

关于“横观各向同性砂土的强度准则”的讨论

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Discussion on “New strength criterion for sand with cross-anisotropy”

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《岩土工程学报》2016年第38卷11期刊出“横观各向同性砂土的强度准则”一文^[1](以下简称“原文”)。原文定义了一个新的无量纲各向异性参量 $\Lambda(\sigma, F)$, 用于度量应力张量与结构张量的相对方位, 利用该各向异性参量将SMP准则推广, 得到一个新的适用于横观各向同性砂土的强度准则。拜读原文后, 受益良多, 同时认为存在可以进一步完善之处, 在此指出, 以期探讨。

基于岩土材料各向异性的物理机理, 原文构造一个新的无量纲数 Λ 作为各向异性参量, 其表达式为(参见原文式(12))

$$\Lambda(\sigma, F) = \frac{\sigma_N - \sigma_{SMP}}{I_1} \quad (1)$$

原文指出, 由该各向异性参量所建立的各向异性本构模型的表达式是显式的, 但 Λ_{T0} 与 Λ_{T90} 的求解方式原文并未给出; 由于缺乏 Λ 、 Λ^2 与 δ 之间函数关系的解析式, 原文中图5与图6的绘制思路并不明确; 假设 $\tan \Phi'$ 与 Λ^2 具有线性关系的依据并不充分。

鉴于 σ_N (沉积面上正应力大小)、 σ_{SMP} (SMP上正应力大小)以及 I_1 (应力张量的第一不变量)所描述的是同一应力状态, 三者之间必然存在一定的联系。

以二维情况为例, 如图1所示, 大主应力方向角 δ 反映了沉积面与大主应力之间的位置关系; 卓越剪切方向是剪切带的生成方向, 具有唯一性, 在二维情况下与SMP重合, 与大主应力方向之间的夹角为 $\zeta = 45^\circ + \varphi_{cr}/2$; 卓越剪切方向与沉积面之间的夹角为 θ , 满足 $\theta = |\zeta - \delta|$ 。

因此, 沉积面上应力 σ_N 与SMP上 σ_{SMP} 均可由主应力张量 σ 通过坐标变换得到

$$\sigma_N = M_N \sigma M_N^T \quad (2)$$

$$\sigma_{SMP} = M_{SMP} \sigma M_{SMP}^T \quad (3)$$

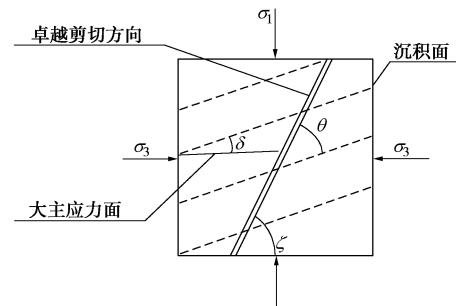


图1 大主应力方向与卓越剪切方向示意图

Fig. 1 Angle of major principal stress and dominant shear direction
式中, M_N , M_{SMP} 为转换矩阵, 满足

$$M_N = \begin{bmatrix} \cos \delta & -\sin \delta \\ \sin \delta & \cos \delta \end{bmatrix}; \quad M_{SMP} = \begin{bmatrix} \cos \zeta & -\sin \zeta \\ \sin \zeta & \cos \zeta \end{bmatrix} \quad (4)$$

将式(4)展开可得

$$\begin{cases} \sigma_N = \sigma_1 \cos^2 \delta + \sigma_3 \sin^2 \delta, \\ \tau_N = \sigma_1 \sin \delta \cos \delta - \sigma_3 \sin \delta \cos \delta, \end{cases} \quad (5)$$

$$\begin{cases} \sigma_{SMP} = \sigma_1 \cos^2 \zeta + \sigma_3 \sin^2 \zeta, \\ \tau_{SMP} = \sigma_1 \sin \zeta \cos \zeta - \sigma_3 \sin \zeta \cos \zeta. \end{cases} \quad (6)$$

$$\begin{cases} \sigma_{SMP} = \sigma_1 \cos^2 \zeta + \sigma_3 \sin^2 \zeta, \\ \tau_{SMP} = \sigma_1 \sin \zeta \cos \zeta - \sigma_3 \sin \zeta \cos \zeta. \end{cases} \quad (7)$$

$$\begin{cases} \sigma_{SMP} = \sigma_1 \cos^2 \zeta + \sigma_3 \sin^2 \zeta, \\ \tau_{SMP} = \sigma_1 \sin \zeta \cos \zeta - \sigma_3 \sin \zeta \cos \zeta. \end{cases} \quad (8)$$

二维情况下, 应力不变量可以写作:

$$I_1 = (\sigma_1 + \sigma_3)/2, \quad \sqrt{3J_2} = \sigma_1 - \sigma_3 \quad (9)$$

相应地, 主应力可以表示为

$$\sigma_1 = (2I_1 + \sqrt{3J_2})/2, \quad \sigma_3 = (2I_1 - \sqrt{3J_2})/2 \quad (10)$$

因此, 式(1)的解析形式为

$$\frac{\sigma_N - \sigma_{SMP}}{I_1} = \frac{\sqrt{3J_2}}{2I_1} (\cos 2\delta - \cos 2\zeta) \quad (11)$$

将 $\zeta = 45^\circ + \varphi_{cr}/2$ 代入式(11), 得

$$\Lambda(\sigma, F) = \frac{\sqrt{3J_2}}{2I_1} (\cos 2\delta + \sin \varphi_{cr}) \quad (12)$$

如原文图5所示, λ 与 δ 之间满足严格的三剪函数关系, 当 $\lambda=0$ 时, $\delta=45^\circ+\varphi_{cr}/2$, 即沉积面与 SMP 重合。与 Pietruszczak 等^[2]、Kong 等^[3]以及 Gao 等^[4]相似, 本文所定义的各向异性参数也是为了描述大主应力方向与沉积面之间的位置关系, 或主应力张量基矢与主组构张量基矢的位置关系。原文假设 $\tan\Phi'$ 与 λ^2 有单调关系, 并进一步假设 $\tan\Phi'$ 与 λ^2 具有线性关系:

$$\tan^2\Phi'(\lambda)=\alpha+\beta\lambda^2, \quad (13)$$

相当于假设强度参数与大主应力方向角之间满足特定的三角函数关系, 根据已有试验规律该假设是合理的^[1-4]。

总之, 式(1)所定义的各向异性参量实为一个主应力方向角的三角函数, 原文未将该解析式给出, 望加以补充完善。

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第四届GeoShanghai国际会议通知

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Important Dates: Abstract due: April 30, 2017; Acceptance of abstract: May 31, 2017; Full paper due: August 31, 2017; Acceptance of full paper: November 30, 2017; Final full paper due: January 31, 2018.

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