

**RAILWAY ENGINEERING
(CENG 5242)**

**CHAPTER 2
RAILWAY LINE & SUBGRADE**

Chapter 2 Railway Line & Sub grade

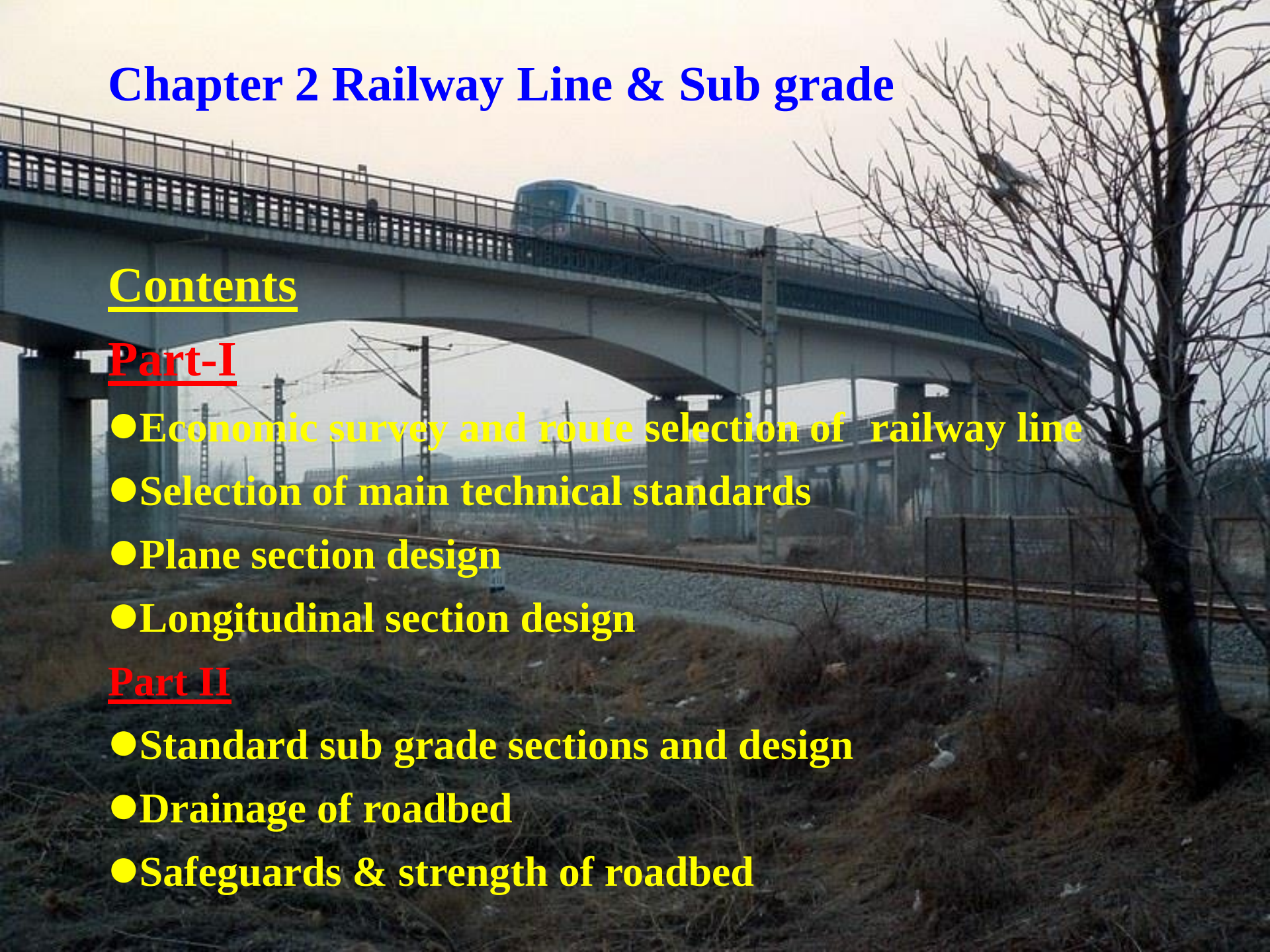
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Part-I

- Economic survey and route selection of railway line
- Selection of main technical standards
- Plane section design
- Longitudinal section design

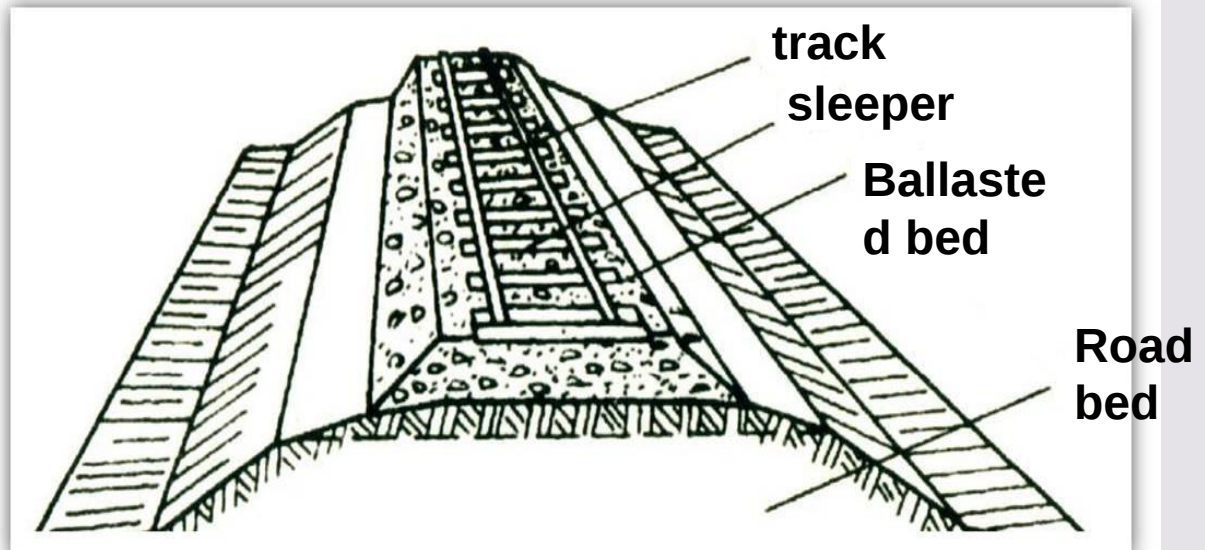
Part II

- Standard sub grade sections and design
- Drainage of roadbed
- Safeguards & strength of roadbed



Introduction

- Rail line is the foundation of operation.
- It is a whole structure consisted of the roadbed, bridge building and rail.
- **Center line of the route is all about every Thing!**
 - Economy(cost)
 - Safety
 - Type of structures to design etc... all determined by CL.
 - Station location



Typical ballasted
track section

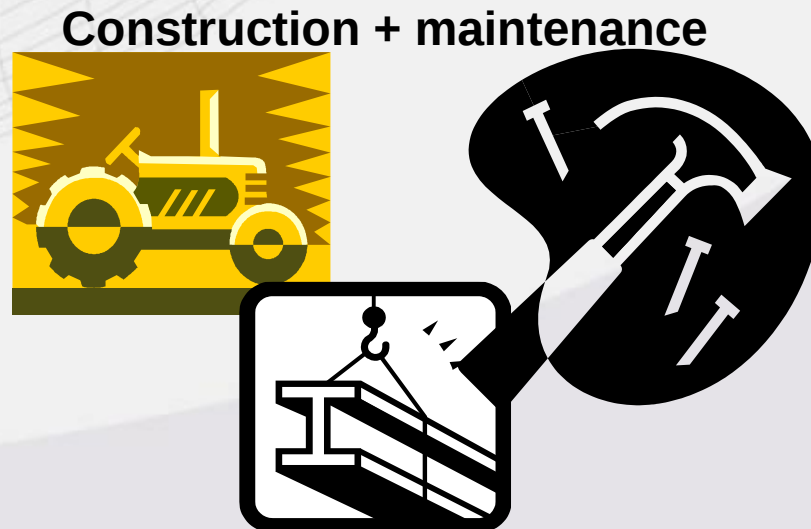
2.1 Economic survey and route selection

Three stages:

1. **Earlier stage:** research, survey and preliminary design work.
2. **Basic construction stage :** first to do the measurement, technical design and construction design, then begin to construct it, finally check it into production.
3. **Effect of feedback:** several years later, to evaluate the design and construction quality by investigate the engineering quality, technical index and economic benefits.



Study and design



Construction + maintenance



Feedback & evaluation

Route selection...

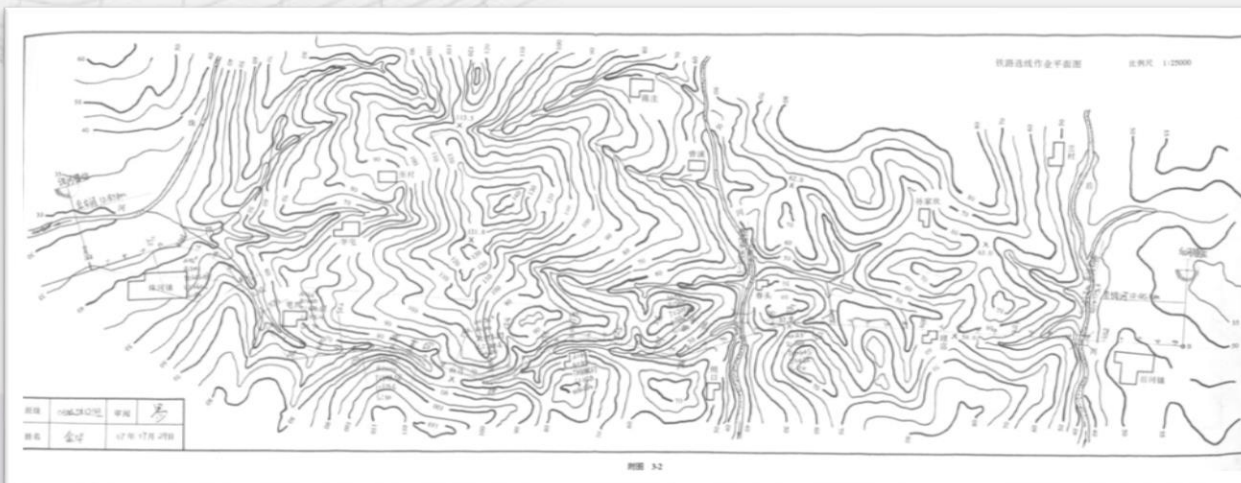
Route selection criteria:

- shortest , direct route,
- detour unsuitable geology, link important sites
- Cost effective (user & construction)
- Minimum earthwork,
- locally materials,
- Environmental friendly
- aesthetic value etc.

Balancing these parameters and requirements



target



Survey and Economy- for classification

- *Railway level based on the annual volume of freight and passenger*
- *Directly affect your survey & route selection*

According to the economic importance, Chinese classification

Railway level	Status	Volume of freight and passenger
Level I	play the backbone role	$\geq 20\text{Mt}$
Level II	play the backbone role	$< 20\text{Mt}$
	Play the contact and auxiliary role	$\geq 10\text{Mt}$
Level III	Serve for a region	$< 10\text{Mt}$

Selection of main technical standards

1) Design speed

shall be determined after technical and economic comparisons in terms of the project role in railway **passenger and freight transport** network, transport demand, engineering specifications to meet the demand of *travel time target*.

2) Maximum gradient

- The maximum gradient is the steepest grade allowed to be used on a railway line.
- The maximum gradient shall be determined according to the *design speed, locomotive power, traffic organization mode, safety and ride comfort, annual volume of traffic*, etc.

Selection of main technical standards...

3) *Numbers of main lines*

-double track or single track railway

4) *Minimum plane curve radius*

- Minimum plane curve radius is the minimum one to be used in a projected railway.
- Minimum plane curve radius shall be determined according to railway classification, designed speed, traffic organization mode, safety and ride comfort, and engineering working conditions, etc

Selection of main technical standards...

5) Available length of arrival and departure line

- Arrival-departure lines are built at stations specially for train reception and departure
- The available length of arrival and departure line is the maximum length of arrival and departure line that can be used to trains stopping without influencing the operation working on adjacent lines

6) Kind of traction and types of locomotives(or EMU type)

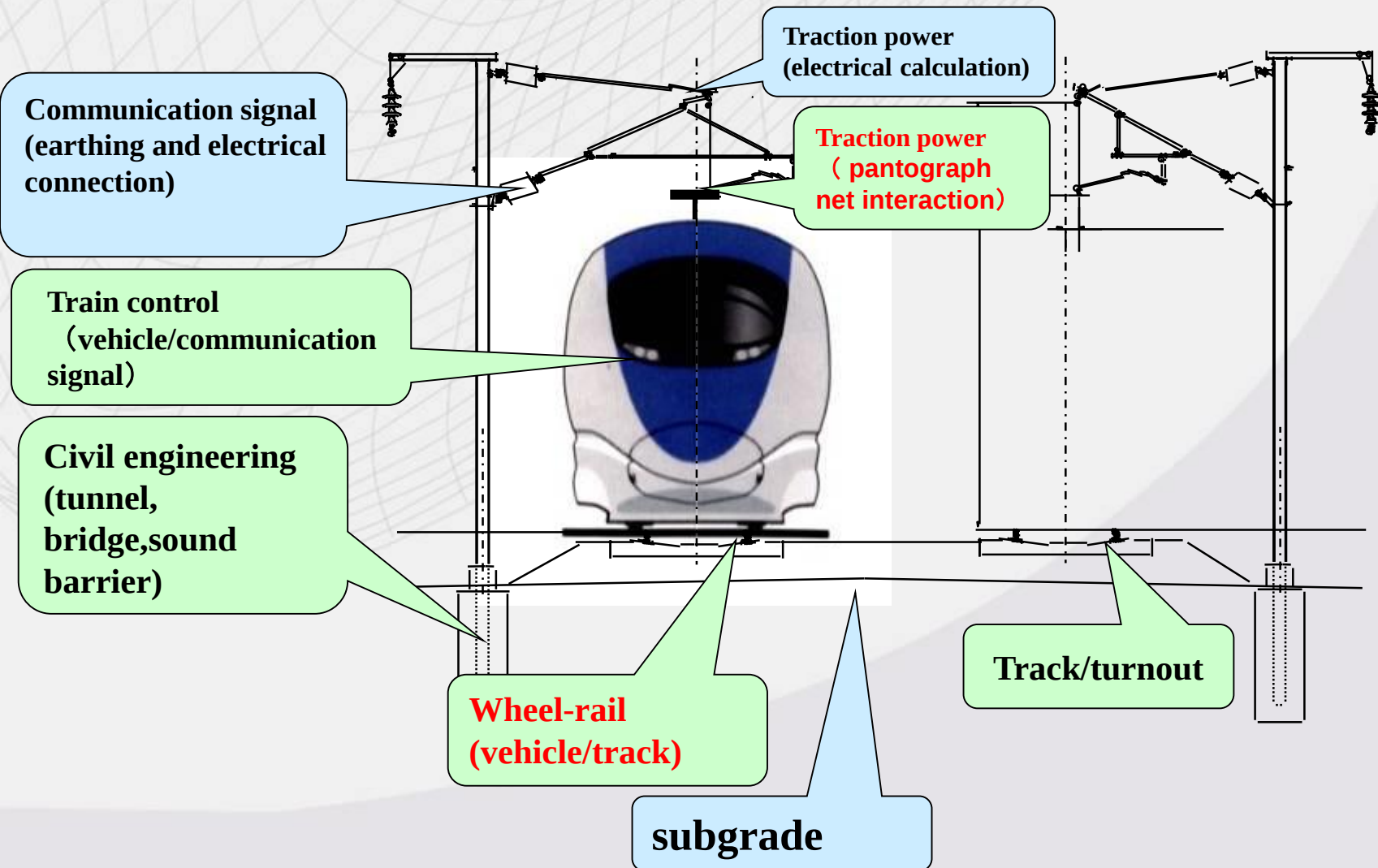
- There three kinds of traction in railway industry, *electric traction, diesel traction and vapor traction*.
- Kind of tractive energy greatly influences the railway with respect to traffic capacity, line standard and economy.

Selection of main technical standards...

7) Tonnage Ratings

- *Tonnage ratings tell how many tons a given locomotive can haul over a particular engine district*
- Comparative tonnage ratings over alternative routes can be a major factor in route location.
- In building trains, yardmasters need to know *how many tons* can be placed behind a given locomotive consist or what *horsepower* is needed to move a proposed tonnage

Railway system interaction



Railway Alignment Design and Geometry

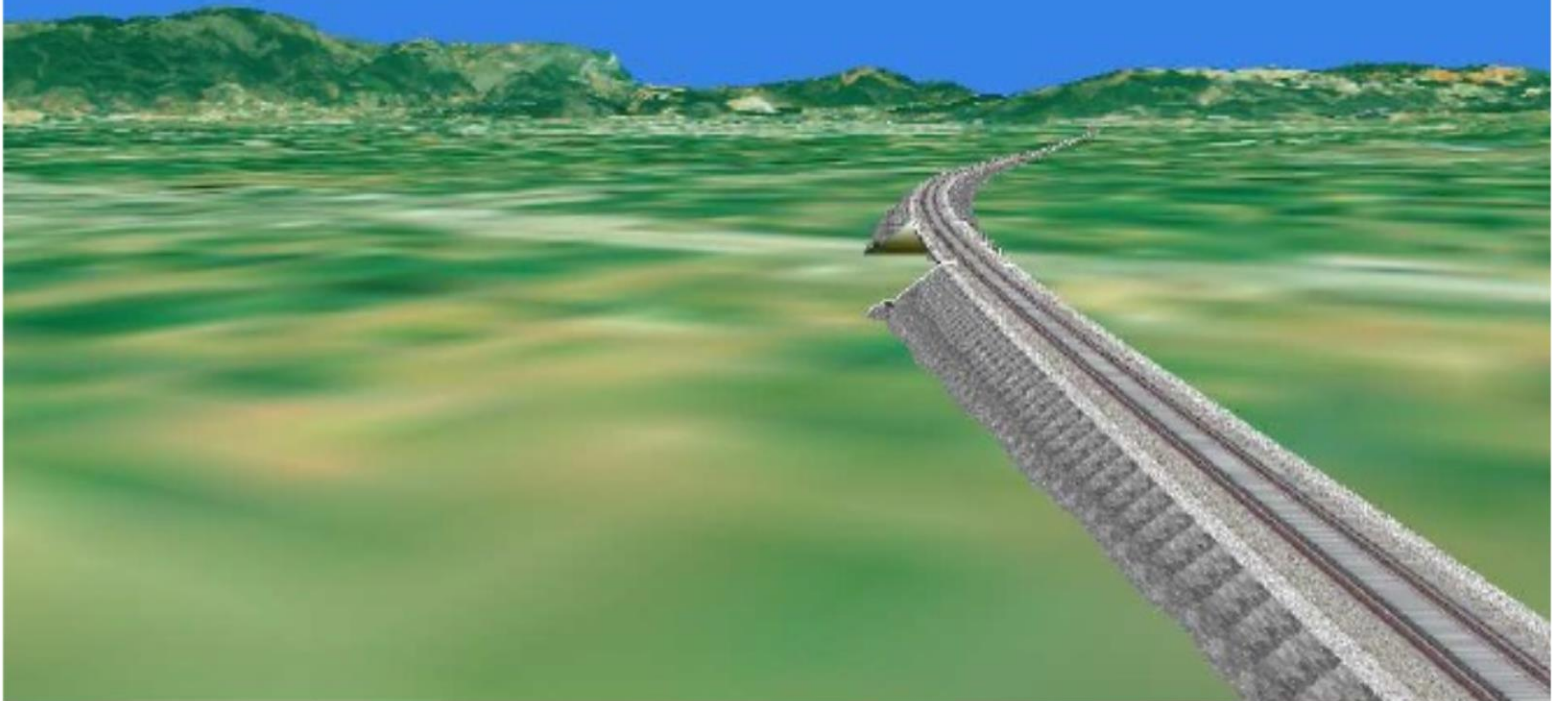


Topics

- **Horizontal Alignment and**
- **Profile/Vertical geometry**
- **Subgrade structure**

Permanent way

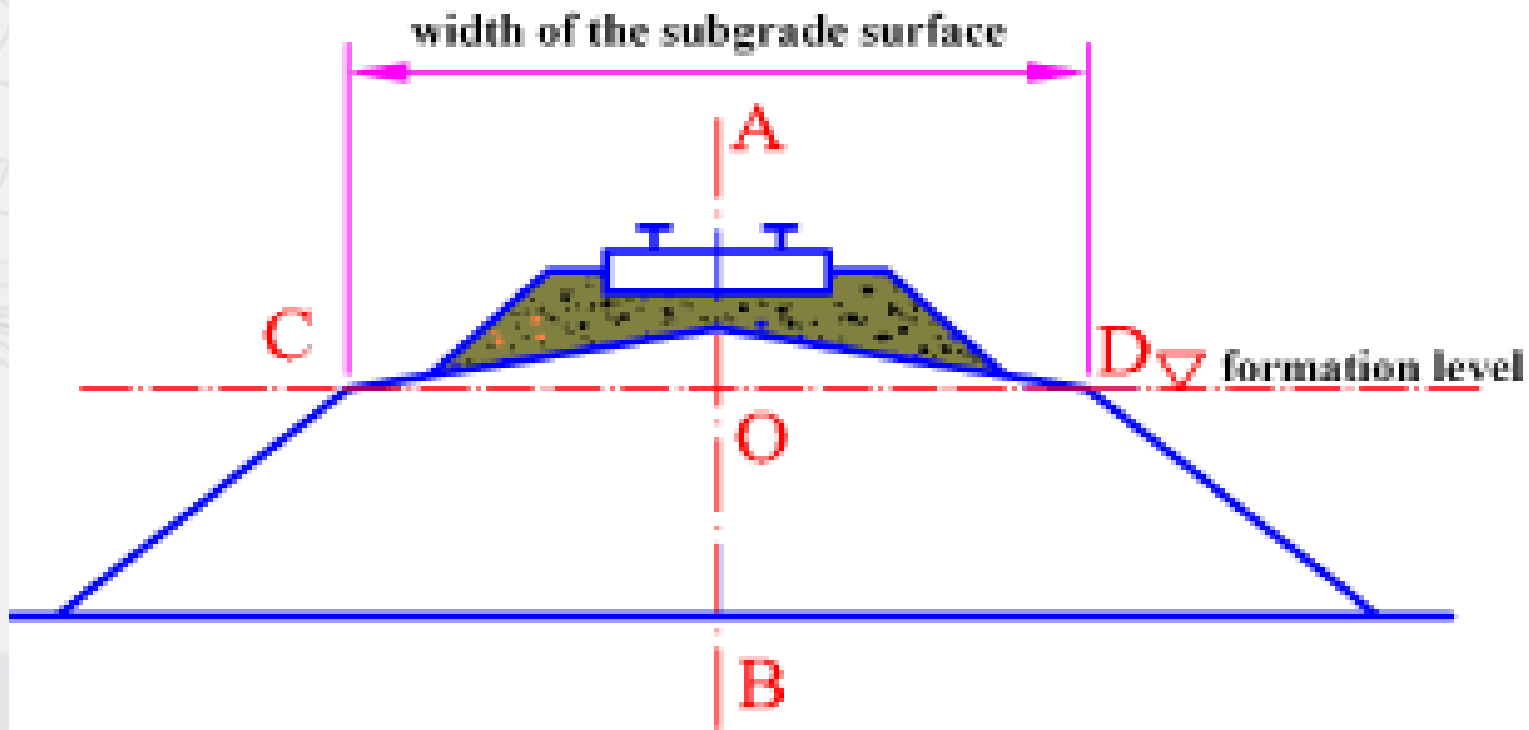
- **Railway permanent way is a three-dimensional space strip civil engineering works.**



2.2 *Plane section of Railroad line*

Centre line is used to show the place of a line in space.

Line AB is the center line of the track as well as cross section of the track.



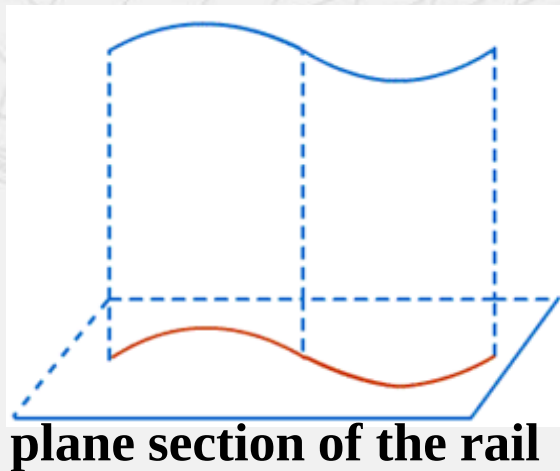
Alignment

- *Railway alignment* means *space position* of the central line of railway permanent way. It is expressed in the line linked central points of cross-section longitudinally, as in figure right. It is called as center line in short.
- Planar and longitudinal section of alignment



Plane and profile sections

- The planar projection of centre line is called plane section of the rail; and its vertical projection is called longitudinal section of the rail.
- The plane section of the rail is consisted of straight line and curve (circular curve and easement curve).



**longitudinal section
of the rail**



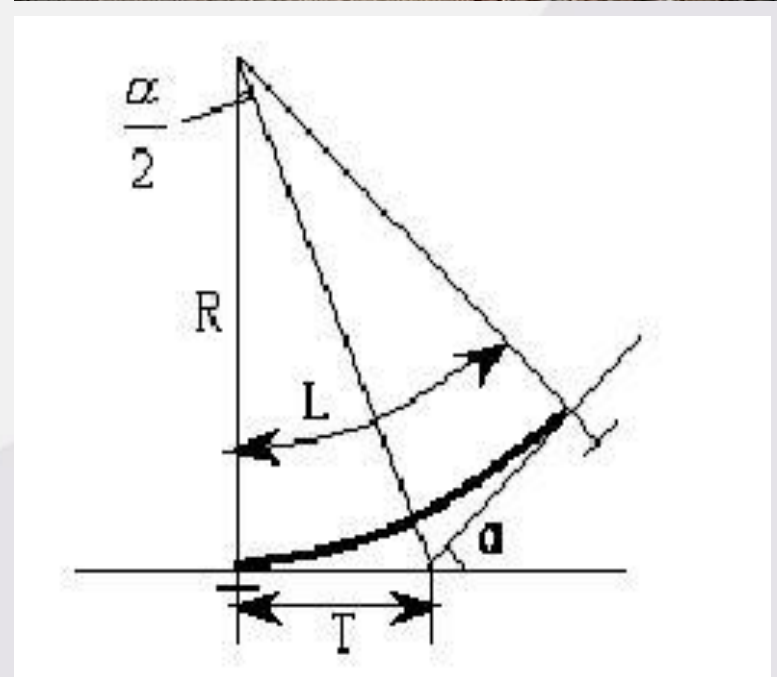
1. Plane design

■ Constituent parts of the curve

The curve is set when the line turns or when two straight lines intersect.

It includes:

- ✓ **curve radius, R**
- ✓ **corner angle, α**
- ✓ **curve length, L**
- ✓ **Tangent length, T**
- ✓ **easement curve length, L_0**



Composition of plane design

- circular curve

When out of consideration of easement curve:

tangent length:

$$T_c = R \cdot \tan \frac{\alpha}{2} \text{ (m)},$$

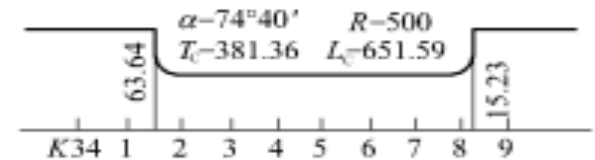
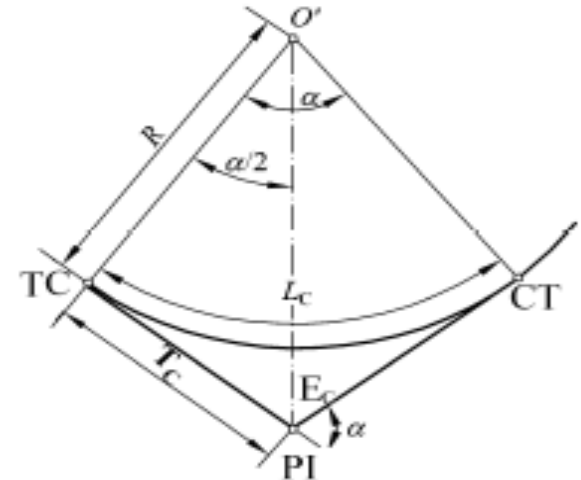
curve length:

$$L_c = \frac{\pi \cdot \alpha \cdot R}{180} \text{ (m)},$$

External length:

$$E_c = R \cdot \left(\sec \frac{\alpha}{2} - 1 \right) \text{ (m)}$$

arc length of L_0 : $L = \frac{\pi R}{180} (m)$



Single curve

(1) Curve radius's effect for operating

It is harmful while it is small, because:

- *Limit the speed of train;*
- *Increase wheel abrasion;*
- *Increase rail equipment;*
- *Increase maintenance costs.*



(2) The relationship of speed and curve radius

$$V = \sqrt{\frac{hR}{11.8}}$$

V - speed of train, km/h;

h - elevation of outer rail, mm;

R - curve radius, m

(3) The maximum speed on curve

The maximum permissible value for elevation of outer rail:

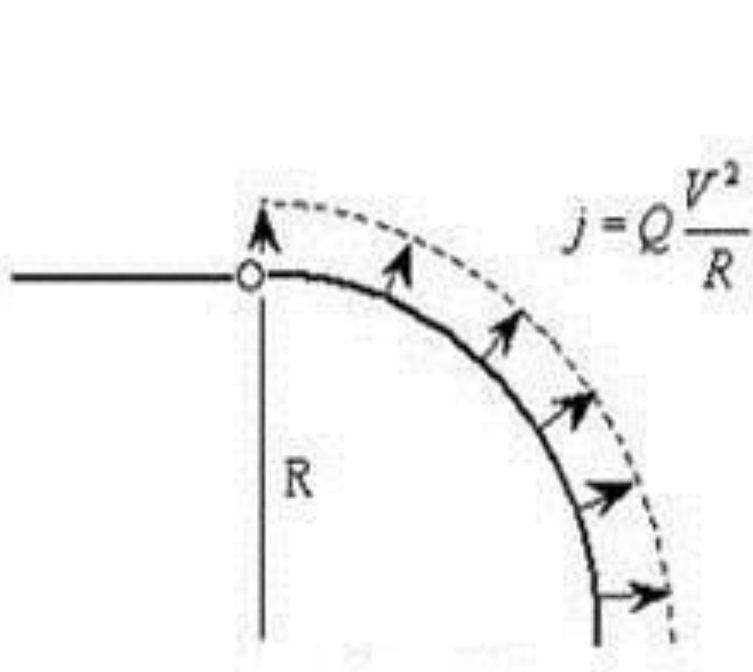
☐ *125mm for single track, and 150mm for double track.*

☐ *In addition, can consider some inadequate superelevation, 70mm for ordinary district and 90mm for hard district.*

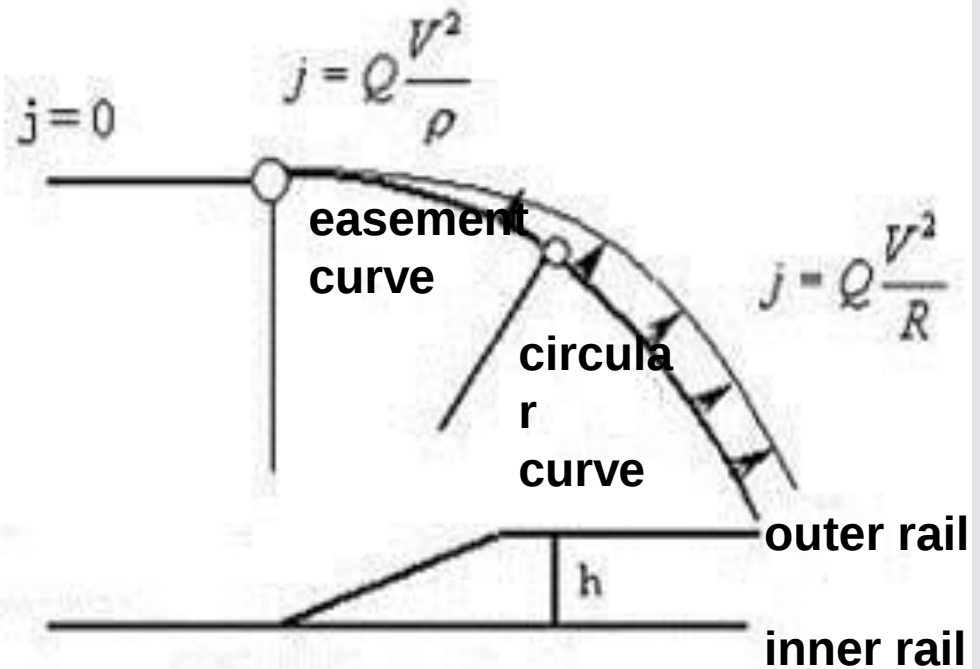
And the formula can be:
$$V = \sqrt{\frac{(h_{\max} + h_q) R}{11.8}}$$

3. Easement curve

Easement curve is set between straight line and circular curve.



(a) Without easement curve



(b) With easement curve

(1) Characteristic of easement curve

- ❖ **Its curve radius decreased gradually from the infinite to circular curve radius R , or on the contrary;**
- ❖ **While running, the centrifugal force of train is gradually added or gradually reduced;**
- ❖ **The widen value of track gauge is also gradually added or gradually reduced;**
- ❖ **And so as to the elevation of outer rail.**

It is set for safety and riding comfortableness.

(2) Formula of easement curve

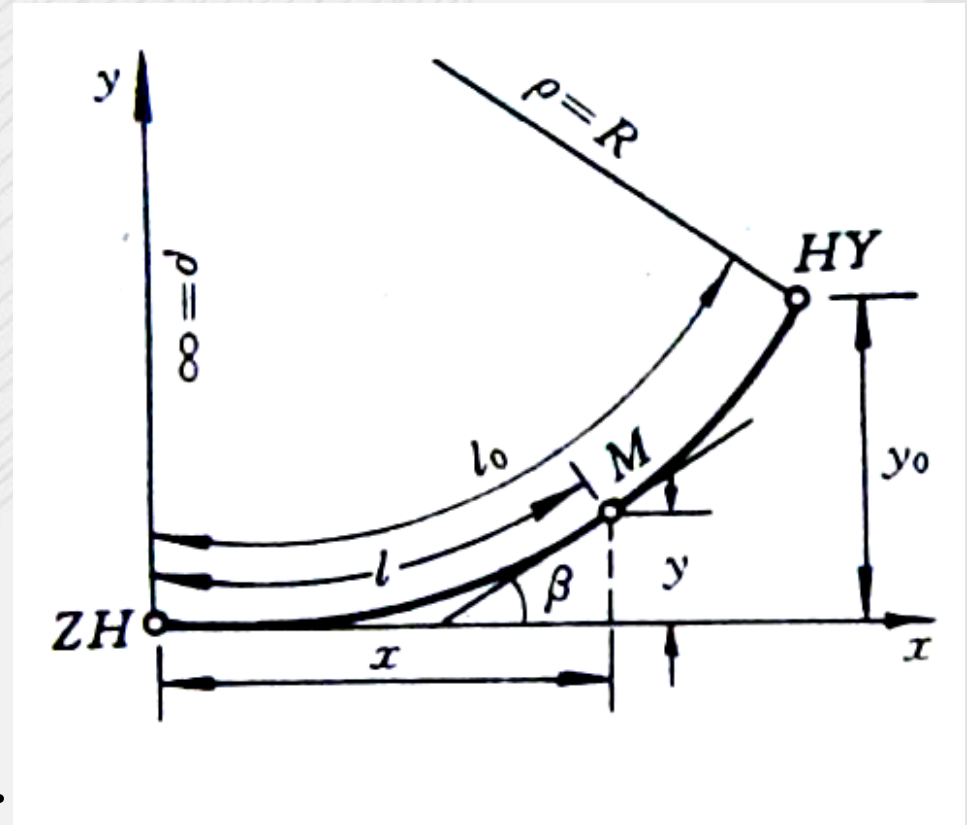
$$y = \frac{x^3}{6Rl_0}$$

Y - ordinate, m;

X - abscissa, m;

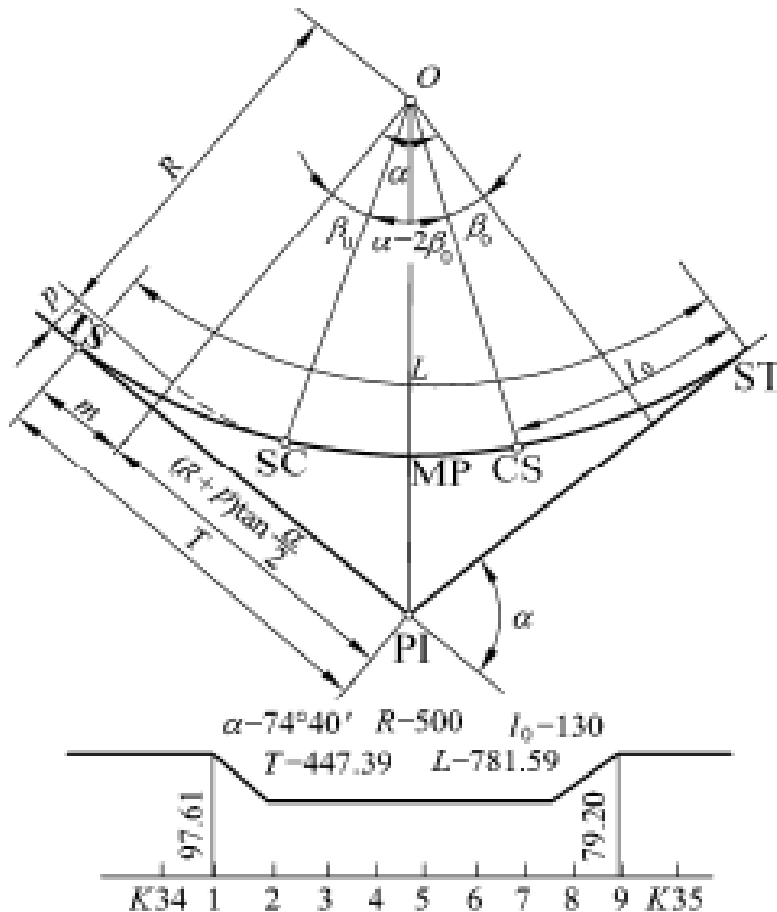
R - circular curve radius , m;

L₀ - easement curve length, m.



Curve radius (m)	Level 1			Level II			Level III	
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)
4000	30	30	20	20	20	20	20	20
3000	40	30	20	30	20	20	20	20
2500	50	40	20	30	30	20	20	20
2000	60	50	30	40	30	20	20	20
1500	80	70	40	50	40	30	30	20
1200	100	80	50	60	50	30	30	30
1000	120	100	60	70	60	40	40	30
800	150	120	70	90	70	40	50	40
700	150	120	90	70	40	40	50	40
600	140	110	90	110	90	60	60	60
550	140	110	90	130	110	70	70	50
500	130	100	90	130	100	80	70	60
450	120	100	80	120	100	80	80	80
400	120	90	80	120	90	80	90	70
350	110	90	70	110	90	70	100	70
300				100	80	70	100	70
250							90	70

3) Element calculation



Common curve

**tangent
length:**

tangent length: $T = (R + p) \operatorname{tg} \frac{\alpha}{2} + m \quad (\text{m})$

**curve
length:**

curve length: $L = \frac{\pi}{180} R \alpha + l_0 \quad (\text{m})$

**external
distance:**

external distance: $E = (R + p) \sec \frac{\alpha}{2} - R \quad (\text{m})$

**length of
tangent:**

length of tangent: $m = l_0/2 - \frac{l_0^3}{240R^2} \approx l_0/2 \quad (\text{m})$

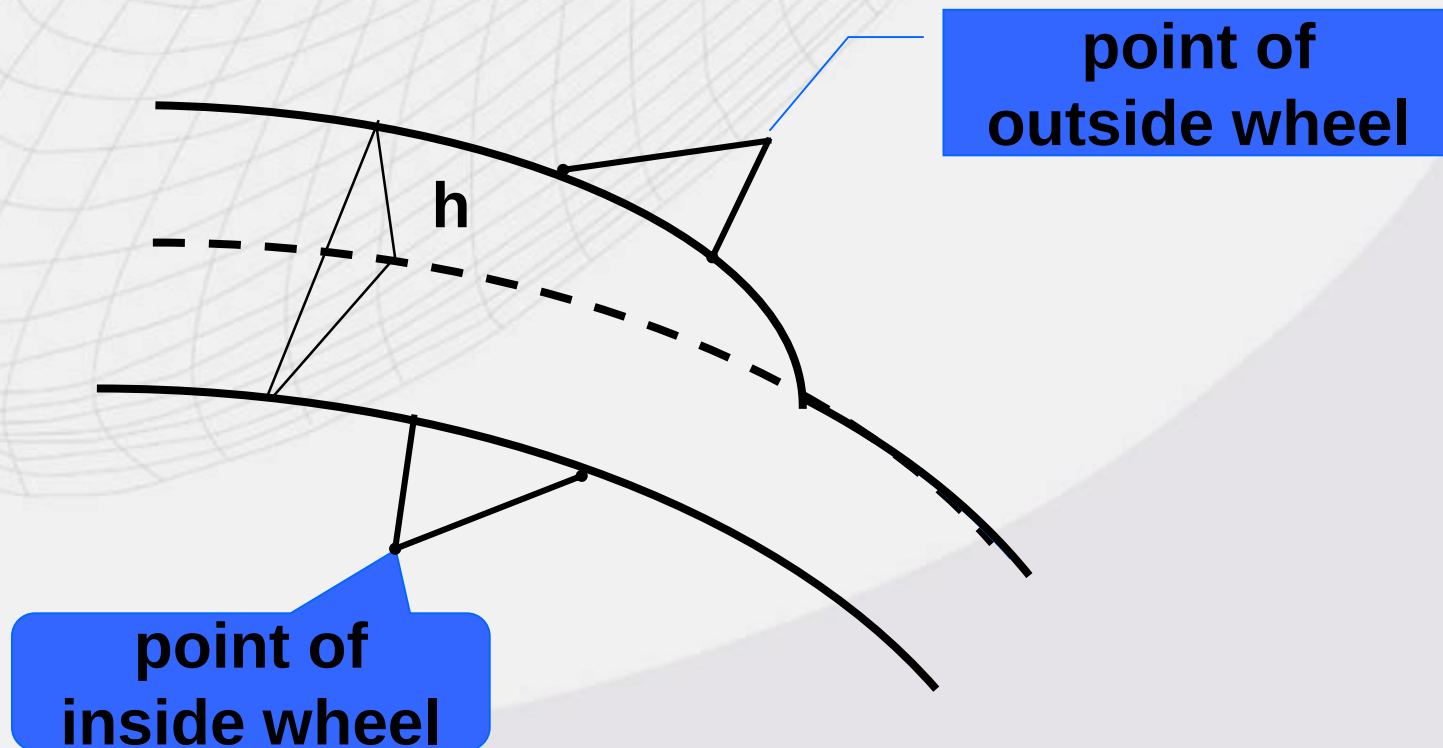
inset :

inset : $p = l_0^2 / 24R \quad (\text{m})$

Length of easement curve

- 1) calculated according to the diminishing gradient of superelevation

The principle: the inside wheel which is impending can't climb up the rail.



$$\therefore i_o = \frac{h}{L_o}$$

$$\therefore i_o \leq \frac{k_{\min}}{L_{\max}}$$

if h and i_o are known, so :

$$L_o \geq \frac{h}{i_o} \text{ (m)}$$

$K_{\min}$ - the minimum height of wheel(mm); L_o —length of easement curve (m);

$L_{\max}$ - the maximum wheelbase(mm); h —superelevation(mm) .

I_o -gradient of superelevation, usually $\geq 2\%$;

2) calculated according to the comfort level of passengers

The principle: wheel's speed of up and down cannot be too fast.

$$f = \frac{h}{L_o / V_{\max}} = \frac{h \cdot V_{\max}}{3.6 L_o} \text{ (mm / s)}$$

f — speed of wheel

L_o — length of easement curve (m);

h — superelevation(mm) .

$$L_o \geq \frac{h \cdot V_{\max}}{3.6 f} \text{ (m)}$$

rules:

Existing lines

$$L_0 \geq 10h/V_{\max}$$

$$L_0 \geq 7h/V_{\max}$$

ordinary district: $f=28\text{mm/s}$ and

hard district : $f=40\text{mm/s}$ and

of which, $V_{\max}$ is the real maximal velocity, km/h.

new lines

ordinary district: $f=32\text{mm/s}$

hard district : $f=40\text{mm/s}$

of which, $V_{\max}$ is the designed maximal velocity, km/h.

Attentions :

- ① use the two methods to work out L_0 , chose the bigger one;
- ② length of L_0 is usually between 20-150m.

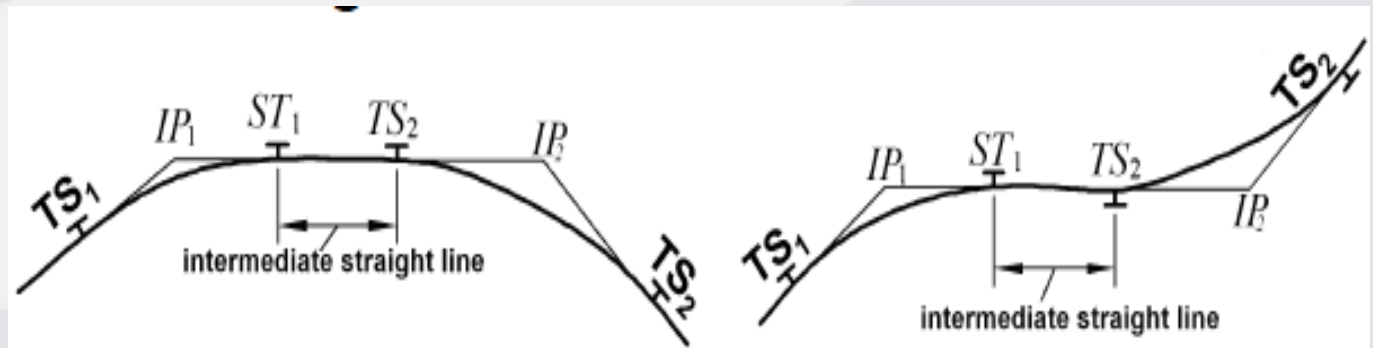
Principles of straight Line

- Straight lines shall be to reduce intersections, based on topography
- To reduce curve resistance which can be calculated as;

$$A_r = w_r \times L_y = \frac{600}{R} \times \frac{\pi \times \alpha \times R}{180} = 10.5\alpha$$

where w_r — unit curve resistance (N/kN)
 L_C — length of circular curve (m)

- Intermediate straight line /b/n two adjacent curves
- Track maintenance requirement
- 2-3 standard rail
- orient maintaining machine
- prevent lateral swing of train-safety and comfort,
- to avoid vibration

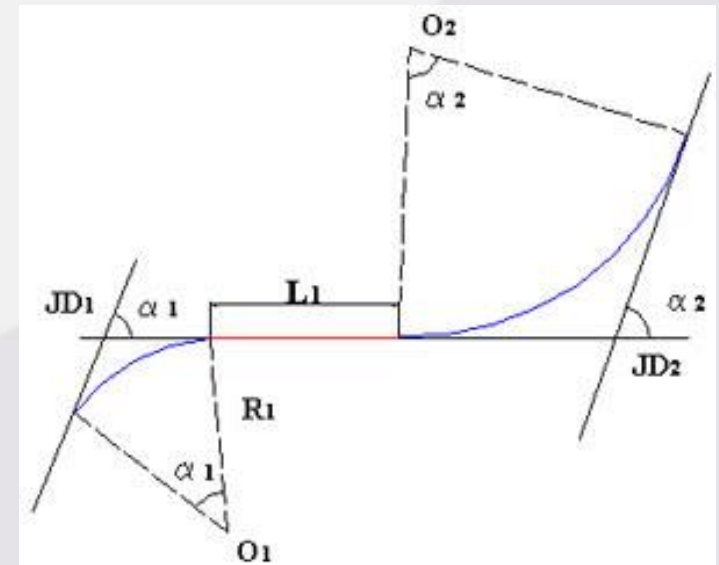
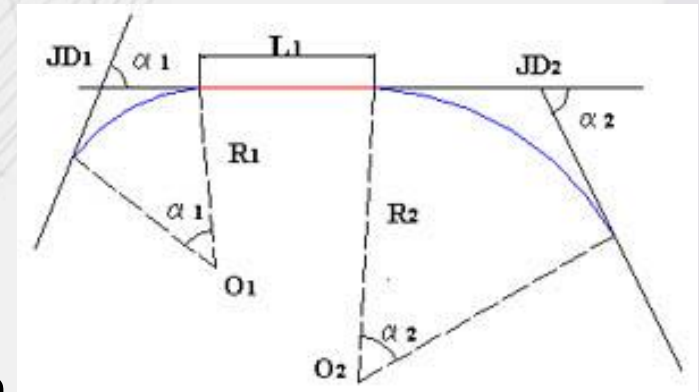
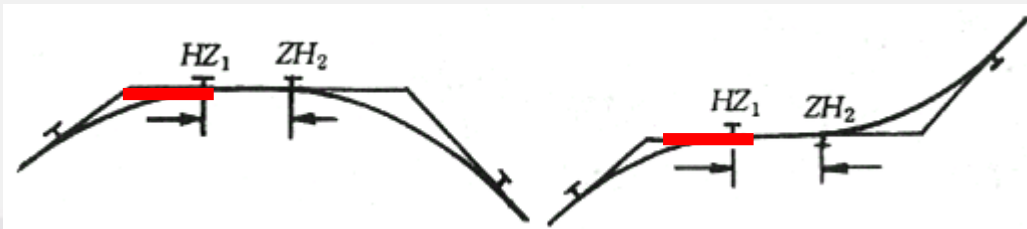


4. same direction adjacent curve, reverse curve and intermediate straight line

Definition

- The two same directional curve are called same direction adjacent curve;
- And the two adverse directional curve are called reverse curve;

The line between them is called intermediate straight line.



The length of intermediate:

Rail level	Ordinary district	Hard district
I	80	40
II	60	30
III	50	25

5. Train resistance

Basic resistance: the resistance exists even the train is running on flat and straight line; it resists any time;

Additional resistance: such as *ramp resistance, curve resistance, tunnel resistance and so on; the direction of the additional resistance and the train are opposite.*

curve additional resistance:

The resistance is larger on curve than on the straight line; the increased part is called curve additional resistance, curve resistance for short.

causes:

when running on curve, there exists more friction.

Formula :

$$\varpi_r = \frac{600}{R} \text{ (N/KN)}$$

From $\varpi_r = \frac{600}{R} \text{ (N/KN)}$

we know: the smaller the curve radius is, the larger curve resistance there exists, the more adverse influence it has.

ϖ_r - unit curve resistance(N/KN);

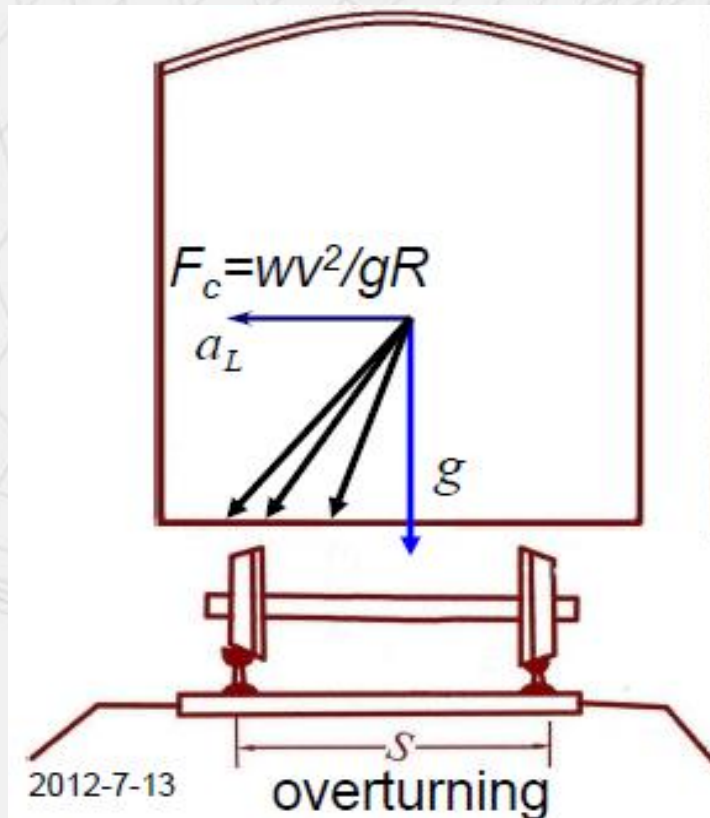
R - curve radius(m);

600 - experiment data.

The minimum curve radius:

Rail level	Speed (km/h)	minimum curve radius	
		Ordinary district	Hard district
I	160	2000	1600
	120	1200	800
	80	500	450
II	120	1000	800
	80	450	400
III	100	600	550
	80	400	

Principles of determining minimum radius



Train rounding a curve

$$a_L = \left(\frac{V}{3.6} \right)^2 \cdot \frac{1}{R}$$

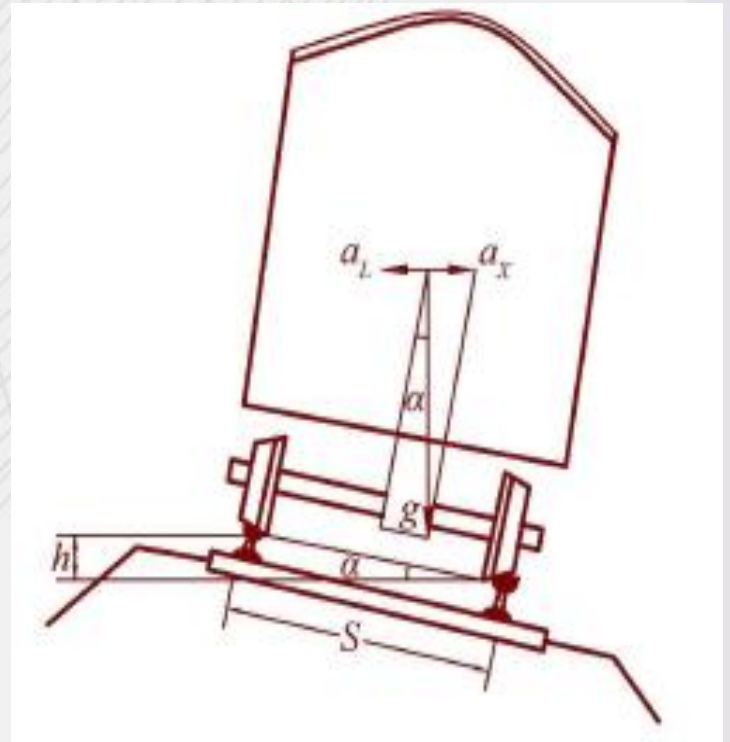
Superelevation

Raising the outside rail a distance h in mm above the inside rail

1. Elevate outside rail by h or
2. elevate outside rail by $h/2$ and lower inside rail by $h/2$

Function of superelevation

- To counteract the effects of F_c
- both wheels bear equally on the rails
- both rails will be equally stressed and weared
- acceptable traveling comfort
- high track stability and safe train operation



Superelevation formula

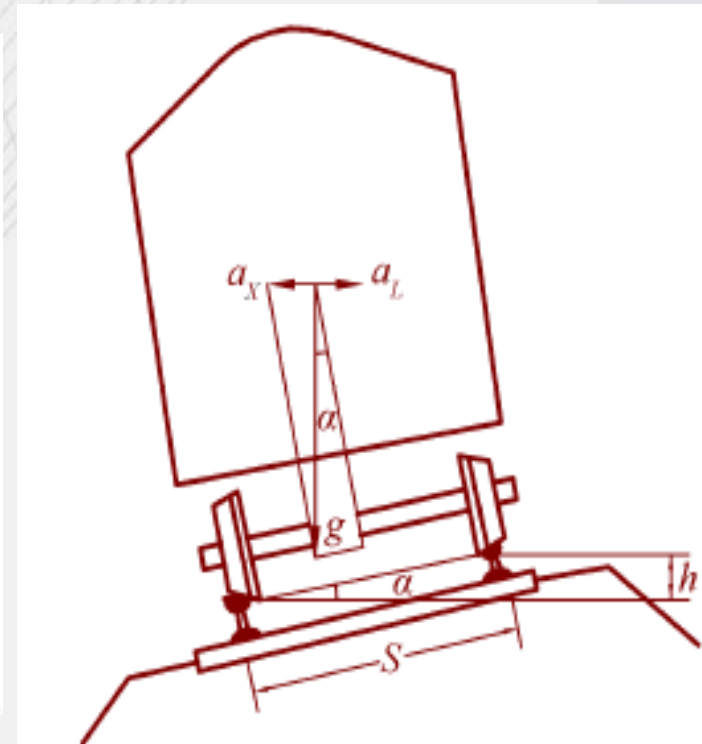
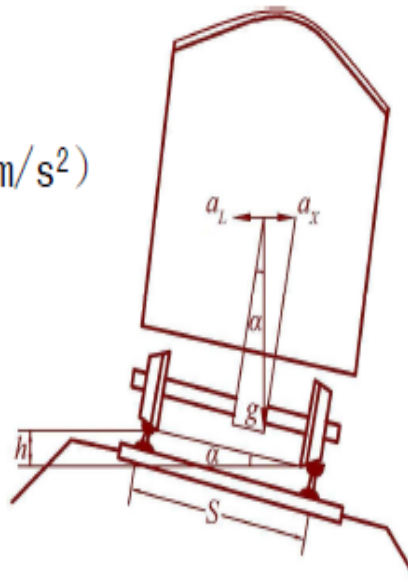
$$a_L = \left(\frac{V}{3.6} \right)^2 \cdot \frac{1}{R} \quad (\text{m/s}^2)$$

$$a_X = g \cdot \tan \alpha \approx g \cdot \sin \alpha = g \cdot \frac{h}{S} \quad (\text{m/s}^2)$$

$$\text{let: } a_L = a_X$$

$$\text{then: } \left(\frac{V}{3.6} \right)^2 \cdot \frac{1}{R} = g \cdot \frac{h}{S}$$

$$h = \frac{S}{gR} \left(\frac{V}{3.6} \right)^2$$



$$a_X = g \cdot \tan \alpha \approx g \cdot \sin \alpha = g \cdot \frac{h}{S} \quad (\text{m/s}^2)$$

For standard gauge track, $s = 1500\text{mm}$

$$h = \frac{1500 \times V^2}{3.6^2 \times 9.81 \times R} = 11.8 \frac{V^2}{R}$$

Maximum allowable superelevation

From the requirements of safety operation and stability of train and travelling comfort of passengers (when it negotiates the curve or stops at the curve in case of emergency)

- *with some eccentricity factor of safety of center of mass of the train*
- *it should be limited to some value*

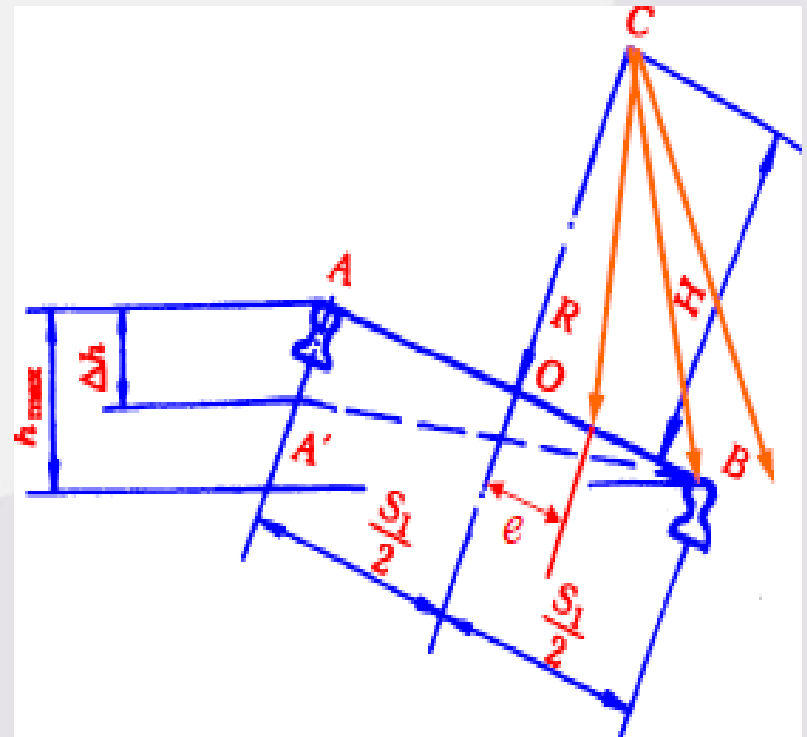
On any curve there is always unbalanced superelevation.

- *Deficient superelevation*

$$h_d = 11.8 \frac{V_{\max}^2}{R} - h$$

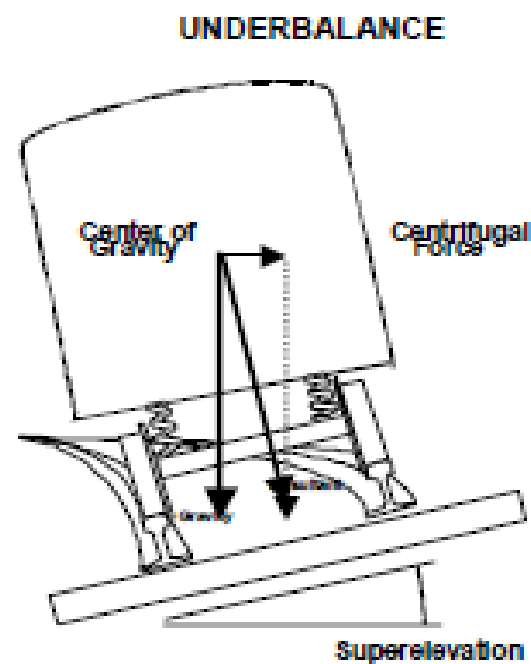
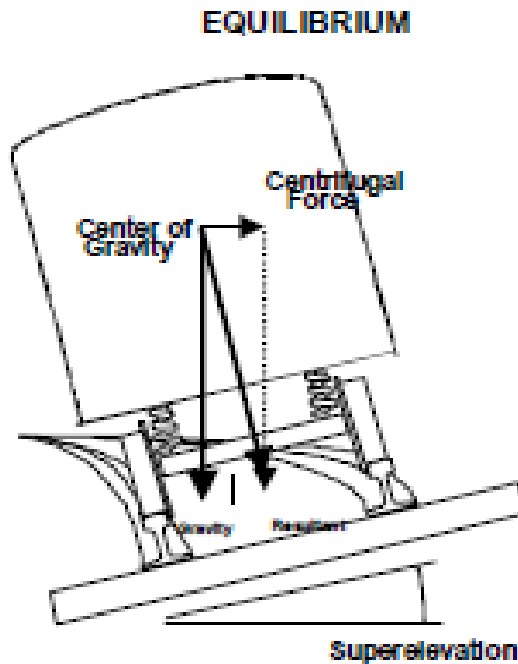
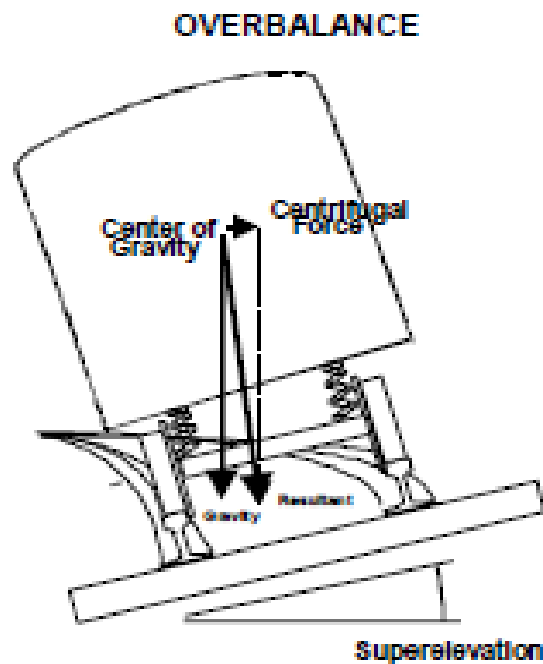
- *Surplus superelevation*

$$h_s = h - 11.8 \frac{V_{\min}^2}{R}$$



Maximum allowable superelevation- AREMA Calculation

Overbalance, Equilibrium and Underbalance



$$V_{\max} = \sqrt{\frac{E_a + 3}{0.0007D}}$$

Amount of Underbalance

$V_{\max}$ = Maximum allowable operating speed (mph).

E_a = Average elevation of the outside rail (inches).

D = Degree of curvature (degrees).

Minimum radius, maximum radius and maximum speed at curve

1. -from comfort and stability requirement minimum radius of the curve should be determined
2. -from track maintenance and regularity the maximum radius should be limited to allowable value

 Maximum speed at the curve also has to satisfy stability and comfort against overturning.

Railway clearance,,,,,,,,,,,,,,,,, /chapter 5, 6/

Vertical and lateral clearances

Plane of a line

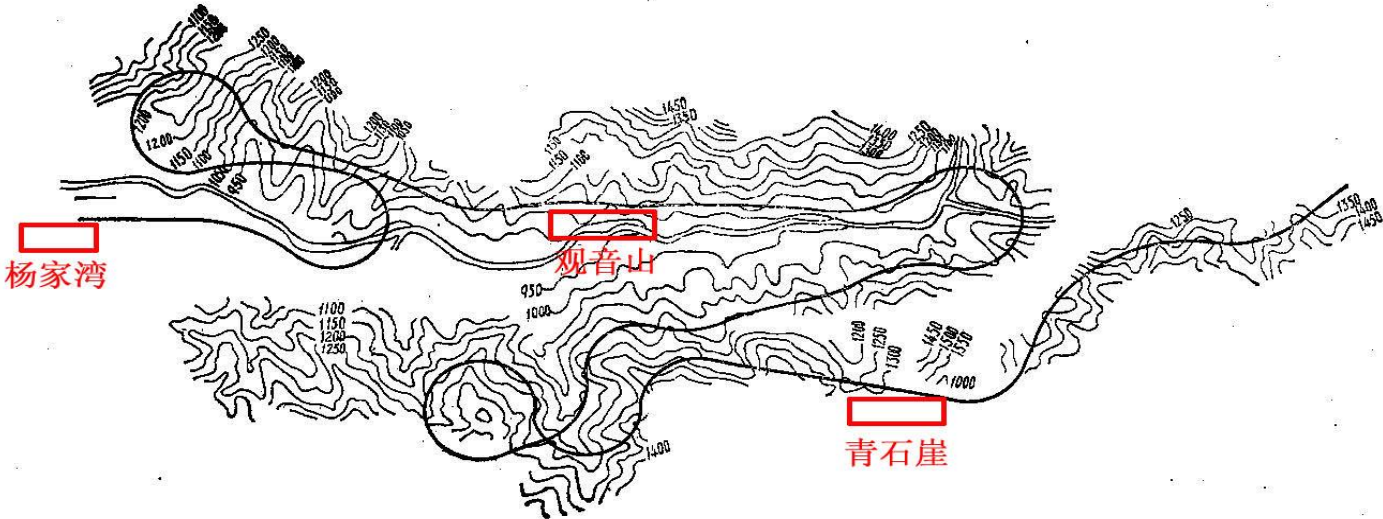
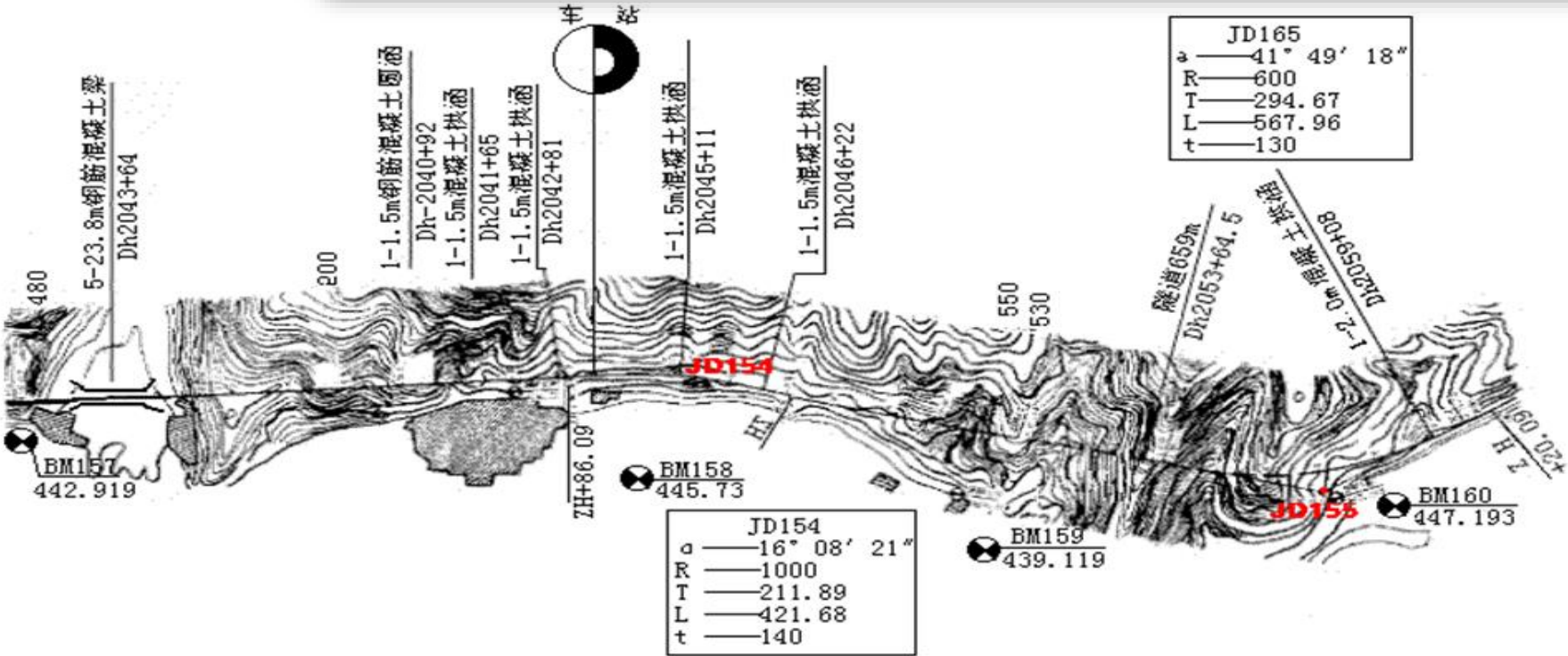


图 3-16 宝成线通过秦岭展线



2.3. Profile design of Railway Line

Main design components are

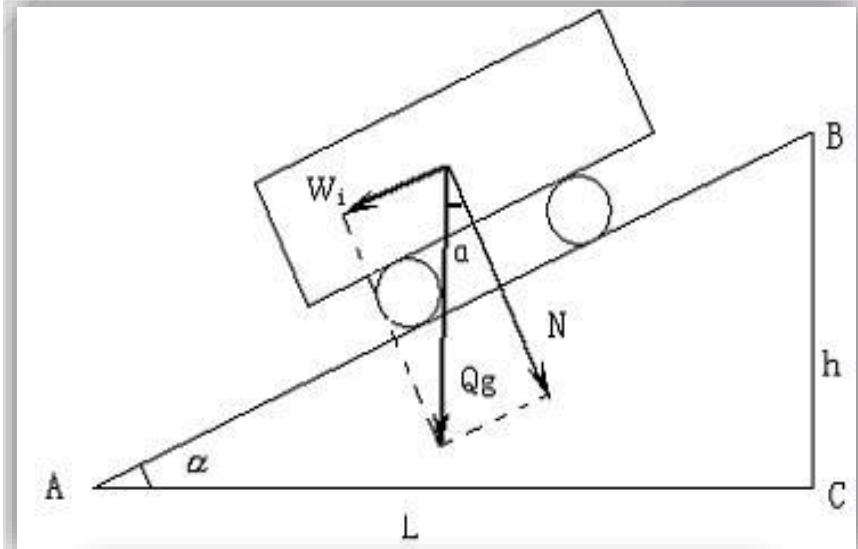
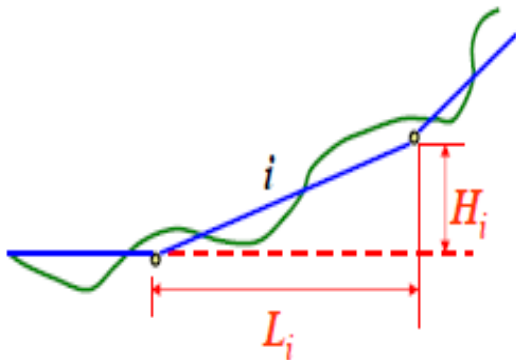
- 1. Gradient (algebraic difference)**
- 2. Vertical curve (sag or crest)**
- 3. Radius of curve**

2.3. The longitudinal section of rail line

The longitudinal section of rail line is consisted of **flat road**, **ramp** and **vertical curve**.

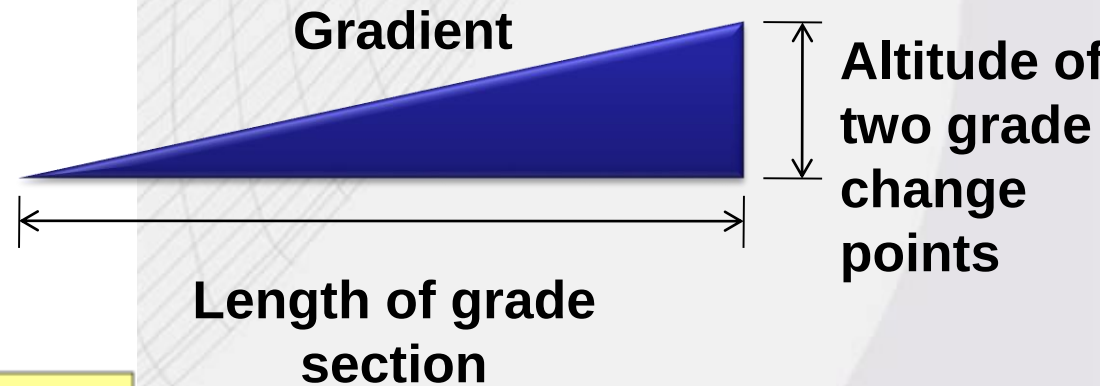
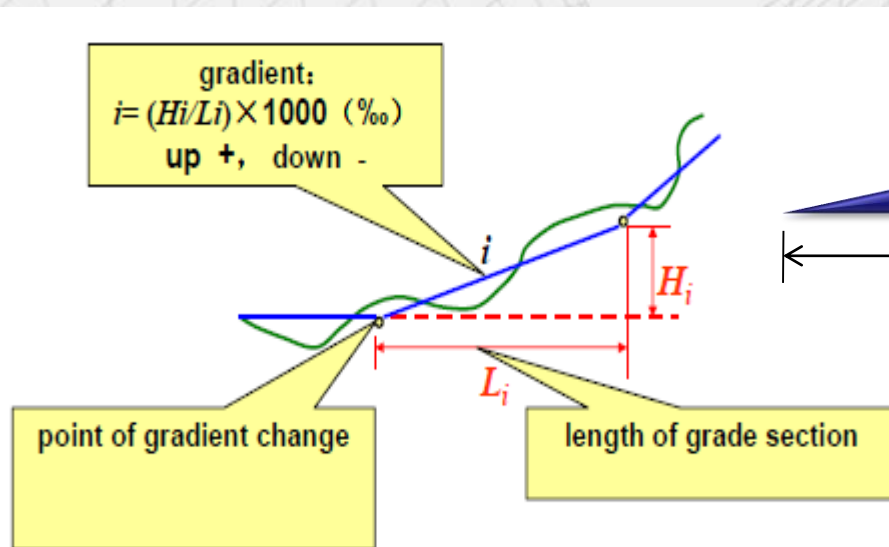
1. The gradient and vertical curve

— The railway profile is composed of grade sections which length and gradient is different each other. The feature of grade section is expressed in the length and gradient



$$i_{\text{‰}} = \frac{h}{L} = \tan \alpha$$

Features of grade



Gradient and length are used to represent characteristic of grade section.

Length of grade section is refer to the horizontal range between two grade change points.

What to do...?

- Determining the maximum grade
- Determining the length of grade section
- Determining the connection at the point of gradient change
- Design the grade section

Vertical Geometry - Grades

Highway –
4% common
6% on ramps
Up to 8% on
county roads

Rail – rarely exceeds 1%
(2-2.5% for industry lines)



LRT – maximum 4 to 6%
Up to 10% for short sections

Maximum calculated gradient

$$i_{\max} = \frac{(\lambda_y F_j - W_0) \times 10^3}{Mg} = f_j - w_0$$

$$i_{\max} = \frac{3600 \cdot p_k - w_0 \cdot g \cdot V_{\max}}{g \cdot V_{\max}}$$

where M —— The total mass of MU (t);

$i_{\max}$ —— maximum calculated gradient;

$V_{\max}$ —— maximum designed speed(km/h);

w_0 —— unit basic resistance of EMU under the calculated speed (N/kN);

F_j —— calculated tractive effort(kN);

p_i —— average power per ton mass of MU (t);

λ_y —— utilization coefficient of tractive effort;

g —— acceleration of gravity(m/s²);

➤ **E.g. for a CRH3 EMU composed of 3 motors and 3 trailers, with 21.05 kW/t of average unit power per ton mass run upward at speed of 300km/h, the maximum gradient can be calculated as follows:**

$$\begin{aligned} w_0 &= 0.66 + 0.00245V + 0.000132V^2 \\ &= 0.66 + 0.00245 \times 300 + 0.000132 \times 300^2 = 13.275 \quad (\text{N/kN}) \end{aligned}$$

$$i_{\max} = \frac{3600 p_k - w_0 \cdot g \cdot V_{\max}}{g \cdot V_{\max}} = \frac{3600 \times 21.05 - 13.275 \times 9.81 \times 300}{9.81 \times 300} = 12.47$$

- The result indicated that under the given condition, a CRH3 EMU can run on a grade of 12‰ with speed of 300 km/h.
- To add the number of motors can increase the total power of EMU so that the unit power per ton mass can be increased. On the other hand, to reduce the number of car in a unit can also attain the purpose to increase the unit power per ton mass. In this way, the maximum gradient in railway line for passenger traffic will not be limited by traction power.

➤ **Ruling grade**

- The ruling grade is defined here as the maximum gradient over which a tonnage train can be hauled at a given speed by a given locomotive consist or horsepower

➤ **Helper grade**

- The maximum grade used in sections trains being hauled by two or more locomotives

● calculation of ruling grade

$$i_x = \frac{\lambda_y F_j - (P \cdot w_0' + G_x \cdot w_0'') \cdot g}{(P + G_x) \cdot g}$$

where G_x —— The norm of traction mass (t);

$i_{j\max}$ —— maximum calculated gradient;

w_0' —— unit basic resistance of locomotive under the calculated speed (N/kN);

w_0'' —— unit basic resistance of rolling stock under the calculated speed(N/kN);

● e.g3—1 In a railway line for mixed freight and passenger traffic, trains composed of cars with rolling bearing that is hauled by SS3 electric locomotive, if the tractive mass is 3 500 tons, the calculated maximum gradient is: ($V_j=48$ km/h, $F_j=317\,800$ N, $P=138$ t):

$$w_0' = (2.25 + 0.019 \times 48 + 0.00032 \times 48^2) = 3.899 \text{ (N/kN)}$$

$$w_0'' = (0.92 + 0.0048 \times 48 + 0.000125 \times 48^2) = 1.4384 \text{ (N/kN)}$$

$$i_x = \frac{0.9 \times 317800 - (138 \times 3.899 + 3500 \times 1.4384) \times 9.81}{(138 + 3500) \times 9.81} = 6.48 \text{ (‰)}$$

takes $i_x = 6\text{‰}$

● algebraic difference between adjacent gradients

■ definition

- algebraic difference between adjacent gradients shall be expressed in absolute value of the algebraic difference Δi .

$$\Delta i = |i_1 - i_2| \quad (\text{‰})$$

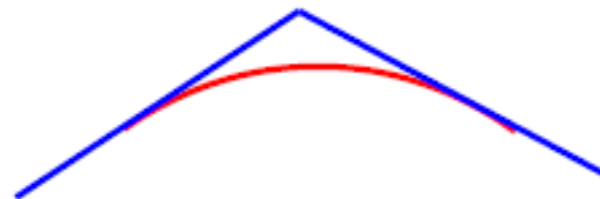
● VERTICAL CURVES

■ definition

- For smooth riding (and good appearance) vertical curves provide a gradual transition from one grade to another.

■ Vertical curve type

- The circular arc
- Parabola arc



2. Radius of vertical curves

- Ensure No derailment**
- Riding comfort**
- No coupler separation**
- Meet maintenance requirement**

sag or crest vertical curves

Minimum length of grade section.....



**Take care
of phasing
of curves**

2. Additional resistance for gradient

It exists when train is running on the ramp.

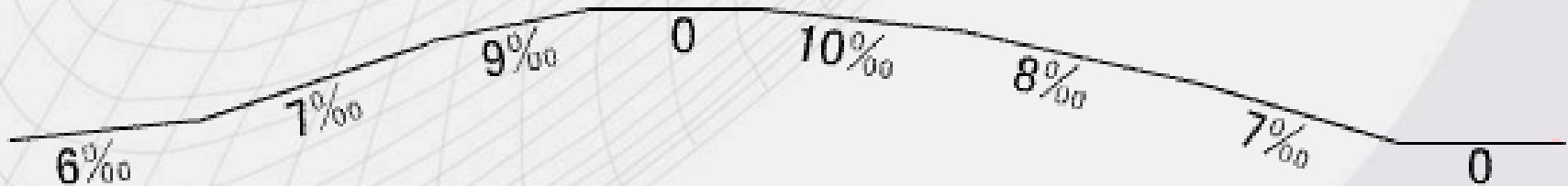
Its value w_i (N/KN) is equal to the thousandth of gradient.

There are positive and negative additional resistance for gradient, the negative one has the same effect as traction.

3. Limiting gradient and pusher grade

(1) Selection for limiting gradient

The bigger the gradient is, the bigger the resistance there exists, and the smaller the train traction weight is.



Definition:

The gradient which can decide the maximum cargo weight of a locomotive is called the limiting gradient.

It is often equaled to the maximum gradient.

(2) Conversion gradient

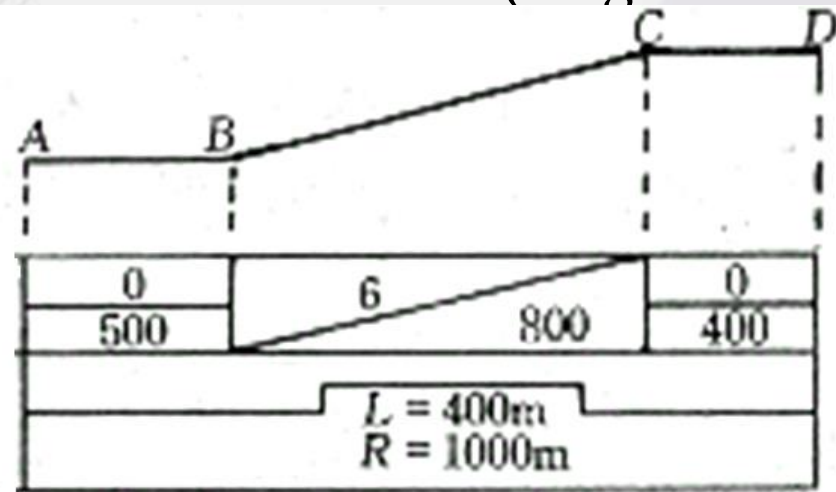
If there has curve on the ramp, the additional resistance is include of additional resistance for curve and gradient.

so: $\varpi = \varpi_r + \varpi_i$

The conversion gradient:

$$i_c \text{ ‰} = (\varpi_r + \varpi_i) \text{ ‰} = (i_r \pm i) \text{ ‰}$$

Example: Evaluate the conversion gradient of BC section.(length of train is 800m).



$$i^{BC} \text{ ‰} = (\varpi_r + \varpi_i) \text{ ‰} = \left(\frac{600}{1000} \times \frac{400}{800} - 6 \right) \text{ ‰} = -5.70 \text{ ‰}$$

$$i^{BC} \text{ ‰} = (\varpi_r + \varpi_i) \text{ ‰} = \left(\frac{600}{1000} \times \frac{400}{800} + 6 \right) \text{ ‰} = 6.30 \text{ ‰}$$

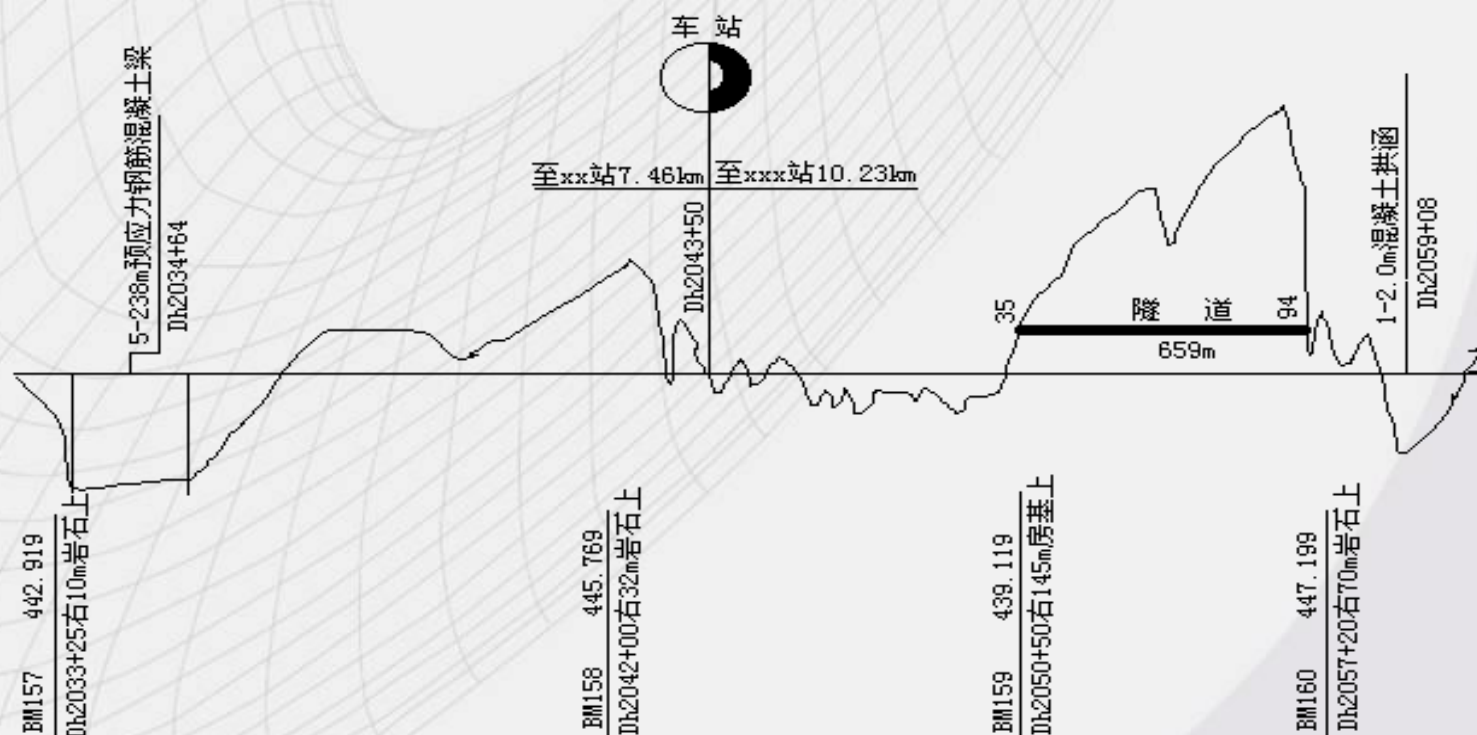
(3) The pusher grade

On some special hard sections, we can :

- a) Build a tunnel to across it;*
- b) or use a ramp with its gradient beyond the limiting gradient, which is called the pusher grade .*



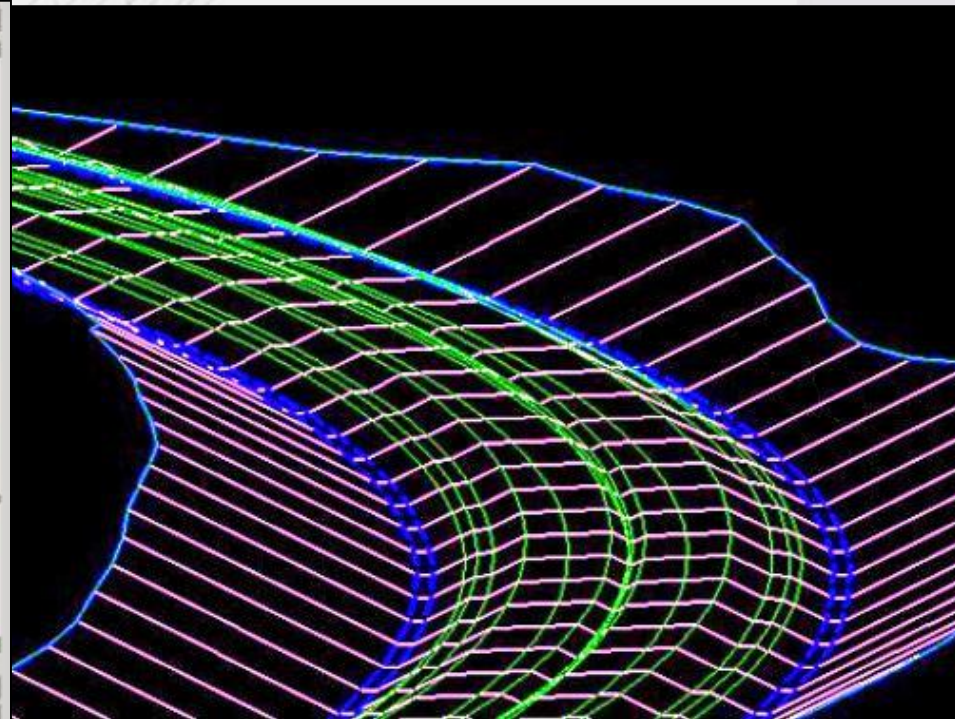
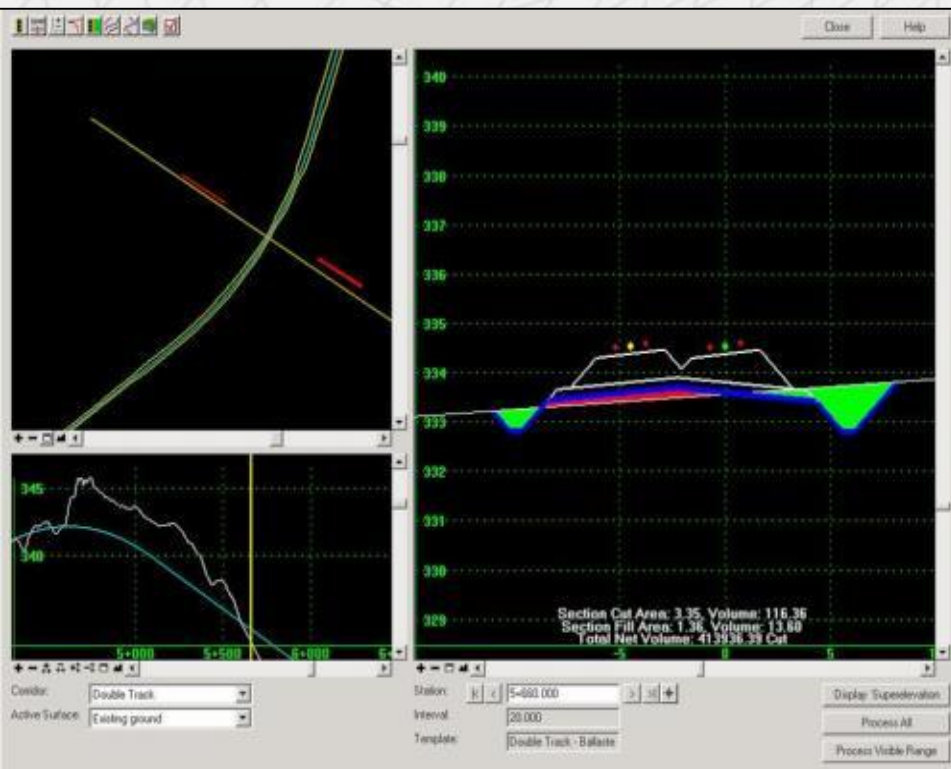
4. longitudinal profile of railway



地质情况	卵石层，覆盖粘沙土。		黄土质粘沙土	砂砾岩，山坡上覆盖碎石及黄土质砂粘土加碎石。		碎石，砂粘土夹碎石。	碎石，砂粘土夹土。	砾岩，砂砾岩。		花岗岩
路肩设计标高	457.15 457.25	457.45	457.15	456.55	456.10	455.77	454.85	453.35	451.55	450.65
设计坡度	1		1.5				5	4.5		
地面标高	443.50	442.38	460.73	470.10	514.08	448.78				
加标			-38	-90	-81	-11	-18	-25		
百米标	2040		2050		2060					
线路平面设计连续公里	86.09		1-140		707.77		03.77		71.73	
	$\alpha-16^{\circ}08'21''$ R-1000 T-211.89 L-421.68				$\alpha-41^{\circ}49'18''$ T-294.67 R-600 L-567.96		1-130		20.09	

Design Views

- Rail Track Interface
- 3-D model



Sample software output

Part -II

Railway Sub grade

Definition :

- is the prepared earth on which the railroad ballast section and track structure are built
- A sub grade is an **earth structure**, which is formed through excavating or filling and can bear the track structure directly, including *section sub grade* and *sub grade of station and yard*.
- Railway sub grade is the foundation of the track, it inherit and pass on the weight of track and the moving load of train

Characteristics

The sub grade is the ***weakest and most unstable part*** in railway line works. If the sub grade does not have sufficient stability, it'll be impossible to maintain proper track alignment, profile(surface) and cross level.

In order to ensure the smoothness of the track, following conditions shall be satisfied during the design.

Main Design contents:-

- a) Control of sub grade deformation
- b) Evenness of sub grade rigidity
- c) Stability under train operation;
- d) Stability under natural conditions



The four basic geometric features are:

- ✓ ☐ Width of top of subgrade or bottom of cut
- ✓ ☐ Height of fill or depth of cut
- ✓ ☐ Side slopes of fill or cut
- ✓ ☐ Provision for drainage

Typical Section - Railroad



Two main functions of the railroad subgrade are:

- To bear the traffic load without becoming damaged
- To drain off the water to the side.

Vertical Load Distribution

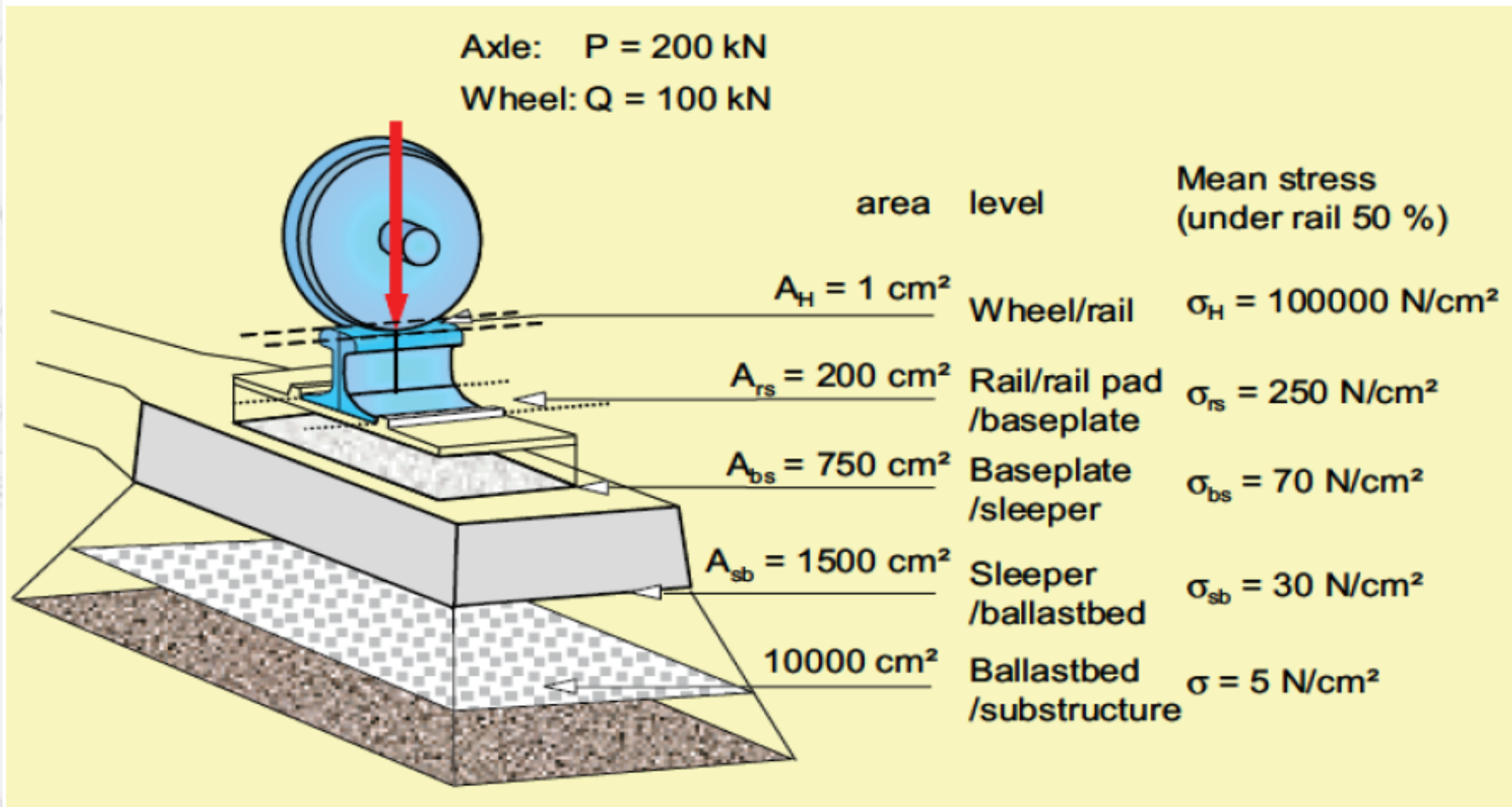


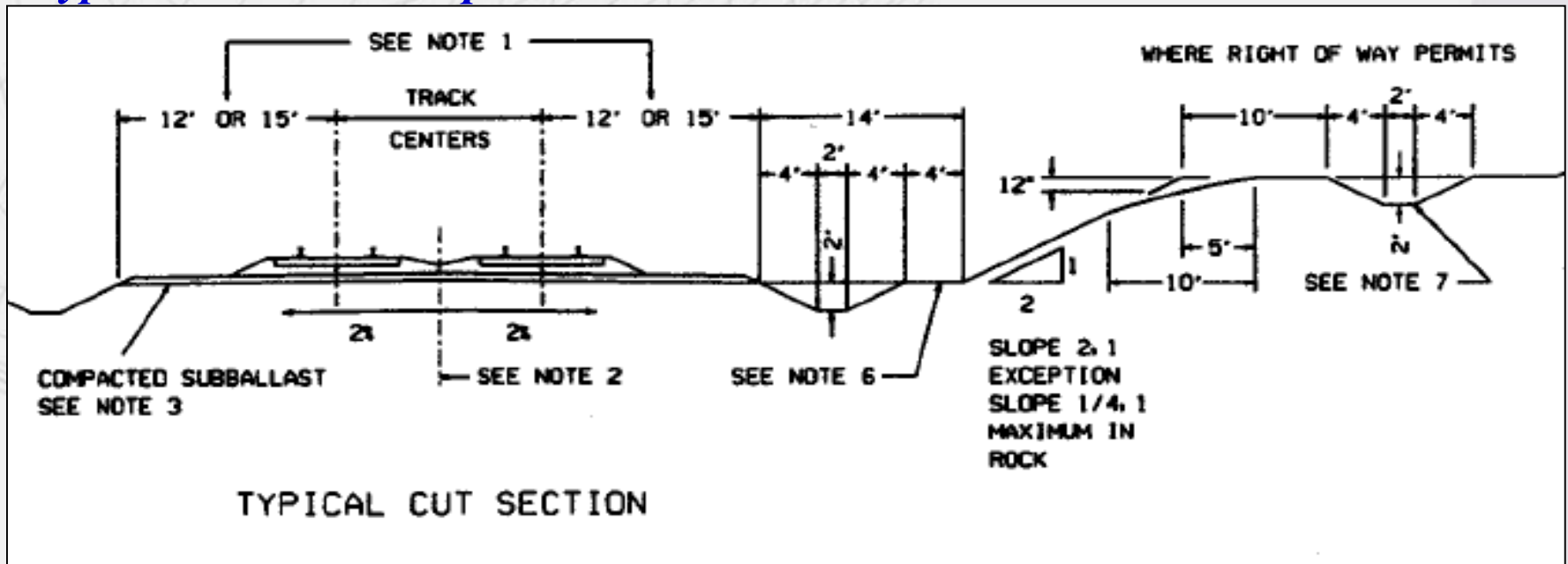
Fig 2: Principle of load transfer (modern track Technology)

1. Roadbed sections

Usually, the cross section perpendicular to the center line is called the roadbed section.

According to the topography and the shape of the cross section, the roadbed section can be divided into six types.

Typical section - multiple tracks

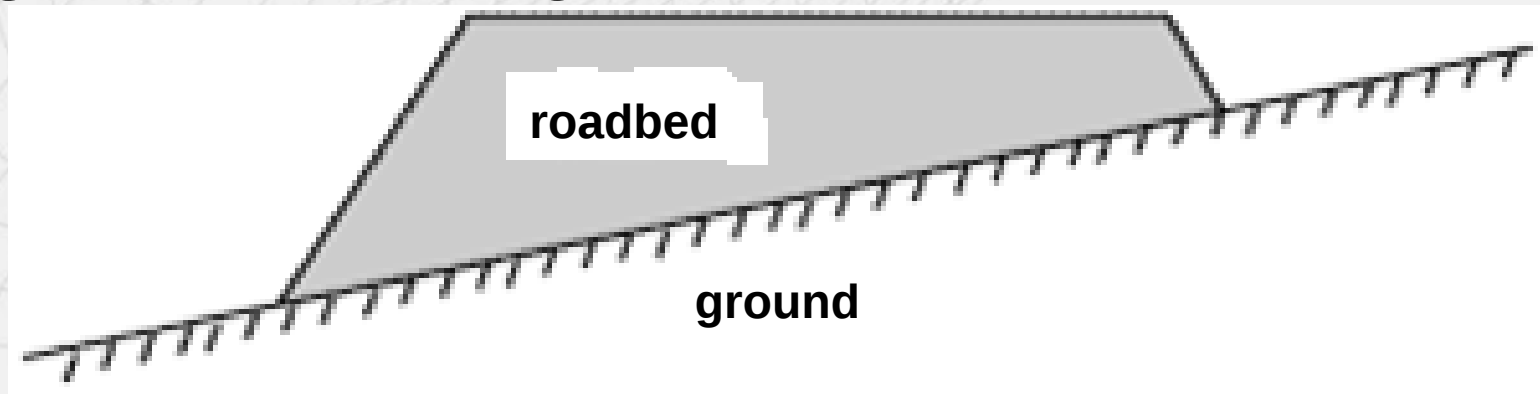


- Track centerlines minimum 13' apart
- Roadbed sloped to drain
- Sometimes wider shoulders for maintenance purposes

Roadbed sections cont..

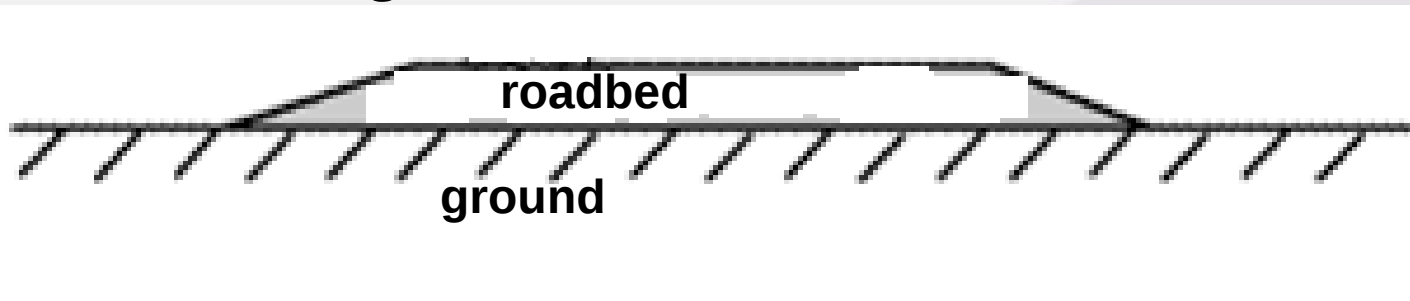
(1) Embankment

The roadbed forms through filling of soil and stone, while the design of which is above ground.



(2) Roadbed without filling or digging

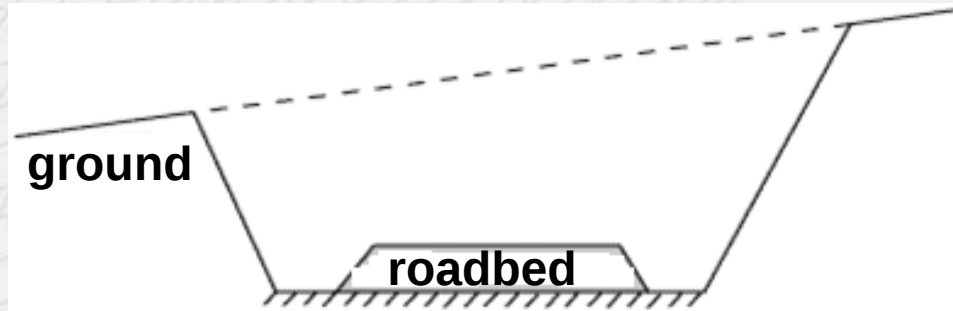
The design of roadbed is the same as ground, and it can directly be laid on the ground.



Roadbed sections cont..

(3) Through cut

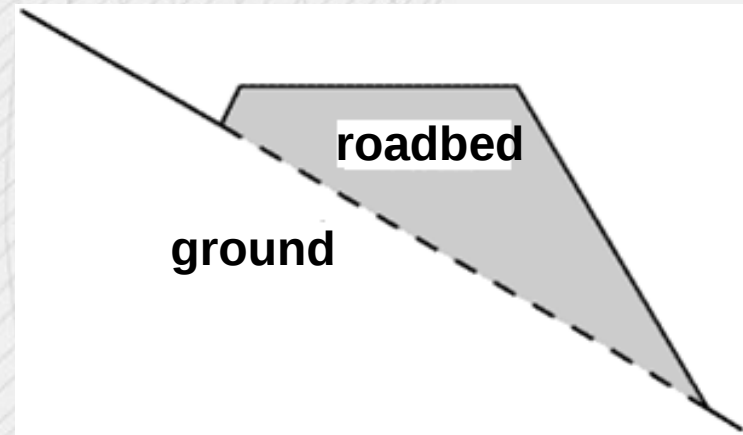
The roadbed forms through digging, while the design of which is under ground.



Roadbed sections cont..

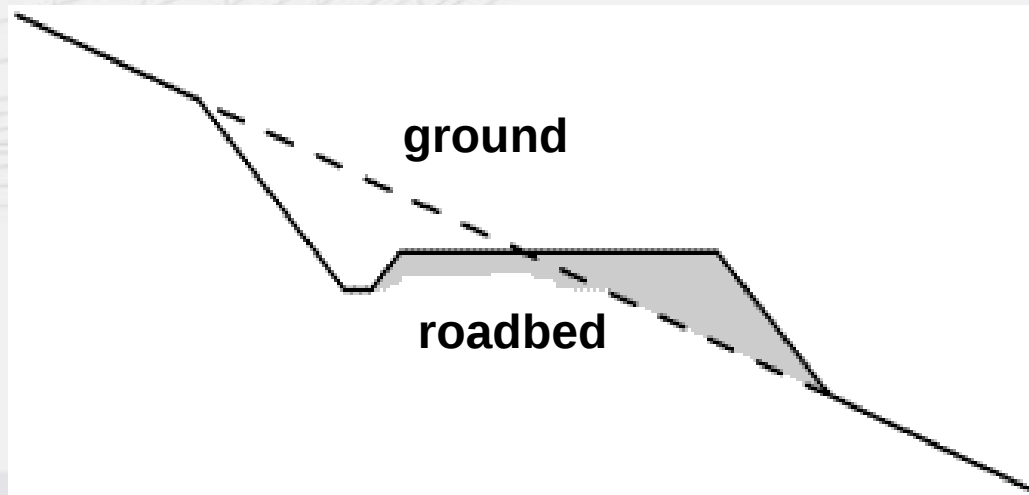
(4) Half-embankment

In the mountain areas, some of the roadbed is formed through filling.



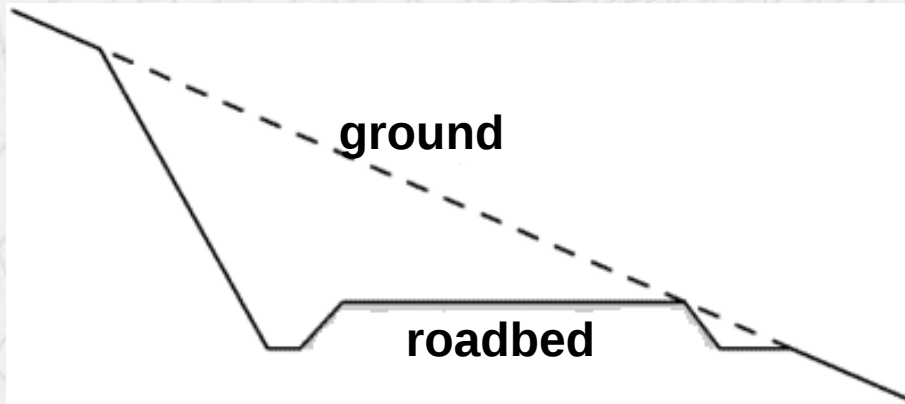
(5) Side-hill cut

The roadbed is formed through filling and digging.



(6) half through cut

In the mountain areas, some of the roadbed is formed through digging.

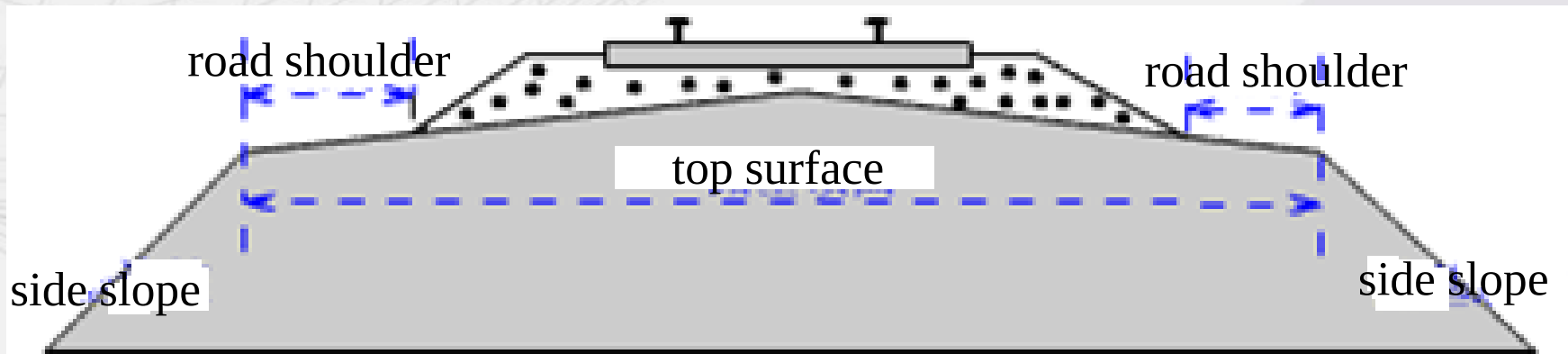


Generalized

Roadway is the strip of land containing the track, ditches, and other facilities needed for the operation of the railroad

Roadway width must be wide enough to accommodate the track side ditches portion of embankment or cut slopes parallel service roads and other structures and facilities necessary for the operation of the railroad

2. Form of roadbed



a) top surface of roadbed

Top surface of roadbed is where the rail laid on;

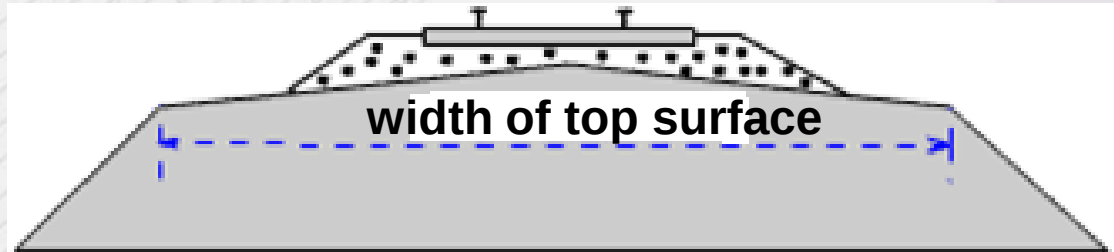
width of top surface is refer to the distance from one side of the road shoulder to another side.



form with road camber



form without road camber



✓ the shape

with road camber: soil without water permeability

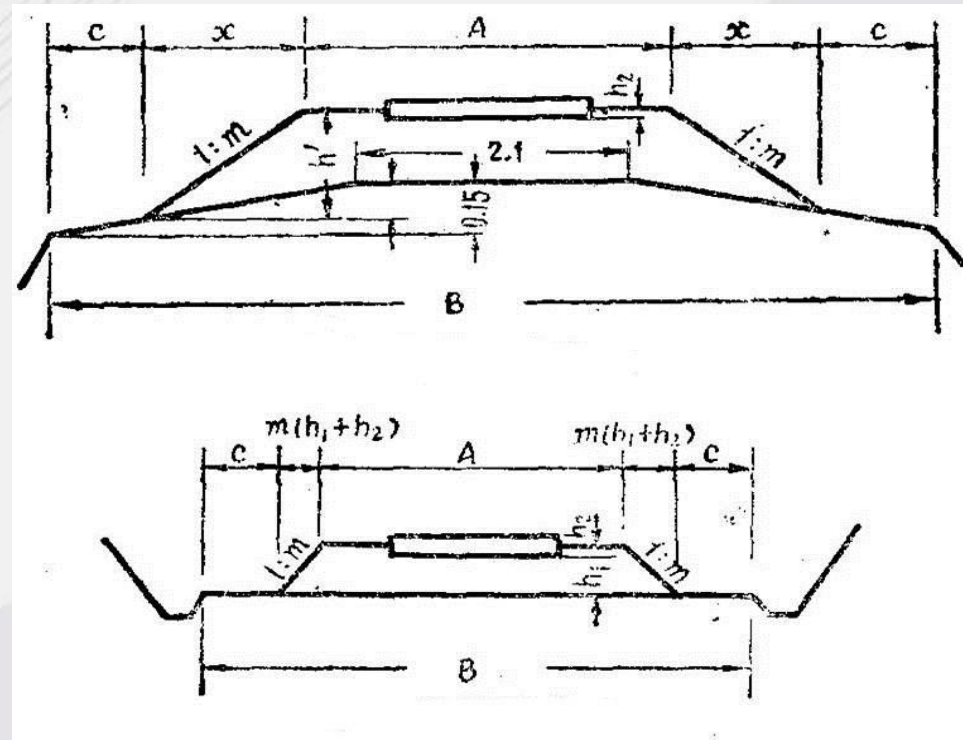
[ladder-shaped—single line and triangle—double line]

without road camber: soil with water permeability

✓ characteristic

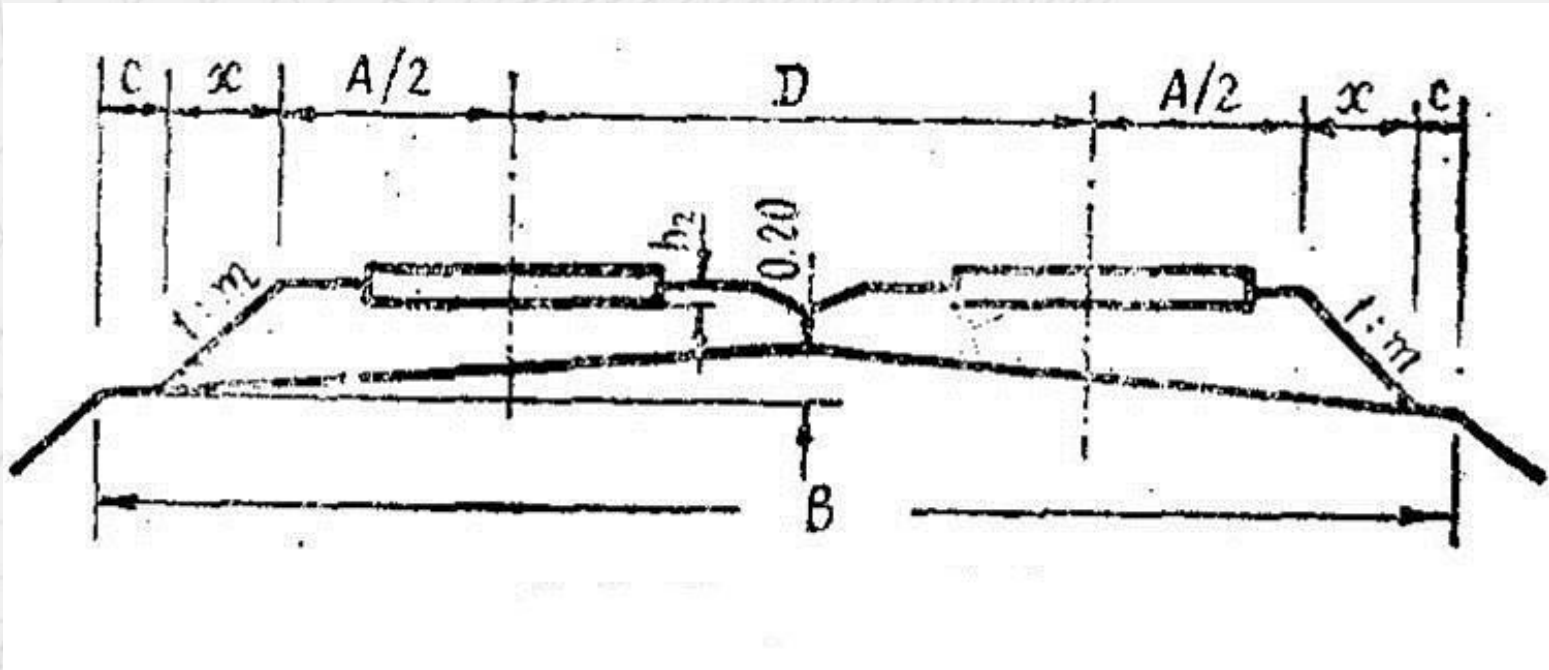
a. the roadbed without road camber is higher;

b. on curve section, the outside roadbed must be widen;



b. double line(soil without water permeability)

$$B = 2C + 2x + A + D$$



b) road shoulder and side slope

Road shoulder: those part without ballast bed;

Side slope: the slope apart from road shoulder.



Function of road shoulder:

- 1) bear the force, strengthen the stability of roadbed
- 2) keep ballast bed compacted
- 3) be convenient for the setting of signs
- 4) for the walk of workers

(3) Ancillary facilities

Function : to ensure the strength and stability of roadbed.

① Drainage facility



② safeguards

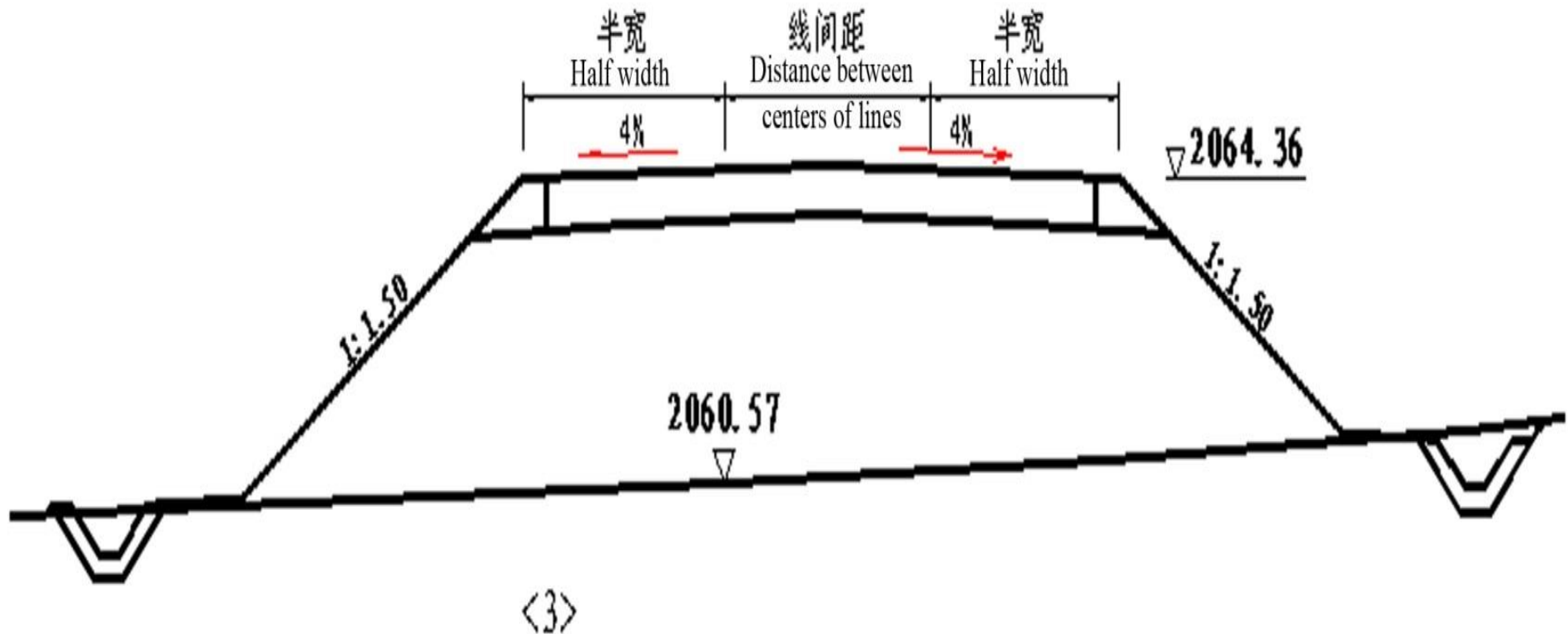


vegetation



retaining wall

Design of sub grade surface



- **Shape of the sub grade surface:** 4% crown slope/herringbone drainage slopes are set from the sub grade center to both sides and the sub grade surface shall remain triangular when the curve is widened.

Width of the sub grade surface:

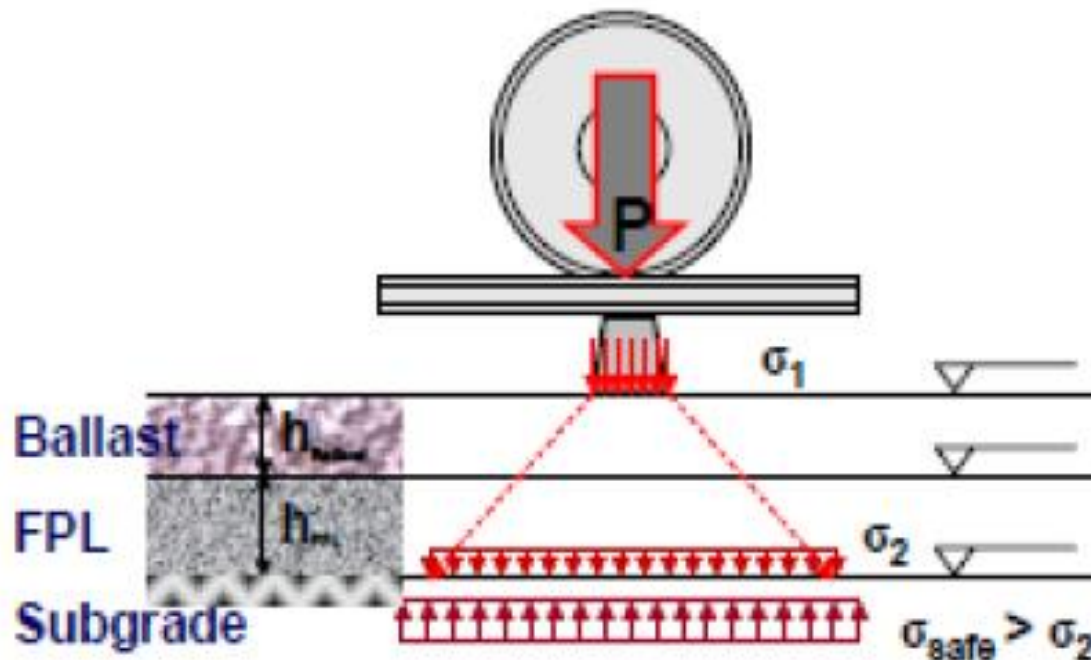
- It shall be determined according to following factors, design speed, long-term track type, number of main line, distance between centers of lines, curve widening, sedimentation and widening of road shoulders, road maintenance type (mechanical maintenance or manual maintenance), the overhead contact system tower and setup of cable trench and pit etc.
- There are corresponding specified speed target values for standard sub grade with different width in straight sections.

Generally railway subgrade design content includes:

- a. Design of subgrade surface (shape, width, formation level etc.)
- b. Design of subgrade bed (thickness, filling materials and compacting requirements)
- c. Design of embankment
- d. Design of cutting
- e. Design of transitional section
- f. Ground treatment (mainly for the embankment base and the cutting foundation base in special cases)
- g. Side slope supporting and retaining and protection (including embankment and cutting)
- h. Design of subgrade drainage system
- i. Design of cut-fill adjustment
- j. Design of land utilization

Subgrade design procedures:

1. Determine Allowable subgrade stress
2. Determine stress at sub ballast-subgrade interface due to superstructure load
3. Compare load stress with allowable stress
4. Determine formation/natural ground bearing capacity
5. Based on formation layer stress determine the thickness/depth of subgrade



Ballast depth (ballast and subballast combined) = f(applied stress, tie reaction, and allowable subgrade stress)

Different countries develop their own formula to determine the depth of formation level.

–**Talbot Equation**

$$h = (16.8Pa/Pc)^{4/5},$$

where -h = Support ballast depth, Pa= Stress at bottom of tie (top of ballast), *Pc= Allowable subgrade stress*

Note: Stress distribution independent of material

–**Japanese National Railways Equation**

$$Pc = 50Pa / (10 + h^{1.25})$$

–**Boussinesq Equation**

$$Pc = 6P / 2\pi h^2, \text{ where } P = \text{wheel load (lbs)}$$

–**Love's Formula**

$$Pc = Pa (1 - [1 / (1 + r^2/h^2)]^{3/2})$$

Where, r = Radius of a loaded circle whose area equals the effective tie bearing area under one rail

Subgrade Allowable Stress (Pressure)

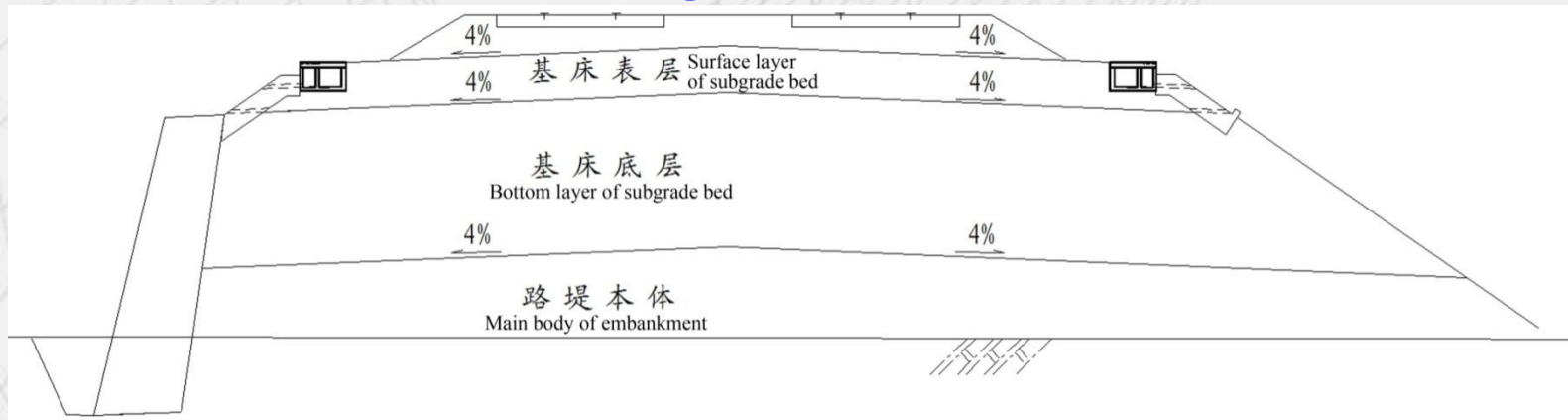
- "Traditional" design value of 20 psi

AREMA recommends limiting stress to 25 psi

Using soil strength with a factor of safety

- ✓ AREMA recommends a factor of safety of at least 2 and as much as 5 or more depending on the traffic (wheel loads and load repetitions) and soil conditions.
- ✓ Company design standards will dictate (e.g. Army allows a design unconfined compressive strength (q_u) of $1.0 q_u$ for "normal" traffic levels -less than 5 MGT/yr -and design of $0.8 q_u$ when traffic levels exceed 5 MGT.)
- ✓ Hay recommends factor of safety of 1.5 as applied to an ultimate bearing capacity of $<2.5 q_u$, thus allowable stress $<1.67 q_u$.

Thickness of sub grade bed



Designed Speed (km/h)	Surface Layer Thickness (m)	Bottom Layer Thickness (m)	Total Thickness of Subgrade Bed (m)
$V \leq 160$	0.6	1.9	2.5
$V = 200$	0.6	1.9	2.5
$200 < V \leq 250$	0.7	2.3	3
$V \geq 300$ $V \geq 300$ with ballast	0.4	2.3	2.7
$V \geq 300$ $V \geq 300$ without ballast	0.7	2.3	3

Material type

Designed Speed (km/h)	Surface Layer of Sub grade Bed (m)	Bottom Layer of Sub grade Bed (m)
$V \leq 160$	Group A filling materials	Group A or Group B filling materials or improved soil
$V = 200$	Graded crushed stone or graded sand gravel	Group A or Group B filling materials or improved soil
$200 < V \leq 250$	Graded crushed stone	Group A or Group B filling materials or improved soil
$V \geq 300$ $V \geq 300$ with ballast	Graded crushed stone	Group A or Group B filling materials or improved soil
$V \geq 300$ $V \geq 300$ without ballast	Graded crushed stone	Group A or Group B filling materials or improved soil

Ground treatment

- ✓ When sub grade bed of soil cutting can not satisfy material and strength requirements, replacement measures are usually adopted.
- ✓ *Common measure for ground improvement*

- ❖ *Replacement of bed course*
- ❖ *Impact (vibration) rolling*
- ❖ *Heavy tamping and heavy tamping replacement*
- ❖ *Bagged sand well and plastic drainage board*
- ❖ *Crushed rock pile*
- ❖ *Sand compaction pile*
- ❖ *Lime-soil (cement-soil) compaction pile*
- ❖ *Pile trusted-expanded in column-hammer*
- ❖ *Cement-soil mixing pile*
- ❖ *Rotary jet grouting pile*
- ❖ *CFG pile*
- ❖ *Reinforced concrete pile net (pile raft) structure*
- ❖ *Reinforced concrete pile board structure*

3. Drainage of roadbed

The subgrade should be designed with complete & expedite drainage system

Effect of water

- *Surface water*: *erode the roadbed which make the soil soft*
- *Ground water*: *increase the humidity of roadbed and lowering the bearing force.*

Principal sources of water to be considered:

- ✓ *Rainfall directly on the track structure*
- ✓ *Surface water flowing toward and infiltrating the track structure*
- ✓ *Water flowing within the track structure*
- ✓ *Ground water*

Techniques used to reduce infiltration:

1. *Sloping the upper surface of the sub grade and top formation*
2. *Placement of clean ballast*
3. *Construction of cess drains below the bottom of the top formation*
4. *Shaping embankment shoulders so that water flows away from the track*

(2) Surface drainage of roadbed

1) arrangement of drainage ditch

- ① arrange it along the line;
- ② rail cant must $\leq 2\%$;
- ③ the size should be able to avoid water from overflow;
- ④ when two different size ditches are connected, there should be transition section;
- ⑤ for those special soil area, the ditch should use measures which prevent leaking and scouring.

2) facilities

Embankment:

- drainage ditch
 - place: two sides of embankment;
 - function: drain off water around embankment;
 - section: the same as side ditch.
 - used when the place cannot build a drainage ditch.
- rectangular tank

Through cut:

side ditch

place: one side or two sides of the roadbed;

function: drain off water from the side slope;

section: ladder-shaped, 0.4-0.6m deep and 0.4m

wide;

slope: 2—8‰

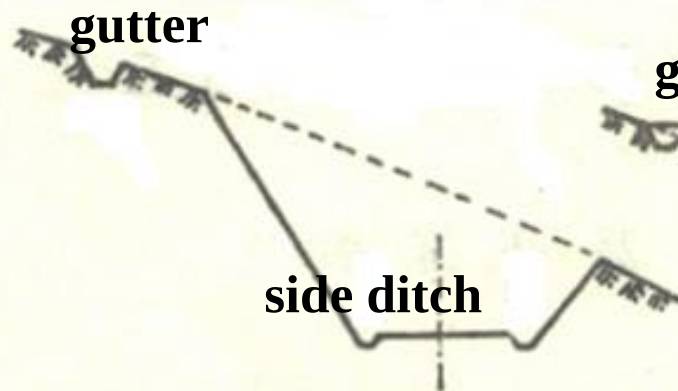
gutter

place: edge of through cut;

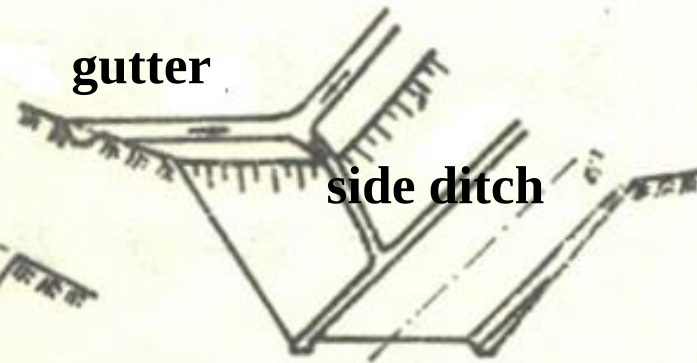
function: intercept water flowing into through cut;

section: the same as side ditch.

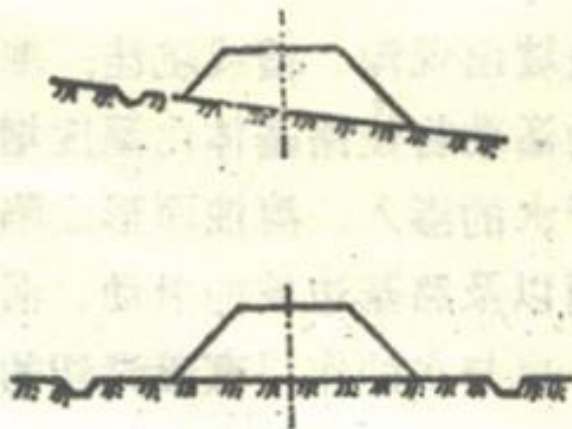
slope: 2—8‰



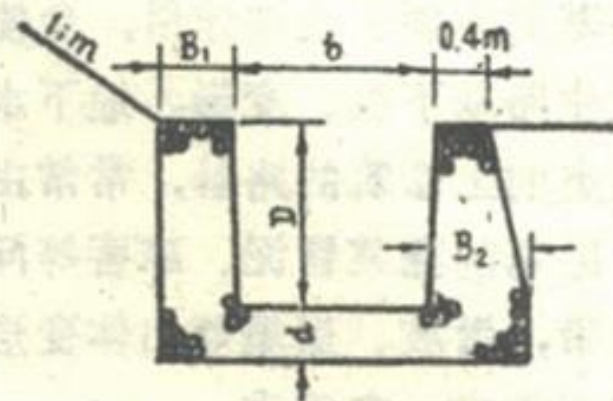
(a) side ditch



(b) gutter



(c) drainage ditch



(d) rectangular tank

(3) Ground drainage of roadbed

1) methods:- intercepting, dredging, lowering & sealing

2) facilities

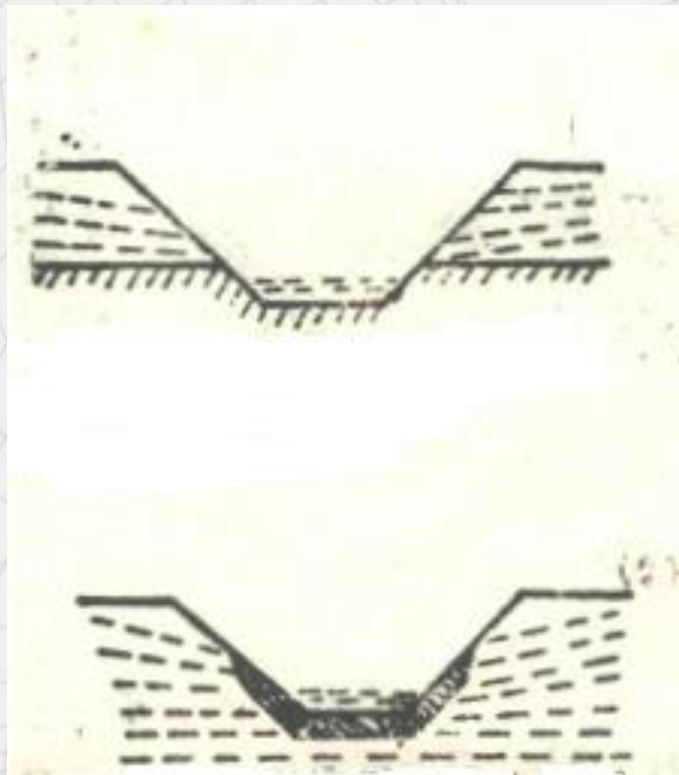
① Open ditch and deep sink

function: drain off ground water;

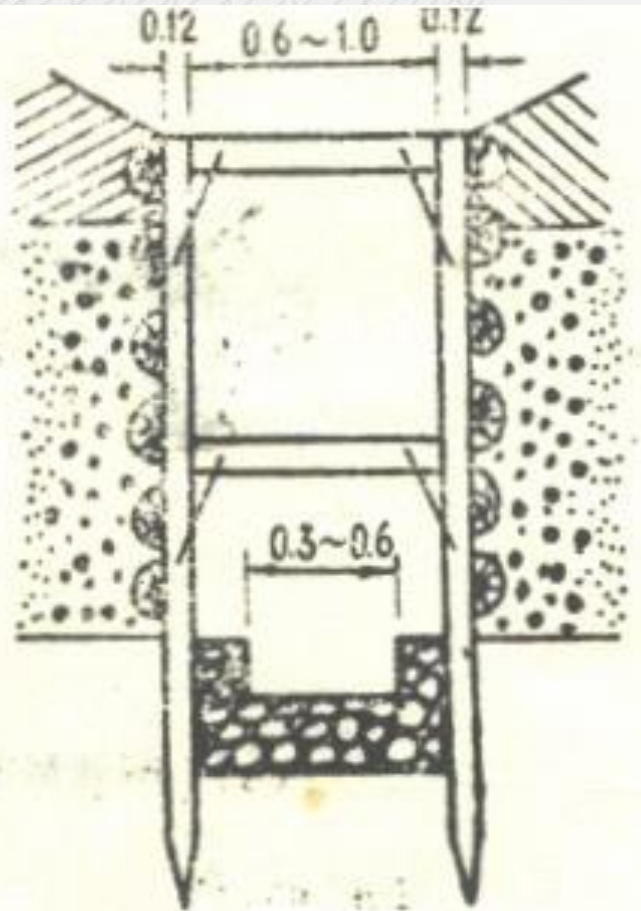
place: along the line;

section: open ditch: ladder-shaped

deep sink: rectangular



a. open ditch



b. deep sink

② slope sewer

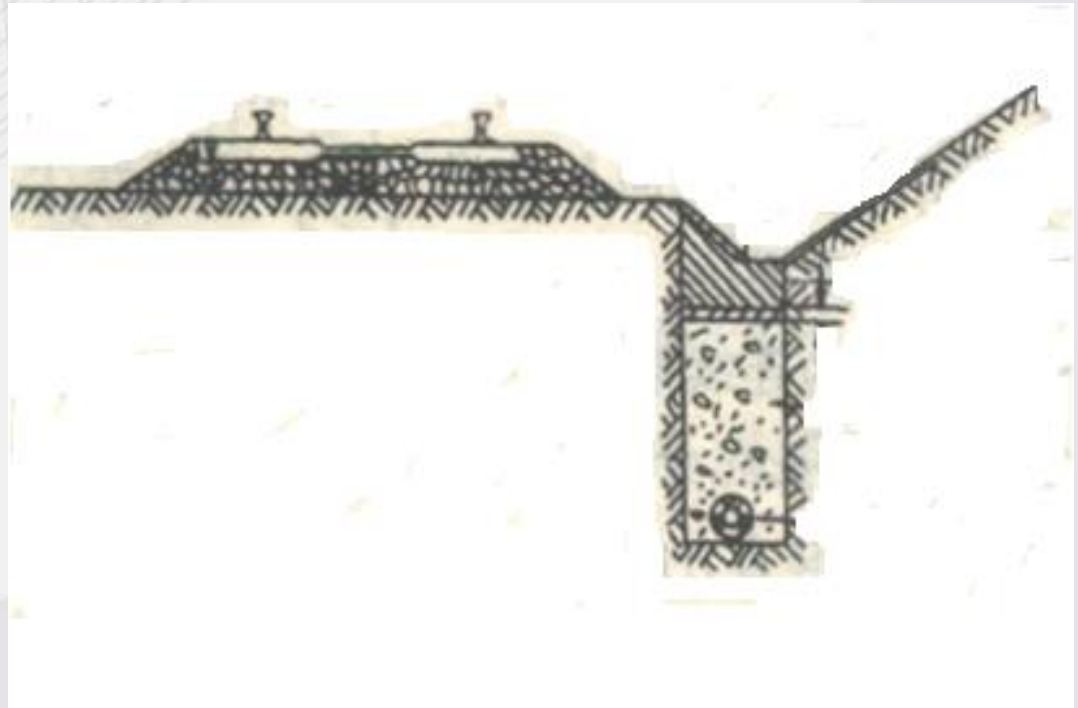
Function:

drain off ground water of the side slope;
support the side slope and keep it steady.

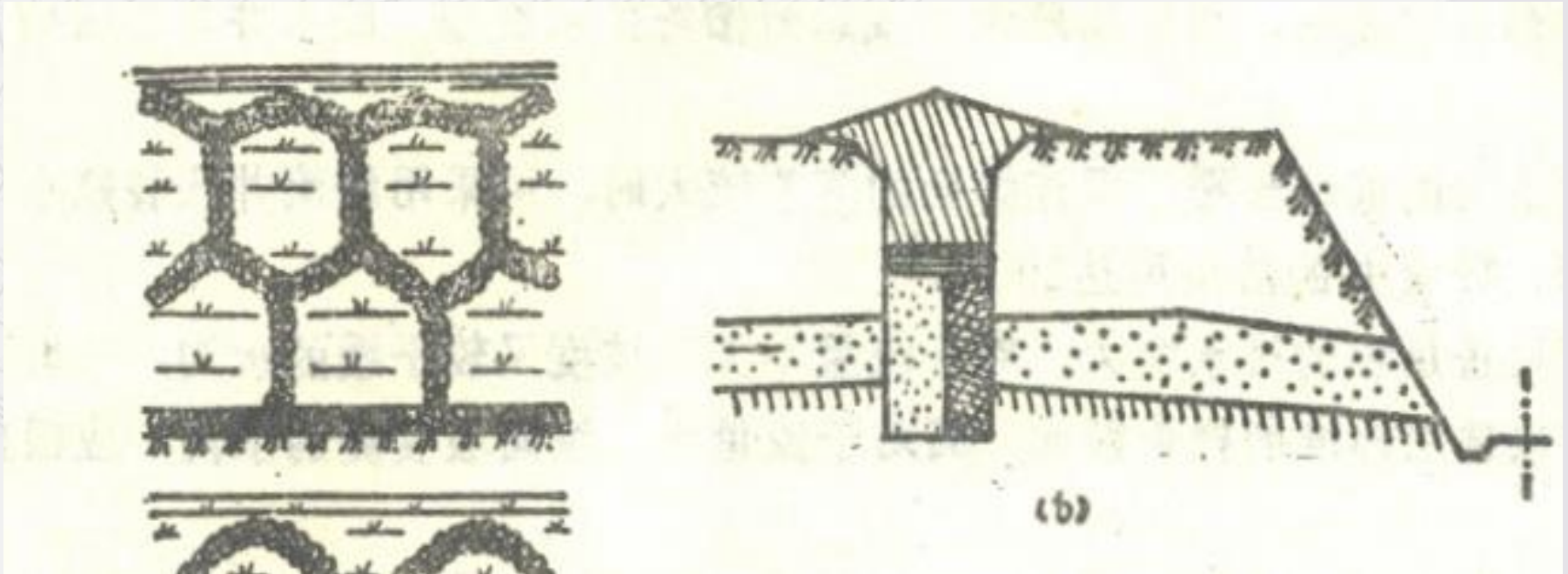
③ water-intercepted sewer

Function:

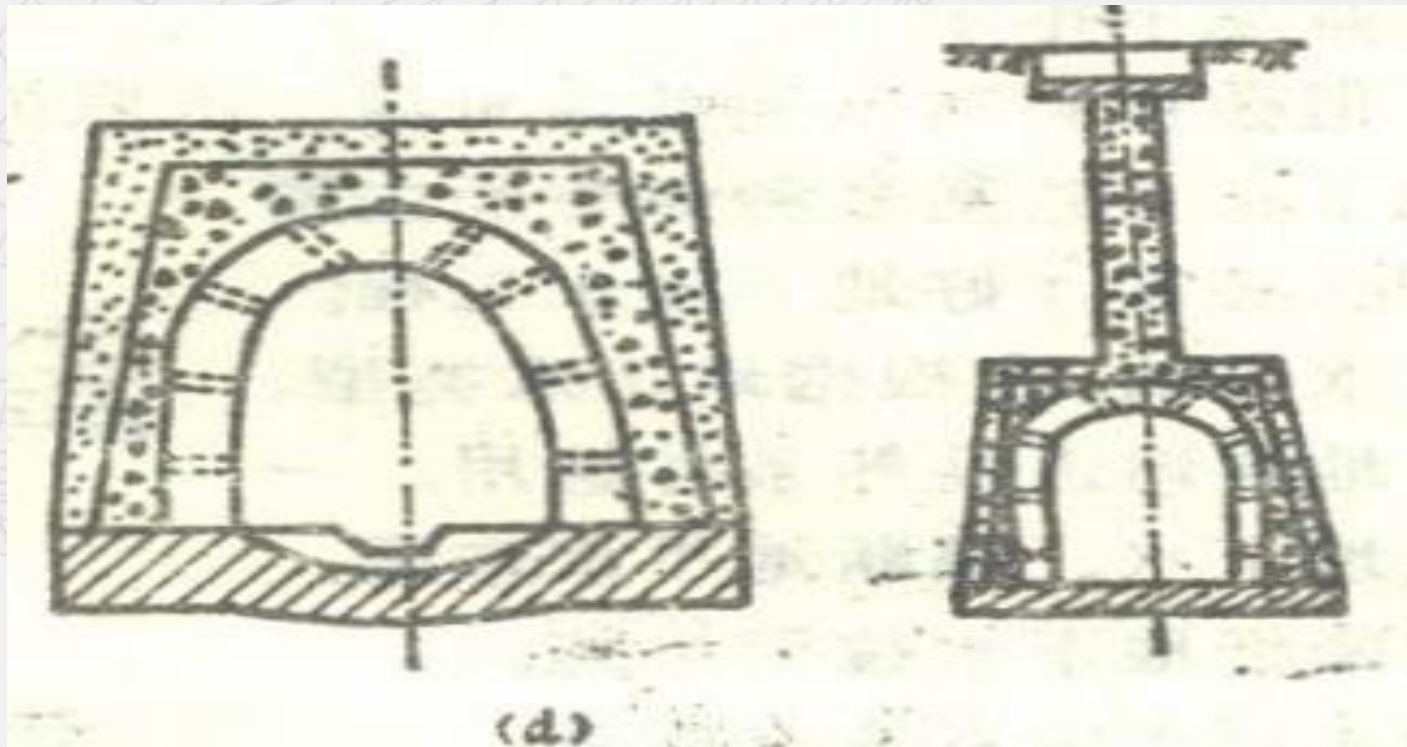
- To intercept ground water;
- build in the roadbed.



④ sewer below side ditch



⑤ seeping hole



2. Safeguards and strengthening of roadbed

1. Safeguards of roadbed

Appropriate measures shall be selected for protection of side slopes (cutting slopes and embankments) according to soil property, lithology, hydrogeologic condition, ratio and height of side slope, requirements for environment protection and soil & water conservation.

In principle, measures shall be taken for protection of all slopes.

(1) Types

safeguards of side slope

safeguards of erosion

(2) Safeguards of side slope

1) plants

grass—for small gradient (1:1.25) and low height side slope;

turf—for big gradient and high height side slope;

trees—for small gradient side slope.

2) civil engineering works

(3) Safeguards of eroding

1) direct safeguards

turf;

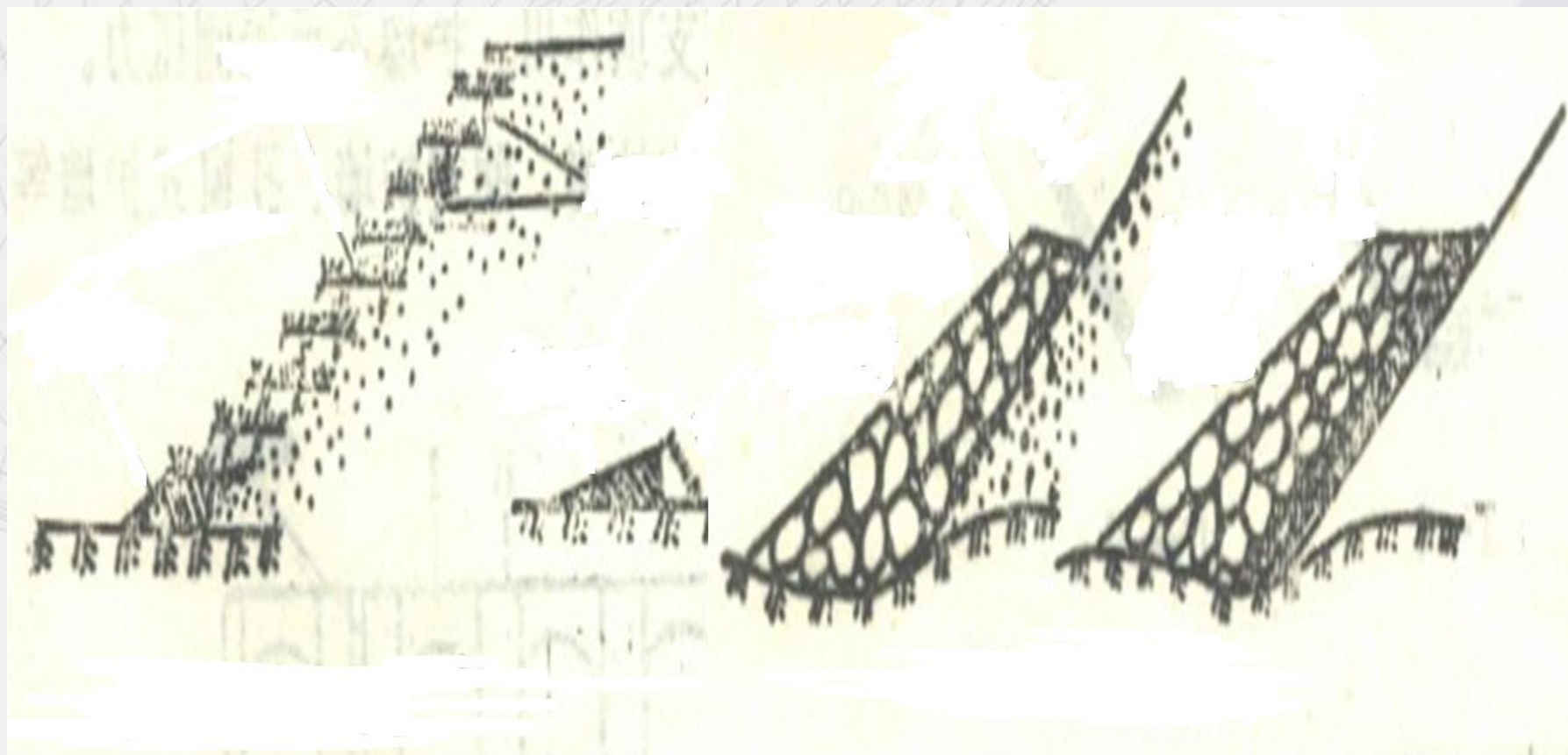
stone;

dry stone and mortar;

floor slab slope;

retaining wall ;

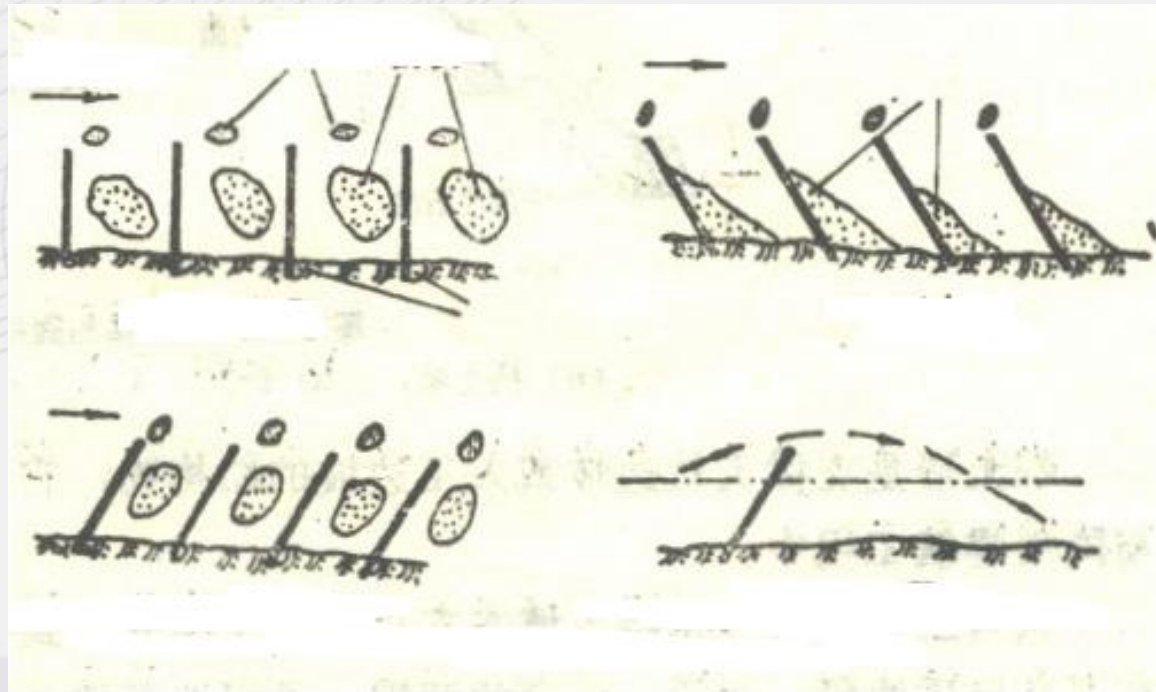
gabion slope.



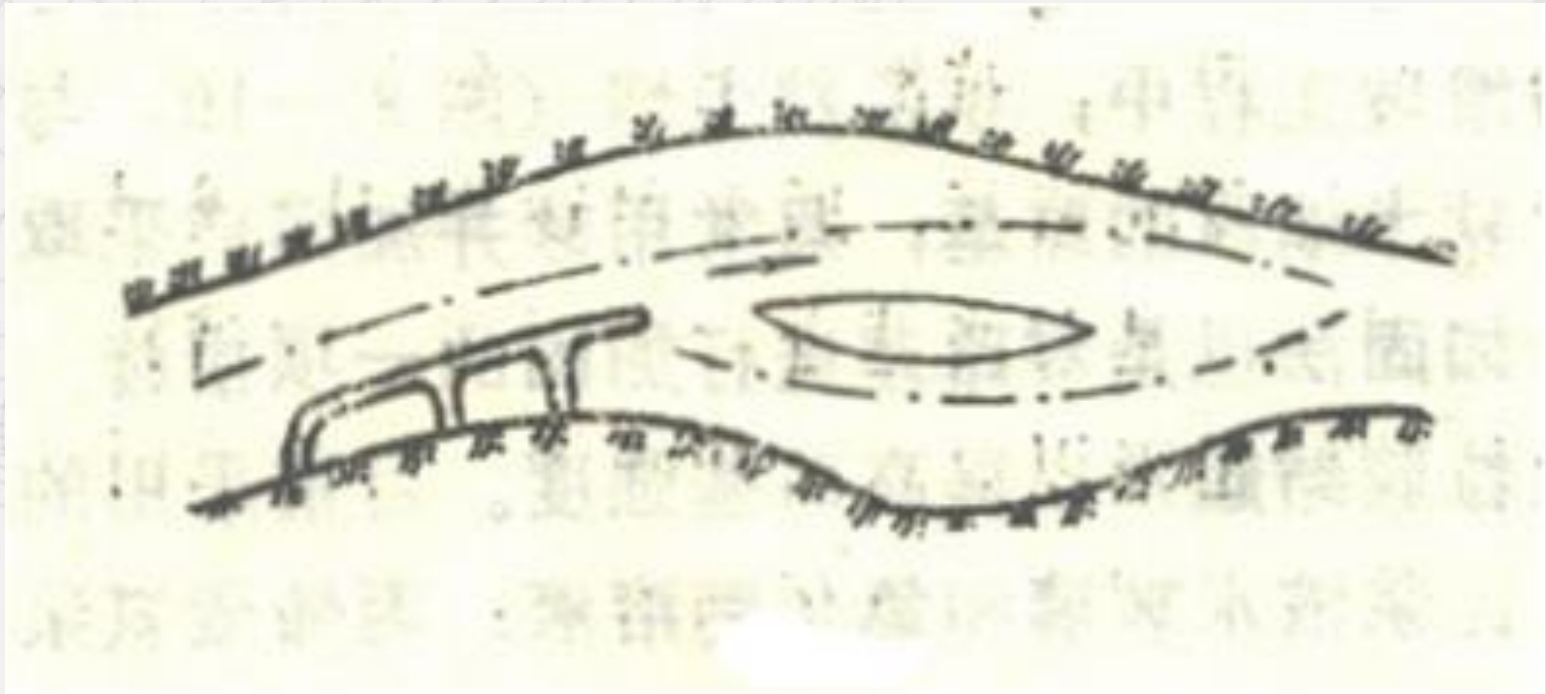
2) indirect safeguards

to guide the water flowing into another direction.

① vertical dam

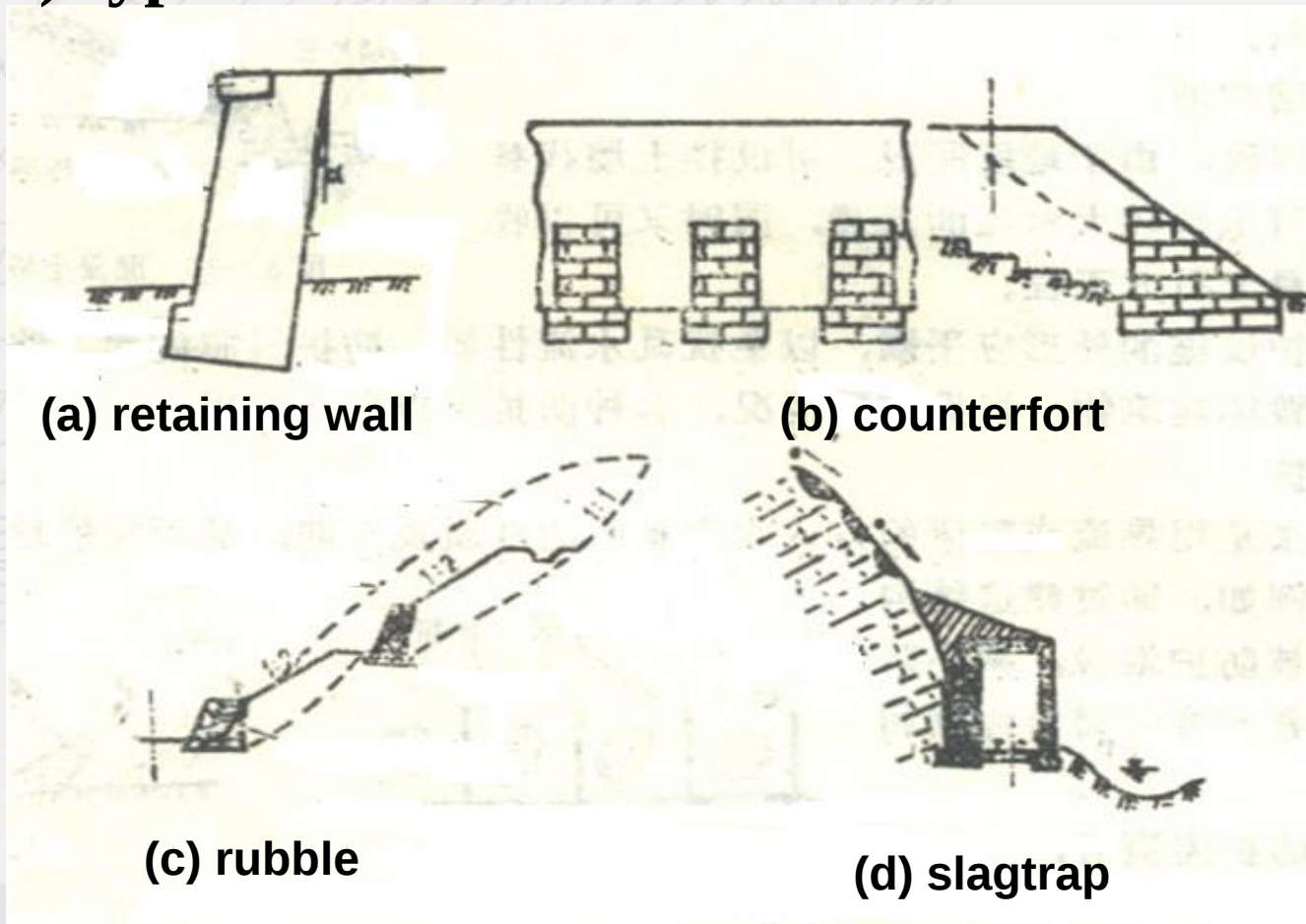


② straight-forward dam



2.6.2 Strengthening of roadbed

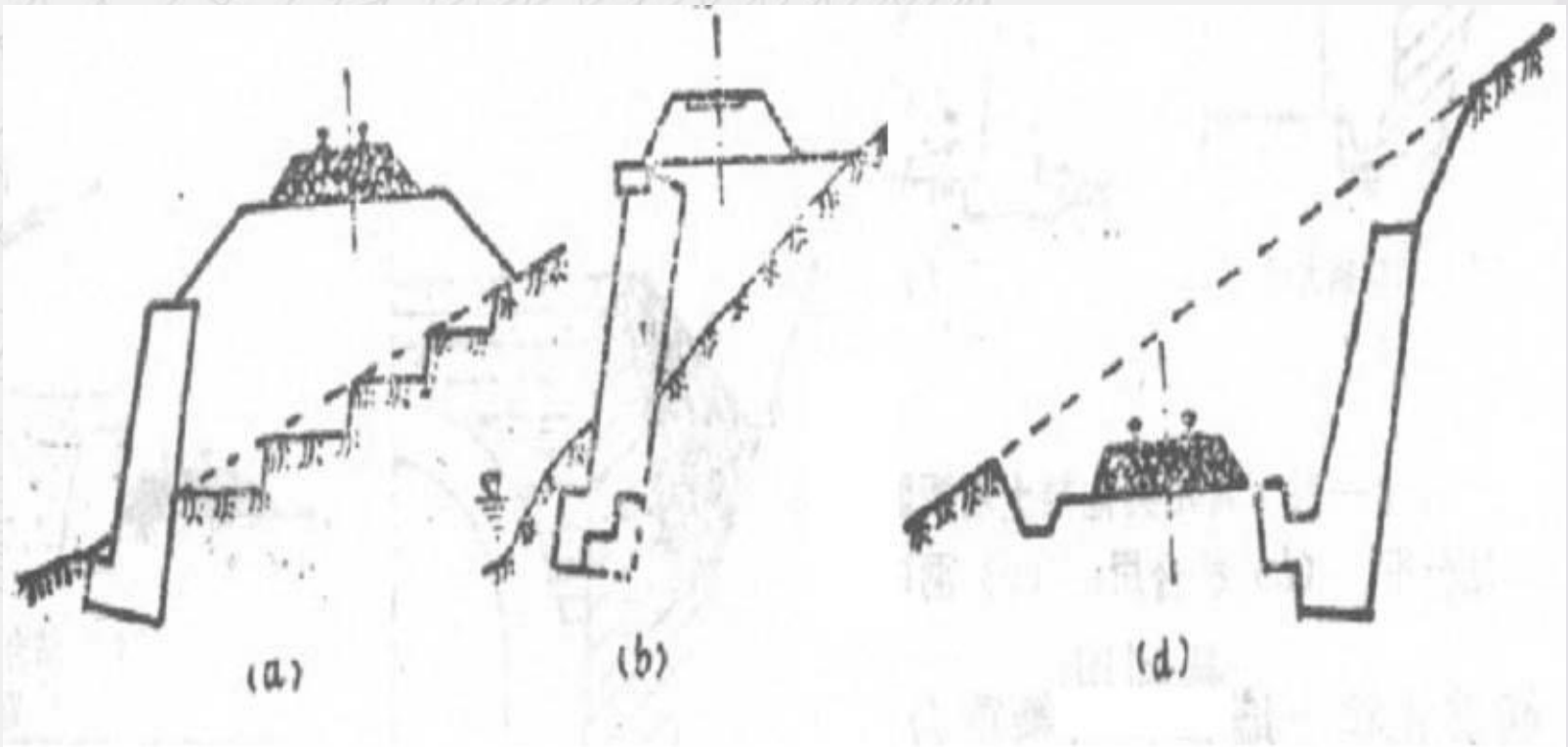
(1)Types



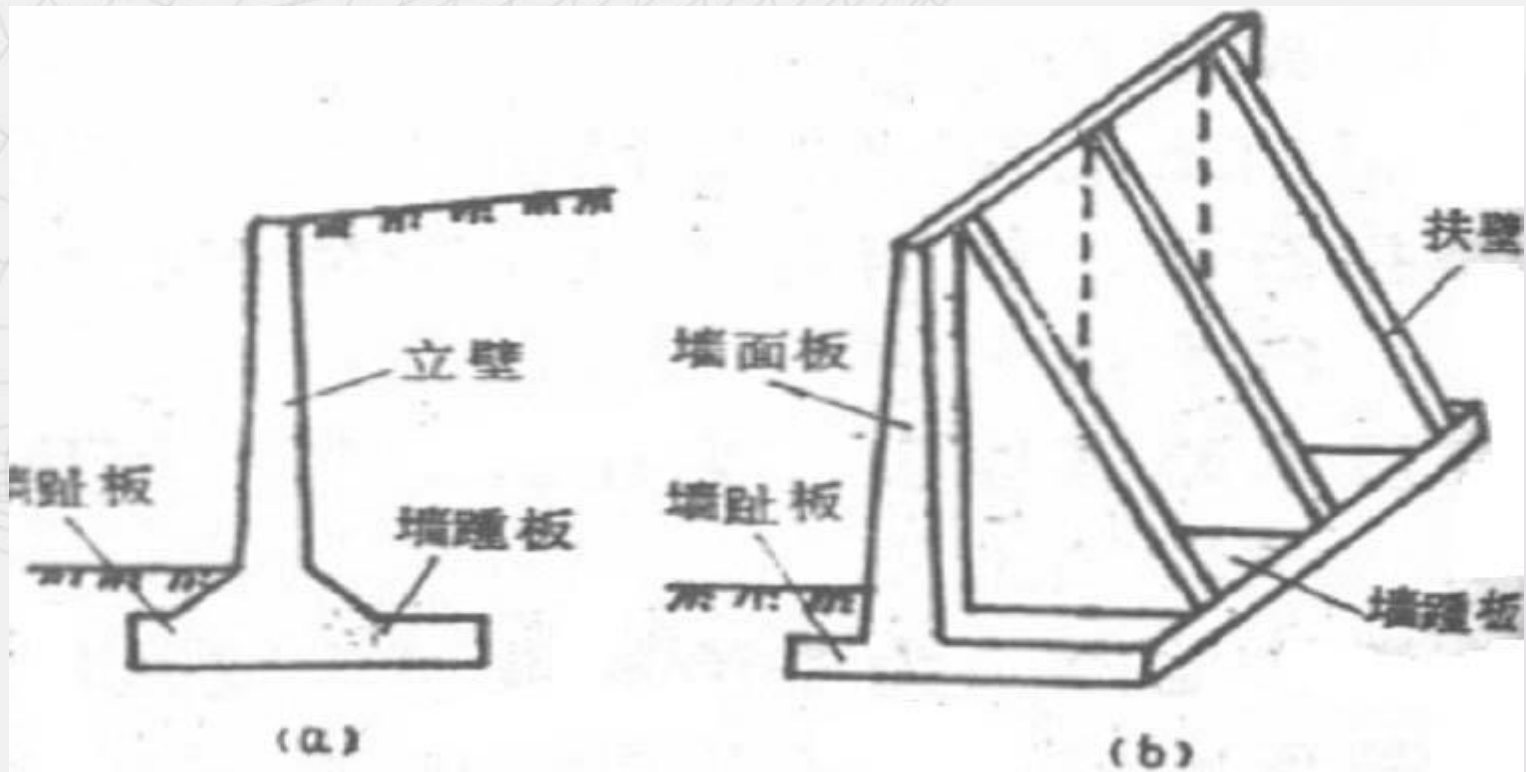
(2)Retaining wall types of structure:

- 
- ① gravity type**
 - ② cantilever type**
 - ③ counterfort type**
 - ④ anchored type**
 - ⑤ pile board type**
 - ⑥ rubble type**

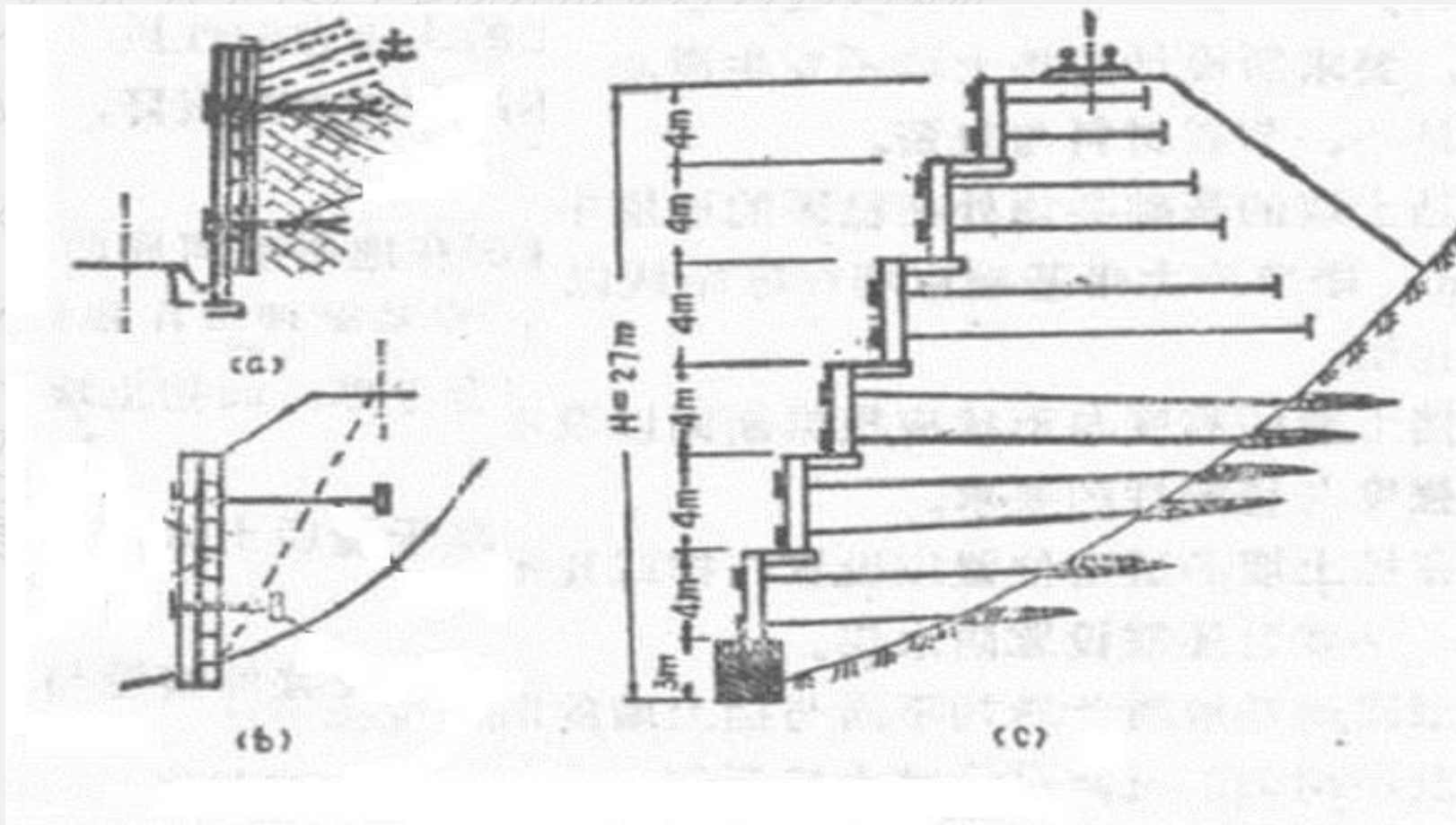
① gravity type



- ② cantilever type
- ③ counterfort type



④ anchored type

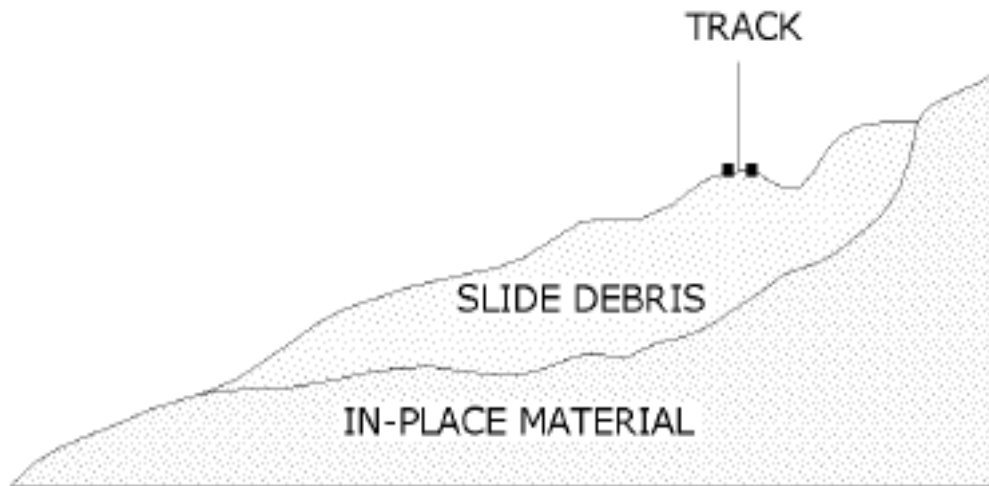


2.7 Instability, sub grade work cases & Lessons

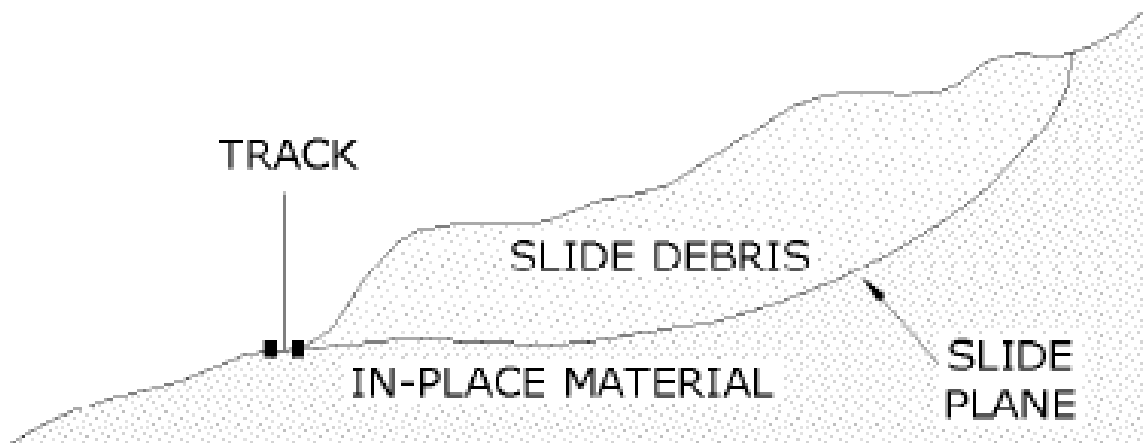
2.7.1 Instability

- + Instability results when the shear strength of the soil is not sufficient to support the loads applied to it**
- + The term landslide is used to define all types of mass movement of soil or rock, where the mass moves down slope under the influence of gravity only**
- + Instability that affects the track can be classified according to the impact that it has on the track.**

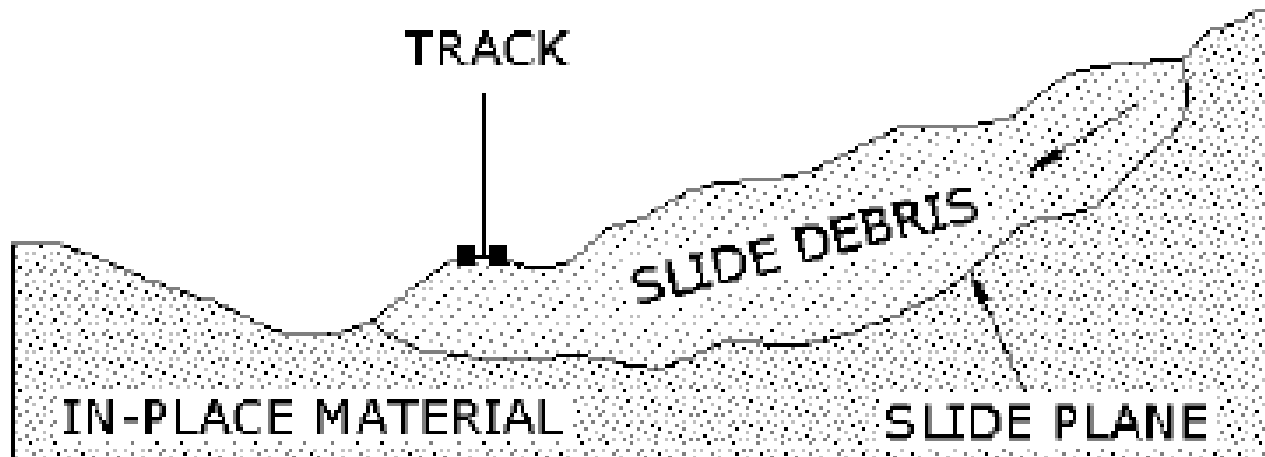
1. **A slide that encompasses a track and will disrupt the track by cutting the alignment. Once the track moves out of line, it is no longer serviceable.**



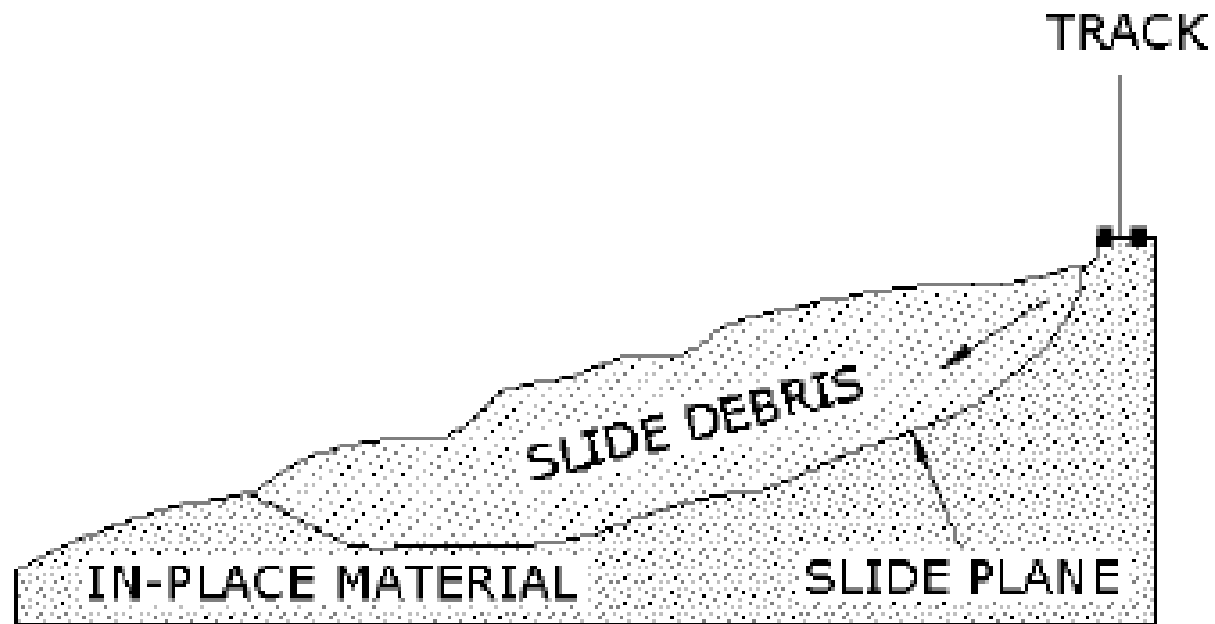
2. A landslide upslope where the toe crosses the track, burying it in under slide debris.



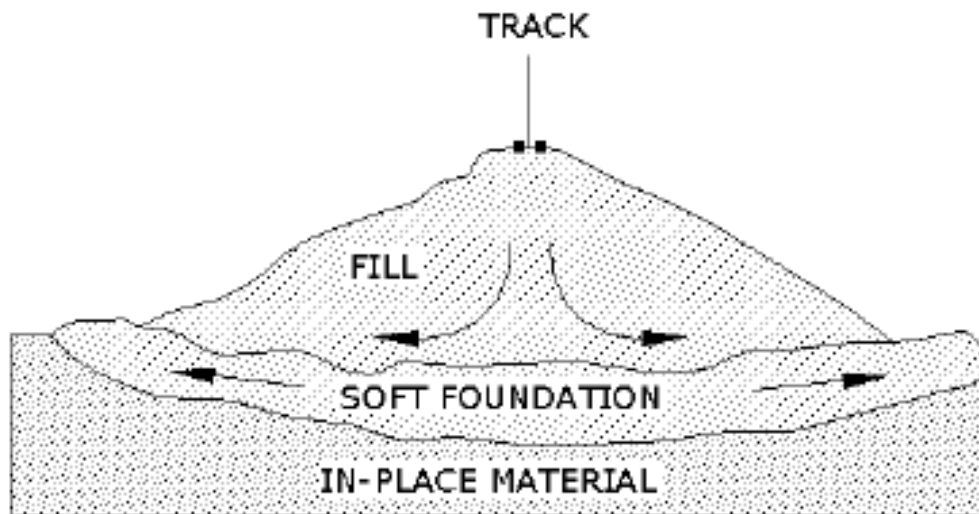
3. The track being heaved up in response to upward movement of the toe of a landslide.



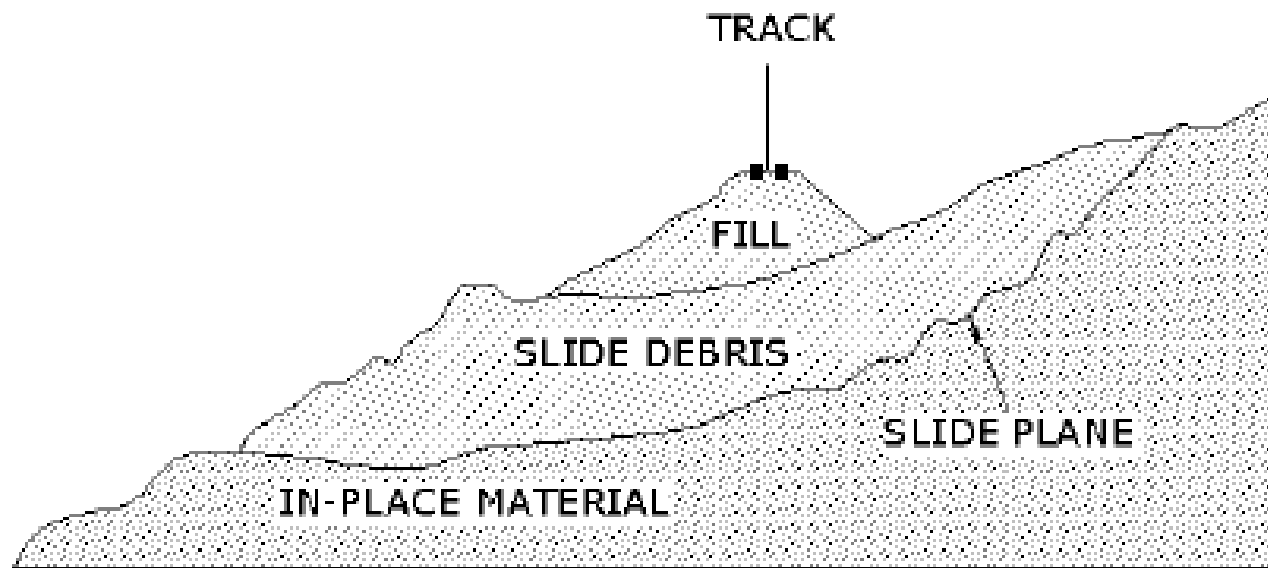
4. An event where a landslide threatens the track, perhaps by encroaching on the down slope shoulder.



- 5. Base failure in fills on soft foundations can cause the fill to spread and settle. While this may be mistaken as settlement, it is actually a shear movement involving the foundation soils. It is common on organic terrain and other soft foundations.**



6. How locations over old landslides may be reactivated due to a change in stresses within the landslide mass. Many of the ancient landslides are extremely large, and the limits of the landslides may be difficult to detect.



In general, the stability of a slope is dependent upon:

- ◆ **The shear strength of the soils.**
- ◆ **Pore water pressure within the soils that make up the slope (this can be roughly measured by knowing the water table).**
- ◆ **The geometry of the slope, particularly the slope angle and changes of slope.**
- ◆ **Any surcharge loading such as fill or bank widening material stored on the slope or train loads.**

Landslides occur either as a result of reduction in **soil strength or an increase in the **loading** on the slope.**

Reductions in soil strength can occur as the result of:

➤ **An increase in pore water pressure, reducing the available shear strength of the soil.**

In the case of moisture sensitive soils, the amount of water needed to cause this

2.7.2 Sub grade Work Cases and Lessons



Lessons: Pay great attention to stability of slope outside side slope designed for railway.



Lessons: Pay great attention to stability of works such as construction roads adjacent to railways in soft soil area.



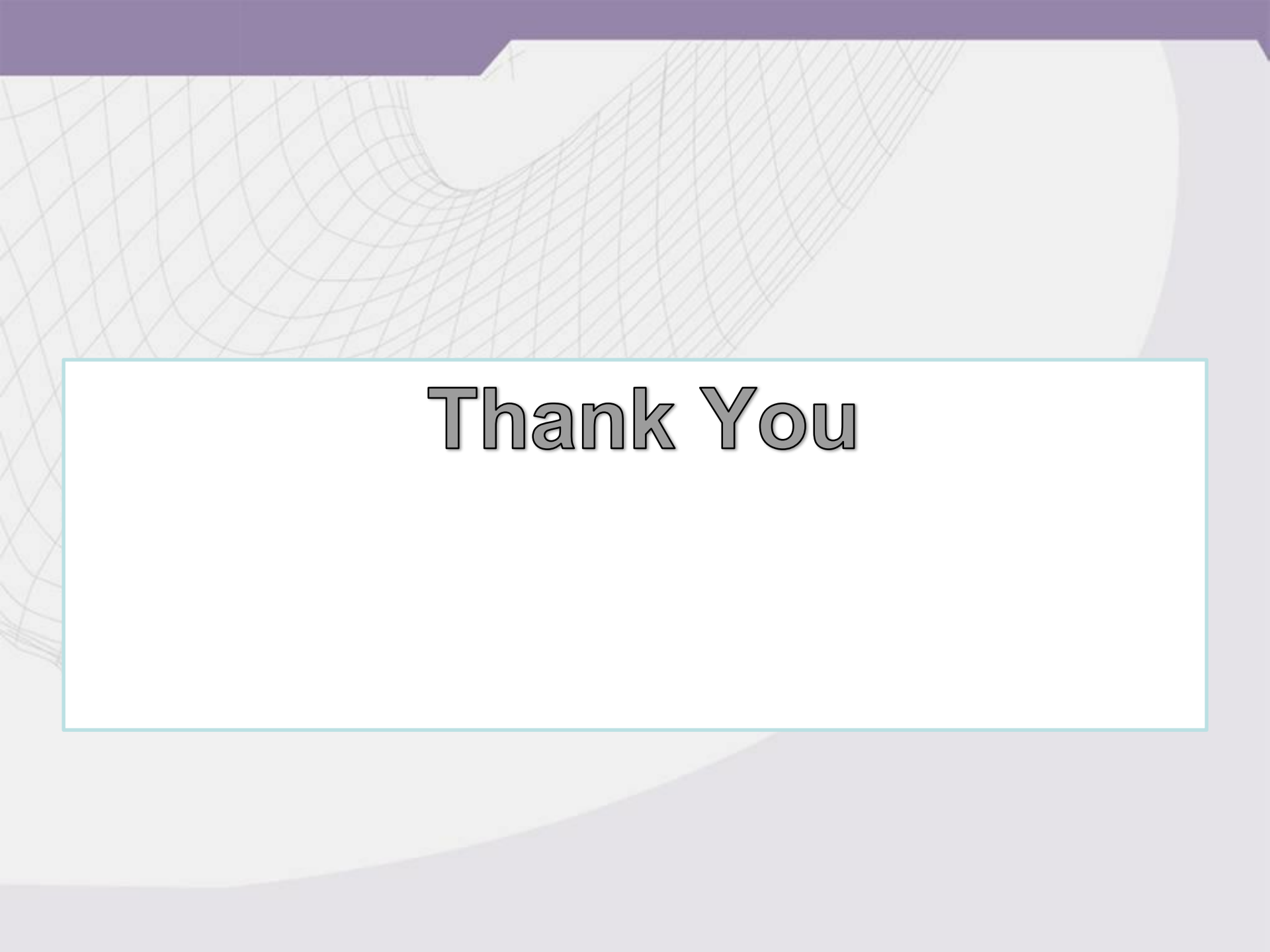
**Lessons: Pay great attention to spoils
above road cutting and drainage
smooth.**



Lessons: Pay great attention to stability of high fill in sloping terrain (stratum) sections.



Lessons: Pay great attention to exploration and rectification of karst subgrade.



Thank You