

# Modelling and performance analysis of a reinforcing loess embankment

Zhang, Y., Tao, L., Zou, Z. & Wang, F.  
*College of Civil Engineering, Beijing University of Technology, China*

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**ABSTRACT:** Loess, with penetrability, collapsibility, slaking, is uniform in grain and high in porosity and low in moisture content. In the northwest China, geological calamities, such as soil erosion, slope slide, debris flow and landslip, etc, frequently occur in the loess area in the condition of large rainfall, which may bring tremendous loss and damage to highway. Geosynthetics is an effective method to the solution of these problems. The construction process of loess reinforcement embankment is modeled using FLAC. Based on uniaxial compression test and dynamic modulus input technique with programmable FISH, the compact quality of loess can well be depicted. A reinforcing expressway embankment in Ningxia is modeled using this method, and the results are close to the field data. At the same time, the internal force distribution in geogrid is analyzed, and reinforcing effect is appraised. These results may help promote the application of geosynthetics in loess embankment.

## 1 INTRODUCTION

The development of Western China brought great opportunity to transportation, at the same time, the challenge of many geotechnical problems are also faced. The road construction technology in loess area is one of the problems.

Reinforced soil technology is a revolution in the domain of geotechnical engineering and it provides an effective approach to these problems. Reinforced soil can not only increase the shear strength of soil, but also enhance its deformation ability. Triaxial test (Lei, 2000) was carried out to investigate the constitutive relation and strength of loess; standpoint of composite and stress circle method was used to explain performance enhancement of reinforced soil. Different reinforcing methods and reinforcing mechanism under different confine pressure were investigated (Xie, 2004). However whether the test results can be applied to practical engineering still need to be further studied. Because of the elastoplasticity of loess it will be compacted during embankment construction. The change of loess property is significant to study the gradually increased strength, distortion and stability embankment.

The construction process of loess geosynthetic-reinforced embankment is simulated using FLAC. Based on uniaxial compression test and dynamic modulus input technique with programmable FISH,

the compact quality of loess can well be depicted. A reinforcing expressway embankment in Ningxia Province is modeled using this method, and the results are close to the field data. At the same time, the internal force distribution in geogrid is analyzed, and reinforcing effect is evaluated.

## 2 NUMERICAL MODEL

FLAC was used in modeling embankment construction process. Geogrid is modeled by cable element, provided that cable is tensile, its weight is neglect and its ends were connected with soil. It was presumed that the constitutive relation of geogrid was perfect elastic-plasticity.

The modulus and density of loess increase during embankment construction. How to consider this variety is important to the simulation. Commonly, Duncan-Chang model is assumed to model soil constitutive relation, but this model does not well reflect the compaction of loess. In this paper Mohr-Coulomb failure criterion and ideally elastic-plasticity is presumed. The modulus of loess changes according to the stress level. The description of this variety is achieved with the aid of uniaxial compression test, the modified soil compression modulus model and dynamic modulus input technique with programmable FISH. Detailed information about dynamic modulus

input technique is shown in Fig. 1. The modified soil compression modulus can be expressed as follows (Lin, 1996):

$$E = \beta E_s \quad (1)$$

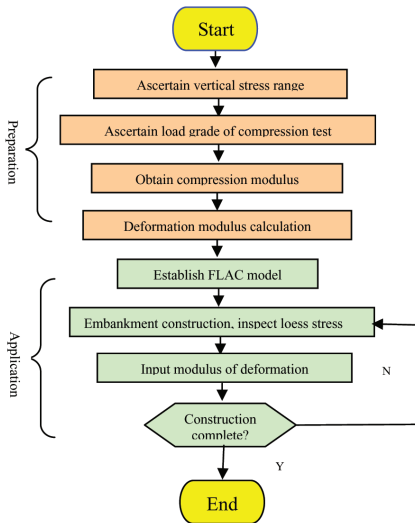


Figure 1. Input scheme of dynamic modulus.

where  $E$  is modulus of deformation;  $E_s$  is laboratorial uniaxial compression modulus;  $\beta$  is modified coefficient.

### 3 REINFORCED LOESS EMBANKMENT TEST

#### 3.1 Experiment introduction

One trial road section of expressway in the northwest China is chosen as experiment section. The subsidiary road section runs parallel with the main road. This area covers non-self-weight collapsible loess. Defensive seismic intensity is 8 degree. The embankment is 8.3 m high; 4 layers geogrid, 5 settlement plates, 16 vertical and horizontal earth pressure cells are installed (shown in Fig. 2) in the experiment section. The property of geogrid is listed in Table 1.

Exploratory investigation shows that 0.2~5.0 m depth loess, 0.2~0.8 m depth scree and tertiary mudstone are laid in turn from ground. Embankment earth fill is loess. According to laboratory test, mechanical property parameters of the embankment and formation are shown in Table 2.

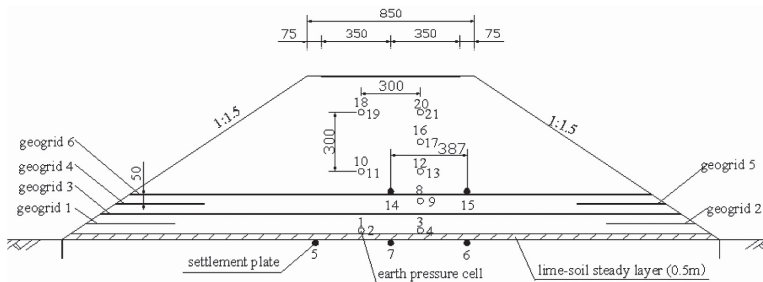


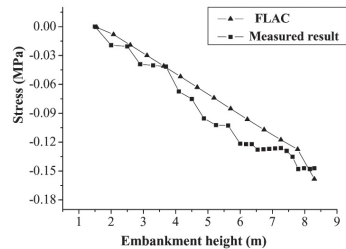
Figure 2. The reinforcement scheme and monitoring point layout of loess embankment.

Table 1. Main parameters of geogrid.

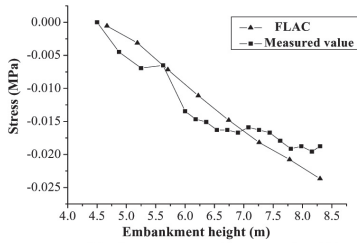
Property	Mass	Yield strength	Extensibility	Tensile force at 2% extensibility	Tensile force at 5% extensibility
PP biaxial geogrid	300 (g/m <sup>2</sup> )	15 (kN/m)	<16%	5kN/m	8 kN/m

Table 2. Soil parameters of embankment and formation.

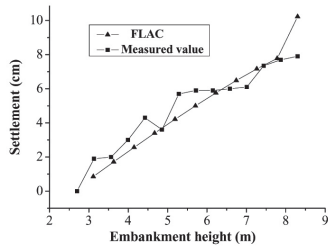
Soil	Depth (m)	Cohesion (kPa)	Friction angle (°)	Vertical stress (kPa)	Density (Kg/m <sup>3</sup> )	Bulk modulus (MPa)	Shear modulus (MPa)
Embankment filler	8.3	13	26.6	0 ~50	2.19e3	3.22	1.932
				50 ~100	2.2e3	4.747	2.848
				100 ~200	2.21e3	8.253	4.952
Upper subgrade soil	1	1	28.8	—	1.74e3	7.6	4.56
Lower subgrade soil	3.6	13	28.8	—	1.74e	45.6	27.36



(a) Stress comparison at point 8



(b) Stress comparison at point 17



(c) Settlement comparison at point 14

Figure 3. Comparison of modeling and measured results

### 3.2 Comparison of modelling and measured results

$\beta$  of 1.30 is used in the modelling. Fig. 3 shows the comparison between measured values of settlement plates, earth pressure cells and modelling results.

The comparison shows that modelling results are quite close to the measured values. The FLAC model can basically reflect the performance of loess embankment. At the same time, the calculated vertical stresses are much closer to measured values than that of the horizontal stresses, which may be related to the assumption that the Poisson's ratio is constant. In fact, Poisson's ratio changes with the compaction of loess. If the variation of Poisson's ratio during loess compaction is found, the modelling results will be more even precise. Furthermore, the modeling results of the middle points in embankment are more accordant with measured values than that of lower and upper points. This may be related to the boundary conditions in FLAC model. In the FLAC model, the foundation soil is only 4.6 m depth and the vertical displacement at the bottom is restricted, whereas the tertiary mudstone under the foundation is deformable

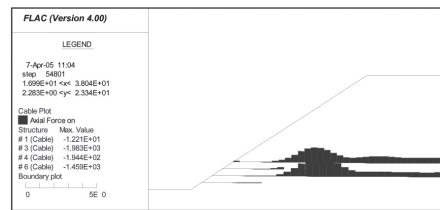
under additional stress, which will influence the modelling results.

### 3.3 Geogrid mechanical analysis

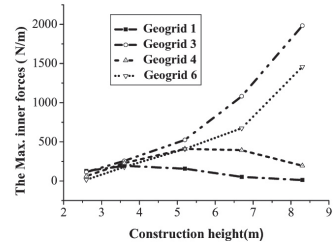
Figure 4 shows the comparison of geogrid inner forces at different construction heights  $H$ .

#### 3.3.2 Magnitude of inner force

As the construction height grows, the maximal inner forces of short geogrid 1,4 grow at first and then decrease; the maximal inner forces of geogrid 3,6 grow quickly. In the long geogrids, the maximal force of geogrid 3 is greater than that of geogrid 6. The effect of long geogrids are more apparent than that of short ones, and the grids underside is more obvious than that of the upside, which is different from geosynthetic-reinforced embankment in limited load condition, in which the force of upper reinforcement is greater than that of the lower (Bathurst. 2000). This may be relates to the location of the maximal embankment settlement (He. 2005). Moreover, the maximal force is 1983 N/m, which is smaller than the yield intensity 15000 N/m. in this case the geogrid works at elastic stage.



(a) Inner force of geogrids at  $H=8.3m$



(b) Comparison of the Max. inner forces at different construction heights

Figure 4. Axial force analysis of geogrid.

#### 3.3.3 The location of the maximal tensile force

As the construction height grows, the location of maximal tensile force of geogrid moves inside, and the effect of short geogrid weaken, which may be related to the stability of embankment. The circular radius is small when the embankment isn't high, and tension force of each geogrid is basically in the same order of magnitude. On the other hand, the higher embankment becomes, the bigger radius is, which

Table 3. Embankment stability coefficient.

		Construction and operation stage		Seismic stage	
		Bishop method	Double wedge method	Bishop method	Double wedge method
Embankment stability	Reinforcement	1.519 > 1.25	1.675 > 1.25	1.333	1.415
	No reinforcement	1.455 > 1.25	–	1.277	–
Overall stability	Reinforcement	1.482 > 1.25	–	1.294 > 1.1	–
	No reinforcement	1.421 > 1.25	–	1.244 > 1.1	–

may increase the tension force of the long geogrid, the tension of the short ones decrease.

### 3.4 The stability analysis of embankment

The software GEOSLOPE written by Professor Bathurst is used to analyze embankment stability. In the software, the Bishop method is used to analyze the stability of non-reinforced embankment; the modified Bishop method and the modified two part wedge method can be used to analyze the stability of reinforced embankment. The modified two part wedge method can only compute stability of the embankment body, and it assumes that the slide point is located at the intersection of geogrid and slope surface. It can search the potential surface when embankment slides along reinforcement.

Considering embankment stability under earthquake, the horizontal seismic load can be obtained by the formula:

$$E_{hs} = C_i C_z K_h G_s \quad (2)$$

where  $C_i$  of 1.7 is importance factor;  $C_z$  of 0.25 is synthetic influencing coefficient;  $K_h$  of 0.2 is horizontal seismic coefficient;  $G_s$  is weight of embankment.

According to the demand as computing stability of reinforced embankment, the results are obtained as follows shown in Table 3.

As can be seen, the global stability coefficient is bigger than that of the embankment, which may be related to the weakness of upper part of the foundation relative to the lower part of foundation and embankment. The stability coefficient of the reinforced is a little larger than that of non-reinforced. The stability coefficient difference between the Bishop method and the double wedge method is small, and the result is far beyond the demand.

According to the analysis above, in the experiment section, the reinforcing effect is not obvious under the geology condition, construction condition and loading condition.

## 4 CONCLUSIONS

The numerical method of FLAC is used to simulate the construction process of the reinforced embankment. Through the comparison of the modelling and measured results, the conclusions can be drawn as follows:

Laboratory compression test and dynamic modulus input method are adopted in this research to study the performance of reinforced embankment. The method used to calculate loess deformation modulus under different pressures is proposed. The compaction performance can be well modeled.

As the embankment constructed, the mechanical performances of long geogrid and short geogrid are different. When the embankment becomes higher, the tension force of short geogrid weakens; while the tension force of long geogrid increases quickly.

The comment on effect of reinforcement should not only include embankment stability improvement, but also should include the effect of adjusting uneven settlement and base stress of embankment. The characteristic of the loess is complicated. Series tests should be done to study the interaction between the loess and reinforcement, which is very important to analyzing the loess reinforcement mechanism. In addition, if the non-linear K-G model is chosen whose bulk modulus and shear modulus changes during loading, and relevant parameters can be obtained from appropriate test, it will be better to reflect the performance of the loess.

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