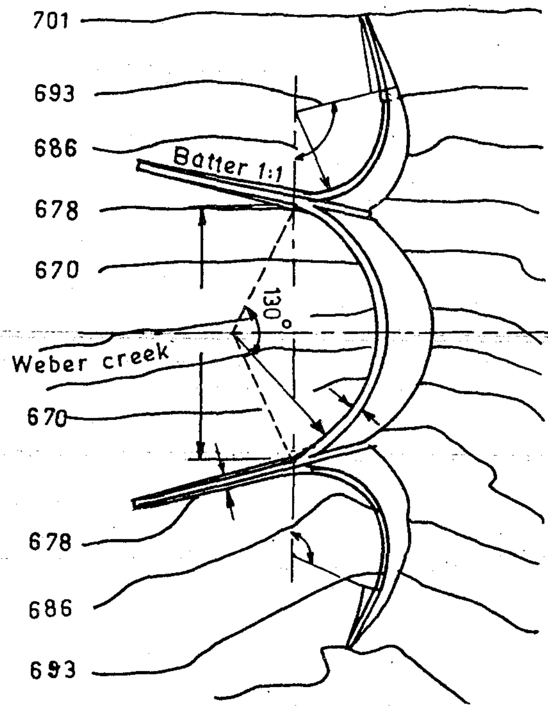


Fig. 27.14. Site plan of Webber creek dam (an example of long span multiple arch dam).

27.4.3. Other Types of Buttress Dams. In addition to the above described two general types of buttress dams, certain other types, such as *multiple dome type ; massive head type ; columnar buttress type ;* etc., have also been adopted at some places, as discussed below :

27.4.3.1. Multiple dome type. Such a type of buttress dam is quite understandable, as it uses a number of *domes* instead of a number of arches as used in a multiple arch type of dam, and all other features remaining the same. Such a dam can help in increasing the buttress spacing, but requires sites, where stable foundations can be had at greater depths. The *Coolidge dam on San Carlos river in Arizona is an example of this type of a dam, which is 76.2 m high with buttresses @ 54.8 m apart.*

27.4.3.2. Massive head types. This type of buttress dam is the one, which does not use slabs or archs for upstream face, but the heads of the buttresses themselves are enlarged to meet each other, and thus, to form a continuous water supporting surface, as shown in Fig. 27.15. When the enlarged heads are *cylindrical* on the outerside, it is known as *round head deck* (Fig. 27.15 *a*) ; and when they converge to a point, it is known as a *diamond head deck* (Fig. 27.15 *b*).

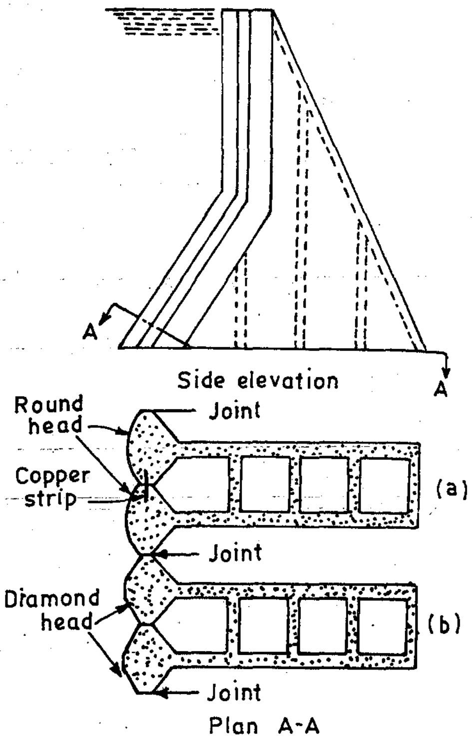


Fig. 27.15. Massive head type of buttress dam.

These *massive head buttress dams* are, infact, considered as improvement over all other types of buttress dams, as they offer, several **advantages**, such as :

(*i*) The construction work is easier, as mass concrete can be laid together in the entire dam body.

(*ii*) Since water pressure acts radially in a cylindrical type, and perpendicularly in a diamond type, all pressures are normally *compressive.* The bending as well as diagonal tension in the upstream part of the dam are, thus, absent in this type of dams.

(*iii*) Since the deck is not to be reinforced, there is no question of its failure by rusting of steel, as may happen in an ordinary slab type of buttress dam.

(*iv*) For smaller heights, they prove to give more economical buttress spacing, as compared to other two types of buttress dams.

(*v*) Such a dam body offers more resistance to sliding, because, it is considerably heavier, and has a greater sectional area along the horizontal planes.

27.4.3.3. Columnar buttress type. As shown in Fig. 27.16, this type is a modification of the ordinary slab type, as the deck here, is supported on columns. Very few dams have been built, since they offer the following *disadvantages*:

(*i*) they require very strong and stable foundations.

(*ii*) more skill is required in constructing the buttresses ; and even then, they cost practically as much as other conventional types.

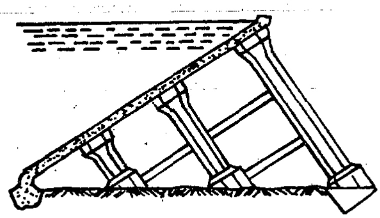


Fig. 27.16. Columnar buttress dam.

PROBLEMS

1. (*a*) Define an arch dam and a double arch dam. What are the important types of arch dams, and what are their major differences ?

(*b*) What is meant by 'the best central angle of an arch dam', and what is its value ?

2. (*a*) Contrast the design criteria for a gravity dam and that for an arch dam by the cylinder theory. What are the relative advantages of constant radius, constant angle, and variable radius dams ?

(*b*) What are the considerations for the choice of a buttress dam in preference to other types ? When do we go in for the massive head type ?

(*c*) What is meant by the following :

(*i*) Economic buttress spacing

(*ii*) Best central angle of an arch dam.

3. (*a*) Distinguish between the constant radius and constant angle layouts of an arch dam. Obtain the value of the best central angle for the latter.

(*b*) Enumerate the different types of buttress dams ; and explain as to how a slab type of buttress dam differs in its design, as compared to a concrete gravity dam.

4. (*a*) State the condition under which you would recommend the construction of an arch dam ; and explain the various methods of layout of an arch dam.

(*b*) How do you ascertain the absolute economic value of buttress spacing for an ordinary buttress dam ?

5. State the conditions under which you would recommend the construction of an 'arch dam'. Draw neat sketches of various types of arch dams and state the circumstances under which you would recommend them.

6. (*a*) What is the 'master curve' as used in connection with buttress dams ? What is its use, and how is it drawn ?

(*b*) What are multiple arch dams, and how do they differ from ordinary arch dams and double arch dams ? Draw line sketches for all these types of dams.

7. (*a*) Massive head type of buttress dams are considered to be the best of all the available types of buttress dams. Why ?

(*b*) Enumerate the design methods or theories, that are used in the design of arch dams. Which of these theories or methods, is used to compute approximate result, and which one is used for obtaining precise results. Explain any one of these in nut-shell.

8. (*a*) Differentiate between 'introdos' and 'extrodos', as are applicable in arch dams.

(*b*) What are double curvature arch dams, and how do they differ from arch dams ?

(*c*) What is the difference between a 'constant centre arch dam' and a 'constant angle arch dam' ?

(*d*) What is meant by economic spacing of buttresses ; and how is it related to dam height and upstream slope of buttress dam ?

9. Write short notes on any four of the following :

(*i*) arch dams.

(*ii*) buttress dams.

(*iii*) methods of layout of an arch dam.

(*iv*) design principles involved in arch dams.

(*v*) master curve for economic buttess spacing.

(*vi*) best central angle for an arch dam.

(*vii*) design criteria for a slab type of buttress dam, and its comparison with the design of a gravity dam.

(*viii*) massive head type of buttress dams.

(*ix*) multiple arch dams.

(*x*) double curvature arch dams.