Effectiveness of Geogrid Reinforcement in Splicing Region in Embankment Widening

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ABSTRACT

Differential settlement in splicing region in embankment widening always causes breakage to the pavement, the global stability of the embankment can be improved and the differential settlement can be reduced in splicing region of embankment by geogrid reinforcement. And the working mechanism of geogrid reinforcement was introduced basing on the investigation on the causes of common problems in road widening project. In addition, the finite element method soft package PLAXIS was employed to calculate the tensile forces and displacements of the top and bottom geogrid layers after the process of the newly widened embankment construction. The contact element based on Coulomb criterion was adopted to describe the performance of reinforcement-soil interface during the calculation, and the variation law of geogrid tensile forces under different pavement surface load was also analyzed. The tensile force, the settlement and the lateral displacement of geogrid were calculated with the changed influencing coefficient of geogrid-soil interface. The results show that the displacement and the tensile force of the bottom geogrid layer are the biggest, and the tensile force of the geogrid gradually reduces to be zero from the junction point to the point further than 4 m from the junction. Moreover, the tensile forces of the geogrid layers increase with the vertical load on the pavement surface, and the peak value of the tensile forces decreases with the influencing coefficient of geogrid-soil interface.

KEYWORDS: embankment widening; numerical analysis; geogrid; tensile force; displacement

INTRODUCTION

The traffic volume rapidly increases with economic growth, the original road already cannot satisfy the requirement of traffic in China, and the problem requires an increase in road capacity. Thus, many of the original roads need to be widened, after widening, differential settlement in the lap joint of the new and the old embankments appeared, and it easily lead to a large number of longitudinal and transverse cracks in the pavement [1]. The global stability of the embankments can be improved and the differential settlement between new and old embankments can be reduced by the geogrid reinforced in embankment junction. The geogrid reinforcement in the lap joint plays a prominent role in the road widening projects[2-3].

The geogrid reinforcement in the junction of new and old embankments has been extensively used in many road widening projects, however the theory for calculation and design of the geogrid reinforcement still absent [4-7]. New kinds of geogrid are produced continually with the development of material science and manufacturing technique at present [8-13]. Because there are few theoretical researches, the application of the geogrid reinforcement in the embankment junction is restricted seriously.

In order to release the restriction on design of the geogrid reinforcement between new and old embankments, a series of analysis on tensile forced of the geogrid layers, the settlement of the pavement and lateral displacement of the post constructed embankment were carried out.

MECHANISM ANALYSES

Distress in road widening

As the compression relatively small in the embankment, the displacement of embankment is mainly caused by the settlement of subgrade. In the road widening project, the settlement of old embankment is not equal to that of new embankment,which leads to extra-stress in the lap joint after the road widening. The differential settlement also causes lateral displacement of the post constructed embankment and pavement breakage of the newly paved pavement. In addition, the tensile stress of the lap joint between the new and the old embankments increases with the increase of the differential settlement. When the stress increases to the critical value of the lap joint, the longitudinal cracks in the pavement will further expand and the newly constructed embankment slips laterally, which will interfere with the normal service of the road.

Therefore, due to differential settlement between new and old embankment, cracks were firstly produced in subgrade and then gradually developed to the road surface, causing the deformation and damage of pavement structure.

The main causes of differential settlement in the junction region of the old and new embankment are: (1) the resistances provided by the old embankment are insufficient to support newly constructed embankment, which leads to slide of the post constructed embankment along the slope of the original embankment. (2) the degree of consolidation of the subgrade of newly constructed embankment is different from the original one, thus consolidation settlement of the newly constructed embankment is bigger than that of the original embankment.

Treatment Principle

Geogrid used in road widening project can effectively reduce the differential settlement and improve the integrity and stability of the embankment mainly due to: (1) geogrid is made from flexible material with good ductility, it is able to strengthen the overall performance of the embankment and spread the load on the pavement adequately, thus improve the bearing capacity and decrease the uneven settlement; (2) the friction between soil and geogrid reduces the horizontal displacement of the embankment fill, meanwhile, the reinforcement provides additional tensile forces to restrict the lateral deformation; (3) the meshes of geogrid provide good interlocking effects, which can increase the soil shear strength and restrict the lateral displacement of embankment.

In splicing region of new and old embankment, the interlock and the friction effects of geogrid improve stress and strain state of embankment to avoid crack of the sliding damage. Geogrid reinforcement effect improves the overall stability and bearing capacity of embankment fill, and reduces the differential settlement of roadbed, hence avoid longitudinal and transverse cracks in the new and old embankment junction, and lower the transverse slope rate of newly constructed embankment.

FEM ANALYSIS

A typical widened embankment section was chosen form Chang-an highway, the finite element model was established to investigate the effect of the geogrid reinforcement in the splicing region between the new and old embankment. The FEM soft package PLAXIS was employed to establish a 2D numerical model to simulate the section, the geometry model is shown in Figure 1. Three layers of geogrid were spread from the bottom to the top of the widened embankment with 1m spacing respectively in the newly constructed embankment, the anchorage length of geogrid in the old embankment is 1.5 m, and 6.5 m in the new embankment, *p* is uniformly distributed load on the pavement.

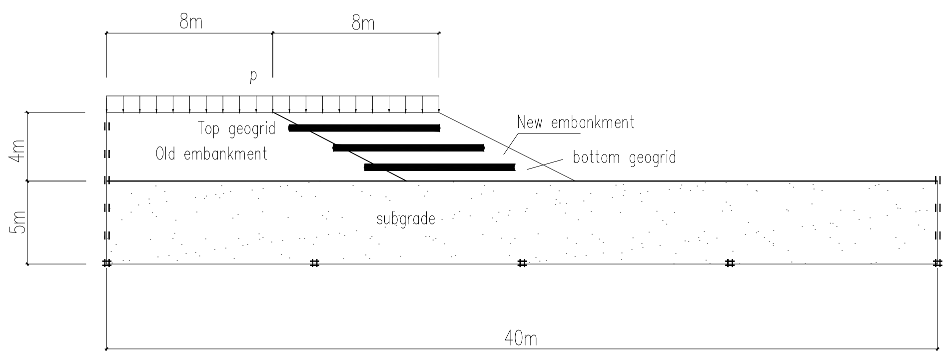

Figure 1: Geometry model for numerical simulation

Constitutive model of geogrid and soil contact element

Coulomb shear failure criterion was employed to describe the interface action between geogrid and filling of embankment [14], the shear strength of geogrid-filling interface is τ_n, it is given by $\tau_n = c_i + \sigma_n \tan\varphi_i$, in which friction coefficient $\mu = \tan\varphi_i = k\tan\varphi$, cohesion $c_i = kc$, thus the shear strength τ_n can be expressed as

$$\tau_n = c_i + \sigma_n \tan\varphi_i = k(c + \sigma_n \tan\varphi) \quad (1)$$

where φ_i is the interface equivalent limit angle of internal friction, c is the cohesion of embankment filling, φ is the internal friction angle of the embankment filling, $\boldsymbol{k}$ is the interfacial interaction coefficient of geogrid and soil interface.

In the newly construct part of embankment, the embankment filling, the subgrade soil, the geogrid using different materials models, and contact element is employed to describe the interface strength of geogrid and its surrounding soil interface according to the formula (1). Geogrid is described by ideal lineal elastic model based on generalized Hooke’s law, the subgrade soil, the embankment filling in the old and the newly constructed parts are described by Mohr-Coulomb ideal elastic-plastic model. The main parameters of the materials are obtained from laboratory test, herein listed in Table 1.

Table 1: material parameters for numerical simulation

Parameter	E (MPa)	ν	C (kPa)	φ (°)	γ (kN/m³)
Old embankment filling	30	0.32	25	18	18
New embankment filling	20	0.38	15	20	18
Subgrade Soil	30	0.30	28	20	18
Geogrid	4000	0.2	150	35	26

The effective area of geogrid per unit length of is A=0.0003 m^2/m, hence the tensile stiffness EA=1200 kN/m.

Displacement and tensile force of geogrid after construction

When the new embankment filling is completed, the displacements and tensions of the top and the bottom layers of geogrid in the new embankment are shown in Figure 2 to Figure 4.

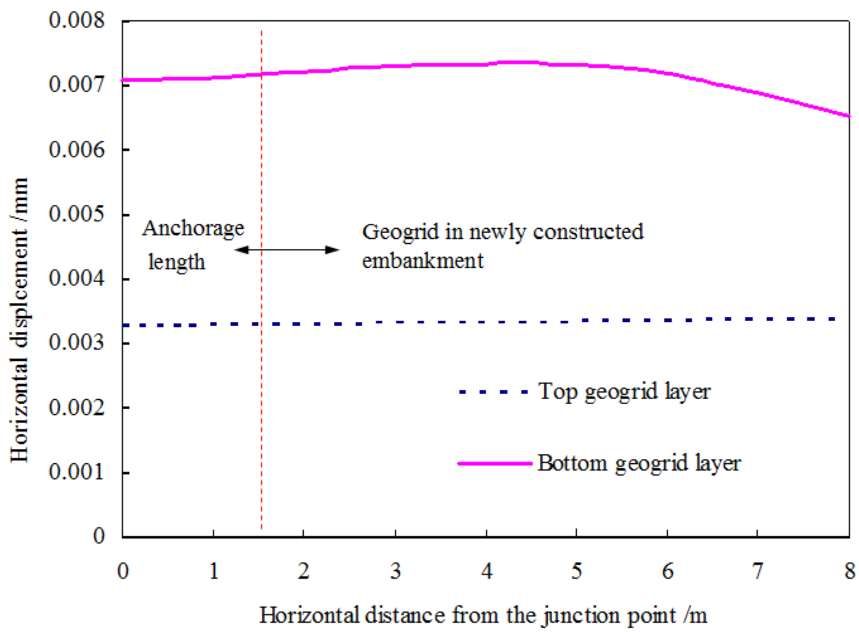

Figure 2: Horizontal displacements of geogrid

Figure 2 illustrates that with the increase of distance from the junction of the new and old parts of embankment, the variation of the horizontal displacements of the geogrid layers is negligible. The horizontal displacement of the top geogrid layer is about 50% of that of the bottom one, the main cause of the horizontal displacement is the lateral movement of the embankment filling, and the results imply that geogrid reinforcement can reduce the lateral displacement of the embankment filling.

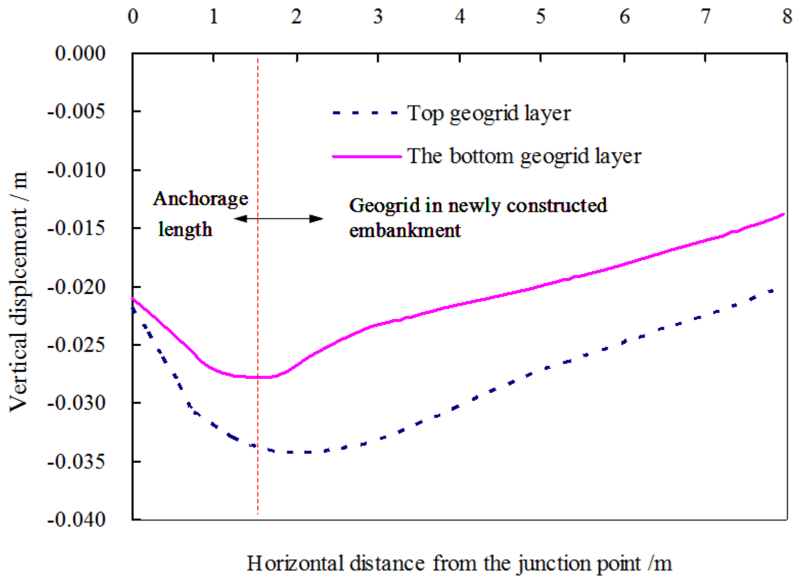

Figure 3: Vertical displacement of geogrid

The vertical displacements of the top and the bottom geogrid layers are shown in Figure 3. It can be seen that the vertical displacement of the top geogrid layer is larger than that of the bottom one. With the increase of distance from the junction point of the new and old parts of embankment, the vertical displacements of geogrid layers firstly increase gradually. The settlement of the geogrid at the anchorage part in the old embankment increases with the distance from the junction, and the difference of vertical displacements between the top and the bottom geogrid layers almost remain constant with the increase of the distance in the newly constructed embankment.

The tensile forces of the top and the bottom geogrid layers are drown in Figure 4.

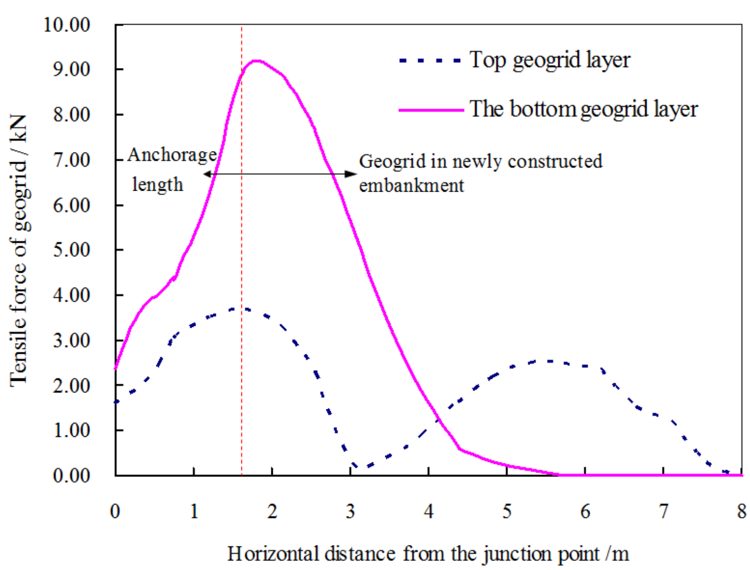

Figure 4: Tensile force of geogrid

It can be seen form Figure 4, the tensile force of the bottom geogrid is larger than the top one, the tensile forces of both the top geogrid and the bottom geogrid have the greatest valuer at the junction point, the tensile force of bottom geogrid decreases with the increase of distance from the junction point to both the newly constructed and the old parts of the embankment, however, the tensile force of the top geogrid layer firstly decreases until 1.6 m from the junction point and then increase with the increase of the distance, and at about 4.5m from the junction point the tensile force decrease again. The main cause is that the embankment filling has an obvious lateral displacement at the shoulder of the newly constructed embankment, which results in the friction on the geogrid and tensile force of the geogrid.

Influencing of the load on the pavement

As the tensile force of the bottom geogrid layer is greater than that of the top one, only the variation of the tensile force of the bottom geogrid is shown herein, the tensile force of the bottom geogrid under different pavement vertical load are drown in Figure 5.

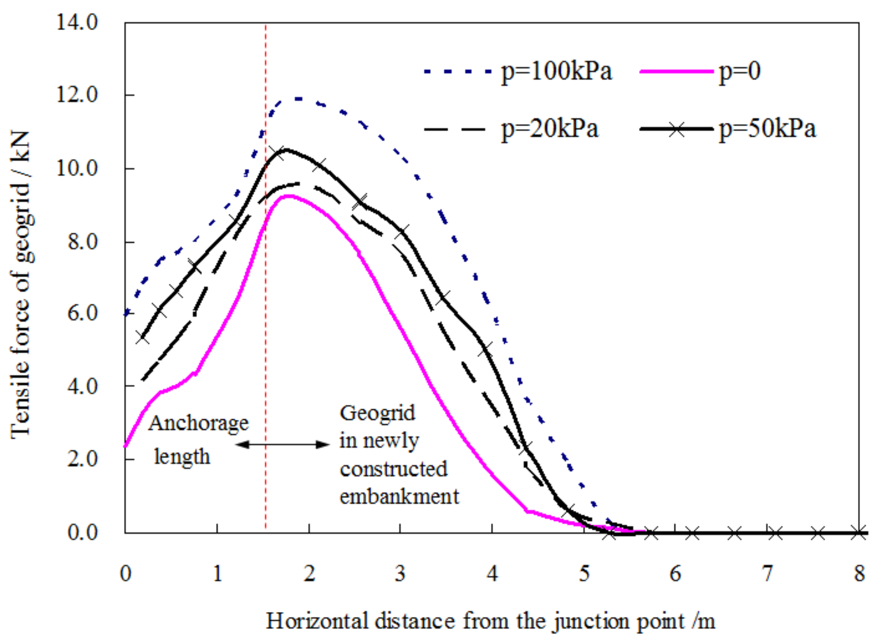

Figure 5: Tensile force of bottom geogrid

It can be seen from the Figure 5, the distributions of the tensile force along the geogrid are similar and the tensile force of the geogrid gradually increases with the increase of the vertical pressure on the pavement. Therefore, in the embankment widening design, the possible load on pavement after construction should be fully considered, the design and calculation should be according to the probable largest load.

Influence of the geogrid-soil interface coefficient

The geogrid-soil interface coefficient *k* is employed to describe the interface strength of the geogrid and soil, a series of calculation is carried out to investigate the influence of the geogrid-soil interface coefficient, the tensile force of the bottom geogrid is as shown in Figure 6.

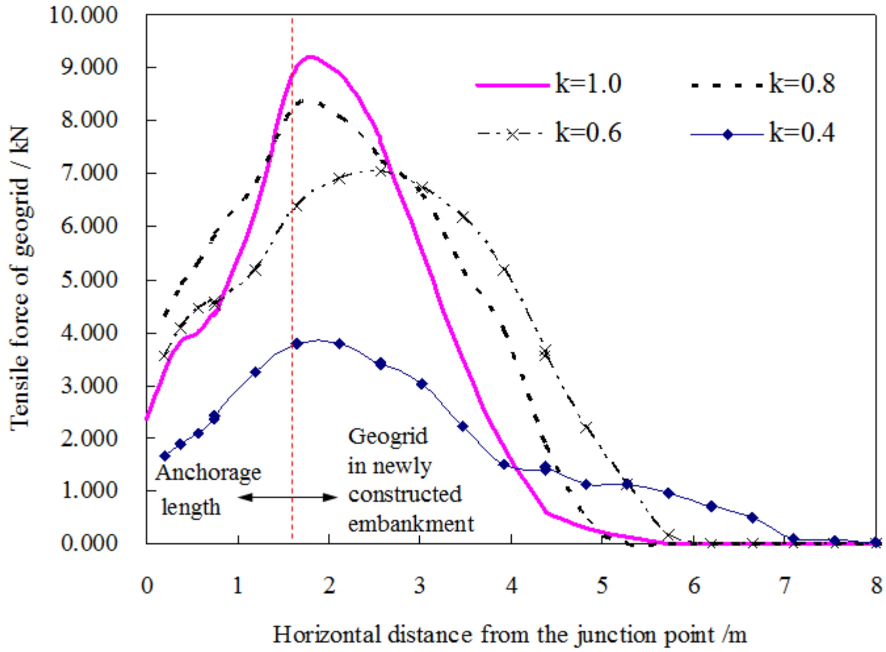

Figure 6: Tensile force of bottom geogrid

From Figure 10, it can be seen that the peak value of the tensile force decreases with the decrease of the coefficient, however the tension resistance length of the geogrid increases. As all length of geogrid has tensile force when k=0.4, in this condition the slippage occurred in the surface of geogrid and filling, the geogrid cannot bring enough constraint to the newly constructed embankment.

CONCLUSIONS

(1) The variation of the horizontal displacements of the geogrid layers is neglectable. The horizontal displacement of the top geogrid layer is about 50% of that of the bottom one, the main cause of the horizontal displacement is the lateral movement of the embankment filling, and the results imply that geogrid reinforcement can reduce the lateral displacement of the embankment filling.

(2) The vertical displacement of the top geogrid layer is larger than that of the bottom one. With the increase of distance from the junction point of the new and old parts of embankment, the vertical displacements of geogrid layers firstly increase gradually. The settlement of the geogrid at the anchorage part in the old embankment increases with the distance from the junction, and the difference of vertical displacements between the top and the bottom geogrid layers almost remain constant with the increase of the distance in the newly constructed embankment.

(3) The peak value of tensile force of geogrid is at the point in the junction of the old and the newly constructed embankment. The tensile force and the vertical displacement of the bottom geogrid layer decrease with the increase of the distance from the junction point, the variation of horizontal displacement is negligible. The tensile force of bottom geogrid decreases with the increase of distance from the junction point to both the newly constructed and the old parts of the embankment, however, the tensile force of the top geogrid layer firstly decreases until 1.6 m from the junction point and then

increase with the increase of the distance, and at about 4.5m from the junction point the tensile force decrease again.

(4)The distributions of the tensile force along the geogrid are similar and the tensile force of the geogrid gradually increases with the increase of the vertical pressure on the pavement. Therefore, in the embankment widening design, the possible load on pavement after construction should be fully considered, the design and calculation should take the probable largest load into account. The tensile forces and displacements of the geogrids increase with the vertical load on the pavement surface, and the lateral displacement and the differential settlement of the pavement decrease with the influencing coefficient of geogrid-soil interface.

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