Research on deformation law of geogrid-reinforced expansive rock due to moisture absorption

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ABSTRACT: Geogrid-reinforcement can improve the strength and limit the lateral deformation of soil. In this paper, physical model tests are made to study the deformation characteristics of reinforced-soil under the condition of interaction of a variety of geogrids with expansive rock. Research indicates that obvious expansion deformation takes place in expansive rock under the condition of moisture absorption, which causes soil mass to be damaged due to tensile crack. Geogrids embedded make it possible to obviously decrease the lateral deformation of expansive rock, but they affect little the vertical settlement of soil. At the same time, geogrids can effectively restrain the occurrence and development of cracks, and alter the development law of expansion deformation in expansive rock. More importantly, geogrids exert significant effects on the transport process of moisture content.

1 INTRODUCTION

Expansive rock is a kind of weak rock that is softened, expanded, decreased obviously in strength as soon as it meets with water. Engineering problems caused by its poor engineering characteristics are taken place frequently in all parts of the world. There are about 300km long reaches which are related to expansive rocks (soils) in channels built along the South-to-North Water Transfer Project (Middle Route) in China. How to treat expansive rock (soil) in term of engineering to assure the stability of channel slope is one of main engineering roadblocks in the South-to-North Water Transfer Project.

Geogrids embedded in soil can form a compound reinforced soil, the effect of which improves the strength and limits the lateral deformation of soil has been widely accepted by the engineering community. But whether it is applied to slope protection projects with expansive rock still lacks of example verification, and research into its mechanism is lesser. Sharma[1] conducted laboratory model tests on how to restrain expansive soil's heave deformation with geopiles, and the results indicated that the friction effect between expansive soil and geogrids can restrain the expansion deformation, and heave decreased with increasing diameter of the geopile and increase in the particle size of the fill material. Xu[2] studied the characteristics at the interface between expansive soil and geogrids as well as the mechanism of interaction by pull-out test, and obtained a number of factors to affect interfacial friction factors. Gupte[3] introduced an example that polypropylene woven geotextiles in India are utilized to deal with the road foundation of expansive soil. Observations in the field showed that the road foundation reinforced by geotextile had not be obviously failed after eight months. Kameshwar[4] employed laboratory experiment to study the effect of strengthening the road foundation of expansive soil by using geogrids as horizontal reinforced material.

In this paper, for expansive rock canal reach of the South-To-North Water Transfer Project (Middle Route Scheme) in Xinxiang city, Henan province, the authors adopted laboratory model tests to study the expansion deformation characteristics for non-reinforced and geogrid-reinforced expansive rock after moisture absorbtion. Test results obtained have been successfully applied to the South-To-North Water Transfer Project (Middle Route Scheme).

2 GENERAL DESCRIPTION OF THE TEST

2.1 *Basic properties of expansive rock*

Expansive rocks used in the test were taken from Luwangfen canal reach of the South-To-North Water Transfer Project (Middle Route Scheme) in Xinxiang city. They are muddy limestone of Luwangfen group in Pliocene Series of Neogene system with a free expansion ratio of about 50%. According to provisions in *the Technical Specification for Building Construction in Expansive Soil Regions (GBJ 112-87)*, soil sample is weak expansive soil, its basic physical features are shown in Table 1.

2.2 *Basic properties of geogrids*

Geogrids used in the test includes three types, uniaxial oriented geogrids HDPE50, HDPE80 and biaxial oriented geogrid SS30. The mechanical indices obtained by unconstraint tensile test are shown in Table 2.

Table 1 physical and mechanical parameters of muddy limestone

Specific gravity of soil particles	Water content	Dry weight density	Optimum water content	Maximum dry density	Liquid limit	Plastic limit	Free expansion ratio	Expansion force	Cohesion	Internal friction angle
G_s	Ω	γ_d	ω_{op}	γ_{dmax}	ω_{17L}	ω_p	δ_{ef}	F_e	C_{cq}	φ_{cq}
	%	kN/m^3	%	kN/m^3	%		%	kPa	kPa	°
2.72	14.70	16.66	18.70	17.20	36.2	18.6	57	3.68	55.7	33.9

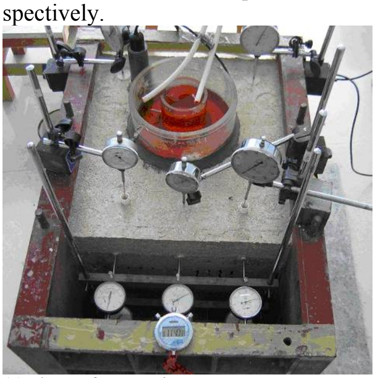
Table 2 Mechanical property of geogrids

Type of reinforced materials	Tensile strength (KN/m)	Elongation (%)	Strength corresponding to 2% elongation(kN/m)	Strength corresponding to 5% elongation(kN/m)
HDPE50	52.32	11.98	15.81	29.83
HDPE80	85.10	10.55	30.37	55.23

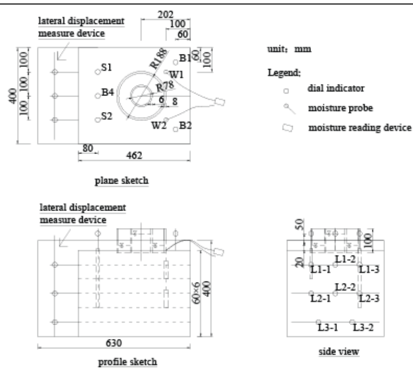
Type of reinforced materials	Longitudinal				Transverse			
	Tensile strength (kN/m)	Elong. (%)	Strength corresponding to 2 % elong. (kN/m)	Strength corresponding to 5% elong. (kN/m)	Tensile strength (kN/m)	Elong. (%)	Strength corresponding to 2 % elong. (kN/m)	Strength corresponding to 5% elong. (kN/m)
SS30	31.42	15.87	9.08	19.95	35.00	10.29	14.03	26.16

2.3 *Layout for model test equipment and observation instruments*

The size of soil sample is 462mm×400mm×360 mm in the model box which is formed mainly through welding by using steel plates. Soils with certain water content are compacted in 6 layers. After consolidation for 24 hours under a natural state, dial gauges monitoring the lateral displacement are placed, and then water begins to be supplied by dual rings at the top. During the experimentation, water levels in internal and external rings are constant at 5cm and 2cm from the top surface of soil sample, respectively.



(a) photo of test equipment



(b) Layout of observation instruments

Fig.1 Sketch plan of the model test

Variables to be observed in the test include deformation (vertical & lateral displacement and internal displacement of soil mass) and water content. Monitoring instruments are arranged as shown in Fig.1. The points No.B1,B2 & B4 are the vertical displacement gauges, and the points No.L1-1 to L3-2 are the lateral displacement gauges(total 8 points). Furthermore, the points No.S1 & S2 are the internal displacement gauges. ML2x moisture content probes made in England are used to measure the water content in real time, respectively located at the surface of soil sample (point No.W1) and at 12cm embedded depth (point No.W2). Before testing, water content probes are calibrated.

When the rate of deformation at each gaging point is smaller than 0.05mm/h, the deformation is believed to be basically stable, and then the test stops.

2.4 *Test scheme*

Contributory factors including different initial moisture content and dry density of muddy limestone, as well as the different strengths and diverse types of geogrids, number of reinforced layers are tested by comparison, and the restraint effect of geogrids on the deformation due to moisture absorption of expansion rock are studied, test schemes are shown in Table 3.

Table 3 Model test scheme

Test No.	Soil sample		Reinforced materials	
	Water content	Density	Reinforced materials	Number of reinforced layers
No1-1	14%	1.75		
No1-2	18%	1.75	NA	NA
No1-3	18%	1.65		
No2			HDPE50	Double-layer
No3-1				Single-layer
No3-2				Double-layer
No3-3	14%	1.75	HDPE80	Double-layer, no anti-packing at the end*
No4			SS30	Double-layer

* Note: Unless specially indicated, the ends of geogrids are anti-packed.

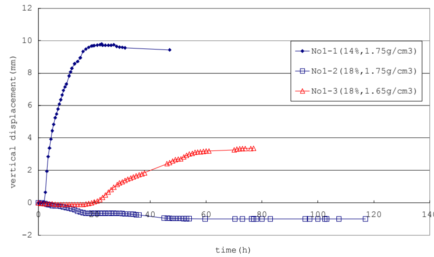
3 TEST RESULTS AND ANALYSIS

3.1 *Initial moisture content and dry density*

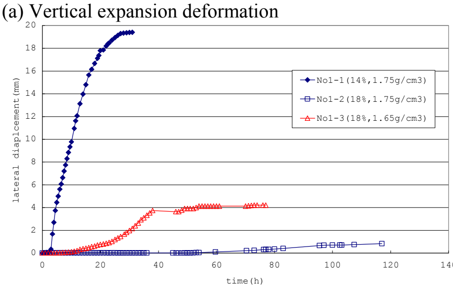
The development law for expansion deformation of muddy limestone under the conditions of different initial moisture contents and dry densities is mainly compared in Fig.2. It can be observed from test results that the increase in initial moisture content or the reduction in dry density contribute to the decrease of expansion deformation.

When initial moisture content is 14% and dry density is 1.75g/cm^3 (No.1-1), with the increase of water content, obvious penetrating transverse cracks occur near the free surfaces. These cracks are about 8mm wide and 6.8cm deep (as shown in Fig.3). Vertical expansion capacity can reach up to 10mm; lateral expansion shows that the deformation above is larger than the below, its maximum expansion capacity is 19.4cm. When initial moisture content is increased up to 18% (No.1-2), cracks are not produced in the model, and it shows that soil mass at vertical direction is a compression deformation.

It can be seen from water content's monitoring results that different initial water content and dry density of muddy limestone have also greater influence on the water content movement process of non-saturated soil mass. As for No.1-1, after 1h on-test, water content at shallow layer shows a fast increase tendency, after 5h it tends to be basically stable; after 10h water content at deep layer begins to change, and until 28h it tends to be stable. As for Scheme No.1-2, water content at shallow layer within 10h is reduced; on the contrary, water content at deep layer shows no change basically.



(a) Vertical expansion deformation



(b) Lateral expansion deformation

Fig.2 Displacement comparison under different initial moisture content and dry density conditions of model tests

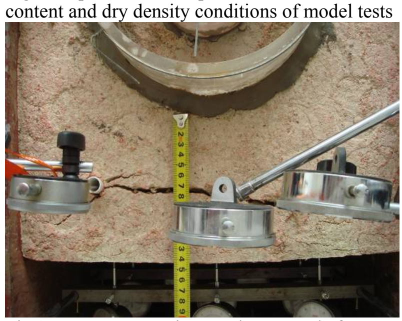


Fig.3 Transverse tension crack occurred after test for No1-1

3.2 *Reinforcement of geogrids*

Fig.4 shows the influence of different geogrid-reinforcement manners on the deformation of muddy limestone. It follows that all kinds of geogrid exert little effect on the reduction of vertical expansion deformation, its expansion capacity equals basically to non-reinforced soil. But the effect of geogrid-reinforcement on the restraint of lateral deformation is quite obvious, its specific decrease amplitude is related to geogrid's type and strength, layout manner as well as number of reinforced layers etc.

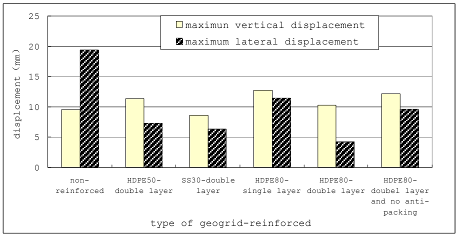


Fig.4 Different expansion deformation with different geogrid-reinforcement manners of muddy limestone

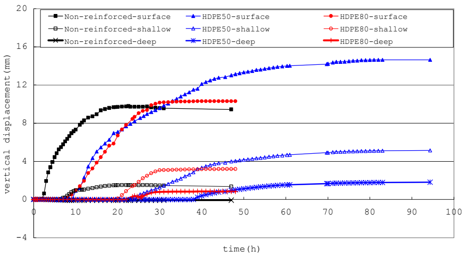


Fig.5 Vertical expansion deformation at different depth in the soil mass with geogrids
Note: surface-Point No.B4; shallow-Point No.S2; deep-Point No.S1

Reinforcement of geogrids can restrain the expansion deformation of muddy limestone, at the same time, it changes the expansion development mode of muddy limestone during the process of moisture absorption. Fig.5 shows the curves of internal layered displacements of soil mass obtained by different schemes. It can be seen that as for non-reinforced muddy limestone, vertical expansion deformation after absorbing moisture occur mainly at shallow layer of soil mass, and there are almost no expansion at deep position of soil sample, but expansion deformation with geogrid-reinforced at different embedded depths of soil mass develops slowly with time, and its final deformation capacity is far more than that of non-reinforced soil.

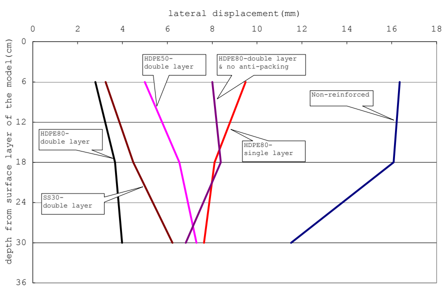
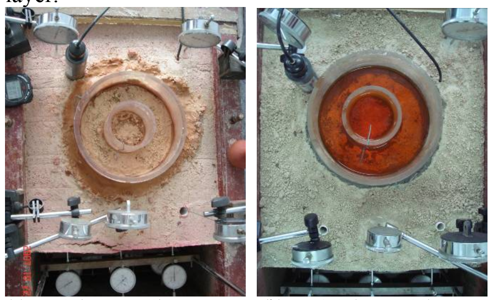


Fig.6 Schematic for lateral deformation pattern of soil mass after soil mass is treated by different reinforced geogrids

Fig.6 is a schematic for final lateral shape due to moisture absorption by different reinforced schemes. It can be seen that under the condition without geogrids, lateral expansion capacity shows that the deformation above is larger than the below, soil mass topples towards the free surface, and penetrating tension cracks appear. However, geogrid-reinforcement (in particular double-layer reinforcement) affects obviously the cracks. As shown in Fig.7, only fine micro-fissures occur partially in the model tests; and lateral deformation mainly occur in the bottom of soil sample, it develops greater with time, and finally exceeds the deformation at upper layer.



(a) No.2 (HDPE 50) (b) No.3-2 (HDPE80)
Fig.7 diagram for crack development with geogrid-reinforced

It can be found from the change process of water content that geogrid-reinforcement also has obvious influence on the movement process of moisture content under the condition of one-dimensional infiltration. Table 4 gives the change-time of water content at different embedded depths measured by ML2x probes. It can be seen that under the condition of the same initial water content and density, geogrid-reinforcement make the water are more difficult to infiltrate into the soil mass, and the time when water content at shallow layer begins to vary and becomes stable is far longer than that of non-reinforced soil, which exerts much more obvious influence on the water content at deep layer. In addition, it can be found from water content and density results measured by sampling in layers after the test, water content with geogrid-reinforcement are universally smaller than that of non-reinforced soil model (as shown in Fig.8).

Table 4 Influence of different reinforcement schemes on the change in water content

Test No	Soil sample	Water content at shallow layer Change	stable	Water content at deep layer Change	stable
NO1-1	Non-reinforced	1h	5h	10h	22h
NO2	HDPE50	4h	14h	48h	56h
NO3-1	HDPE80	3h	9h	19h	37h
NO3-2	HDPE80	Reduce firstly, increase after 2.5h	24h	13h	28h
NO4	SS30	Reduce firstly, increase after 2.5h	3h	46h	58h

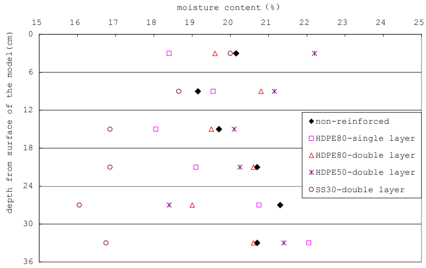


Fig.8 Distribution of water content in layers after the tests

The possible reasons are analyzed as follows: (1) when the model is prepared by volume-weight method, the neglection of geogrid's volume causes the density of finished sample possibly to be more than its originally-determined value, i.e. after geogrids are laid, the density of the model is higher than that of non-reinforcement soil model. The greater the density, the smaller the permeability of soil mass. (2) Although geogrid has gridded structure and can allow the water to pass through it, corresponding effective area of wetted cross-section is decreased, therefore, as for soil mass at deep position, its infiltration capacity is significantly smaller than that of non-reinforcement soil model.

3.3 *Different types of geogrids*

The laboratory experiment results showed that the effect of geogrid types on the restraint of expansion deformation is quite different. Similarly, model tests with three types of geogrids (HDPE50, HDPE80 and SS30), which have double-layer reinforcement and the anti-packed end of geogrid, are analyzed as follows (corresponding schemes are No.2, No.3-2 and No.4, respectively). Fig.9 is the diagram for comparison of lateral expansion deformations in the first layer (the depth from surface is 6cm). It can be observed that geogrid-reinforcement can evidently restrain the lateral expansion, but geogrids with different types and different strengths will have relatively different restraint effects. The lower the strength of uniaxial oriented geogrids, the poorer the effect of restraining deformation capacity. During the initial period of the test, biaxial oriented geogrid restrains the lateral deformation evidently, until the late period of test, expansion capacity increases relatively fast, but final expansion deformation is still smaller than that of HDPE50. Table 5 lists the different lateral expansion deformation. It can be observed that with double-layer reinforcement and anti-packing end, HDPE50 geogrids can reduce the lateral expansion deformation about 37%~70%, HDPE 80 geogrids can decrease by about 65%~83%, and biaxial oriented geogrids SS30 can reduce the lateral expansion capacity by about 46%~80%.

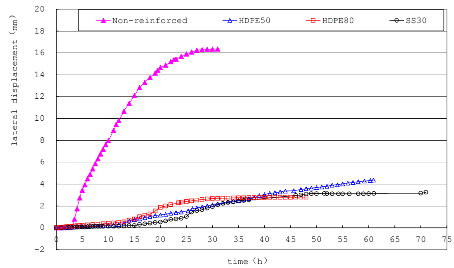


Fig. 9 Comparison of lateral expansion deformation with different geogrids

Table 5 Lateral expansion deformation with different strength geogrid (in mm)

	Average lateral deformation					
	First layer (6cm from the surface)		Second layer (18cm from the surface)		Third layer (36cm from the surface)	
	20h	Final	20h	Final	20h	Final
No.1-1	14.66	16.36 (31h)	14.98	16.09	10.57	11.51
No.2 HDPE50	1.17	4.99 (94h)	0.38	6.5384	-0.05	7.30
No.3-2 HDPE80	1.86	2.79 (48h)	0.28	3.67	-0.26	3.99
No.4 SS30	0.53	3.25 (71h)	2.66	4.48	-0.37	6.22

3.4 *Different number of reinforced layers*

Taking the HDPE80 geogrid as an example, different numbers of reinforced layers are compared (No.3-1 & No.3-2). Single-layer reinforcement refers that one layer of geogrid is laid only at the 24cm depth from the top of the model.

Fig.10 shows the curves for lateral expansion deformation vs time corresponding to gaging point at first layer(which depth is 6cm from the surface). It can be seen that for single-layer geogrid-reinforcement, lateral expansion will be still subjected to restraint action to a certain extent. At L1, farthest from reinforced layer at the bottom, lateral expansion capacity is decreased to 58% of non-reinforced soil, but double-layer geogrid-reinforcement can decrease the lateral deformation at this position up to 17% of non-reinforced soil.

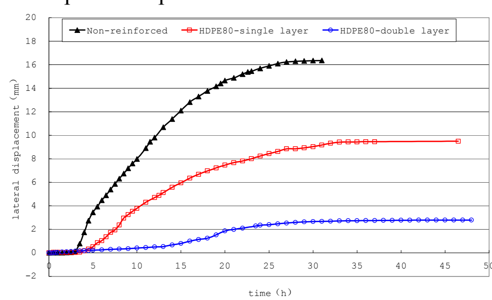


Fig. 10 curves of lateral deformation vs time for different numbers of geogrid-reinforced layers

3.5 *geogrid's end*

Comparison tests on different treatment manners of the end are carried out (No.3-2 &No.3-3). In No.3-2, the end of geogrid is anti-packed towards the upper layer, and in No.3-3, the end of geogrid is not anti-packed. It can be seen from Fig.11 that for no-anti-packed geogrid, the time for lateral deformation begining to develop agrees with that of non-reinforced soil, but the development rate of deformation is slower, the time to reach up to a stable state is quite longer, its ultimate deformation is 48.9%~59.3% of non-reinforced soil. However, for anti-packed geogrid, the time of geogrid-reinforced soil begining to deform greatly prolongs, and the ultimate deformation reduces which is only 17.1%~34.6% of plain soil model. It follows that different treatment manners of the end contribute to reduce about 25%~32% of lateral deformation.

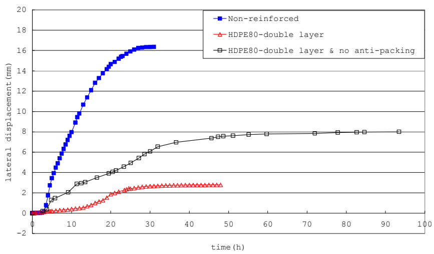


Fig.11 Influence of different treatment manners of the end on lateral expansion deformation

4 CONCLUSIONS

(1) After muddy limestone absorbs the moisture, its deformation develops stably, and tension cracks are produced near the free surface, but cracks become gradually stable with the infiltration of moisture content, deformation is related to initial water content and density of soil sample. The greater the initial water content, the smaller the expansion deformation; when it is increased up to its optimum water content, soil mass does not basically expand, which shows an obvious compression deformation.

(2) Muddy limestone with geogrids can restrict the initial vertical deformation to a certain extent, but finally, it can possibly increase the ultimate expansion deformation .

(3) Muddy limestone with geogrids has an obvious effect on the limit of its lateral deformation. When number of reinforced layers is the same, the higher the strength of uniaxial oriented geogrids, the better the effect of its restraining deformation. Double-layer reinforced HDPE80 can reduce the lateral deformation to 17%~35% of non-reinforced soil. The interaction of biaxial oriented geogrids and uniaxial oriented geogrids with soil mass is possibly quite different, even if biaxial oriented geogrids SS30 has lower strength, the effect of its restraining the deformation is also slightly better than that of uniaxial oriented geogrid HDPE50, the anti-packing of the end for HDPE80 geogrid contributes to at least 25%~32% of lateral expansion deformation.

(4) Muddy limestone with geogrids change the development pattern and the law of deformation. Vertical deformation of non-reinforced muddy limestone after moisture absorption mainly occur within a given depth of shallow layer in soil mass, soil at deep position does not expand basically, with the gradual downward movement of water, lateral deformation develops layer-by-layer, which finally shows that the deformation above is larger than the below and toppling towards free surface, and penetrating tension cracks occur in soil mass. However, reinforced geogrids exert an obvious effect on the restraint of cracks in soil mass, fine micro-fissures are only induced locally, and surface expansion of reinforced soil in vertical direction is restrained, but the expansion of soil mass at deep position develops relatively fast, far faster than that of non-reinforced soil, lateral deformation also mainly occurs in lower layer and becomes greater with time, finally it will exceed the deformation capacity at upper layer, which shows that the deformation above is smaller than the below.

(5) Muddy limestone with geogrids has an evident influence on the movement process of moisture content after moisture absorption. Under the one-dimensional infiltration condition, reinforcement of geogrids makes the water more difficult to infiltrate into soil mass, the time when water content at shallow layer begins to change and becomes stable is far longer than that of plain soil.

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REFERENCES:

Sharma, RS; Phanikumar, BR. 2005. Laboratory study of heave behavior of expansive clay reinforced with geopiles. Journal of geotechnical and geoenvironmental engineering, 131(4), 512-520

XU L, LI L, FANG B & LIU, L. 2002. Analysis on the affecting factors of interface friction coefficient between expansive soil and geogrid by pullout tests. Proceeding of 7th International Conference on Geosynthetics, Nice, France, 1357-1360

Gupte A, Satkalmi V & Bhonsle S, Viswanadham B.V.S. 2006. Performance of road reinforced with polypropylene geotextile - a case study. Proceedings of the 8th International Conference on Geosynthetics, Japan

Kameshwar Rao, Tallapragada1, Anuj Kumar Sharma. 2008. Experimental study of use of geogrids as horizontal reinforcing element in swelling subgrades. Proceedings of The 4th European Geosynthetics Conference, Edinburgh, Scotland.