Research into Treatment Theory and Technique for Expansive Soil Geological Disasters

Mem. Muroran Inst. Tech., 59（2009）165～171

特　　集

Research into Treatment Theory and Technique for Expansive Soil Geological Disasters

Xian-min LI*, Yan-hui LIANG*, Peng ZHANG* and Yong-he WANG**

(Received 27 May 2009, Accepted 20 November 2009)

In this paper the bad geological characteristic and the huge disaster caused by expansive soil are elaborated. When constructing the road in expansive soil area, the origin and performance of roadbed disease such as slope stability failure, roadbed settlement, mud pumping, ballast bag and so on are elaborated emphatically. Meanwhile, the expansion and shrinkage mechanism of expansive soil have been studied from such aspects as physical-chemistry-mechanics effect, material composition and microscopic structure, external influencing factors and so on. Then, in view of the roadbed disease of highway in expansive soil area, such expansive soil treatment and reinforcement methods as physical improvement, chemistry improvement, physics-chemistry improvement, biological improvement are summarized and proposed.

Keywords : Expansive soil, Swell-shrink mechanism, Roadbed disease, Treatment theory and technique

1　INTRODUCTION

In the world there are more than 40 countries where exists the expansive soil which spreads six continents. In China the expansive has such outstanding features as broadly distribution, more types, complex characteristic and so on. The expansive soils create the extremely huge harm. In America, the loss of the expansive soil is more than double of the loss sum created by such disasters as flood, hurricane, earthquake and so on. Also, the economic loss for the expansive soil question approximately amounts to above $ 15 billion every year. In China railway engineering, the expense used for treatment the expansive soil reach several million Yuan each kilometer. Therefore, research into the treatment theory and technique for expansive soil of geological disasters have the significant economic significance and project practice value(1).

* Henan Provincial Transportation Research Institute Com. Ltd, Hanghai Middle Road No.219, Zhengzhou City, China
** School of civil engineering & architecture, central-south university, Changsha City, China

2　THE EXPANSIVE SOIL ENGINEERING CHARACTERISTIC AND ITS SWELL-SHRINK MECHANISM

2．1　Characteristic of expansive soil

Expansive soil distributed broadly, formed in the natural geological process, is one kind of more crevasses and having remarkable swell-shrink characteristics geologic body, and its distribution are very widespread. The clay ingredient of expansive soil is mainly composed of the strongly hydrophilic mineral

montmorillonite and other clay mineral. As one kind of high plastic clay is sensitive to the environment moistheat change, its chief feature is that the expansive soil is polydisperse particle, rich water affinity clay, richly big the liquid limit, big swell-shrink characteristics, absorbing water swell and softening, dehydration shrink and hard crack, overconsolidation and more crevasses, distortion repeatedly and so on. In the soil body, the crevasse disorderly distribute, and do the special harm to all kinds of shallow light engineering construction[1,2,3,4,5].

2．2 Basic swell-shrink mechanism of expansive soil

The swell-shrink of expansive soil, in fact, is the soil body mechanics characteristic change caused by the soil water's "gain and loss". The expansive soil moisturemovement is the quite complex physical-chemistry-mechanics effect action process. It is not only decided by its material composition and microstructure characteristic, but also having close relation with the environmental condition at which it locates. The explanation theory of expansive soil's swell-shrink mechanism mainly includes the crystal lattice expansion theory, the double-electrode layer theory, the microstructure theory and so on.

2．2．1 Crystal lattice expansion theory

The reason about swell of expansive soil is that in the expansive soil there are expandable crystal lattice structures (Fig. 1). Among the crystal lattice, there is the van der Waal's force interconnection, so the hydrone easily enter between the unit cell and form the water film interlayer; thus the unit cell's distance increases, and these results in the soil body volume expansion. But the crystal lattice expansion theory limits merely in the crystal interlayer, and the wedging action of adsorption bound water film, smectites having expansion crystal lattice structure. This theory does not considered the adsorption bound water action among the clay particle and the aggregate[1,2,4].

2．2．2 Double-electrode layer theory

There are some negative charges on the clay surface, as a result of electrostatic attraction's function. In the water solution, the cation will be attracted to come up on the soil particle surface, the clay mineral particle with negative charge will adsorb hydration cation, and ganging together is called the electric double layer. In the electric double layer, the ion has the adsorptive capacity to hydrone, which makes directional arrangement under electric field action of force, and forms the superficial bound water in clay mineral pellet's periphery, hydration shell. Because the binding film accumulate and wedge to open the earth particle, this increases the distance between the solid particles and swell the soil body. Based on bound water film thickness's change between the electric double layers on the clay particle surface, the electric double layer theory has explained the clay swell-shrink phenomenon (Fig. 2).

The electric double layer theory has made up insufficiency of the crystal lattice expansion theory to explanation swell-shrink reason about cohesive soil, and developed the application of bound water film in expansion theory. The electric double layer theory enables us to have the possibility to change the counter-ion ingredient and density of electric double layer on the clay particle surface through the electro-chemical means or the ionic exchange action. Also, the electrochemistry character of the clay mineral, and this reduce diffusion layer's thickness and bound water's quantity, so as to lower the swell-shrinkage distortion of expansive soil.

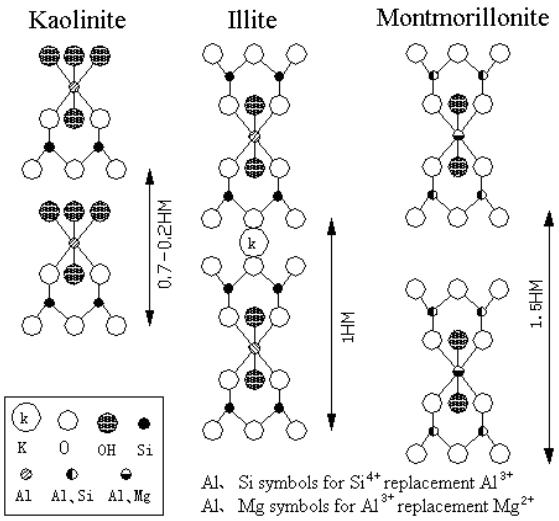

Fig. 1. Main clay minerals lattice structure chematic drawing

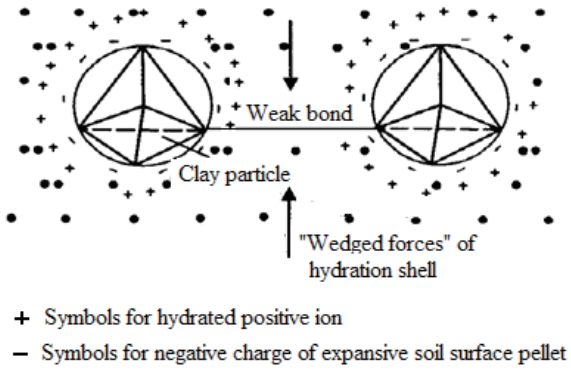

Fig. 2 Electric double layer(hydrated shell) action mechanism schematic drawing

2．2．3 The microstructure theory

The electric double layer theory has the universal practicability, but cannot explain phenomenon the swell

distortion of some expansive soil whose ingredient is mainly the illite, which is reverse bigger than that of the expansive soil whose ingredient is mainly the montmorillonite. Through macroscopic and the microscopic synthetic study on the expansive soil, Shiwen LIAO pointed out that the reason and the mechanism that expansive soil produce swell-shrink distortion is decided not only by the material ingredient, but also spatial microstructure characteristic of these material ingredient; and it is believed that the material ingredient of expansive soil is material base which produces distortion, the microstructure characteristic is the spatial condition which forms swell-shrink, when the above intrinsic factor is met, namely the expansive soil will swell when gaining water and shrink when losing water.

2．2．4 physical-mechanics theory

The physical-mechanics theory about expansive soil includes mainly effective stress theory, capillary vessel theory, elastic theory and so on. These theories thought that the swell of the expansive soil is caused by the physical-mechanics effect which produced by the water-soil interaction under certain external process. After fractional saturation of expansive soil absorbing water, the soil pore water pressure and the effective stress will change, the capillary vessel potential energy and the surface tension change accordingly, and caused the pellet elasticity effect, and the volume of the expansive soil increase.

3 THE HIGHWAY SUBGRADE FAILURES IN EXPANSIVE SOIL AREA

In highway engineering, because of surface layer weathering effect, swell with wet and shrinkage with dry effect, as well as the insufficient compaction or protection and so on, the many highway subgrade distress will be created frequently[6,7]. The performance and origin of common roadbed distress in expansive soil area are as follows.

3．1 Failuer of expansive soil embankment and slope

When surface layer of expansive soil’s cutting slope is severely-weathered and is soaked the water, it easy to occur such yield flow failure phenomenon along the slope face downward as local slide collapse, local slippery and large-scale landslide. Since the side slope destruction of the expansive soil has long term latentcy, many road unceasingly occurred the landslide after operating for 3~5 years later. And the side slope failure has the shallow layer characteristic, generally in 1m thickness, with no obvious sliding face and crack, shorter distance, and it usually can stabilize voluntarily on the slope face. Yet many landslides, which are 1.0~3.0m thickness, have obvious slippery bed, and have gentle frontal steep rear wall in the slippery bed, so more landslide appear with pullbehind and occur in groups, present lengthwise and imbricate shape, some landslides towed from toe to the top of slope, and those have substantially destructiveness. The scope of expansive soil landside mass relate closely with the depth of atmospheric influence, the type and structure of soil, but does not relate obviously with the slope contour and size, therefore slow down slope gradient or lower slope altitude cannot enhance the slope stability, so fundamentally preventing landslide, people should adopt effective slope protection, draining water and waterproofing measures. Meanwhile people should carry on the modification or reinforcement processing to the expansive soil mass in slope.

3．2 The wave-form settlement distortion pavement and subgrade

In construction and operation period, after the expansive soil roadbed suffering weathering and soaked by rain, under the action of swell with wet and shrinkage with dry effect, the soil body will occur the disintegration, together with non-uniform change of water content in the subgrade. All of these factors will cause earth pad produce the unequal settlement, and the road surface will present the wave form distortion. The wave-form settlement distortion of embankment is more obvious, the embankment becomes higher and accordingly the settlement bigger, and this may cause the road surface distortion destruction when the distortion is serious. The wave-form distortion of pavement directly restricts vehicles' travel speed and influences riding comfortableness, simultaneously the traffic accident's blasting fuse has also been buried.

3．3 Mud pumping of roadbed

Under the wet cyclical effect in the dry season and the rainy season, by the vehicles travel load's action, the expansive soil roadbed which is not replaced or sealed treatment will be caused superficial relaxation. After pavement water seepage and subgrade soil soaked rain water, the soil body disintegrate and the intensity reduces, and the topsoil of bedding come about sliming. Under the vehicle’s load cyclical action, the soil pore water pressure accumulates unceasingly, the sliming roadbed soil pushes in the granular base and splashes along pavement crack and expansion joint and so on. This causes the roadbed to produce mud pumping phenomenon. The roadbed mud pumping phenomenon is often followed by the roadbed bigger settlement and the pavement wave distortion, therefore, it seriously influence traffic safety and cause the traffic interruption.

3．4 Ballast pouch of roadbed

After subgrade soil sliming, base course's crushed stone and so on are easy to fall into or pushed in foundation bedding soil and forms the saccate structure. The ballast pouches will destroy the pavement structure,

at the same time, those become the water seepage channel and water carrier in the roadbed. Further those cause deep soil body wet and sliming, namely intensifying the ballast pouch's development, finally those result in the vicious circle.

3．5 Road border longitudinal crack and collapse

Usually, because the mechanical roller compaction not arrive the road border section, the later settlement of road border become bigger. Also, because of its free face, it is specially sensitive to the atmospheric physics action, therefore after water loss the shrinkage strain of road border is far bigger than that of dike body under the alternation of wetting and dry action. The investigation found out that the expansive soil road border apart from the outer edge approximately on the 0.5~1.0m of it is easy to produce longitudinal crack phenomenon. Road border longitudinal crack phenomenon occurs more in the dry season, it may amount to several dozens of meters even over a hundred meters long, generally 20~40mm wide, approximately 1.0~1.5m deep. After the road border has the longitudinal crack, although it does not immediately influence road's security of service, but if it is not repaired promptly, the longitudinal crack forms the seep channel of roadbed, causes the surface water very easily permeate roadbed, and causes the road border collapse. The height of road border collapse is more in 1m, and may be bigger than 1m when collapse is serious.

4 TREATMENT METHODS OF EXPANSIVE SOIL ROADBED

At present, in domestic and foreign according to its improvement mechanism, the methods of expansive soil improvement may divide into two types; one is the physical property improvement methods, for example to add non-expansive coarse sand filling materials and so on, and the other is chemistry improvement methods, for example, adding lime, cement, gypsum, sodium silicate and so on, in order to play the good role to reduced or the permanent control disease.

4．1 Physical property improvement methods

The physical improvement methods include such many methods as soil replacement method, humidity control method, compaction control method, totally closed method, mixing sand method, Geocell or Geogrid reinforcement method, Geotextile reinforcement method, soil nail wall reinforcement method, the pile foundation reinforcement method and so on[5,6,7].

Soil replacement method is to dig out the part expansive soil and enclosed with the unexpansive cohesive soil or coarse-grained soil. In the replacement roadbed soil thickness, it should consider that the soil water content rapid change zone's depth which is caused by rain, generally the depth may be 1.0~2.0m deep, namely the replacement thickness of strong expansive soil is about 2.0m, and middle expansive soil is about 1.0~1.5m. The slope protection effect of soil replacement is closely related with such construction factors as the soil water content, dry unit weight, soil type, soil block size, laying soil thickness, rolling quality and so on. If the quality of replacement soil meets each technical specification requirement and some supporting measures are taken, this method is really effective to the roadbed stability of slope.

Humidity control method includes two methods, prewetting method and maintaining stable water content method. In order to control the change of expansive soil water content, to maintains water content little evaporation and prevent rain water to permeate in the roadbed slope or the foundation soil during construction, some necessary measures should be adopted, for example, in the construction process reserving covering layer, before lining soaking the expansive soil and controlling critical humidity and so on, sometimes using the plastic membrane or the asphalt to cover on expansive soil slope face.

Compaction control method is to make the expansive soil’s compaction to the request density. The method can effectively reduce the swell of expansive soil when it is in low dry density and high moisture content, but the high water content's expansive soil is very difficult to gain compaction, when soil body roller compaction is lower than the volume weight, and the strength of it is smaller. Similarly, it cannot meet the engineering need. The compaction control method has low expense, but has certain sphere of application, generally it is suitable for the weak expansive soil ground. After expansive soil compaction its dry density will increase, moreover the cohesion and the angle of internal friction will also increase, ground bearing capacity will enhance.

Totally closed method is also named ladlecover method, is to fill in the expansive soil in the core of bank and encircle the dike body with the non-swelling earth. The thickness of ladlecover soil layer should not be smaller than 1m, and the ladlecover soil layer should be built tightly and totally close the expansive soil in order to restrict the temperature change in the dike, namely waterproof and preservation moisture. But the side slope spot is often the construction roller compaction weak spot. If the closed soil layer and the embankment soil are constructed in layered filling and roller compaction together to reach the similar compactness, then the treatment effect will be better.

Mixing sand method is improvement of the expansive soil through adding non-expansive coarse sand filling materials and so on, the main role is to change the constitutive property, particle combination of the natural or disturbed expansive soil, and make the expansive soil to become the non-swelling earth or to

reduce its swell-shrink characteristics. If mixed the sandy gravel in the lime to synthetically treat expansive soil embankment, the swell-shrink characteristics of expansive soil is eliminated in chemistry, the grain composition is optimized in physics and its compaction character and bearing capacity is improved. Before applying mixing sand method, the reasonable mixture ratio of mixed material must be determined, and the construction technology feasibility must be demonstrated. The experiment proved that for the expansive soil, as a rule the swell potential will reduce with granulated substance content percentage's increase. The influence of sand mixed in expansive was considered to be caused by lots of soil pores capillary vessel channels which reduce the soil siphoning to correspondingly.

Geocell or Geogrid reinforcement method is that through laying the level Geocell or Geogrid in the expansive soil embankment of construction, to make the best of the friction force and the snap-in force between Geonet and filling soil, to increase the shearing strength of the soil body, to restrict expansive soil' swell distortion, and finally to achieve the stable roadbed the goal. Because expansive soil embankment's weathering depth is generally in 2m, adding Getnet length in the soil is within limits slope surface certain scope, and the construction is convenient. At the same time, after adding Geonet in the earth, adopting the steep ratio of slope may save the land compared to the normal filling embankment, the technology and the economic effect is all good. It is a kind of method which is worth using and promoting.

About the Geotextile reinforcement method, soil nail wall reinforcement method, the pile foundation reinforcement method and so on is no longer discussed in detail here.

4．2 Chemistry improvement methods

Using chemical methods to improve expansive soil, in the one hand, compound itself may consolidate the soil body and play the role of cohesive soil particle. On the other hand, the compound with the earth can carry on a complex physics-chemical reaction and change hydrophilcity of expansive soil [8,9,10]. It includes the following method.

In chemical improvement fluid method, through the microscopic analysis and the physical mechanics experiment to the soil mass improved by modifier, we know that certain organic positive ion compound can change the charge distribution of the montmorillonite mineral crystal structure, weaken the negative electricity repulsion, and stop hydrone to enter the crystal layer and the granule, increase adsorption and the cementation between the loose particle keep down the swell-shrink distortion of the expansive soil. After improvement the expansive soil's shearing strength parameter also has comparatively large degree enhancement. Simultaneously, the organic chemistry grouting material is one kind of non-toxic, tasteless, odourless liquid. After chemistry solution is firmly adsorbed by earth, it will not drained and not create the environment pollution. Chemistry modifiers include such organic and inorganic compounds as the alkyl benzyl pyridine compound, the polyhydroxyl polynitrogen atom polymer, Conder SS, the mulching plastic net's polymer, the phosphoric acid, the acrylate series, the liquid polybutadiene, the solution of NaCl, $AlC1_3$, $CaCl_2$ and so on.

Lime stabilization method is the most commonly-used improvement methods in engineering practice. The lime solidification appears as a result of the base exchanges, the cementation, interaction of clay particle and lime. The reinforcement mechanism of lime stabilization foundation soil is mainly because expansive soil contains major content dissociation aluminum silicon ions, after mixed with lime, the expansive soil carry on the cation exchange action, aggregation, solidification like the cement effect, after the curing the plastic limit of the soil may be enhanced greatly and its plasticity index may be reduced great degree, finally the swell-shrink behavior of expansive soil is eliminated. The lime action on earth level relates to the lime dose, degree of grinding of soil and lime, mixing uniformity, age and so on, particularly lime dosage influence is more remarkable to the lime soil properties, soil-lime should be determined by such experiments as physics and mechanical properties, swell-shrink characteristics, water stability and so on.

Mixing cement improvement method, the cement chemical composition is mainly Tricalcium silicate, Dicalcium silicate, Tricalcium aluminate and so on. After these mineral of clinker in the cement meeting the water, they have the chemical reaction, hydrated reaction, and produce such main hydrated products as Calcium silicate hydrate, Calcium hydroxide, hydrated Calcium aluminate, hydrated Calcium ferrite, hydrated Calcium sulphoaluminate and so on. These hydrates have the cementation, with the lapse of time, they has had the congealment and induration, enable mixture strength to have great degree enhancement. the cement solidification action is due to the mutual cementation among of calciate, the aluminous hydrate and the grain, agglutinate gradual dehydration and the neogenic crystallization, thus reducing the liquid limit and bulk strain and increasing the shrinkage limit and shearing strength. When the cement content increases, the improvement earth's expansion ratio reduces, the reducing reason is similar to the lime, but the cement will have the bigger condensation which transforms the clay into the even more granular earth, thus cause the expansion rate to decrease, but lime is more effective than cement with aspect to reducing the expansion rate.

Fly ash, cement, lime mixed modification method. There are lots of active SiO_2, $A1_2O_3$, Fe_2O_3 and CaO and so on in the fly ash, the pellet is quite even and belong to poor grain size distribution, and the density is

low, through adding fly ash, to mainly change the expansive soil the gradation and the coherency and to reduce its expansibility. The cement, lime mixed modification method is one kind of quite ideal improvement method, the proportion of two additives should be decided according to the improvement earth's request. In this kind of mixed chemical additive, the lime obviously reduces the earth expansion rate and the cement increases the earth the strength characteristic. The quicklime, fly ash mixed improvement method. After fly ash and the quicklime mixed, under certain moisture content condition they has a series of hydration reaction, and produce such compounds which is water-fast stable crystallization resultant as hydrated Calcium silicate, hydrated Calcium aluminate, as well as hydrated Calcium ferrite and so on, these compounds may harden gradually in the air and water, and play the reinforcement role to expansive soil so as to limit its expansibility.

Mixing slag composites improvement method. Such composites as expansive soil, slag, cement, lime, sand and so on is called "the slag composites earth" which is put into mortar as slope protection material. The expansive soil improved by slag composite may basically lose the expansibility. The slag composites earth's strength changes with the age, the strength of age one year is 3-8 times of age 28d, when carried on the soaking quick shear test under no vertical stress condition. The cohesive strength value with the slope face is 17~52kPa, moreover the slag composites earth have good property to resist swelling with wet and shrinkage with dry[10].

The pressure injection grouting improvement method is to apply the lime white or the cement mortar injection scheme to reinforce expansive soil slope, under the high pressure the lime white enters the earth from lateral and longitudinal direction of grouting hole, along the soil body crevasse or the new fracture face caused by grouting precipitate and form many lime arteries or the lime thin layer. Bulk soil body among the crevasses is all wrapped up by the lime white, the chemical reactions react unceasingly along crevice between the lime and the earth, and this cause grout arteries to play the role of anti-water, thereby prevent the water content to change and enhances the integrated intensity of soil body. Using jet grouting, directional jet grouting or sprinkler irrigation, the grout under high pressure form not only the pulpous state structure, but also may form the lime or soil cement coagulation bodies which have certain structure and shape, or forms the boards and piles composite anti-slide body which can adapt to the bigger distortion. The commonly used grouting materials include lime, cement, sodium silicate, resin, polyacryiamide and so on.

4．3 Other improvement methods

Physics-chemistry improvement reinforcement method is applying both physical and chemical effect to improve the expansive soil. It refers to according to the certain proportion mixing expansive soil with lime, cement, fly ash, slag as well as the mixture of them, and adding ration active catalyst to promote modifier and earth to react each other, and finally achieving the goal to stabilize expansive soil.

The biological improvement method is to make use of the biology surface active agent to attach on the clay mineral surface, so it can reduce the liquid level tension, cause the clay mineral surface hydrophobization, and break down mineral surface hydration shell or cause it to become thin, thereby cause the intergranular cohesive force to increase, enhance the earth shearing strength, and finally reduce the swell-shrink characteristic of expansive soil.

5 CONCLUSIONS AND SUGGESTIONS

On the part of the expansive soil question's treatment technology, many further deep researches need to be done. Aiming at the key question of expansive soil embankment fill, based on preserving moisture and anti-seepage, carry on the expansive soil embankment filling technology deep study. To deepen expansive soil's modification experimental study on optimizing mixing lime, fly ash and firming agent, in order to determine the best mixed dosing and effective construction technology all kinds of expansive soil distribution area. To carry on modification expansive soil research through the manual mixing soil, namely to research mixture filling possibility of mixing the non-expansive soil with the different rank's expansive soil, including the whole mixing method, sandwich method, totally closed method and so on, to be built by contract the law three kinds, to study separately the performances adopting different methods to fill embankment, and to determine reasonable mixing ways and construction methods. To develop the Geotextile reinforcement expansive soil embankment's technology, and to research into reinforcement design methods, construction technology and the suppression swell-shrink effect of adopting Geogrid and Geonet crushed rock pile to reinforce roadbed in lateral and longitudinal direction. To research into measures of the slope excavation, combined reinforcement, protection technology of expansive soil cutting slope, and to pull off the long-term stabilization of cutting slope under downloading and wetting-drying cycle condition.

REFERENCES

(1) Shi-wen LIAO, The expansive soil and railway engineering, Beijing: Chinese Railroad Publishing House, (1984)
(2) Xian-min LI, Yong-he WANG , Hong-bin XIAO, Kinematics analysis of the expansive clay growth curve, Journal of china coal society, Vol.18, No.2, (2003), p157-161.
(3) Guo-lin YANG, Yong-he WANG, Xian-min LI, The test

study on engineering characteristics of Tan-Shao freeway expansive soils, Journal of railway science and engineering, Vol.2, No.1, (2005), P62-67.
(4) Xian-Min LI, Yong-He WANG, Contrast study on the compaction expansive soil swelling-shrinkage velocity characteristic, Journal of the China railway society, Vol.25, No.2, (2003), p25-29.
(5) Xian-min LI, Yong-he WANG, Regression analysis of the expansive clay swell-shrink distortion rule, Journal of XiangTan mining institute, Vol.18, No.2, (2003), p30-33.
(6) Jian-pu ZHOU, Xian-min LI, Research into compaction expansive clay distortion curve characteristic, Highway, No.1, (2003). P25-29.
(7) Jian-pu ZHOU, Xian-min LI, Yong-he WANG, Correlation Experimental study on expansive soil distortion characteristic in a highway in Hunan, Highway, No.4, (2004), p114-118.
(8) Jian-pu ZHOU, Xian-min LI, The relation of expansive soil characteristic with external influence conditions in Tanshao freeway, Hydrogeology and engineering geology, No.5, (2003), p79-82.
(9) Xian-Min LI, Yong-He Wang, Guo-lin YANG, Experimental study on Compaction expansive soil engineering deformation characteristic, Rock and Soil Mechanics, Vol.24, No.5, (2003), p826-830.
(10)Tuo-de LI, Zhong-Xiu ZHAO, Improvement engineering properties of expansive soil with slag composite materials, Chinese Journal of Geotechnical Engineering, Vol.15, No.5, (1993), p11-13.