STUDY ON EARTHQUAKE RUPTURE RESPONSE OF OVERLYING SOIL SITE UNDER DIP-SLIP FAULT DISPLACEMENT

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ABSTRACT :
In order to achieve the earthquake rupture response characteristic of overlying soil site under dip-slip fault displacement, the pseudo-static elastic-plastic finite element method is used in the study. Factors such as the depth of overlying soil site and fault dip are taken into account. The earthquake rupture characteristics of overlying soil under dip-slip fault displacement were studied by numerical illustration. Calculating results show that the rupture response of overlying soil site caused by reverse fault movement is severe than that caused by the normal fault displacement.
KEYWORDS: dip-slip fault, overlying soil site, earthquake rupture

1. PREFACE

In order to assure the safety of engineering structures near active faults, the ground surface rupture displacement under the action of fault displacement should be studied, and this is beneficial to the seismic risk analysis of a project site. Many attentions have been paid to the study of damage to engineering and structures caused by fault displacement. Utilizing centrifugal machine, the simulating test of soil site model under bedrock upright movement (normal fault) or horizontal movement (strike-slip fault) was conducted by Dong Jincheng and Liu Shouhua[2](1996), numerical simulation of the centrifugal machine test was also carried on, the soil's double yielding side model was applied in the analysis. Taniyama and Watanabe[4](2000) finished a sand box experiment, in which the soil's elastic-plastic model of Drucker-Prager rule was used to simulate the experiment. The result is that the minimum fault vertical displacement needed for run-through soil site is 3%-5% of the depth of overlying soil when the depth of overlying soil is 30-50m, when the depth of overlying soil is 70m, the minimum fault vertical displacement is 7% of the depth of overlying soil. Guo Endong and Feng Qimin[3](2000) performed the earthquake shaking table test of the overlying soil model, and studied the earthquake rupture response of the models under reverse fault and the strike-slip fault displacement, numerical study was also carried on based on the test. Ramancharla and Meguro[5](2001) adopted "Applied Element Method"[6] to conduct the numerical simulation of the response of overlying soil under dip-slip fault movement, some qualitative conclusions were drawn.
Here, the earthquake rupture characteristics of overlying soil under dip-slip fault displacement are studied by pseudo-static elastic-plastic finite element method, factors such as the depth of overlying soil, the dip angle

of the fault and so on are considered in the study, the earthquake rupture displacement and the rupture state of overlying soil are analyzed.

2. PSEUDO-STATIC ELASTIC-PLASTIC FINITE ELEMENT METHOD

The dynamic response equation of a structure under external loads is:

$$[M]\{\ddot{\delta}\}+[C]\{\dot{\delta}\}+[K]\{\delta\}=\{P(t)\} \tag{1}$$

in the equation, $[M]$ is the mass matrix, $[C]$ is the damping matrix, $[K]$ is the total stiffness matrix of the structure, δ is the system's total displacement vector of fixed coordinate corresponding to the structure, $\{P(t)\}$ is the external load. The earthquake rupture response of overlying soil can be simplified as an equivalent static problem when neglecting the influence of the speed and acceleration of fault movement. The equation may be rewritten as:

$$\begin{bmatrix}[K]_{ss} & [K]_{sb}\\ [K]_{bs} & [K]_{bb}\end{bmatrix}\begin{Bmatrix}\{\delta\}_s\\ \{\delta\}_b\end{Bmatrix}=\begin{Bmatrix}\{P\}_s\\ \{P\}_b\end{Bmatrix} \tag{2}$$

where $\{\delta\}_s$ is the displacement response of free nodes, $\{\delta\}_b$ is the fault displacement which is applied to the structure through restrained nodes, $\{P\}_s$ is the external force on the free nodes, when the earthquake displacement is only inputted by the restrained nodes, $\{P\}_s=\{0\}$, then:

$$[K]_{ss}\{\delta\}_s+[K]_{sb}\{\delta\}_b=\{0\} \tag{3}$$

formula (3) is the finite element equilibrium equation that is adopted to calculating the earthquake rupture displacement response of overlying soil under fault movement.

The linear strengthened Mohr-Coulomb elastic-plastic model is applied in the analysis, after the soil unit go into the plastic yielding state, the soil elastic constant is taken as E_p=0.1E_i, and the elastic modulus matrix will be replaced by elastic-plastic modulus matrix. After the soil unit cracked, the elastic modulus is taken as 5% of the initial tangent elastic modulus. After the soil unit was in the plastic stage, assuming there exists only form changing, but no volume changing, then Poisson ratio μ_t=0.5, there will exist the circumstances that the denominator of $1-2\mu$=0, to avoid this case, μ_t is taken as 0.485.

3. ANALYSIS MODEL OF OVERLYING SOIL

The response of overlying soil under dip slip fault movement may be simplified as plane strain problem, the plane's four nodes equal parameter element is used in the analysis. Fig. 1 is the sketch map of overlying soil model under reverse fault movement, the right is symmetrical with the left, the left side of the central line is on top of the up plate of the fault, and the right side of the central line is on top of the down plate. The size of the overlying soil calculating model of the normal fault is the same with the reverse fault, but the direction of bedrock movement is opposite.

If the displacement of the up plate is U, then, the displacement of the bottom boundary node i of overlying soil on the side of the up plate is U_i:

$$U_i = \begin{Bmatrix} u \\ v \end{Bmatrix} = \begin{Bmatrix} U\cos\alpha \\ U\sin\alpha \end{Bmatrix} \qquad (4)$$

in equation (4): u 、 v is the displacement of the node i in the horizontal and vertical direction, α is fault dip.

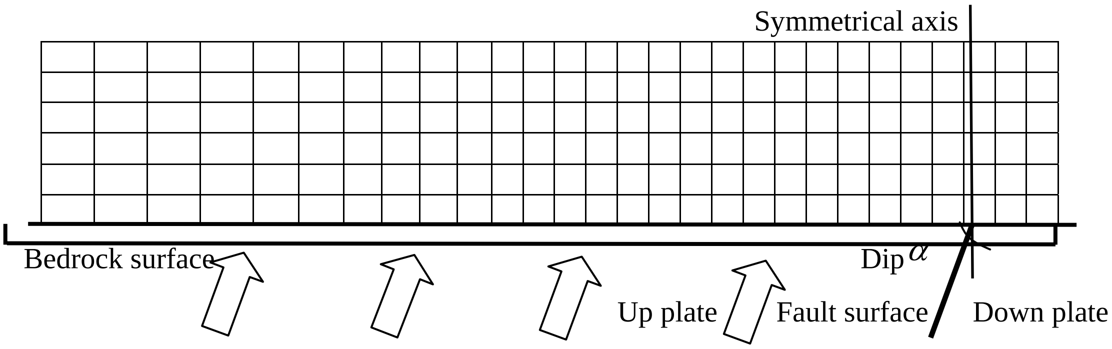

Fig. 1 the sketch map of the overlying soil model of the reverse fault

During analysis, the soil parameters are defined as: the property of soil is sub-sticky, cohesive force $c = 58Kpa$, angle of internal friction $\varphi = 20.2^{\circ}$, the constant $k = 160$, $n = 0.91$, soil unit weight $\gamma = 20\,kN/m^3$, the coefficient of the flank press K_0 =0.43.
Considering the influence of the boundary condition to the element stress, the length of the model is taken as 300m, the bottom of the model is entirely-fixed boundary, the left and the right side of the model is free.

4. NUMERICAL ANALYSIS

When the normal fault moved, the up plate of the fault moved in the direction of the gravity, if the overlying soil couldn't keep balance, it would collapse under the gravity, and forming the ground surface rupture. When the reverse fault moved, the up plate of the fault rushed upwards, which would make directly cut-action to the overlying soil, making the soil layer up-heave, and forming rupture. Because the movement of the normal fault and reverse fault is different, the rupture response of overlying soil is also different. The same model was used in the analysis in order to analyze the earthquake rupture response characteristics of the normal fault and the reverse fault.

4.1. The Comparison of Normal Fault and Reverse Fault

The depth of overlying soil is 30m, the fault dips are both 60°, the displacement of the fault is 2.0m, the

rupture state of overlying soil under normal fault and reverse fault are shown in Fig. 2 and Fig. 3.
From the two Figs, one can find that the rupture state of overlying soil was quite different under normal fault and reverse fault displacement. As to normal fault, because the up plate of the fault moving to the right-down, making the upside soil collapsed downwards and ripped, to reverse fault, because the reverse rushing of up-plate, the overlying soil of down plate subjected to upside tension and cracked.
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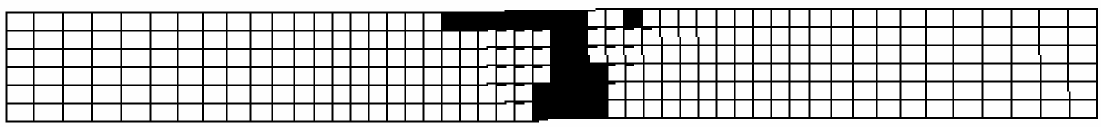

Fig. 2 run-through rupture state of overlying soil under normal fault displacement

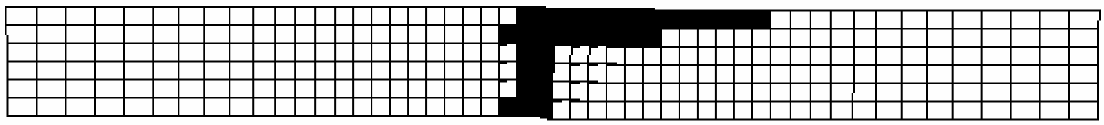

Fig. 3 run-through rupture state of overlying soil under reverse fault displacement

4.2. Parameter Study: Overlying Soil Site with Varied Depths

For universality, the dip of the fault is 60°, calculating the earthquake rupture response of the normal fault and the reverse fault respectively for models with different overlying soil depth, evaluating the ground surface displacement difference dy at two locations, the steepest point of the ground and 15m to the left and right. dy (When the movement of the fault is 2.0m) and the minimum fault displacement needed for run-through soil site are listed in table1.
Fig. 4(a) and Fig. 4(b) are ground surface displacement sketch map of 30m depth overlying soil model of the normal fault and the reverse fault with 2.0m's fault movement, and Fig. 4(c) and Fig 4(d) are ground surface displacement sketch map of 60m depth overlying soil model.

Table 1

Normal fault			Reverse fault		
The depth (m)	dy (m)	The run-through displacement (m)	The depth (m)	dy (m)	The run-through displacement(m)
20	1.605	0.96	20	1.620	0.40
30	1.323	1.40	30	1.418	0.92

40	1.001	2.48	40	1.036	2.08
50	0.744	3.96	50	0.766	3.92
60	0.602	>6.0	60	0.610	>6.0

Wang Zhongqi(1983) pointed out that the movement of the bottom bedrock generally didn't lead to run-through rupture when the displacement is less than 3m and the depth of overlying soil is over 50m, this point of view is proved by the calculating results of the paper.

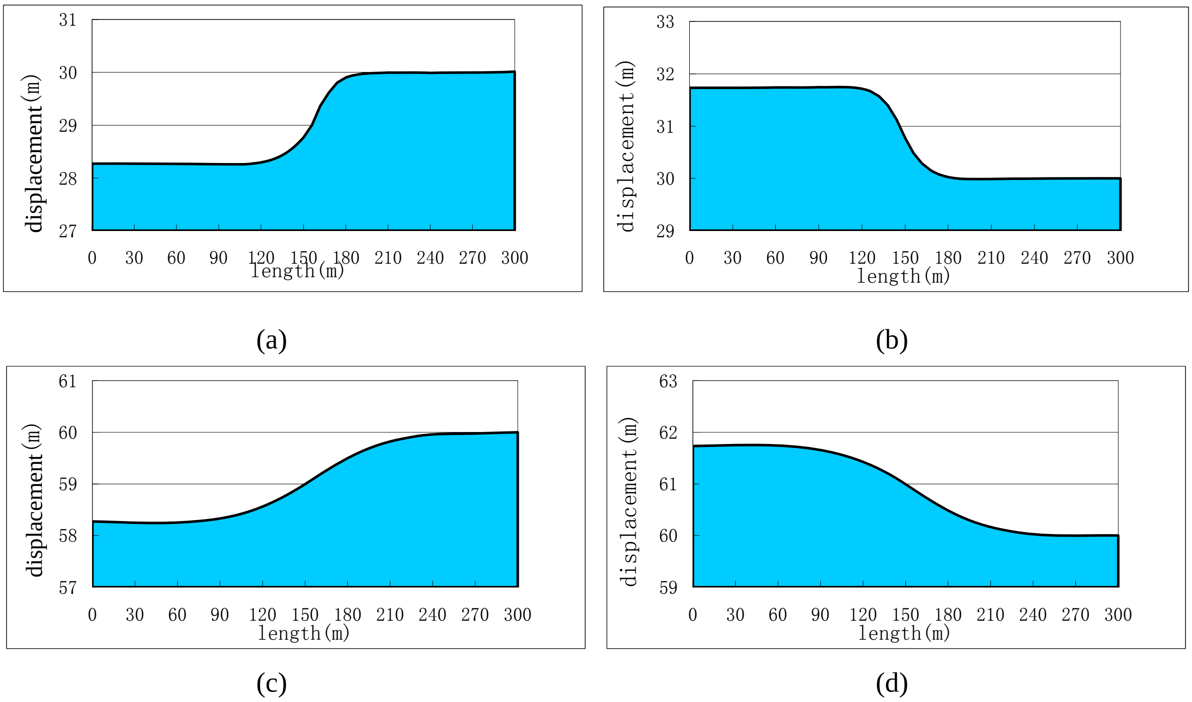

Fig. 4 ground surface displacement of overlying soil under normal and reverse fault displacement

4.3. Parameter Study: Overlying Soil Site with Varied Fault Dip

Here, the depth of overlying soil is 30m, the earthquake rupture response of normal fault and reverse fault with different fault dip have been analyzed respectively. When the movement of the fault is 2.0m, the calculating results are shown in the table 2, Fig. 5 is the sketch map ground surface displacement of overlying soil site under normal fault and reverse fault displacement.

Table 2

Normal fault			Reverse fault		
Fault dip（o）	dy (m)	The run-through displacement (m)	Fault dip（o）	dy (m)	The run-through displacement (m)
30	0.832	>2.0	30	0.953	1.04

45	1.096	1.80	45	1.203	0.96
60	1.323	1.40	60	1.418	0.92
75	1.480	1.40	75	1.502	0.92
90	1.536	1.32	90	1.536	1.32

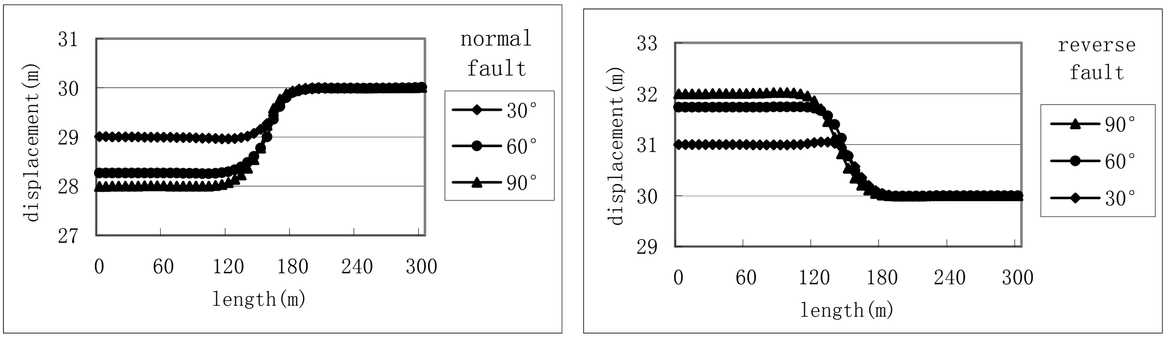

Fig. 5 ground surface displacement of overlying soil under normal fault and reverse fault displacement

5. CONCLUSIONS

From the analysis, the following conclusions can be drawn:
a) With the increase of the depth of overlying soil, the ground surface rupture displacement difference of overlying soil will decrease on either normal or reverse fault, the slop of ground surface will become gentle, the minimum fault displacement needed for run-through soil site will increase.
b) The ground surface rupture displacement difference caused by reverse fault would be greater than that caused by normal fault, the minimum fault displacement needed for run-through soil site on reverse fault is smaller than that on normal fault. When the depth of overlying soil is less than 40m, the minimum fault displacement needed for run-through soil site on reverse fault is obviously smaller than that on normal fault, when the depth of overlying soil is more than 40m, the ground surface displacement difference of overlying soil on normal and reverse fault have no much difference, so do the rupture state.
c) whether normal fault or reverse fault, when the depth of overlying soil is over 50m, generally, the fault displacement (0.0-3.0m) can't make run-through rupture.
d) With the increase of fault dip, the ground surface rupture displacement of overlying soil on normal fault or reverse fault will be bigger, when the dip angle is 90°, the ground surface rupture displacement is the biggest, and this is the most adverse case.
e) With the increase of fault dip, the minimum normal fault displacement needed for run-through soil site will be smaller, the overlying soil will be more and more prone to be broken. As to reverse fault, with the increase of fault dip, the minimum fault displacement needed for run-through soil site becomes smaller at first, then will increase, when the dip angle is 90°, the fault displacement needed to make the run-through rupture is the biggest.

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