NTUA-SAND MODEL

Description

The NTUA-SAND Model (Andrianopoulos et al 2010a, b, 2011) is a bounding surface plasticity model with a vanished elastic region, developed to accurately simulate the rate-independent dynamic response of non-cohesive soils under small, medium and large cyclic strain amplitudes. This is achieved using a single set of values for the model constants, irrespective of initial stress and density conditions, as well as loading direction. The model is equally efficient in simulating the monotonic response.

The model builds on the constitutive efforts of Manzari & Dafalias (1997) and Papadimitriou & Bouckovalas (2002) and adopts three open cone-type non-circular surfaces, with their apex at the origin of stress space. These surfaces, named critical state surface, bounding surface and dilatancy surface, correspond to the deviatoric stress ratios at critical state, peak strength and phase transformation, respectively. The aperture of these surfaces is explicitly related to the state parameter ψ (Been and Jefferies, 1985), thus allowing the incorporation of the Critical State Theory of Soil Mechanics. The non-linear soil response under small to medium cyclic strain amplitudes is governed by a Ramberg-Osgood type hysteretic formulation, aiming at accurately simulating the shear modulus degradation and the hysteretic damping increase with cyclic shear strain. Furthermore, an empirical index of the directional effect of fabric evolution scales the plastic modulus, aiming at accurately simulating the rates of excess pore pressure build-up and permanent strain accumulation leading to liquefaction or cyclic mobility. To ensure numerical stability, the UDM employs the modified-Euler integration scheme with automatic error control and substepping (Sloan et al. 2001).

A detailed *description* of the constitutive model, its calibration process and its simulative potential are given in the following publications:

Andrianopoulos K. I., Papadimitriou A. G., Bouckovalas G. D. (2010), "*Explicit integration of bounding surface model for the analysis of earthquake soil liquefaction*", International Journal for Numerical and Analytical Methods in Geomechanics, 34 (15): 1586-1614

Andrianopoulos K. I., Papadimitriou A. G., Bouckovalas G. D. (2010), *"Bounding surface plasticity model for the seismic liquefaction analysis of geostructures*", Soil Dynamics and Earthquake Engineering, 30(10): 895-911

Andrianopoulos K. I., Papadimitriou A. G., Bouckovalas G. D. (2011), *"Applications of the NTUA-SAND model for the seismic liquefaction analysis of geostructures*", Proceedings of the 2nd International *FLAC/DEM* Symposium, paper no. 77.

Extra References

Been K., Jefferies M. G. (1985), "*A state parameter for sands*", Geotechnique, 35 (2): 99-112

Papadimitriou A. G., Bouckovalas G. D., Dafalias Y. F. (2001), *"Plasticity model for sand under small and large cyclic strains",* Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 127(11): 973-983

Papadimitriou A. G., Bouckovalas G. D. (2002), "*Plasticity model for sand under small and large cyclic strains: a multiaxial formulation*", Soil Dynamics and Earthquake Engineering, 22:191-204

Manzari M. T., Dafalias Y. F. (1997), "*A critical state two-surface plasticity model for sands*", Geotechnique, 47(2): 255-272

Sloan S. W., Abbo A. J., Sheng D. (2001), "*Refined explicit integration of elastoplastic models with automatic error control*", Engineering Computations, 18(1/2): 121-154

Application of the model on various geotechnical problems can be found in:

Bouckovalas G., Tsiapas Y, Theocharis A., Chaloulos Y. (2017), *"Ground response at liquefied sites: seismic isolation or amplification?"*, Soil Dynamics and Earthquake Engineering (in press)

Andrianopoulos K., Agapoulaki G., Papadimitriou A. (2016), *"Simulation of seismic response of passively stabilised sand"*, Geotechnical Research 3 (2), 40-53

Chaloulos Y., Bouckovalas G., Karamitros D. (2013), *"Pile response in submerged lateral spreads: common pitfalls of numerical and physical modeling techniques"*, Soil Dynamics and Earthquake Engineering 55, 275-287

Karamitros D., Bouckovalas G., Chaloulos Y. (2013), *"Insight into the seismic liquefaction performance of shallow foundations"*, Journal of Geotechnical and Geoenvironmental Engineering 139 (4), 599-607

Bouckovalas G., Papadimitriou A., Niarchos D., Tsiapas Y. (2011), *"Sand fabric evolution effects on drain design for liquefaction mitigation"*, Soil Dynamics and Earthquake Engineering, 31(10): 1426-1439

Valsamis A., Bouckovalas G., Papadimitriou A. (2010), *"Parametric investigation of lateral spreading of gently sloping ground"*, Soil Dynamics and Earthquake Engineering, 30: 490-508

Model input parameters

Model Parameters		
Name	**Description**	**Value for Nevada sand** (Andrianopoulos et al. 2010b)
void_cr	Model parameter $(e_{cs})_a$ – *Critical state line location at p´=98.1kPa (=Γ_{cs} – λln98.1)*	0.809
lamda	Model parameter λ – *Slope of Critical state line*	0.022
mc_comp	Model parameter $M_{c\,c}$ – *Critical state strength in triaxial compression*	1.25
kb_comp	Model parameter $k_{c\,b}$ – *Effect of ψ on peak deviatoric stress in triaxial compression*	1.45
kd_comp	*Effect of ψ on dilatancy deviatoric stress in triaxial compression*	0.3
m_c	Model parameter c – *Ratio of deviatoric stress ratios at critical state in triaxial extension (TE) over triaxial compression (TC)*	0.72
m_b	Model parameter B – *Elastic shear modulus constant*	600
m_a1	Model parameter α_1 – *Non-linearity of 'elastic' shear modulus*	0.6
m_g1	Model parameter γ_1 – *Reference cyclic shear strain for non-linearity of 'elastic' shear modulus*	0.00025
m_poiss	Model parameter v – *Elastic Poisson's rario*	0.33
ao	Model parameter A_o – *Dilatancy constant*	0.8
ho	Model parameter h_o – *Plastic modulus constant*	15000
no	Model parameter N_o – *Fabric evolution constant*	40000
m_void	Void ratio	0.65-0.75
stol	Substepping parameter STOL – *Tolerance value*	0.001
dt_min	Substepping parameter ΔT_{min} – *Minimum step size*	0.001

Extra UDM parameters

Property Name	Description
set_po	When set to 0, the initial stress-state variables r_{ij}^{LR} (shear stress ratio tensor at last load eversal), η_1 (variable used in the calculation of the elastic shear modulus) and N (variable used in the calculation of the plastic modulus coefficient, accounting for fabric evolution) are re-initialized. The default value is 0, so that the UDM initializes at first execution.
fabric	When set to 0, all variables related to fabric evolution (f_{ij} f_p and F_m) are set to 0.
ivar_*name*	Internal variables used for saving and restoring the current model's state. These appear as model properties but they should not be modified by the user.

Included documents / files

modelntuasand003.dll	Dynamic Link Library (DLL) file of the NTUA_SAND model, compiled using Microsoft Visual Studio 2005 and Itasca Constitutive Model libraries v.003. (**compatible with FLAC Version 7.0**)
modelntuasand002.dll modelntuasand002_64.dll	Dynamic Link Library (DLL) file of the NTUA_SAND model, compiled using Microsoft Visual Studio 2005 and Itasca Constitutive Model libraries v.002. (**compatible with FLAC3D Version 4.0 - 32 & 64 bit**)
modelntuasand005.dll modelntuasand005_64.dll	Dynamic Link Library (DLL) file of the NTUA_SAND model, compiled using Microsoft Visual Studio 2005 and Itasca Constitutive Model libraries v.005. (**compatible with FLAC3D Version 5.0 - 32 & 64 bit**)
dss2d_v7.dat dss3d_v4.dat dss3d_v5.dat	example input file for undrained cyclic shear strain test (FLAC v7.0) example input file for undrained cyclic shear strain test (FLAC3D v4.0) example input file for undrained cyclic shear strain test (FLAC3D v5.0)

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