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NUMERICAL STUDY ON DAMAGE TO MOUNTAIN TUNNELS UNDER FAULT MOVEMENT

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ABSTRACT :
Recent earthquakes indicate that tunnels can not be considered as structures invulnerable to earthquakes, especially in areas crossing a fault. Under the earthquake load, damage of tunnels is easy to happen because of the fault movement. The finite element method is used to study on the response of mountain tunnel with fault movement under different conditions. The study conditions are fault strike (normal fault, reverse fault and strike-slip fault), fault width and surrounding rock classification. By the simulation, some meaningful results have been obtained. The large area failure is easy to occur under the condition of normal fault. Under the condition of strike-slip fault, the stress of tunnel is concentrated at the position of fault, and the stress in both active and driven plate is small. The influence degree of reverse fault is between the other two faults. The damage range of mountain tunnel is increased with the larger fault width. The tensile stress peak of soft rock is smaller than that of hard rock, but the damage range is larger.

KEYWORDS: tunnel, soft rock, hard rock, fault, maximum principal stress

1. INTRODUCTION

The characteristics of fault fracture zone is low strength, easy deformation, large permeability and weak water-resistance, and these characteristics are different from the two plates. Under the earthquake load, because of the mutation of geological, fault movement often occurs. When the tunnel is across the fault, accidents often happen caused by the fault movement. The result is showed by some researches that the main index of tunnel destruction is the relative displacement, and the more relative displacement, the more serious destruction.The mountain tunnel is inevitable to cross the seismic fault, so it should be noted and studied. The seismic design method about small section (such as buried pipeline) has been studied, but the aseismic problems of big section (such as tunnel) are seldom studied. Though many special design scheme and engineering measures have been taken, when the tunnel is across seismic fault, but the systematic and theoretical analysis of the scheme and measures are very few. By using MIDAS software, the response and damage pattern of tunnels under fault displacements are studied in this thesis.

2. ESTABLISHMENT AND ANALYSIS OF FINITE ELEMENT MODEL

2.1 The equation of finite element theory

The load is applied through multi-step during simulation. The finite element equation to simulate mechanical state at different stage is as follows:

$$\{[K_0]+[\Delta K_i]\}\{\Delta\delta_i\}=\{\Delta F_{ir}\}+\{\Delta F_{ia}\}$$

$[K_0]$: the total stiffness matrix before loading

$[\Delta K_i]$: the increment or reduction of support's structural stiffness during applying load

$\{\Delta F_{ir}\}$: boundary initial node force array at each stage

$\{\Delta F_{ia}\}$: the increment of nodal load matrix in each load step

$\{\Delta\delta_i\}$: the increment of displacement array in each load step

2.2 Finite element model:

The finite element software MIDAS/GTS is used to construct a three-dimensional model which is composed of tunnel lining and surrounding rock. The model's size is 400 meter length, 106.2 meter width and 80 meter height. The plate element is used for tunnel lining, and solid element is used for surrounding rock. A inclined weak rock is set in the middle of surrounding rock to simulate fault, and the fault's dip is 45°. The finite element model and mesh are showed as Fig.1:

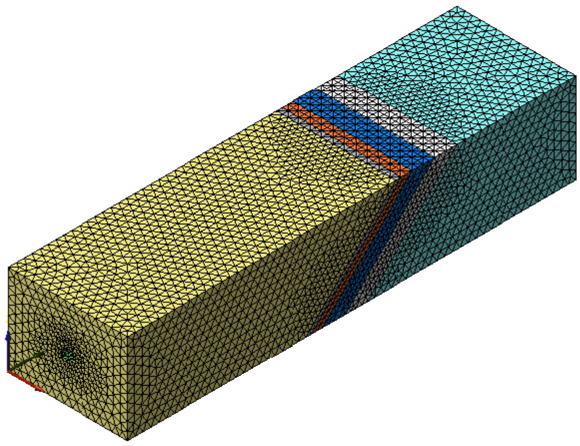


Fig.1. The finite element model and mesh

Material parameters are showed in table 1:

Table 1 Material parameters

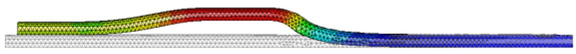
parameters	Lithologic characters	E	μ	γ	structure thickness	C	φ
Hard rock	granite	25 Gpa	0.2	26 KN· m^{-3}	—	1.7 Mpa	45°

Soft rock	siltstone	6.5 Gpa	0.20	24.3 KN· m^{-3}	—	0.52 Mpa	33.8°
fault （hard rock）	siltstone	3.8 Gpa	0.30	22 KN· m^{-3}	—	0.6 Mpa	25°
fault （soft rock）	shaly sand	1.3 Gpa	0.33	17 KN· m^{-3}	—	0.6 Mpa	25°
Tunnel lining	—	35.5 Gpa	0.20	25.5 KN· m^{-3}	0.5m	—	—

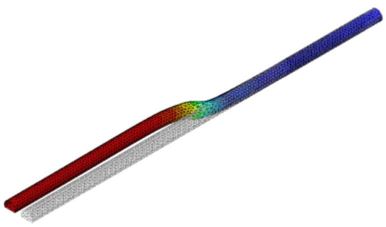
2.3 Analysis on tunnel lining under different work conditions

The effect of fault movement is simulated by imposing forcible displacement load on the hanging wall rock. The values of forcible displacement load in horizontal and vertical directions are both 1 meter, and imposed by 10 steps. The change of tunnel lining's stress is analyzed by different step loading condition, and the normal fault, reverse fault and strike-slip fault are simulated by changing the direction of displacement load. The deformation of tunnel under fault movement is showed as Fig.2:

Normal fault



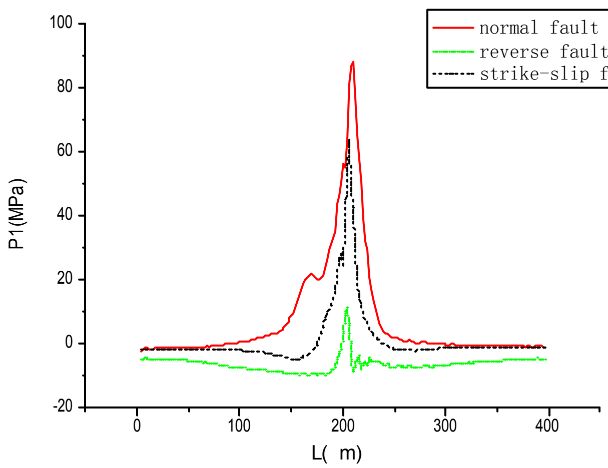
Reverse fault

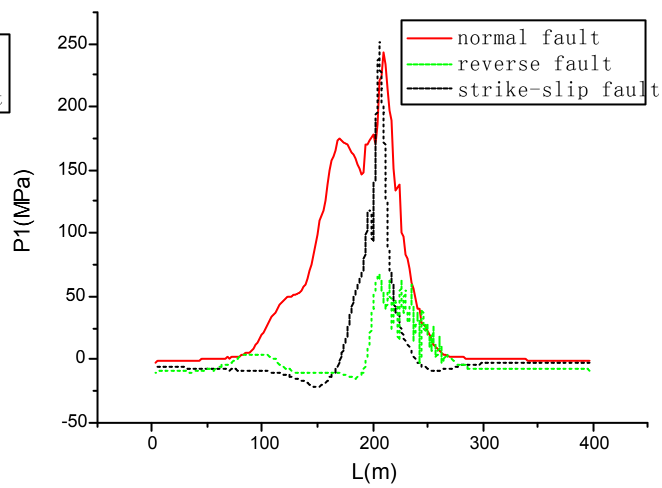


Strike-slip fault

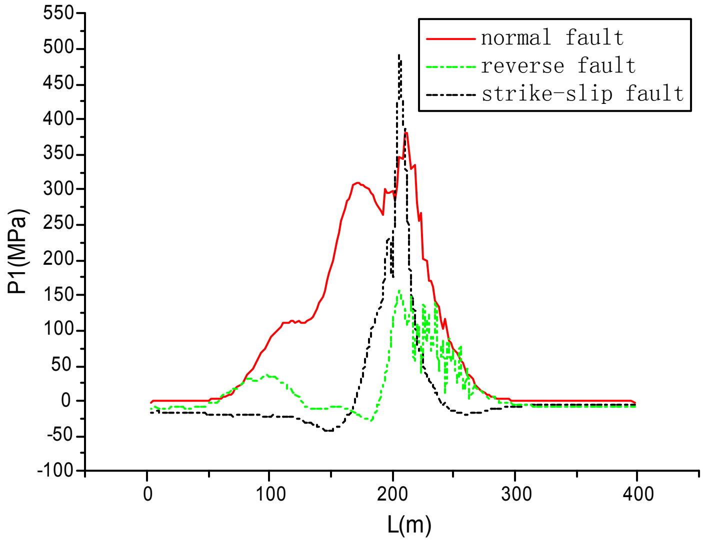
Fig.2. The deformation of tunnel

5 meter, 20 meter and 100 meter are used to analyze the change of tunnel stress with different fault width. The condition of soft rock is mainly simulated. The maximum principal stresses of tunnel roof and floor are simulated under different fault conditions. The simulated results of 5 meter fault width are showed as Fig.3 and Fig.4.





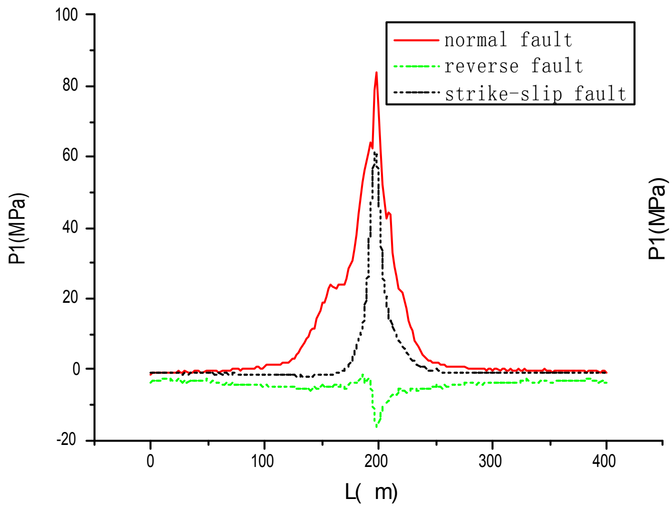
The first load step The fifth load step



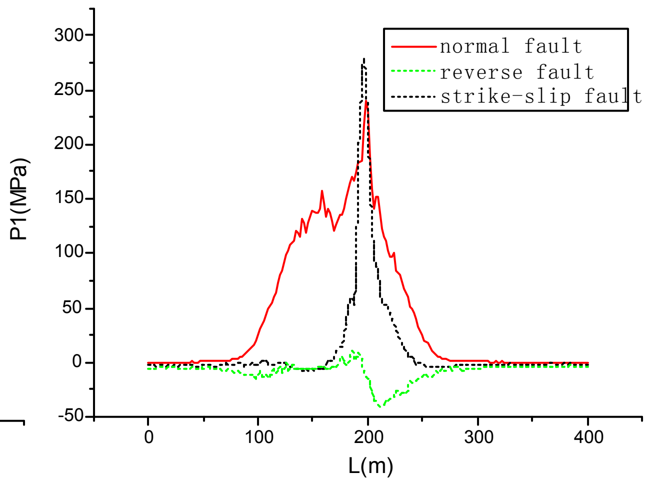
The tenth load step

Fig.3. The maximum principal stresses of tunnel roof

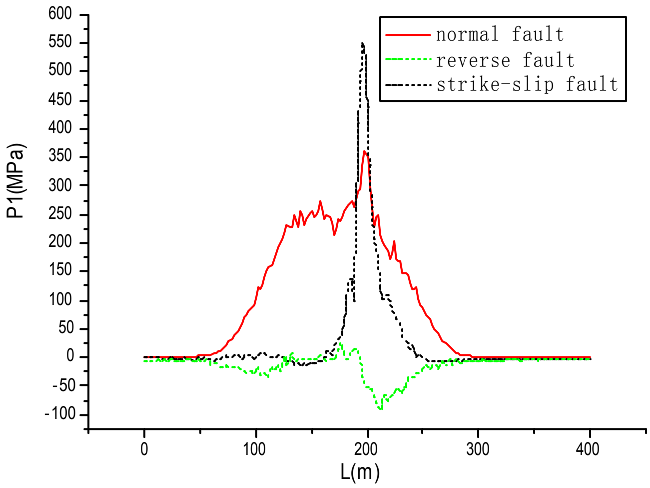
In the first step, the peak tensile stresses of the tunnel roof all occur at fault under the three work conditions. The value of tensile stress is biggest in normal fault, smallest in reverse fault, and the value of strike-slip fault is between them. In the fifth step, under the condition of normal fault, a peak tensile stress occurs at about 50 meters to the fault in the active plate. The peak compress stress of the reverse fault occurs at about 10 meters to the fault. In the last step, the peak tensile stress of strike-slip fault is biggest, but its damage range is smallest. The biggest damage range occurs in normal fault.



The first load step



The fifth load step

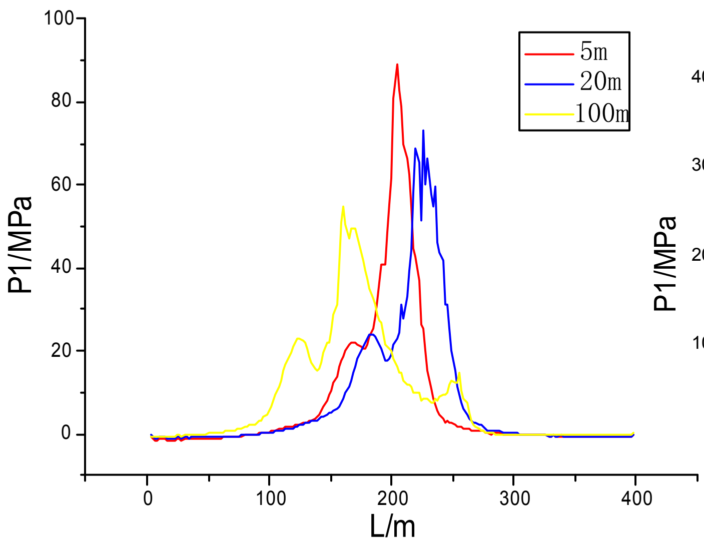


The tenth load step

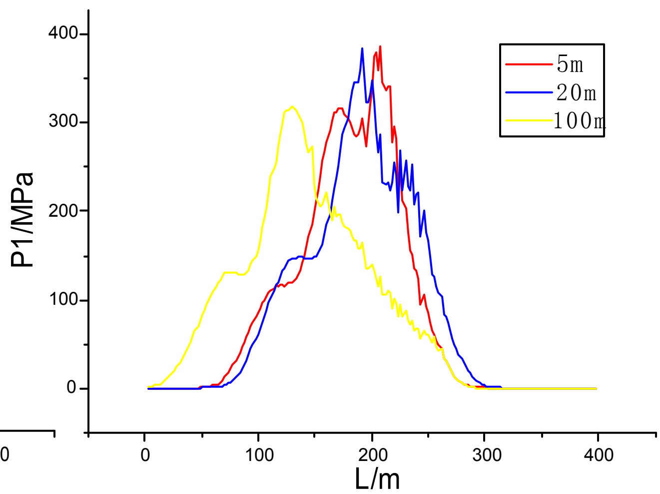
Fig.4. The maximum principal stresses of tunnel floor

The simulated results of the tunnel floor are showed as follows: In the first step, the peak stresses are all at the fault under the three conditions. The tensile stress under normal fault condition is bigger, and that under strike-slip fault condition is smaller. The stress of tunnel floor under reverse fault is compressive stress. In the fifth step, the peak stress of strike-slip fault is bigger than that of normal fault. In the last step, the peak compressive stress and damage range both are increased.

The tunnel lining is damaged seriously under normal fault condition, so the different widths(5meter, 20 meter, 100 meter) and different surrounding rock are analyzed under this condition. The results are showed as Fig.5 and Fig. 6



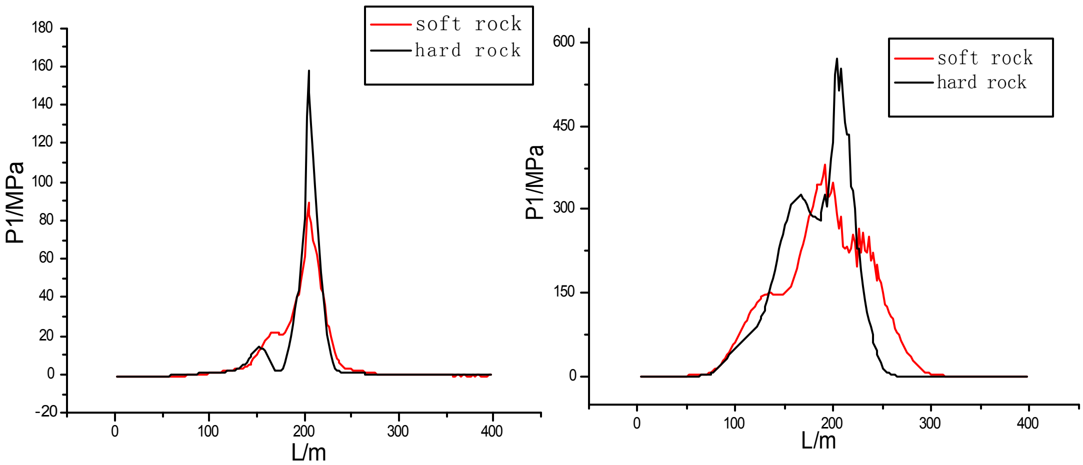
The first load step



The last load step

Fig.5. The maximum principal stresse of tunnel roof with different fault width

In the first step, a small peak stress is generated at about 50 meter to the fault in the active plate under the three different conditions, in which the fault has different width .the biggest peak stress is generated at the position of fault, and the more fault width, the smaller the peak stress is. From the last step, the result can be concluded; the damage range is increased with the more displacement. And the more fault width, the more the damage range is.



The first load step The last load step

Fig.6. The maximum principal stresse of tunnel roof with different surrounding rock

In the first step, the peak tensile stresses are both generated at the position of fault, and the stress value of soft rock is smaller than that of the hard rock. In the last step, the peak stress of soft rock is close to the active plate, but the peak stress of hard rock is close to the driven plate.

3. CONCLUSIONS

The fault with 5 meter width and soft surrounding rock is mainly analyzed. Some results also can be made by comparing with the different width (20 meter, 100meter) and hard surrounding rock. The following conclusions and remarks can be made based on the analysis.

1. The work condition of normal fault:

The stresses, generated in the tunnel roof and tunnel floor, both are tensile stress. The biggest peak stress is at the fault. Another peak stress is generated at the position, which is about 50 meter to the fault. With the more load step, the peak tensile stress and damage range are both increased.

2. The work condition of reverse fault:

The stress, in the tunnel roof, is tensile stress. But the stress is compressive stress in the tunnel floor. The biggest peaks of both tensile and compressive stress are both at the fault. With the more load step, the peak compressive stress and damage range are increased.

3. The work condition of strike-slip fault:

The stresses are both tensile stress in the tunnel roof and floor. The peak tensile stress is at the fault. In the first step, the stress is smaller than that under condition of normal fault. With the increased load step, the peak stress is increased more quickly, and exceeds the stress of the strike-slip fault. But the damage range under this condition is the smallest.

4. The different fault width of 5m, 20m and100m

Under the three different fault width conditions, the biggest peak tensile stresses are all generated at the fault, and the bigger fault width, the smaller the peak stress is. Another peak stress is generated at the position about 50 meters to the fault. This peak stresses of the three conditions are nearly equivalent in first step, but with the more load step, the bigger fault width, the smaller the stress is. The bigger the fault width, the bigger the damage range is.

5. The soft surrounding rock and hard surrounding rock

In the first step, the peak tensile stresses are both generated at the fault. In the last step, the position of peak stress of soft rock is close to the active plate, but it is close to the driven plate under the condition of hard surrounding rock. In the same step, the peak stress of soft rock is smaller than that of hard rock, but its damage range is bigger than the hard rock's.

From all above results, the peak stress is generated at the position of fault. The stress value and influence area in active plate is bigger than that in driven plate. During the fault movement, the most serious damage is generated under the condition of normal fault. And the more fault width and softer surrounding rock is easy to damage.

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