

RAILWAY ENGINEERING (CENG 5242)

CHAPTER 6
INTRODUCTION TO TUNNELS & BRIDGES

INTRODUCTION TO TUNNEL & BRIDGE

Part I- Tunnels



Tunneling

Uncertainty Engineering,

Hidden Activity

6.1 Definition and Function of Tunnel

Definition of a tunnel

- A tunnel is an underground passageway, completely enclosed except for openings or egress, commonly at each end.
- A tunnel is an artificially constructed underground passageway for move of mankind, animals, water or goods. For example, underpass, water conduits, diversion tunnels, subway, highway tunnels, and railway tunnels, etc.
- A tunnel is relatively long and narrow; in general, the length is more (usually much more) than *twice the diameter*.

6.1 Definition and Function of Tunnel

Tunnels for different usages



Function of Tunnel

Functions of a tunnel

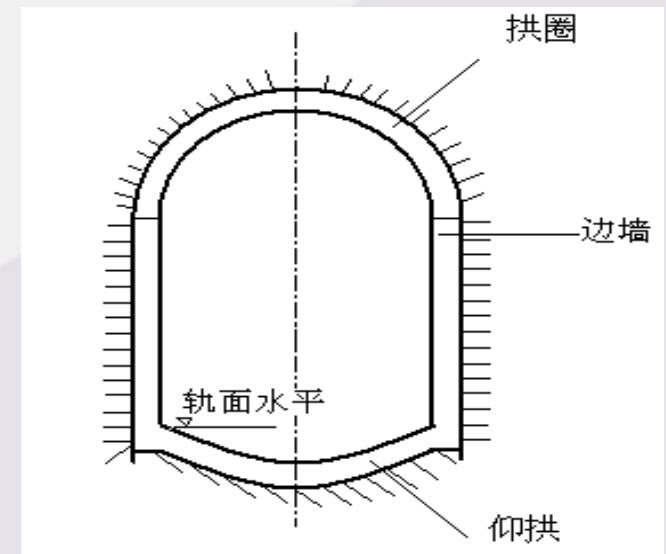
A tunnel may be for

- foot traffic
- vehicular road traffic
- rail traffic
- a canal
- aqueducts to supply water for consumption or for hydroelectric stations or for sewers
- routing power cables, or
- telecommunication cables, or
- permitting wildlife to cross highways, or
- giving an entrance to escape from an area, fortifications, or
- storages, etc.

Function of Tunnel

(1) Form of tunnel

1. Main body building—tunnel portal and tunnel trunk. The role is to keep the stability of tunnel and to ensure the safe operation of train.
2. Ancillary building—refuge hole, drainage and ventilation facilities. To ensure the safety, maintenance and repair of tunnel.



Function of Tunnel- *Main body building*

The **materials** should have enough **strength and durability**; While on special section, there also requires anti-freeze, anti-permeability and resistance for erosion.

Tunnel lining and support design

- Rock mass classification
- Loads etc

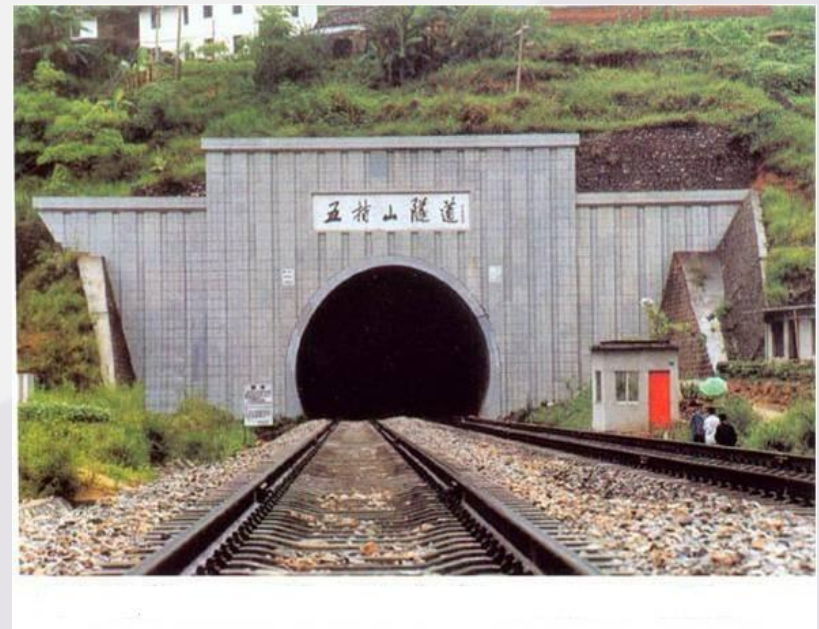


Function of Tunnel- Main body building

(b) tunnel portal

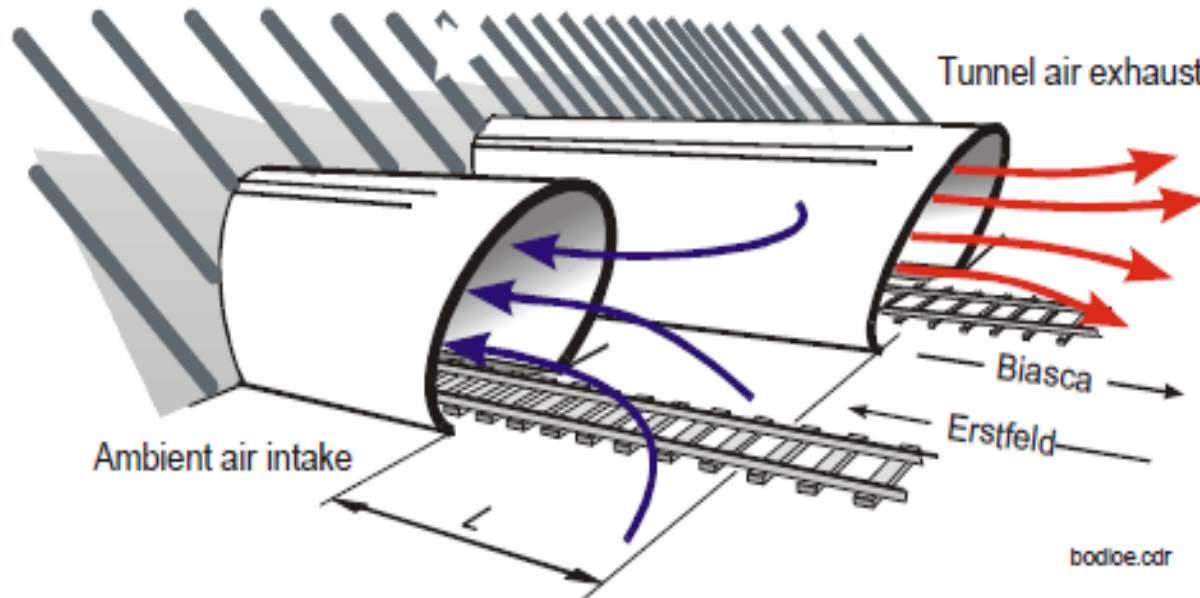
The main question is to choose the location of entrance:

To considerate it combined with the terrain, geology, hydrogeology, construction and operation conditions



Aerodynamic Design of Portals

Staggered arrangement of portals for reducing air recirculation, i.e. the intake of warm and humid waste air from the exit tube into the entrance tube is reduced



Issues have to be taken into account for the design of the portals

1. Recirculation -partly high temperatures and humidity are expected in the tunnel., i.e. the intake of warm and humid waste air from the exit tube into the entrance tube,

2. To ensure safety on roads passing near the portals, fog generated by waste air must be avoided as far as possible.

3. During the passage high-speed trains through portals characteristic and strong pressure fluctuations are generated, which can affect the comfort of train passengers. Therefore, the **pressure fluctuations** must be attenuated with suitable measures.

Function of Tunnel- *ancillary building*

(c) ancillary building

1. refuge hole

the small ones — to ensure the safety of workers

the big ones — to store the materials

There sets a small hole per 60m and a big hole per 300m on both sides of the tunnel.

2. ventilation facilities- to expel from harmful gas

Two forms: natural ventilation and mechanical ventilation.

3. drainage facilities- to drain out water (from seepage or GWT) with longitudinal drains to minor side outlet tunnels

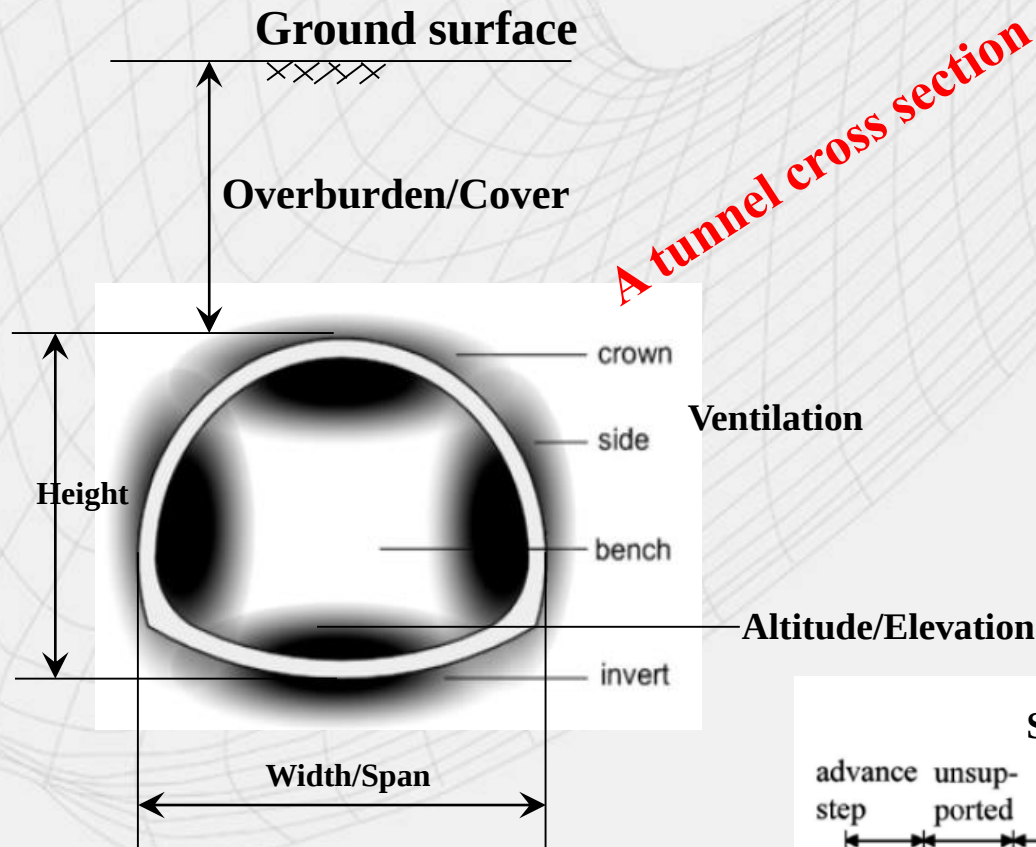
(2) clearance of tunnel



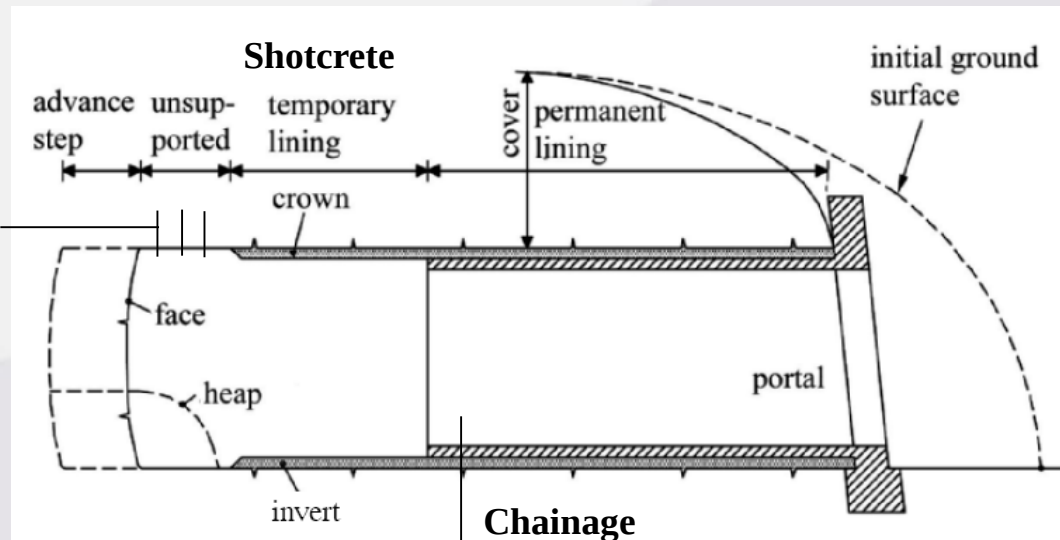
Typical Underground Space



Cross section and Notations in tunneling



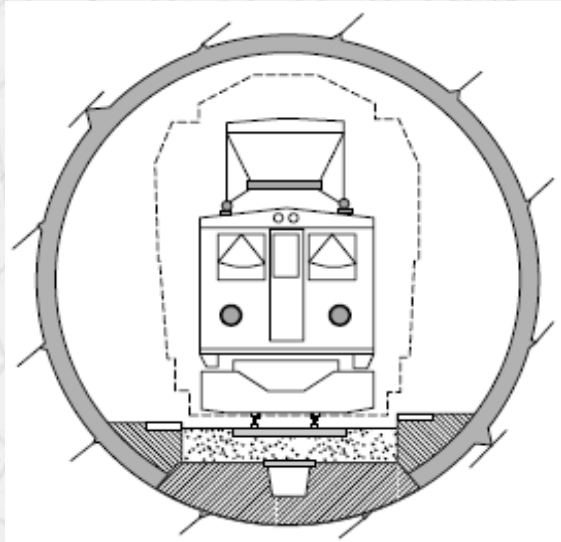
Rock bolt



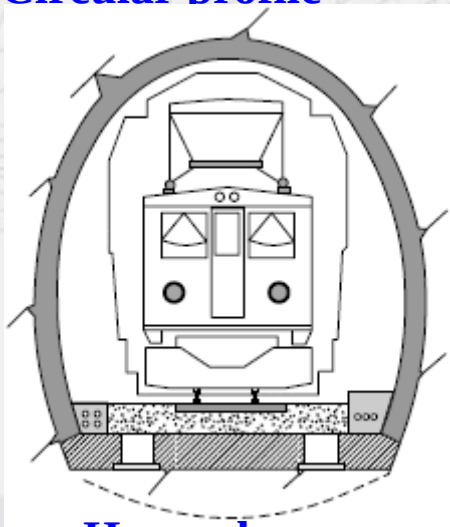
Longitudinal sections of heading

Cross sections (Profiles)

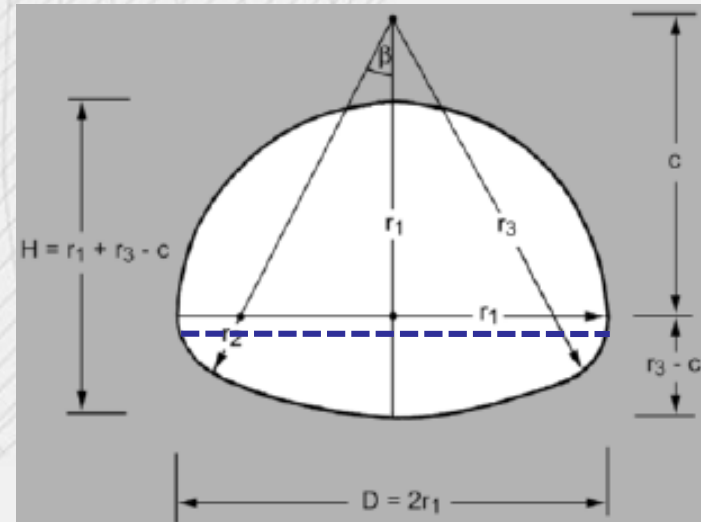
Popular profiles



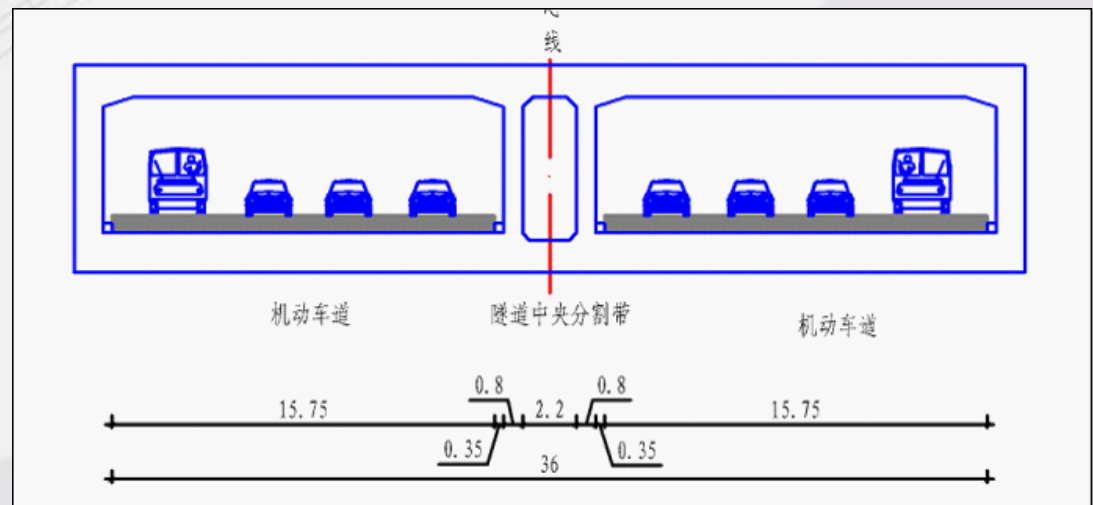
Circular profile



Horse shoe

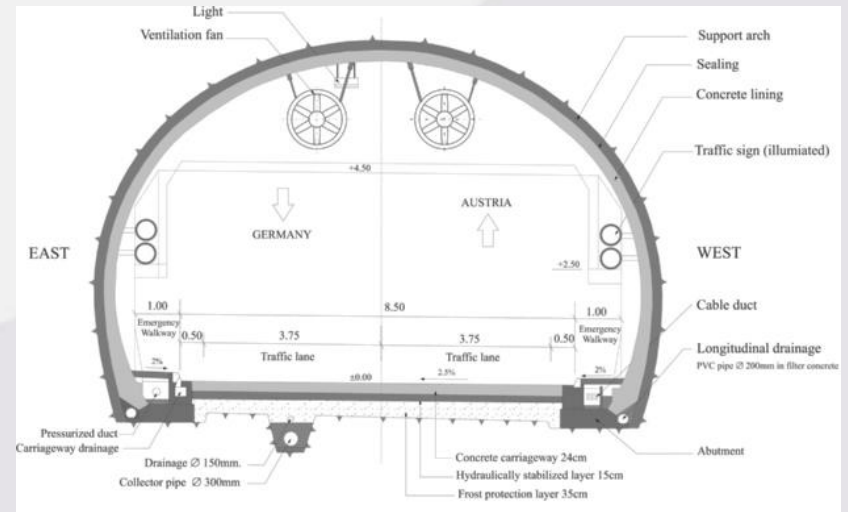
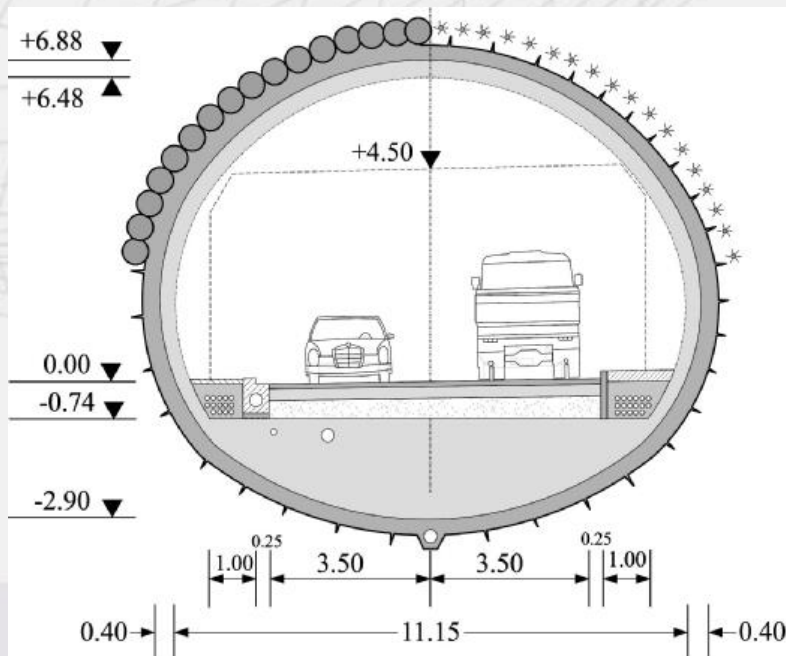
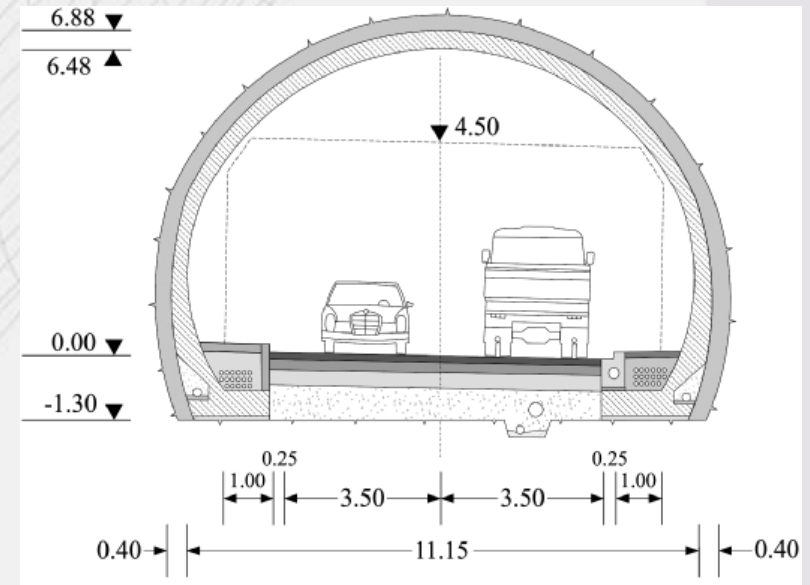
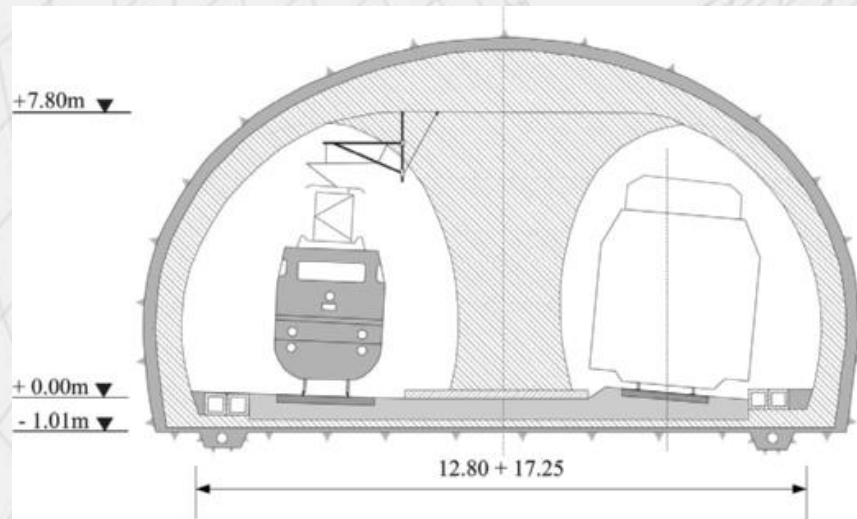


Mouth (oblate) profile

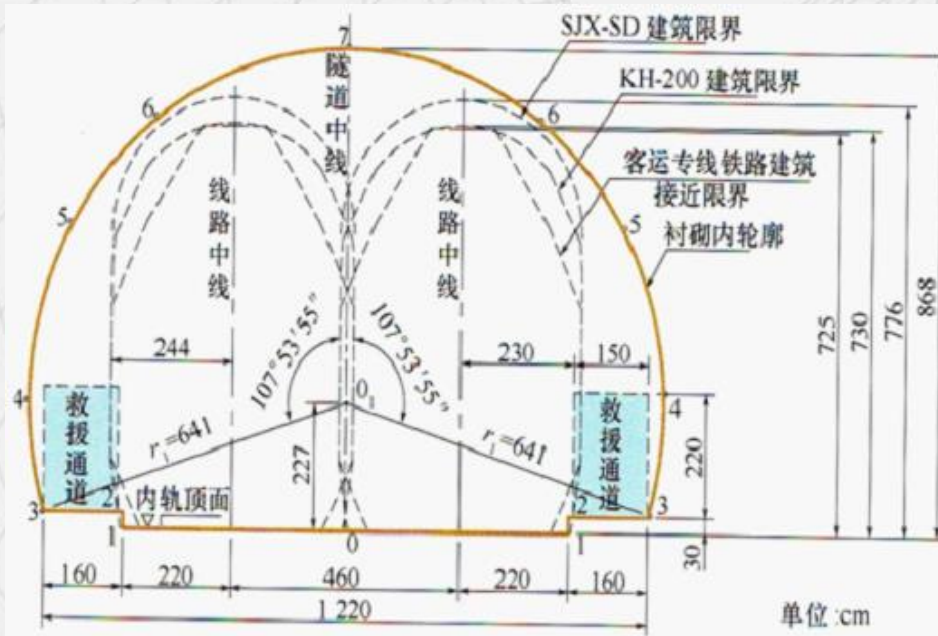


Rectangle

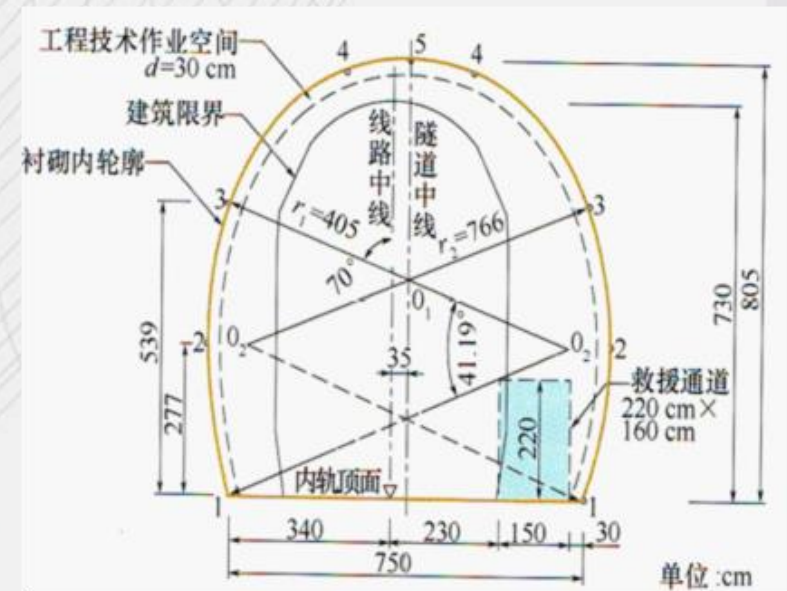
Various profiles are conceivable



Railway tunnel profile



Two tracks



One track



Aerodynamic pressure rise

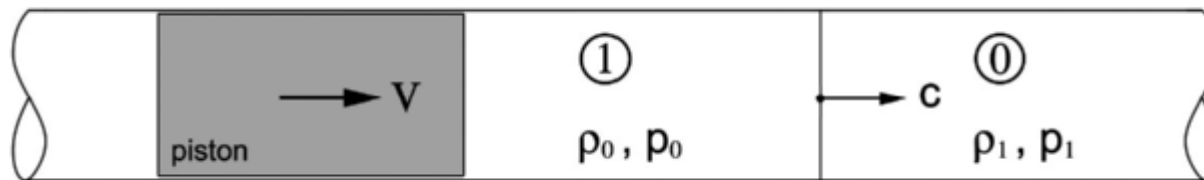
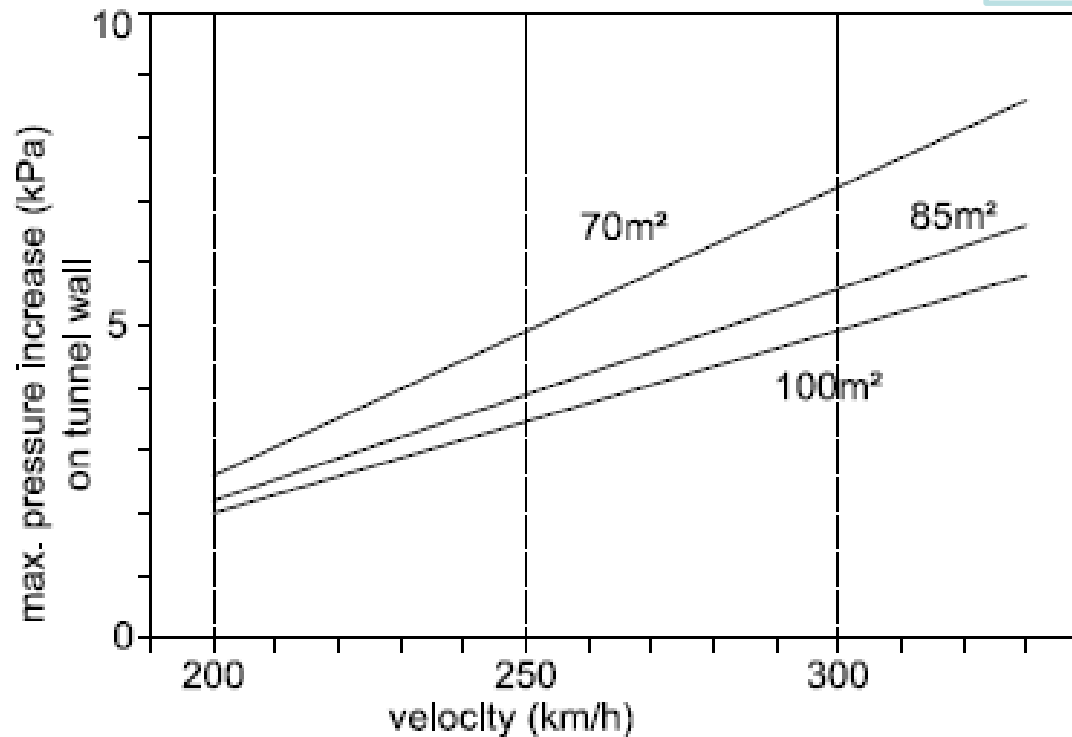


Fig. 1.16. Piston moving within a tube

An aerodynamic pressure rise



- causes discomfort of the passengers (unless the cars are pressure-tight), and,
- Produces noise near exit, and,
- constitutes a load acting upon the lining.

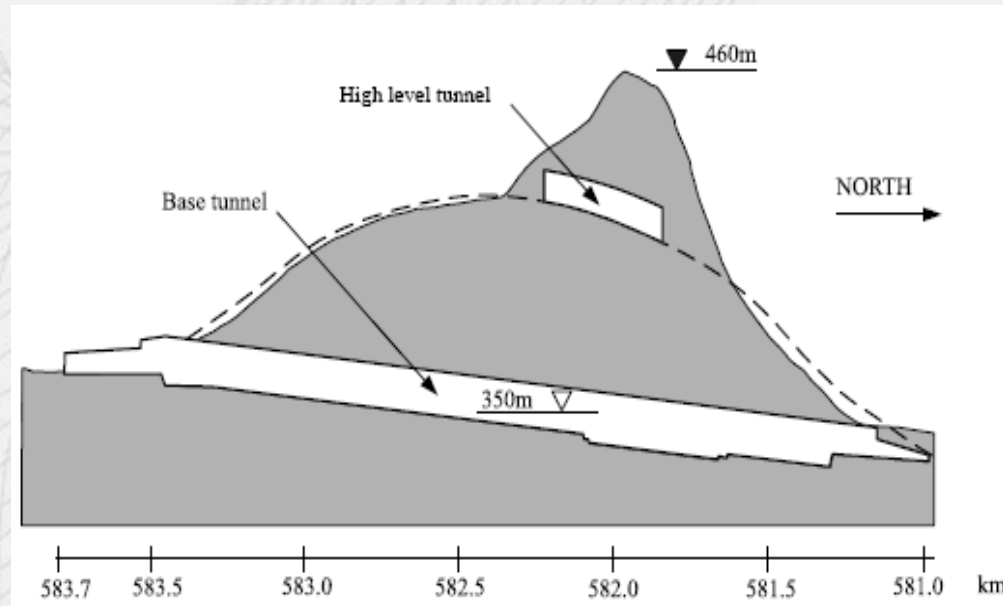
Fig. 1.17. Aerodynamic pressure rise on the tunnel wall due to entrance of high speed trains

Choice of tunnel alignment



1. Depends on geotechnical conditions, traffic, hydrological, risk management, excavation method (drill & blast or TBM).
2. To minimize the disturbance of the environment, aspects of vibration (e.g. due to blasting), noise and ventilation should be considered.
3. In road tunnels, straight alignments longer than 1,500m should be avoided, as they could distract the driver.
4. Furthermore, to avoid excessive concentration on one point, the last few meters of a tunnel should have a gentle curve in plan view.

Choice between a high level tunnel and a base tunnel



- A high level tunnel is much shorter and reduces geological risk (because of the reduced cover). On the other hand, the operation is more expensive because of increased power consumption and increased wear of the wagons. Velocity is reduced and traffic interruptions or delays during winter must be factored in.
- A base tunnel is much longer and, therefore, much more expensive and difficult to construct. But it offers many operational advantages.

Installations in tunnels:

- Installation for traffic control
- Installation for telecommunication
- Ventilation
- Fire protection
- Illumination of road tunnels
- Drainage



Design methods tunneling

Design of tunnel support

- *Analytical methods*
- *Observational methods*
- *Empirical methods*

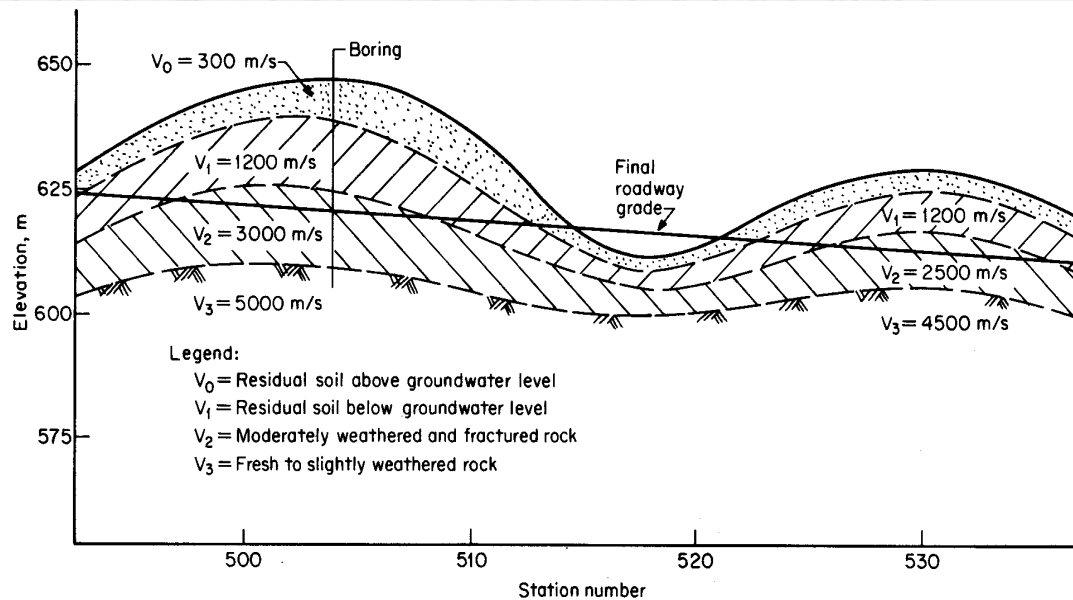
All the methods requires geological input data and consideration of statutory safety regulations.



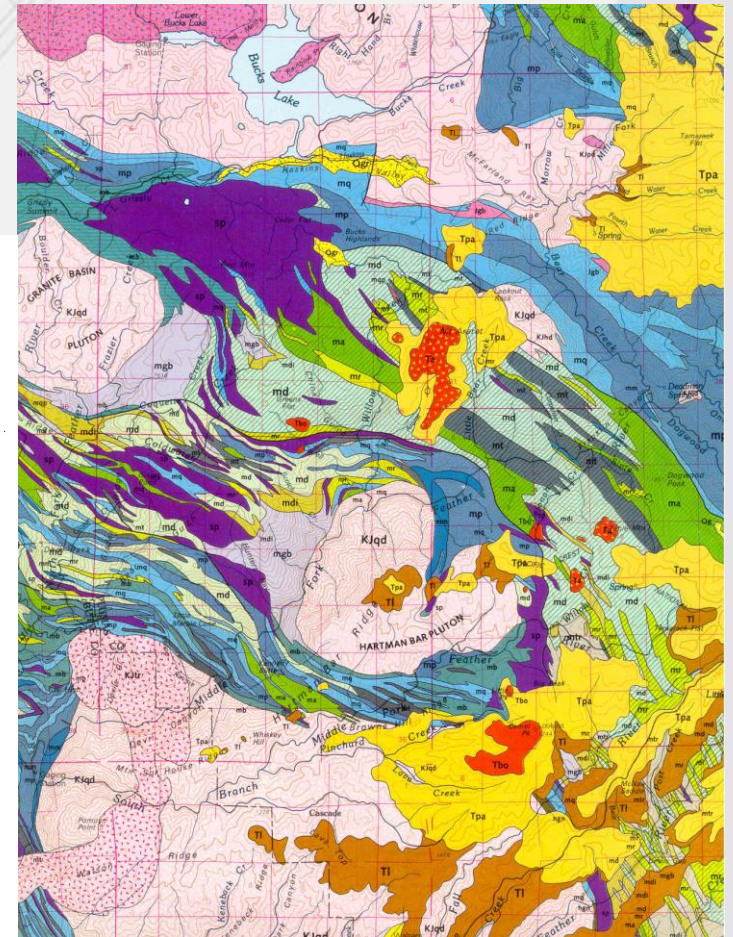
Rock log samples

Uncertainties in tunneling

- **Load ?**
- **Material (rock condition) ?**
- **Water ?**
- **Caves ?**
- **Shear zones ?**



Example of a subsurface section prepared from a continuous refraction profile.



Empirical methods

Rock classifications are the best know empirical approach for assessing the stability of underground openings in rock , including:

- ***RSR, Rock Structure Rating, 1972, by Wickham***
- ***RMR, Rock Mass Rating, 1973, by Bieniawski***
- ***Q system, 1974, by N. Barton***

The **empirical approach**, based on rock mass classifications, is the most popular probably because of its basic purpose of **simplicity and ability to managing uncertainties.**



Six parameters are used in estimating RMR:

- ✓ Uniaxial compressive strength of intact rock material, R1
- ✓ rock quality designation RQD, R2
- ✓ joint or discontinuity spacing, R3
- ✓ joint condition, R4
- ✓ ground water condition, R5 and
- ✓ joint orientation, R6.

$$RMR = R1 + R2 + R3 + R4 + R5 + R6$$

Application of RMR- Support Pressure

$$p_v = \frac{0.75 \cdot B^{0.1} \cdot H^{0.5} \cdot RMR}{2 RMR}, \text{ MPa}$$

where,

- B = span of opening in metres,
- H = overburden or tunnel depth in metres (>50m), and
- p_v = short-term roof support pressure in MPa.

Experience suggests that:

➤ 10 points should be added to get RMR for undisturbed rock masses in situations where TBMs or road headers are used for tunnel excavation;

➤ 3 to 5 points may be added depending upon the quality of the controlled blasting.

Goel and Jethwa (1991)

Q-System , Rock Mass Quality Norwegian Geotechnical Institute (NGI)

$$Q = \left[\text{RQD} / J_n \right] \left[J_r / J_a \right] \left[J_w / \text{SRF} \right]$$

where,

RQD = Deere's Rock Quality Designation ≥ 10 ,

J_n = Joint set number,

J_r = Joint roughness number for critically oriented joint set,

J_a = Joint alteration number for critically oriented joint set,

J_w = Joint water reduction factor, and

SRF = Stress reduction factor.

Approximate measures of:

- | | | |
|---|---|---|
| a. Block size (RQD / J_n) | : | It represents overall structure of rock mass |
| b. Inter block shear strength (J_r / J_a) | : | It has been found that $\tan^{-1}(J_r / J_a)$ is a fair approximation to the actual peak sliding angle of friction along the clay coated joints (Table 8.7) |
| c. Active stress (J_w / SRF) | : | It is an empirical factor describing the active stress |

Rock Quality Designation (RQD)

The RQD value in percentage is the rating of RQD for the Q system. In case of a poor rock mass where RQD is less than 10 percent, a minimum value of 10 should be used to evaluate Q.

Joint Set Number (Jn)

Joint Roughness and Joint Alteration (Jr and Ja)

Joint Water Reduction Factor (Jw)

Stress Reduction Factor (SRF)

Formula relating to Q value

$$RMR = 9 \ln Q + 44$$

$$E(GPa) = 10^{\frac{RMR-10}{40}}$$

$$c = \frac{RQD}{J_n} \times \frac{1}{SRF} \times \frac{\sigma_c}{100}$$

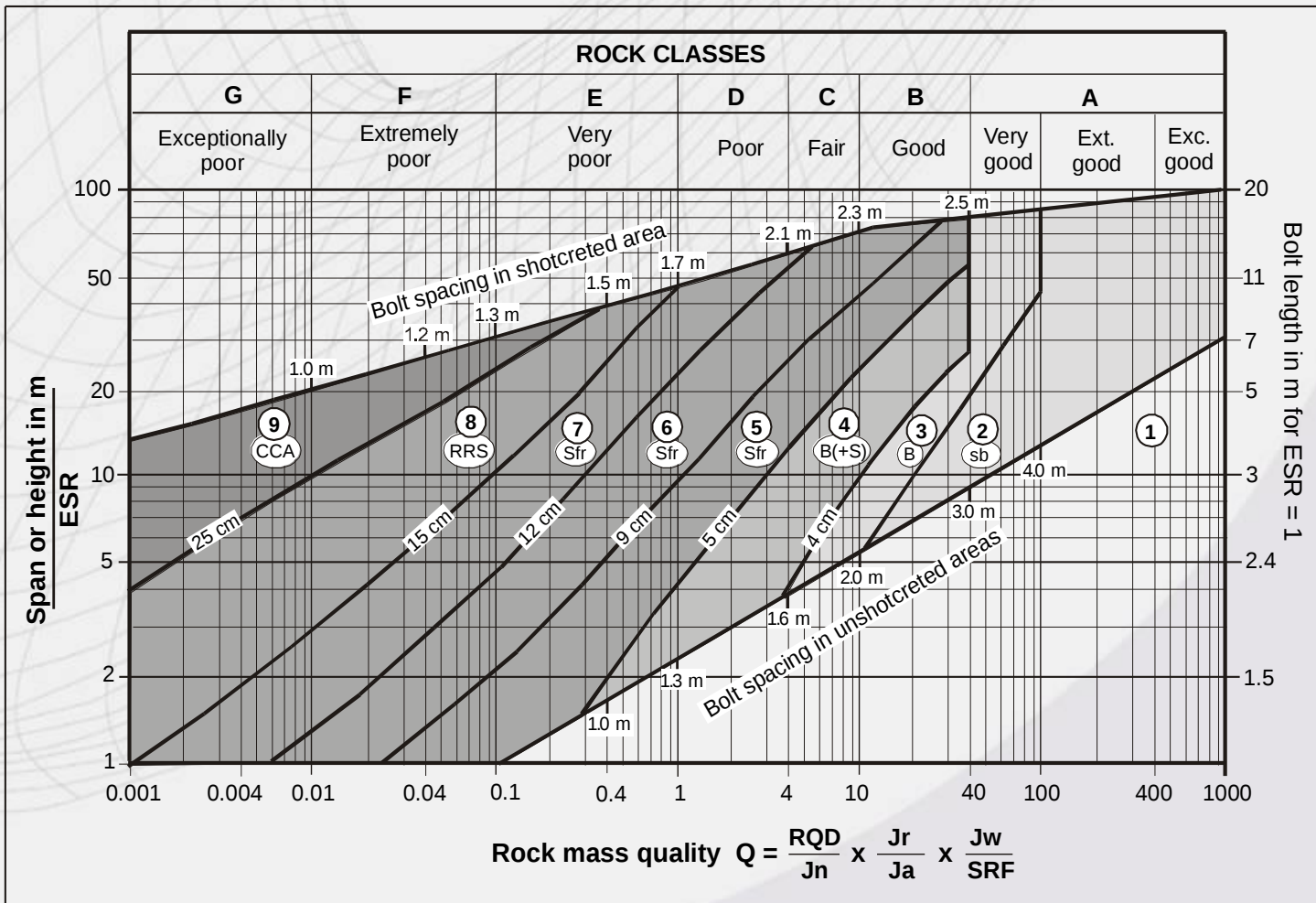
$$V_p = 3.5 + \log Q$$

$$\phi = \tan^{-1} \left(\frac{J_r}{J_a} \times J_w \right)$$

Settlement at crown: $\Delta(mm) = \frac{SPAN(m)}{Q}$

Support pressure: $P_r = 0.1Q^{-1/3}$

Rock support design by Q-chart



REINFORCEMENT CATEGORIES:

- | | |
|---|--|
| 1) Unsupported | 5) Fibre reinforced shotcrete and bolting, 5 - 9 cm, Sfr + B |
| 2) Spot bolting, sb | 6) Fibre reinforced shotcrete and bolting, 9- 12 cm, Sfr + B |
| 3) Systematic bolting, B | 7) Fibre reinforced shotcrete and bolting, 12 - 15 cm, Sfr + B |
| 4) Systematic bolting,
(and unreinforced shotcrete, 4 - 10 cm), B(+S) | 8) Fibre reinforced shotcrete, > 15 cm,
reinforced ribs of shotcrete and bolting, Sfr, RRS+B |
| | 9) Cast concrete lining, CCA |

Estimating support pressure from Q value

$$p_v = (0.2/J_r) Q^{-1/3}$$

$$p_h = (0.2/J_r) Q_w^{-1/3}$$

where,

p_v = ultimate roof support pressure in MPa,

p_h = ultimate wall support pressure in MPa, and

Q_w = wall factor.

Range of Q

Wall Factor Q_w

> 10

5.0 Q

0.1 - 10

2.5 Q

< 0.1

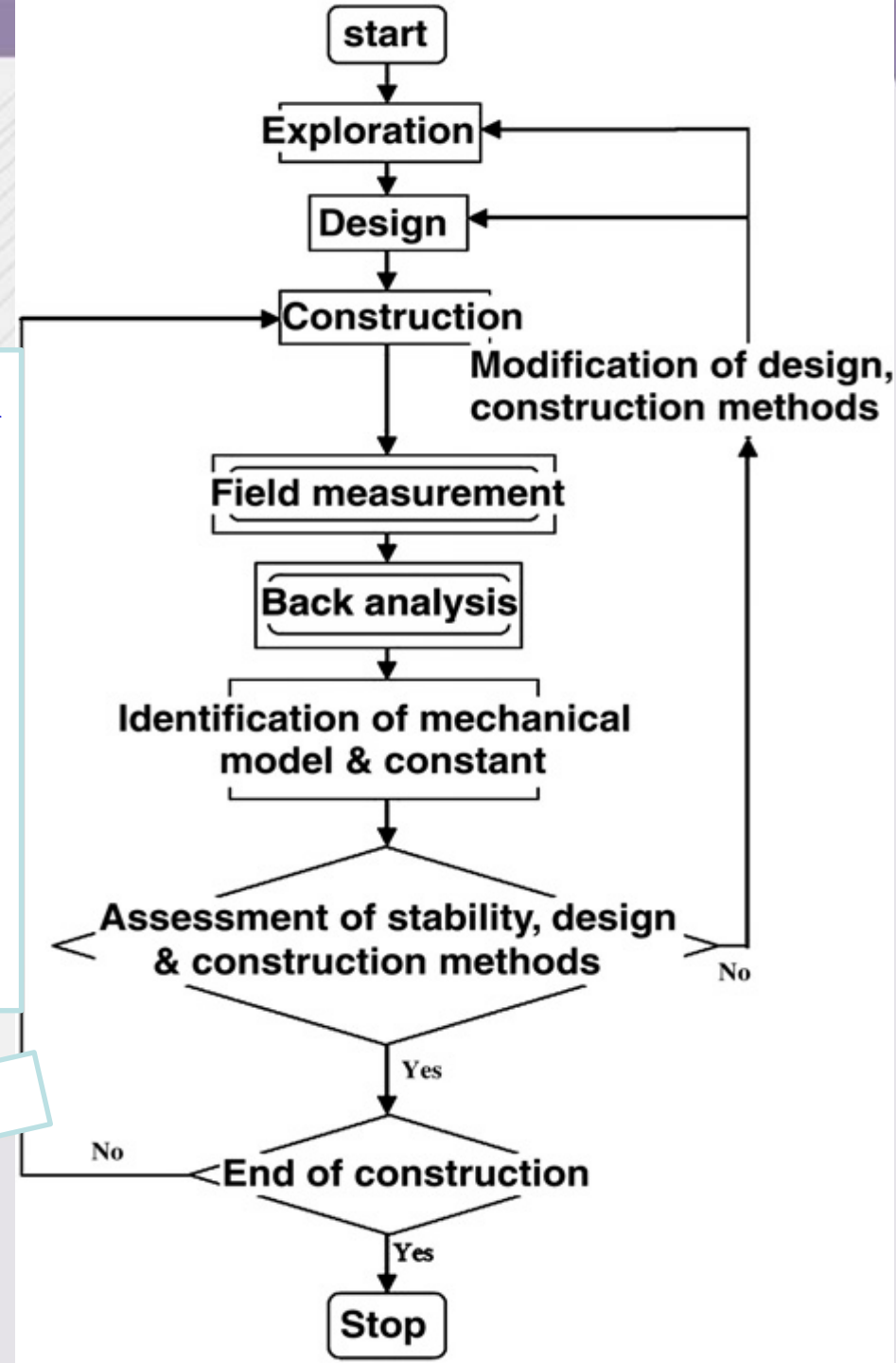
1.0 Q

Observational methods

Rely on actual monitoring of ground movement during excavation to detect measurable instability, and on the analysis of ground-support interaction, including:

- ✓ NATM, New Austrian Tunneling Method
- ✓ NMT, Norwegian Method of Tunneling
- ✓ ITM, Informational Tunneling Method

Cyclic routines in an observational method

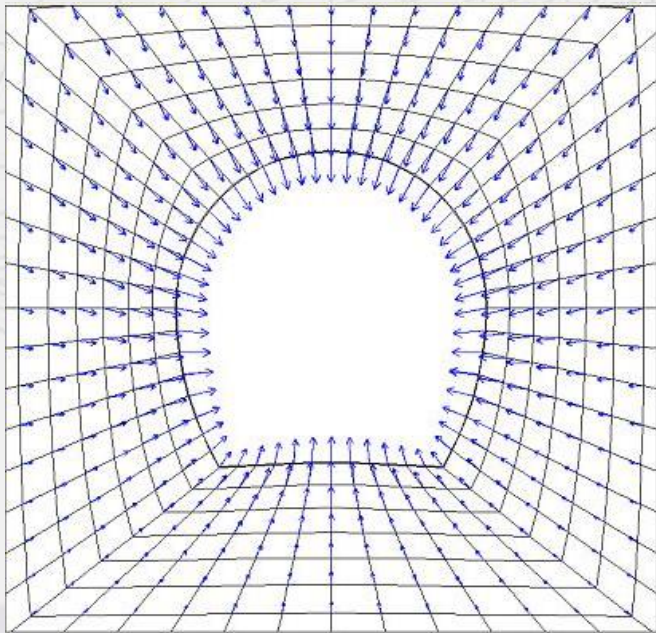


Analytical methods

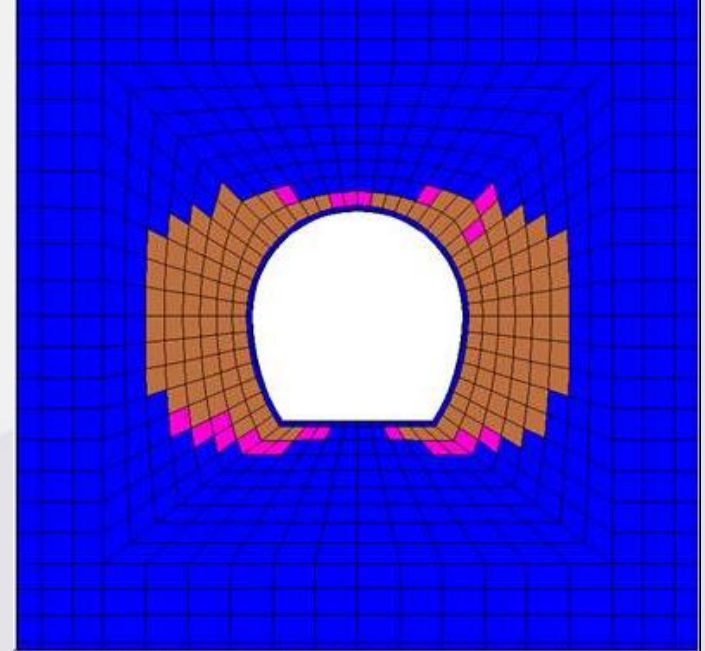
Utilize the analyses of stresses and deformations around openings.

They include such techniques:

- ✓ Closed form solutions
- ✓ Numerical methods (FEM, FDM, BEM, DEM etc.);
- ✓ Analogy simulations
 - Electrical
 - Photo-elastic
- ✓ Physical modeling.



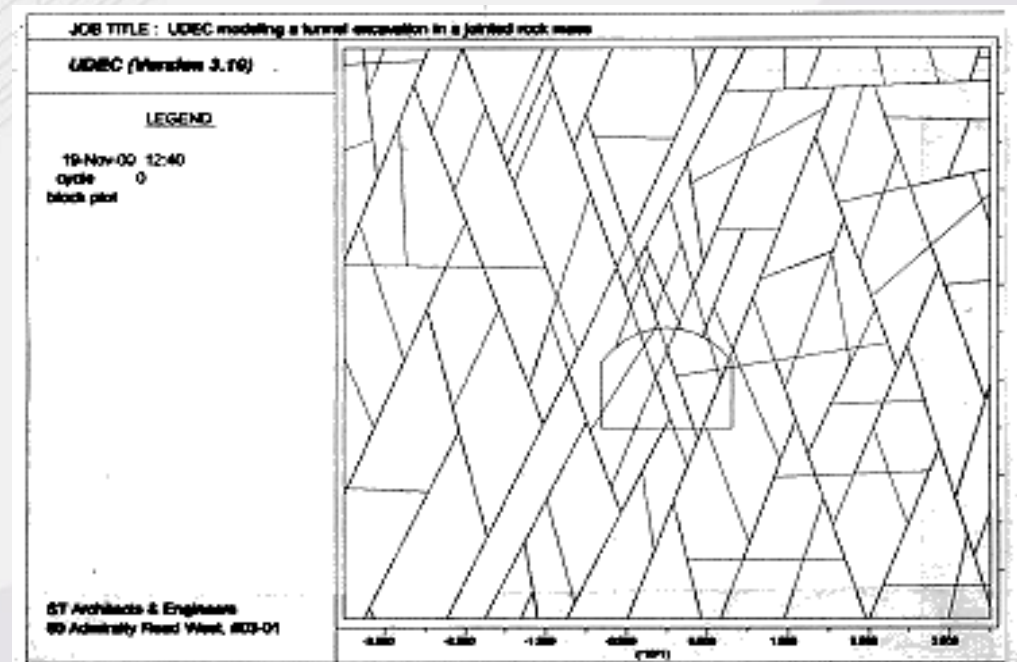
Displacement vector



Yielding zone

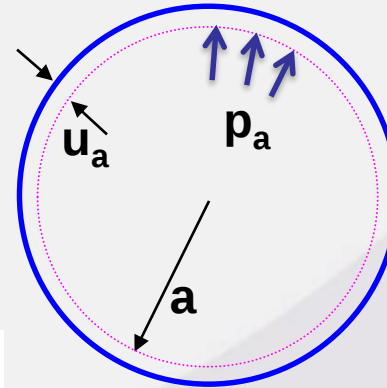
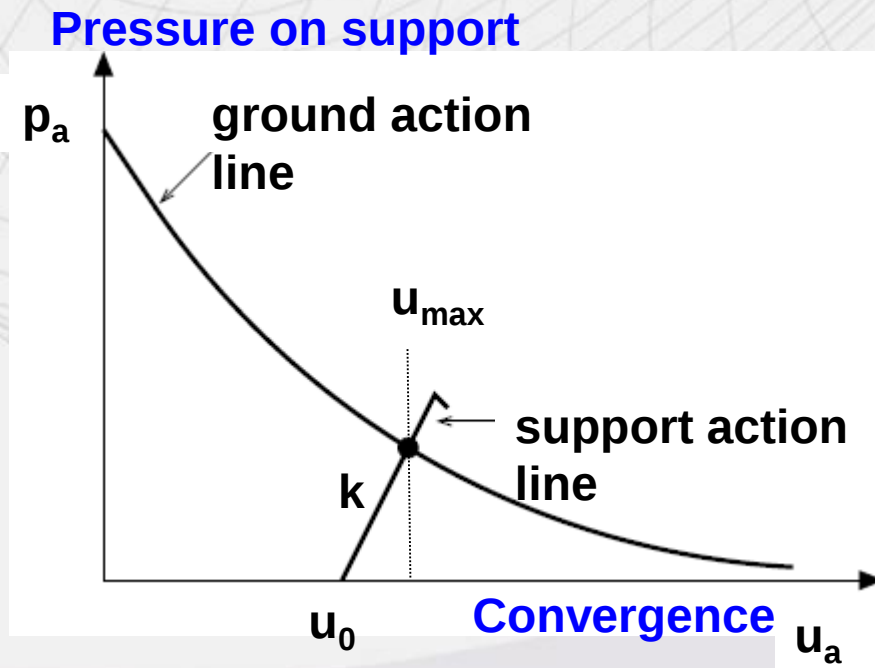
Key steps in numerical modeling

- ✓ *Establishment of the computational model*
- ✓ *Boundary condition*
- ✓ *Selection of constitutive models*
- ✓ *Material parameters*
- ✓ *Initial stresses*
- ✓ *Excavation process*
- ✓ *Support application*



Convergence-confinement method

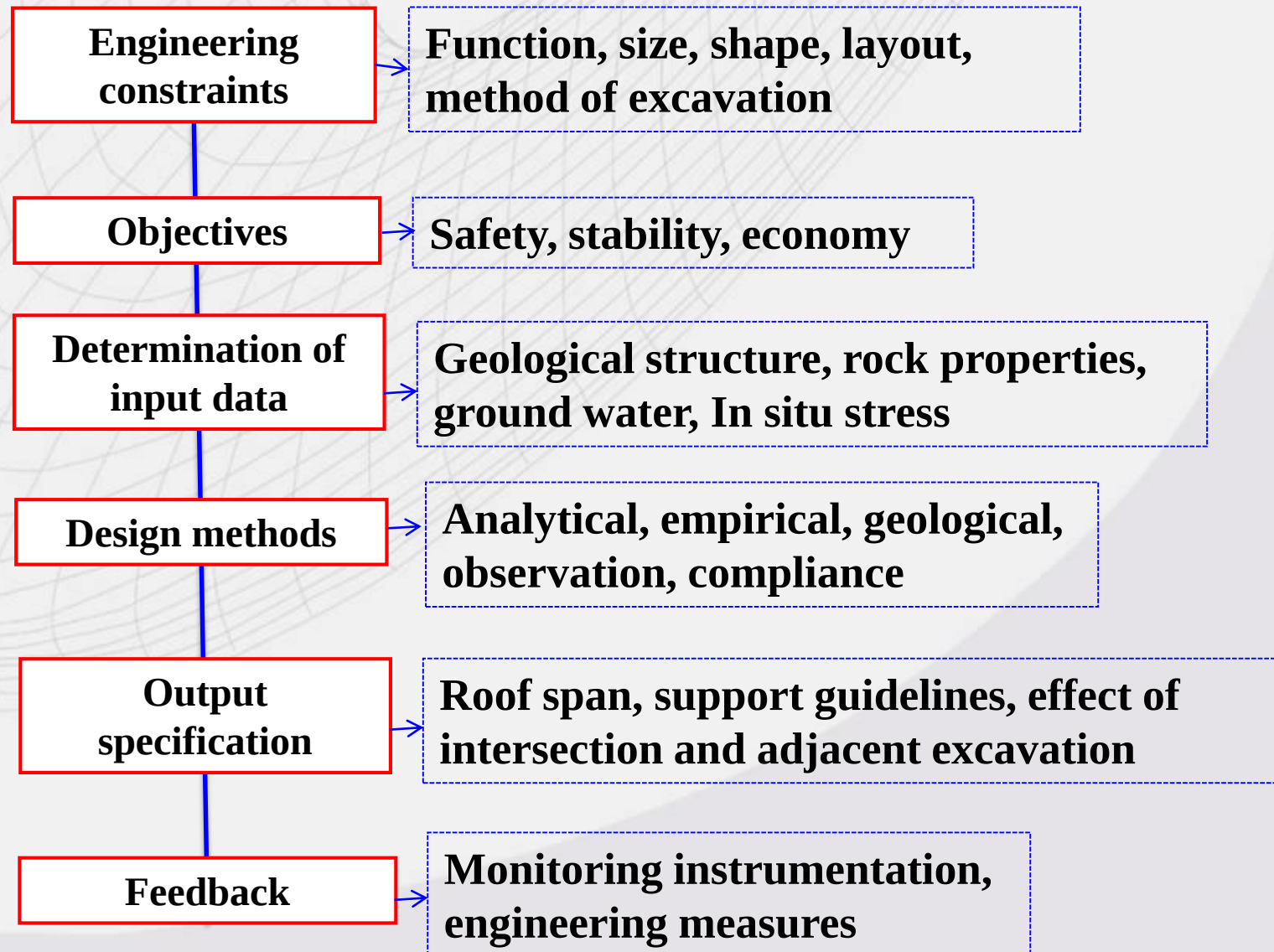
The convergence-confinement method (CCM, it is also called **rock support-interaction analysis**) is to design the rock support by determining the interaction point of rock action lines and support action lines.



Rock support design

- A given allowable deformation u_{max}
- Stiffness, K (support type)
- Installation time, or deformation (u_0)

Simplified design chart for tunneling



Input data

1. Geological structure:

- Site investigation, borehole logging, rock mapping

2. Rock properties

- Stiffness (Young's modulus, Poisson ratio)
- Strength (UCS, tensile strength, cohesion, friction angle)
- Uniaxial compression test, triaxial compression test, brazilian shear test, point load test, shear test, tension test, rock mapping

3. Ground water

- Site investigation, ground water monitoring

4. In situ stress

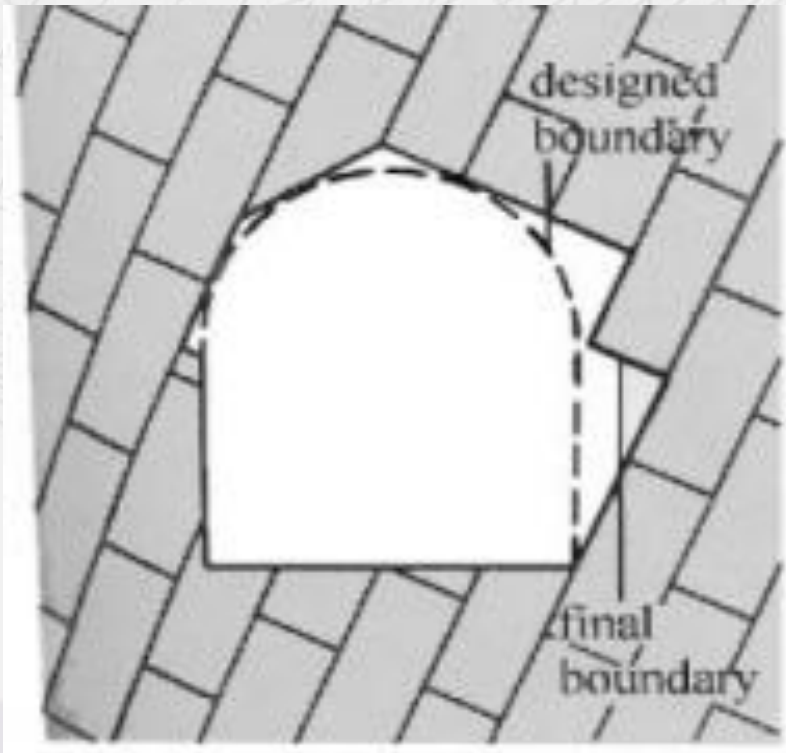
- Site investigation, stress measurement

Rock mass = intact rock + joints (Fractures)

From ISO (boundary b/n soil and rock)

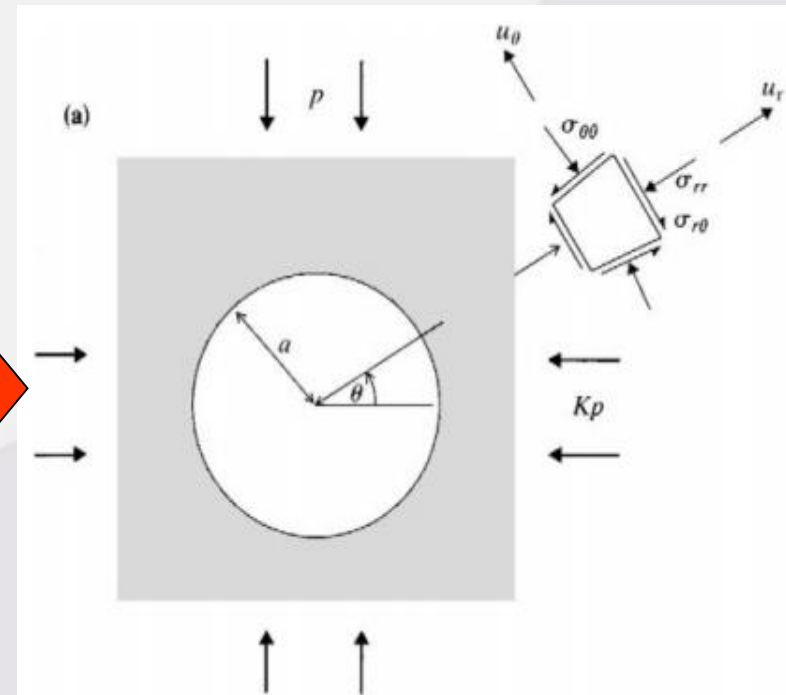
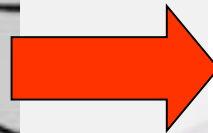
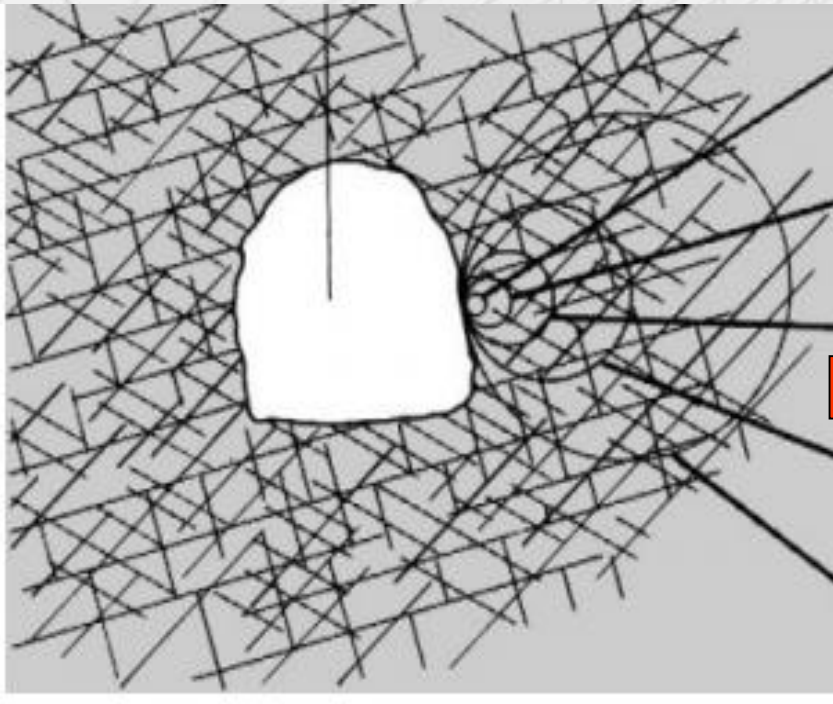
Rock: $UCS \geq 0.6 \text{ MPa}$

Soil: $UCS < 0.6 \text{ MPa}$

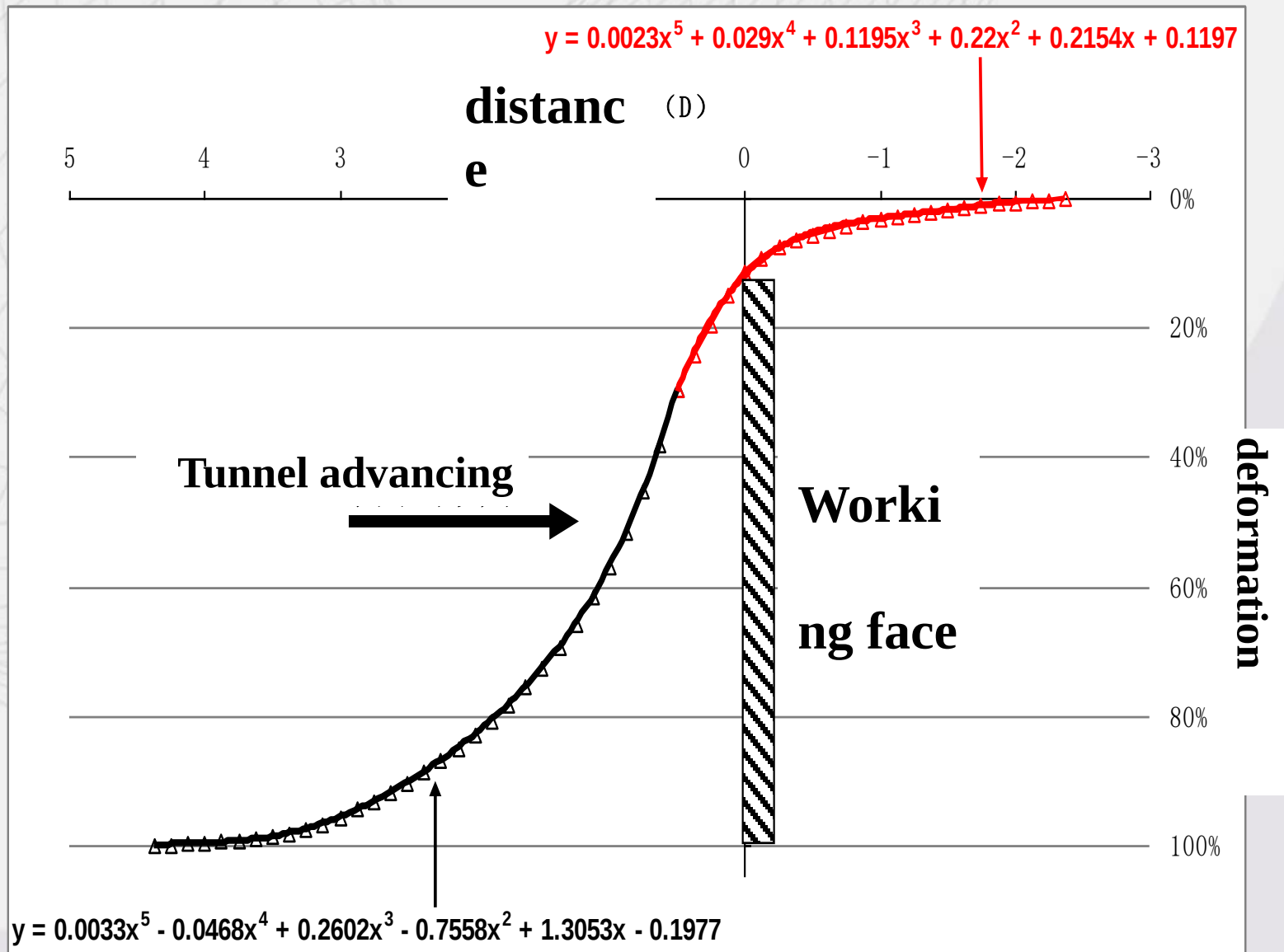


Assumptions in tunneling analysis

- Homogeneous
- Continuous
- Isotropic
- Elastic or, elastic ideal plastic but obey Mohr-Coulomb Criteria
- Circular tunnel
- Infinite overburden
- No water



Rock deformation changes along advancing



6.2 Tunneling techniques

- ✓ **NATM, New Austrian Tunneling Method**
- ✓ **NMT, Norwegian Method of Tunneling**
- ✓ **ITM, Informational Tunneling Method**

NATM

The New Austrian Tunneling Method (NATM) is a misnomer, as it is not a method of tunneling but a strategy for tunneling which does have a considerable uniformity and sequence.

The NATM is based on the philosophy of "**Build as you go**" approach with the following caution.

- **Not too stiff, Nor too flexible**
- **Not too early, Nor too late**

The New Austrian Tunneling Method (NATM) appears most *suitable for soft ground* which can be machine or manually excavated,

➤ **where jointing and over break are not dominant,**

➤ **Where a smooth profile can often be formed by smooth blasting and,**

➤ **where a complete load bearing ring can (and often should) be established.**

Basic principles of NATM are:

- Mobilization rock mass strength,
- Rock bolt and shotcrete protection (**soft support**) to preserve the load-carrying capacity of the rock mass,
- Monitoring the deformation of the excavated rock mass,
- Providing flexible but active supports, and
- Closing of invert to form a load-bearing support ring to control deformation of the rock mass.

NMT

Norwegian Method of Tunneling (NMT)

NMT appears **most suitable for good rock** even where jointing and over break are dominant, and where drill and blasting method or hard rock TBM's are the most usual methods of excavation.

Bolting is the dominant form of rock support since it mobilizes the strength of the surrounding rock mass in the best possible way.

It is understood in NMT that **$[B+S(fr)]$** are the two most versatile tunnel support methods, yet devised and used extensively, because they can be applied to any profile as temporary or as a permanent.

ITM

ITM (Informational Tunneling Method) has become the dominant method in tunneling. It combines advantages from NATM, NMT, etc. and adopts new development in modern technologies to collect informational data during the tunneling.

- ✓ Geological data
- ✓ Rock deformation data
- ✓ Rock support stress
- ✓ Construction quality data
- ✓ Environmental data (gas density, working face monitoring, etc.)
- ✓ Other data

Quiz

Shallow overburden/cover has a drawback in tunneling technique. Explain why?

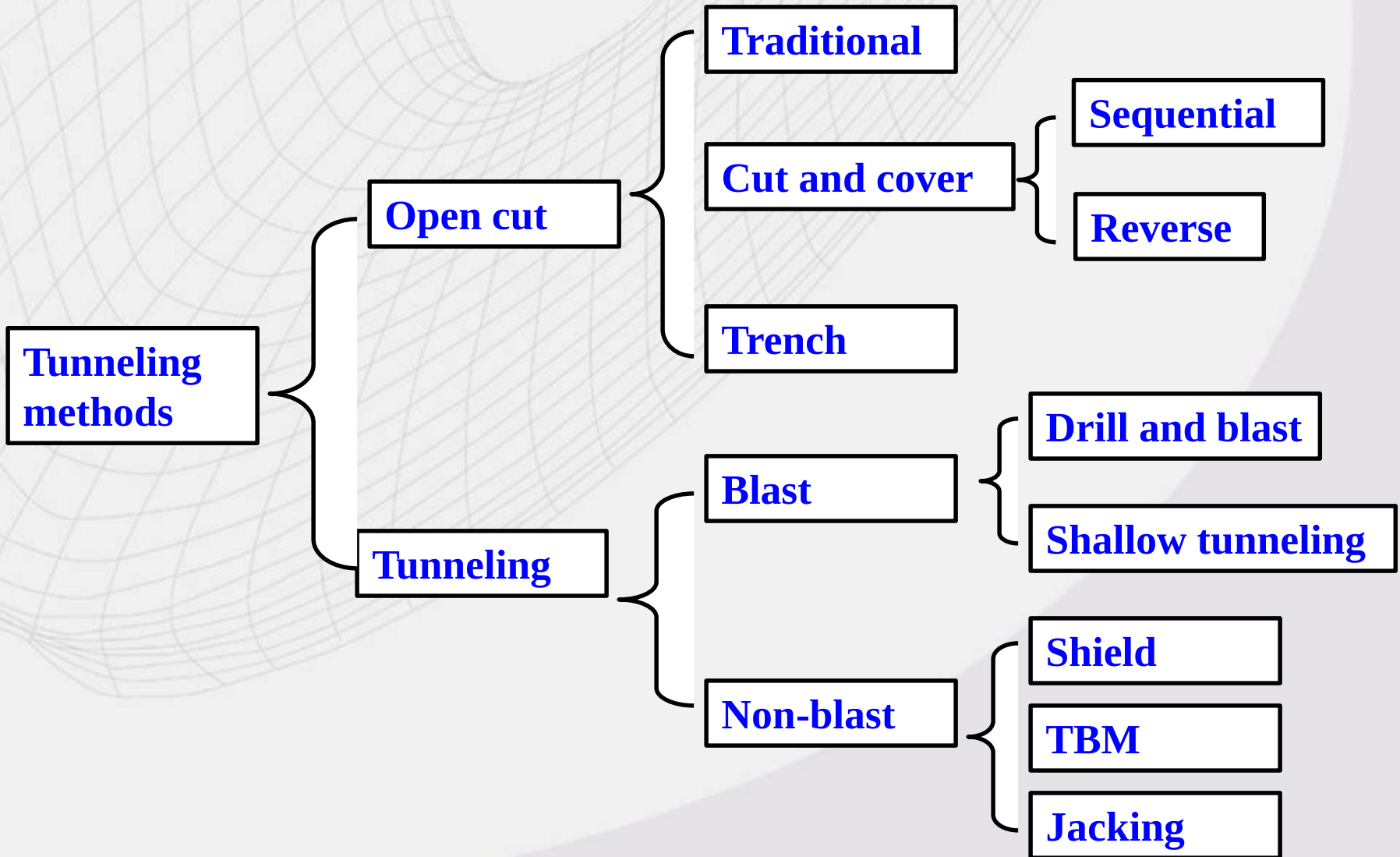
Tunnel construction techniques

1. Open cut
2. Tunneling

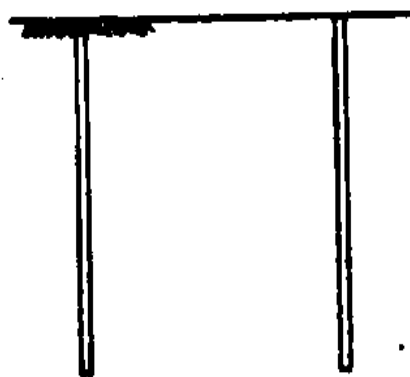
Summary

Features of tunneling:

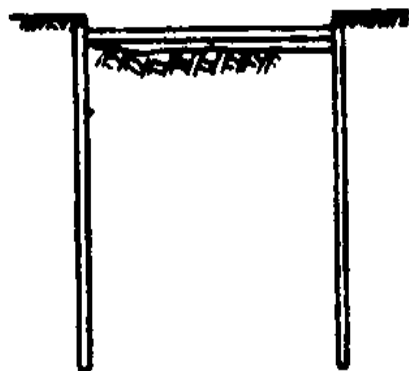
- *Tunneling method changes with geological condition;*
- *Less working face, usually 2 working faces only;*
- *Narrow working space, more disturbances to each other;*
- *Poor construction environment, poor air quality, dark, wet;*
- *Difficult in repair during operation.*



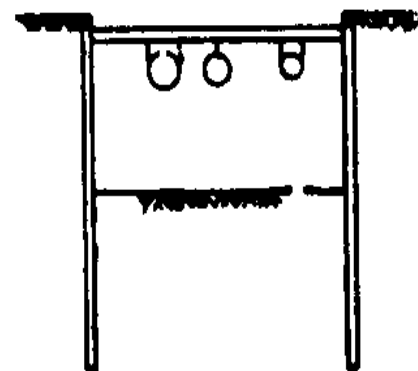
Open cut sequence



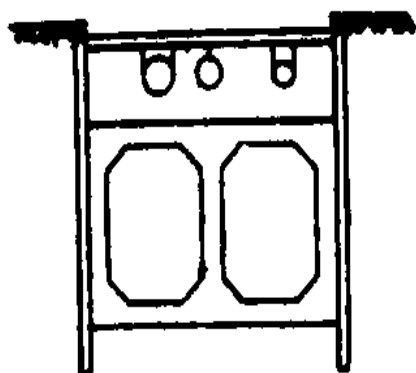
a 打桩



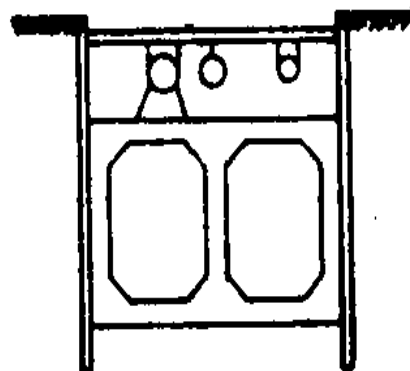
b 路面开挖



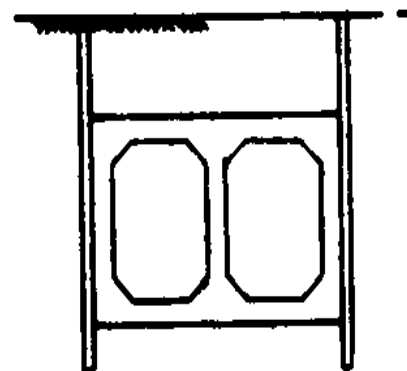
c 埋设物支承防护和开挖



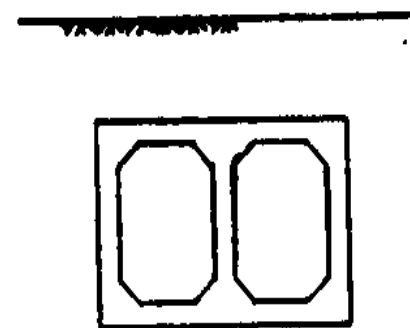
d 结构施工



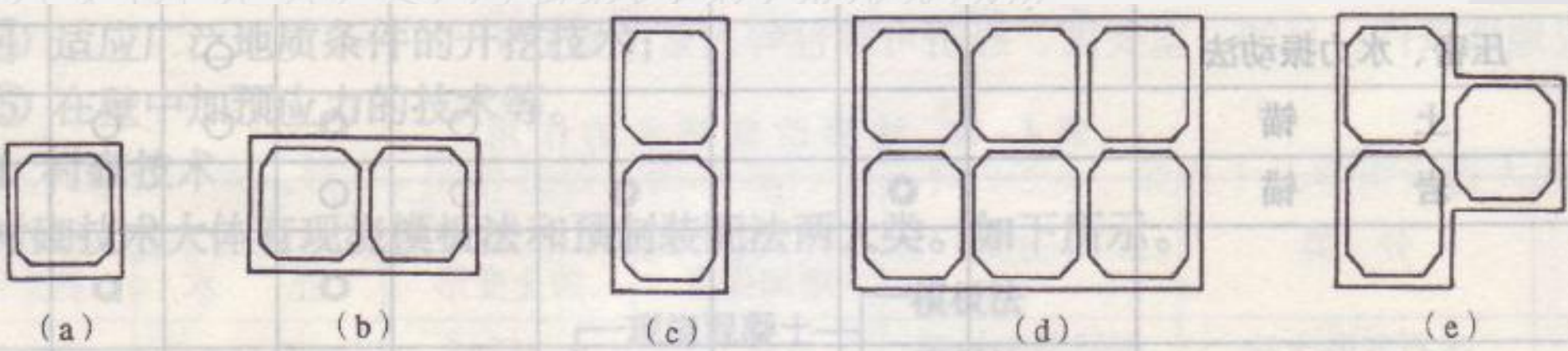
e 埋设物支承修筑



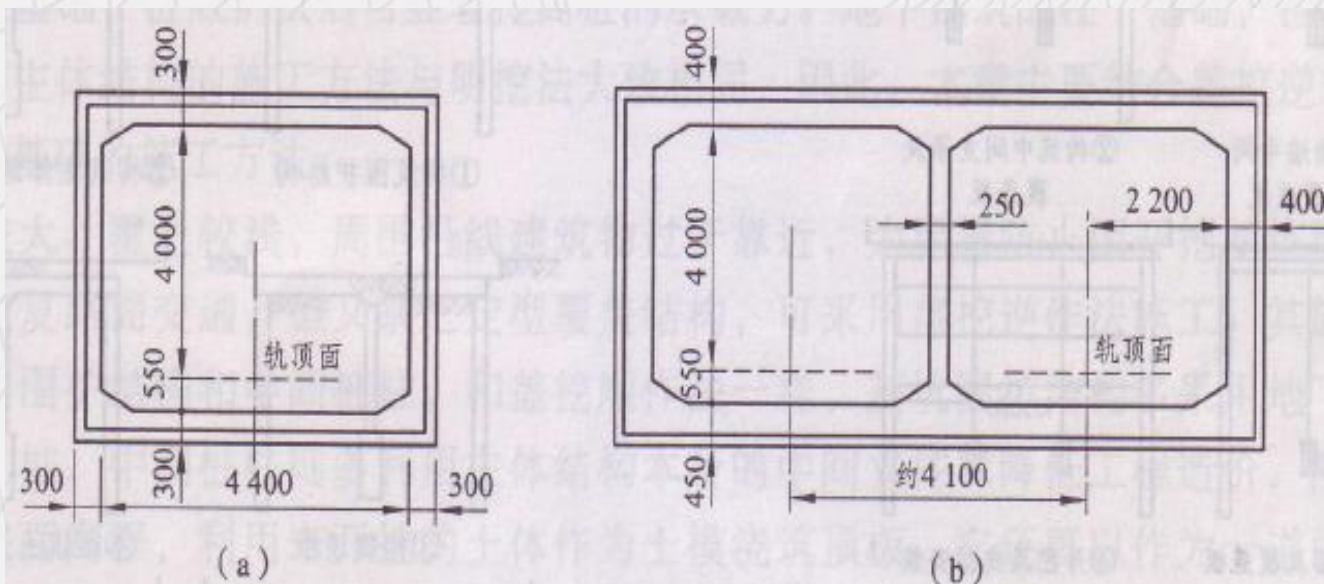
f 回填



g 拔桩, 恢复路面

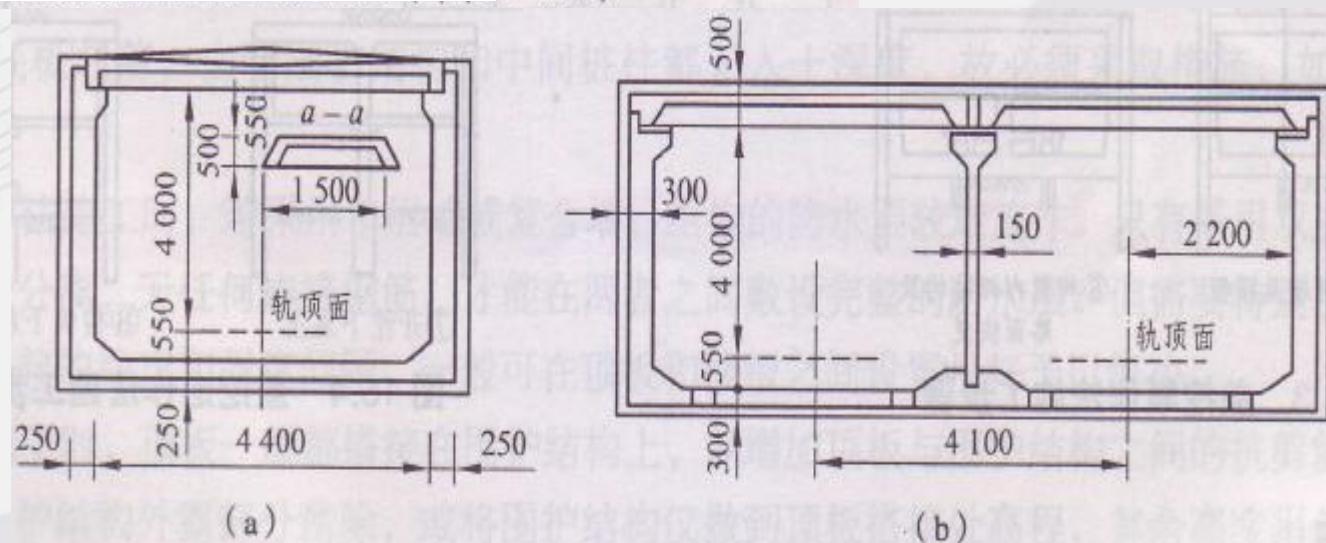


type of tunnel sections



cast lining

: mm)



assembly lining

: mm)

Cut and cover

Sequential

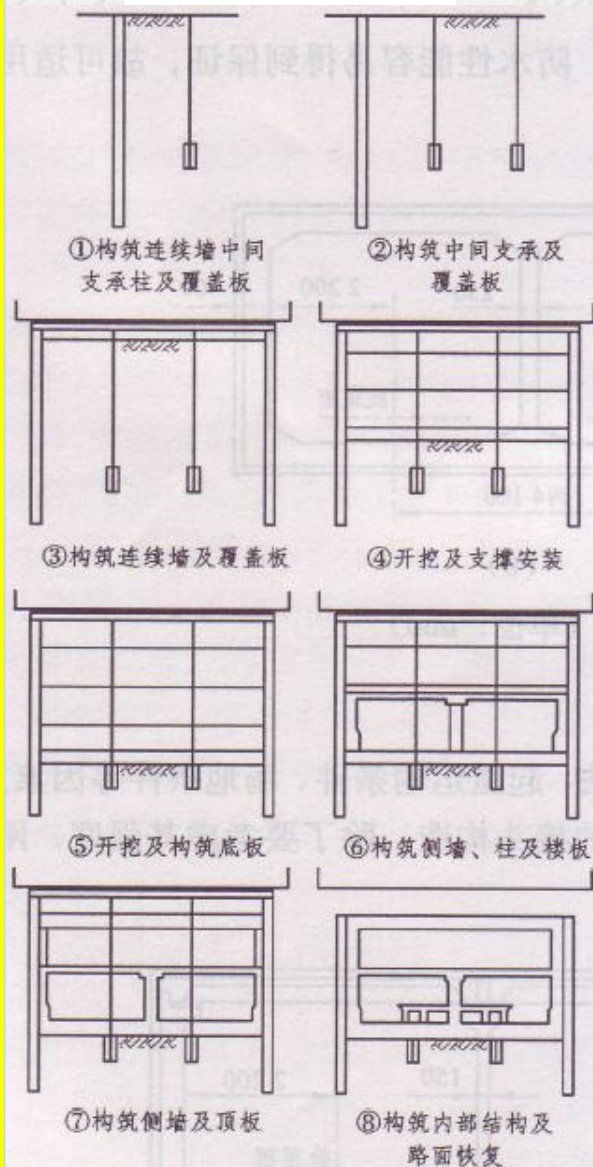


图 15.3 盖挖顺作法施工步骤

Reverse

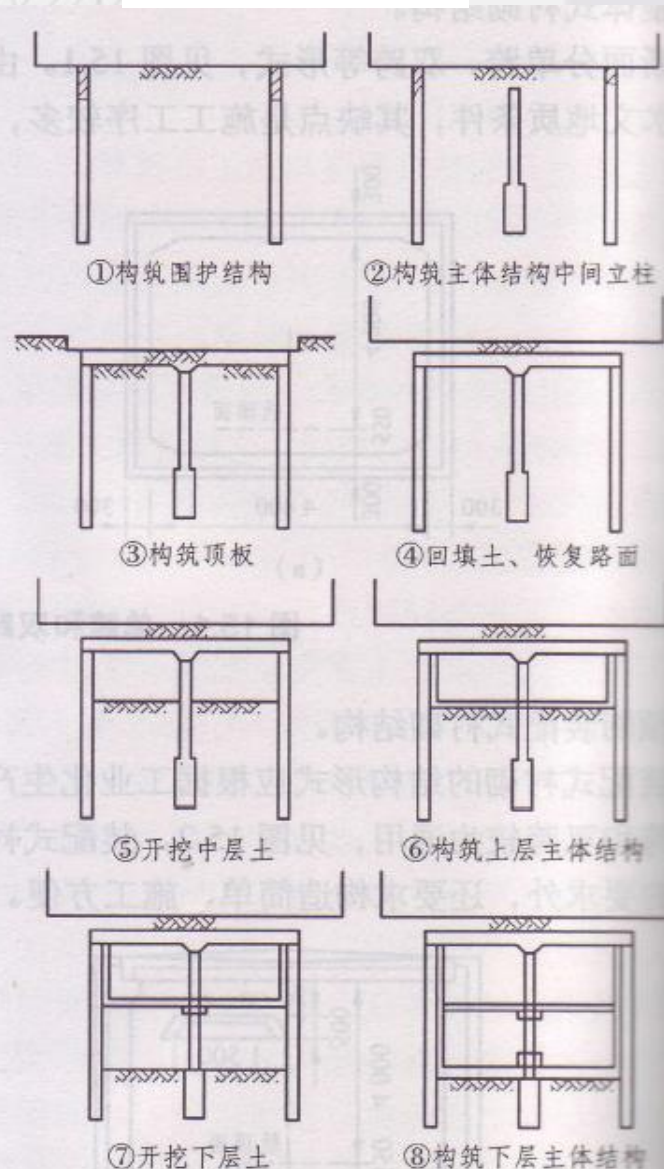


图 15.4 盖挖逆作法施工步骤

The reverse cut & cover method is applicable:

- There are important building or structures nearby;
- A big horizontal pressure;
- A deep excavation;
- A quick close.

Partial excavation

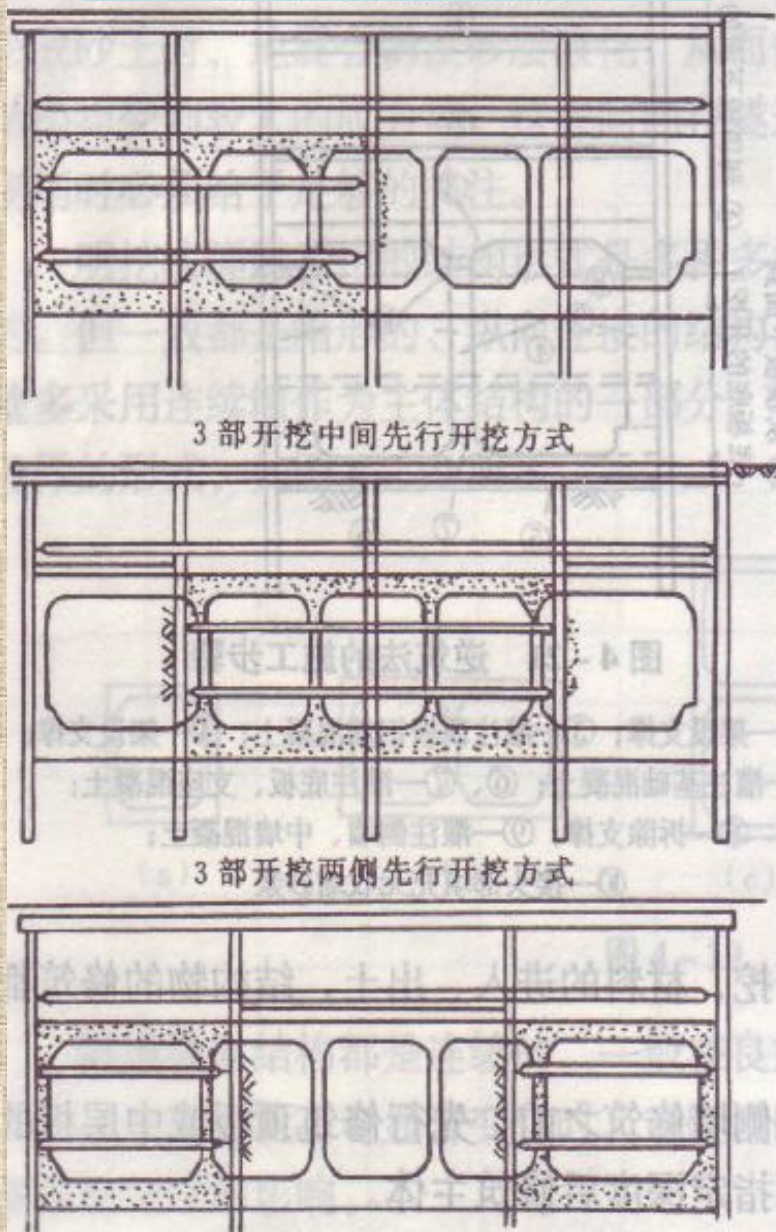


图 4-22 分部开挖法的种类



Partial excavation

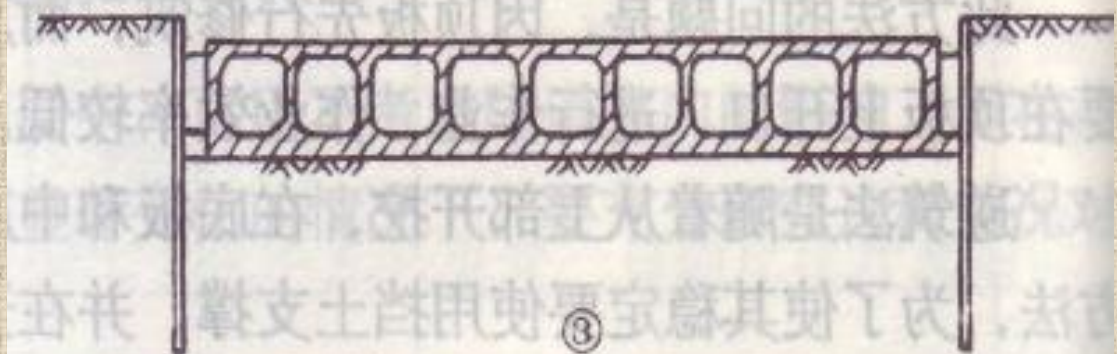
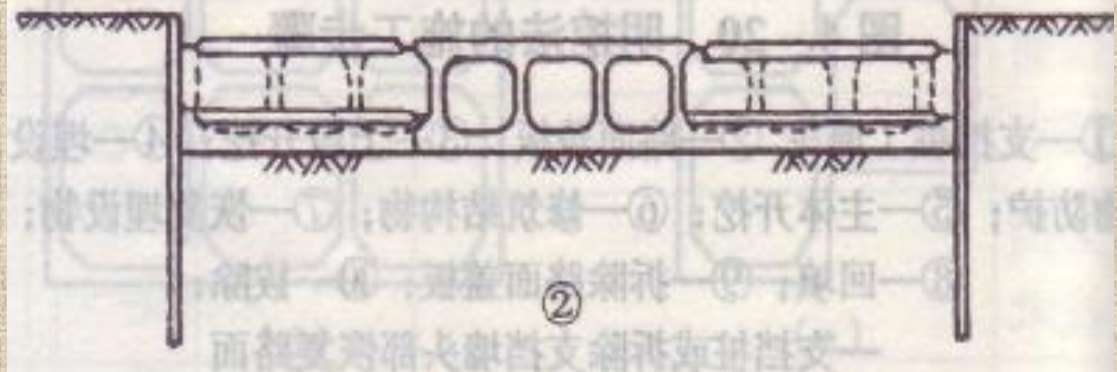


图 4-23 施工顺序

Trench method

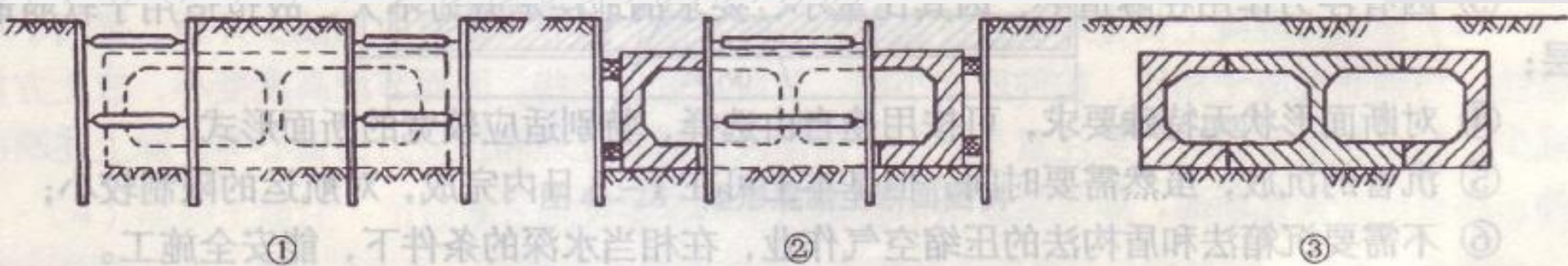


图 4-24 明挖式沟槽法的施工顺序

Immersed tube tunnel sections

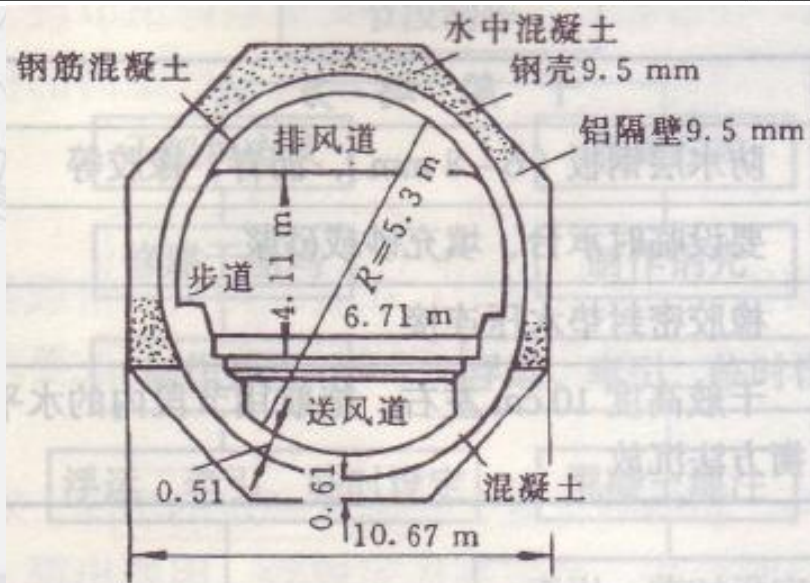
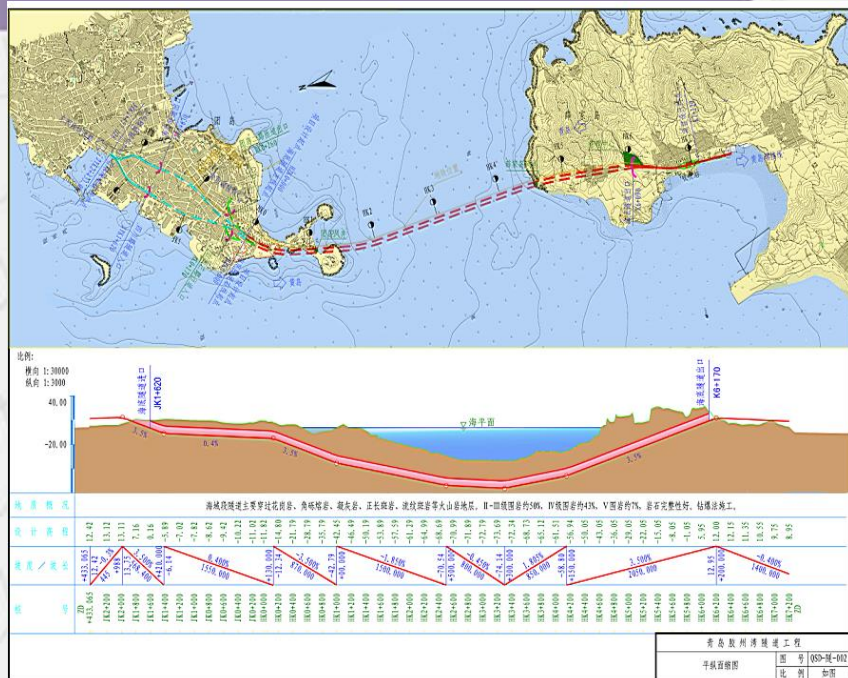


图 4-26 圆形钢壳断面图例

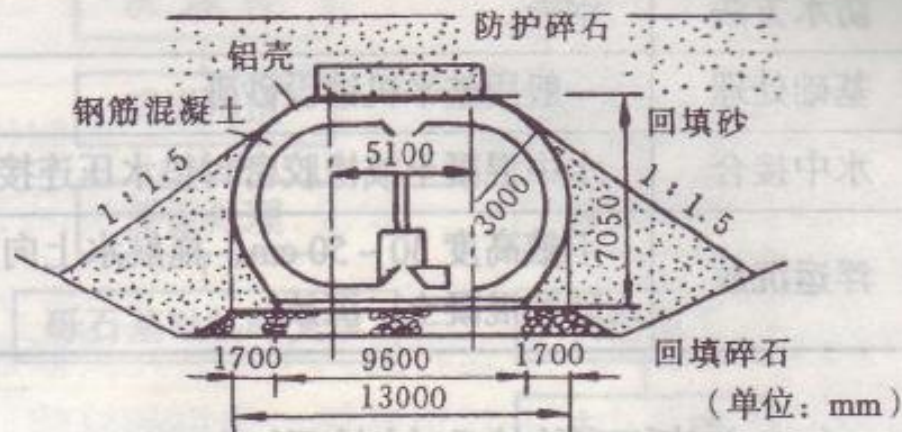


图 4-27 圆形钢壳断面图例

Chapter 6

Part II - Railway Bridges

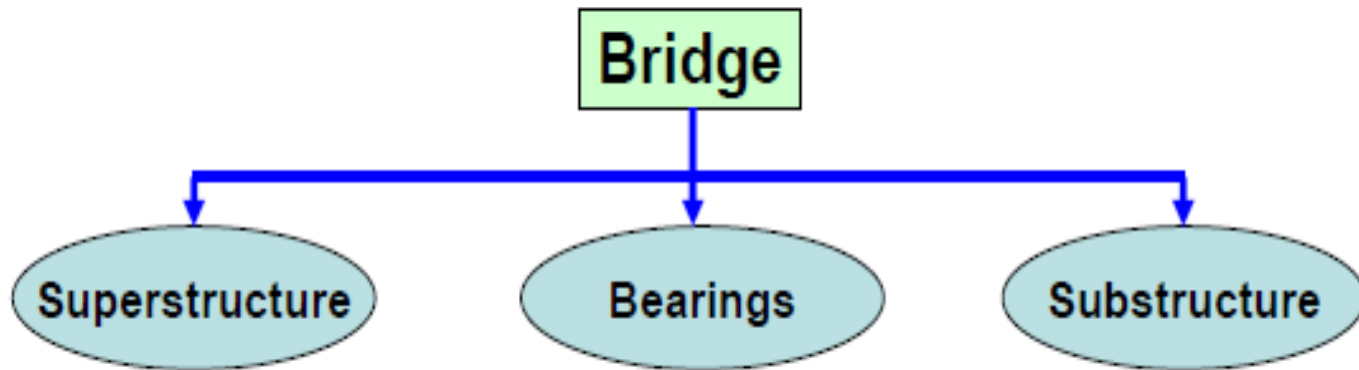
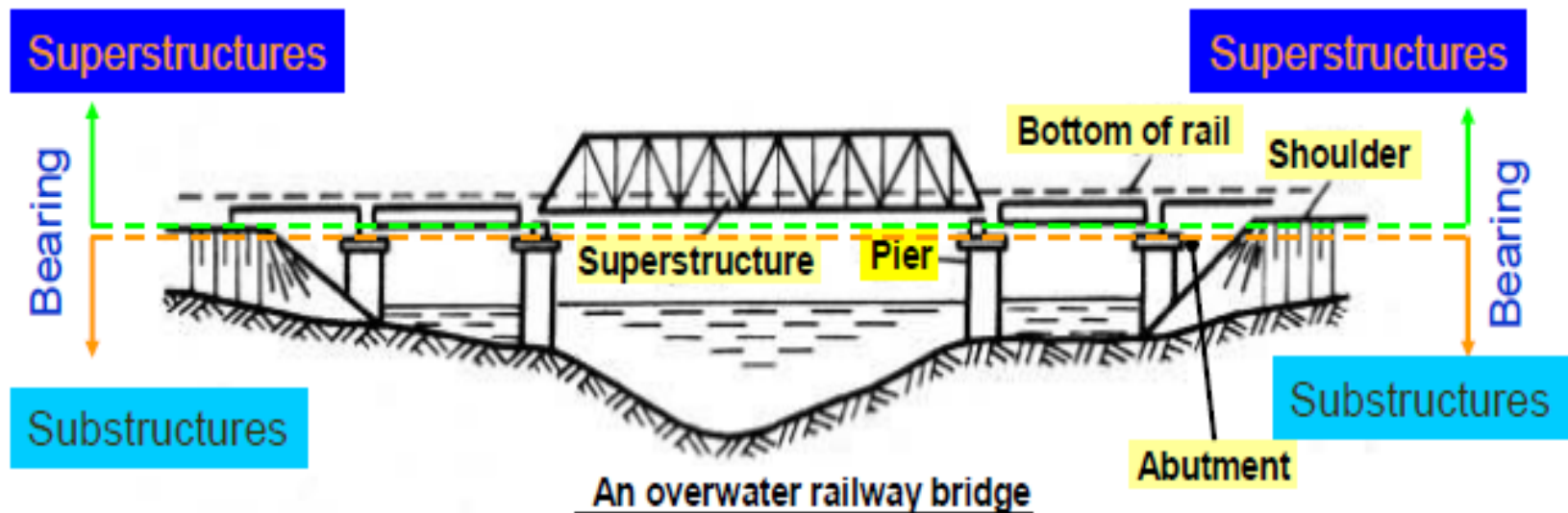


Build a bridge, then you will have friends!



Layout and components Railway Bridge

- A layout of a typical railway bridge



Introduction to Railway Bridge

Use and Functionality

- **Superstructure**: comprises all the components of a bridge above the supports
 - Girders, truss, arch, etc.
- **Substructure**: consists of all elements required to support the superstructure and overpass roadway
 - Piers, abutments, foundations, etc.
- **Bearings**:
 - To transmit loads from the superstructure to the substructure, and
 - To accommodate relative movements between the superstructure and the substructure.

Bridge components: use and functionality

(1) Functions

function: *be convenient for the train to cross over the river and the valley or other buildings.*

Types based on function:

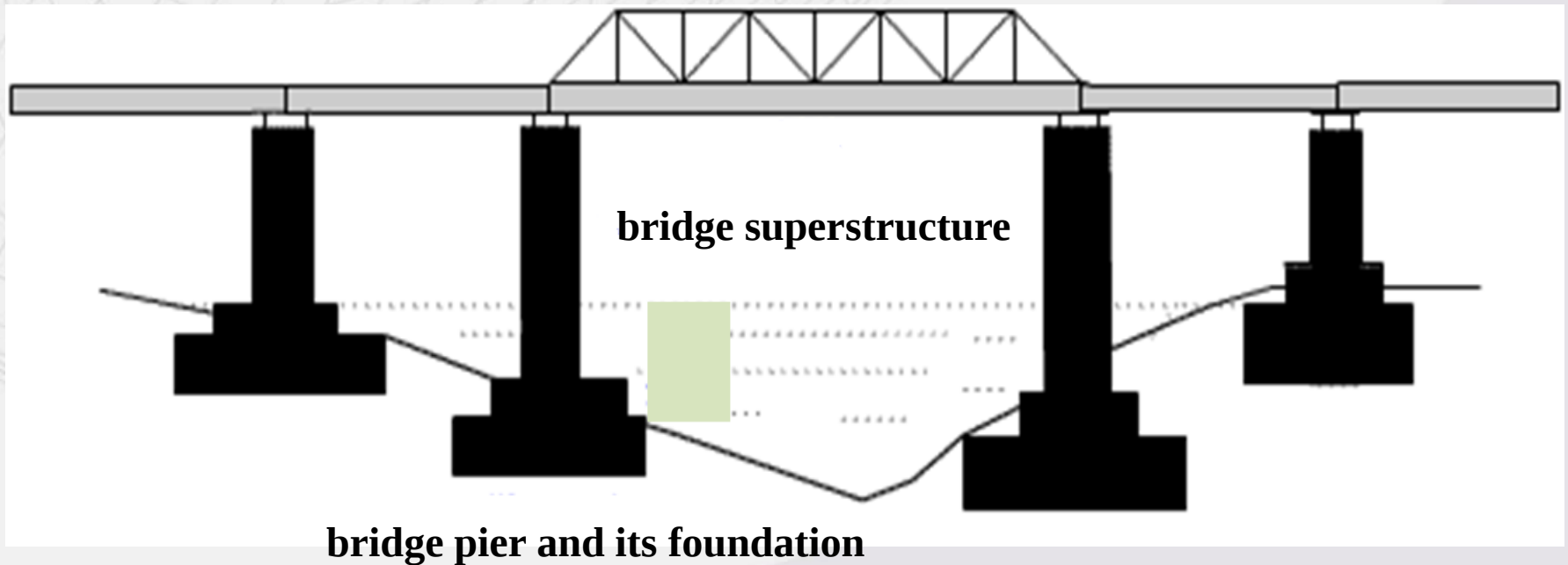
- *bridges cross over the river*
- *bridges cross over the valley*
- *bridges cross over the line or highway*
- *bridges cross over the downtown, industrial estate or crop area*



Bridge components: use and functionality

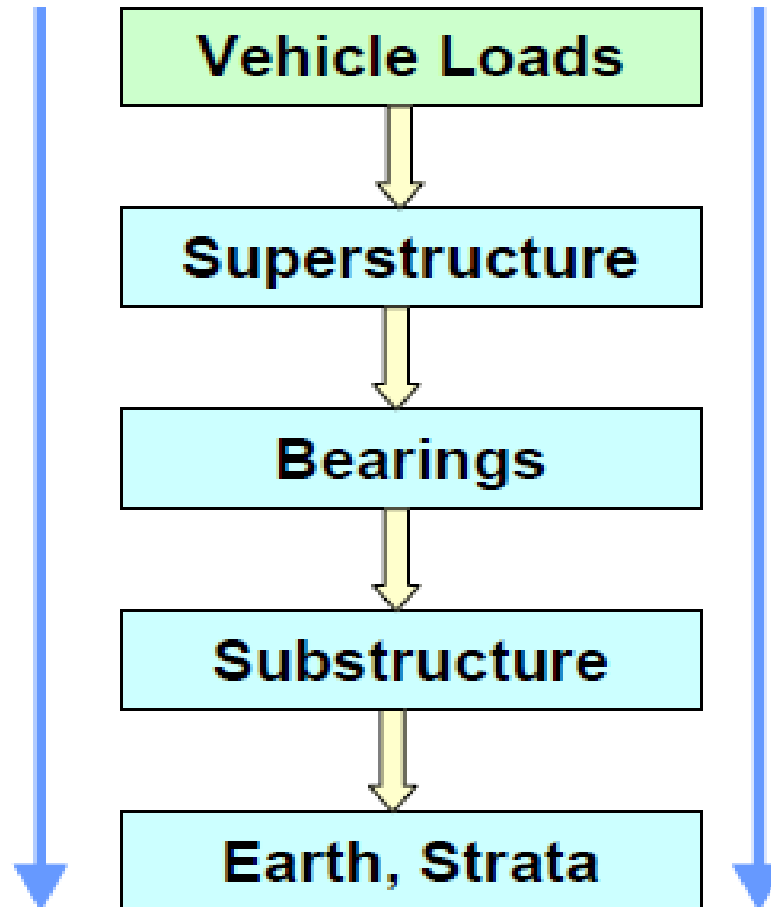
(2) The structure

It includes: *bridge floor, bridge superstructure, bridge pier and its foundation.*



Bridge components: use and functionality

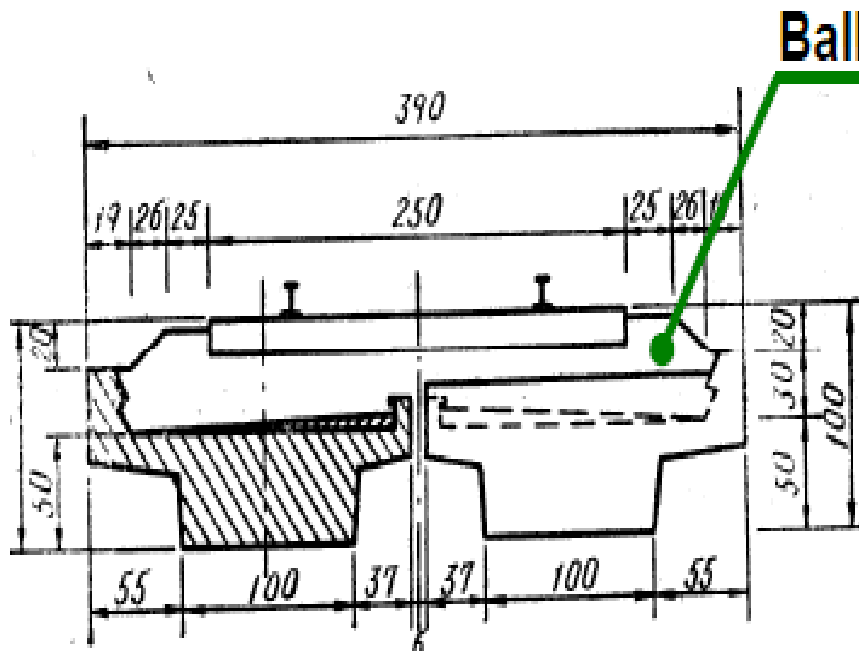
Load Transfer



Bridge components: use and functionality- *Deck Configuration*

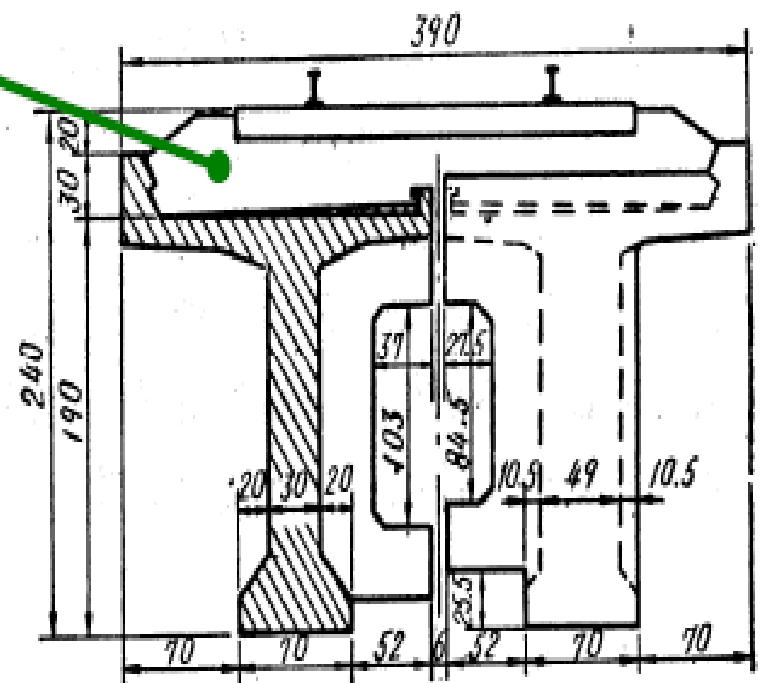
Deck Configuration

Deck Configuration (1): Conventional deck (in China)



Concrete Slab Bridges (Unit: cm)

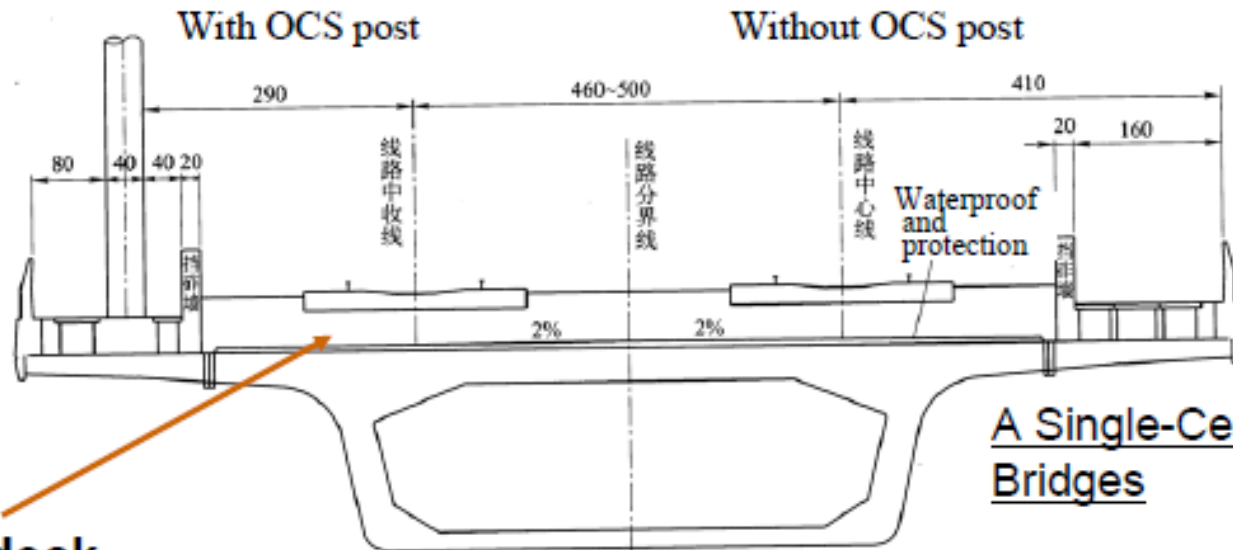
Ballast



T-Beam Bridges (Unit: cm)

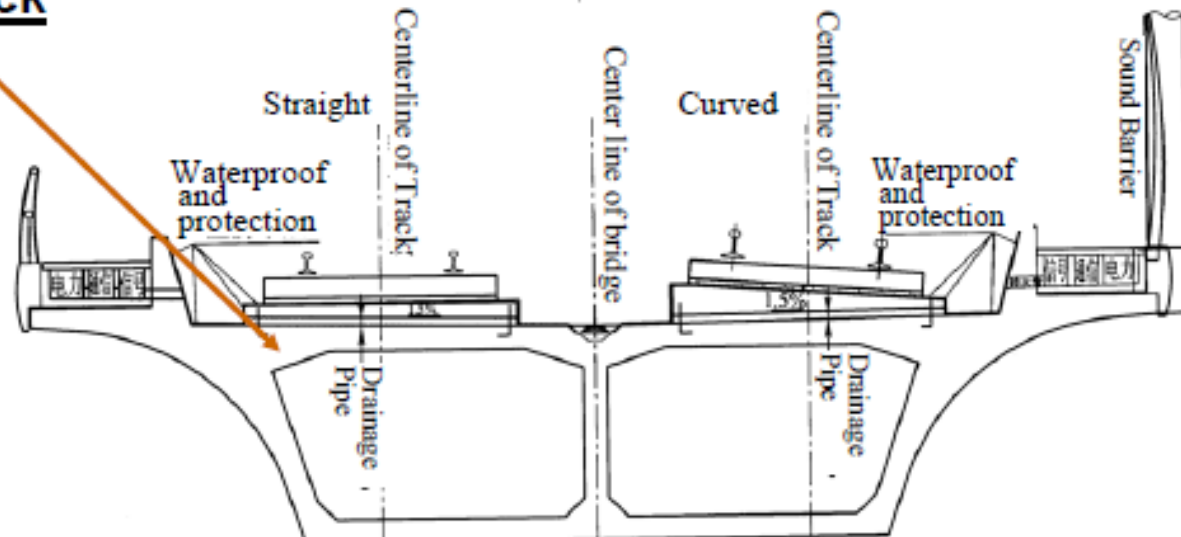
Bridge components: use and functionality

Deck Configuration (2): High-Speed-Rail bridge deck (in China)



A Single-Cell Box Girder Bridges

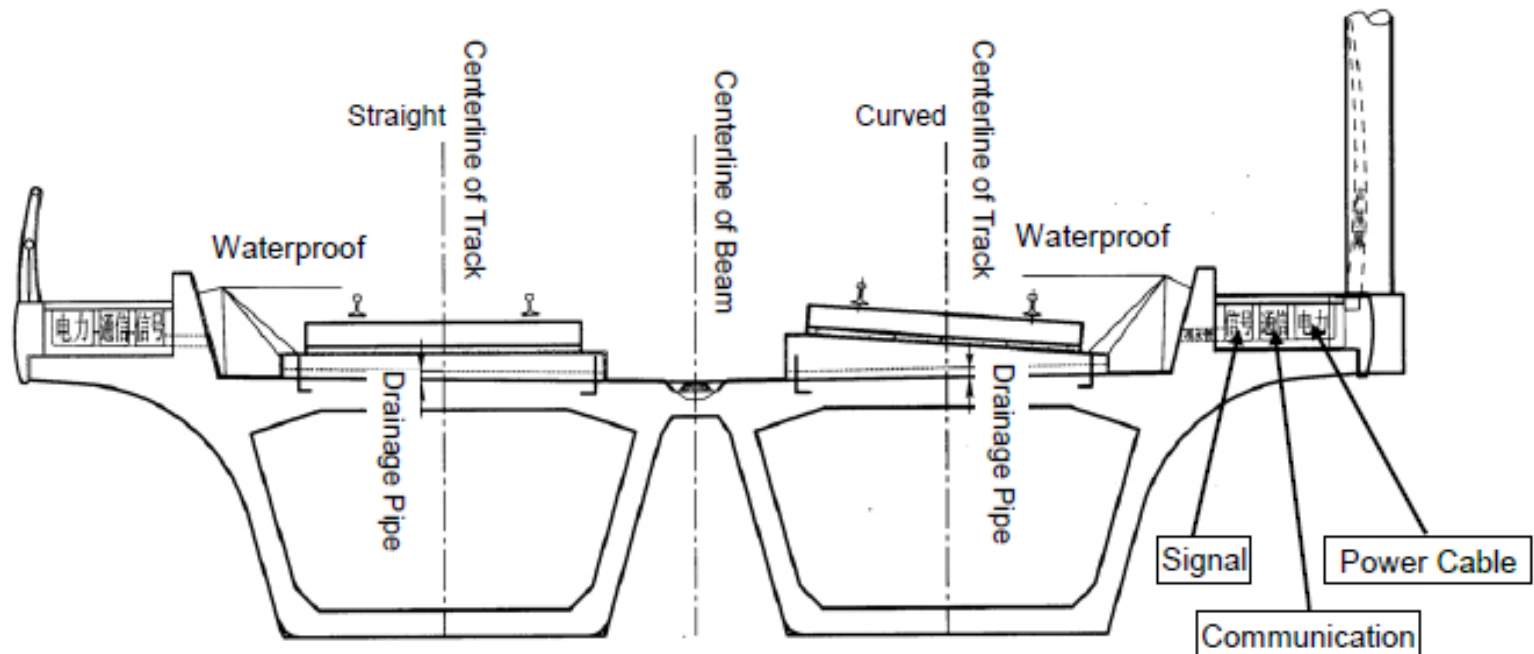
Ballastless deck



Bridge components: use and functionality

Deck Configuration (3): High-Speed-Rail bridge deck (in China)

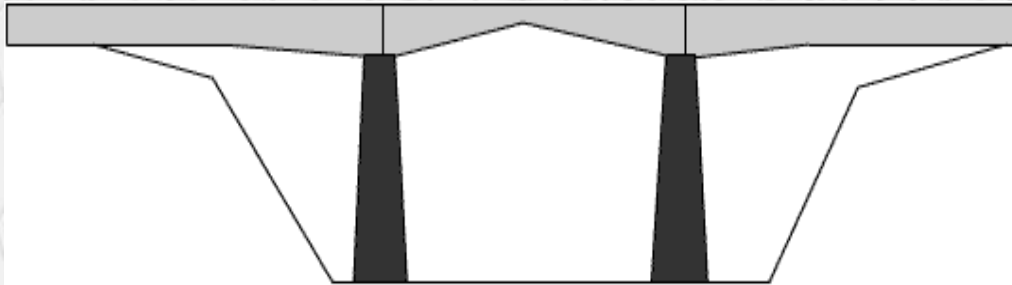
Ballastless deck



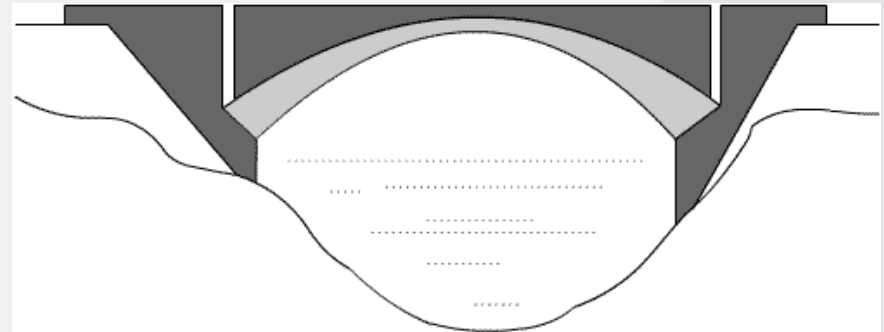
Multi-Box Girder Bridges (two boxes with single cell each)

Bridge components: use and functionality

(3) Types of bridges

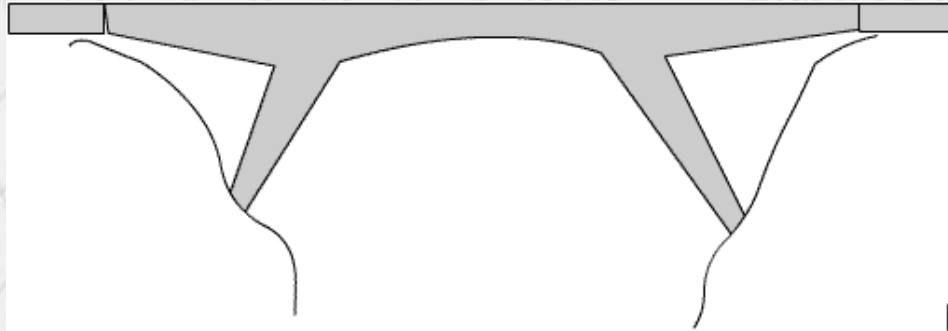


1) beam bridge

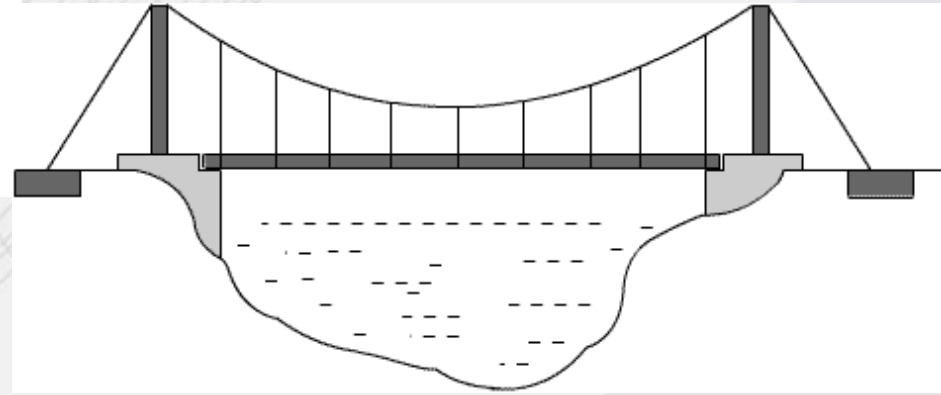


2) arch bridge

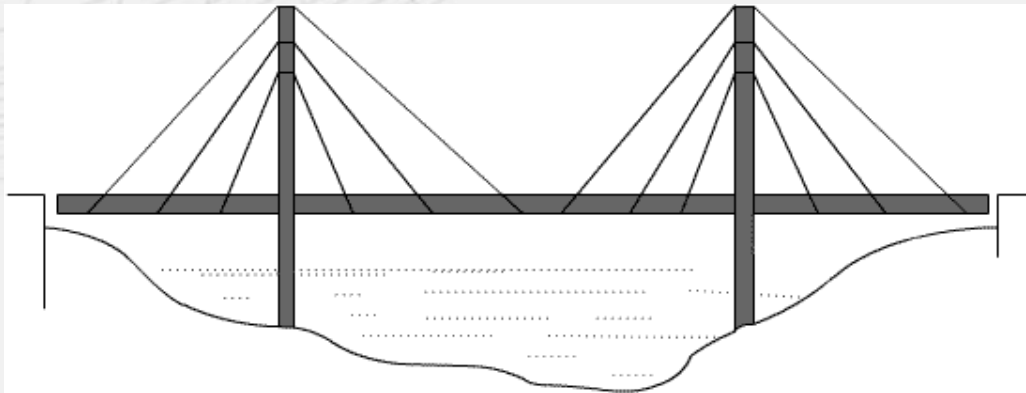
Bridge components: use and functionality



3) rigid frame bridge



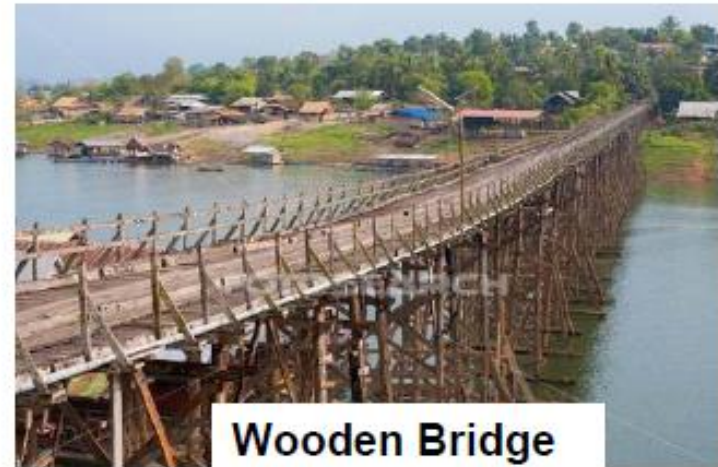
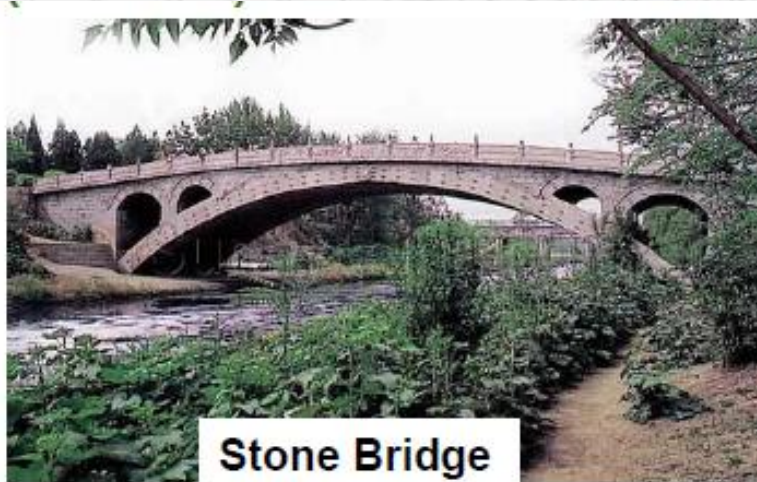
4) suspension bridge



5) combined system bridge

Bridge components: use and functionality

Based on Material Type



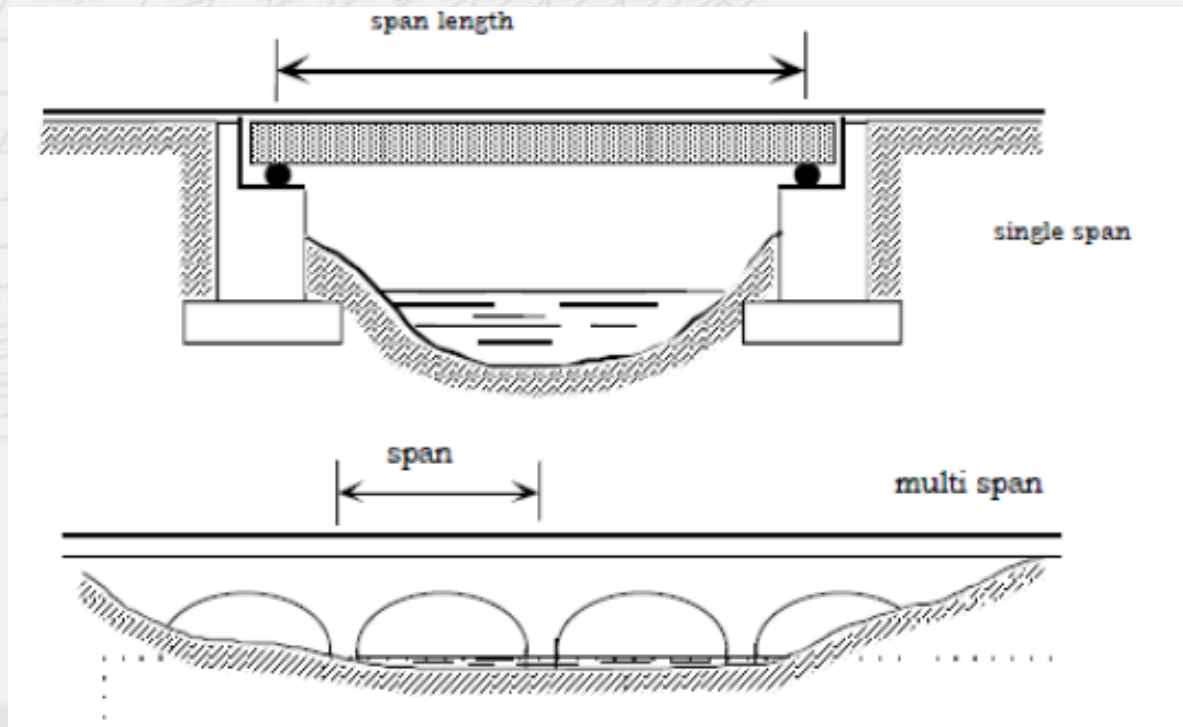
Bridge components: use and functionality

Based on Span Length

Short Bridges: 6-30m

Medium Bridges 30-100m

Long Bridges $> 100\text{m}$



Types of Bridges

According to whether the main structure is below, above, or coincides with the deck line.

- ❖ Main Structure Below the Deck Line

Arch Bridges

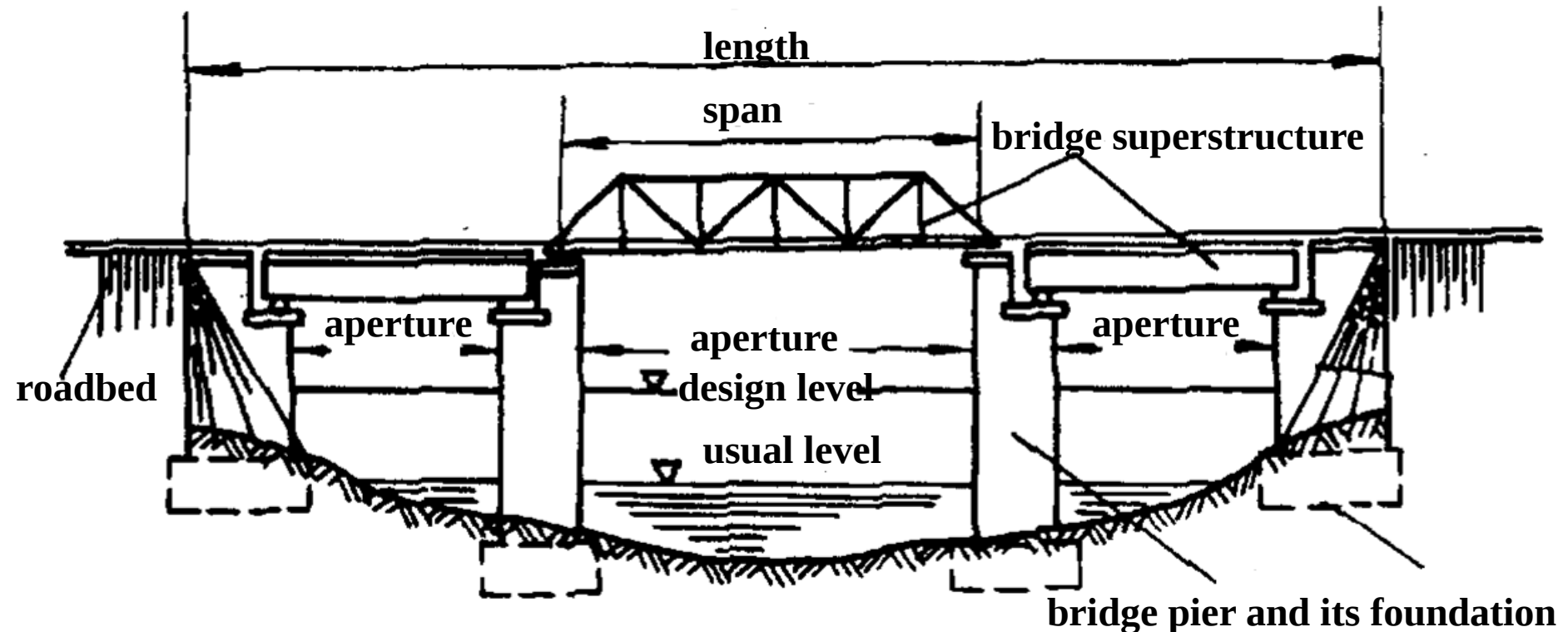


New River Gorge Bridge, West Virginia

- ❖ Main Structure above the Deck Line
- ❖ Main Structure Coincides with the Deck Line

(4) Index of bridge design

- 1) **length**—distance between two sides' retaining wall
- 2) **Span**—distance between two support point of bridge superstructure
- 3) **Aperture**—distance between two bridge superstructures on the design level
- 4) **Clearance** - vertical height from the design level to the bottom of bridge floor

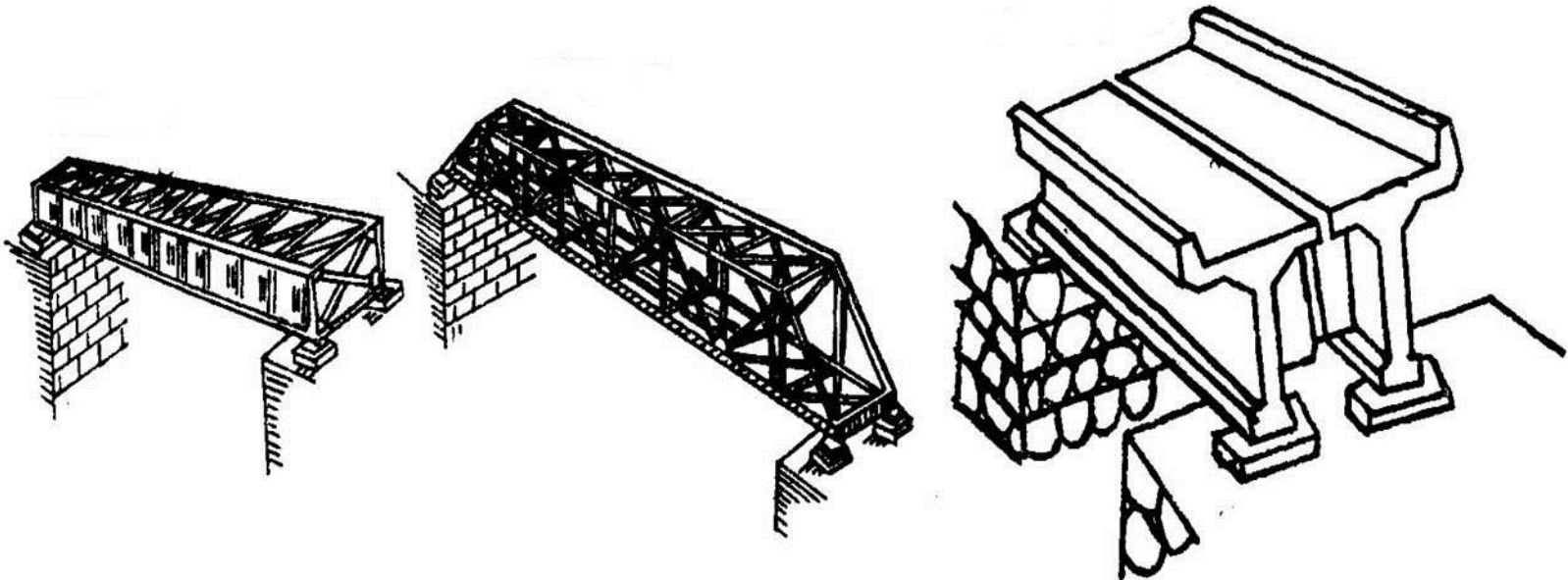


Bridge components: use and functionality

(4) structures of bridge superstructure

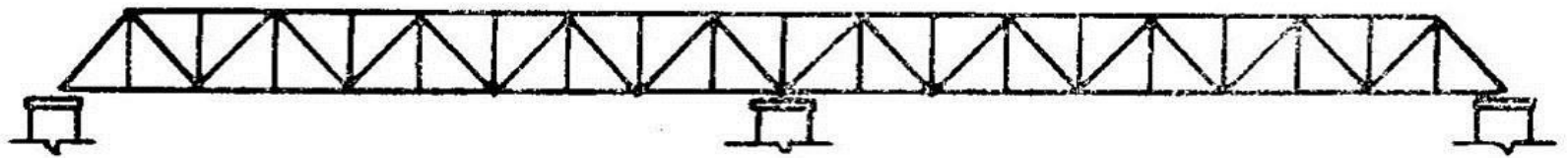
1) beam structure

① simply supported beam—one hole and one beam

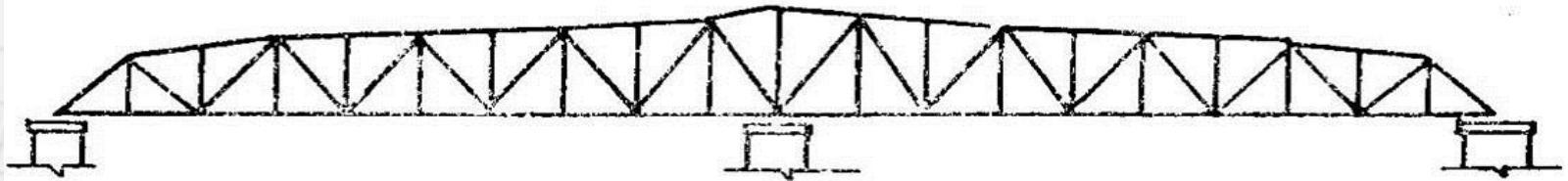


Bridge components: use and functionality

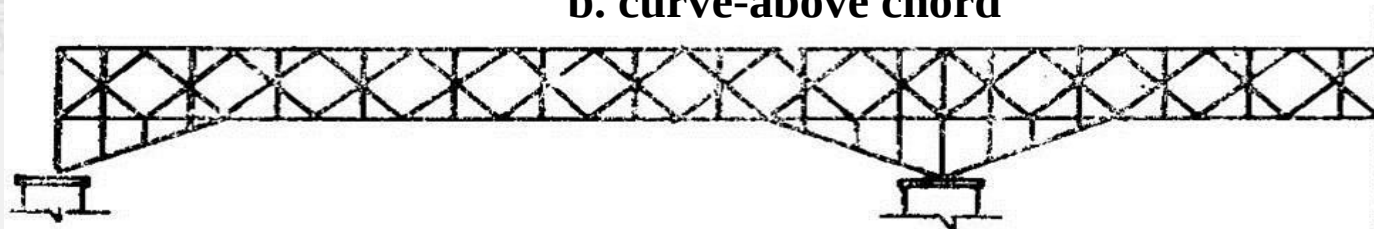
② continuous beam—one beam with many holes



a. parallel chord



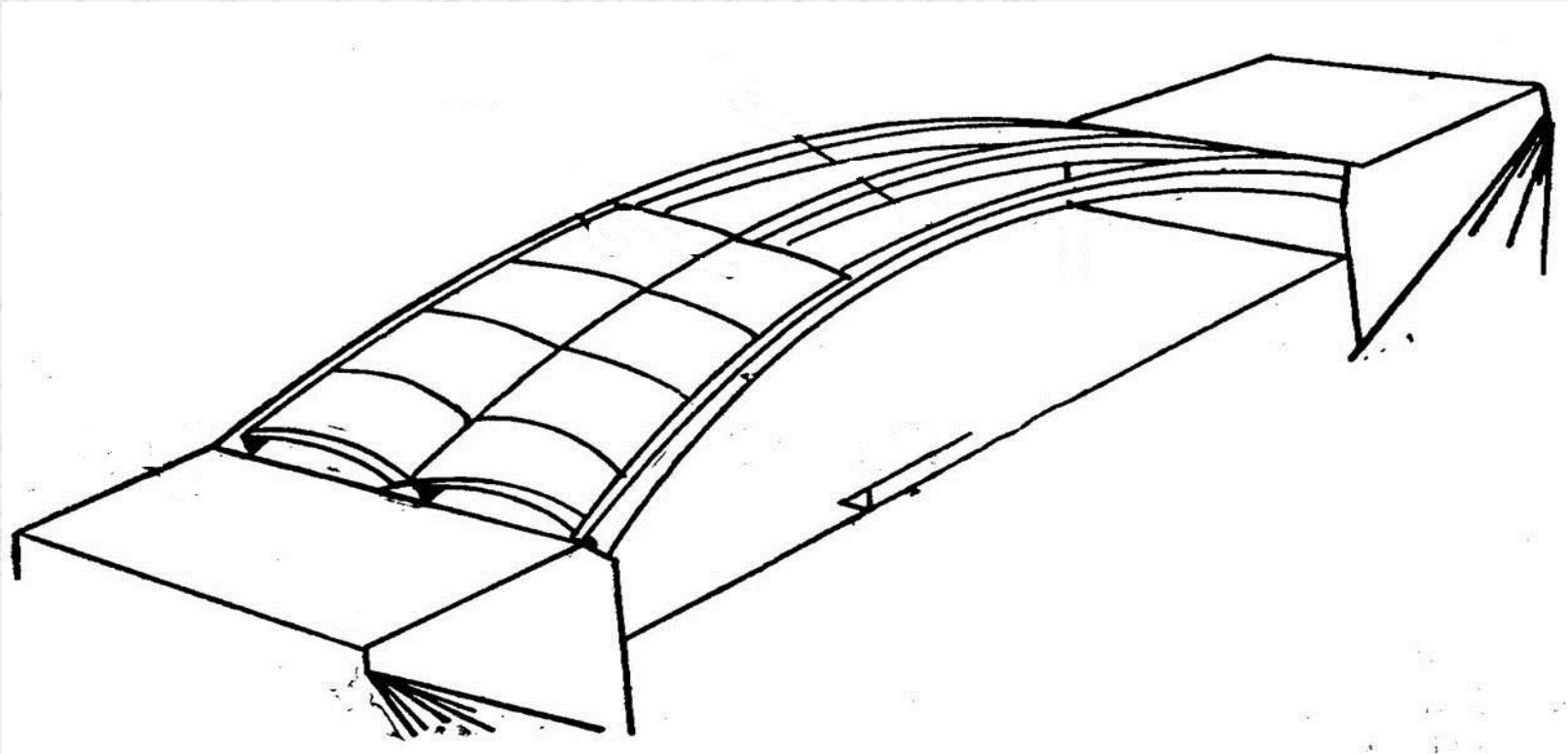
b. curve-above chord



c. curve-below chord

Bridge components: use and functionality

2) arch structure



Bridge components: use and functionality

① Force Analysis

Q- load

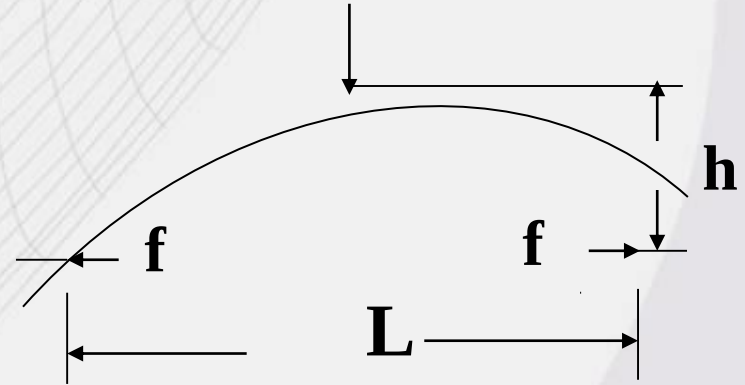
f -horizontal resistance

F -rise-span ratio: $F = h / L$

L -span

h -vector

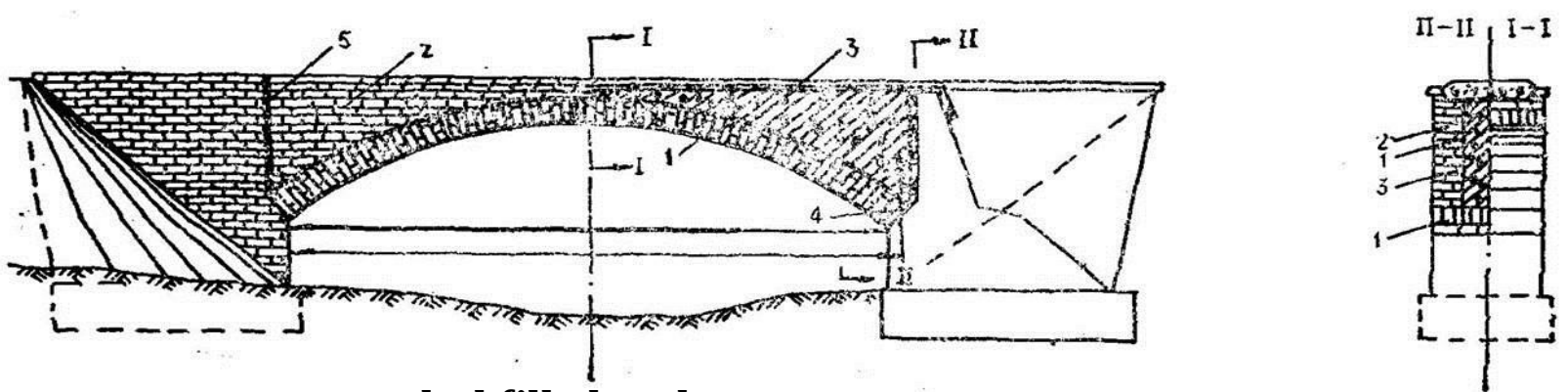
$F \leq 1/6$ is jack arch; $F > 1/6$ is steep arch



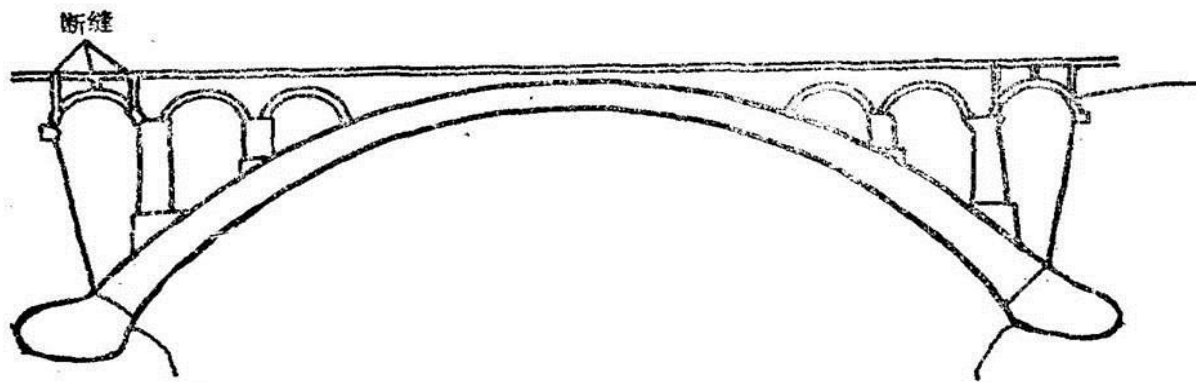
- ② can use materials which has great resistance to pressure and not easy be stretched.
- ③ demand higher requirements for geological conditions.

Bridge components: use and functionality

- ⑤ According to the structure, it can be divided into spandrel filled arch and open spandrel arch.



spandrel filled arch



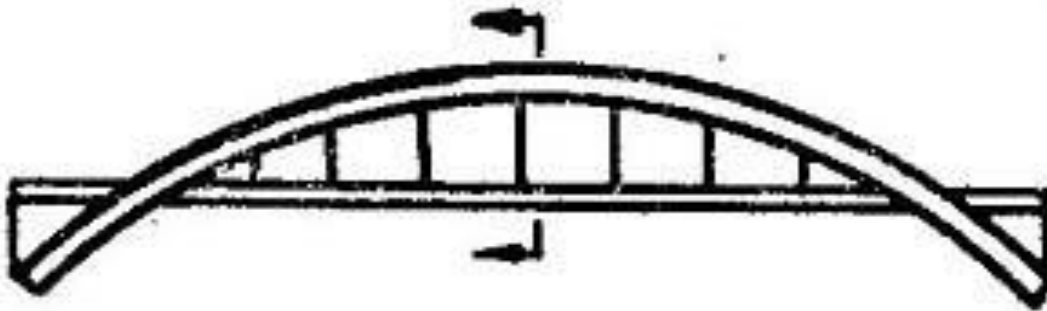
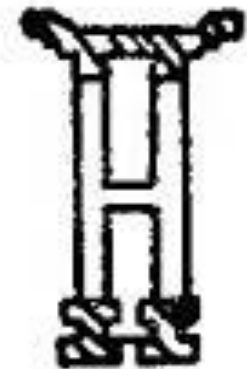
open spandrel arch

Bridge components: use and functionality

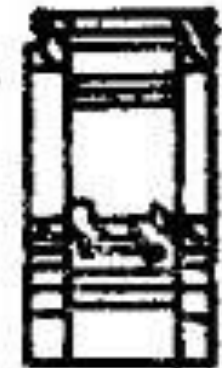
According to force support, it can be divided into *above-support, middle-support and below-support*.



(a)

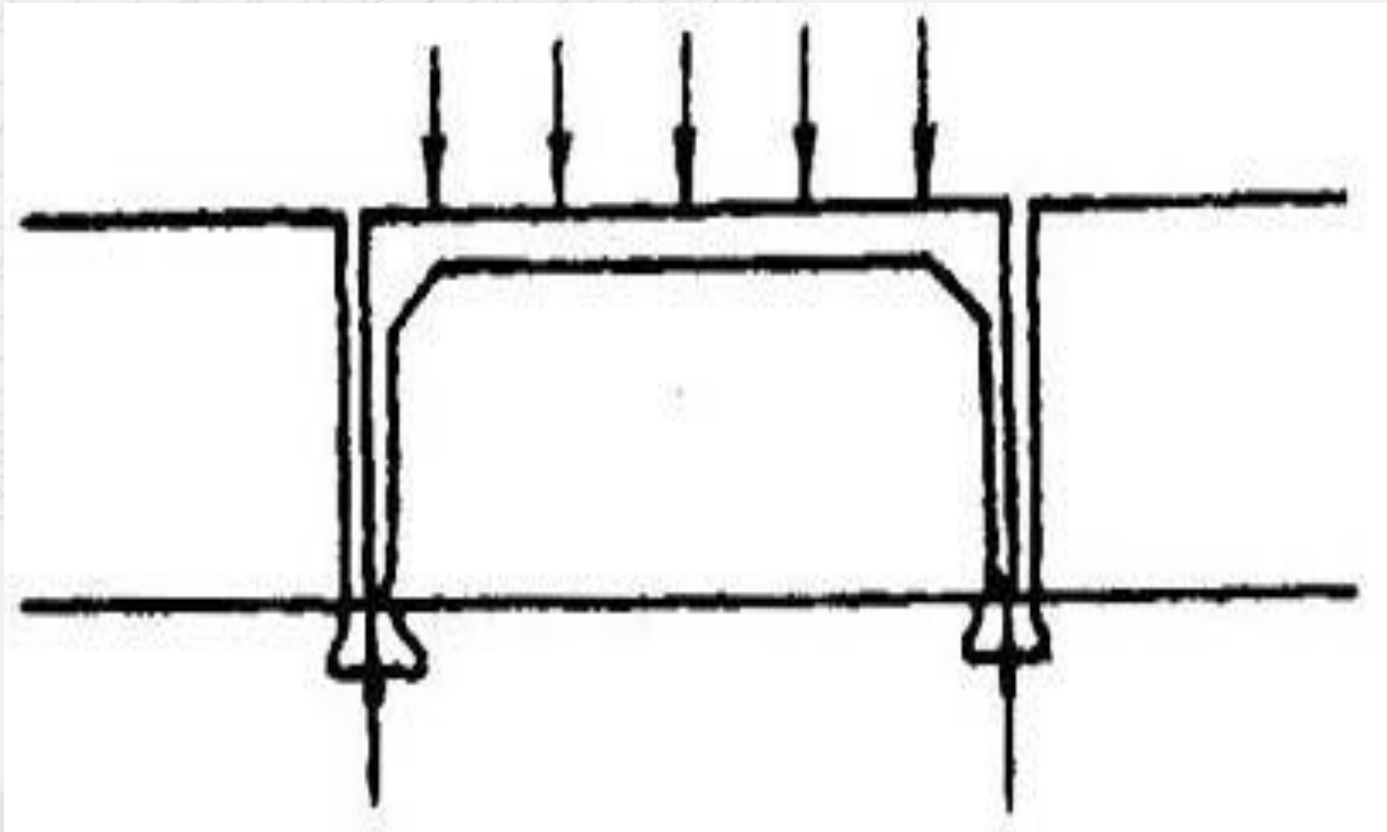


(b)



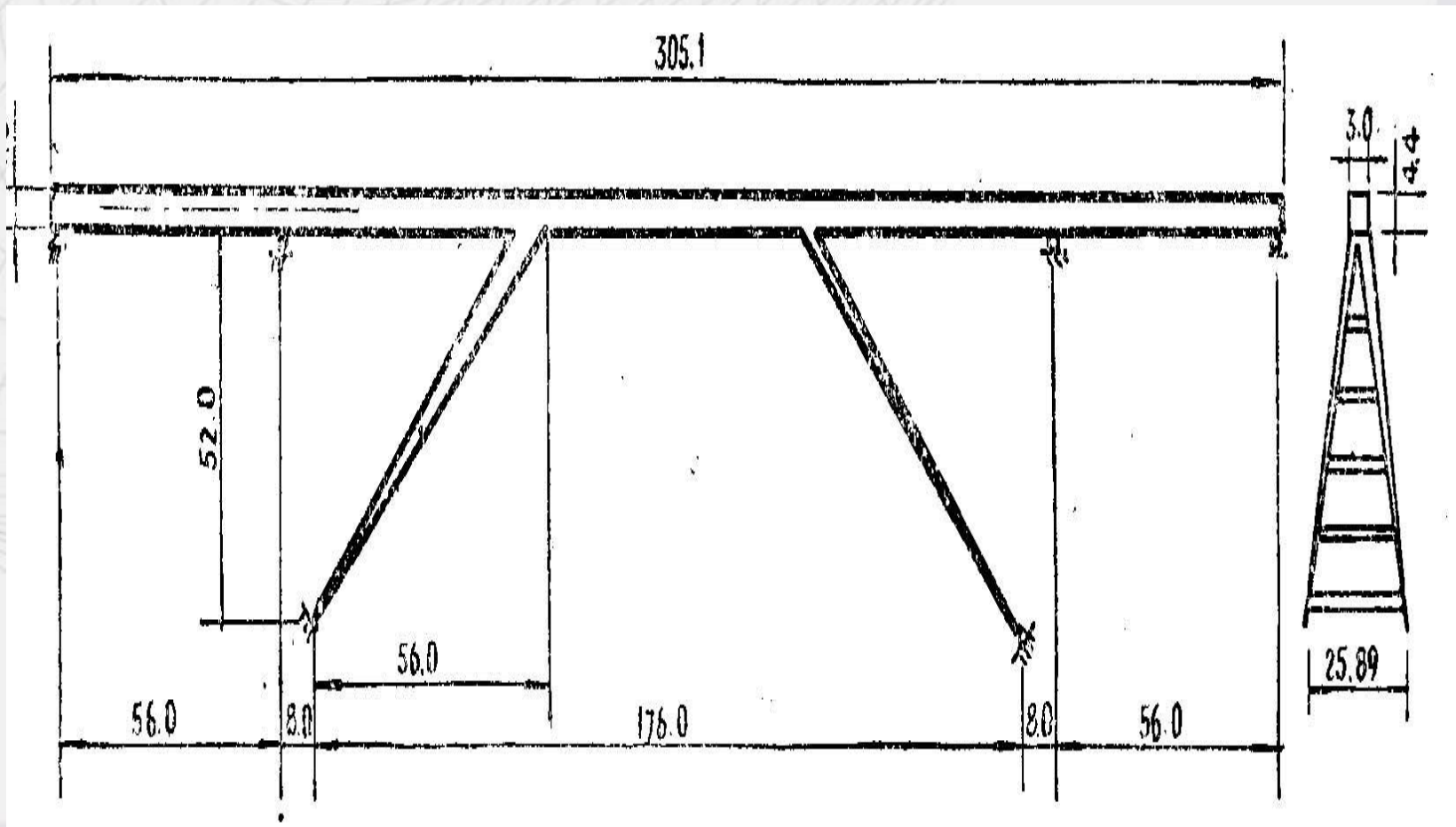
Bridge components: use and functionality

3) rigid frame structure
types:
gate-type



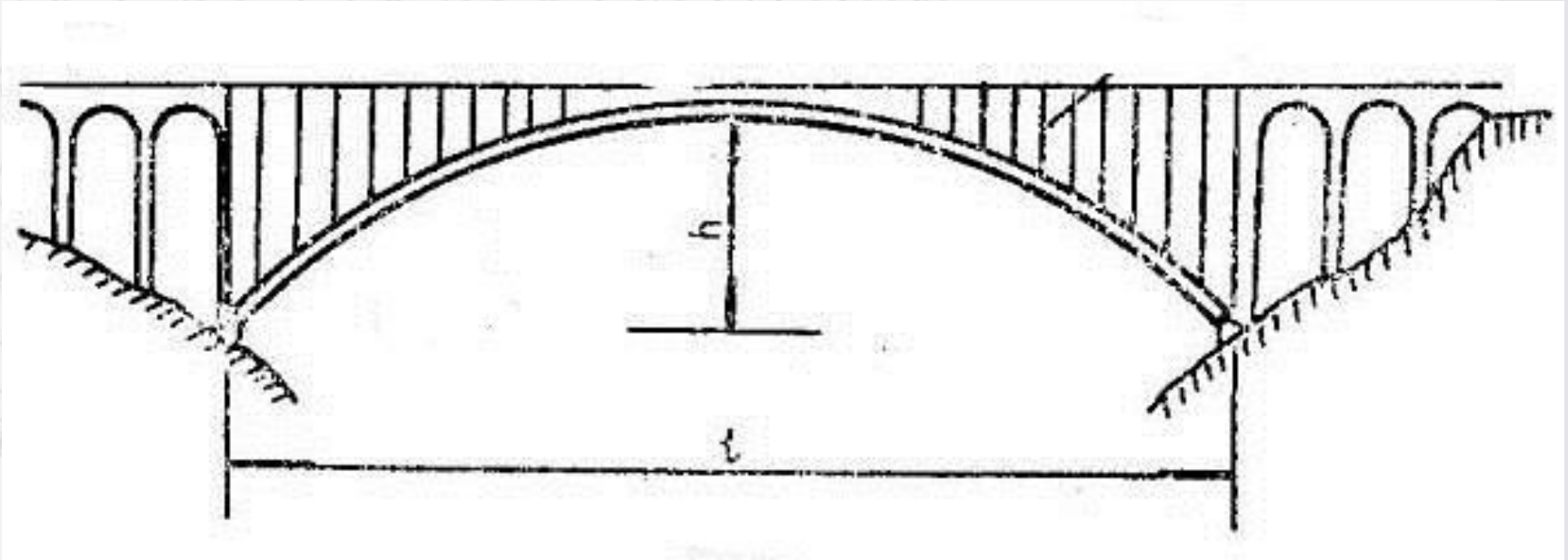
Bridge components: use and functionality

leg-inclined type

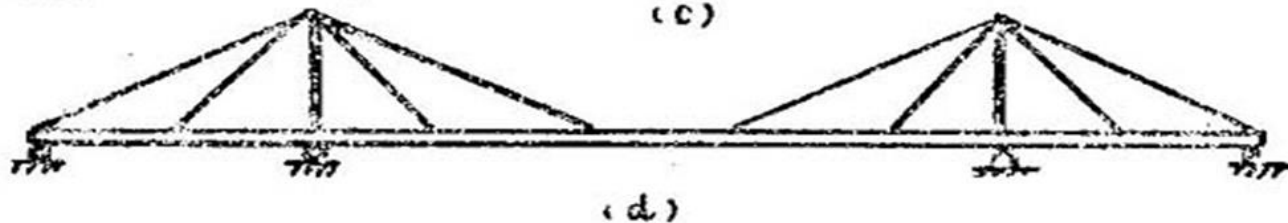
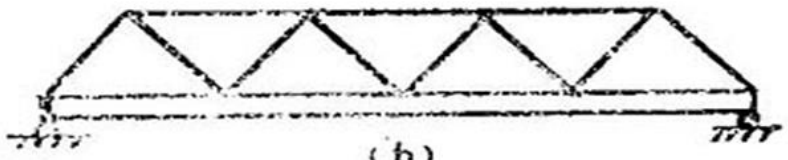
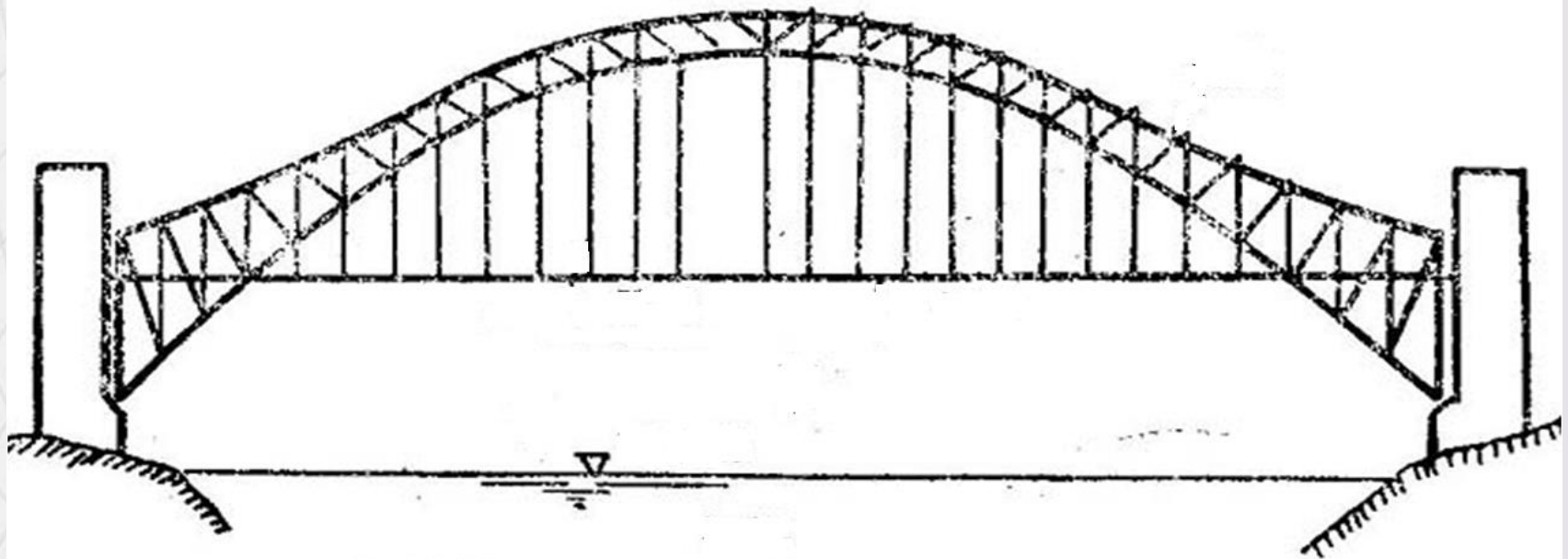


Bridge components: use and functionality

4) combined system structure



Bridge components: use and functionality



Summary of the Structural Types of Arch Bridges



Fixed arch



Single-hinged arch



Two-hinged arch

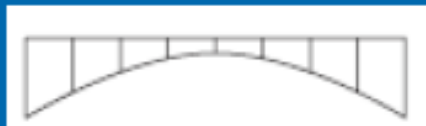


Three-hinged arch

Deck arch



Filled spandrel



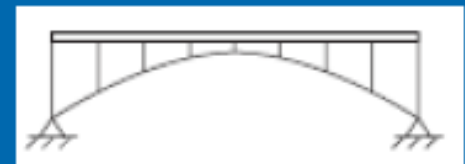
Open spandrel



Braced spandrel



Moment-resistant rib



Stiffened deck



Half-through arch



Half-through arch(tied arch)

Through-type arch



Tied arch
(through arch)

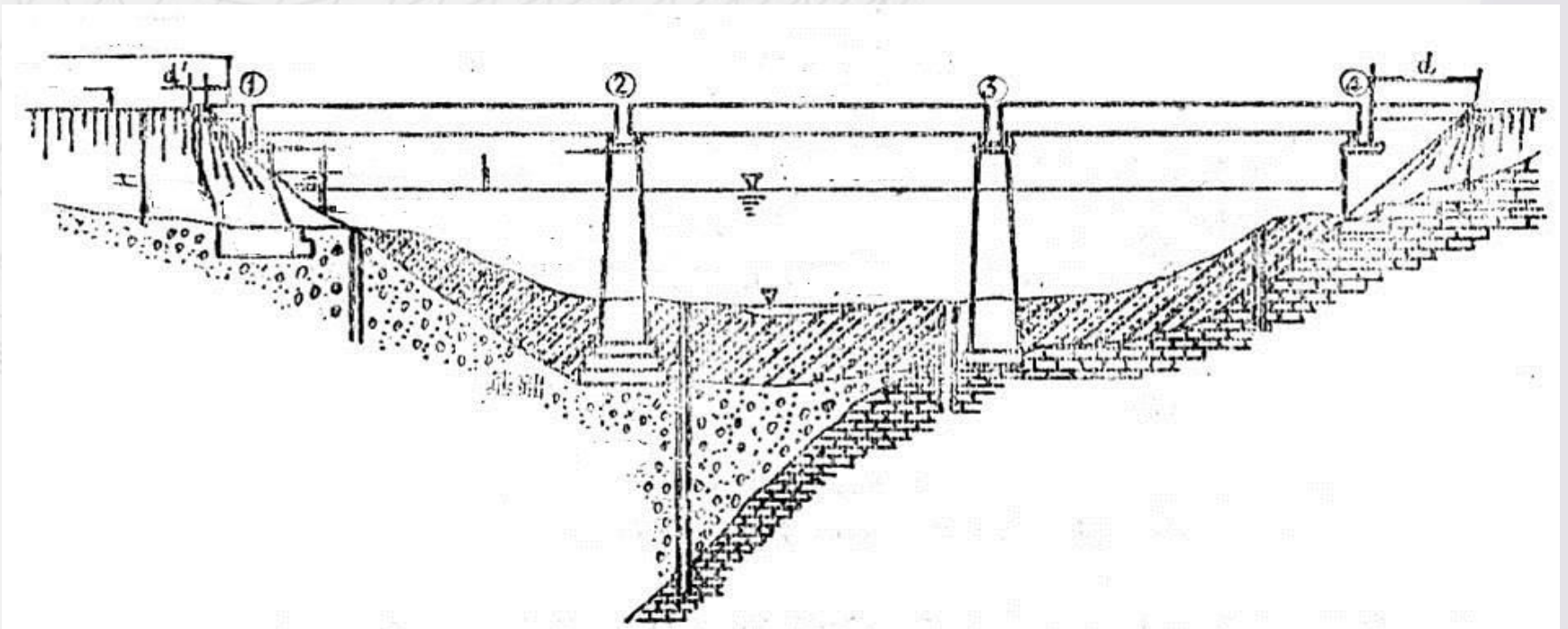


Stiffened deck arch
(through arch)

Bridge components: use and functionality

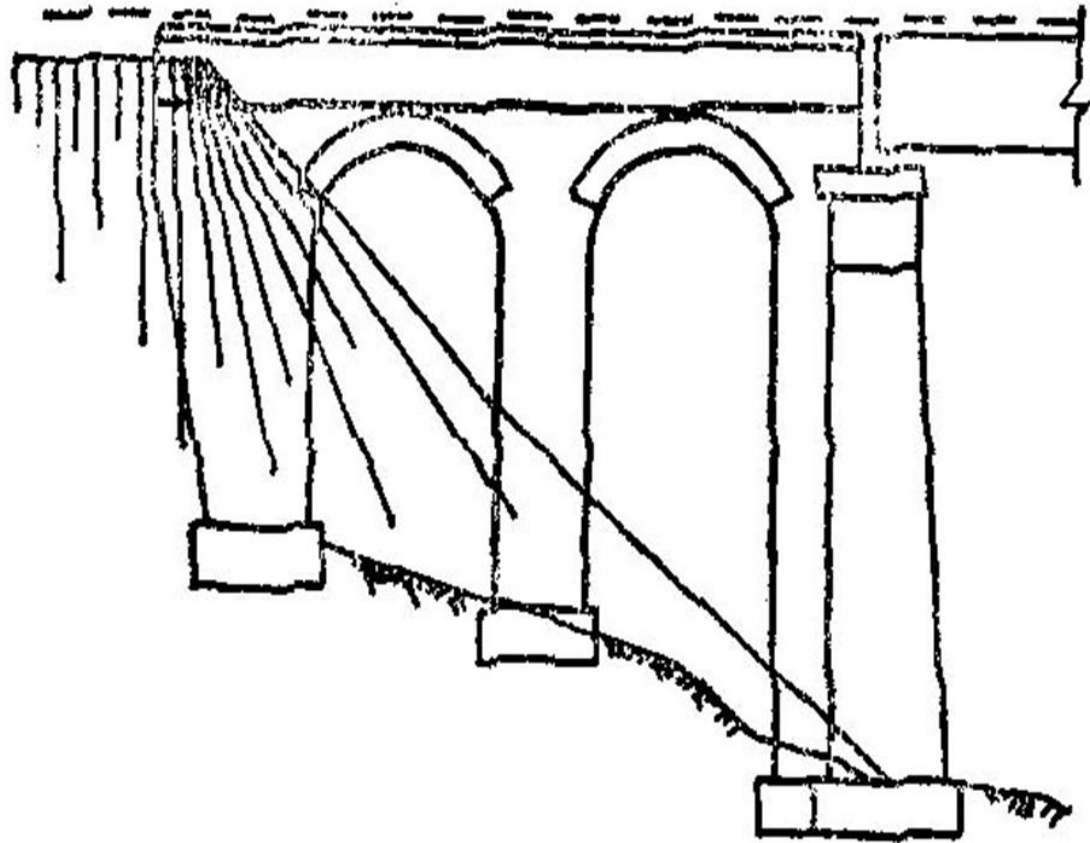
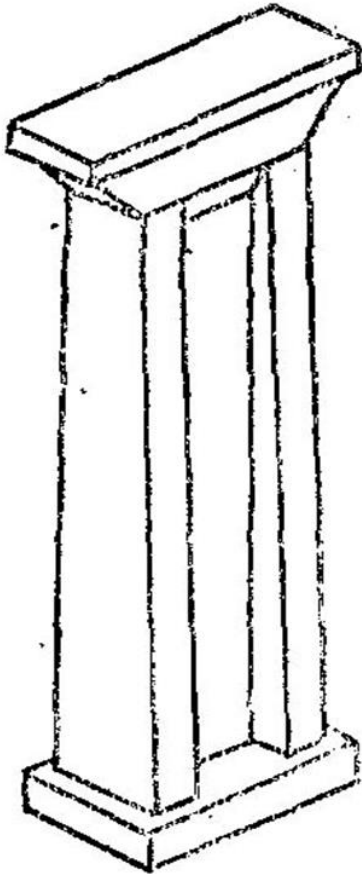
(5) bridge pier and its foundation

1)function: support the bridge superstructure

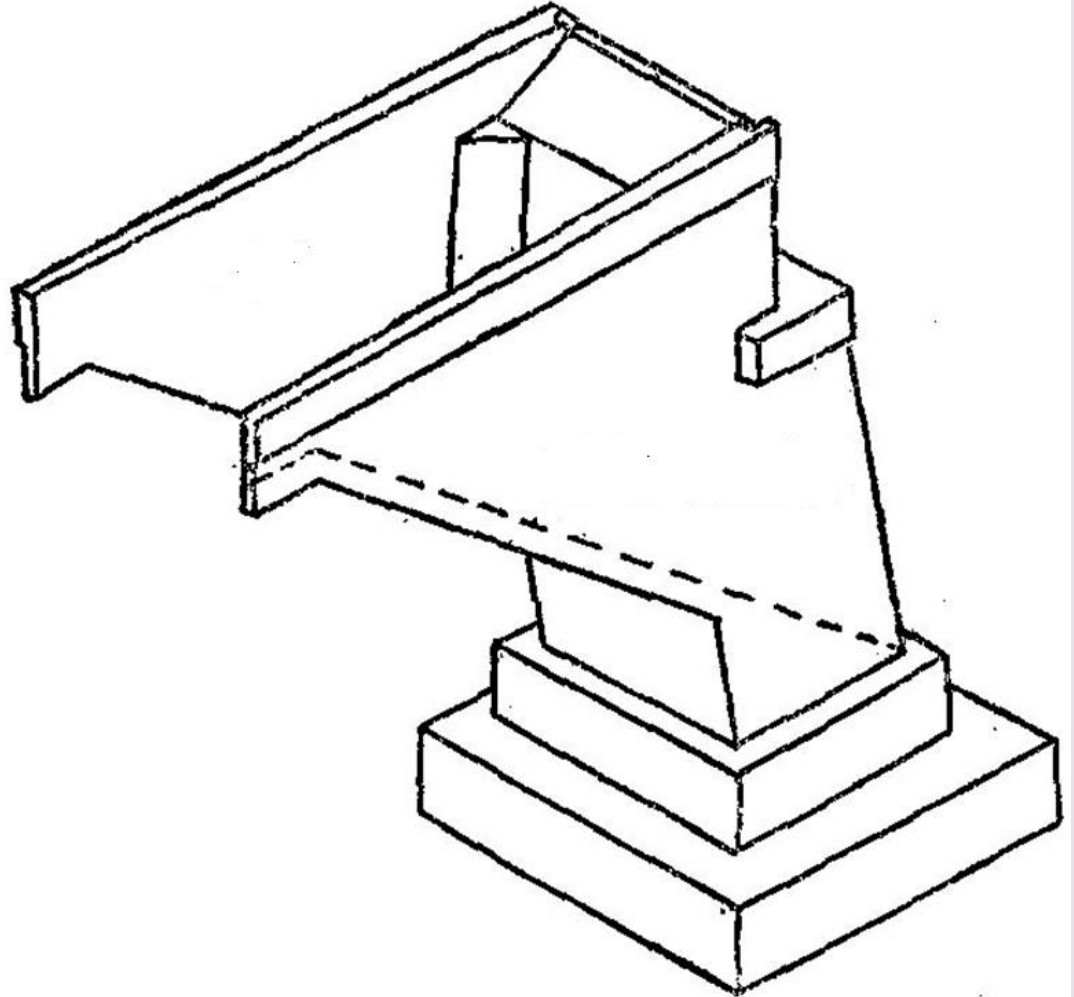
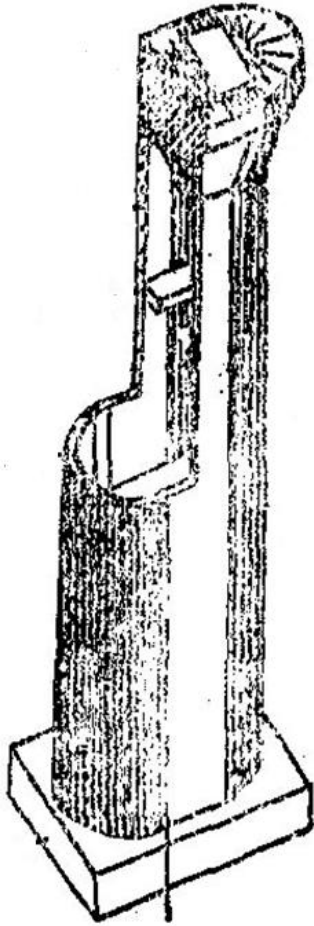


Bridge components: use and functionality

2) types



Bridge components: use and functionality



Design Loadings for Railway Bridges

Design Live Load

- China's standard design loadings for railway bridges:

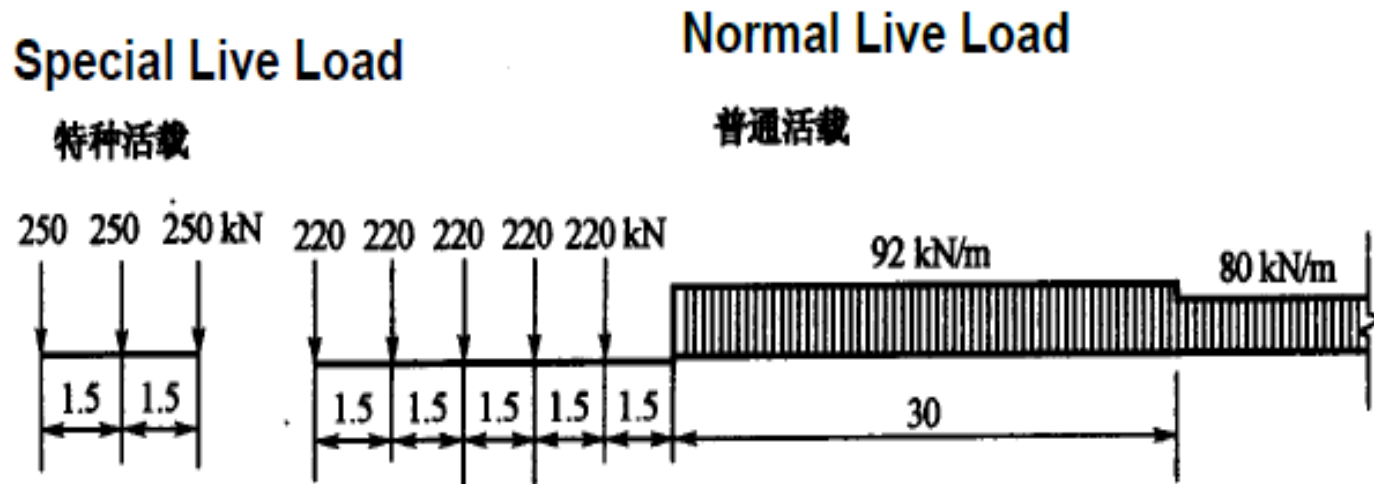
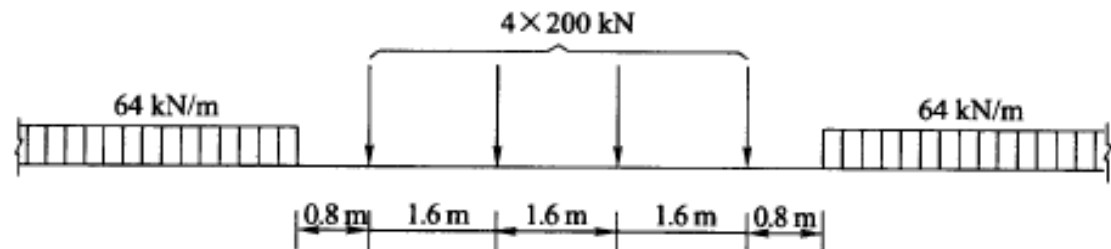


图 4.3.1 “中—活载” 图式 (距离以 m 计)

Design Live Load

- China's standard design loadings for High-Speed Railway bridges:



Standard Loading

图 1.0.7—1 ZK 标准活载图式

Special Loading

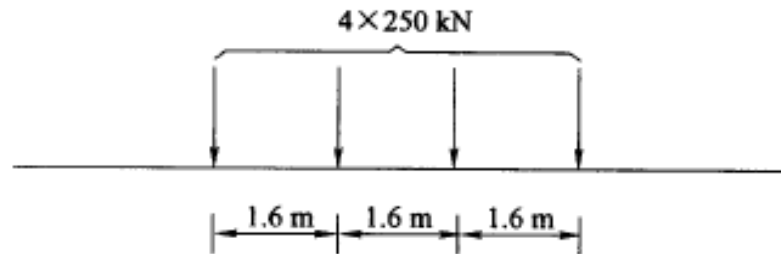
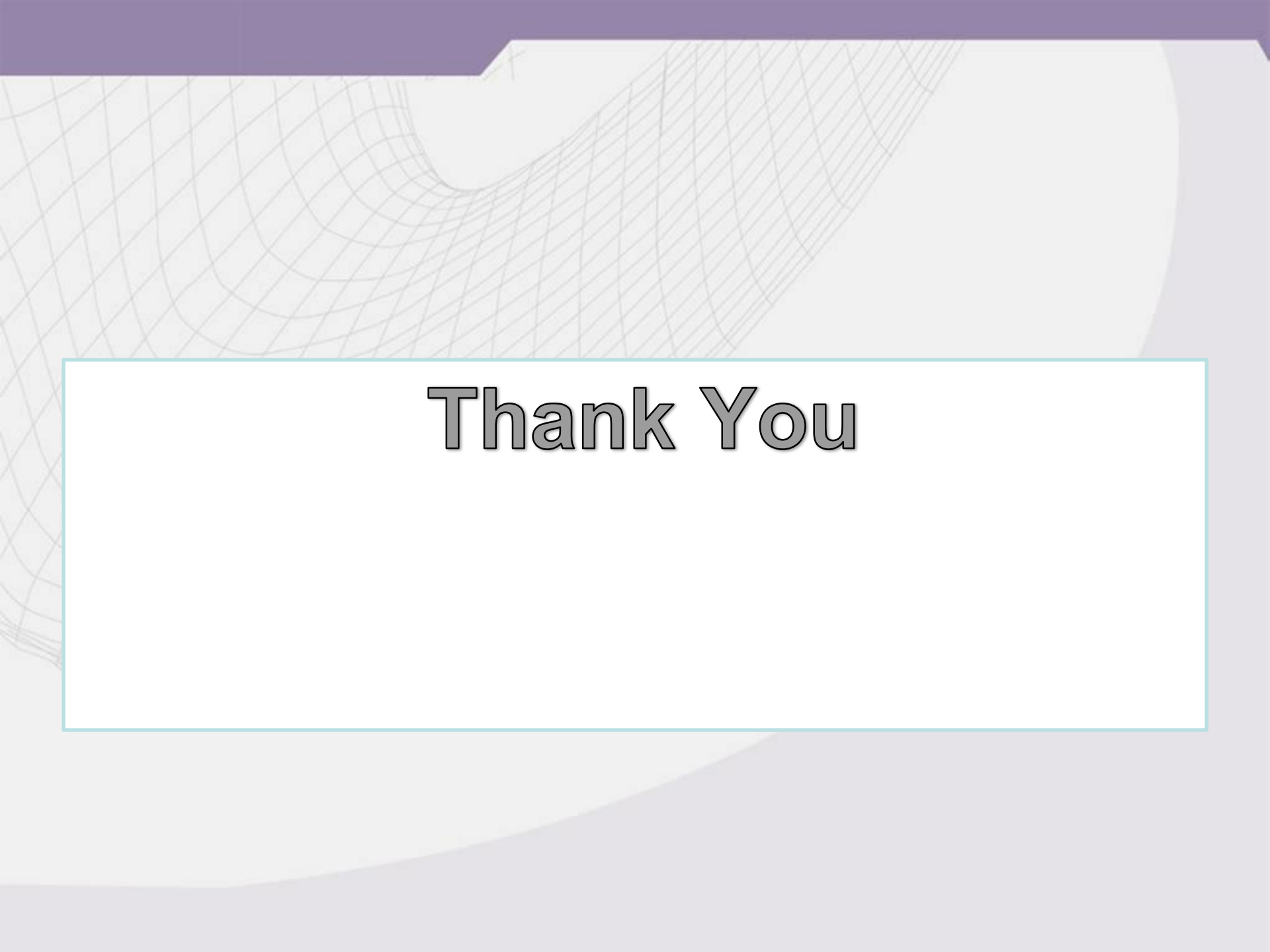


图 1.0.7—2 ZK 特种活载图式

The background of the slide features a light gray wireframe grid pattern that curves and flows across the top and left sides. A solid light blue rectangular box is positioned in the center, containing the text "Thank You".

Thank You