Arch Dams

Translated from the slides of

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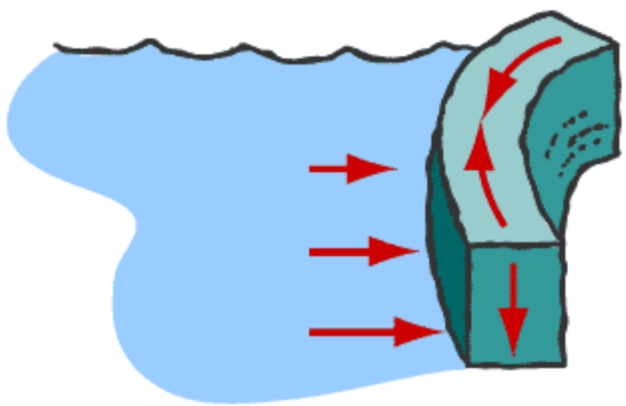
by his kind courtesy

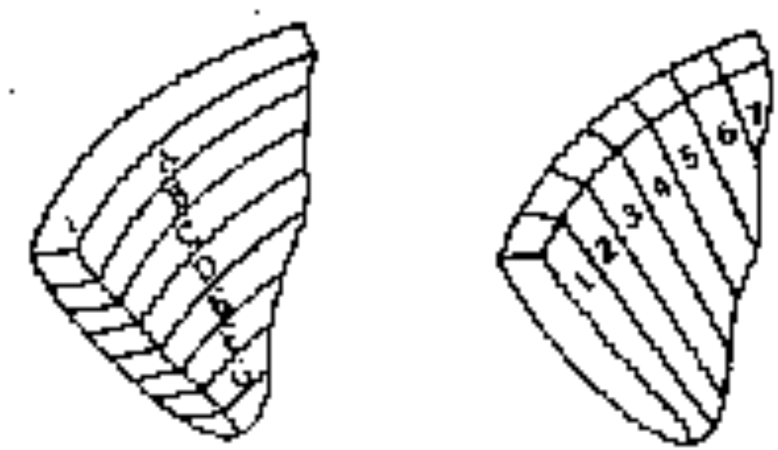
ercan kahya

Arch Dams

- Curved in plan and carry most of the water thrust horizontally to the side abutments by arch action.
- A certain percentage of water load is vertically transmitted to the foundation by cantilever action.



Arch Dams



(a) Series of horizontal arches

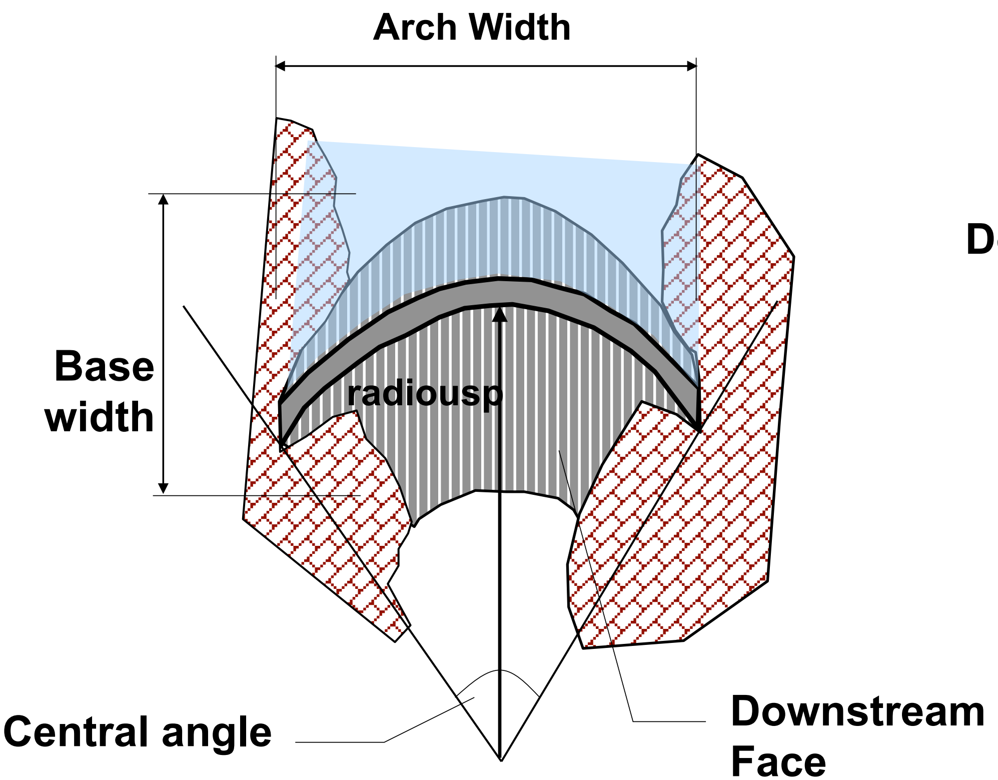
(b) Series of vertical cantilevers

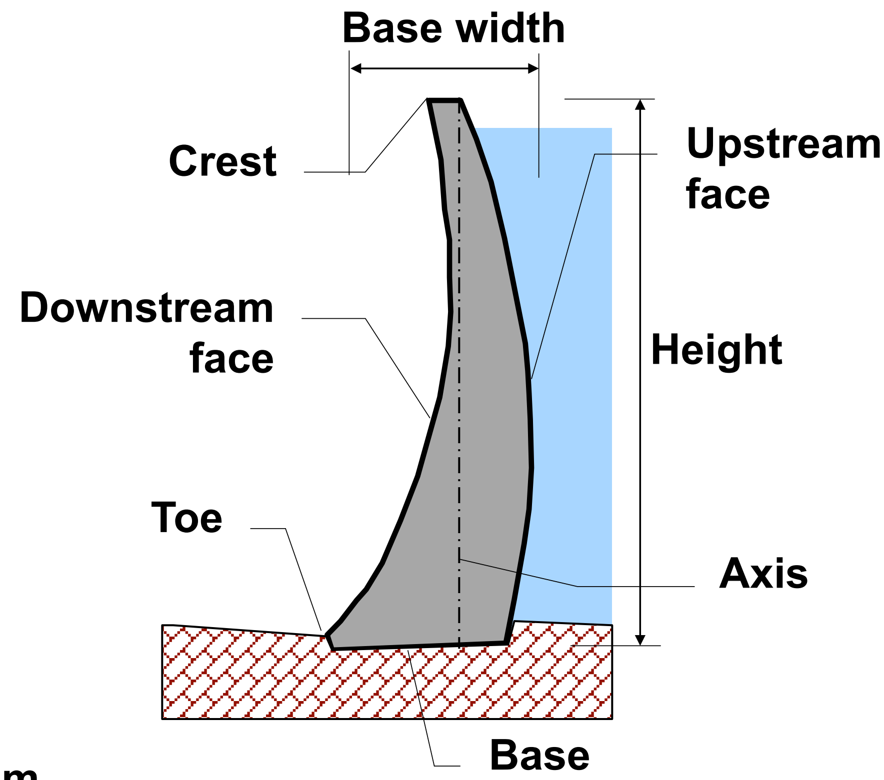
Figure 2.10. Series of horizontal arches and vertical cantilevers

Arch Dams

- <u>Where & why we design it</u>:
  - Appropriate when "Width / Height of valley" (B/H) < 6
  - Rocks at the base and hillsides should be strong enough with high bearing capacity.
  - To save in the volume of concrete.
  - Stresses are allowed to be as high as allowable stress of concrete.
  - Connection to the slope of hillsides should be 45^{o} at least.

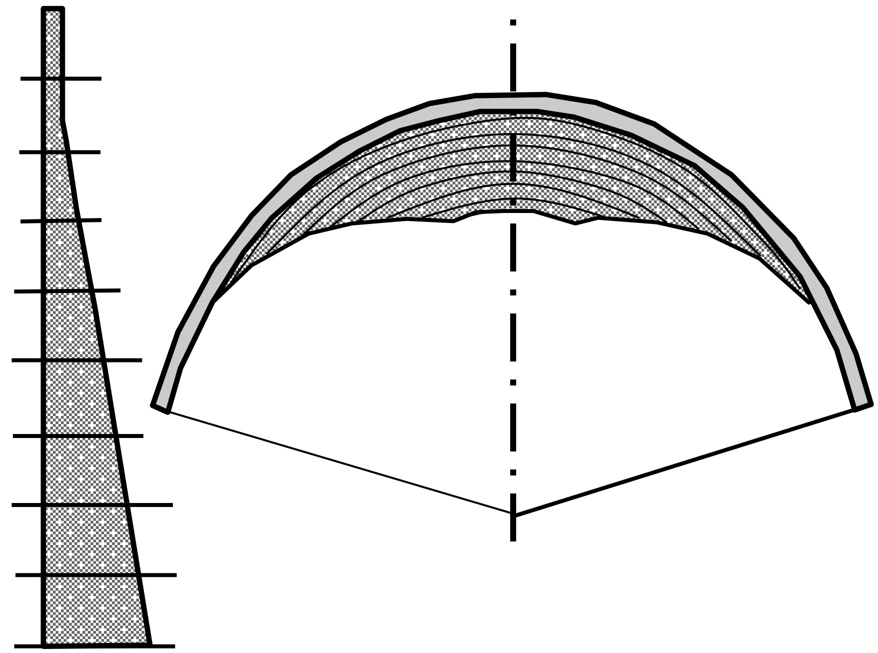
Arch Dams


Arch Width
Base
width
radiousp
Central angle
Downstream
Face


Base width
Crest
Upstream
face
Downstream
face
Height
Toe
Axis
Base

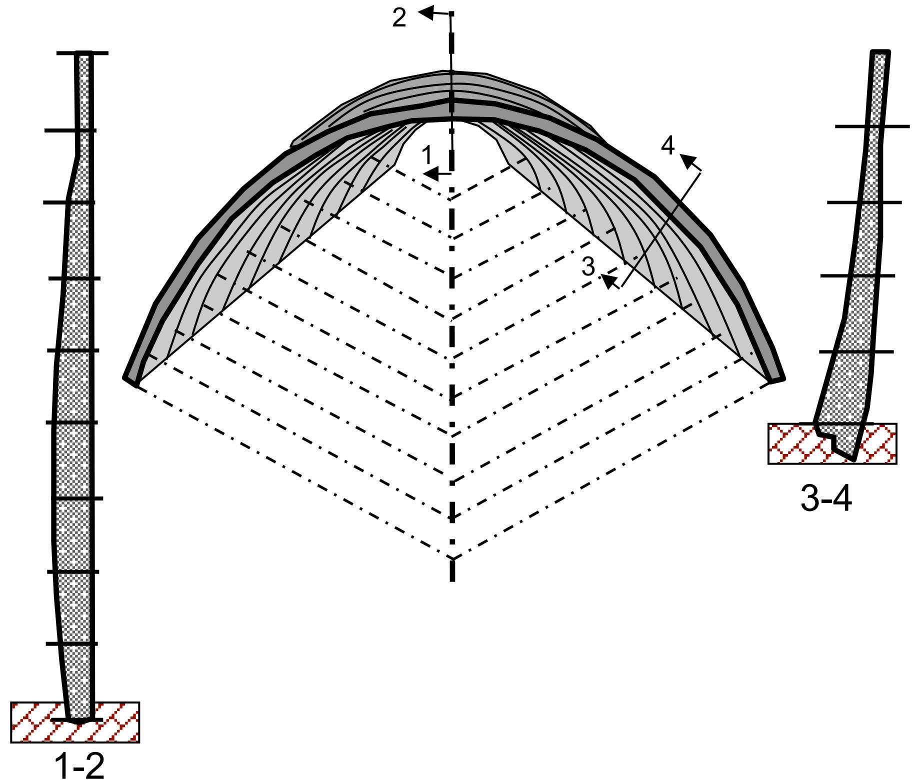
Arch Dam Types

- Constant Center Arch Dam (variable angle)
  - Good for **U-shaped** valleys
  - Easy construction
  - Vertical upstream face
  - Appropriate for middle-high dams



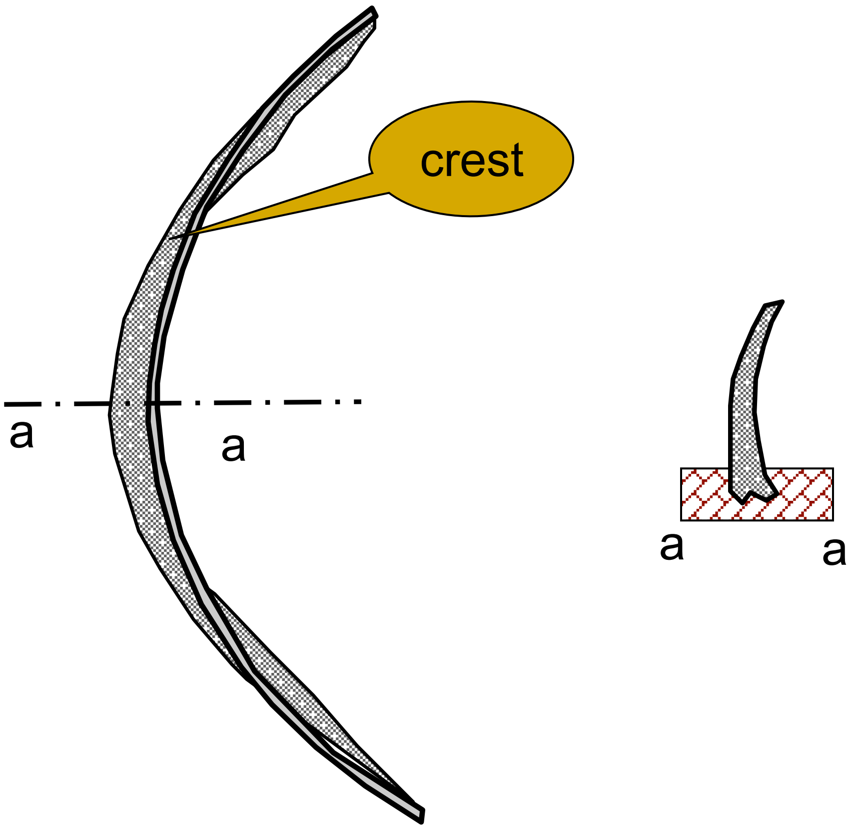
Arch Dam Types

- Variable Center Arch Dams (constant angle)
  - Good for **V-shaped** valleys
  - Limited to the ratio of B/H=5
  - Best center angle: 133º 34´
  - To obtain arch action at the bottom parts

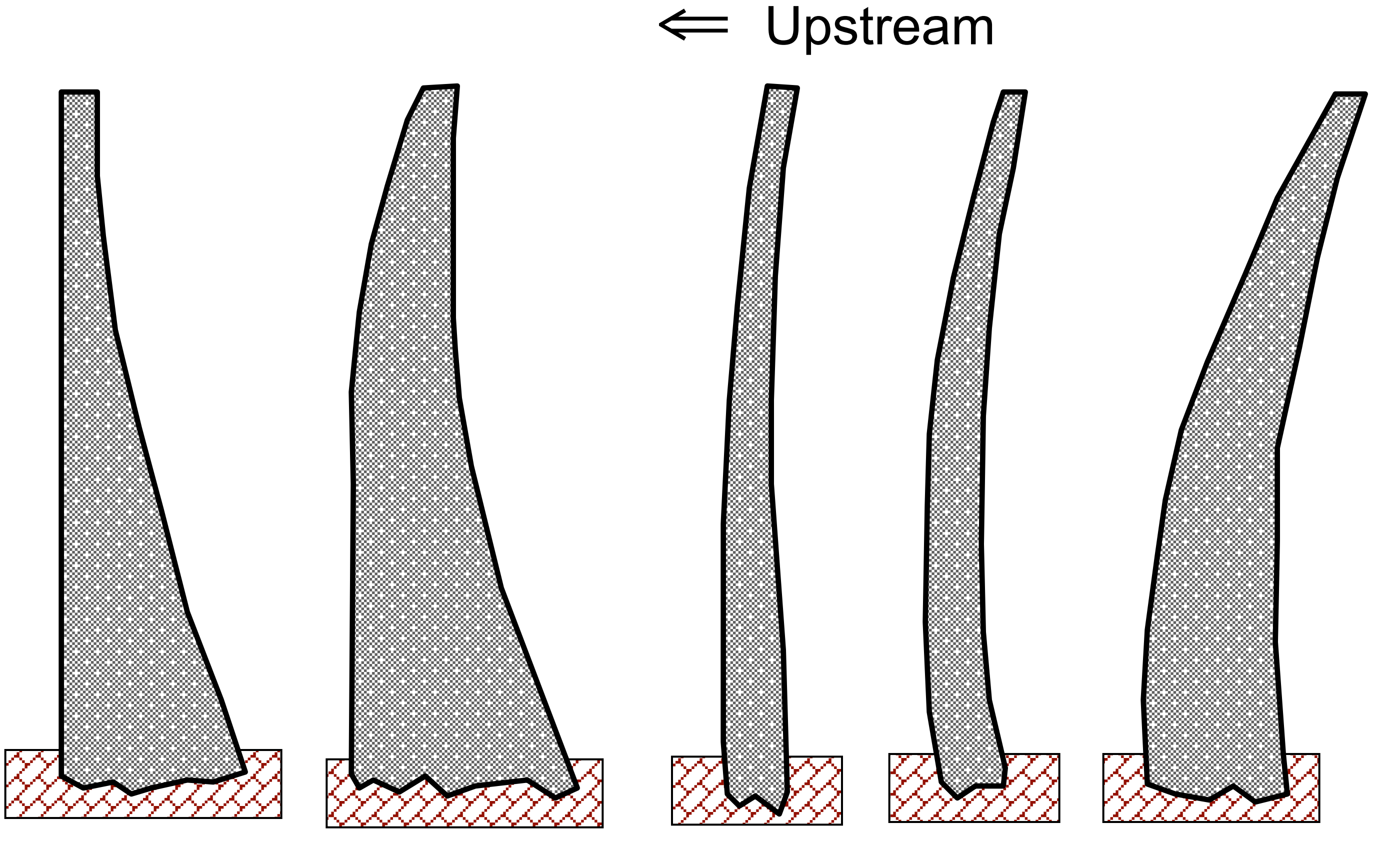


Arch Dam Types

- Variable Center – Variable Angle Arch Dams
  - Combination of the two above.
  - Its calculation based on shell theory applied to arch dams



Arch Dam Types



Arch Dams

- **3.6.2 DESIGN OF ARCH DAMS**

Structural Design: → Load distribution in the dam body
& beyond scope of this course

- Independent ring method
- Trial load method
- Elasticity theory
- Shell theory

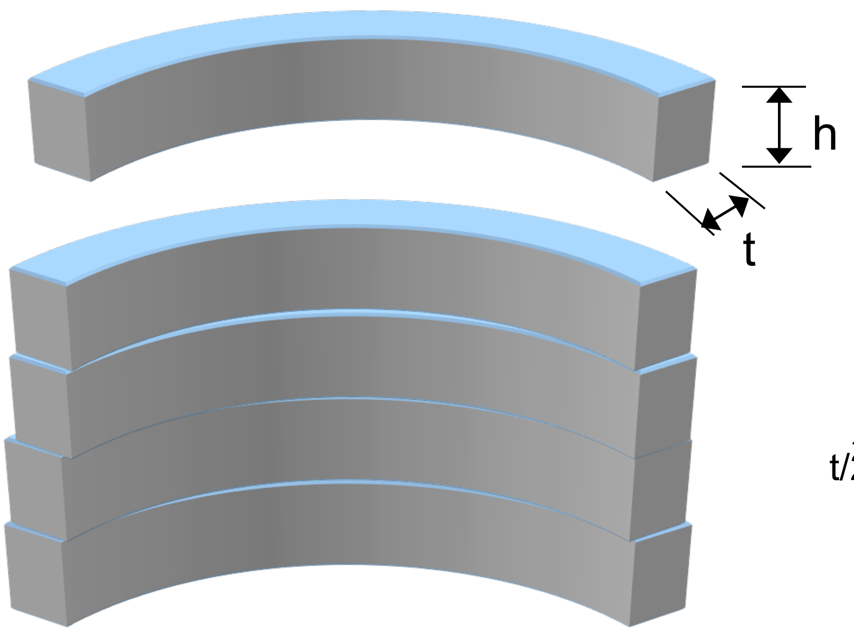
Arch Dams

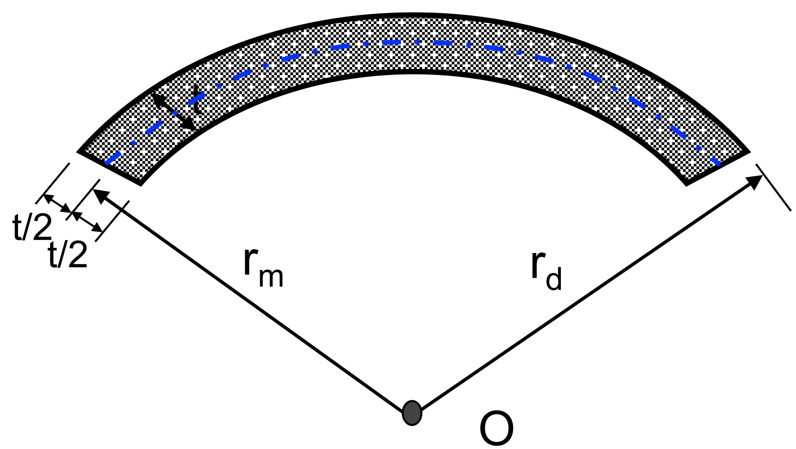
- Hydraulic Design

  - Determination of thickness at any elevation
  - Effect of uplift force – ignored
  - Stresses due to ice & temp changes-important
  - Arch action - near the crest of dam
  - Cantilever action - near the bottom of dam
  - Horizontal hydrostatic pressure is assumed to be taken by arch action

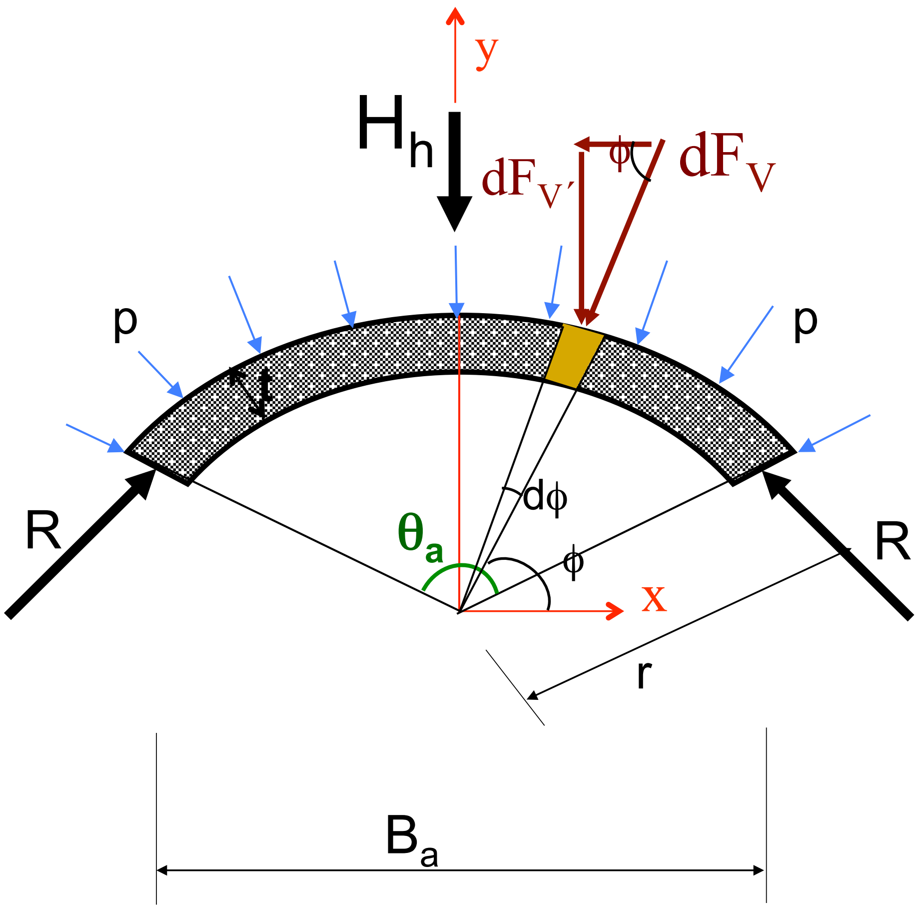
Arch Dams (design principles)

- Independent Ring method:





$$r_m = r_d - t/2$$



Differential force for infinitely small elemental piece with center angle of dφ :

$$dF_V = p \, . \, r \, . \, d\phi$$

Vertical component:

$$dF_V{}' = p \, . \, r \, . \, d\phi \, . \, Sin\phi$$

Arch Dams (design principles)

- **Total horizontal force**:

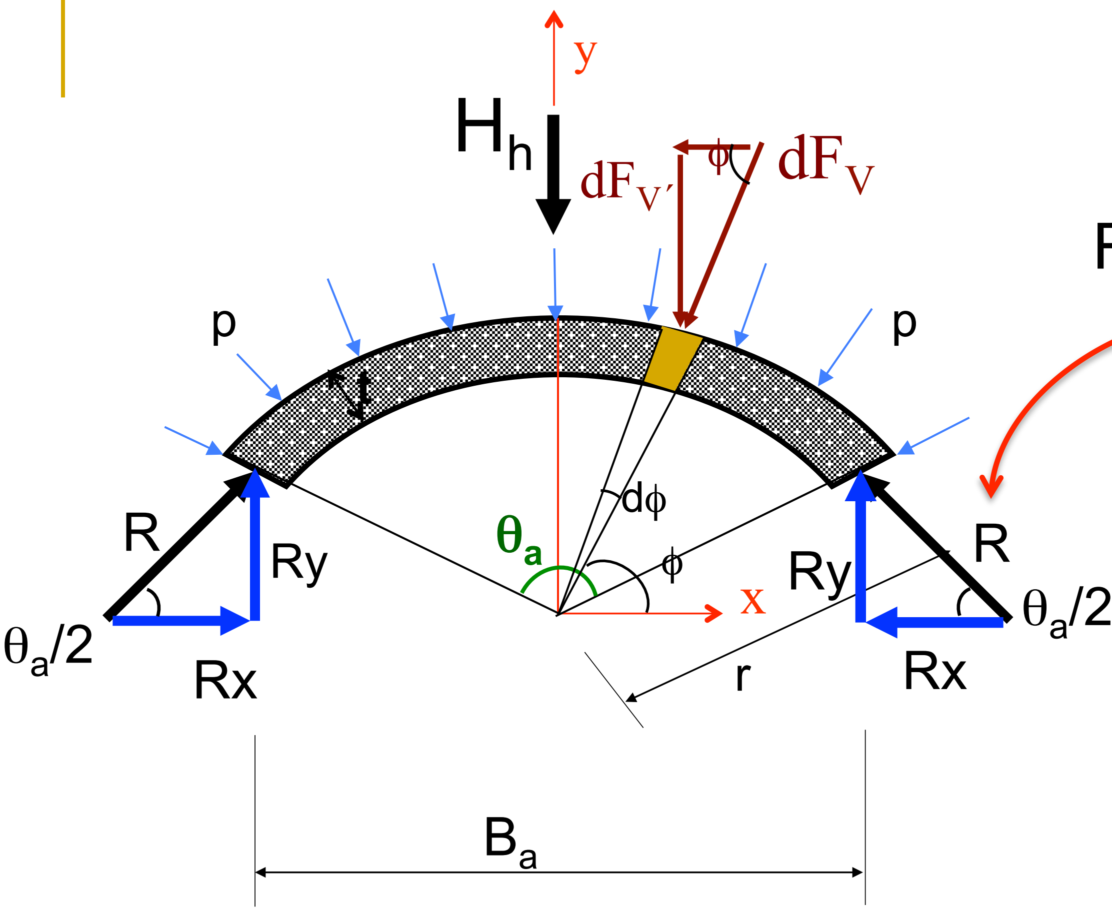
$$H_h = 2\gamma .h.r.Sin\frac{\theta_a}{2}$$

h : height of arch lib from the reservoir surface
r : radius of arch
θ_a: central angle

- Equilibrium of forces in the flow direction (y):

$$H_h = 2\,R_y$$

R_y: reaction force at the sides in y direction **[= $R\ sin\ (\theta_a/2)$]**



Reaction of the sides (R):

$$R = \gamma . h . r$$

The required thickness of the rib (t) when **t** << **r** :

$$\sigma \approx R / t$$

$$t = \frac{\gamma . h . r}{\sigma_{all}}$$

σ_{all} : allowable working stress for concrete in compression

Arch Dams (design principles)

The **volume of concrete** for unit height for a single arch:

$$V = L\,t$$

L: arch length **($L = r\,\theta_a$)** (note that θ_a is in radians)

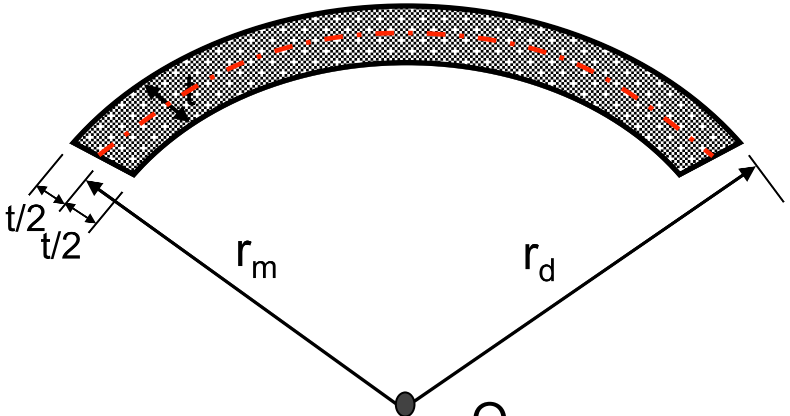
$$V = \frac{\gamma . h}{\sigma_{all}} r^2 \theta_a$$

Arch Dams (design principles)

The required thickness of the rib (t):

- Pressure $p = \gamma \times h$:

$$t = \frac{p \times r_d}{\sigma_{all}}$$



$r_m = r_d - t/2$

Reduction factor for base pressure at arch dams is zero (m=0)

Arch Dams (design principles)

- The **optimum θ_a** for minimum volume of arch rib:

$$dV / d\theta = 0 \quad \rightarrow \quad \theta_a = 133^o\,34'$$

► This is the reason why the constant-angle dams require ***less concrete*** that the constant-center dams

► Formwork is more difficult

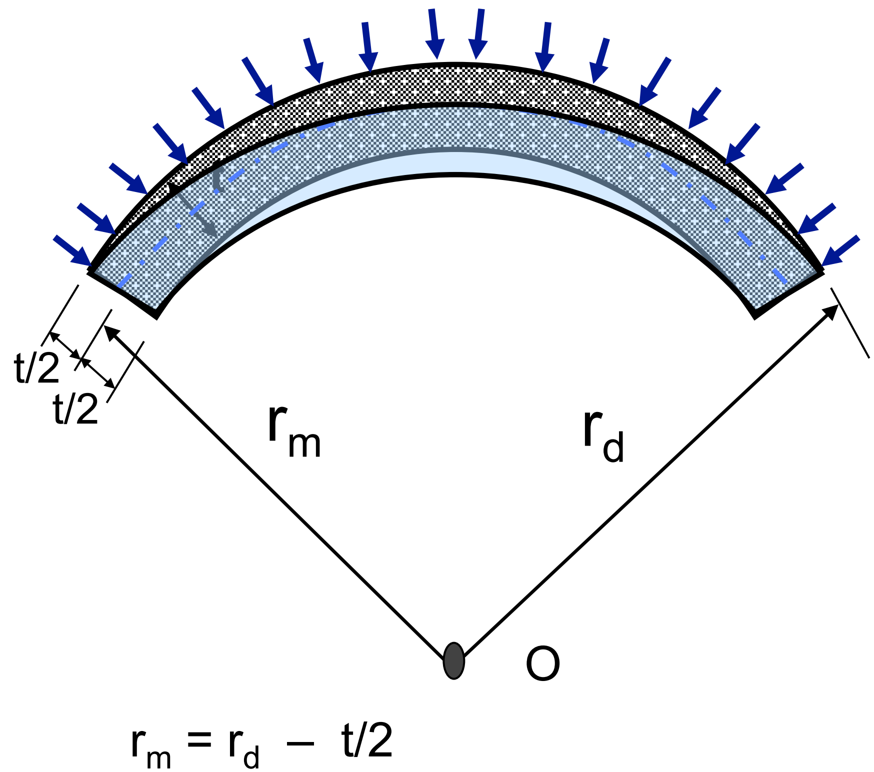
► In practice; $100^o < \theta_a < 140^o$ for the constant-angle dams

Arch Dams (design principles)

- **Displacement in an arch ring:**

$$\delta = \sigma_{all} \frac{r_m}{E}$$

E = Concrete elasticity modulus
r_m = Radius from ring axis



For the relation between center angle (2ϕ), beam length (L) & arch radius (r):

$$r = \frac{L}{2 \times \sin \phi}$$

Örnek

- Yüksekliği 120 m olan bir barajın ağırlık ve kemer-ağırlık türünde yapılması halleri için taban genişliklerini ve birim kalınlıktaki hacimlerini karşılaştırınız. Barajda taban su basıncı küçültme faktörü 0.8 dir. γ_b = 2.4 t/m³

Çözüm: Ağırlık baraj için:

$$\gamma' = \frac{\gamma_b}{\gamma_w} \qquad \gamma' = \frac{2.4}{1.0} = 2.4$$

$$\frac{b}{h} = \sqrt{\frac{1}{\gamma' - m}} \qquad \frac{b}{120} = \sqrt{\frac{1}{2.4 - 0.8}} \qquad b = 120 \times \sqrt{\frac{1}{2.4 - 0.8}}$$

b= 95 m.

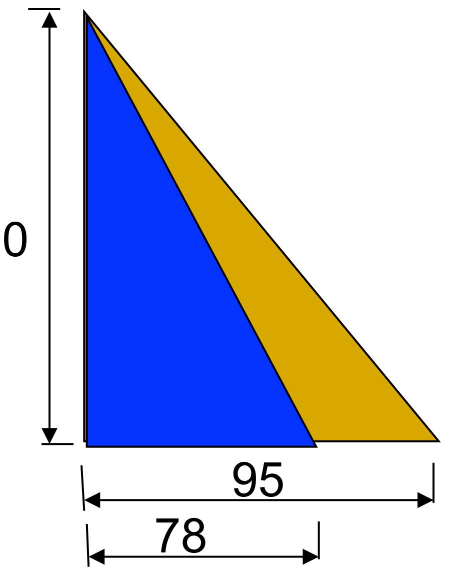
Hacim= $120 \times 95 \times \frac{1}{2} = 5700 \ m^3$

- Kemer-Ağrlık baraj için:

m = 0 $\frac{b'}{h} = \sqrt{\frac{1}{\gamma'}}$ $b' = 120 \times \sqrt{\frac{1}{2.4}} = 78 \ \text{m}$

$$\text{Hacim} = 120 \times 78 \times \frac{1}{2} = 4680 \ \text{m}^3$$

$$\text{Hacim azalması}: \frac{5700 - 4680}{5700} = \%\ 18$$



Ağırlık yerine kemer-ağırlık seçmeyle beton hacminde %18 azalma olacaktır. Bu seçim ancak yamaçlar yeterince sağlam olduğunda yapılabilir.

Örnek

- Yüksekliği 80 m olacak bir sabit yarıçaplı (silindirik) kemer barajda tabandaki maksimum kemer kalınlığının, en fazla baraj yüksekliğinin ¼ üne eşit olması istendiğine gore kemer yarıçapını hesaplayınız. Kemer halkalarının emniyet gerilmesi 220 t/m^2, betonun elastisite modülü 2×10^6 t/m^2 olduğuna göre tepede anahtar noktasında ortaya çıkacak sehimi bulunuz.

Çözüm

$$r_d = t \times \frac{\sigma_h}{p}$$

t = h/4 alalım t = 80 / 4 = 20 m :

p = $\gamma \times h$

$$r_d = \left(\frac{h}{4}\right) \times \frac{\sigma_h}{(\gamma \times h)}$$

$$r_d = \frac{1}{4} \times \frac{\sigma_h}{\gamma} = \frac{1}{4} \times \frac{220}{1} = 55 \text{ m}$$

$$r_m = r_d - \frac{t}{2} = 55 - \frac{20}{2} = 45 \ m$$

$$\delta = \sigma_h \frac{r_m}{E}$$

$$\delta = 220 \times \frac{45}{2 \times 10^6} = 0.005 \text{ m}$$

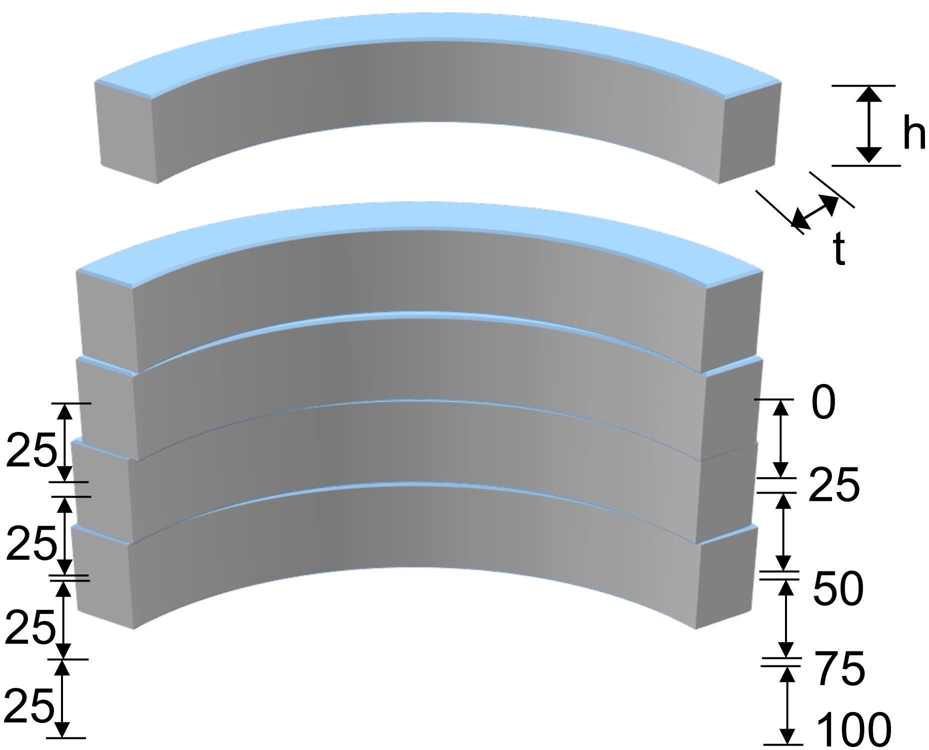
0.5 cm sehim oluşur.

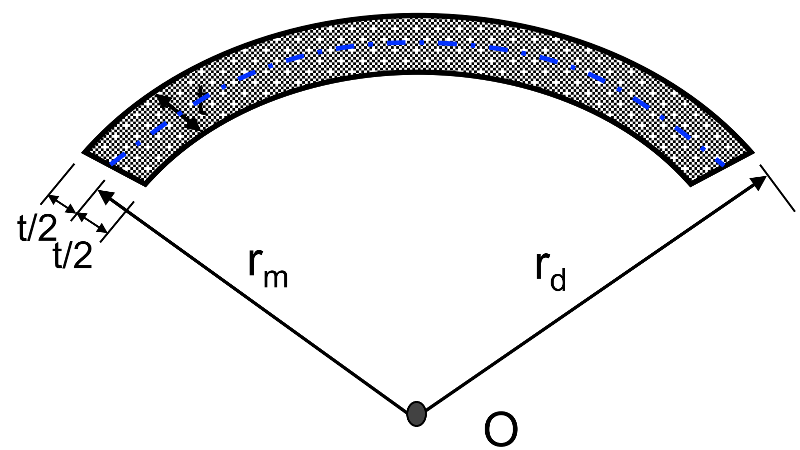
Örnek

- Yüksekliği 100 m ve tepe genişliği 5 m olacak bir kemer barajın tepeden itibaren 0, 25, 50, 75 ve 100 m derinliklerdeki eksen yarıçapları sıra ile 95, 80, 63, 58, 50 m dir. Betonun emniyet gerilmesi 300 t/m^2 ve elastisite modülü 2×10^6 t/m^2 dir. Her seviyede kemer halkasının kalınlık ve sehimini bulunuz.

Kemer Barajlar (Hesap Esasları)

- Bağımsız Halkalar Yöntemi





$r_m = r_d - t/2$

Çözüm

$$\sigma_h = \frac{2}{3}\sigma_{b_{em}} = \frac{2}{3}\times 300 = 200 \quad t/m^2$$

$$r_d = r_m + \frac{t}{2} \qquad t = \frac{p\times r_d}{\sigma_h} \qquad t = \frac{\overbrace{(\gamma\times h)}^{p}\times\overbrace{\left(r_m + \frac{t}{2}\right)}^{r_d}}{\sigma_h} = \frac{\overbrace{(\gamma\times h)}^{p}\times(r_m + 0.5\times t)}{\sigma_h}$$

$$t = \frac{\gamma\times h\times r_m + \gamma\times h\times 0.5\times t}{\sigma_h} \qquad t = \frac{\gamma\times h\times r_m}{(\sigma_h - \gamma\times h\times 0.5)}$$

γ = 1 t/m³ , σ_h = 200 t/m² için: $$t = \frac{h\times r_m}{(200 - h\times 0.5)}$$ bulunur.

Sehim: $$\delta = \sigma_h \frac{r_m}{E}$$

$$t = \frac{h \times r_m}{(200 - h \times 0.5)}$$

$$\delta = \sigma_h \frac{r_m}{E}$$

Sıra No	Baraj tepesinden itibaren derinlik h (m)	Eksen yarıçapı rm (m)	Kemer kalınlığı t (m)	Sehim δ (cm)
1	0	95	0,00	0,95
2	25	80	10,67	0,80
3	50	63	18,00	0,63
4	75	58	26,77	0,58
5	100	50	33,33	0,50