# Parameter determination and construction of forked tunnel

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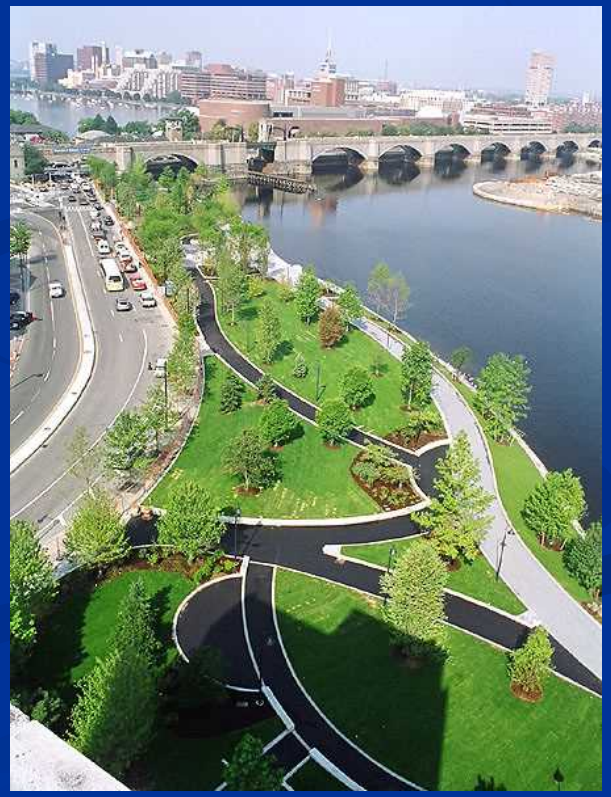
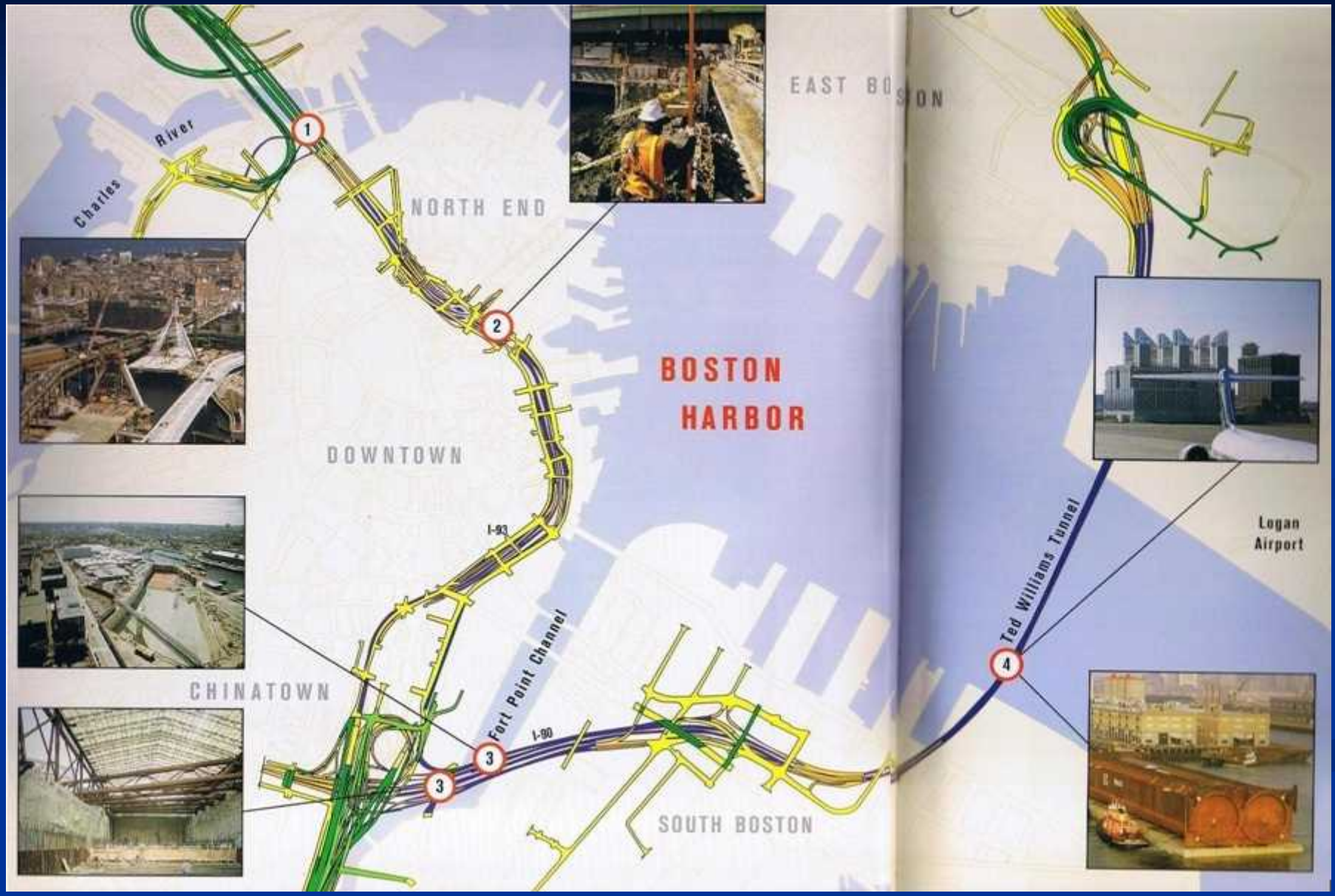
# 1 Engineering summery

With the rapid development of underground traffic, the scale of the engineering is getting larger, and tunnel with a single form can no longer meet the engineering requirements. Whether it’ s a city subway, highway tunnel or railway tunnel, plane crossing and three-dimensional crossing between tunnels are becoming more and more common.

- **Central Artery/Tunnel Project ( CA/T ) , Boston, USA ;**



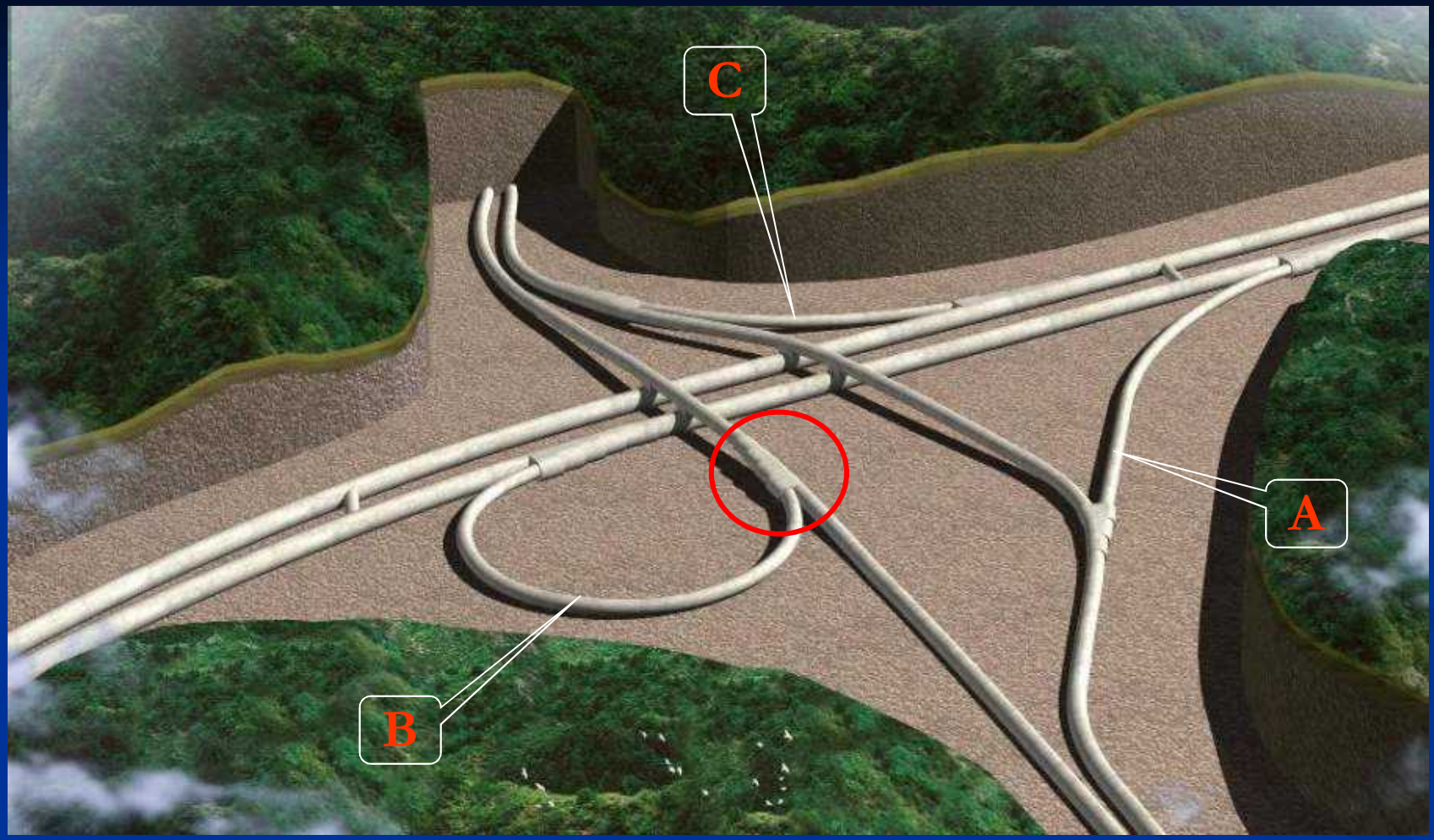

Charles River
NORTH END
EAST BOSTON
BOSTON HARBOR
DOWNTOWN
CHINATOWN
SOUTH BOSTON
I-93
I-90
Fort Point Channel
Ted Williams Tunnel
Logan Airport
1
2
3
3
4

◆**Annular two-way, 4 lane underground expressway, Tokyo, Japan.**

The completed Shinjuku line has a total length of 11 km, with 6 entrances and 9 ventilation stations.


◆**The Zhongguancun underground ring corridor, Beijing China.**

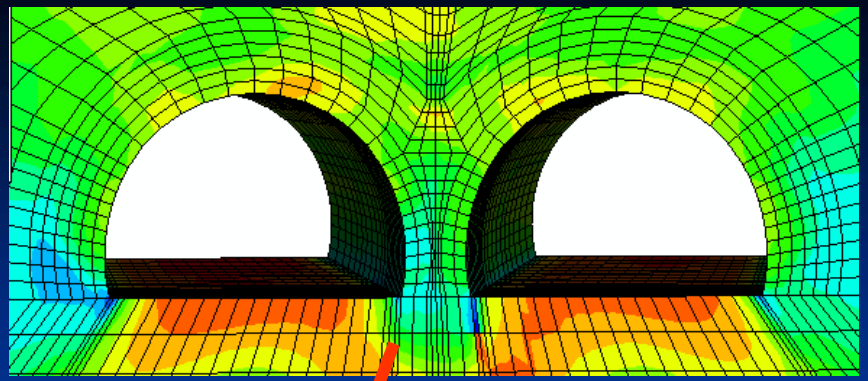
It has a total length of 1.9 km, with 6 entrances and 4 exits.

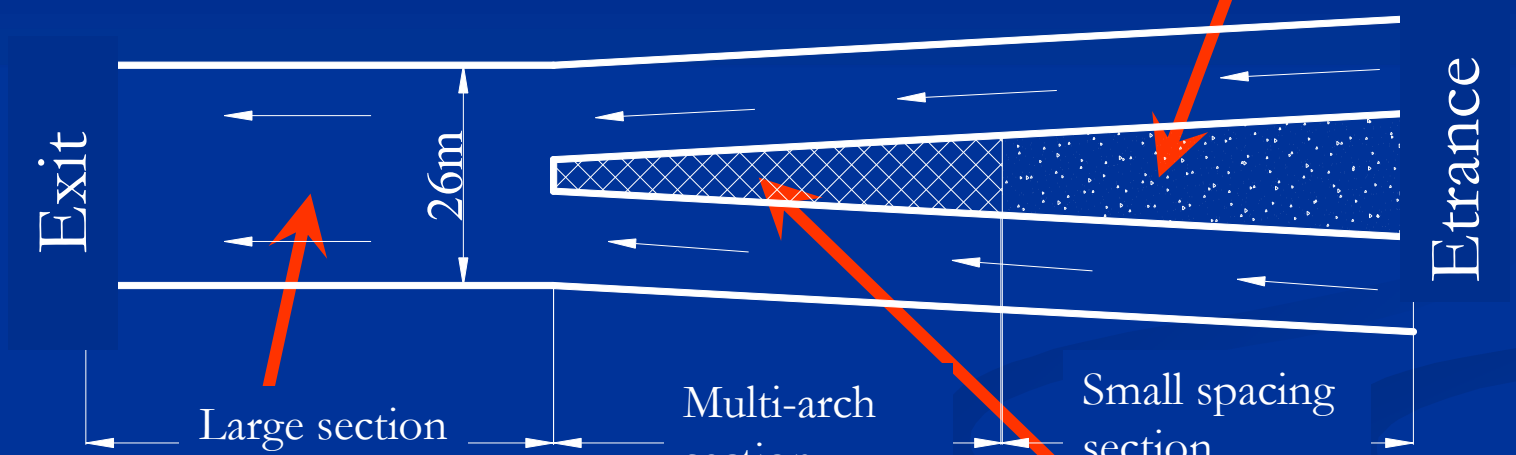


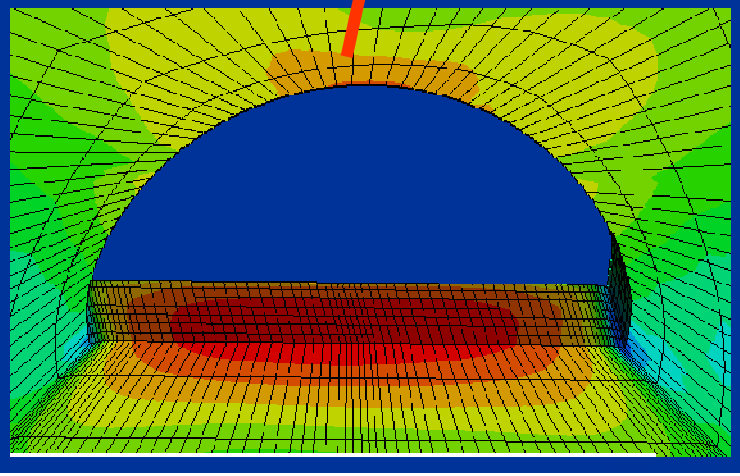

- The new completed Wanshishan tunnel (at Xiamen Chenggong Road) undercrosss Zhonggushan tunnel, with three ramps, a total of 4 tunnels branching.

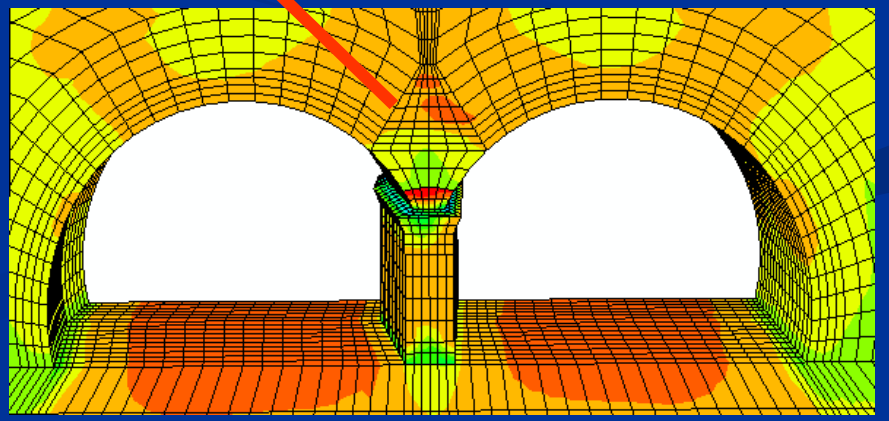
**◆Forked section of Baziling tunnel at Shanghai-Chengdu West Expressway, China**

◆The forked section is about 500m long, the section form is gradually transiting from the four lane arch to the multi-arch, small spacing and standard spacing separation, in which the maximum single hole excavation width is more than 26 meters.





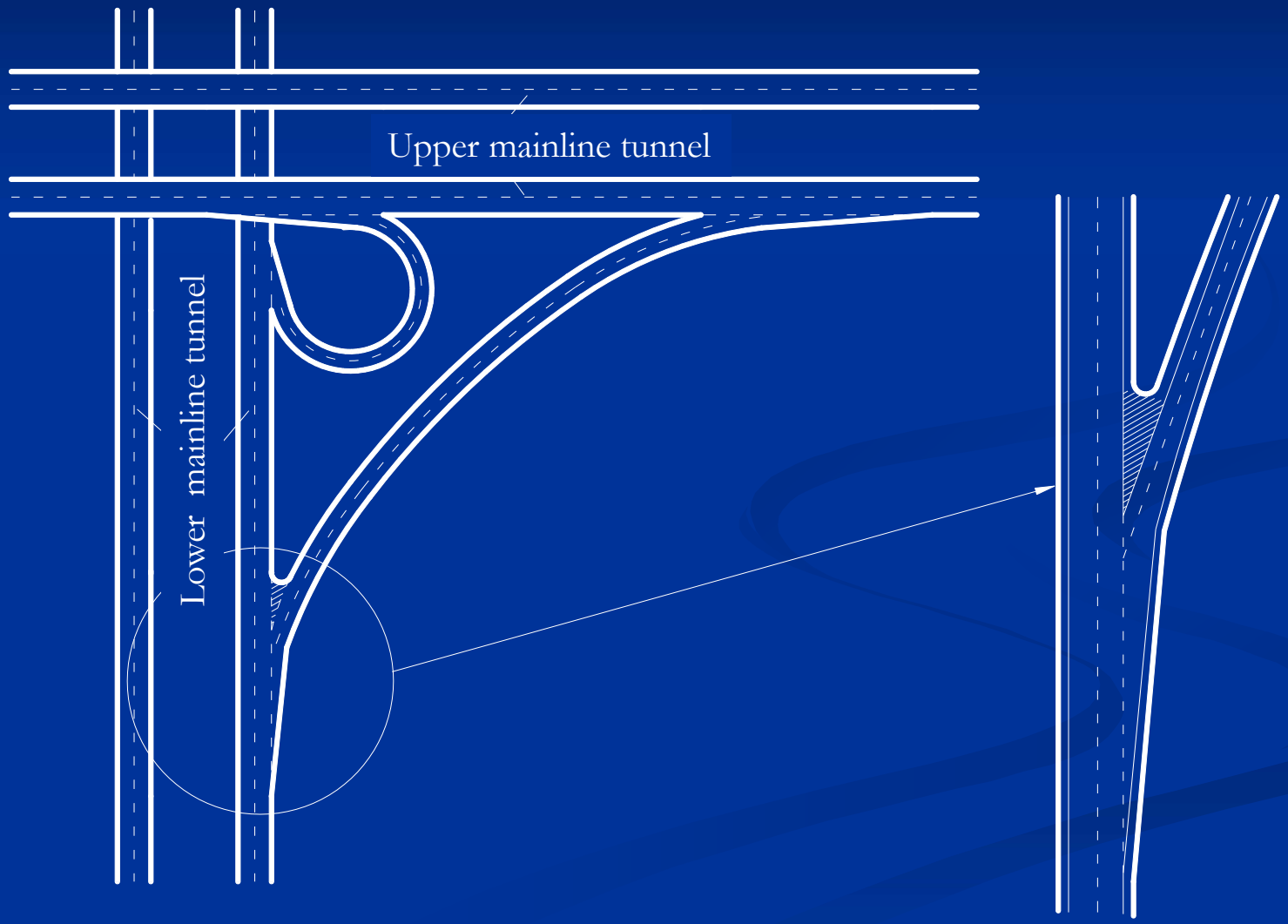


◆**Forked section of Jiaozhou Bay undersea tunnel and Guizhou road ramp tunnel.**

◆**Forked section of Jiaozhou Bay undersea tunnel and Guizhou road ramp tunnel.**

- Guantouling tunnel (at Wenzhou-Fuzhou railway) undercrosss Maotouling tunnel (at Hongjiang-Sanya highway), which is the first highway, railway tunnel overpass in China.
- The forked tunnel between running tunnel (Grand theater to science museum) at Shenzhen Metro Line 1 and Line 2 tie line subway.
- The forked tunnel from Huangzhuang to Kenan Road at Beijing Metro Line 10.

**The mainly discussion here is about bifurcation between the main tunnel and the ramp tunnel of underground interchange.**

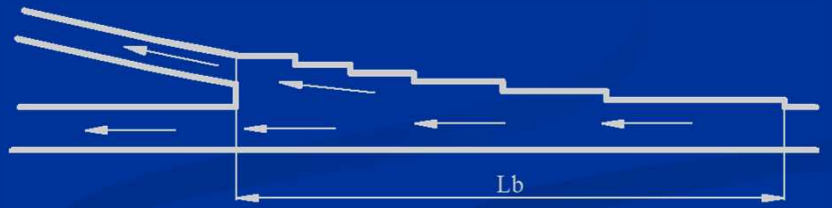


# 2 Geometric parameter determination

## 2.1 Length of transmission section

Separation from the mainline tunnel to the ramp tunnel, or confluence of the ramp tunnel to the mainline tunnel, they both involved the plane crossing between two tunnels, and this is the key point of Underground Interchange, and the most complicated and most difficult part of the construction.

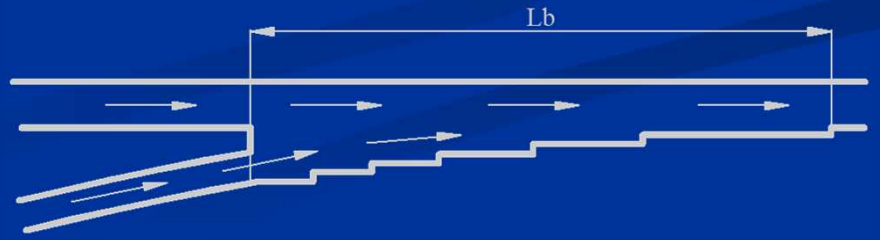
① **Deceleration section length after separation**




$$L_b = L_0 + \frac{v_1 t}{3.6} - \frac{1}{2} a_1 t^2 + \frac{1}{25.92 a_2} \left| (v_1 - 3.6 a_1 t)^2 - v_2^2 \right|$$

② **Acceleration section length before confluence**

$$L_b = L_0 + \frac{v_1 t}{3.6} + \frac{v_1^2 - v_2^2}{25.92 a}$$



$L_0$ ——Transition section length from highway specification;

$t$ ——Engine sustained deceleration time, usually 3 seconds;

$a_1$、 $a_2$—— Deceleration of engine and brake;

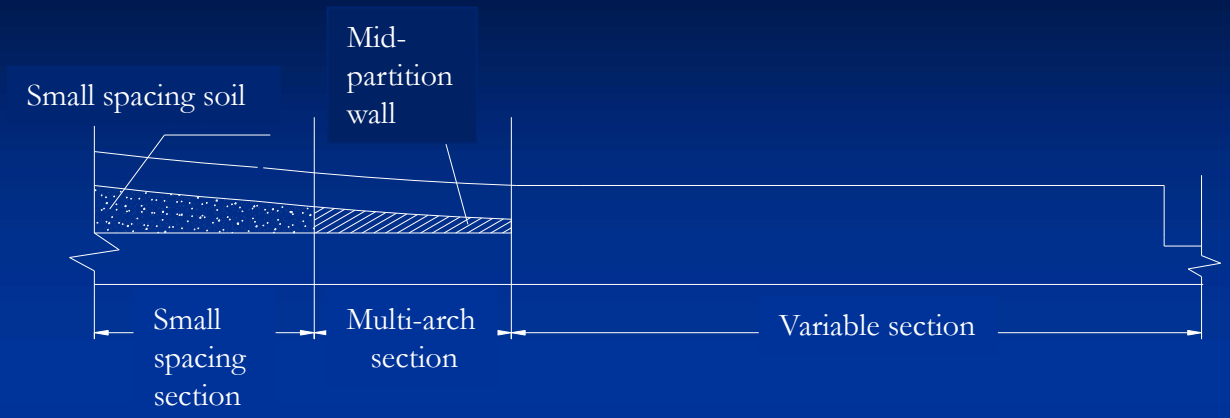
Recommended value from AASHTO

| Main lane designed speed（km / h） | Ramp designed speed（km / h） | deceleration（m/s²） | | $L_0$（m） |
|---|---|---|---|---|
| | | $a_1$ | $a_2$ | |
| 80 | 40 | 0.8 | 1.6 | 70 |
| 60 | 30 | 0.6 | 1.2 | 60 |

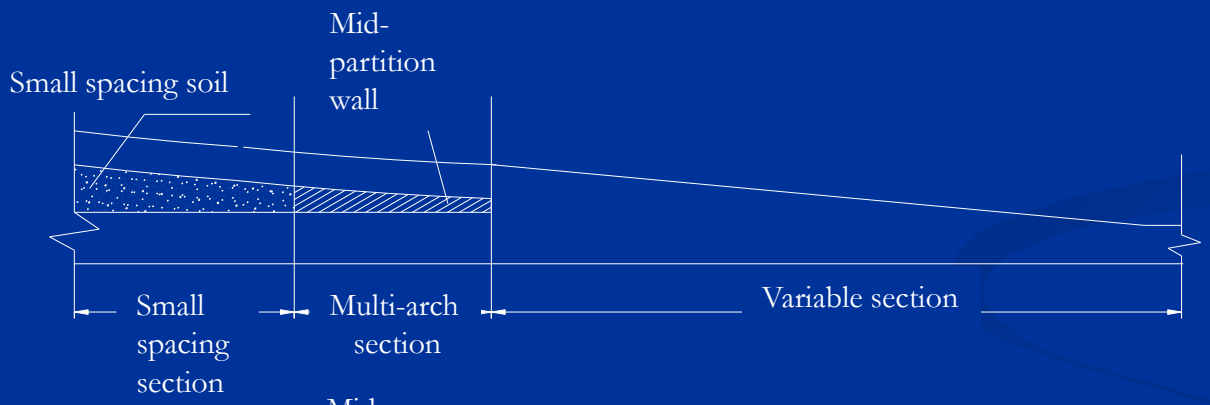
① Before separation, $L_b = 217m$, after confluence $L_b = 322m$

② Before separation, $L_b = 170m$, after confluence $L_b = 214m$

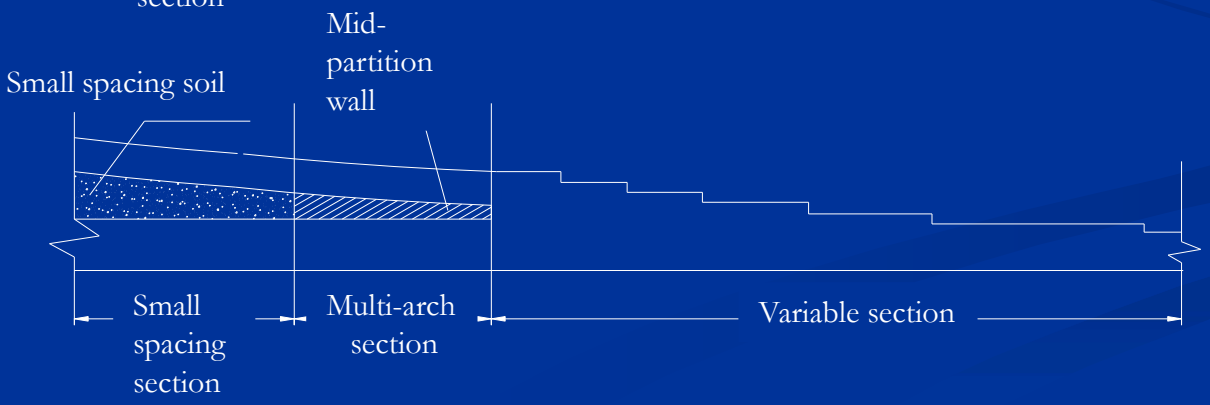
# 2.2 Plane layout of transmission section




Sudden change mode




Gradual change mode

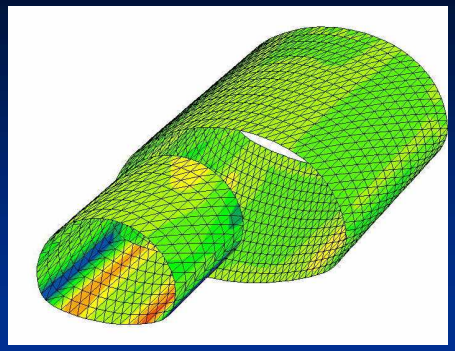



Step mode

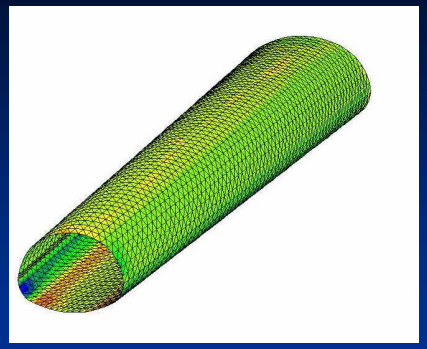
# Comparison of the three ways

| Layout method | Advantage | Disadvantage |
|---|---|---|
| Sudden change mode | The section structure is sample, the operation procedure is simple, and the construction organization is easy. | Large amount excavation work, the transmission section is large span tunnel, so it is difficult to construct. |
| Gradual change mode | The excavation work is small and the stress state of structure and surrounding rock are good. | The span of the tunnel becomes wider and the steel support is difficult to be processed, so the integral injection molding lining can not be carried out. |
| Step mode | The excavation amount is between the two schemes above. | Different specifications formwork jumbo were needed, stress concentration is easy to appeared at corners on surrounding rock and structure. |

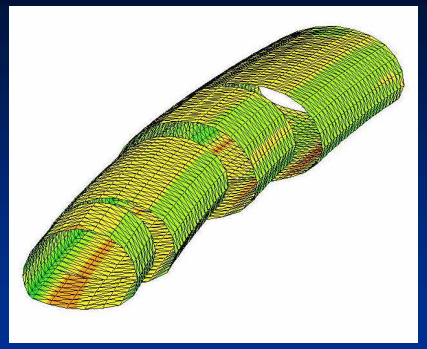
# Numerical simulation mesh of Primary support



Sudden change mode



Gradual change mode

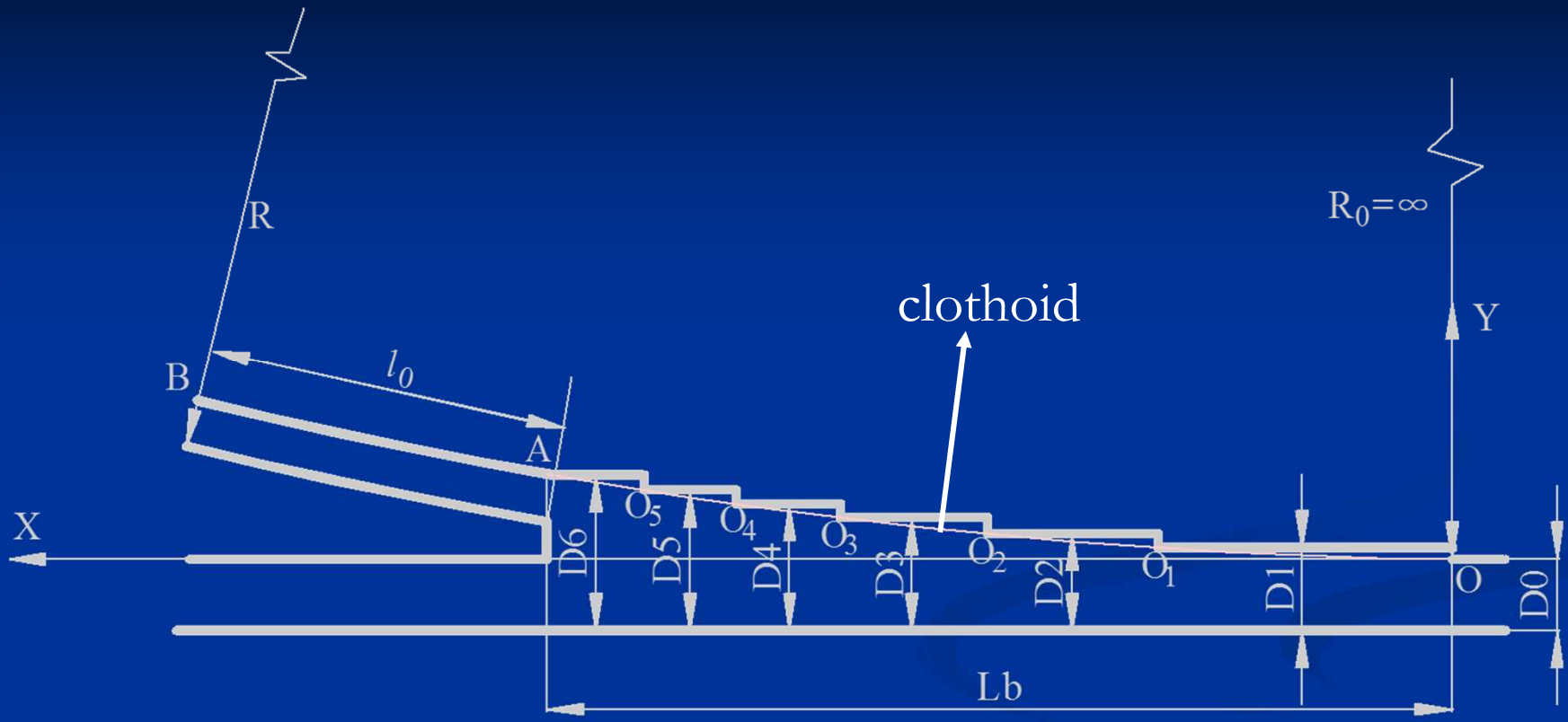


Step mode

| Contrast item | Sudden change | Gradual change | Step |
|---|---|---|---|
| Surface subsidence | 9.65cm | 4.69cm | 4.95cm |
| Primary support moment | 462kN.m | 265kN.m | 420kN.m |
| Plastic zone percentage | 33.15 | 14.8 | 26.36 |

**Conclusion : the step mode is the best.**

# 2.3 Step layout parameter of transmission section




$$\begin{cases} x = l - \dfrac{l^3}{40r^2} \\ y = \dfrac{l^2}{6r} - \dfrac{l^4}{336r^3} \end{cases} \xrightarrow{r = A^2/l} \begin{cases} x = l - \dfrac{l^5}{40A^4} \\ y = \dfrac{l^3}{6A^2} - \dfrac{l^7}{336A^6} \end{cases}$$

$$\begin{cases} x_A = L_b \\ y_A = 2.0 + (D_z + 0.5 + 0.3 + 0.1)\cos\phi_B \approx 2.9 + D_z \end{cases}$$

The parameter of the colothoid line is obtained by substituting the upper formula: $A^2$

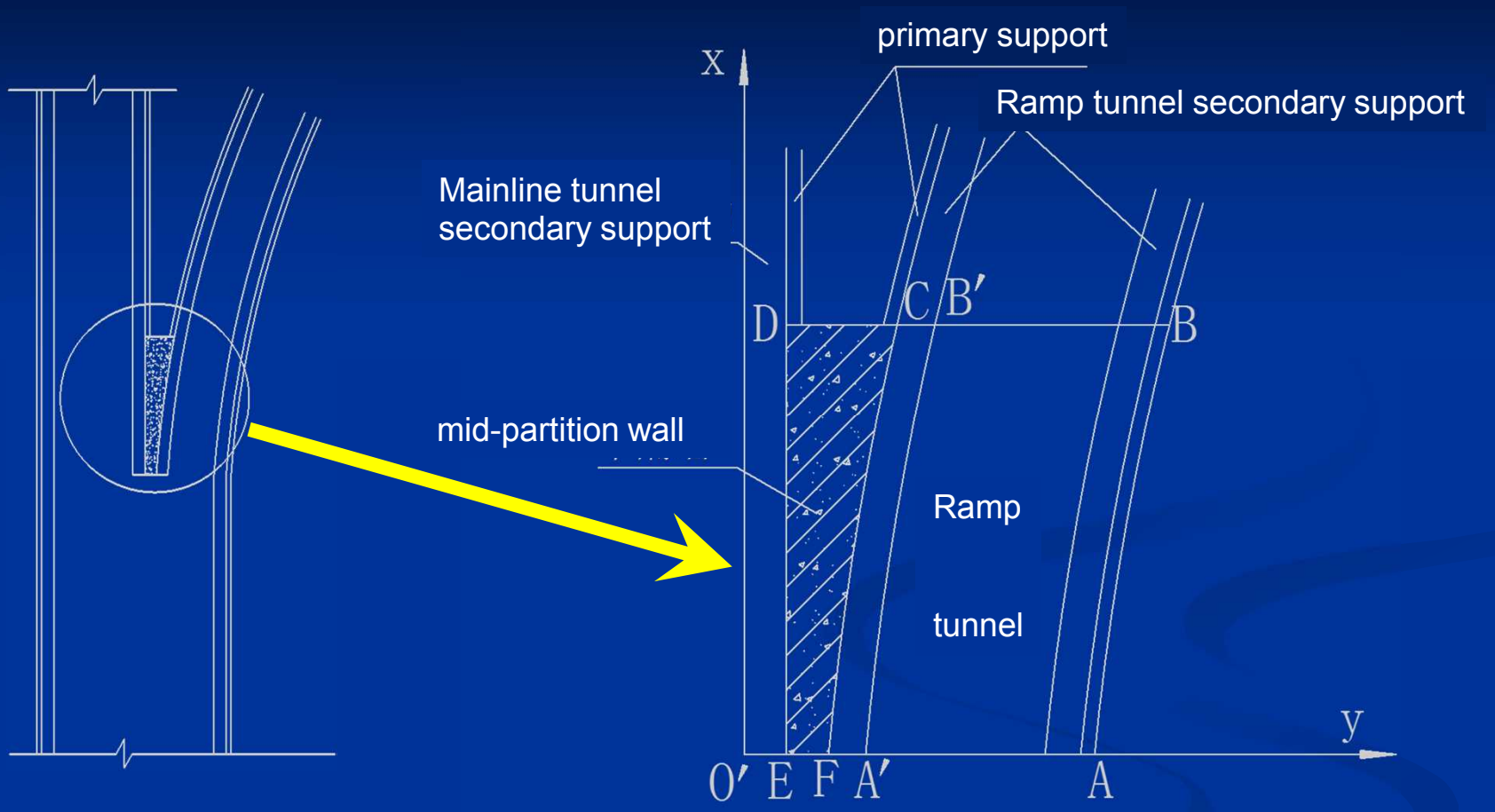
The excavation width of the tunnel each time : $\Delta d$ （usually 2.0m）

The span and length of the tunnel after each excavation: $D_i$ $l_i$

$$\begin{cases} D_i = D0 + m \cdot \Delta d \\ l_i = x_{0i} - x_{0i-1} \end{cases}$$

$m = 1、2 \ldots excavation\ times$

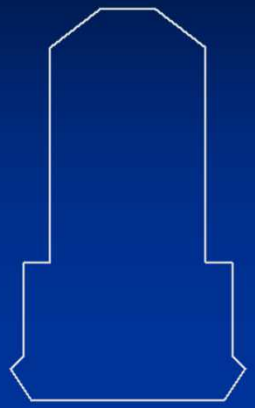
# 2.4 Plane parameters of mid-partition wall in multi-arch section




**The plane geometry parameter is:**

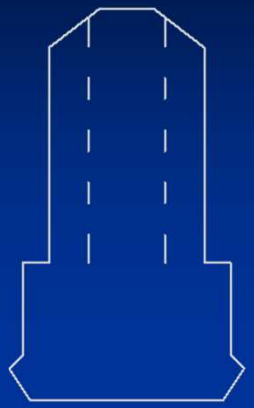
$$\begin{cases} l_{EF} = 1.0m \\ l_{DE} = x_B - x_A \\ l_{DC} = y_B - 10.78 \end{cases}$$

## ■2.5 Section form of mid-partition wall in multi-arch section



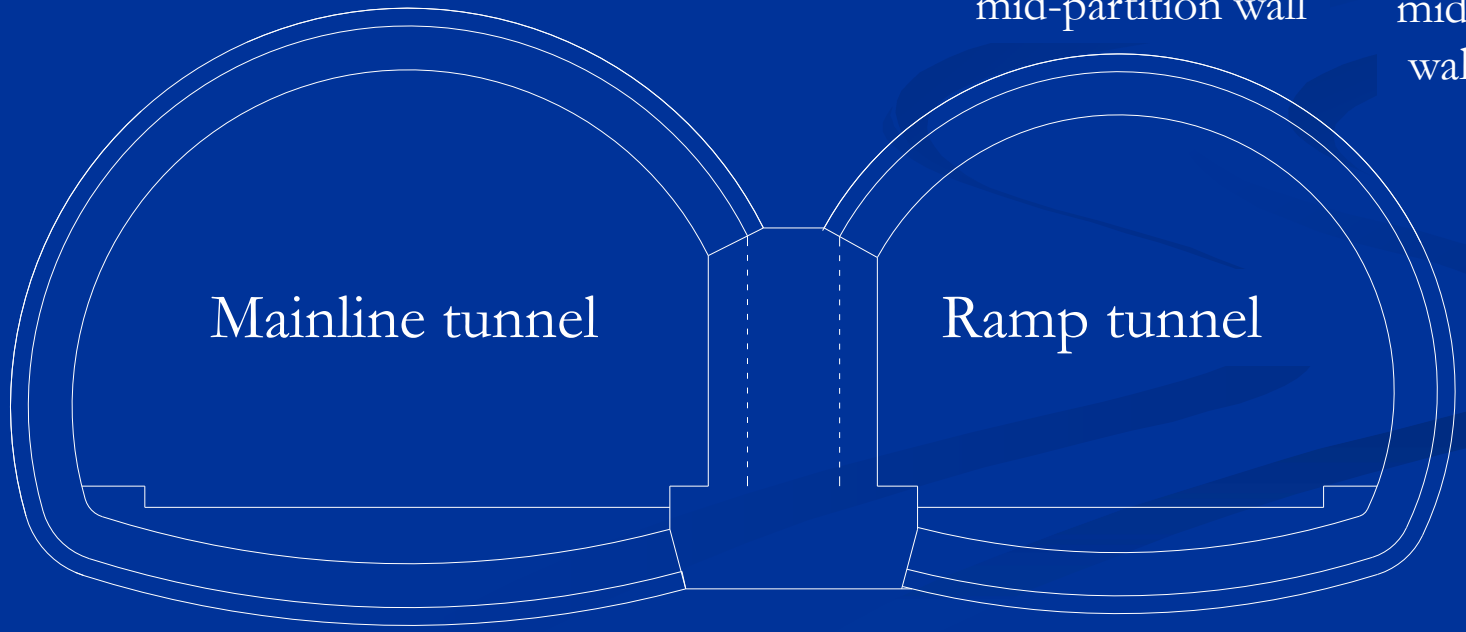
(a) unitary straight mid-partition wall

(b) unitary curved mid-partition wall

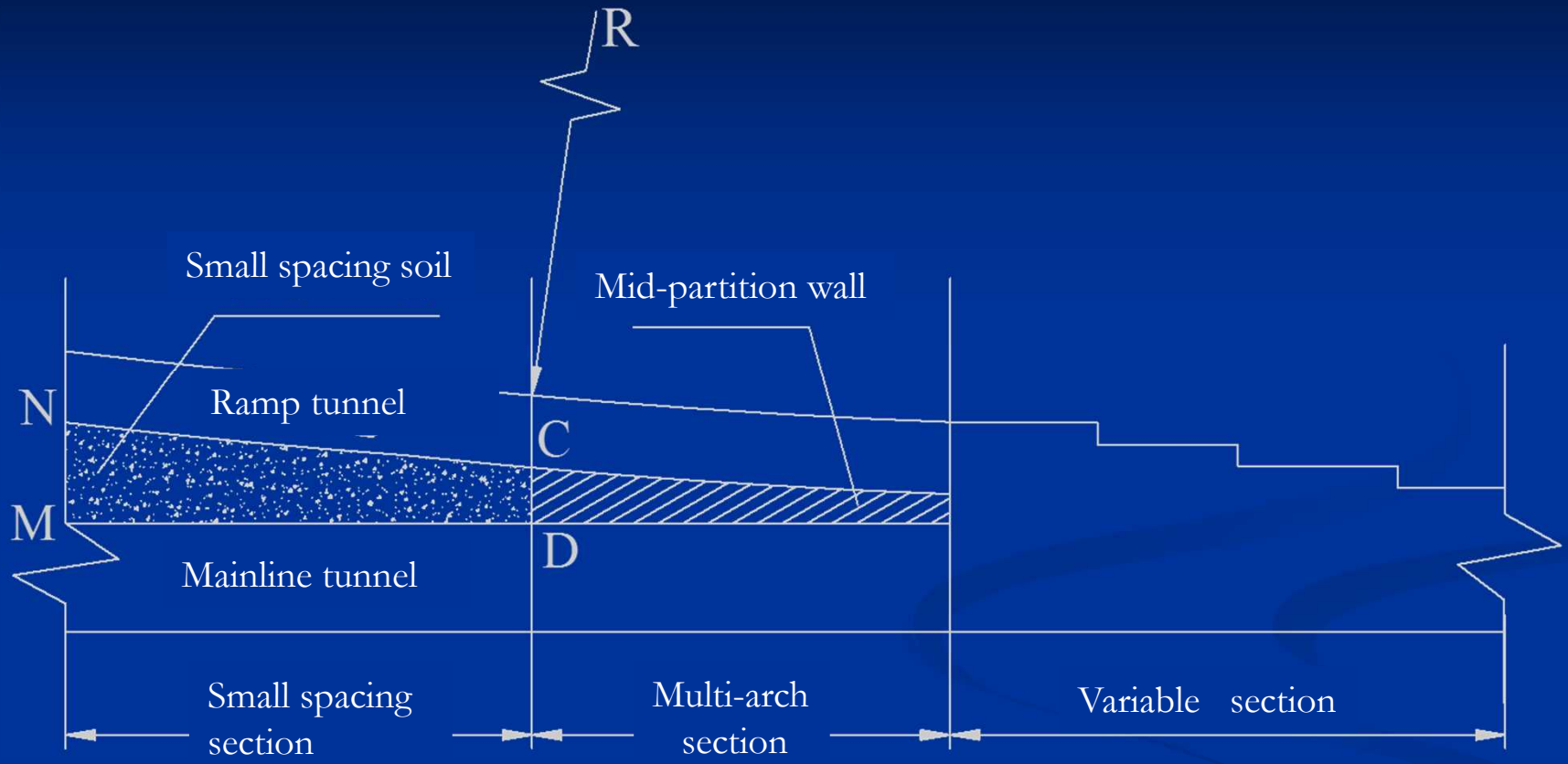


(c) combined straight mid-partition wall

(d) combined curved mid-partition wall

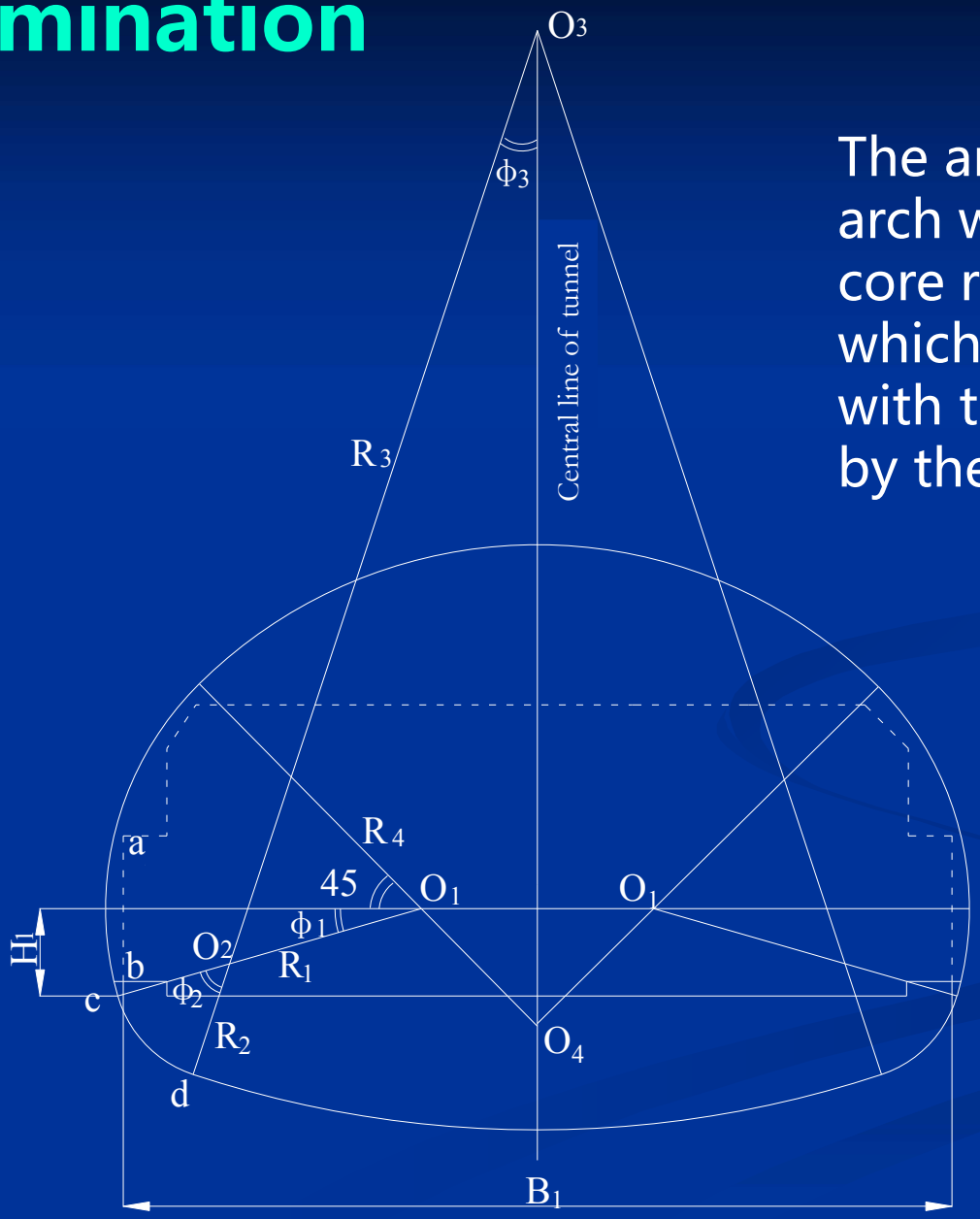


# 2.6 Determination of plane geometric parameters of small spacing section




$$l_{MD} = \sqrt{R^2 - [R\cos\phi_c - (l_{MN} - l_{DC})]^2} - R\sin\phi_c$$

# 3 Transmission cross-section parameter determination




The arch part and the arch waist are three core round arches, which is connected with the inverted arch by the inverted arc.

$$R_{1i} = \sqrt{H_{1i}^2 + \frac{B_1^2}{4}} + 0.15$$

$$R_{3i} = R_{2i} + \frac{(R_{1i} - R_{2i})\cos\phi_{1i} + (i-1)\Delta B/2}{\sin\phi_{3i}}$$

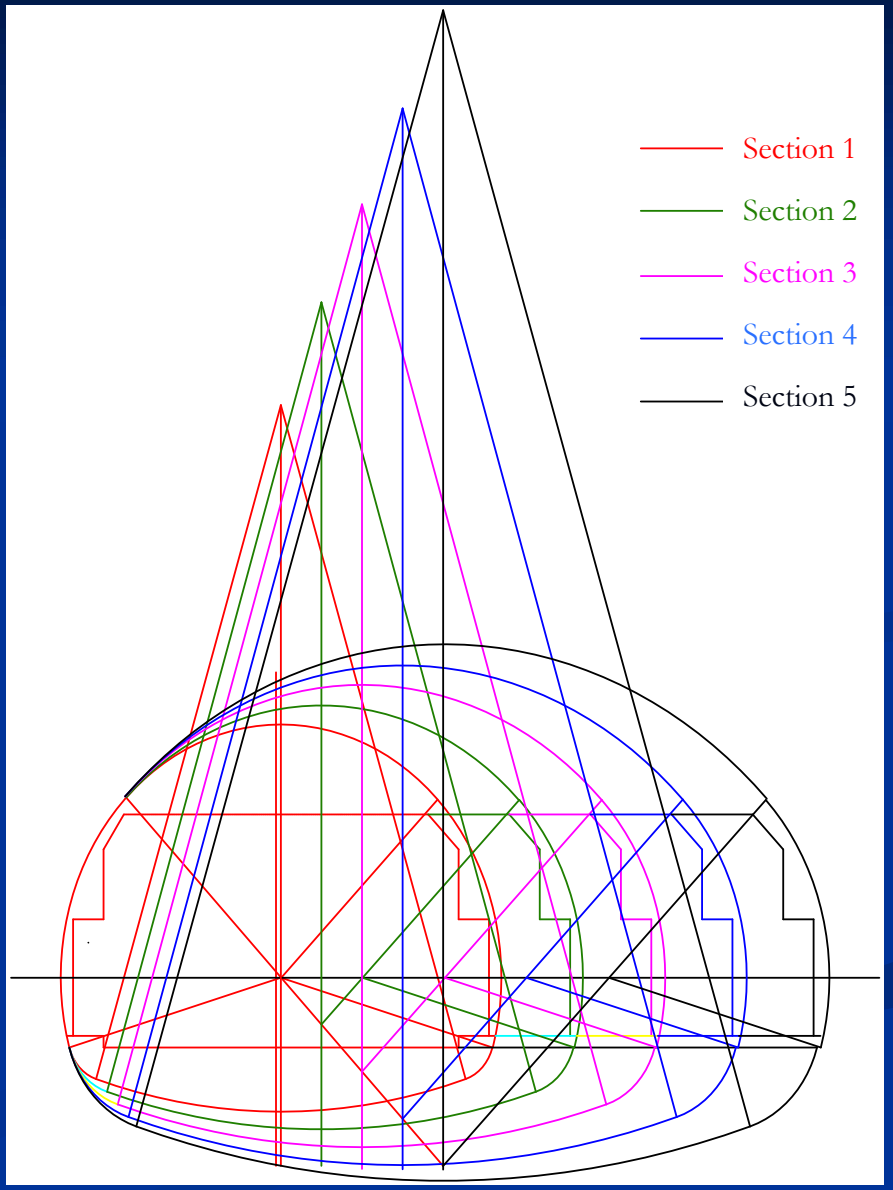
$$R_{4i} = R_{1i} + \sqrt{2}(i-1)\Delta B/2$$

$$\phi_{1i} = \sin^{-1}\frac{H_{1i}}{R_{1i}}$$

$$\phi_{3i} = 90^\circ - \phi_{1i} - \phi_{2i}$$

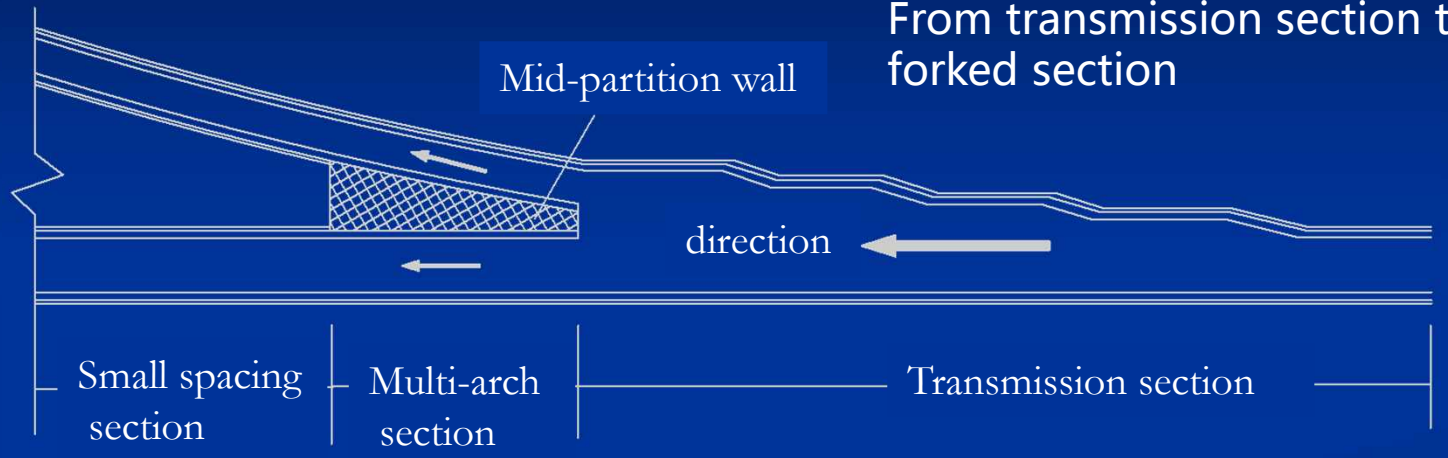
$$\phi_{2i} = 60^\circ$$

$$R_{2i} = 1.0 + (0.2 \sim 0.4)(i-1)$$

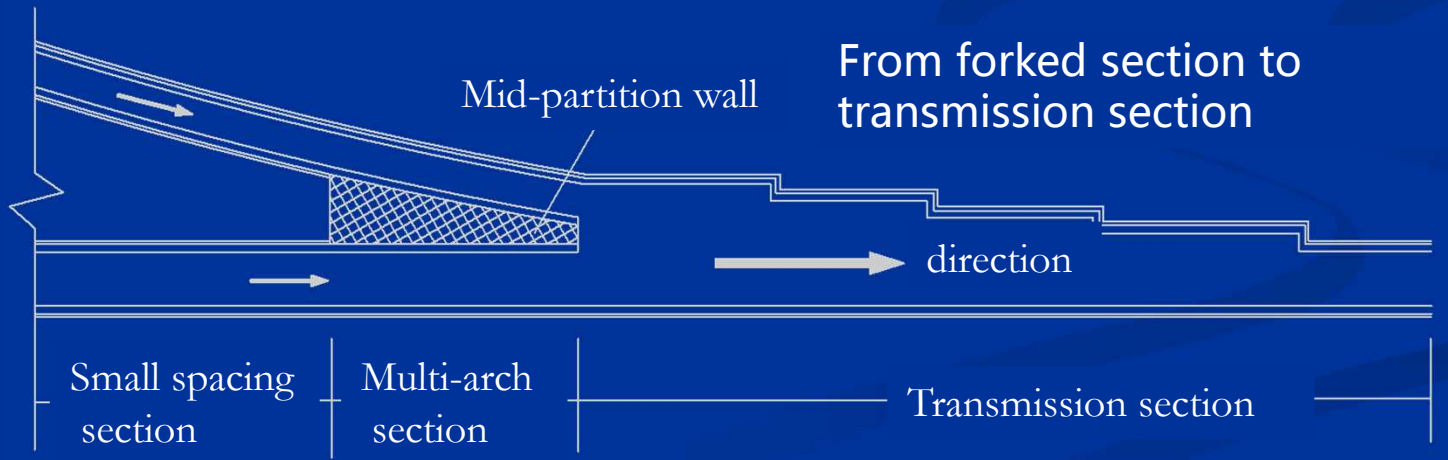


# 4 Forked tunnel construction

## 4.1 Overall construction sequence

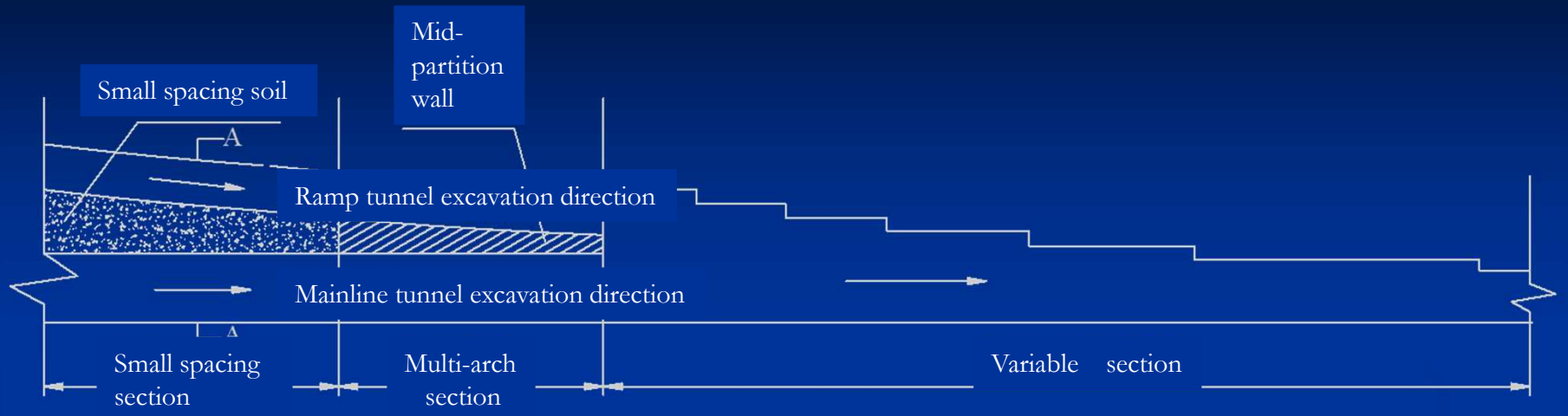


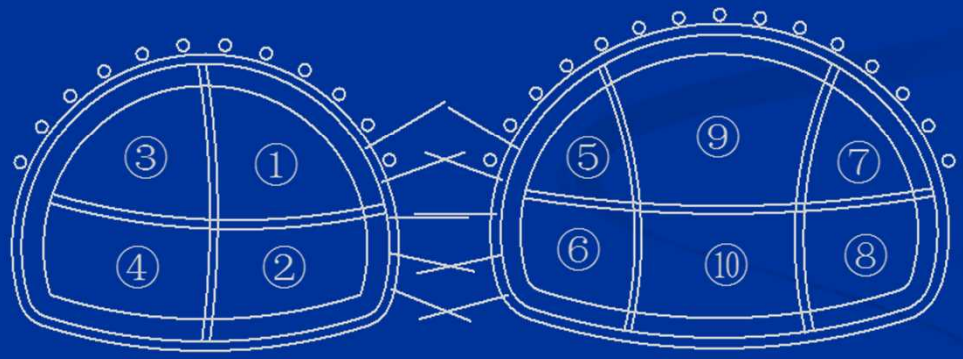

（a） Plan 1




（b） Plan 2

# 5.2 Small spacing section construction

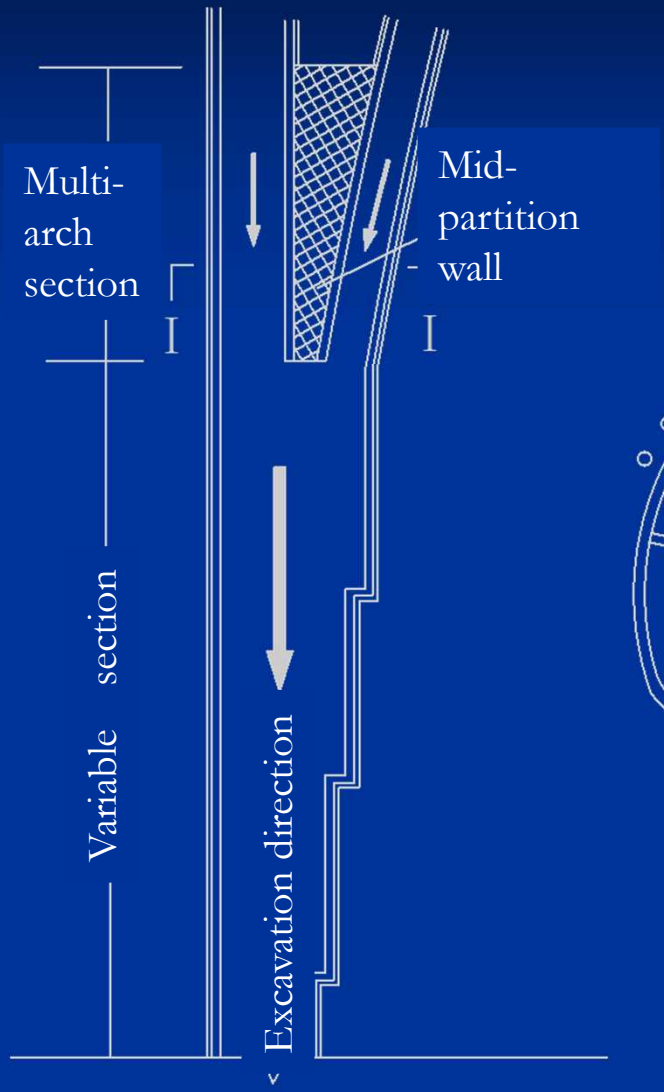


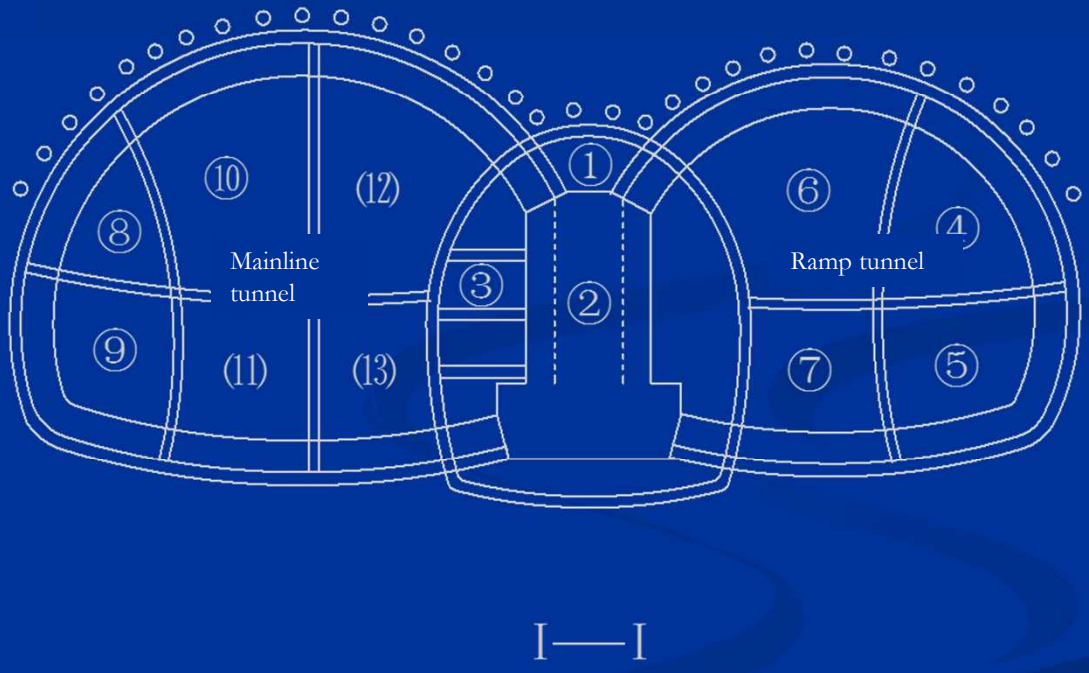

A—— A cross-section

First excavate the ramp tunnel, then reinforce the small spacing soil and then excavate the mainline tunnel.

# 5.3 Multi-arch section construction

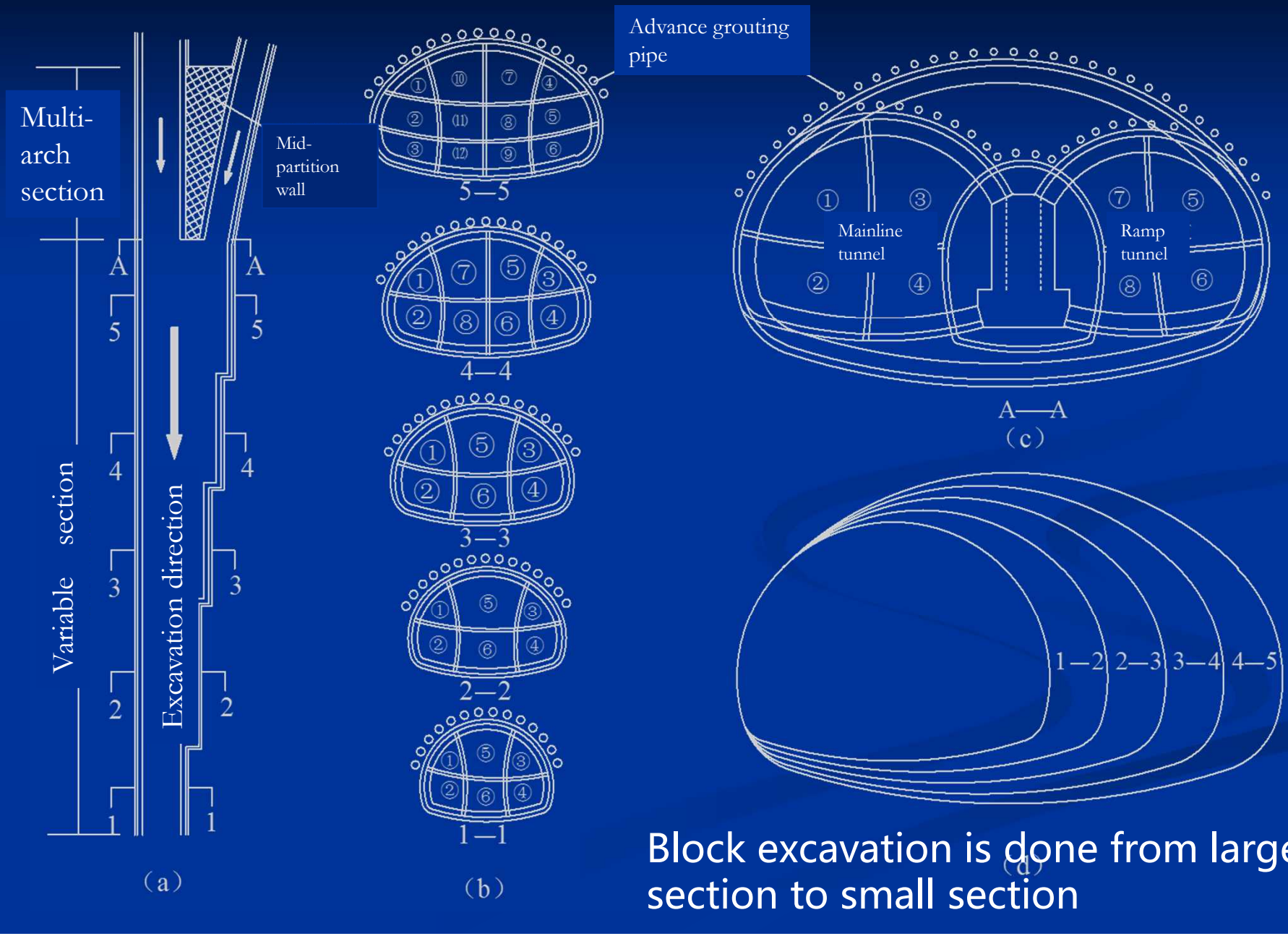



First excavate the middle pilot heading, then construct mid-partition wall.




After the temporary support is arranged on one side of the main tunnel, the ramp tunnel shall be excavated before the mainline tunnel is excavated.

# 5.4 Transmission section construction



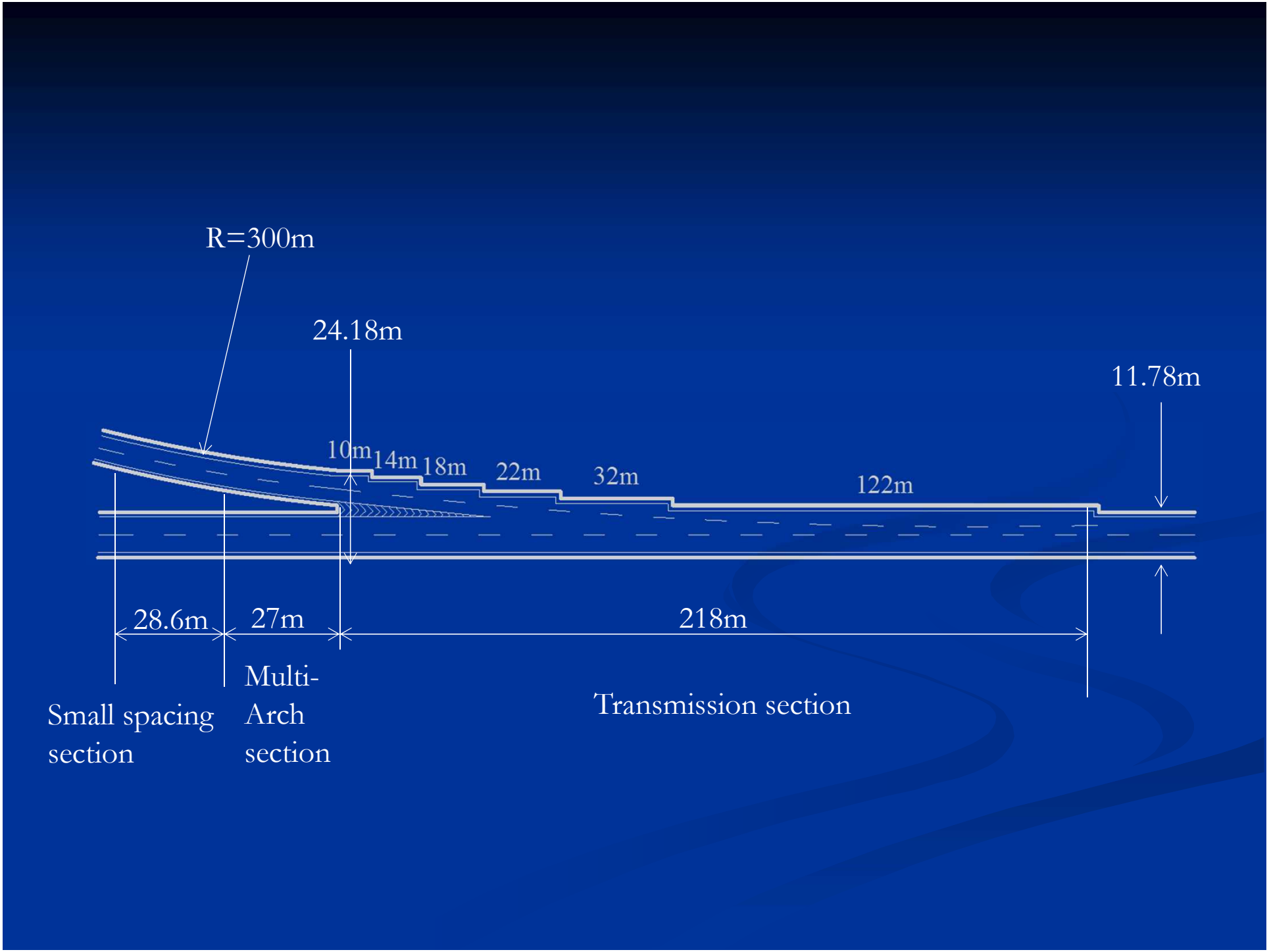

Block excavation is done from large section to small section

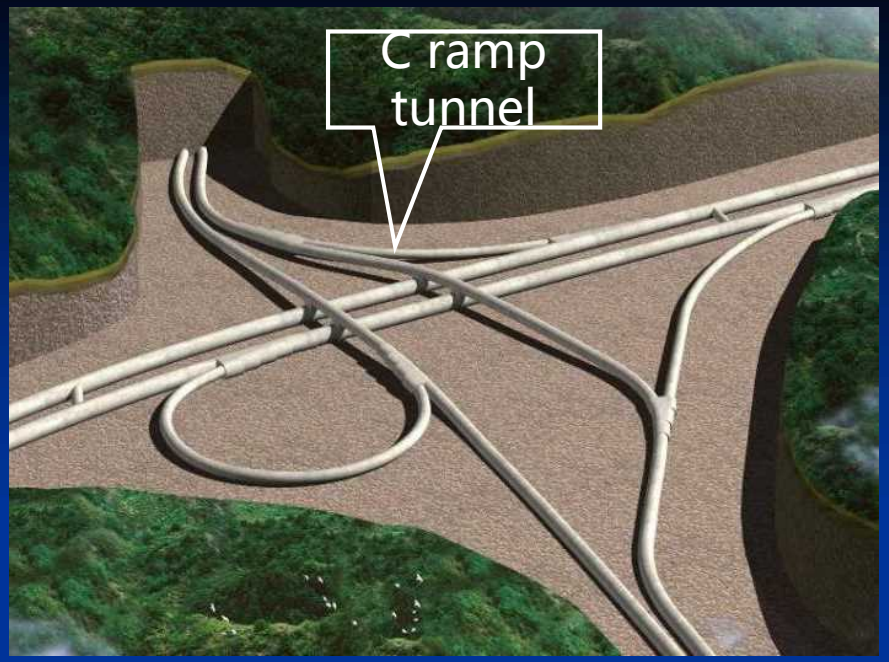
The effect diagram after completion

# 5 Engineering case

In Xiamen Chenggong Road, the designed speed of Wanshishan main tunnel is $v_1$=80km/h， and the designed speed of C ramp tunnel is $v_2$=40km/h when transit to Huyuan Road, so the transmission section length is 218m before separation . The excavation width of ramp tunnel is 8.88m， so the total excavation width is 11.78m， if the excavation width each time is 2.0m， the largest span will be 24.18m after 6 excavations.

| Step excavation span（m） | 14.4 | 16.4 | 18.4 | 20.4 | 22.4 | 24.18 |
|---|---|---|---|---|---|---|
| Step length (m) | 122 | 32 | 22 | 18 | 14 | 10 |


R=300m
24.18m
11.78m
10m
14m
18m
22m
32m
122m
28.6m
27m
218m
Small spacing section
Multi-Arch section
Transmission section




Step at C ramp

Zhonggushan tunnel interchange

Mid-partition
wall at C ramp

# End

# Thanks!