Calculating method of reinforced bedding in the geosynthetics reinforced and pile supported embankment

Etude sur méthode de calcul des semelles de ferraillage pour fondation de route appuie par réseaux de piquets d'armature

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ABSTRACT

Based on the current study of geosynthetics reinforced and pile supported embankment(GRPS) China and abroad, the loads and deformation of reinforced bedding undertaken, influence of dynamic load and intensity of reinforced bedding were analyzed by field test, model test and numerical simulation, the study was based on embankment soil arching effect, lateral spreading effect and geosynthetics deformation properties. The vertical embankment load by arching effect was analyzed by global arching, the tensile force of geosynthetics by that load was analyzed by cable, and ground reaction and initial deflection of geosynthetics were taken into account. Friction of embankment bottom was considered when analyzing tensile force by lateral spreading effect. Reliability of this method was validated, that perfects and promotes the theory of GRPS.

RÉSUMÉ

l'étude se fait autour du principe mécanique de l'effet de terre et l'effet de pousse du talus ainsi que de la déformation du grillage qui en résulte, en basant sur l'étude actuelle sur méthode de calcul des semelles de ferraillage en Chine comme à l'étranger et par essai et analyse sur la charge , la déformation, l'influance de la charge dynamique et la résistance d'éléments de ferraillage sur site ou au laboratoire. On utilise la théorie de voute à bille pour l'analyse sur contrainte horizontale de l'effet de terre, la théorie de suspension pour l'analyse sur la traction de l'élement due à la contrainte horizontale en tenant compte de la réaction de fondement et de la déflection préliminaire de l'élement. En calculant la traction de l'élement due à l'effet de pousse du talus, on a tenu compte du frottement du fond de base. Ce qui a amélioré la méthode de calcul des semelles de ferraillage pour fondation de route appuie par réseaux de piquets d'armature. La faisabilité de cette méthode de calcul a été justifiée au cours des calculs exemplaires. Donc cette méthode de calcul a déveoppé la théorie de la structure de base de route appuie par réseaux de piquets d'armature.

Keywords: Ground treatment; Geosynthetics reinforced and pile supported embankment(GRPS); Reinforced bedding; Soil arching effect; lateral spreading effect

1.INTRODUCTION

Geosynthetics reinforced and pile supported embankment(GRPS) is widely used, the scholars at home and abroad have carried out many researches including methods like numerical simulation, field and model tests since structure is hit by complexity of the subgrade "soil arching effect" and "cable/membrane effect", but do not still reach agreement[1].

As early as 1943, Terzaghi confirmed that the exist of soil arching effect in soil mechanics, herefrom the main models successively having brought forward: Terzaghi soil arching model[2], soil arching model based on Marston theory[3], wedge soil arching model[4-5], pyramidal soil arching model[6], Hewlett & Randolph hemispherical soil arching model[7-8]. For the calculation of reinforced tension, the adopted cable/membrane theories in general are Catenary method[9], Carlsson method[10], SINTEF method[11]. The methods of lateral spreading effect of side slope are as follows: Kempfert method[12], Love method[13], Geduhn/Vollmert method[14] and so on. In recent 20 years, the calculation methods of GRPS have been listed in various countries norms or handbooks such as England[15], Japan[16], Germany[17] and Northern Europe[18].

2.MECHANISM OF REINFORCED BEDDING IN GRPS

The mechanism study of reinforced bedding in GRPS are carried on by such methods like numerical simulation, field test and model test[19].

2.1 *The bearing loads of reinforced body*

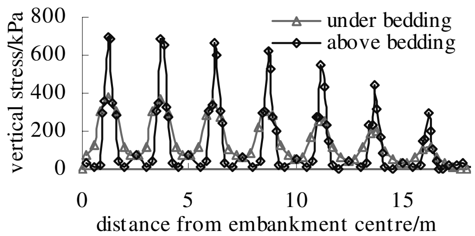

Fig. 1 Typical result of numerical simulation (pile spacing s=2.5m, size of pile cap a=1.0m)

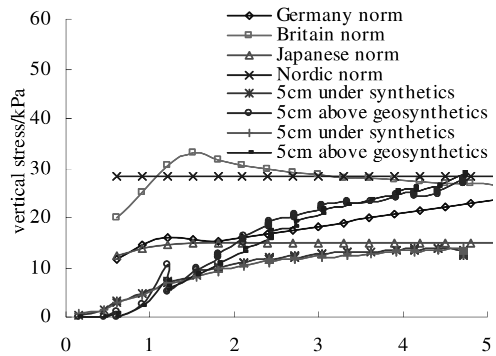

Fig .2 Stress comparison of soil between piles

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Numerical simulation indicates that the embankment appeard the obvious arch as multi-level load carried on, the vertical stress above and under the bedding corresponding to pile cap increased observably with the increased filling height; the increasing velocity of stress corresponding to soil between piles is less than that of pile cap distinctly, as shown in Fig.1.

In the field test, the soft ground of 25m depth has been treated by GRPS, the pile is reinforced concrete pile (diameter of pile is 0.5m, pile spacing is 2.5m, size of pile cap is 1.5m×1.5m), crushed rock layer of 0.6m is laid on the cap, two-dimensional geosynthetics of 80kN/m intensity is installed inside the crushed rock layer. For the centre of embankment, stress of soil between piles increases with filling height, variety tendency of stress above the bedding is close to that of German norm, as shown in Fig.2.

In the model test of embankment centre, according to the similarity theory, test system consists of two parts: taking steel pipe as pile, polystyrene board as soil and its geometric similarity ratio is 6:1. Eight tests have been arranged including one pile spacing(s=0.4m), three pile cap(a=0.089, 0.17 and 0.25m), two geosynthetics intensity(40kN/m, 30kN/m) and two mode of border fixing. During the filling, average vertical stress of soil between piles above and under bedding increased with increasing height, the stress above bedding was close to that of Germany norm, as shown in Fig.3, there also exited partial stress under bedding. The initial deform state of geosyntheics had some effects on efficiency of arch forming.

The model test of side slope indicates that tensile force of upper geosynthetics caused by lateral spreading effect was greater than the lower, as shown in Table 1.

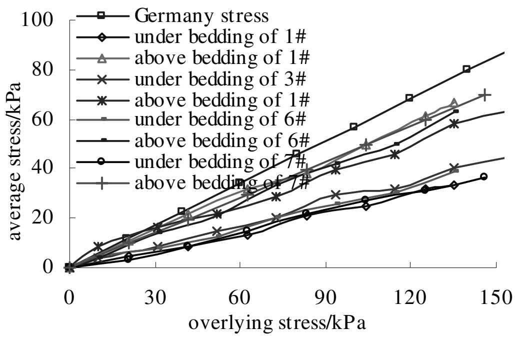

Fig .3 Average stress of soil between piles(s=0.4m,a=0.089m,q=0~150kPa)

Table 1. Comparison of composite force of active earth pressure and tension by lateral spreading effect(kN/m)

Test No.	composite force of active earth pressure	tension by lateral spreading effect of lower	tension by lateral spreading effect of lower	Total tension
1#	16.0	3.8	7.1	11.0
2#	22.9	1.4	1.9	3.3
3#	15.0	5.2	8.6	13.7
4#	12.7	1.3	2.7	3.9

2.2 *Stress and deformation of geosynthetics*

Results of numerical simulation indicate that tension of geosynthetics above pile was greater than that above soil, and the greatest was normal to the pile side. The tension reduced with the increasing modulus of subjacent bed, modulus of soft soil and ratio of replacement, and the tension increased with increasing modulus of geosynthetics, as shown in Fig.4.

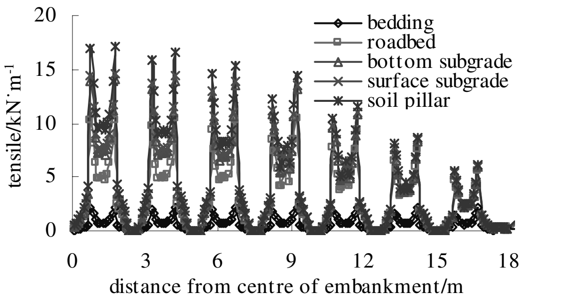

Fig. 4. Typical numerical result of tension of lower geosynthetics of cross-section of pile center

The field and model tests indicate that the tension of geosynthetics between two piles was greater than that among the four piles, the tension of lower between two piles and vertical to the cap side was greater than that parallel to the cap. For the bedding of two layer geosynthetics, the bearable load of lower was the 1/2~2/3 of total load, as shown in Fig.5 and Fig.6.

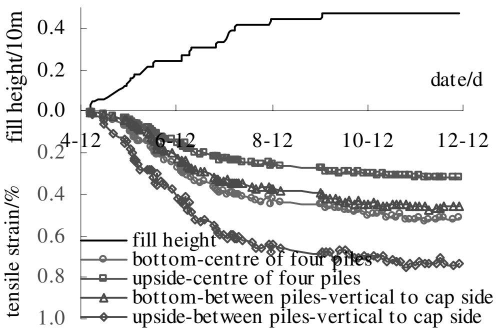

Fig. 5. Strain of geosynthetics of field test

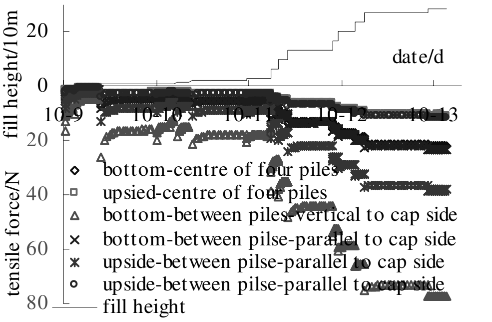

Fig .6. Tension of geosynthetics of model test

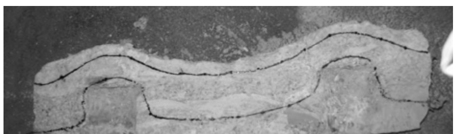

Fig. 7. Deformation of bedding injected(pile centre)

The cement mortar was injected after the model test loading had finished, the shape of geosynthetices after deformation indicate the deformation of cross-section of pile centre was more obvious than that of of soil centre, vertical load was suffered mainly by geosynthetics between piles, the shape of geosynthetices after loading was similar to cable shape, as shown in Fig.7.

2.3 *Effect of dynamic load*

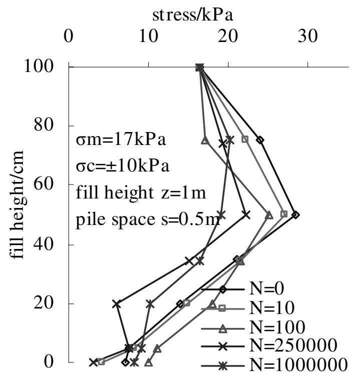

Fig. 8. Stress variation with numbers of load (z=1.0m)

Dynamic model test had been studied by German Heitz[20]. If h/s>1.5, the dynamic load did not affect the arch almost, if h/s<1.5, the dynamic load reduced the function of arch effect, the bearable stress of bedding increased, and it assumed that stress delivered on the bedding for dynamic load was 1.5 times than that of dead load approximately, as shown in Fig.8.

2.4 *Discuss of geosynthetics intensity*

Geo-technic synthetic material had obvious creep characteristics. And the tension increased with increasing load from geosynthertics laid to construction finished. During the operation, the strain of geosynthetics increased with the time elapsing because of creep, and stress relaxation of geosynthetics, the variation course of intensity and tension is as shown in Fig.9. So for the strain of minimum intensity limited value was assumed as 10%. The intensity could be acquired by creep test according to serviceable life.

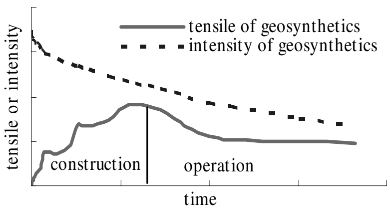

Fig. 9. Tension and intensity of geosynthetics with time

Disrepair during laying, biochemistry action and so on should be considered. Therefore, allowable intensity of geosynthetics could be determined by formula as following.

$$[T] = \frac{T_{cr}}{F_C F_D}$$

Where T_{cr}=tension intensity by 10% strain in the serviceable life, kN/m;F_C= material assurance coefficient considering disrepair during laying;F_D= durability assurance coefficient considering weather resisting property, drug resistance and long-term deterioration property.

Value of F_D is from 1.0 to 2.0 generally, it need not consider whether there being no sunlight irradiating, geosynthetics being handled fairly during construction and pH=5~9. If geosynthetics is used in soil, F_C could be thought as 1.0, if in macadam, the value should be fixed according to specific condition. Nordic norm assumes the value of F_C as Table 2.

Table 2. Modified coefficient considering disrepair

type	clay/silt	sand	gravel(natural)	gravel(man-made)	Macadam
$1/F_C$	0.91	0.83	0.77	0.72	0.67

3.METHOD OF REINFORCED BEDDING OF GRPS

3.1 *The method of arch effect*

3.1.1 *Stress of soil between piles*

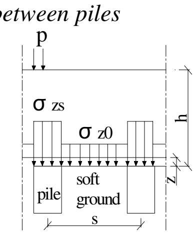

Fig. 10. Calculation sketch of vertical stress of GRPS

The stiffness difference between soil and pile arouses the soil arch effect, more embankment load is transferred to piles mostly. To analyze the arch effect of GRPS, the achievement of Zeaske[21] and Zaeske and Kempfert[22] is adopted. For the embankment above the arch, the stress by overburden and traffic load is assumed equably, the self-weight stress linear distribution. The average stress on the face of pile cap, is deduced as following approximately (sketch shown in Fig.10).

$$\sigma_{z0} = \lambda_1^{\chi}\cdot(\gamma+\frac{p}{h})\cdot\left(h\cdot(\lambda_1+h_g{}^2\cdot\lambda_2)^{-\chi}+h_g\cdot((\lambda_1+\frac{h_g{}^2\cdot\lambda_2}{4})^{-\chi}-(\lambda_1+h_g{}^2\cdot\lambda_2)^{-\chi})\right)$$

Where γ=unit weight of embankment soil; p= dead and live load surcharge, including dead load (p_j) and dynamic load (p_d, p_d'), when h/s<1.5, p_d'=1.5p_d; s= center-to-center pile spacing; d= diameter of the pile or cap, if not circular, can be transferred by following formula $d=\sqrt{4A_s/\pi}$,

A_s= area of pile cap; h_g=height of soil arch, if h≥s/2, h_g=s/2, if h＜s/2, h_g=h; $K_{crit}=\tan^2(45°+\varphi'/2)$, passive earth pressure coefficient;φ'=friction angle of embankment;

$$\chi=\frac{d\cdot(K_{crit}-1)}{\lambda_2\cdot s};\quad \lambda_1=\frac{1}{8}\cdot(s-d)^2;\quad \lambda_2=\frac{s^2+2\cdot d\cdot s-d^2}{2\cdot s^2}.$$

If the modulus of soils of ground is high enough and the opposite force is strong enough, the stress and strain need not be checked. According to German study, intensity of geosynthetics should be checked if the stiffness ratio of pile and soil is more than 100. The stiffness of pile could be gotten by loading test, which could be calculated by the formula as follows.

$$k_{s,T}=\frac{F_s}{s_T\cdot A_s}$$

Where F_s=load born by pile; s_T=the settlement of pile in test.

3.1.2 *Stress of pile cap*

According to soil arch effect, the average stress of pile cap could be calculated as follows:

$$\sigma_{zs}=((\gamma\cdot h+p)-\sigma_{z0})\frac{A_E}{A_S}+\sigma_{z0}$$

Where A_E=unit area of single pile bearing load. So, the load of pile bearing is: $F_s=\sigma_{zs}\times A_S$.

The total load born by pile should include the load transferred by geosynthetics. Generally, the load of pile is: $F_s=(\gamma\times h+p)\times A_s$

3.1.3 *Vertical stress of reinforced bedding*

Average vertical stress of reinforced bedding born is:

$$\sigma_g=\sigma_{z0}-\sigma_d$$

Where σ_{z0}= average vertical stress of soil by arch effect; σ_d=average opposite force of ground.

The average opposite force of ground is:$\sigma_d=2/3\times k_s\times f$.

Where f= deflection of geosynthetics centre; k_s=combined stiffness of ground in depth of treatment. Coefficient 2/3 roots in average deformation of soil between piles.

Combined stiffness of ground is: $k_s=E_{s,k}/t_w$.

Where $E_{s,k}$=compression modulus of ground; t_w=depth of treatment.

3.2 *The method of tensile force of geosynthetics*

3.2.1 *The tensile force by vertical stress*

It is assumed that geosynthetics could bear tensile force not flexural torque, there is uniform load on the bedding, the form of geosynthetics is similar to cable after loaded-on, it is calculated by horizontal parabola.

According to cable theory by uniform load, the balanceable differential equation of cable element is built (as shown in Fig.11), parabola equation is:

$$y=-\frac{4f'}{l^2}x^2+f'$$

If the centre deflection of geosynthetics is f', the area of oblique line is: 2f'×l/3.

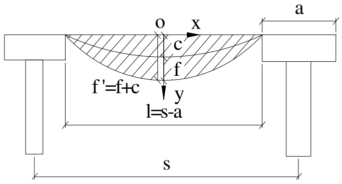

Fig. 11. Deformation sketch of geosynthetics of GRPS

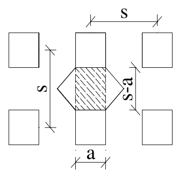

Fig. 12. Planar area sketch of geosynthetics

Then, the maximal tensile force of geosynthetics is:

$$T_{\max}=\frac{ql}{2}\sqrt{(\frac{l}{4f'})^2+1}$$

$f'=(s-a)\sqrt{\frac{3}{8}\varepsilon}=l\sqrt{\frac{3}{8}\varepsilon}$, thus $T_{\max}=\frac{ql}{2}\sqrt{1+\frac{1}{6\varepsilon}}$.

Considering the possible occurrence of initial deflection of geosynthetics c, total deflection of geosynthetics centre is:

$$f'=\sqrt{\frac{8c^2+\varepsilon(8c^2+3l^2)}{8}}.$$

Where ε=strain of geosynthetics after loaded-on.

The area distribute of soil is divided averagely according to hexagon of heavy line domain as shown in Fig.12, based on the characteristics of tensile force and strain of geosynthetics tested, the load of embankment of hexagon area should mainly suffered by the geosynthetics of dotted line domain, which is the action area of geosynthetics.

So, the average stress of geosynthetics is:

$q=(s+a)\times\sigma_g/2a$

the tensile force by arch effect is:

$$F_{G,M}=T_{\max}=\frac{(s+a)(s-a)}{4a}\sigma_g\sqrt{(\frac{s-a}{4f'})^2+1}$$

3.2.2 *The tensile force by lateral spreading effect*

Owing to the result analysis of field and model tests, the tensile force by lateral spreading effect should be considered, and horizontal active earth pressure is mainly suffered by geosynthetics and ground commonly, as shown in Fig.13. The friction provided by ground relates to soil indicator of ground and mesh size of geosynthetics. The friction is:

$$R_u=G\cdot\tan\varphi_d\cdot p_s=\frac{1}{2}\gamma\cdot h^2\cdot n\cdot\tan\varphi_d\cdot p_s$$

Where G=deadweight of embankment slope; φ_d=initial friction angle of foundation base; $p_s=1-S_{geosynthetics}/S_{total}$=area ratio of soil and total unit mesh of geosynthetics; S_{total}=total area unit mesh of geosynthetics, $S_{total}=dt\times dl$;; $S_{geosynthetics}$=area of geosynthetics unit mesh,

$$s_{geosynthetics}=(dl-\sqrt{2}nt)\cdot wt+(dt-\sqrt{2}nt)\cdot wl+nt^2,$$

For m layers, the area is $m\times S_{geosynthetics}$ (as shown in Fig.14);γ=soil density of embankment; h=height of embankment; n=slope degree of embankment.

Tensile force of geosynthetics by lateral spreading effect is:

$F_{G,S}=E_{ah}-R_u$

$Eah=\gamma\times h^2\times K_{ah}/2+p\times h\times K_{ah}$

If $F_{G,S}<0$, $F_{G,S}=0$;

Where K_{ah}=active earth pressure coefficient.

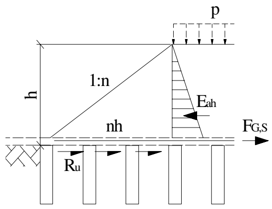

Fig.13 Sketch of side slope

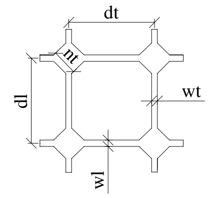

Fig.14 Mesh size of geosynthetics

3.3 *The total tensile force of reinforced bedding*

The tensile force of geosynthetics in longitudinal direction of GRPS is: $F=F_{G,M}$. And the tension in transverse direction is: $F=F_{G,M}+F_{G,S}$.

4.SUMMARY

(1) The British and German norms adopt semicircle and hemispheric arch respectively, Nordic and Japanese norms adopt flare angle. Vertical stress of soil between piles by arch effect in German norm is based on assuming supporting structures under the bedding, equal to sum of the bedding and soils between piles, and close to test results.

(2) Partial load of embankment is undertaken by soils between piles. The value is related to modulus and deformation of soil.

(3) The composite force of active earth pressure tested is greater than tensile force of geosynthetics caused by lateral spreading effect obviously, it should be considered.

(4) The force of geosynthetics vertical to the pile cap is bigger than that parallel to the cap. The tensile force by lateral spreading effect of upper layer is bigger than that lower one. The deformation shape of geosynthetics is close to cable. It should assume that vertical load of embankment mainly be born by the geosynthetics between pile cap.

(5) Vertical stress caused by arch effect adopts spherical arch theory, tensile force caused by which adopts cable theory, and considering favorable influence of opposite force of ground and initial deflection of geosynthetics.

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