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Study on constitutive model of excavating foundation pit soil

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ABSTRACT

The stress of the soil mainly for unloading instead of regular loading in the process of excavating foundation pits, but conventional loading test methods were taken to determine the soil parameters and applied to the numerical analysis and design calculation for a long time. The stress-strain curve of the soil masses is nonlinear, so there is a great difference between the loading modulus and the unloading modulus of the soil masses, which has great impact on the deformation of soil masses. During the pit excavation, the soil stress-strain relationship is also affected by the stress path. The paper deduced the expression of unloading modulus according to unloading stress-strain curve relationship expressed in form of the hyperbolic, and explored the relationship between the initial unloading modulus and initial deviation stress, then established a nonlinear geotechnical material constitutive model applies to underground excavation soil, comparing with traditional loading mechanical model Duncan-Chang. Numerical simulation showed that the model unloading were closer to the engineering practice than conventional algorithms.

KEYWORDS

Foundation pit excavation; Soft soil; Unloading tangent modulus; Stress-strain relationship; Constitutive model; Numerical simulation.

INTRODUCTION

Conventional loading test methods were taken to determine the soil parameters and applied to the numerical analysis and design calculation for the foundation pit engineering. In fact, the soil mass stress is mainly an unloading process and stress-strain relationship has its special rules in the process of foundation pit excavation,[1] many scholars have studied it in this respect. Lambe[2] proposed the method of stress path at the earliest; Zeng Guoxi et al[3] pointed out the stress-strain relationship of soft clay has not only the nonlinear characteristics, but also by the influence of stress path; Nagaraj T S and Sridharan A[4] developed automatic different stress paths test instrument, and experimental study on a relatively dense sand; Malanraki and Toll[5] made triaxial shear test on artificially structured clay under shear process constantly changing stress paths; Callisto and Rampello[6] made true triaxial test on the natural hard clay under different stress paths; Experimental study on sandy soil Lade and Duncan[7] showed that, the stress-strain curve is different because of the different stress paths, though the initial and final stress state is the same; According to the test Mei Guoxiong and Chen Hao[8] showed that the lateral unloading soil's stress-strain curve also presents hyperbolic relationship, and deduced lateral stress strain relationship model reflecting the pit side soil under the conditions the lateral unloading actual stress paths; Zhang Wenhui[9] found that the slope of the stress-strain curve is no longer a tangent modulus under the conditions the lateral unloading stress path drainage shear test and the slope of the stress-strain curve is still the tangent modulus under condition of the lateral unloading stress path in the consolidated undrained shear and the axial unloading stress path experimental condition. The research of MA Xiao-wen and AI Yingbo[10] advances in soil behaviors under excavation unloading, summarized the research findings from the conventional triaxial unloading tests, K_0 consolidated triaxial unloading tests and true triaxial tests, and put forward the existing problems and potential research topics in this field; Li Ping et al[11] used the layer-rise summation method, derived the simplified formula to apply the compression parameters to the calculation of the value of rebound deformation; The study of Liu Guoqing et al[12] shows that in Wuhan area the soft soil deformation characteristics under unloading condition are closely related to the unloading path and unloading ratio, the stress-strain shows a hyperbolic relationship with high nonlinearity and normalized characteristics.

Because most of the foundation pit excavation are drainage condition, according to the relationship between the stress and the strain of the hyperbolic hypothesis, this paper conducted divisional study on the unloading soil deformation modulus in the periphery and the bottom of foundation pit, and to establish constitutive relation, which be applied to the foundation pit engineering numerical calculation.

THE SOFT SOIL UNLOADING NONLINEAR CONSTITUTIVE MODEL

The tangent modulus under the conditions of unloading

For common long and narrow foundation pit, we generally discuss its stress and strain state according to plane strain problems. As shown in figure 1, the foundation pit passive area soil at the bottom and active area soil in surrounding, different points stress path is change in the process of foundation pit excavation, its main stress path have two types of[3] : in the active area, the stress state is vertically constant, levelly unloading; In passive area, the stress state of vertical unloading quantity is greater than level unloading quantity, whose representative stress path is vertical unloading and level to stay the same. As noted in Literature[9], under conditions of the lateral unloading stress path drainage shear test and the axial unloading stress path test,relationship between tangent modulus and the slope of stress strain curve respectively are: $E_t = 2E_u/(1+2\mu)$ and $E_t = E_u$. Where E_t is Unloading tangent modulus; E_u is $(\sigma_a\text{-}\sigma_r)\text{-}\varepsilon_a$ the slope of Curve; μ is tangent Poisson's ratio.

Figure 2 is the stress-strain curve of typical unloading test, if transform coordinate system from $q\sim\varepsilon_a$ to $q\text{-}q_c\sim\varepsilon_a$, the following form of hyperbolic relationship is applicable for any curve in the graph:

$$q - q_c = \frac{\varepsilon_a}{a + b\varepsilon_a} \quad (1)$$

Where $q=\sigma_a-\sigma_r$ is the deviation stress, σ_a is the axial pressure, σ_r is the radial stress; $q_c=\sigma_{ac}-\sigma_{rc}$ is the initial deviation stress, σ_{ac} is the initial axial pressure, σ_{rc} is the initial radial stress;ε_a is the axial strain;a is the reciprocal of the initial tangent modulus;b is the reciprocal of asymptotic line value of stress difference.

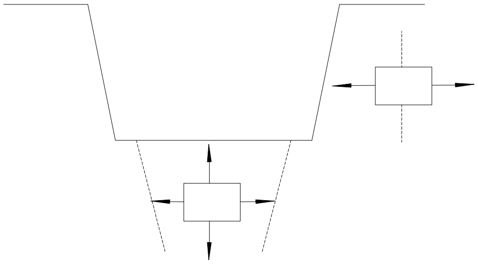


Figure 1 : Soil mass stress state map of foundation pit excavation

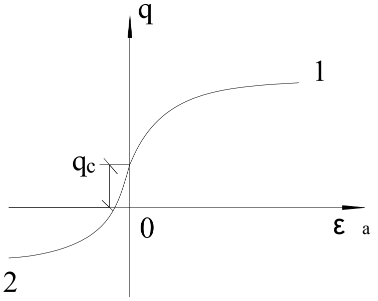


Figure 2 : The stress-strain curve of typical unloading test

By deducting, for compression soil sample:

$$E_u = \left[1 - \frac{(q-q_c)(1-\sin\varphi)}{2c\cos\varphi + 2\sigma_r\sin\varphi - q_c(1-\sin\varphi)} R_f\right]^2 E_{ui} \quad (2)$$

For tensile soil samples:

$$E_u = \left[1 + \frac{(q-q_c)(1+\sin\varphi)}{2c\cos\varphi + 2\sigma_r\sin\varphi + q_c(1+\sin\varphi)} R_f\right]^2 E_{ui} \quad (3)$$

So, under condition of unloading,the soil tangent modulus are as follows:
For the active area lateral unloading soil around foundation surrounding:

$$E_t = \frac{2}{1+2\mu}\left[1 - \frac{(q-q_c)(1-\sin\varphi)}{2c\cos\varphi + 2\sigma_r\sin\varphi - q_c(1-\sin\varphi)} R_f\right]^2 E_{ui} \quad (4)$$

For the passive area axial unloading soil in the bottom of foundation pit:

$$E_t = \left[1 + \frac{(q-q_c)(1+\sin\varphi)}{2c\cos\varphi + 2\sigma_r\sin\varphi + q_c(1+\sin\varphi)} R_f\right]^2 E_{ui} \quad (5)$$

The initial unloading modulus

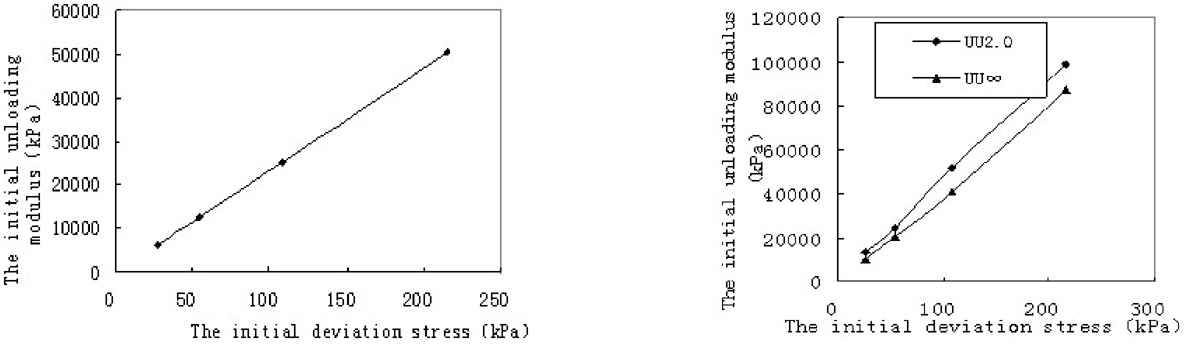
Literature[9] discusses the initial unloading modulus change rule under the condition of different stress path consolidation pressure, in order to make the initial modulus of unloading value can better used for numerical calculation, choosing the representative stress path UU0.0(the vertical load is unchanged only level unloading), UU2.0(the ratio of Vertical unloading and level unloading is 2), UU∞(only the vertical unloading the level loading is unchanged)unloading hyperbolic curve fitting, obtained the initial unloading modulus value under the condition of the different initial deviation stress, as is shown in TABLE 1.

TABLE 1 : The initial unloading modulus value

The initial unloading modulus (kPa)		Stress path		
		UU0.0	UU2.0	UU∞
The initial deviation stress (kPa)	27	6280	13250	10250
	54	12630	24500	20490
	108	25000	52130	40980
	215	50420	98600	86960

Compression damage specimens in active area

As shown in TABLE 1, along with the increase of the initial deviation stress in UU0.0 stress path, the initial unloading modulus linear increase, as shown in Figure 3(a) below.



(a) Compression specimen **(b) Tensile specimens**

Figure 3 : Relationship between initial unloading modulus value and initial deviation stress

The linear fitting, there is:

$$\boldsymbol{E_u=234.1q_c-47.4} \tag{6}$$

Passive area tensile damage specimens

As shown in TABLE 1, along with the increase of the initial deviation stress in UU2.0, UU∞ stress path, the initial unloading modulus also linear increase, as shown in Figure 3(b) above.
The linear fitting, there is:

$$\boldsymbol{E_{ui}= 431.9q_c-206.1} \tag{7}$$

q_c available in the calculation:

$$\boldsymbol{q_c=(1-K_0)\gamma h} \tag{8}$$

Where:K_0 can be attained through the K_0 meter test;γ is unit weight of soil,kN m^{-3};*h is* the soil depth,m.

Tangent poisson's ratio

Definition tangent Poisson's ratio as follows:

$$\mu_t=\left|\frac{\Delta\varepsilon_3}{\Delta\varepsilon_1}\right| \tag{9}$$

As in the lateral unloading stress path tests, the volume deformation test curve is relatively complex; it is difficult to derive from the tangent Poisson's ratio practical expression. Engineering application, we can refer to Daniel and Olson (1974) advice, assume that μ_t change as stress level S linear:

$$\mu_t=\mu_i+(\mu_f-\mu_i)S \tag{10}$$

Where, μ_i is initial Poisson's ratio,approximately calculated by $\mu_i=K_0/(1+K_0)$; μ_f is Poisson ratio when destroyed,because μ_t increases as stress level S increases, when S value is high, may work out $\mu_t > 0.5$, the test may also measure the $\mu_t > 0.5$; this is because it has the dilatancy. However, in finite element calculation, $\mu_t \geq 0.5$ will lead to the unreasonable result. Therefore, in the actual calculation, when $\mu_t > 0.49$, often artificially make $\mu_t = 0.49$.
By deducing, tangent Poisson's ratio expressions are as follows:
When the vertical principal stress is less than the level stress:

$$\mu_t=\mu_i+(\mu_f-\mu_i)\times\frac{\left[(\sigma_a-\sigma_r)-(\sigma_{ac}-\sigma_{rc})\right](1+\sin\varphi)}{-2c\cos\varphi-2\sigma_3\sin\varphi-(1+\sin\varphi)(\sigma_{ac}-\sigma_{rc})} \tag{11}$$

When the vertical principal stress is not less than the level stress:

$$\mu_t=\mu_i+(\mu_f-\mu_i)\times\frac{\left[(\sigma_a-\sigma_r)-(\sigma_{ac}-\sigma_{rc})\right](1-\sin\varphi)}{2c\cos\varphi+2\sigma_3\sin\varphi-(1-\sin\varphi)(\sigma_{ac}-\sigma_{rc})} \tag{12}$$

The soft soil nonlinear elastic unloading constitutive relationship

In hyperbolic model, the elastic constants exists as unloading tangent modulus and tangent Poisson's ratio, namely get soft soil nonlinear elastic constitutive relationship when considering unloading:

$$\{\sigma\}=[C]\{\varepsilon\} \tag{13}$$

Where, strain vector $\{\varepsilon\}=\{\varepsilon_x\ \varepsilon_y\ \varepsilon_z\ \gamma_{xy}\ \gamma_{yz}\ \gamma_{zx}\ \}^T$;stress vector $\{\sigma\}=\{\sigma_x\ \sigma_y\ \sigma_z\ \tau_{xy}\ \tau_{yz}\ \tau_{zx}\ \}^T$;elastic matrix $[C]$ as follow:

$$[C]=\frac{E_t(1-\mu_t)}{(1+\mu_t)(1-2\mu_t)}\left\{\begin{matrix} 1 & \frac{\mu_t}{1-\mu_t} & \frac{\mu_t}{1-\mu_t} & 0 & 0 & 0 \\ \frac{\mu_t}{1-\mu_t} & 1 & \frac{\mu_t}{1-\mu_t} & 0 & 0 & 0 \\ \frac{\mu_t}{1-\mu_t} & \frac{\mu_t}{1-\mu_t} & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1-2\mu_t}{2(1-\mu_t)} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1-2\mu_t}{2(1-\mu_t)} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1-2\mu_t}{2(1-\mu_t)} \end{matrix}\right\} \tag{14}$$

Where, E_t and μ_t were determined through type (4) or (5) and type (11) or (12) according to the relative size of vertical principal stress and the principal stress level, respectively.

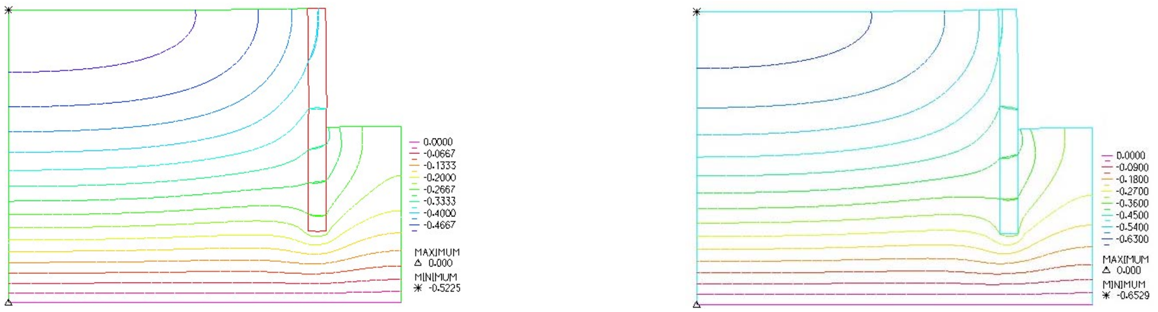
EXAMPLE ANALYSES

In order to use the existing finite element software nonlinear solving platform and large finite element software ADINA material depot development function, the unloading constitutive model established this paper was added into its material depot.

Calculation model and parameters

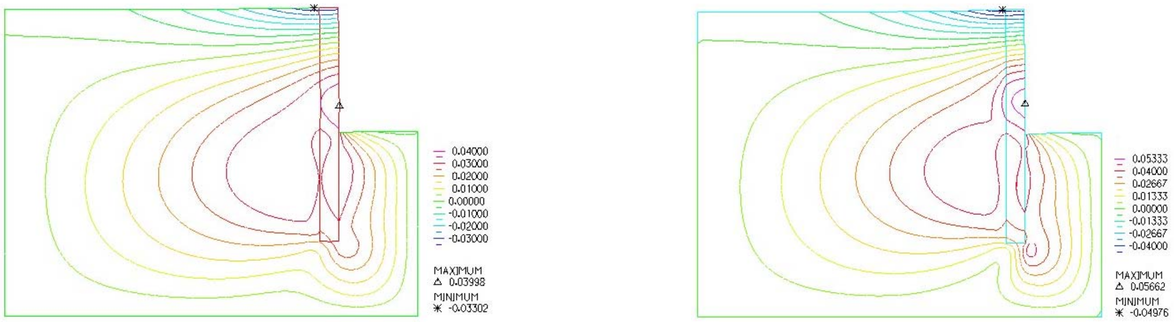
Assume that the size of the foundation pit length is 10 m, deep 8 m. The depth of the calculation model is 20 m, take half of foundation pit inside as the width of the calculation model, namely 5 m; after the lateral wall around the foundation pit take 20 m, underground continuous wall thickness of 1.2 m. Underground continuous wall using linear elastic material simulation: $E=2.6\times10^4$kN m^{-3},Poisson's ratio $\mu=0.3$, unit weight $\gamma=22.0$ kN m^{-3}, The soil parameters: $\gamma=19.0$ kN m^{-3},$c=24.6$kPa,$\varphi=27.4^{\circ}$,$R_f=0.90$.

Calculation result analysis



(a) Conventional results **(b) Unloading results**

Figure 4 : Vertical displacement equivalence value maps (unit:m)



(a) Conventional results **(b) Unloading results**

Figure 5 : Level displacement equivalence value maps (unit:m)

From the Figure 4 and Figure 5, the proposed model results significantly greater than conventional loading algorithm calculation results, it showed the shearing strength of soil is reduced and the ability to resist deformation reduced in the process of foundation pit excavation axial unloading. So, the calculation results of unloading model are closer to the engineering practice than the conventional results.

CONCLUSIONS

(1) Soil foundation pit excavation unloading stress-strain relationship has two types: compressed and elongation, which all can be approximately simulated with hyperbolic.
(2) The initial unloading modulus has a linear relationship with initial deviation stress.

(3) This attained modulus formula not only applied to general deformation calculation, but also applicable to the numerical analysis. Example calculation analysis in this paper showed that unloading model is closer to the engineering practice than the conventional results.
(4) In the practical engineering, it must be strictly distinguish between the loading and unloading to get a more accurate results by using the different material constitutive model and calculation method.
(5) It should be stressed that many aspects of this paper still deserves further investigation, such as the value size of initial unloading modulus. In lateral unloading stress path, the soils have the over-consolidated strength properties, strength parameter c, φ are different with general situation, how to more reasonably select of formula parameters is the important content in the further work.

REFERENCES

[1] V.Silvestri, R.Diab; Stress distributions and paths in clays during pressuremeter tests, Canadian Geotechnical Journal., **38**, 542-552 **(2001)**.

[2] T.W.Lambe; Stress path method, Journal of the soil Mechanics and Foundation Division ASCE., **93(SM6)**, 309-331 **(1967)**.

[3] Zeng Guoxi, Pan Qiuyuan, Hu Yifeng; The behavior of excavation in soft clay ground, Chinese Journal of Geotechnical Engineering, **3**, 13-22 **(1988)**.

[4] T.S.M.K.Nagaraj, A.Sridharan; Incremental Loading device for stress path and strength testing of soils, Geotechnical Testing Journal., **2**, 35-46 **(1981)**.

[5] V.Malanraki, D.G.Toll; Triaxial tests on weakly bonded soil with changes in stress path, Journal of Geotechnical and Geoenvironmental Engineering, **27**, 282-291 **(2001)**.

[6] L.Callisto, S.Rampello; Shear strength and small-strain stiffness of a natural clay under general stress conditions, Geotechnique, 52, 547-560 **(2002)**.

[7] P.V.Lade, J.M.Duncan; Stress-path dependent behavior of cohesion-less soil," Journal of Geotechnical Engineering ASCE., **102(GT1)**, 42-48 **(1976)**.

[8] Mei Guoxiong, Chen Hao, Lu Tinghao, Yin Zongze; Research on lateral stress-strain relation on side of foundation pit with lateral unloading, Chinese Journal of Rock Mechanics and Engineering., **29**, 3108-3112 **(2010)**.

[9] Zhang Wenhui; The research on the influence of the stress path to the lateral deformation and relationship between soil pressure and lateral displacement in foundation pit engineering, Dissertation of master degree, Hohai University, Nanjing, **(2003)**.

[10] Ma Xiaowen, Ai Yingbo; Review of soil behaviors under excavation unloading of foundation pits," Chinese Journal of Geotechnical Engineering, **33**, 182-186 **(2011)**.

[11] Li Ping, Chen Yumin, Shen Yang; Simplified analysis method of pit rebound deformation, Journal of PLA University of Science and Technology (Natural Science Edition), **13**, 88-91 **(2012)**.

[12] Liu Guoqing, Ning Guoli, Chen Houzhong, Zhang Xianyu; Study on stress-strain normalization of soft soil under excavation unloading in Wuhan area, Building Science, **28**, 46-49 **(2012)**.