Finite Element Simulation of Strain Localization on a Shear Band of Structural Soil

Hong-Ru LI, Yuan ZHONG, Hua-Pen ZHAO, Sheng-Hong AI

Institute of Geotechnical Engineering, Xi'an University of Technology, Xi'an, Shanxi 710048, China

lhr2008@126.com

Keywords: Structure, Binary-medium Mode, Shear Band, Plane Strain Compression, Finite Element Simulation.

Abstract: Based on the theory of breakage mechanics, the structural soil are conceptualized as binary-medium model consisting of bonding brick and frictional band. Shear band is structural soils' breakage, localization band sprout and development is dynamic process that bonding brick is translating into frictional band. Applied the binary medium model, the speciality and law of structural soil localization band sprouting and expanding are analysised with the numerical simulations of compression under plane strain condition, find that the strain localization on a shear band of structural soil at originally is some sets discontinuous little local breakage area step by step developed, connected and formed the shape of whole destruct with the external load increased; the location different of bug in the soil effected the local shear band germination and progress.

Introduction

Under the load, with the increasing of load, the deformation field of Geotechnical material often showed the concentration within a narrow strip. Deformation field in this area is different from the band area, deformation field in this area is not uniform, while the regional strain field outside the band kept uniform, which is common shear zone in rock and soil or rock engineering[1]. It has been proved that the generation of shear zone can largely reduce the bearing capacity of the materials, and the shear band will produce much effect to the stability of the structure. Therefore the study of shear band formation mechanism is gradual failure process of soil and the basis of analyzing the practical engineering soil stability[2-6]. Therefore, the study of soil shear band localization problem, more and more attention by people, has become the current international common focus in academic circles and geotechnical problems.

In recent years, domestic and foreign scholars have studied soil shear zone problem in different aspects, and it is mainly using indoor test to study of localized shear band. Jiang Ming-jing[7] using the triaxial test results discussed the shear zone formed the macroscopic mechanical condition and the dip Angle t in the structural clay, and with the help of scanning electron microscopy analyzed appropriate shear zone and its surrounding soil microstructure; Desrues and Viggiani[8] discussed the thickness of the shear zone according to the experimental results; Wang Zhu-pin[9] with fly ash as a test of soil, using surface features of digital image measuring technique studied the triaxial shear zone of the sample morphology, stress and strain characteristics of shear band sample and shear band formation conditions and influencing factors. In terms of theoretical research, Bjerrum[10] gradual theory extended mechanism of the shear zone better due to considering the impact of stress concentration and punching distribution on shear band extension process; Qian Jiangu[11-12] studied the two-dimensional and three-dimensional isotropic hardening model according to postulate Drescher material stability and analyzed shear zone by using non coaxial bifurcation; Huang Maosong[13-14] studied localized shear zone in soil with complex theory. With the fantastic spur of computer performance, the numerical simulation can represent the initiation and development of shear band and provide favorable complementary role in experimental results and theoretical analysis, which is accordance with the development direction of shear zone research. Song[15] etc. put forward a way of discontinuous displacement field structure and the discontinuous area integral solution. The soil shear zone in the discontinuous displacement field is simulated with the improved extended finite element method, and studied the extension process of shear band,

which has great inspiration significance. Sun Dean[16] carried the numerical simulation for over-consolidated clays of the shear zone under different stress path; Xu Lianmin[17] etc. studied the plane strain tests deformation localization problem in the over-consolidated clays sample with the implicit stress integration algorithm of high accuracy.

In this paper, based on the theory of damage mechanics of structural soil binary medium constitutive model, studied the influence factors of shear zone initiation, development and the performance of the shear zone development characteristics of different stages.

Binary Medium Constitutive Model of Structural Soil

Binary medium model is to geotechnical material abstract as structure block with cohesion properties and friction with the friction properties of dual structure, and on the meso-scale structure block as ideal brittle material and the friction belt as hardening elastoplastic material or nonlinear material, through cementing element damage and gradually conversion to the friction element in the load process to explain the breakage of the geotechnical materials process. Geotechnical material is big volume and mostly are working under compressive and shear conditions, because of structure belt can also assume a certain load, local damage will not cause the overall damage, which is the work mechanism of binary medium model. The essence of localization shear band Initiation and development is a dynamic process which the structural soil structure block transform into the structure belt, using the binary medium model to study the initiation and development of shear band localization can be up from mesoscopic analysis law of development of localized shear band start. The author makes two kinds of medium load sharing ideal into a parallel in the binary medium mode model, which stress-strain relation is:

$$\sigma = (1-\lambda_v)\sigma_i + \lambda_v \sigma_f \tag{1}$$

or $$\sigma = \left[(1-\lambda_v)E_i + \lambda_v E_f\right]\varepsilon \tag{2}$$

Among them: σ, ε is the macroscopic stress and strain function in the unit; σ_i and σ_f are respectively structure block (bond) and structural belt (friction element) stress and strain; E_i and E_f are the corresponding deformation modulus. Cementing element used initial compression shear E and μ of undisturbed soil, which is not changed in the process of shearing, while the friction element used the $E-\mu$ model of disturbed soil.

The author considered that the evolution equation of damage rate is from the undisturbed loess and loess triaxial test. Based on triaxial stress-strain relationship curves of soil sample, the author think cementation element gradually damaged and conversation into friction element, the breakage of the friction elements should be enlarged in mechanical process. Assuming the samples of the shear modulus is not reach the structure damage modulus, when the specimen deformation reaches 15% of the secant modulus is the structural belt modulus, so we can get evolution law of damage parameters are as follows:

$$\lambda = \frac{E_i - E}{E_i - E_f} \tag{3}$$

Comprehensive study the effect of confining pressure and moisture content on breakage, the evolution equation of damage rate are as follows:

$$\lambda = 1-\left(1-c\varepsilon_1\right)^{\alpha} \tag{4}$$

Among them: c is 3.34, α is 7.25.

Application of Binary Medium Model for Numerical Simulation of Shear Zone

The formation of shear zone is affected by the sample density, uniformity, boundary conditions

and other factors. Especially for soil sample, because the soil is three-phase material, uneven, and the phenomenon of defective is objective existence, it's hard to avoid it. Bjerrum think that to start the asymptotic damage slope, somewhere of slope must be have some type of discontinuity, such as the existing local damage. So it's well worth studying the impact of inhomogeneity and the existence of defects on structure soil.

The Division of Finite Element Mesh and the Constitutive Model

The numerical simulation using the method of plane strain test, which the sample is 4 cm in width and height of 8 cm, and divided into 20 x 40 = 800 of 8 node quadrilateral quadratic isoparametric element. The cell division and boundary form is shown in figure 1. End constraint levels is only loading up and down to the finite element calculation model, while lateral boundary constraint isn't taken, and loading the pressure of 100 kpa for up and down, samples from both ends up and down load at the same time.

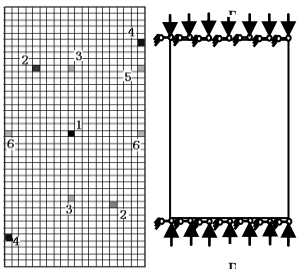

Fig. 1 Meshes and Boundary Condition

At unit partition map where is marked by 1, 2…6 represents the set of friction units in there, and unit of friction modulus is set to 20 kPa to simulate the actual non-uniformity in the soil.

The constitutive model of numerical experiments uses binary medium constitutive model of single parameter breakage. The initial compression shear E_{i0} and μ_{i0} of undisturbed soil samples was used for Cementing element, whose value is not change in the shearing process. The friction element using the $E-\mu$ model of disturbed soil.

Failure Criterion and Numerical Simulation Method

The failure criterion is the Mohr - Coulomb failure criteria. The calculate method uses the incremental iteration method, and the standard of iterative calculation is damage rate $|\Delta\lambda| \le 0.002$. When it meets the demand of iterative calculation, turn to the next step load increment. When the damage rate is more than 0.95, use Mohr - Coulomb failure criterion to judge damage. When there is a new unit damage occurs, set the unit of modulus to 20 kPa and return to the previous step start iterative calculation until there is no damaged unit.

Tab. 1 The Parameters of Constitutive Model

Cementing element					Friction element				
E_{i0} /kPa	μ_{i0}	K	n	Rf	C /kPa	φ /°	G	F	D
3276	0.24	65	0.47	0.72	24	20.5	0.124	0.272	4.8

Analysis and Discussion of the Results

The Diversity of Shear Band Pattern

Set the weak unit in the different locations of the sample, and it can get different forms of localized shear band. The project NO.1 set a weak unit n the middle of the sample. Since the sample

is at both ends load at the same time, in the middle of the sample form cross shear zone type and it is shown in figure 2. There is a final throughout the sample of the shear zone in the cross type shear zone. The project NO.2 set two weak units in diagonal of sample. With the increasing of load, there is a weak unit development gradually dominant, but every place of the shear zone are orthogonal. The two shear zone in the middle of the sample formed a shear band bridge, and to continue with the increasing of load, the two shear zone is connect in the middle of the sample parts eventually, and it's shown in figure 3. The author thinks that although each form an "X" shear zone, but each has advantages in a shear zone. Edge shear zone is generally not affected by the boundary, to develop in the d

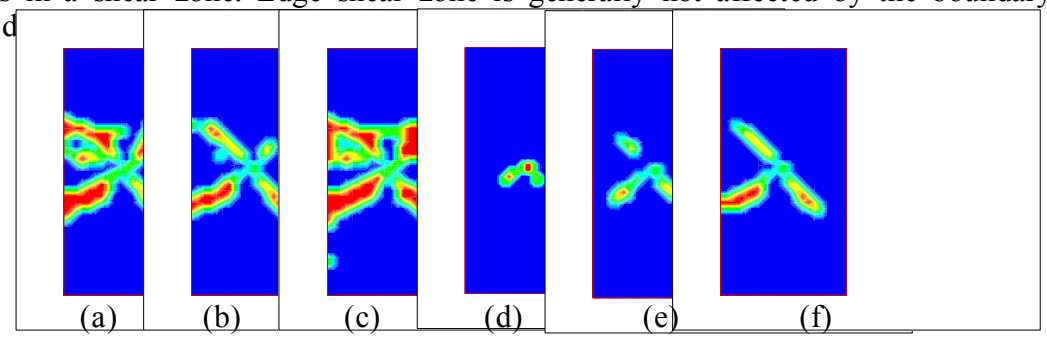

Fig. 2 Process of Shear Band Start Anddevelopment of Project No.1

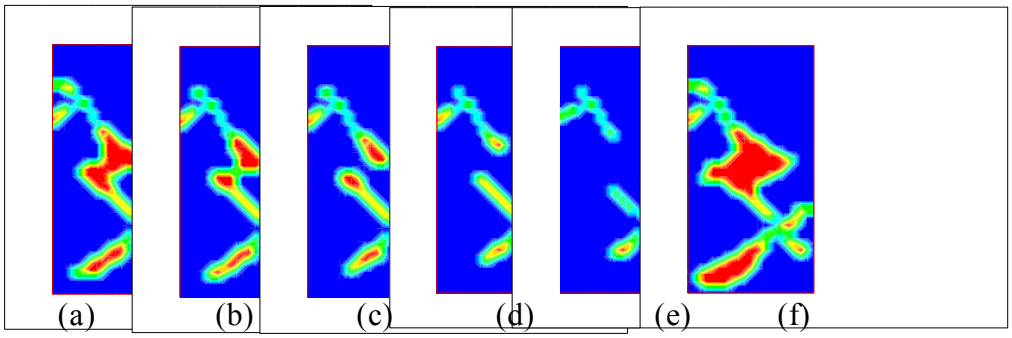

Fig. 3 Process of Shear Band Start and Development of Project NO.2

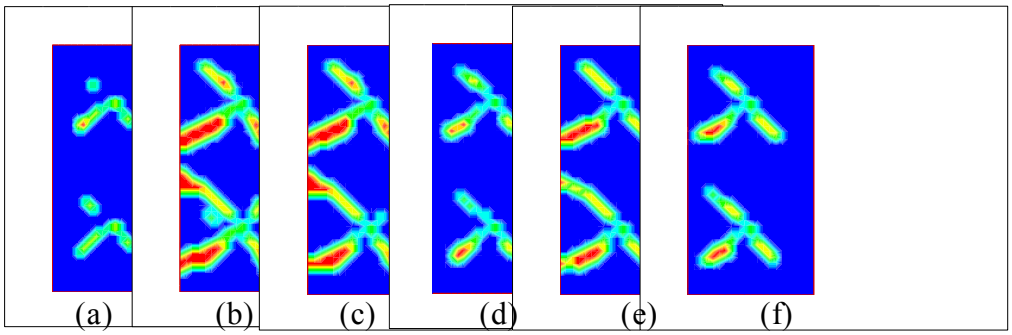

Fig. 4 Process of Shear Band Start and Development of Project NO.3

The project NO.3 set two weak units respectively in sample height 1/4 and 3/4, and their form two different length of shear band which are orthogonal. In the subsequent deformation, the shear zone is suppressed in the same direction of two different locations, and the other direction shear zone is advantage development, finally through the sample. It's shown in figure 4.Because the soil sample particles depends on the arrangement of structural soil, shear zone development towards the direction of the small resistance. It can be prove by figure 5 and figure 6 which are all have this phenomenon.

The project NO.4 set two weak units on both sides against of the sample which is shown in figure 5. The results of numerical experiment is that the shear zone from two weak units rapid development extend to the other party, and form gap shear zone between two units. with a small amount of load increasing, the shear zone connected quickly, and finally completed sample. Although in the development process of the shear zone there are all have the trend of the

conjugate shear zone start happening, but another shear zone is not dominant, it has not been fully developed. The reason is that the shear zone has the law of development for least resistance.

The project NO.5 set weak unit at the centre of one side in the sample. The two different length of conjugate shear band are formed, the one located above the weak unit, the other one located down the weak unit. In the later deformation process, due to the influence of boundary, the development of the shear zone at the bottom is slower than at the upper. The upper shear zone is not affected by boun e.

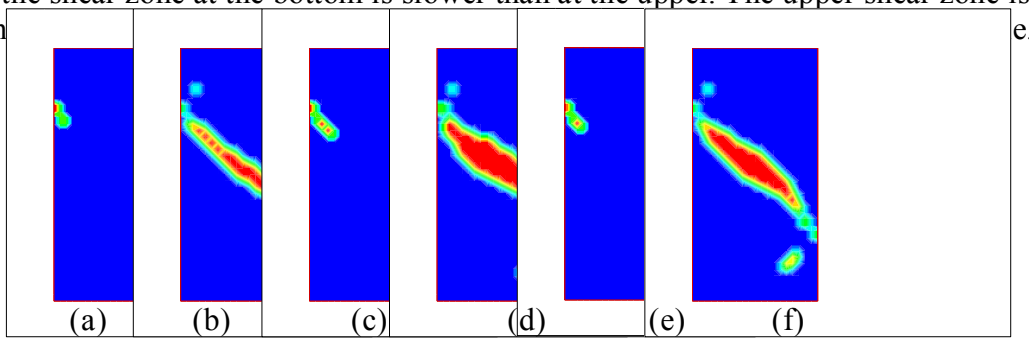

Fig. 5 Process of Shear Band Produce and Development of Project NO.4

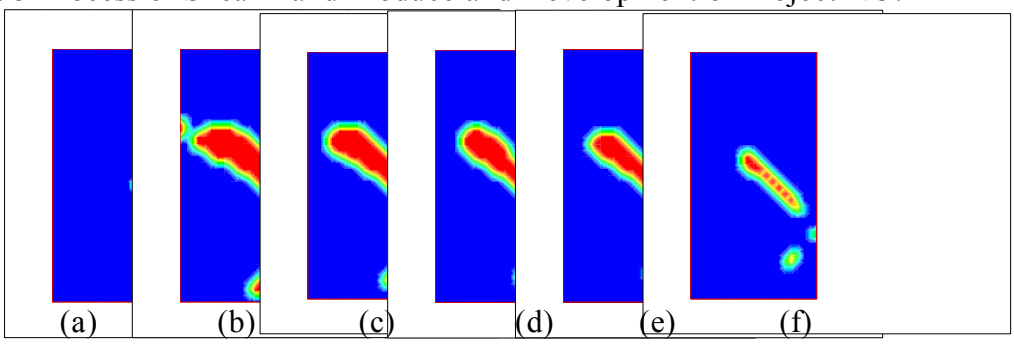

Fig. 6 Process of Shear Band Produce and Development of Project NO.5

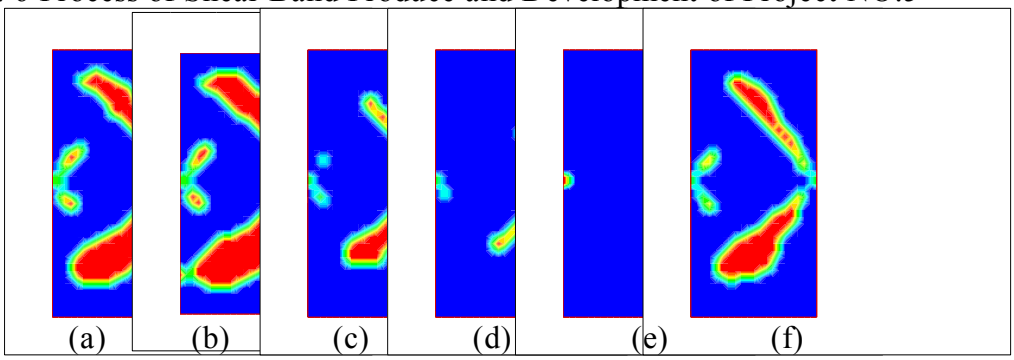

Fig. 7 Process of Shear Band Produce and Development of Project NO.6

The project NO.6 set weak unit respectively in the middle of both sides of the boundary of the sample, and it's shown in figure 7. On both sides there form respective conjugate shear zone, but the shear zone on one side have the obvious advantage, and have been fully developed, while on the other side of the shear zone is restrained, development slowly. This shows that the development of shear band have advantages and disadvantages phenomenon.

Summary and analysis the start and occurrence of the shear band, we can get the following understandings. Firstly, the shear zone is not in a continuous straight line, but a period of line segment, with the increasing of load, a gradual connection to into one, finally through the sample. Secondly, if it has multiple shear zone, there is always a shear zone advantage and eventually get development. Thirdly, in this paper, while it's not given different shear belt deformation figure, but each solution of deformation figure reflects the shear zone is the largest local displacement of deformation gradient. Fourthly, the result of the influence of unit size effect is the width of the shear zone is bigger.

Through set different damage location on the soil sample to simulate the formation of shear zone, we can found that the shear zone is a phenomenon from macro to micro, from local to overall. And we set up the weak unit in order to simulate the inhomogeneity of soil samples as a discontinuous medium, also in order to reproduce the process of development of the shear zone, but the reason of with the weak unit replaced the reality isn't enough, the inside of the soil sample microstructure is very complex. It's still need further discussion for definitions of shear band formation phenomenon.

The Analysis of the Stress-strain Curve

Through analysis the stress-strain curve of different solutions by numerical experiments, which is shown in figure 8, can get the following understandings. Firstly, the test curve in the back is straight, and with the load increasing small, but the deformation is big. The reason is that when the shear zone developed to a certain extent, deformation rate as the load increased, and the rapid formation of shear band and connected in sample. Secondly, the maximum shear stress of numerical sample soil sample are less than the laboratory soil samples. The reason is that introduced the weak unit of 2mm side length in the soil sample, while the actual soil sample may have not so big weak unit. Thirdly, the project NO.4 is the most prone to form the shear zone. The reason is that the two weak unit extremely easily cause the connected of the shear zone, and the damage of the sample.

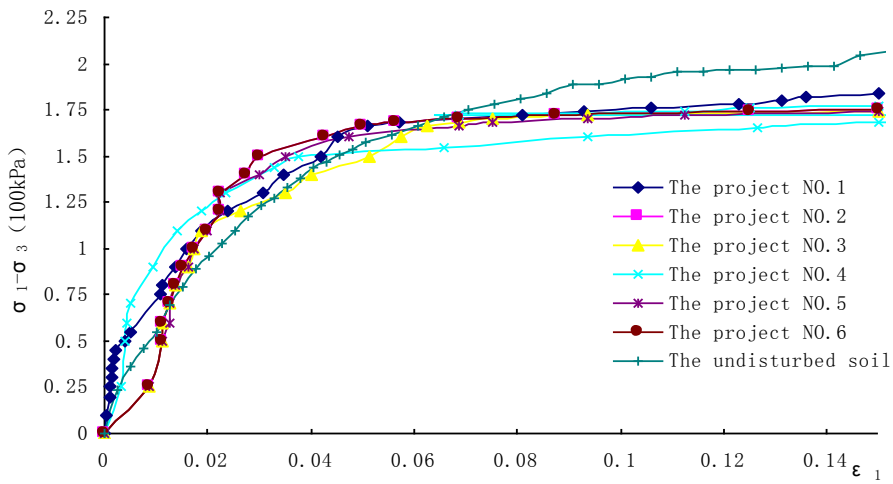

Fig. 8 Curves of Stress-strain of Numerical Testing and Laboratory Testing

Conclusion

In this paper, put forward a mesoscopic simulation method to simulate the development process of structural soil shear zone on the basis of binary medium model. The cementing element was idealized for brittle material, the friction element was idealized for nonlinear elastic material on mesoscopic scale, through the cementing element breakage and gradually transformed into friction until broken in the process of loading to simulate the initiation and development process of soil structural shear zone of. Through the plane strain of finite element numerical example, we can get the following conclusions: (1) The initiation of Shear zone is forming piecewise, with the increasing of external load, the damage region which isn't connected regional gradually connected, and form the shear zone on the macro; (2) The conjugate shear zone is not get synchronous development, there is always one side of the shear zone advantage obviously, and get fully development; (3) When the shear zone developed to a certain degree, even if the external load increase is small, soil deformation will be very big, which is in accord with the actual situation of landslide.

Acknowledgement

This research was financially supported by the Education Department of Shaanxi Provincial Foundation(2010JK717), Loess Soil Mechanics and Engineering Key Laboratory of Shaanxi Province Foundation(13JS073).

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