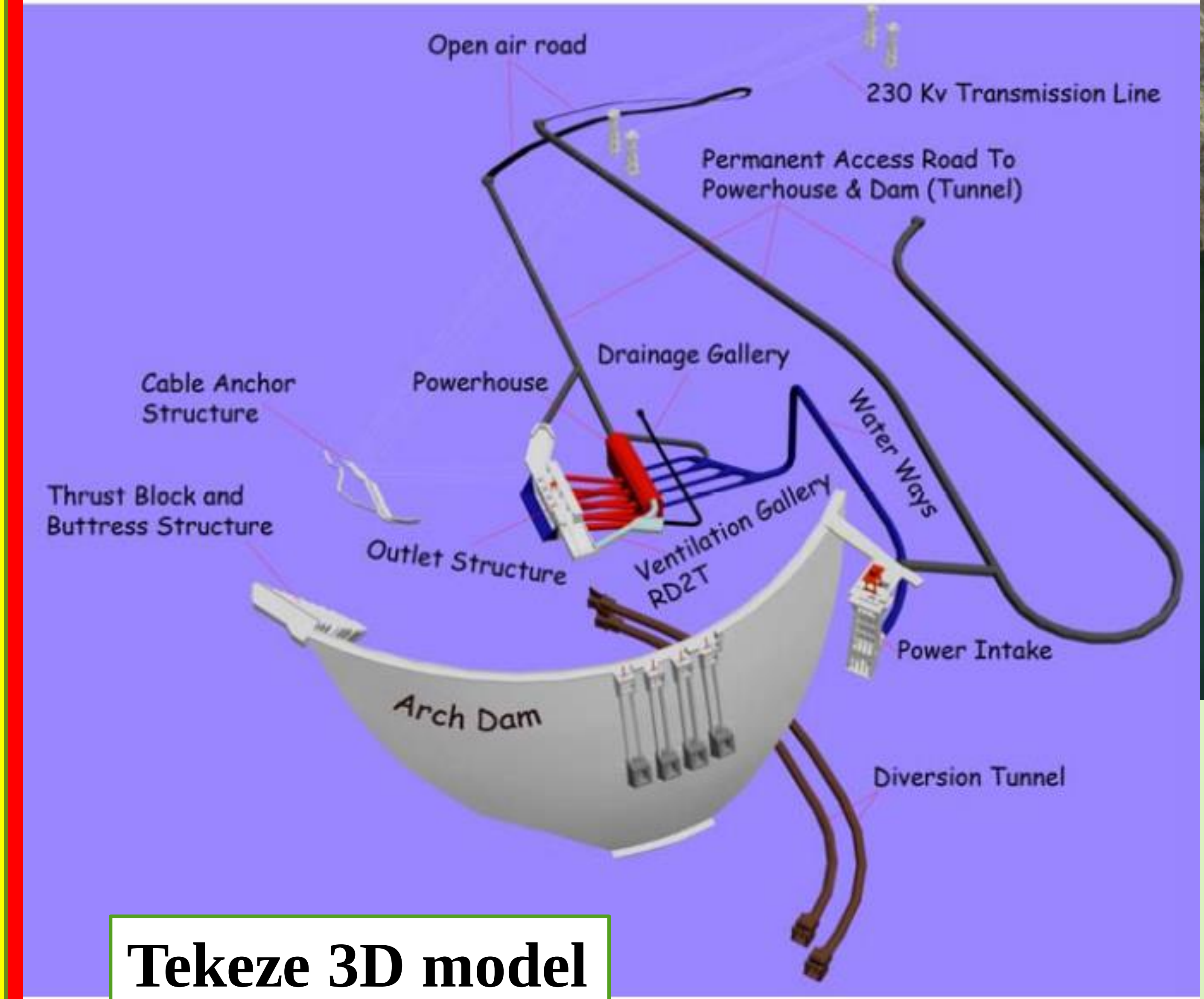
Chapter 5: Design of Hydropower Plants



Tekeze 3D model

Arch Dam upstream view

Design of Civil Structures (cont.)

Hydraulic design of Canals and Tunnels

Head Race (Intake conduits)

- Head race may be a power canal, a pressure tunnel, or a pipe, which in most cases conveys water from intake structure to surge tank, forebay or pressure shaft, depending on the arrangement of the scheme.

Canals

- Canals are appropriate choice when the general topography of the terrain is moderate with gentle slopes.
- However, when the ground is very steep and rugged, it becomes uneconomical to construct canals as it follows longer distances and/or needs provision of cross-drainage works and deep cuts and fills at a number of appropriate locations.
- In such cases, it is advisable to go for tunnels or pipes. The choice, in fact, has to be made based on economic analysis.
- Where the topography of the region presents special formations, the alternating use of open-canal and open-surface tunnel sections may ensure the most economical development.

Canal Sections

- On gentle hill slopes, but especially on steep mountain sides, the canal should closely follow the contour lines of the area.
- Over sufficiently uniform area, the power canal may be designed with an open cross-section through cuts, overfills and in cut-and-fills as shown in the Figure.

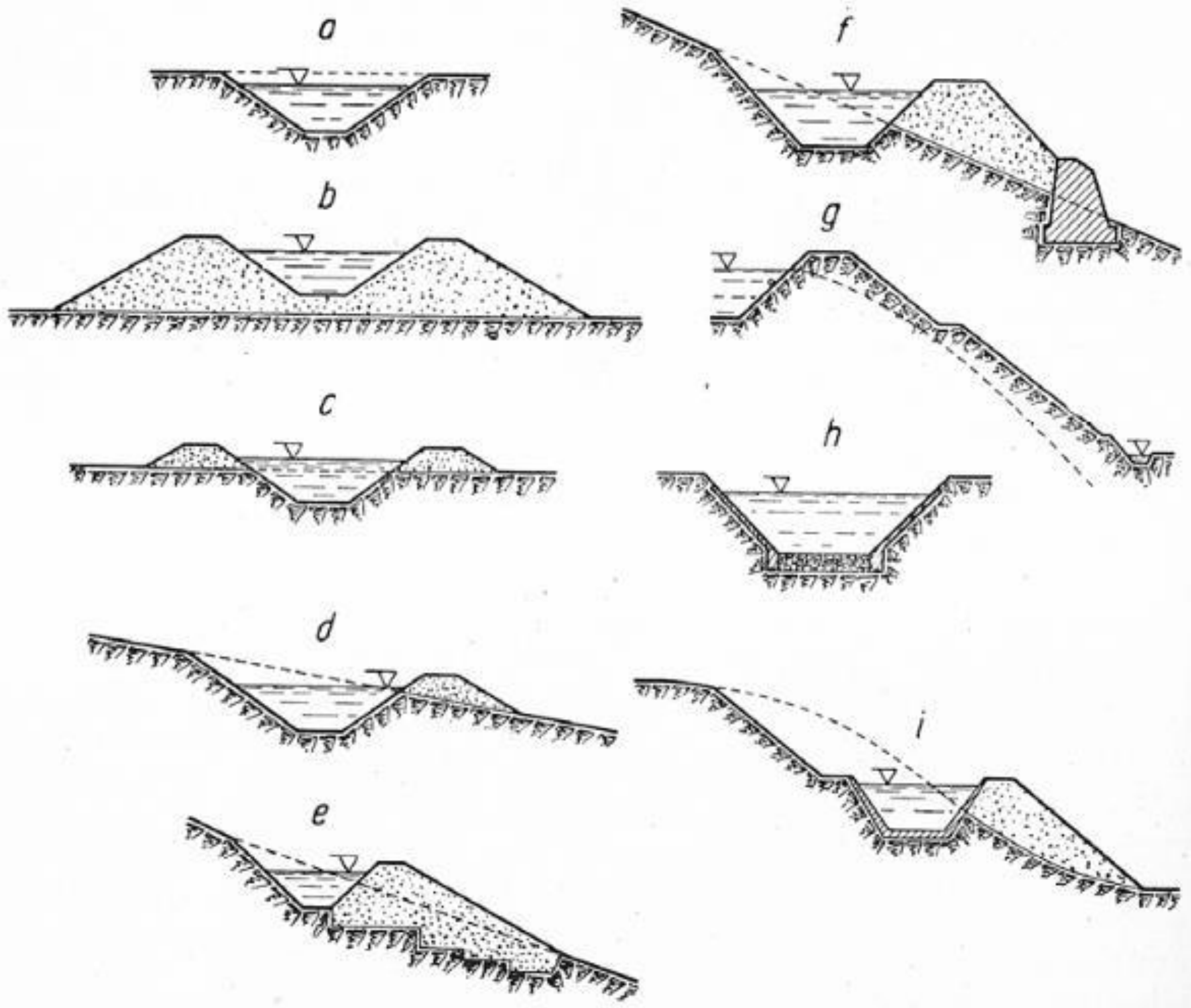
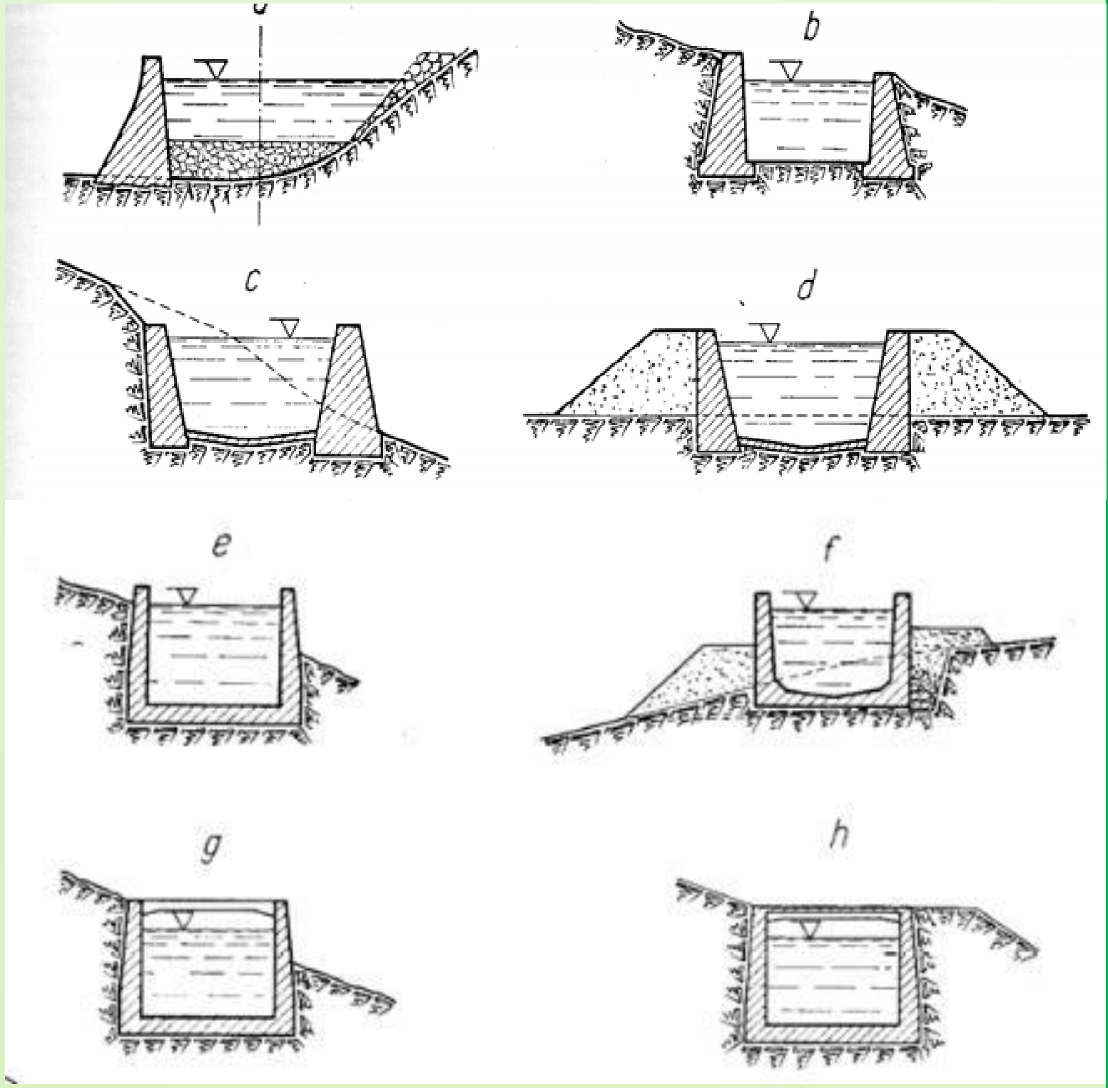


Fig. 1/79. Earth canals: *a)* cut into the ground, *b)* elevated above the terrain, *c)* partly elevated, in level ground, *d)* with cut-and-fill cross section in gently sloping ground, *e)* with cut-and-fill cross section in steep ground, *f)* with cut-and-fill cross section in steep ground, with the bank supported by retaining wall, *g)* in very high fill, *h)* the side slopes lined with concrete, the impermeable bottom protected by a gravel layer, *i)* concrete-lined canal with cut-and-fill cross section

Canal Sections (*contd.)*

- On mountainous slopes it may not be possible to follow the irregular contour lines: deep valleys are to be bridged by aqueducts (such as elevated canals or canal bridges), and high hills crossed by water conveying tunnels.
- Cross-sections of canals located on steep, hilly mountain slopes are shown in the Figure.
- Although a canal located according to these principles involves the construction of relatively more expensive structures, such as bridges and tunnels, the resulting route may still be more economical than that strictly following the contour lines of the hilly area, because
  - The length of the canal will be significantly reduced,
  - The head loss will also be smaller.



Canal Lining

- Power canals may be lined or unlined.
- The lined canals are usually lined with impervious material such as concrete, masonry, or clay.

Canal lining might be carried out to:

- Reduce seepage losses
- Reduce canal surface roughness
- Prevent the growth of weeds
- Reduce damage caused by erosion, rodents, and livestock
- Reduce the required volume of excavation
- Permits the use of rectangular x-section

Concrete Lining

- This is the most extensively used material in power canal lining.
- It is mostly used with trapezoidal cross sections.
- The excavation of a canal for a thin, unreinforced concrete lining is similar to that of an earth canal.
- It should be done carefully to ensure that the lining conforms closely to the desired profile when it is completed; otherwise, the lining will require more material than expected.
- The foundation should be adequately compacted and moistened before the concrete is placed.
- The necessity of moistening the foundation is to prevent the sub-grade from absorbing moisture from the freshly laid concrete making it weak and porous.

Concrete Lining (cont.)

- Concrete sections of a lining can be hand-formed at the site.
- If the side slopes exceed 1 in 1, form works may be necessary to hold the concrete in place until it sets.
- The thickness of the concrete lining may range from 10 to 20 cm, depending on the quality of the concrete and the soil conditions.
- In preparing concrete for lining a canal, it is important to use the minimum amount of water needed for workability. Excess water will cause the concrete to slump and not stay on the canal side slopes.
- A mixture of a 1:3:4.5 (cement : sand : gravel) volume proportion is adequate for lining a power canal.

Brick or Stone Masonry

- This is another most frequently used type of power canal lining.
- Use of stone masonry permits savings by reducing the quantity of cement required as compared to concrete lining.
- Masonry lining consumes only about 25 –30 % of the amount of cement required for poured concrete. Whether brick or stone is used depends on their relative availability and cost.
- With masonry linings, a rectangular canal section is often used. In this case, the sides of the canals are constructed as retaining walls to counteract the lateral forces of either the earth backfill or the water within the canal.
- In the construction of a power canal lined with masonry, the excavation must allow for the thickness of the lining. Before the lining is placed, the canal bottom and sides should be properly compacted to avoid future settling and cracking of the lining.
- To reduce resistance to flow and possible seepage, the masonry surface shall be plastered.

Lining with other materials

- In addition to the commonly used lining materials discussed above, other materials such as bituminous mixtures, soil-cement, wood, clay, chemical sealant, shotcrete, and impermeable membranes are also sometimes used to line power canals
- In special circumstances where the canal alignment is through a terrain having seasonally high water table or where the soils are not freely draining, under-drainage should be provided in order to protect the lining from damage due to uplift pressures.
- Due to temperature variations and shrinkage, cracks may be developed in canal linings and may result in appreciable leakage from the canal.
- In order to minimize these effects, it is necessary to provide contraction joints in the lining at suitable intervals (usually 3 to 8 m).

Canal Design

Canal design involves determination of the following:

- Carrying capacity, velocity of water in the canal & roughness coefficient of the canal surface
- Canal slopes
- Cross-sectional profile of the canal

Carrying Capacity and Velocity

- For the hydraulic design, the discharge is computed from continuity equation as $Q = VA$
- The mean velocity, V, is determined from any of the continuity equations.
- Roughness coefficient is specified from the bed material type.

A *Chezy's equation*

$V = C\sqrt{RS}$

Several equations are available to determine the value of C.

i) Bazin's formula $C = \dfrac{87}{1 + \dfrac{m}{\sqrt{R}}}$ Where m is roughness factor

ii) Maning's Formula $C = \dfrac{1}{n} R^{1/6}$ Where n is Maning's roughness coefficient

The Chezy-Maning equation $V = \dfrac{1}{n} R^{2/3} S^{1/2} = M R^{2/3} S^{1/2}$ Use Tables for M & n.

iii) Kutter Formula $C = \dfrac{41.65 + \dfrac{0.00281}{S} + \dfrac{1.811}{n}}{1 + \dfrac{n}{\sqrt{R}}\left(41.65 + \dfrac{0.00281}{S}\right)}$ in English units

iv) The Agroskin formula $C = 17.72(K + \log R)$

When using Maning's n,

- add 0.001 to the values of the Table if the water carries small amount of silt
- add 0.002 if the bed load is heavy

Flow velocities

- Apart from the hydraulic computations, the flow velocities in the canal or other water conduits in general are determined according to economic point of views (investments, head losses, wear and tear of material, danger of erosion and silting).

- The velocity must be high enough to prevent sedimentation.
- It has to be low enough to prevent **bed erosion** for unlined-and wear by abrasion for lined-canals.
- Lowering the velocity keeps the head loss over the length of the canal to a minimum; however, it increases the cost necessary to construct the canal as the cross-sectional area increases when the velocity lowers.

Maximum velocity		Minimum velocity V_{min} (m/s)
Bed Material	V_{max} (m/s)	
Sand	0.4	To keep any sediment from settling out, the minimum velocity in a canal should not be less than 0. 3 m/s.
Sandy loam	0.6	
Loam	0.6	
Clayey loam	0.8	
Clay	2.0	
Gravel	3.0	
Masonry	3.5	
Asphalt	4.0	
Concrete	5.0	

Maximum Velocities

- Critical bottom velocity (w.r.t. erosion) is given by:
  - Strenberg: $V_b = \xi\sqrt{2d}$ for d is particle size in meters, $\xi = 4.43$
- Maximum permissible mean velocity according to Bogardi and Yen is given by: $V = 22.9 d_m^{4/9} \sqrt{S_S - 1}$ $$V = 22.9 d_m^{4/9} \sqrt{S_s - 1}$$
- Where d_m is mean particle size and S_s is specific gravity of particles.

Minimum Velocities

- There are various recommendations for non silting velocity
  - According to Ludin
    - If V_{min} **>0.3** m/sec, there will be no silting (for silty sediments)
    - V_{min} **>0.3** to 0.5 m/sec, there will be no silting (for sandy sediments)
  - According to R.C. Kennedy $V = Ch^{0.64}$
    - Non-scouring and non silting velocity is given by:
    - Where h is depth of water in meters and C is coefficient varying from 0.54 to 0.7, depending on silt load.

Roughness coefficient

- As water flows in a canal, it losses energy in the process of sliding past the walls and bed material.
- The rougher the material, the more frictional loss and the greater the head drop or slope needed for a given velocity.
- The roughness coefficient, n for various canal materials are given in the following Table below.

Canal material		Roughness coefficient, n
Earth canals	Clay, with stones and sand	0.020
	Gravelly or sandy loam	0.030
	Lined with coarse stones	0.040
Rock canals	Medium coarse rock muck	0.037
	Rock muck from careful blasting	0.045
	Very coarse rock muck	0.060
Masonry canals	Brickwork, well pointed	0.015
	Normal masonry	0.017
	Coarse rubble masonry	0.020
Concrete canals	Smooth cement finish	0.010
	Concrete, unplastered	0.015
	Coarse concrete	0.018
	Irregular concrete surfaces	0.020
Wooden canals	Planed, well jointed boards	0.011
	Unplanned boards	0.012
	Older wooden canals	0.015

Power Canal Slopes

- In plain areas use slope between 5 to 20 cm/km (0.005 to 0.02 %).
- In mountainous areas slopes are as steep as 1 to 2 m/km.
- The canal bed slope can also be estimated using the Manning's equation:

$$S = \frac{n^2 V^2}{R^{4/3}}$$

- The slope found from the above equation should nearly coincide with the available natural topography.
- Otherwise, a different slope should be computed by choosing other values for the velocity within the permissible limit until a satisfactory result is obtained.

Cross-sectional Profile

A semi-circular cross-section

- is the most efficient profile because, for a given canal slope and cross-sectional area, it conveys the maximum flow. However, this form is impractical to excavate.
- It is therefore used primarily with materials which lend themselves to this shape.
- Examples are prefabricated concrete, sheet metal, and wood-stave sections.

A trapezoidal cross-section

- is the most widely used profile for both lined and unlined canals excavated in earth.
- If the canal is unlined, the maximum side slope is set by that slope at which the material will permanently stand under water.
- The magnitude of the side slope of a lined trapezoidal canal depends on the nature of the material on which the lining will rest, but usually steeper than unlined canals.
- In general, it should be nearly equal to the angle of repose of the natural soil so that no earth pressure is exerted on the back of the lining.
- The banks of a lined canal resting on almost any free-draining material requires slopes not steeper than 1:1.
- For a trapezoidal canal with a given side slope, the most efficient cross-section is one in which a semi-circle can be inscribed in the wetted area. For this section, it can be shown that the length of either sloping side of the wetted area is half its top width.

Suggested side slopes for trapezoidal canals

Canal material	Side slope (V:H)
Firm rock	1:1/4
Fissured and disintegrated rock	1:1/2
Clay	1:3/4
Clayey loam	1:1
Loam	1:3/2
Sandy loam	1:2
Sand	1:3
Lining	1:1

- A rectangular cross-section
  - is often most appropriate when excavation is undertaken in firm rock.
  - It is also commonly used when the canal incorporates properly constructed masonry walls.
  - Use of a rectangular canal reduces the excavation required.
  - For the most efficient rectangular cross-section, the width of the canal is twice the depth of the wetted area and, like a trapezoidal section, is a section in which a semi-circle can be inscribed.
- Freeboard Allowance:
  - Freeboard is provided above the design water level for safety purposes.
  - **For earth canal the lower limit is 35 cm and the upper limit is 140 cm.**
  - Generally the $free\ board\ = [0.35 + h/4]m$.

  Where h is depth of flow.
  - Allowances should be made for bank settlements.
  - For lined canals, the top of the lining is not usually extended for the full height of the free board. Usually it is extended to 15cm to 70cm above the design water level.

Water Loss in Power Canals

- Water losses are due to:
    a. seepage
    b. evaporation
    c. leakage at gates
- Generally b) and c) are of minor importance.
- Seepage losses from earth canal may be described according to the following procedures:

Davis and Wilson

$$q = \frac{C}{10{,}000} P \sqrt[3]{h}$$

$$(q \; in \; m^3/s.km)$$

Where C = coefficient depending on soil type and lining (see Table below)

P = wetted perimeter of canal in m

h = depth of water in m

Davis and Wilson Coefficient C

Canal	Lining or soil type	C
Lined	Concrete lining 75 to 100mm thick	1
	Clay lining, compacted, 150 mm thick	4
	Light bituminous lining	5
	Clay lining, compacted 75 mm thick	8
	Thin lining of asphalt or cement mortar	10
Unlined	In loam	12
	In loamy silt soil	15
	In silty soil	20
	In sandy silt soil	25
	In silty sand soil	30
	In fine sand	40
	In sands of medium fineness	50
	In sandy gravel	70

Example

A trapezoidal channel on a clayey loam formation has a base width b = 6 m and side slopes 1H:1V. The channel bottom slope is So = 0.0002 and the Manning roughness coefficient is n = 0.022. Compute the depth of uniform flow if Q = 12.1 m3/s and identify the state of flow.

Tunnels

- Tunnels are underground conveyance structures constructed by special tunneling methods without disturbing the natural surface of the ground.
- In many modern high head plants, tunnels form an important engineering feature.

In the headrace of water conveyance system,
tunneling is popular because of the following reasons:

- It provides a direct and short route for the water passage thus resulting in considerable saving in cost
- Tunneling work can be started simultaneously at many points thus leading to quicker completion
- Natural land scape is not disturbed
- Tunneling work has become easier with development techniques of drilling and blasting and new mechanical equipment
- Development of rock mechanics and experimental stress analysis has given greater confidence to engineers regarding stability of tunnels.

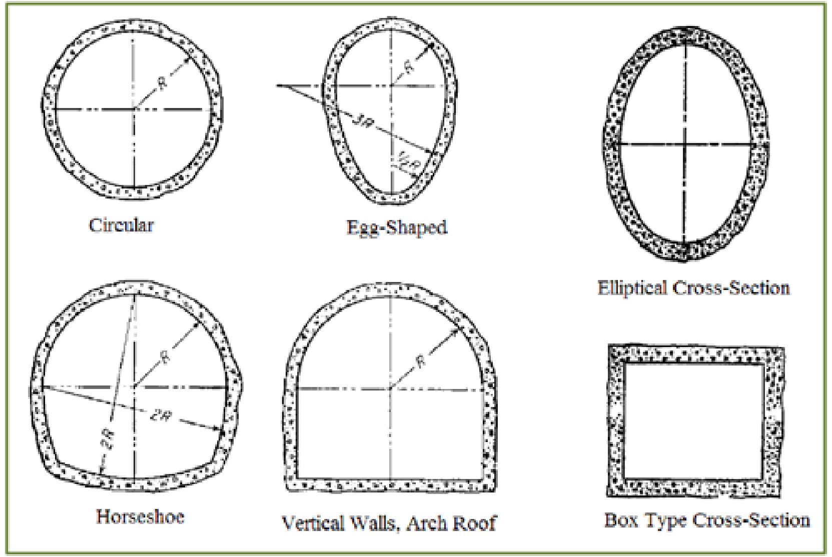
Tunnels of hydropower projects fall into two categories:

- **Water carrying tunnels:** These include head race or power tunnels, tail race tunnels or diversion tunnels. Flows in water tunnels are usually under pressure (pipe flow), but sometimes free-flow (open channel flow) can be experienced, especially, in tailrace tunnels. The design of free-flow tunnels follow the same principles as used in the design of open canals.
  - Head race tunnels: are tunnels that convey water to the surge tank.
  - Tail race tunnels: could be free flowing or pressure tunnels depending on the relative position of turbine setting and tail water level.
  - Diversion tunnels: are constructed for the purpose of diverting the stream flow during construction period. Normally they are not of high pressure but should have sufficient flood carrying capacity. Such tunnels either plugged with concrete or converted in to some use such as spillway tunnel at the completion of the project.
- **Service tunnels:** These may be:
  - Cable tunnels: to carry cables from underground power house to the switch yard
  - Ventilation tunnels: fitted with fans at the open end to supply fresh air to the underground
  - Access or approach tunnels: this is a passage tunnel from surface to underground power house.

Classification of Tunnels

- In addition to the above classification tunnels may be classified on the basis of shape, alignment and design aspects.
  - ➢Circular shape
  - ➢Horseshoe shape
  - ➢D-shape

Different Shapes of Tunnels



Tunnel Alignment

- A name tunnel indicates a very small bottom slopes, i.e. tunnels are aligned nearly horizontal.
- Shaft is a tunnel with vertical alignment or inclined shaft when it is steeply inclined.
- It is very crucial to investigate in detail the geology of the strata through which a tunnel would be passing. Sound, homogenous, isotropic, and solid rock formations are the most ideal ones for tunneling work. However, such ideal conditions are rarely present, and rather the rock mass exhibits various peculiarities.
- There may be folds, faults, joint planes dipping in a particular direction, weak strata alternating with good strata, etc.
- Thus, the alignment of a tunnel should be fixed keeping in view these phenomena.
- The alignment, for instance, should as far as possible avoid major fracture planes.

Design Aspects

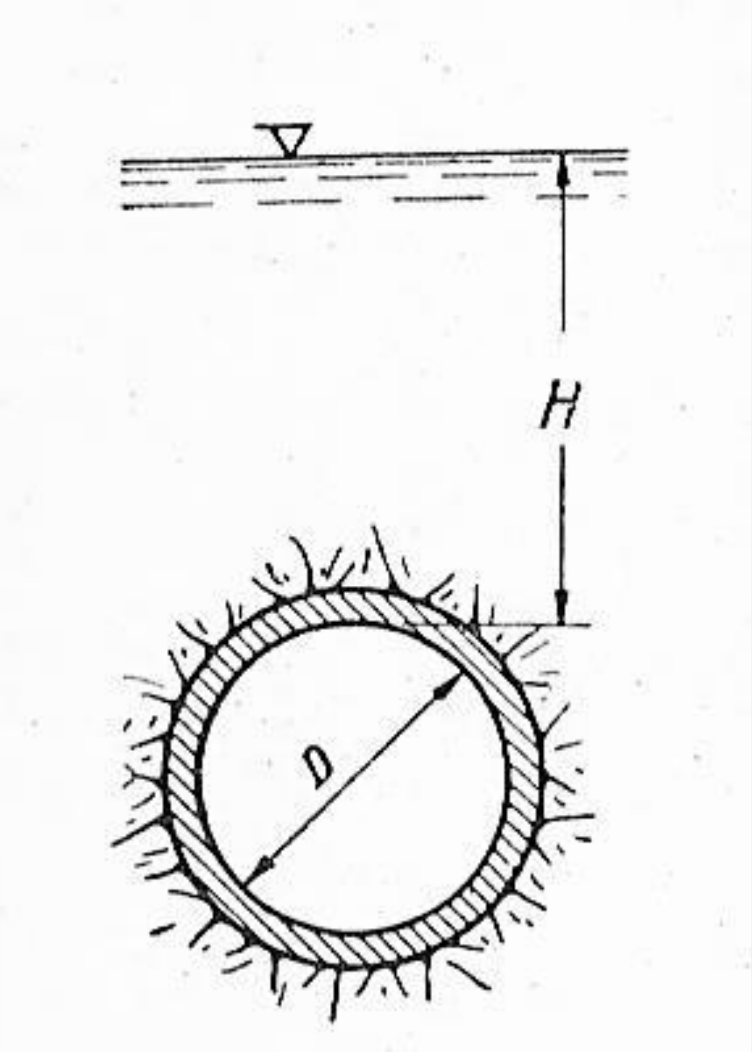
- **Lining:** Lining is a protective layer of concrete, R.C. or steel on the inner surface of the tunnel and it is an important aspect in classification of tunnels. Thus tunnels may be lined, unlined or partially lined. Tunnels in good, sound rock may left unlined.

Lining of tunnels is required:

- For structural reasons to resist external forces particularly when the tunnel is empty and when the strata is of very low strength.
- When the internal pressure is high, i.e. above 100m
- When reduction in frictional resistance and therefore the head loss is required for increasing capacity
- For prevention or reduction of seepage losses
- For protection of rock against aggressive water

Pressure tunnels: are classified according to pressure head above the soffit of the tunnel. Accordingly, tunnel may be grouped into,

- Low-pressure tunnels, with H lower than 10 m,
- Medium-pressure tunnels, with H from 10 to 100 m,
- High-pressure tunnels, with H higher than 100 m.



- In the case of low-pressure tunnels the tunnel surface may frequently be left unlined except for visible fissures.
- A watertight lining is usually required for tunnels operating under medium and high heads.
- Seepage is more likely to occur as the head increases, water may leak through the smallest fissures and cracks.
- Moreover, under high-pressure it may penetrate the otherwise watertight rock and render it permeable.

Low Head Tunnels

- The trimmed rock surface may be sufficient by only sealing visible fissure with concrete or cement mortar or granite layer
- Full lining my be warranted only if external rock load or aggressively or water head loss reduction justify it .

Medium Head Tunnels

- A water tight lining concrete is almost always needed since seepage is more likely to occur under increasing head.
- If the lining is only for water sealing purposes, and no load is carried by it, the permissible internal water pressure head is determined by the depth of overburden and the quality of the rock.

Medium Head Tunnels *contd.*

- If the tunnel is unlined, or if the lining serves only for water sealing purposes, i.e., carries no load, the permissible water pressure is determined.

Let

- h_r =The depth of overburden over the arch,
- γ_r =Specific weight of the rock.
- γ_w =Specific weight of the water
- $H = internal\ water\ pressure\ head$

Then for equilibrium: $\gamma_w H \leq \gamma_r h_r$

With $\gamma_w = 1\ ton/m^3$, *we have*

$$H \leq \gamma_r h_r$$

Using a factor of safety of η,

$$H = \frac{\gamma_r h_r}{\eta} (m)$$

Recommended factor of safety η = 4 to 6.

With $\gamma_r = 2.4\ t/m^3$ *to* $3.2\ t/m^3$ *and using lower* η values for good quality rock, one gets $H = (0.4\ to\ 0.8)\ h_r$

High Head Tunnels

- Usually steel lining is used (R.C. Concrete lining not satisfactory)
- The steel lining is embedded in concrete filling the annular space b/n the steel lining & the rock. In order to provide proper contact b/n rock and concrete and b/n steel lining & concrete, all voids are filled by grouting with comment mortar.
- The profile of the Pressure tunnel should be such that the roof should always be at least 1 to 2m below the hydraulic grade line
- Saddles should be provided with dewatering provisions and summits should be provided with outlets or shafts.

Flow velocity

- To reduce construction costs, relatively high velocities (higher than in open channels) are permitted in tunnels.

The following velocities are suggested:

- Very rough rock surface---------------1 to 2,0 m/s
- Trimmed rock surface ---------------1.5 to 3.0 m/s
- Concrete surface------------------------2 to 4.0 m/s
- Steel lining-------------------------------2.5 to 7 m/s
- The permissible velocity depends upon the sediment load carried by the water.
- The maximum values in the above recommendation apply when the sediment is of the silt fraction
- For water carrying sharp edged sand in significant quantity, $Vmax$= 2 to 2.5 m/s even in lined section.
- Size of tunnels cannot be reduced arbitrarily.
- Requirements of passability limit the maximum size.
- **Minimum size of Tunnel:** Circular, 1.8 m in diameter; Rectangular, 2m x 1.6m.
- In case of lined tunnels, the computed cross section should be increased by the thickness of the lining.

Tunnel Design Features

Alignment

In aligning water tunnels, the following points should be taken in to account:

- Length of the tunnel: as much as possible short route should be followed
- Location of surge tank & adits: the alignment should provide convenient points for surge tank & adits.
- Rock cover (overburden): sufficient rock cover should be available along the alignment
- Discontinuities: the alignment should, if possible, avoid crossing of weakness zones, joint planes, etc. If crossing of these features is unavoidable, suitable direction of crossing should be considered.
- Rock quality: good quality of rock mass should be sought in aligning the tunnel

Geometrical Shape

The choice of the cross-sectional profile of a tunnel depends on:

- Hydraulic considerations-Circular is preferable
- Stability considerations-Circular is preferable
- Convenience for construction-Horseshoe is preferable
- If drilling rigs are available, a horseshoe cross-section has to be adopted.

Longitudinal Slope

- The minimum slope for a pressure tunnel is limited on the basis of dewatering requirements during construction.
- And also the longitudinal profile of the tunnel should be such that the roof remains below the HGL by 1 to 2 m.
- Likewise, the tunneling method and the equipment employed for transportation of the excavated material (rail or wheel transport) can limit the maximum slope possible to provide.
- The usual practice is to keep the slope of power tunnel gentle till the surge tank and then steeper (even vertical) for the pressure shaft.

Flow Velocity

- The allowable velocities in tunnels depend upon whether it is lined or unlined.
- In unlined tunnels, a velocity of 2 to 2.5 m/s is the upper limit, while in concrete lined tunnels 4 to 5 m/s is often employed.
- The velocities for the pressure shafts, which are generally steel lined, are usually higher than that in the power tunnel.
- The normal range of velocities is between 5 to 8 m/s.

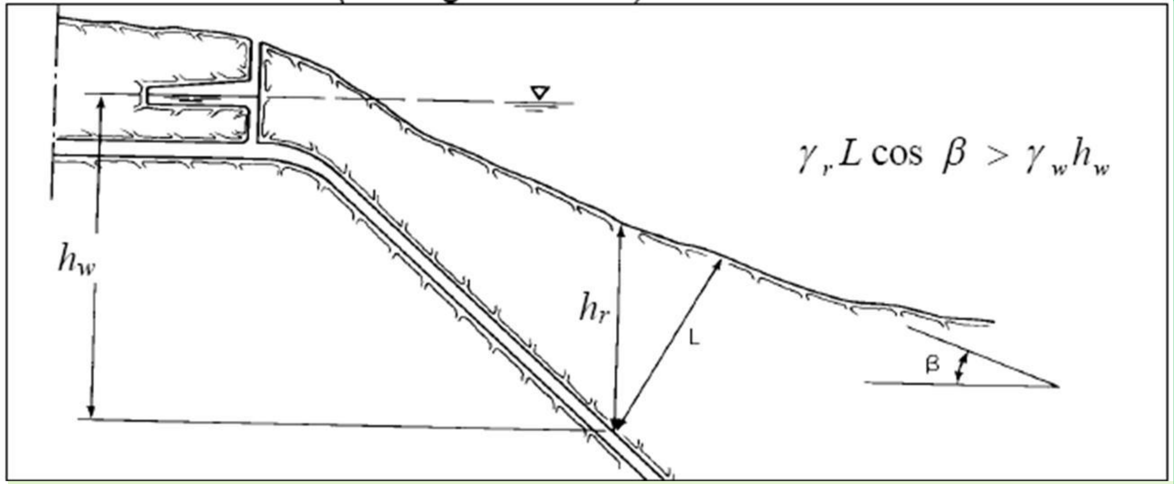
Rock Cover (overburden)

- For pressure tunnels, it is obvious that the overburden on the roof of the tunnel serves to balance the effect of upward force due to internal pressure.
- The required depth of overburden may vary for lined and unlined tunnels.
- In the case of unlined tunnels, the entire internal water pressure is resisted by the overburden rock pressure.

- Where a steep valley side constitutes the overburden above the tunnel, the rule of thumb equation, $H=(0.4 \text{ to } 0.8)h_r$ has to be modified and given by:

$$H = \frac{1}{\eta}\frac{\gamma_r}{\gamma_w} L\cos\beta$$

- Where L is the shortest distance between the ground surface and the studied point of the tunnel (or shaft) and β is the average inclination of the valley side with the horizontal. Practical values of the safety factor η are from 4 to 6.
- The lower limit of the safety factor should be used for greater depth of overburden and for sound rock.
- Whereas for shallow cover and poor rock overburden the upper limit is used.



H=hw= gross water head

- In the case of concrete or steel lined tunnels, the linings are usually designed to carry part or full load of the internal water pressure, and the above equations, given for unlined tunnels, are modified accordingly in determining the required overburden depth.

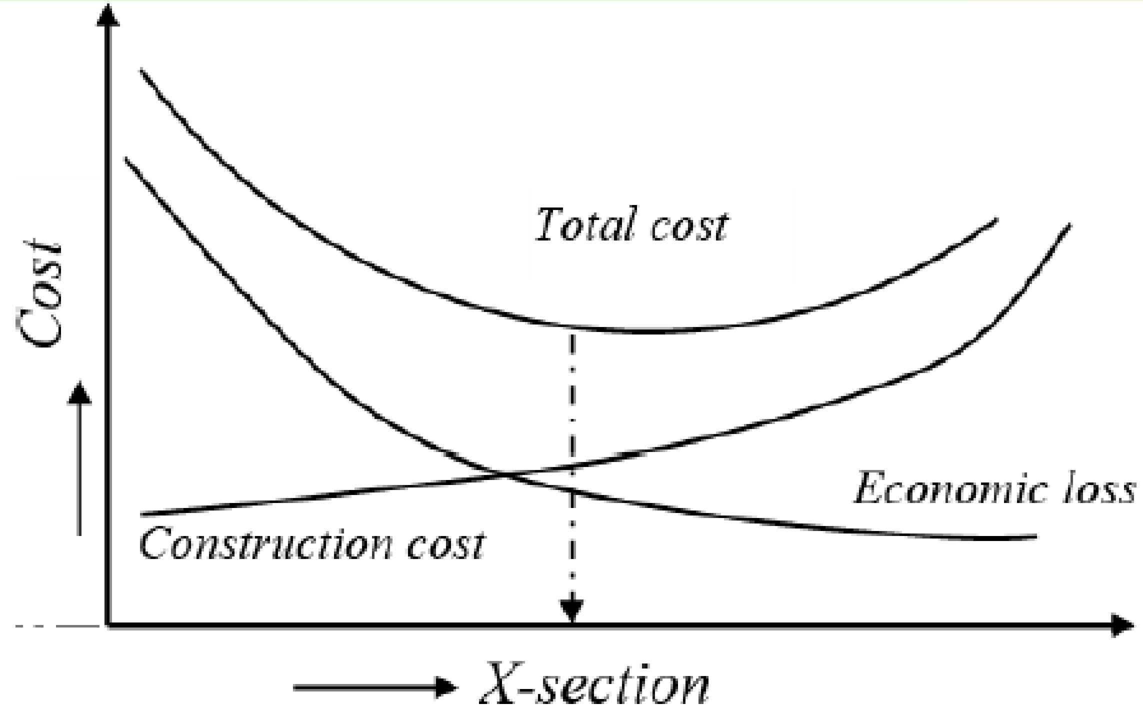
Head Loss

- Head losses in tunnels can be computed using Manning's, Darcy-Weisbach, or Hazen-Williams formulas.
  - Manning formula: $$h_f = n^2 \frac{lv^2}{R^{4/3}}$$
  - Darcy-Weisbach formula: $$h_f = \lambda \frac{l\,v^2}{2g\,D_{eq}}$$
  - Hazen-Williams formula (rarely used): $$h_f = 6.84 \frac{l\,v^{1.85}}{C^{1.85}\,D_{eq}^{\;1.17}}$$

Where, h_f is head loss due to friction, l is tunnel length, v is mean velocity of flow, R is hydraulic radius, D_{eq} is equivalent diameter ($\sqrt{4A/\pi}$), *A* is area of the tunnel x-section, *n* is Manning's roughness coefficient, λ is Darcy-Weisbach friction factor (can be obtained from Moody diagram), and *C* is Hazen-Williams roughness coefficient.

Optimum X-section

- The optimum x-section of a tunnel or a shaft is one for which the sum of tunnel construction cost and the economic loss due to head loss is minimum.
- For a quick initial estimate of the diameter of pressure tunnels, the empirical formula suggested by Fahlbusch can be used:



For concrete-lined tunnels: $D = 0.62\,Q^{0.48}$

For steel-lined tunnels: $D = 1.12\,\dfrac{Q^{0.45}}{H^{0.12}}$

H= static water head

Tunneling Methods

There are three commonly used types of tunneling techniques:

- Cut and cover tunneling
- Conventional “Drill and Blast”
- Use of Tunnel Boring Machines (TBM)

Cut and cover tunneling

- This is a common and well-proven technique for constructing shallow tunnels.
- The method can accommodate changes in tunnel width and non-uniform shapes and is often adopted in construction of underground stations.
- Several overlapping works are required to be carried out in using this tunneling method.
- Trench excavation, tunnel construction and soil covering of excavated tunnels are three major integral parts of the tunneling method.

Conventional "Drill and Blast" Method

- This tunneling method involves the use of explosives.
- Drilling rigs are used to drill blast holes on the proposed tunnel surface to a designated depth for blasting.
- Explosives and timed detonators (Delay detonators)are then placed in the blast holes.

i)Drilling

ii)Charging

iii)Blasting

iv)Ventilating

vi)Scaling

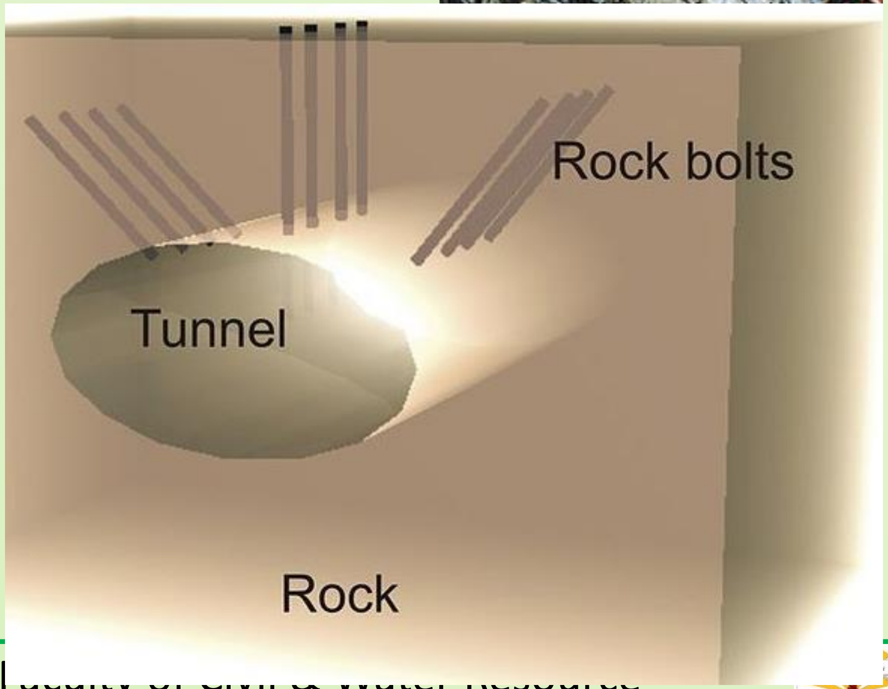
vi)Mucking and hauling

vii)Tunnel supporting

Rock Bolting

- A rock bolt is a steel bar, which is inserted into a hole drilled in a rock to improve the rock competency.
- The distant end has a device which permits it to firmly anchored in the hole and the projecting end is fitted with a plate which bears against the rock surface
- The bolt is placed in tension between the anchor and the plate, thereby exerting a compressive force on the rock.

- Rock bolting in tunnels is carried out according to one of the following two main principles:
- Spot bolting of individual, unstable blocks
- Systematic bolting of a section of the tunnel in a definite pattern
- On average, the length of rock bolts in water tunnels is 1.5 to 4 m and the diameter is 16 to 25 mm. Rock bolting is usually used for an immediate support near the tunnel face.



Shotcreting

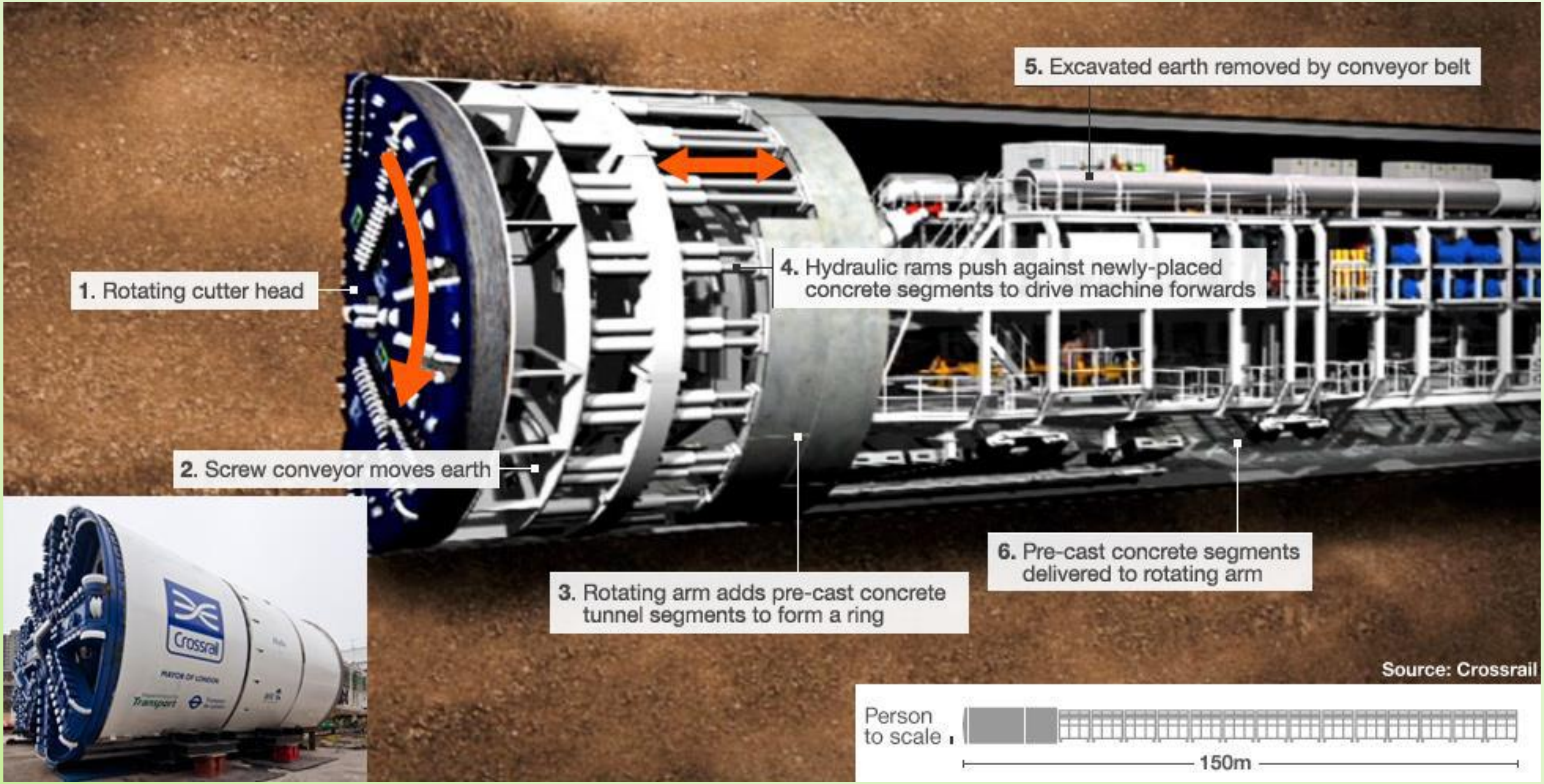
- A shotcrete is a quick-setting concrete plaster shot at rock surfaces pneumatically.
- It creates the best possible rock support condition, which makes it an economical, rapid, and effective means of providing tunnel support.
- In practice the shotcrete is placed in 5 cm layers until a desired thickness is attained.
- The use of steel fibresin the concrete mix has an effect of increasing the strength of the shotcrete. For an immediate support in areas of heavily jointed rock masses or in areas of high rock stresses, steel fibre reinforced shotcrete is commonly used.
- In many cases, the shotcrete is combined with rock bolting for use as a permanent support.
- A combination of steel fibre reinforced shotcreting and systematic rock bolting can replace concrete lining alternative, provided that water inflow and active gouge material in the discontinuities are minimal or absent.
- A general restriction in the use of shotcrete is in areas with water leakage. The main restriction, however, is where weakness zones contain swelling clay (smectite). If shotcreteis applied on such zones, there will be no room for expansion of the swelling clay, and high swelling pressure will be activated when the zones are exposed to water. This may easily destroy the shotcrete lining.

Grouting

- A grout is a mixture of cement and water forced in to rocks around the tunnel periphery.
- Grouting may be performed ahead of the tunneling face (pre-grouting) or behind the tunneling face (post-grouting).
- Pre-grouting is necessary in areas where groundwater inflow makes tunnel driving difficult.
- Probe holes are drilled ahead of the tunnel face to perform permeability testing before deciding the necessity of pre-grouting. Post-grouting is done to improve the stability of the rock mass behind the tunnel face.

Tunnel Boring Machines (TBM)

- TBM is often used for excavating long tunnels.
- An effective TMB method requires the selection of appropriate equipment for different rock mass and geological conditions.
- The TBM may be suitable for excavating tunnels which contain competent rocks that can provide adequate geological stability for boring a long section tunnel without structural support.


5. Excavated earth removed by conveyor belt
1. Rotating cutter head
4. Hydraulic rams push against newly-placed concrete segments to drive machine forwards
2. Screw conveyor moves earth
6. Pre-cast concrete segments delivered to rotating arm
3. Rotating arm adds pre-cast concrete tunnel segments to form a ring
Crossrail
Source: Crossrail
Person to scale
150m