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Fast Analysis System for Tunneling

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Contents

What is the safe design and construction In Tunneling

- **Is the tunneling safe in China ?**
- **What is the safe problem in tunneling ?**

1 Background—Questions

What is the safe design and construction

➢ Tunnel **design** is usually a **blind design**:

- Prior **geological investigation** is often ***not*** **enough**;
- Rock **parameters** is ***not*** **accuracy**;
- Designers usually ***not*** **design bolts and shotcretes**.

So, the tunnel **constructor** is often **blind too**.

➢ They construct tunnel mainly by **experience** not **science**.

1 Background—Questions

How to solving the problem

- Using **Rational (scientific) design** **replace** the **empirical design for tunnel**.

Why we can ***not*** **do the rational design** during tunneling even if we know (get parameters) of the rock of tunnel face after excavation ?

1 Background—Long Time

Because we can

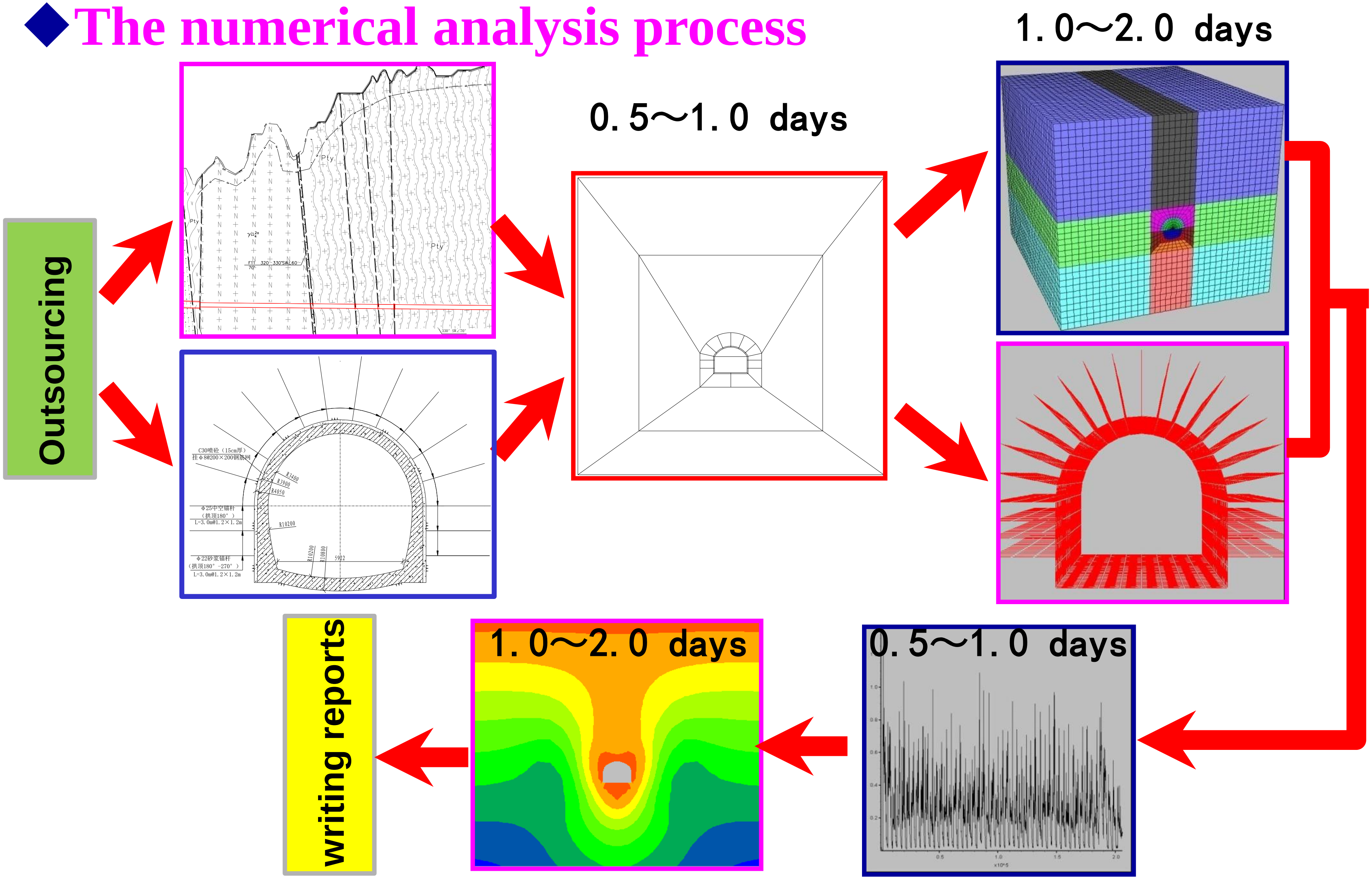
not make **the design calculation**

so fast **that to**

follow **the construction schedule.**

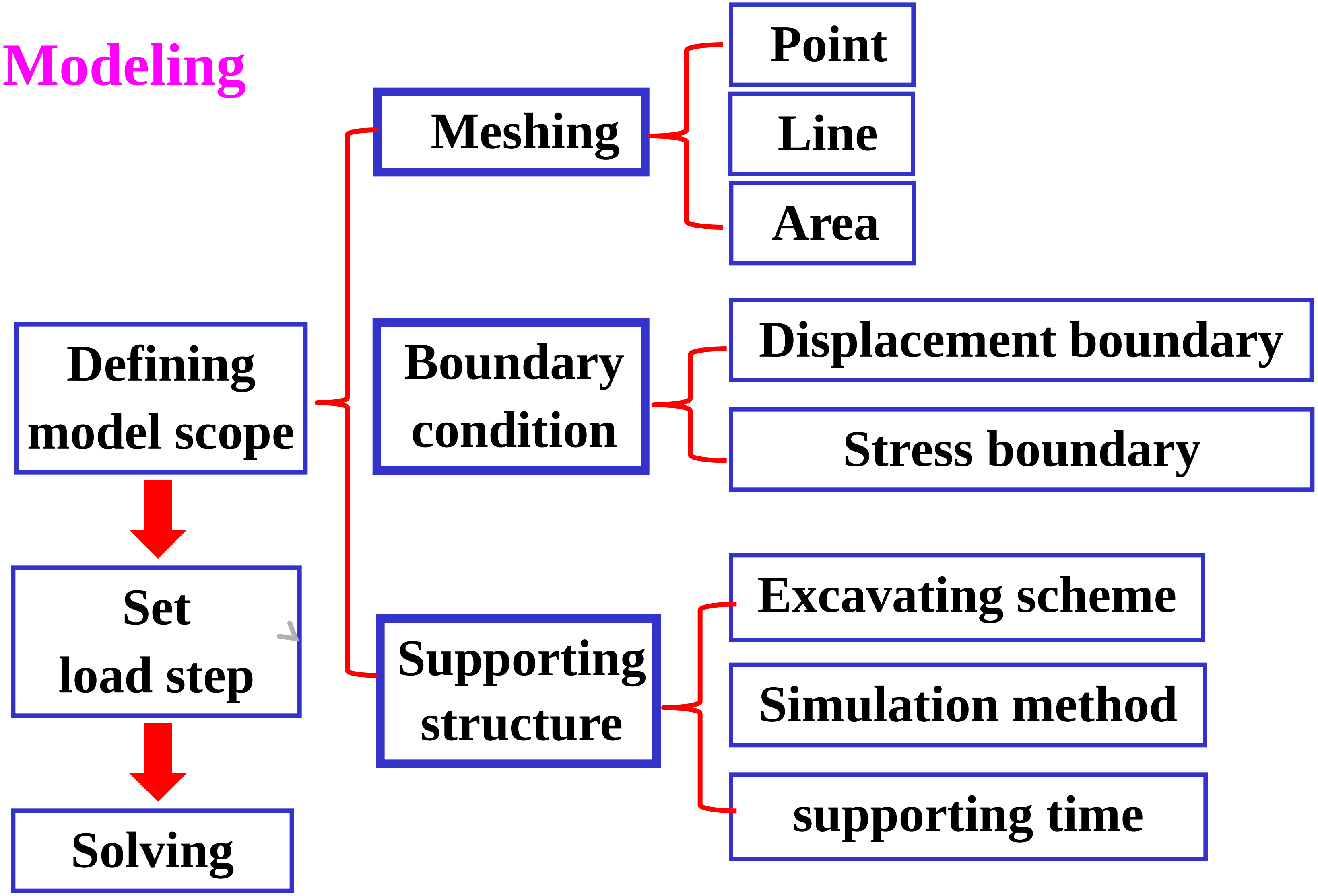
1 Background—Long Time

◆The numerical analysis process



1 Background—Tedious numerical methods

◆Modeling



2 Solution for safe tunneling—Ideal

Can we develop a system which have following features:

- **Fast—from few days reduce to several minutes**
- **Simple to use—apply to ordinary engineers, not professional numerical experts.**
- **Multi-functions:**

✓ **Consider main geological structures of the rockmass**

✓ **Consider excavation and support methods**

✓ **Optimize the support (bolts and shotcret)**

✓ **Quickly back analysis for mechanical parameters of the rockmass**

✓ **Quickly evaluate the stability of surrounding rock and supports**

2 Solution for safe tunneling—Contradiction

◆ **Requirement**

Multifunctions: requiring the large FEM to simulate the particularity of geotechnical engineering (e.g. structural surface, construction measures)

Fast and simple: may not to start with meshing, not involve with elastoplastic/nonlinear solving methods, and the simulation of construction measures **for the users**

Contradiction

2 Solution for safe tunneling—Solving Ideas

- **Prior analysis and research**
- **—Find out the mechanical relations between the tunnel displacements and rock property, load and tunnel size … ….**
- **Not so accuracy-but Fast and simple**
- **—No need to get hundreds or thousands of displacements of all nodes, only 20~30 important points along the tunnel face.**
- **— No need to reach accuracy of 99.99% or 99.999% as most FEM, 80% accuracy is enough !!!**

2 Solutions for safe tunneling

➢Prior analysis

Using the specialized analysis tool to **simulate various tunnels** (different tunnel sizes, rock types, with different geological structures, under different depth and supporting measures)

Analyzing its displacements, stress and supporting forces. (11p,15y)

➢Build the relational database

Studying the correspondence between displacements, stresses and main effect factors to **build the relational database**.

2 Solutions for safe tunneling

➢Form the samples

Taking the relational database of the inputs and outputs of the systematic **numerical tests as main samples**, which is satisfy the stress equilibrium condition, deformation compatibility condition, Elastic-plastic criteria and the strength of supporting structures. And take the **experts experience, field monitoring data and related specifications** as **boundary samples**.

➢Build the automated analysis platform

Using the powerful artificial **neuron network** method to **build the fast intelligence analysis system of tunnels** for the designers and constructors.

3 Building the FAST—Numerical tests

Main influence factors of tunnel stability

- **the size of tunnel**
- **surrounding rock type (E,υ ,C, φ)**
- **the depth of tunnel**
- **faults or joints near the tunnel**
- **supporting structures**

3 Building the FAST—Numerical tests

Tab.1 Parameters of the numerical tests

Parameters	Sampling range	Sampling site
Depth (m)	100～1000	100、500、800、1000
Lateral pressure coefficient	0.38～3.00	0.38、1.00、1.50、2.00、3.00
Deformation modules(Gpa)	0.5～20.0	0.5、2.0、8.0、20.0
Poisson's ratio	0.22～0.32	0.22、0.28、0.32、0.38
Cohesion (MPa)	0.15～1.8	0.15、0.4、0.8、1.8
Internal frictional angle (°)	25～45	25、30、40、45
Fault dip (°)	0～90	0、45、90
Fault distance (diameter)	0.2～1.0	0.2、0.5、1.0
Thickness of fault (cm)	0～200	0、10、20、50、200
Tunnel's span (m)	5～20	6、8、10、15
High-span ratio	0.5～2.0	0.6、1.0、1.5、2.0

3 Building the FAST—Numerical tests

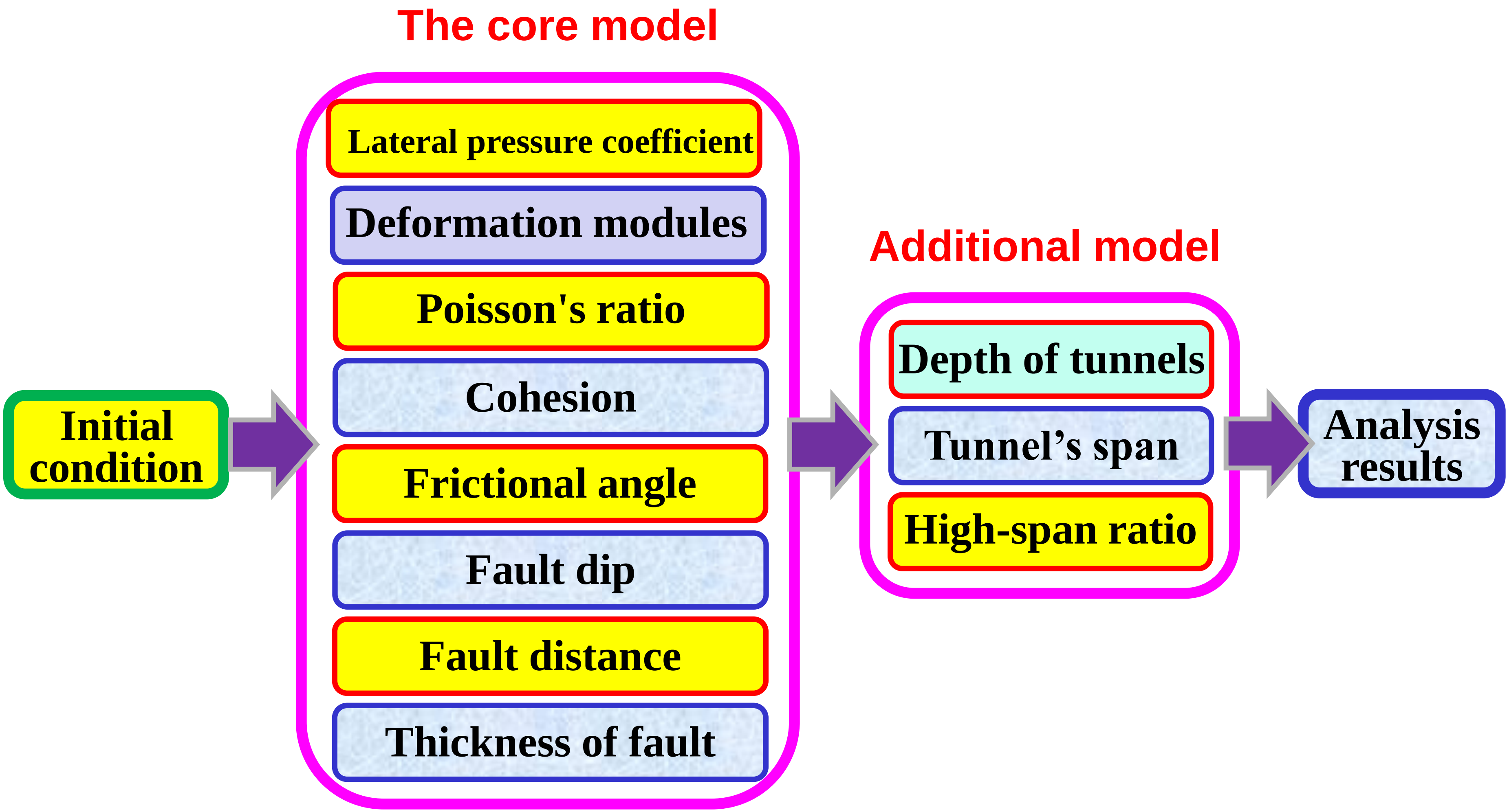
Initial condition →

- Lateral pressure coefficient
- Deformation modulus
- Poisson's ratio
- Cohesion
- Frictional angle
- Fault dip
- Fault distance
- Thickness of fault
- Depth of tunnels
- Tunnel's span
- High-span ratio

→ **Analysis results**

Parallel model

3 Building the FAST—Numerical tests



classify serial model

3 Building the FAST—Numerical tests

- Test scheme design (about 260,000 image tunnels)

Uniform experimental scheme design

Scheme	E	μ	C	Φ	K	α_1	D_1	α_2	D_2
1	20	0.2	0.4	50	1	90	0.2D	90	0.2D
2	0.5	0.28	1.8	25	2.5	180	1D	135	0.5D
3	20	0.2	1.8	40	2.5	0	0.2D	180	0.5D
4	20	0.38	0.15	25	0.38	45	1D	45	1D
5	2	0.2	0.8	50	1	45	0.2D	45	0.5D
6	8	0.2	0.8	40	2.5	135	0.5D	135	0.5D
7	2	0.28	0.8	40	1	180	0.2D	90	0.2D
8	20	0.32	1.8	50	1.5	180	0.2D	45	1D
9	2	0.2	0.4	40	1	180	0.2D	90	0.2D
10	2	0.2	0.8	50	1.5	45	1D	90	0.2D
11	0.5	0.32	0.15	50	1.5	90	0.2D	90	1D
12	20	0.32	0.15	25	2.5	135	0.5D	135	1D

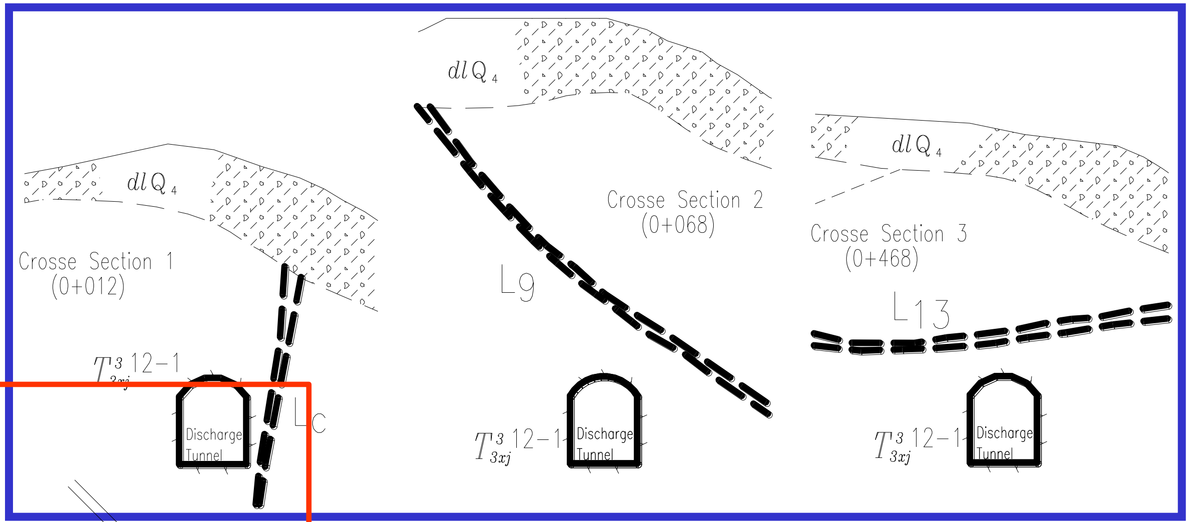
➢Test scheme design

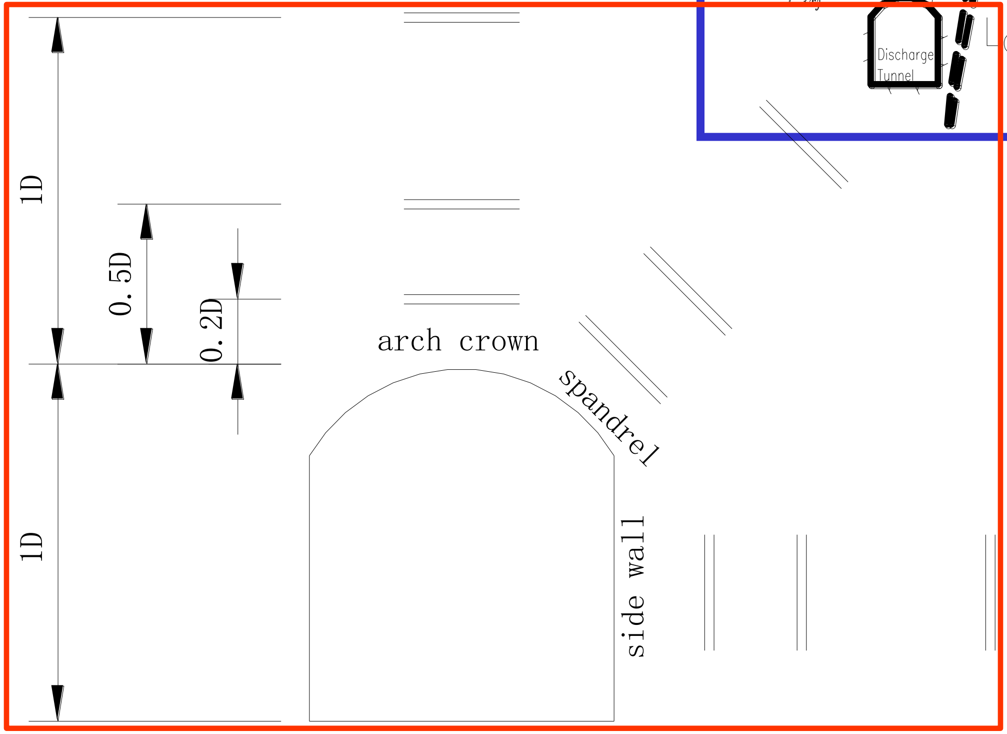
Verification scheme design

Scheme	E(GPa)	μ	C(MPa)	Φ (°)	K_0	α_1 (°)	D_1	α_2 (°)	D_2
1	8	0.32	1.8	30	0.38	0	0.2D	0	0.5D
2	2	0.2	1.8	50	1	0	1D	45	1D
3	2	0.28	0.8	40	1.5	90	1D	180	0.2D
4	0.5	0.28	0.15	40	1.5	0	0.2D	135	0.5D
5	20	0.38	0.4	40	2.5	180	1D	0	0.5D
6	8	0.32	1.8	25	1.5	45	0.2D	45	0.5D
7	8	0.2	0.4	40	1	45	1D	90	0.5D
8	0.5	0.28	0.15	30	0.38	45	1D	135	1D
9	2	0.38	0.8	25	1.5	90	0.2D	90	1D
10	20	0.32	1.8	50	1	90	0.5D	180	0.2D

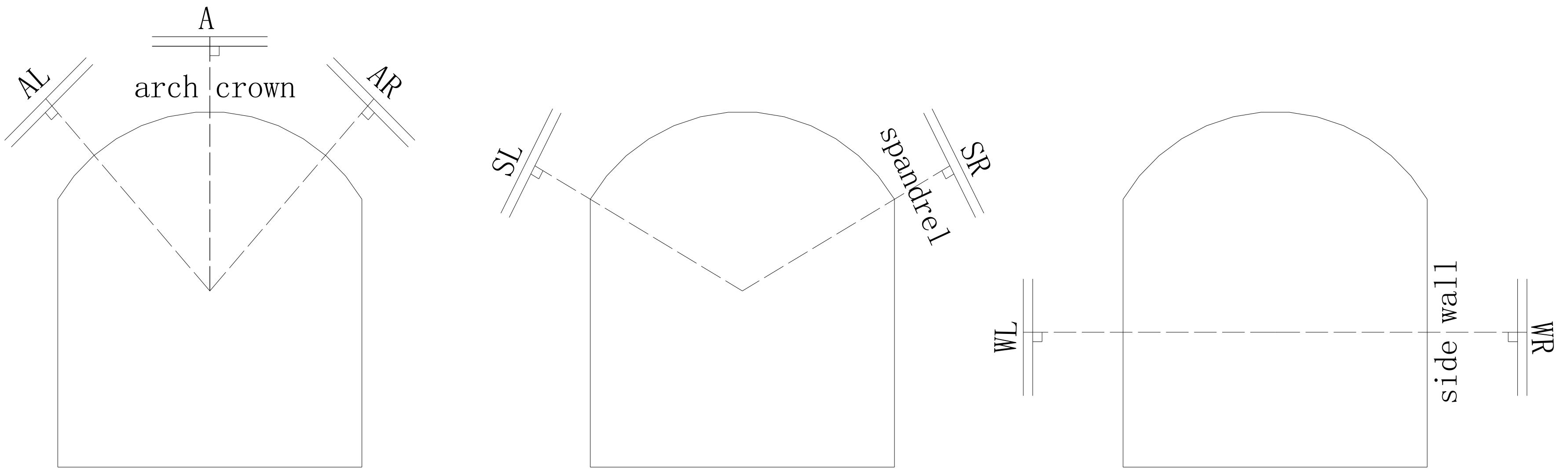
3 Building the FAST—Numerical tests

The modeling for the **position & distance** of faults or joints



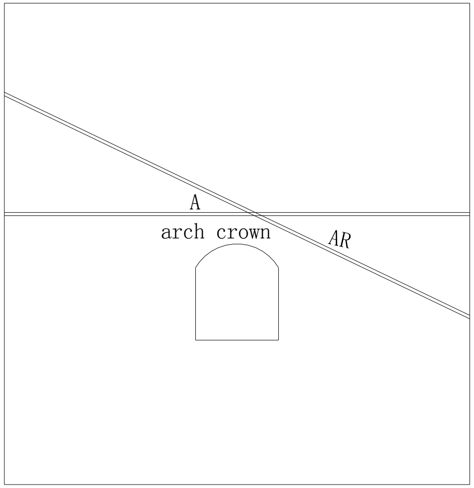


Composition of **two faults**

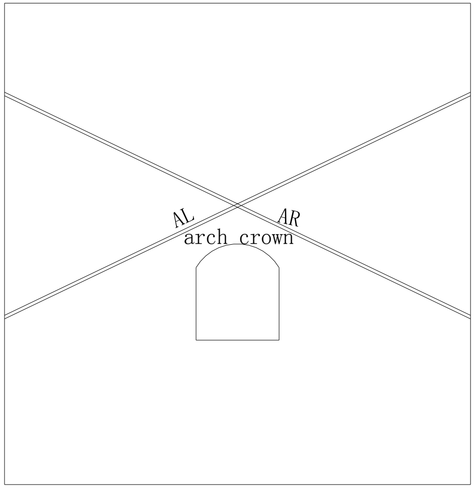


3 Building the FAST—Numerical tests

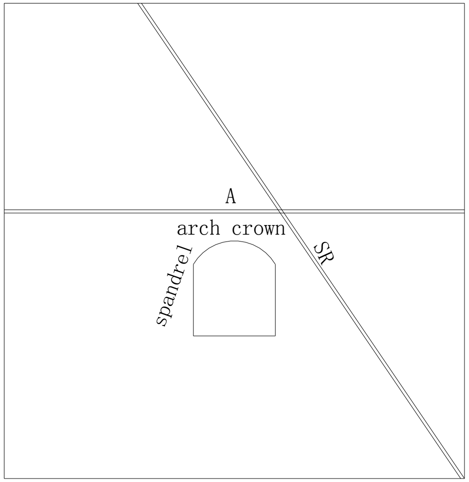
faults on different positions
Of the tunnel



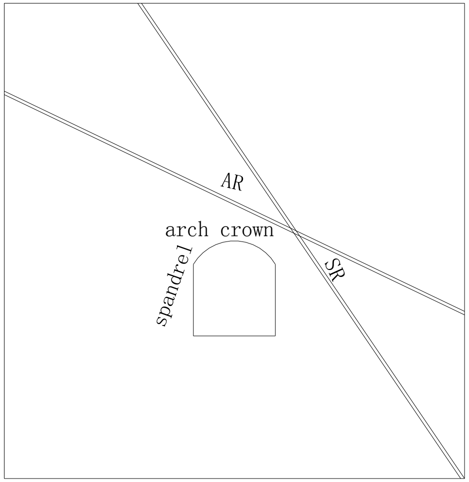
① A+AR



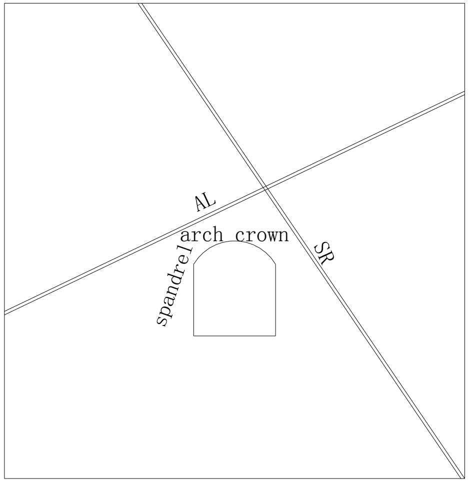
② AL+AR



① A+SR

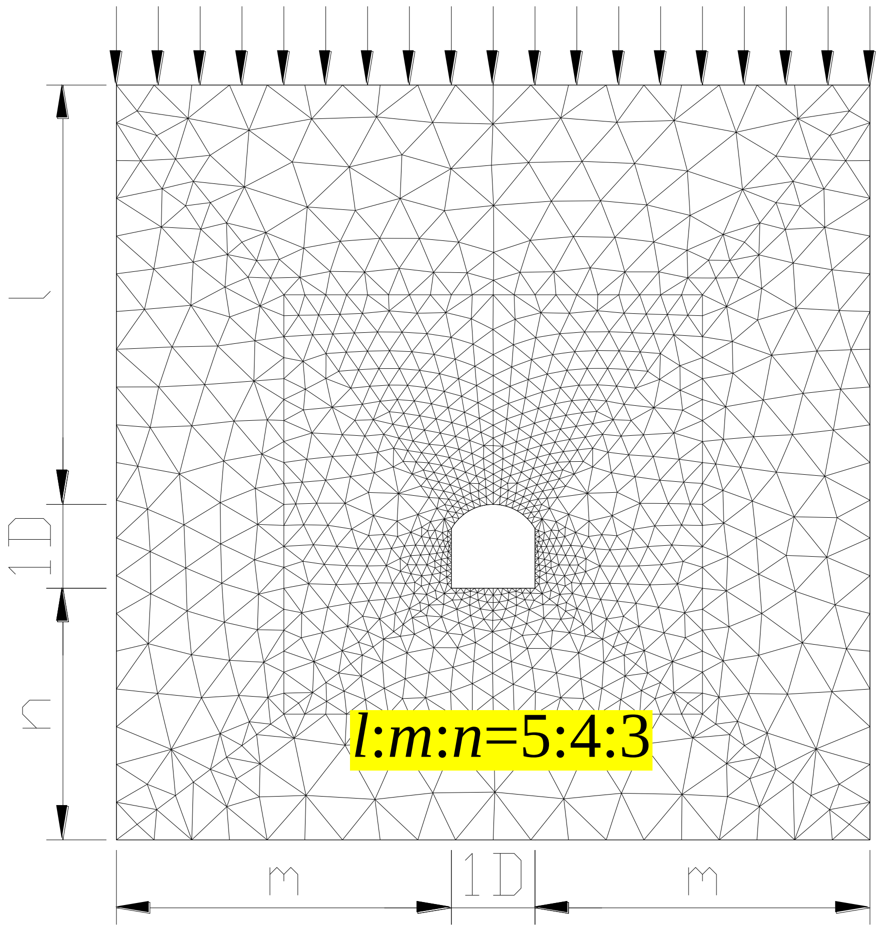


② AR+SR



③ AL+SR

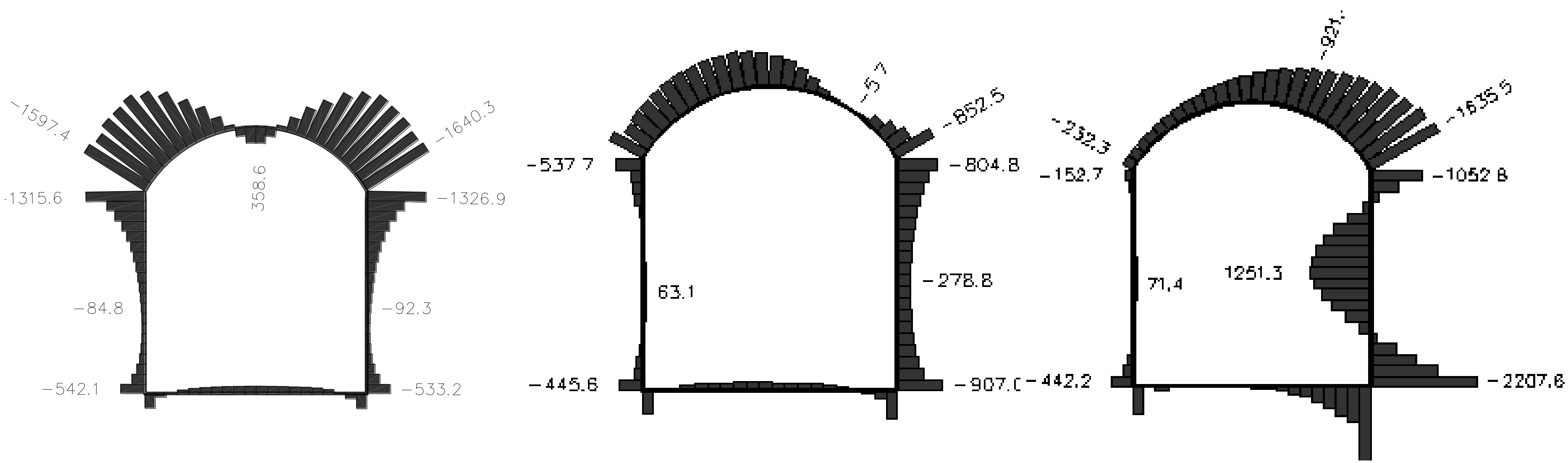
3 Building the FAST—Numerical tests



The FEM model for numerical tests

Some results of numerical tests

(1) The impact of the **weak intercalation** distributed in **vault**, **right spandrel** and **right sidewall.**



➢Supporting time

- **Rock type Ⅲ Stress release rate is 40% ～60%**
- **Rock type Ⅳ Stress release rate is 50% ～80%**
- **Rock type Ⅴ Stress release rate is 60% ～90%**

➢ Support scheme by Chinese code

tunnel span *B*（m） / rock type	*B*≤5	5<*B*≤10	10<*B*≤15	15<*B*≤20	20<*B* ≤25
III	(1)80~100mm shotcrete (2)50mm shotcrete +1.5~2.0m bolt	(1)120~150mm shotcrete (2)80~100mm shotcrete +2.0~2.5m bolt (bar-mat reinforcement,in necessity)	100~150mm shotcrete +bar-mat reinforcement +3.0~4.0m bolt	150~200mm shotcrete +bar-mat einforcement +4.0~5.0m bolt (>5m prestressing force bolt or bolt,in necessity)	–
IV	80~100mm shotcrete +1.5~2.0m bolt	100~150mm shotcrete +bar-mat reinforcement +2.0~2.5m bolt (inverted arch, in necessity)	150~200mm shotcrete +bar-mat reinforcement +3.0~4.0m bolt (inverted arch+>4m bolt, in necessity)	–	–
V	120~150mm shotcrete +bar-mat reinforcement +1.5~2.0m bolt (inverted arch, in necessity)	150~200mm shotcrete+bar-mat reinforcement+2.0~3.0m bolt+inverted arch (steel arch, in necessity)	–	–	–

3 Building the FAST—Intelligence expert system

➢ Support limitations

- **bolt length** should be less than tunnel's diameter.
- **bolt length** should be no less than 1.0m.
- **bolt interval** should be less than one third of tunnel's diameter or one third of bolt length.
- **bolt interval** should be no less than 1.0m or one-tenth of tunnel's diameter.
- … … … …

➢Treating of the weak layer (WL)

Decomposing the effect of weak intercalated layer into the effect of crack and the effect of its affected zone:

The deformation of WIL can be departed into two part:

- ✓ The discontinuous deformation caused by the **slip or open of internal cracks**.
- ✓ The continuous deformation caused by the **filling of WL**.

➢Treating of the Weak Layer (WL)

The **strength of WL** element can be regarded as the **filling's strength** and the effect of WIL's **affected zone** mainly reflected the deformation characteristics of WIL whose parameters are usually referred to the **geotechnical parameters** in no-WIL zone.

$$E_z = \frac{T_z(E_r E_f)}{(T_z - T_f)E_f + T_f E_r}$$

Where, T_z is the thickness of WIL's affected zone ;

T_f is the thickness of WIL;

E_f is the deformation modulus of WIL;

E_r is the deformation modulus of no-WIL rock.

➢Fault impact factor

The **fault impact factor** is the **deformation ratio** of the same key points for two tunnels which are almost the same but **one with fault and the other without fault.**

➢Sample preparation

- **Unified disposal for the inputs**

Let the input bits of sample is x_p(p=1, 2,…, n)， define x_{max} = max{x_p}, x_{min}= min{x_p}, then the inputs could be disposed by the following formula:

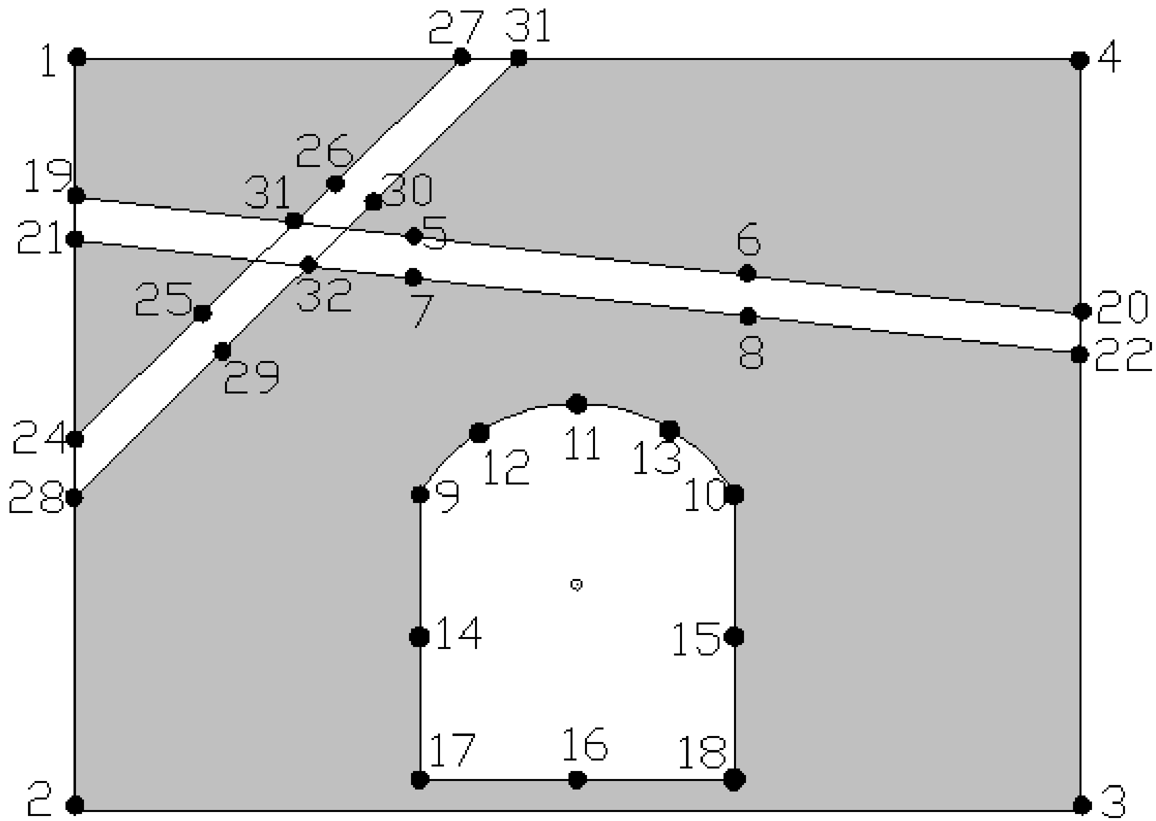
$$\frac{x_p - x_{\min}}{x_{\max} - x_{\min}} \Rightarrow x_p$$

- **Unified disposal for the outputs**

The outputs of the sample is y, considering its particularity, it could be disposed by the following formula:

$$\frac{\lg y}{5} \Rightarrow y$$

➢Network building



32 keypoints×5 variables=160 outputs

3Building the FAST—Neural network model

➢Training network

Have continuously calculated 6 months with 6 high speed computers.

➢Network Testing

The training results when the fault dip is 0°

Scheme	Fault distance/D	Fault thickness/cm	Modulus /MPa	Cohesion /MPa	Friction angle /°	Poisson's ratio	Lateral pressure ratio	Accuracy
1	1	0	3000	1.8	40	0.22	3	90%
2	1	20	6000	0.8	28	0.28	1.5	89%
3	0.5	20	3000	1.8	28	0.32	0.38	87%
4	1	0	15000	1.2	28	0.28	3	91%
5	0.2	20	3000	1.2	50	0.22	0.38	93%
6	0.2	200	3000	1.8	50	0.32	1.5	88%
7	0.2	0	15000	1.8	50	0.28	0.38	89%
8	0.5	200	15000	1.8	40	0.32	3	92%
9	1	0	15000	1.2	50	0.22	1.5	90%
10	1	200	15000	0.8	40	0.28	3	89%
11	1	20	3000	0.8	28	0.32	3	88%
12	1	200	6000	1.2	50	0.32	3	91%
13	1	20	6000	0.8	40	0.22	0.38	88%
14	0.5	0	3000	1.2	28	0.32	1.5	94%
15	0.2	0	6000	1.2	40	0.32	0.38	92%
16	0.5	0	15000	0.8	28	0.28	0.38	89%
17	0.2	0	3000	0.8	40	0.22	1.5	87%
18	0.2	200	3000	0.8	40	0.28	0.38	87%

➢Network Testing

The training results when the fault dip is 40°

Scheme	Fault distance/D	Fault thickness/cm	Modulus /MPa	Cohesion /MPa	Friction angle /°	Poisson's ratio	Lateral pressure ratio	Accuracy
1	*1*	*0*	*3000*	*1.8*	*40*	*0.22*	*3*	**91%**
2	*1*	*20*	*6000*	*0.8*	*28*	*0.28*	*1.5*	**87%**
3	*0.5*	*20*	*3000*	*1.8*	*28*	*0.32*	*0.38*	**86%**
4	*1*	*0*	*15000*	*1.2*	*28*	*0.28*	*3*	**91%**
5	*0.2*	*20*	*3000*	*1.2*	*50*	*0.22*	*0.38*	**90%**
6	*0.2*	*200*	*3000*	*1.8*	*50*	*0.32*	*1.5*	**86%**
7	*0.2*	*0*	*15000*	*1.8*	*50*	*0.28*	*0.38*	**88%**
8	*0.5*	*200*	*15000*	*1.8*	*40*	*0.32*	*3*	**86%**
9	*1*	*0*	*15000*	*1.2*	*50*	*0.22*	*1.5*	**91%**
10	*1*	*200*	*15000*	*0.8*	*40*	*0.28*	*3*	**87%**
11	*1*	*20*	*3000*	*0.8*	*28*	*0.32*	*3*	**87%**
12	*1*	*200*	*6000*	*1.2*	*50*	*0.32*	*3*	**90%**
13	*1*	*20*	*6000*	*0.8*	*40*	*0.22*	*0.38*	**89%**
14	*0.5*	*0*	*3000*	*1.2*	*28*	*0.32*	*1.5*	**92%**
15	*0.2*	*0*	*6000*	*1.2*	*40*	*0.32*	*0.38*	**91%**
16	*0.5*	*0*	*15000*	*0.8*	*28*	*0.28*	*0.38*	**92%**
17	*0.2*	*0*	*3000*	*0.8*	*40*	*0.22*	*1.5*	**88%**

3.Building the FAST—Neural network model

➢Network Testing

The training results when the fault dip is 90°

Scheme	Fault distance/D	Fault thickness/cm	Modulus /MPa	Cohesion /MPa	Friction angle /°	Poisson's ratio	Lateral pressure ratio	Accuracy
1	1	0	3000	1.8	40	0.22	3	89%
2	1	20	6000	0.8	28	0.28	1.5	88%
3	0.5	20	3000	1.8	28	0.32	0.38	88%
4	1	0	15000	1.2	28	0.28	3	89%
5	0.2	20	3000	1.2	50	0.22	0.38	88%
6	0.2	200	3000	1.8	50	0.32	1.5	87%
7	0.2	0	15000	1.8	50	0.28	0.38	90%
8	0.5	200	15000	1.8	40	0.32	3	86%
9	1	0	15000	1.2	50	0.22	1.5	89%
10	1	200	15000	0.8	40	0.28	3	88%
11	1	20	3000	0.8	28	0.32	3	89%
12	1	200	6000	1.2	50	0.32	3	88%
13	1	20	6000	0.8	40	0.22	0.38	87%
14	0.5	0	3000	1.2	28	0.32	1.5	91%
15	0.2	0	6000	1.2	40	0.32	0.38	91%
16	0.5	0	15000	0.8	28	0.28	0.38	90%

3 Building the FAST—Stability Assessment

(1) By Chinese Code

The national standard of “Specifications for bolt-shortcret（GB50086-21)” has specified the deformation allowable ranges for the tunnels in different rock type and depth.

Rock type	Depth (m)		
	<50	50~300	300~500
III	0.1-0.3	0.2-0.5	0.4-1.2
IV	0.15-0.5	0.4-1.2	0.8-2.0
V	0.2-0.8	0.6-1.6	1.0-3.0

Note: the data in table is the percentage of allowable deformation and tunnel’s diameter.

(2) Method based on the improved Finer formula

① The maximum deformation of arch crown when the **plastic zone radius is zero**

$$\delta_{Allowable} = r\sin\phi\left(\gamma H + c\cdot \mathrm{ctg}\phi\right)/2G$$

② The maximum deformation of arch crown when the **plastic zone radius is R**

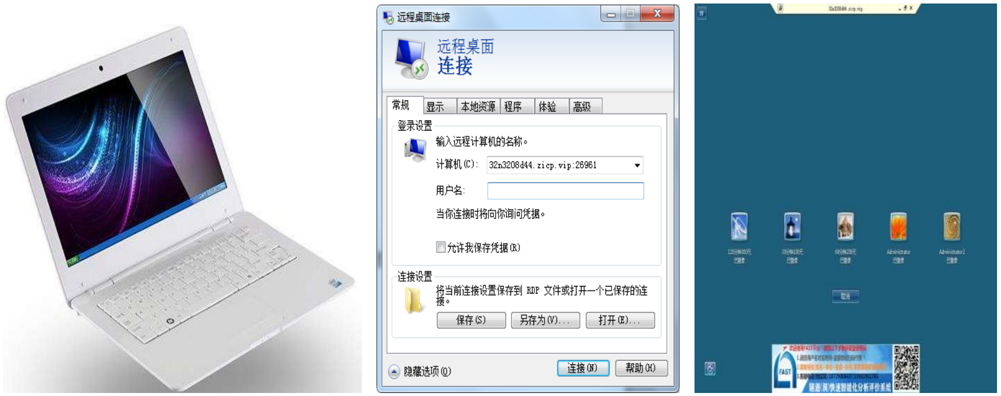
$$\delta_{Allowable} = r(1-\sqrt{1-B})$$

$$B = K_1 K_2 K_3$$

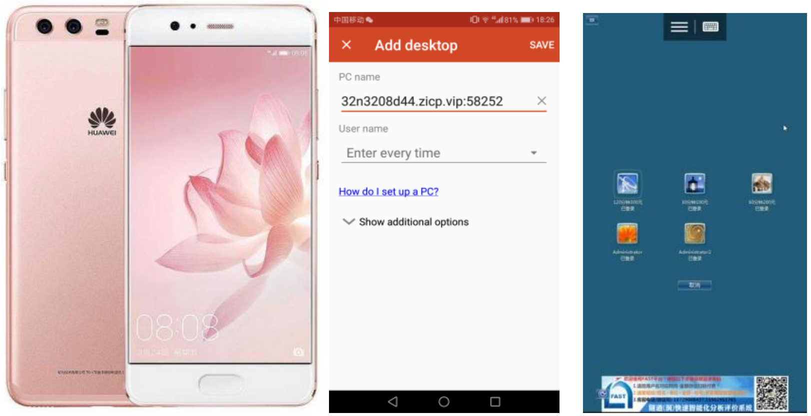
$$K_1 = 2-\frac{1+u}{E}\sin\varphi(\gamma H + Cctg\,\varphi) \qquad K_2 = \frac{1+u}{E}\sin\varphi(\gamma H + Cctg\,\varphi) \qquad K_3 = (\frac{R}{r})^2$$

3 Building the FAST—Operation interface

3 Building the FAST—Operation interface



Computer remote login



Mobile phone remote desktop

Computer users: **D**irect login the remote desktop of windows system

Phone users ： Need to install the APP, *Microsoft Remote Desktop*

PC name：32n3208d44.zicp.vip:26961 or 58252

User name： blank

4 Verification of FAST

The diversion tunnel of Huang river **Jishixia hydropower station**. Weak intercalation(Pjn33) through tunnel roof.

Key points	Results by FINAL	Results by FAST	Relative error
Arch crown	-26.12mm	-25.45mm	3%
Mid leftwall	2.58mm	2.89mm	12%
Mid rightwall	-1.31mm	-1.44mm	10%

4 Verification of FAST

The diversion tunnel of **Zipingbu hydraulic project.**

Weak intercalation(L9, F3) through tunnel.

Key points	Measured results	Results by FAST	Relative error
Arch crown	-24.13mm	-26.62mm	9%
Mid leftwall	35.01mm	30.51mm	13%
Mid rightwall	-13.59mm	-16.03mm	18%

Thank you for your attention!