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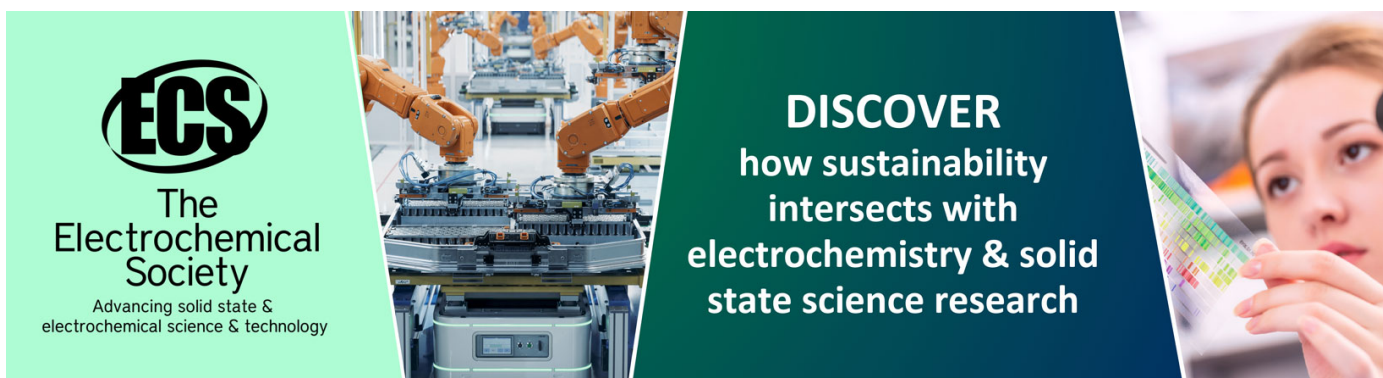
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Discussion on the Displacement and Stability of The Soil Nailing

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Abstract. Because of the advantages such as easy construction, low cost, short construction period and mature construction techniques, soil nailing has been widely used in engineering. However, at present there is lacks of the calculation theory of soil nailing, and shortages also exist in allowable deformation values specified by current specifications: a) the safety factor of soil nailing wall is generally calculated by conventional limit equilibrium method, which has relatively low computational accuracy for complex soil distribution and can not give the relation between deformation and stability of soil nailing structure; b) current soil nailing specifications just simply specify an allowable deformation value without considering features of foundation pit, supporting types and surroundings, and these specifications also determine the early warning value for monitoring without combining the deformation with the stability of foundation pits. Thus, these shortages lead to the downward trend of usage of soil nailing that has good performance-price ratio in fact.

1.Introduction

Soil nailing is widely used in engineering because of its simple construction, low cost, short construction period and mature construction technology compared with many other foundation pit supporting methods. However, the displacement of the soil nailing wall is generally larger than that of the rigid supporting structure, and the existing pit codes take the conservative fixed displacement values as warning values and allowed values (China Academy of Building Research. (1999), China Association for Engineering Construction Standardization. (1997), Ministry of Housing and Urban-Rural Development of People's Republic of China. (2012)) uniformly in accordance with the pit's safety level. So the displacement values of the soil nailing wall measured in practical projects can easily exceed the allowed values. Thus, the cost-effective supporting method has a tendency to reduce its utilization frequency especially in soft soil area and city centers where the pit's displacement is controlled strictly. Projects causing recessive waste by this reason are not rare. For some relative safe pits, once their displacement value passes the requirements they will be forced to backfill and huge economic losses is caused.

The calculation of the stability facto is an important content for the design of soil nailing. Generally, the traditional limit equilibrium method is often used, such as the Sweden method and the Janbu method. However, the calculation results can't reflect the displacement characteristics of the soil nailing wall and the calculation accuracy is not enough for some complicated engineering sites. If the displacement of soil nailing wall can be used to evaluate its stability, in other words, the relation between d&s can be ascertained, it will undoubtedly promote the use of the soil nailing and be helpful for the revision and



improvement of the codes. As we know, limit equilibrium method needs to assume the sliding surface. The traditional SR method can not only overcome this defect, but also be able to calculate the stability factor and displacement. But it's only able to reduce the geotechnical strength parameters, not able to adjust the displacement parameters (such as elastic modulus) according to the stress level of the soil.

So the pit's displacement is underestimated if using the ideal elastoplastic model of SR method. This is also one reason that the measured displacement of soil nailing structure is greater than calculated.

2. Problems existing in deformation and stability of foundation pit

The foundation pit's displacement-control standard in different regional foundation pit codes is showed in Table 1~4 from which we can find out: codes just provide allowed displacement values which doesn't relate to the characteristics of foundation pits, the type of supporting structures, surroundings and so on; Worse still, it doesn't connect the displacement and the stability of foundation pits to determine the early warning value of monitoring parameters; the ambiguous regulations of codes is difficult to reflect the characteristics of foundation pits, and not beneficial to the development of new technology. Under the precondition of the supporting structures' safety, for example, the surroundings of foundation pit is empty, no important underground pipeline goes through and municipal roads and buildings are out of the influence sphere, we can allow supporting structures to have larger displacement absolutely; but if there are some important buildings near the foundation pit and large displacement is not allowed, we can control its displacement through choosing the type of supporting structure. Therefore, controlling the displacement of foundation pit should combine the characteristics of foundation pits and their surroundings instead of making the displacement of supporting structures the smaller the better or regulating the allowed displacement simply. The standard to control displacement should include two parts, one is having no bad effect to surroundings, municipal roads and buildings, the other is having no influence to its normal use (GONG Xiao-nan. (1998)).

Table 1. Allowed horizontal displacement of supporting structure specified by Technical Code for Building Foundation Pit Supporting in Guangzhou Area

<i>safety level</i>	The maximum horizontal displacement of the top of the soil nailing wall
First level	30mm
Second level	60mm
Third level	150mm

Table 2. displacement monitoring standard of supporting structure of Shanghai Standard Code for Design of Excavation Engineering

<i>safety level</i>	displacement of the top of the wall(cm)	Maximum displacement of wall (cm)	Maximum settlement of ground (cm)	Maximum differential settlement
First level	3	6	3	6/1000
Second level	6	9	6	12/1000

Table 3. Allowable horizontal displacement of supporting structure specified by Technical Code for Retaining and Protection of Deep Building Foundation Excavations in Shenzhen Area

<i>safety level</i>	Maximum allowed horizontal displacement(mm)	
	Pile, underground diaphragm, soil nailing wall	steel sheet piles、deep mixing cement piles
First level	0.0025H	/
Second level	0.005H	0.01H
Third level	0.01H	0.02H

Note: H represents the excavation depth (mm)

Table 4. The displacement control standard in foundation specification of Guangdong Province

<i>safety level</i>	horizontal displacement of supporting structure	settlement of the ground
First level	0.002Hand no more than 30mm	0.0015Hand no more than 20mm
Second level	0.004Hand no more than 50mm	0.003Hand no more than 40mm
Third level	0.025Hand no more than 150mm	0.020Hand no more than 120mm

Because the displacement of soil nailing is usually up to a few centimeters to tens of centimeters, general finite element methods are difficult to calculate these large displacement problems. As the Flac software uses Lagrangian grid, which is suitable to analyzing geo materials, it's selected for calculation analysis in this paper.

3. Analysis method - variable modulus strength reduction method

A prominent feature of the soil displacement is that the displacement modulus is related to stress level. The traditional SR method usually only reduces the strength parameters (c, ϕ), not reduce the displacement parameters (E, μ) the ideal elastoplastic model is used in this method. The stability factor calculated by this method is agreed with the one calculated by the traditional limit equilibrium method (ZHANG Yu-cheng. (2007)), but before the structure fails the displacement obtained by traditional SR method is smaller than that by traditional limit equilibrium method. But the traditional SR method can't take the true non-linearity of the soil into consideration. In order to obtain the displacement field which is closer to the truth, the variable modulus SR method is used for analyzing. Based on the SR method, the variable modulus SR method adjusts the elastic modulus parameters according to the stress level, as the Duncan-Chang model does. And a practical constitutive model is established (YANG Guang-hua, ZHANG Yu-cheng and ZHANG You-xiang. (2009)).

The traditional SR method divides the cohesion, c , and angle of internal friction, ϕ by a reduction factor F to get a new set of c, ϕ , and then the new set of material parameters are used to recalculate. Repeat this till the calculated slope reaches a critical state. The final reduction factor F is called the minimum stability factor F_s of the slope. The formulas used above are as follows:

$$c' = c / F \quad (1) \quad \phi' = \arctan(\tan \phi / F) \quad (2)$$

It's unreasonable that the traditional method considers the soil stress to be linear elastic before it yields. In order to simulate the effect of reducing soil strength parameters on the soil displacement parameters better and no longer to presume the soil stress to be linear elastic before it yields, the Duncan-Chang model is taken as reference to adjust the soil displacement parameters with the change of strength parameters. The specific formulas are as follows:

$$E_t = [1 - R_f \frac{\sigma_1 - \sigma_3}{(\sigma_1 - \sigma_3)_f}]^2 E_i \quad (3) \quad E_i = k \left(\frac{\sigma_3}{Pa} \right)^n \quad (4)$$

$$(\sigma_1 - \sigma_3)_f = \frac{2c \cdot \cos \phi + 2\sigma_3 \cdot \sin \phi}{1 - \sin \phi} \quad (5)$$

Therefore, when the soil strength parameters c, ϕ are reduced, the tangent modulus E_t can be obtained by equation (3). That is, the Duncan-Chang model can be used to calculate the displacement parameters before the soil yields. This can reflect the influence of the strength parameters reduction better.

To accord with fact, the initial tangent modulus is suggested to get by in-situ load testing. The initial tangent modulus can be expressed as:

$$E_i = D(1 - \mu^2)w \cdot k_0 \quad (6)$$

Actually, the displacement modulus E_0 can be obtained both by in-situ load testing and the accumulated practice experience. The E_i can also be approximately expressed as:

$$E_i = D(1 - \mu^2)w \cdot k_0 \quad (7)$$

Poisson's ratio can be determined by equation (8):

$$\mu_t = \mu_i + (\mu_f - \mu_i) \cdot \frac{\sigma_1 - \sigma_3}{(\sigma_1 - \sigma_3)_f} \quad (8)$$

μ_i is the initial Poisson's ratio, and μ_f is the Poisson's ratio when the soil destroys. the μ_f can equal 0.49 in this paper, while μ_i should meet the following requirement: $\sin \phi \geq 1 - 2\mu_i$. so the E_t 、 μ_t is determined by Eq.(3),(6),(8) before the soil yields. after it yields, the plastic displacement can be calculated by elastoplastic model. this is the so called variable modulus SR method. Based on the built-in Fish design language in the Flac, Eq.(3),(6),(8) is tranfered to new fish function, which can reflect the change of displacement parameters with the reduction of c 、 ϕ .

4. Deformation and stability analysis of soil nailing support

First, the variable modulus SR method is used to reduce the soil strength parameters. then the Flac synchronizes with the adjusted displacement modulus which accords with the stress level. Therefore, the corresponding relation between horizontal displacement of the top of the soil nailing wall and stability factor is recorded till the wall destroys. by this, the critical failure displacement is determined.

As we can see from Figure 1, in the same soil and with the change of the excavation depth, the d-p curves have the similar sharp. In the case when the stability facto of the stability is the same, the deeper the wall excavated, the greater the horizontal displacement. Thus, the critical failure displacement changes with the variation of the excavation depth, which proves it's unreasonable to determine the control standard of the pit displacement just by the safety level of the pit.

Figures 2 shows the local d-p curves obtained in different soil with the same excavation depth. From these Figures we can see that the sharp of d-p curves are also basically similar to each other. With the same stability facto of the stability, the higher the soil parameters and the smaller the horizontal displacement. Therefore, the critical failure displacement varies with the soil strength.

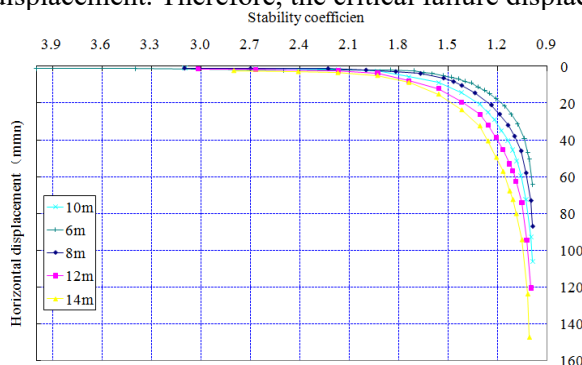


Fig.1 Curve comparison of d&s of soil nailing wall with different heights and the same soil parameters ($c=60\text{kPa}$)

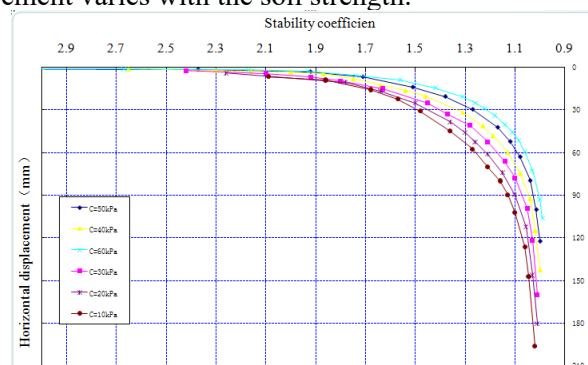


Fig.2 Curve comparison of d&s of soil nailing wall in 6m height of different soil parameters

Figure 3 shows several curves, of which the excavation depth are different. The curves are substantially coinciding. In this curve, there are only two variables, displacement height ratio and stability factor. This curve can dynamically show the displacement corresponding to different stability factor. The results establish the foundation for dynamic construction of soil nailing wall.

Eq. 9 shows the relation between displacement of the top of the wall and stability factor when $c = 60\text{kPa}$. when c equals to other values; the equations can be obtained similarly. By the same method, the displacement can be obtained by its stability factor when c varies from 50kPa to 10kPa . So the displacement and the average of displacement heigh ratio can be obtained. The Figure 10 is the relation curve of the data in Table 6.

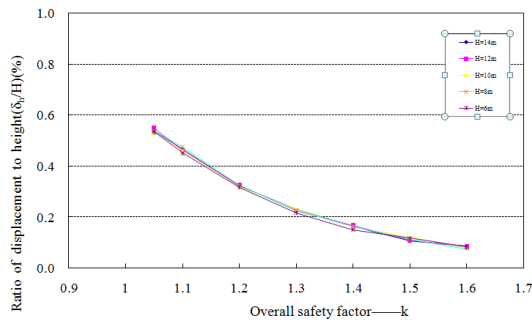
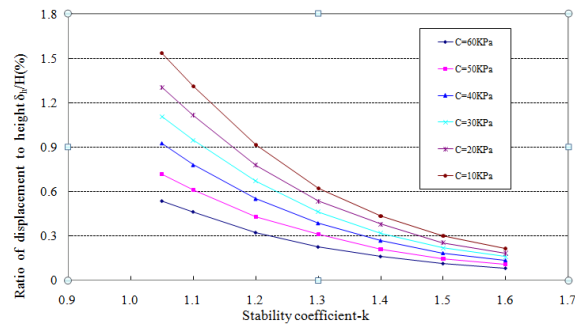


Fig.3 The relation curve of δ_h/H and

Fig.4 The relation curve of δ_h/H and in Eq.9 is obtained by fitting the data in Table 5.



stability factor k in different heights for soil 1
different soil parameters stability factors K

$$\delta_h / H = \left(\frac{1.3913}{k} - 0.5912 \right)^2 \quad (9)$$

Table 5. The average values of δ_h / H with different stability factors

Stability factor	1.05	1.1	1.2	1.3	1.4	1.5	1.6
δ_h / H (%)	0.54	0.46	0.32	0.23	0.16	0.11	0.08

By Eq. 9, if we know the stability factor of the soil nailing wall, the displacement of the top of the wall can be calculated or predicted. Or predict displacement by the known the stability factor. It's very convenient for practical projects application.

Table 6. The average values of δ_h / H with different stability factors and different soil parameters

Stability factor k	1.05	1.1	1.2	1.3	1.4	1.5	1.6
Soil c/ kPa							
50	0.72	0.62	0.43	0.31	0.21	0.14	0.11
40	0.93	0.78	0.55	0.39	0.27	0.18	0.14
30	1.11	0.95	0.67	0.46	0.32	0.22	0.16
20	1.30	1.12	0.78	0.53	0.38	0.25	0.18
10	1.54	1.31	0.91	0.62	0.43	0.30	0.21

As the Figure 4 shows, the relation curve between δ_h/H and stability factor k has a similar form in different soil. With the changes of soil parameters the relation curve changes more regularly. Due to the complex nature of the soil, the displacement analysis of soil nailing is the lack of effective theory. According to the statistical data of 15 practical soil nailing projects, the paper drafts a curve shown in Figure 11. From the comparison of Figure 10 and Figure 11, the relation curve between δ_h/H and stability factor k obtained by this paper's method is similar with that obtained by the engineering data.

Fitting the relation between δ_h/H and stability factor k to the data:

$$\text{Soil 2 } c=50\text{kPa} : \quad \delta_h / H = \left(\frac{1.6196}{k} - 0.6940 \right)^2 \quad (10)$$

$$\text{Soil 3 } c=40\text{kPa} : \quad \delta_h / H = \left(\frac{1.8507}{k} - 0.8004 \right)^2 \quad (11)$$

$$\text{Soil 4 } c=30\text{kPa} : \quad \delta_h / H = \left(\frac{2.0405}{k} - 0.8874 \right)^2 \quad (12)$$

$$\text{Soil 5 } c=20\text{kPa} : \quad \delta_h / H = \left(\frac{2.2311}{k} - 0.9789 \right)^2 \quad (13)$$

$$\text{Soil } c=10\text{kPa} : \quad \delta_h / H = \left(\frac{2.4346}{k} - 1.0754 \right)^2 \quad (14)$$

In practical projects, soil above the excavated surface can be equivalent to a homogeneous soil according to the layer thickness. And then according to the equivalent soil parameters, from $c=10\text{kPa}$ to $c=60\text{kPa}$ select the closest soil's formula, or by the interpolation method to get the corresponding displacement values. so we can predict the allowed maximum displacement value according to the stability factor. Similarly, we can also achieve the stability factor by the monitored horizontal displacement.

5 Conclusions

In order to perfect the soil nailing theory and extent its application, this paper uses the variable modulus SR method to research the relation between the d&s of the pit on basis of the problems existing between them. Except this, the paper proposes displacement height ratio as the unified decision index to determine the relation between d&s. The paper also gives a table which the engineers can check the warning values and the maximum allowed values of the pits displacement from. And the projects have already proved the rationality of the values. the paper offers a criterion for the warning values of the pits displacement.

References

- [1] China Academy of Building Research. (1999). Technical standard for foundation pit support works in construction engineering JGJ 120-99. Beijing: China Architecture and Building Press. (in Chinese)
- [2] China Association for Engineering Construction Standardization. (1997). Specification for soil nailing in foundation excavations CECS96:97. Beijing: China City Press. (in Chinese)
- [3] DUAN Qi-wei. (2007). "Situating monitor and numerical simulation of soil nailing support"(master's thesis). Beijing: Beijing Jiaotong University. (in Chinese)
- [4] Duncan J M, Chang C Y. (1970). "Nonlinear analysis of stress and strain in soils". Journal of the Soil Mechanics and Foundations Division, ASCE 1970; Vol. 96 (5): 1629-1653.
- [5] Ministry of Housing and Urban-Rural Development of People's Republic of China. (2012). Technical code for composite soil nailing wall retaining and protection of excavation GB50739-2011. Beijing: China Planning Press. (in Chinese)
- [6] GONG Xiao-nan. (1998). Handbook for design and construction of deep excavation pits. Beijing: China Architecture and Building Press. (in Chinese)
- [7] Guangdong Association for Engineering Construction Standardization. (1998). Specification for retaining and protection in building excavation engineering DBJ/T15-20-97. Guangzhou: Guangdong Provincial Construction Committee. (in Chinese)
- [8] Guangzhou Institute of Building Science. (1998). Technical regulation for foundation pit support works in construction engineering in Guangzhou GJB02-98. Guangzhou: Construction Commission of Guangzhou Municipality. (in Chinese)
- [9] Yang Guang-hua. (2001). "Hyperbola Model Method in Calculating the Non-linear Settlement of Foundation on Granite Residual Soil". Proceedings of the 7th National conf. on the Numerical Analysis and Analytical Method for Rock and Soil Mechanics. Press of Dalian University of Technology, Sep, 2001:168-171. (in Chinese)
- [10] YANG Gang-huang. (2004). The practical calculation method and appliance on the structure of retaining of building foundation excavation, Beijing, The Geological Publishing House. (in Chinese)
- [11] YANG Guang-hua, ZHANG Yu-cheng and ZHANG You-xiang. (2009). "Variable modulus elastoplastic SR method and its application to slope stability analysis". Chinese Journal of Rock Mechanics and Engineering, Vol. 28(7): 1506-1512. (in Chinese)
- [12] YANG Guang-hua, ZHONG Zhi-hui, ZHANG Yu-cheng, et al. (2010). "Slope stability analysis by local SR method". Chinese Journal of Geotechnical Engineering, Vol. 31(supp.2): 53-58. (in Chinese)

- [13] ZHANG Yu-cheng. (2007). "Stability research of soil slopes based on displacement field and Stress Field"(doctoral thesis). Wuhan: Wuhan University. (in Chinese)