

PLAXIS implementation of HYPOPLASTICITY

including standalone ABAQUS *umat* subroutines

David Mašín

September 12, 2017

Chapter 1

INTRODUCTION

This page is a part of a research project www.soilmodels.info. The aim of this page is to provide user defined subroutine *umat* for the hypoplastic constitutive models, together with an interface for PLAXIS user defined subroutine *UsrMod*.

This site is part of the [soilmodels.info](http://www.soilmodels.info) project. **When using implementations from [soilmodels.info](http://www.soilmodels.info) in your research, please cite it as:** *G. Gudehus, A. Amorosi, A. Gens, I. Herle, D. Kolymbas, D. Mašín, D. Muir Wood, R. Nova, A. Niemunis, M. Pastor, C. Tamagnini, and G. Viggiani. The soilmodels.info project. International Journal for Numerical and Analytical Methods in Geomechanics, 32(12):1571-1572, 2008.* [Letter PDF]

Chapter 2

IMPLEMENTED MODELS - LITERATURE SOURCES

For details of material models available at this web site in the form of finite element implementation, the interested readers are referred to the journal publications. The following literature sources are relevant:

1. Sand hypoplasticity model:

Model formulation is described in von Wolffersdorff (1996) [9]. For details of model calibration procedure, see Herle and Gudehus (1999) [2]. Small strain stiffness formulation (so-called intergranular strain concept) is described in Niemunis and Herle (1997) [8].

2. Clay hypoplasticity model:

The implemented model has been published by Mašín (2013) [6]. This model is an anisotropic version of the general clay hypoplasticity model described thoroughly in Mašín [5]. Structure of the anisotropic stiffness matrix described in Mašín and Rott [7]. Structured-soil specific model features are described in Mašín (2007) [4]. The model can be used with the intergranular strain concept, its original formulation is in Niemunis and Herle (1997) [8], enhanced formulation implemented is in Mašín (2013) [6]. Most of the cited journal papers available here for free download in the form of PDF preprints.

Further details on calibration of material parameters of hypoplastic models can be found here.

Chapter 3

TIME INTEGRATION

Constitutive models are integrated using explicit adaptive integration scheme with local substepping. The constitutive model forms an ordinary differential equation of the form

$$\frac{dy}{dt} = f(t, y)$$

The equation is for finite time step size Δt solved using the Runge-Kutta method. Solutions that correspond to the second- and third- order accuracy of Taylor series expansion are given by

$$y_{(t+\Delta t)}^{(2)} = y(t) + k_2$$
$$y_{(t+\Delta t)}^{(3)} = y(t) + \frac{1}{6}(k_1 + 4k_2 + k_3)$$

where

$$k_1 = \Delta t f(t, y(t))$$
$$k_2 = \Delta t f\left(t + \frac{\Delta t}{2}, y(t) + \frac{k_1}{2}\right)$$
$$k_3 = \Delta t f(t + \Delta t, y(t) - k_1 + 2k_2)$$

The accuracy of the solution is estimated following Fehlberg as the difference between the second- and third- order solutions. The time step size Δt is accepted, if

$$err = \left\| y_{(t+\Delta t)}^{(3)} - y_{(t+\Delta t)}^{(2)} \right\| < TOL$$

where TOL is a prescribed error tolerance. If the step-size Δt is accepted, $y_{(t+\Delta t)}^{(3)}$ is considered as a solution for the given time step and the new time step size Δt^n is

estimated according to Hull

$$\Delta t^n = \min \left[4\Delta t, 0.9\Delta t \left(\frac{TOL}{err} \right)^{1/3} \right]$$

If the step-size Δt is not accepted, the step is re-computed with new time step size

$$\Delta t^n = \max \left[\frac{\Delta t}{4}, 0.9\Delta t \left(\frac{TOL}{err} \right)^{1/3} \right]$$

In the case the prescribed minimum time step size or the prescribed maximum number of time substeps is reached, the finite element program is asked to reject the current step and to decrease the size of the global time step.

Chapter 4

INPUT OF PARAMETERS AND STATE VARIABLES IN PLAXIS

4.1 Hypoplastic model for granular materials

Parameters are specified in the PLAXIS input in the following order:

- Parameter 1 – critical state friction angle φ_c
- Parameter 2 – p_t – shift of the mean stress due to cohesion. The effective stress $\boldsymbol{\sigma}$ used in the model formulation is replaced by $\boldsymbol{\sigma} - \mathbf{1}p_t$. Non-zero value of p_t is needed to overcome problems with stress-free state. If $p_t = 0$, it will be replaced by a default value of 1 kPa. Any other value can be input by user (for basic hypoplasticity, set p_t to very low number, e.g. $p_t = 1.e - 5$).
- Parameters 3-9 – parameters of the basic hypoplastic model for granular materials $h_s, n, e_{d0}, e_{c0}, e_{i0}, \alpha, \beta$.
- Parameters 10-14 – the intergranular strain concept parameters ($m_R, m_T, R, \beta_r, \chi$). If $m_R = 0$ the intergranular strain concept is switched off and the problem is simulated using the basic hypoplastic model.
- Parameter 15 – not used.
- Parameter 16 – initial void ratio corresponding to the zero mean stress e_0 or initial void ratio e . If $Par(16) < 10$, then e is calculated from the mean stress p and from $e_0 = Par(16)$ using Bauer [1] formula. If $Par(16) > 10$, then $e = Par(16) - 10$.

- Parameters 17-22 – initial values of the intergranular strain tensor δ in Voigt notation (δ_{11} , δ_{22} , δ_{33} , $2\delta_{12}$, $2\delta_{13}$, $2\delta_{23}$).

State variables:

The routine uses 14 state variables:

- State v. 1-6 – intergranular strain tensor δ in Voigt notation (δ_{11} , δ_{22} , δ_{33} , $2\delta_{12}$, $2\delta_{13}$, $2\delta_{23}$).
- State v. 7 – void ratio e .
- State v. 8 – not used.
- State v. 9 – Effective mean stress.
- State v. 10 – Number of evaluation of the constitutive model in one global time step (for postprocessing only).
- State v. 11 – Mobilised friction angle φ_{mob} in degrees (for postprocessing only).
- State v. 12 – Normalised length ρ of the intergranular strain tensor δ (for postprocessing only).
- State v. 13 – Suggested size of the first time substep (for calculation controll).
- State v. 14 – free.

The hypoplastic model for granular materials is implemented via user defined subroutine `usermod`. To use the model in PLAXIS, copy the files `UDSM_HPS.dll` and `UDSM_HPS64.dll` into the PLAXIS installation directory. Then, select "user-defined model" from the Material model combo box in the General tab sheet (Fig. 4.1). (Fig. 4.1). After selecting the user-defined model, correct user-defined dynamic library (typically `UDSM_HPS.dll`) needs to be selected in the "Available DLL's" combo box under "Parameters" tab sheet. In the "Models in DLL" combo box, model with ID 1 (Hypoplas. - sand) must be selected. The parameters can then be input into the parameter table (Fig. 4.2).

Parameters of the sand hypoplastic model for different soils have been evaluated by Herle and Gudehus [2]. They are given in Table 4.1. Parameters of the intergranular strain concept for granular materials are in Tab. 4.2.

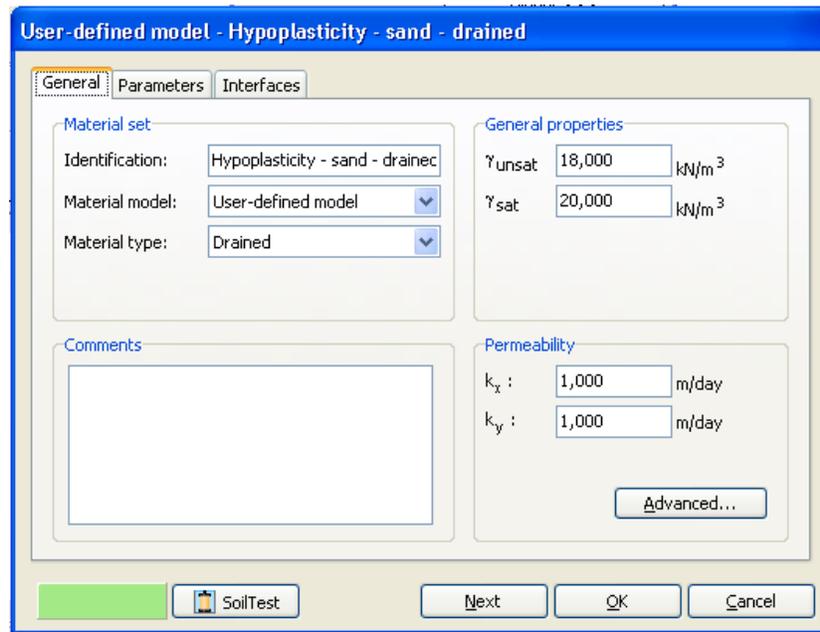


Figure 4.1: Selecting user defined model in the Material model combo box.

4.2 Hypoplastic model for clays

Parameters are specified in the PLAXIS input in the following order:

Parameters:

- Parameter 1 – critical state friction angle φ_c
- Parameter 2 – p_t – shift of the mean stress due to cohesion. The effective stress σ used in the model formulation is replaced by $\sigma - \mathbf{1}p_t$. Non-zero value of p_t is needed to overcome problems with stress-free state. If $p_t = 0$, it will be replaced by a default value of 1 kPa. Any other value can be input by user (for basic hypoplasticity, set p_t to very low number, e.g. $p_t = 1.e - 5$).
- Parameters 3-5 – parameters of the basic hypoplastic model for clays λ^* , κ^* , N .
- Parameters 6 – Parameters of the basic hypoplastic model for clays ν_{pp} (in place of the parameter r of the Mašín (2005) [3] model, calibrated using the same procedure).

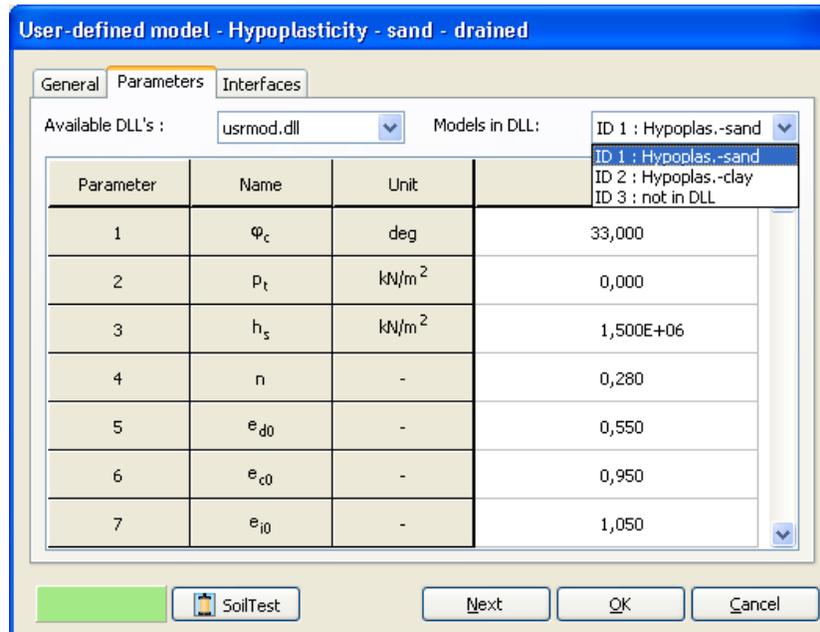


Figure 4.2: Selecting sand hypoelasticity model in the "Parameters" tab sheet.

- Parameters 7 – α_G , ratio of horizontal and vertical shear moduli.
- Parameters 8-10 – parameters of the model for clays with meta-stable structure (k , A and s_f).
- Parameters 11-13 – Intergranular strain concept parameters R , β_r , χ .
- Parameters 14-15 – Very small strain shear stiffness parameters A_g and n_g . If $A_g = 0$ the intergranular strain concept is switched off and the problem is simulated using the basic hypoelastic model.
- Parameters 16 – Intergranular strain concept parameter m_{rat} .
- Parameter 17 – bulk modulus of water K_w for undrained analysis using the penalty approach with user-defined value of K_w . In drained analysis, consolidation analysis, and undrained analysis using PLAXIS option *undrained* K_w should be set to 0.
- Parameter 18 – Specifies vertical direction (set to 2 in PLAXIS2D, 3 in PLAXIS3D, 2 in SoilTest independently whether run from PX2D or PX3D).

	φ_c	h_s	n	e_{d0}	e_{c0}	e_{i0}	α	β
Hochstetten gravel	36°	32×10^6 kPa	0.18	0.26	0.45	0.5	0.1	1.9
Hochstetten sand	33°	1.5×10^6 kPa	0.28	0.55	0.95	1.05	0.25	1.5
Hostun sand	31°	1.0×10^6 kPa	0.29	0.61	0.96	1.09	0.13	2
Karlsruhe sand	30°	5.8×10^6 kPa	0.28	0.53	0.84	1	0.13	1
Lausitz sand	33°	1.6×10^6 kPa	0.19	0.44	0.85	1	0.25	1
Toyoura sand	30°	2.6×10^6 kPa	0.27	0.61	0.98	1.1	0.18	1.1

Table 4.1: Typical parameters of the hypoplastic model for granular materials (Herle and Gudehus [2])

	R	m_R	m_T	β_r	χ
Hochstetten sand	1.e-4	5.0	2.0	0.5	6

Table 4.2: Parameters of the intergranular strain concept for sandy soils (Niemunis and Herle [8])

- Parameter 19 – Parameter α_E (ratio of horizontal and vertical Young moduli). If set to zero, than calculated automatically from empirical formulation $\alpha_E = \alpha_G^{(1/0.8)}$.
- Parameter 20 – Parameter α_ν (ratio of horizontal and vertical Poisson ratios). If set to zero, than calculated automatically from empirical formulation $\alpha_\nu = \alpha_G$.
- Parameter 21 – Parameter α_f . Additional control of non-linearity inside state boundary surface. If set to zero, default value calculated from model parameters is used.
- Parameter 22 – initial void ratio e or overconsolidation ratio OCR . If $Par(19) < 10$, then $e = Par(19)$. If $Par(19) > 10$, then $OCR = Par(19) - 10$.
- Parameters 23-28 – initial values of the intergranular strain tensor δ in Voigt notation ($\delta_{11}, \delta_{22}, \delta_{33}, 2\delta_{12}, 2\delta_{13}, 2\delta_{23}$).
- Parameter 29 – initial value of sensitivity (model for clays with meta-stable structure). If $s = 0$, the basic model is used.

State variables:

The routine uses 16 state variables:

- State v. 1-6 – intergranular strain tensor δ in Voigt notation (δ_{11} , δ_{22} , δ_{33} , $2\delta_{12}$, $2\delta_{13}$, $2\delta_{23}$).
- State v. 7 – void ratio e .
- State v. 8 – Excess pore pressure u for undrained analysis using user-defined value of K_w . In undrained analysis using PLAXIS option *undrained* this variable is equal to 0 and excess pore pressure may be found in standard PLAXIS menu.
- State v. 9 – Effective mean stress.
- State v. 10 – Number of evaluation of the constitutive model in one global time step (for postprocessing only).
- State v. 11 – Mobilised friction angle φ_{mob} in degrees (for postprocessing only).
- State v. 12 – Normalised length ρ of the intergranular strain tensor δ (for postprocessing only).
- State v. 13 – Suggested size of the first time substep (for calculation control).
- State v. 14 – sensitivity s (for model with meta-stable structure).
- State v. 15 – overconsolidation ratio, defined as $OCR = p_e/p$.
- State v. 16 – 0 means model iteration goes without problem. 1 means state boundary surface cut-off has been activated.

The hypoplastic model for granular materials is implemented via user defined subroutine *usermod*. To use the model in PLAXIS, copy the files *UDSM_HPS.dll* and *UDSM_HPS64.dll* into the PLAXIS installation directory. Then, select "user-defined model" from the Material model combo box in the General tab sheet (Fig. 4.1). After selecting the user-defined model, correct user-defined dynamic library (typically *UDSM_HPS.dll*) needs to be selected in the "Available DLL's" combo box under "Parameters" tab sheet. In the "Models in DLL" combo box, model with ID 2 (Hypoplas. - clay) must be selected. The parameters can then be input into the parameter table (Fig. 4.3).

Parameters of the clay hypoplastic model for different soils have been evaluated by Mašín and co-workers. They are given in Table 4.3. Parameters of the model for clays with meta-stable structure are in Tab. 4.4 and typical parameters of the intergranular strain concept for fine-grained soils are in Tab. 4.5.

	φ_c	λ^*	κ^*	N	ν_{pp}	α_G
Brno clay	22°	0.128	0.015	1.51	0.33	1.35
London clay	21.9°	0.095	0.015	1.19	0.1	2
Kaolin	27.5°	0.065	0.01	0.918	0.35	-
Dortmund clay	27.9°	0.057	0.008	0.749	0.38	-
Weald clay	24°	0.059	0.018	0.8	0.3	-
Koper silt	33°	0.103	0.015	1.31	0.28	-
Fujinomori clay	34°	0.045	0.011	0.887	0.36	-
Pisa clay	21.9°	0.14	0.01	1.56	0.31	-
Beaucaire clay	33°	0.06	0.01	0.85	0.21	-
Trmice clay	18.7°	0.09	0.01	1.09	0.09	-

Table 4.3: Typical parameters of the hypoplastic model for clays.

For estimation of α_G , see database from [7], here for free download in the form of PDF preprint.

	k	A	s_f
Pisa clay	0.4	0.1	1
Bothkennar clay	0.35	0.5	1

Table 4.4: Typical parameters of the model for clays with meta-stable structure (from [4])

	R	β_r	χ	A_g	n_g	m_{rat}
London clay (data Gasparre)	5.e-5	0.08	0.9	270	1	0.5
Brno clay (nat.)	1e-4	0.2	0.8	5300	0.5	0.5

Table 4.5: Typical parameters of the intergranular strain concept for clays

Soil - User-defined - London clay

General Parameters Flow parameters Interfaces Initial

Property	Unit	Value
User-defined model		
DLL file		udsm_hps.dll
Model in DLL		Hypoplas.-clay
Parameters		
φ_c	°	21,90
P_t	kN/m ²	0,000
λ^*		0,09500
κ^*		0,01500
N		1,190
v_{pp}		0,1000
α_G		2,000
(k)		0,000
(A)		0,000
(s_f)		0,000
R_{max}		0,05000E-3
β_r		0,08000
χ		0,9000
A_g		270,0
n_g		1,000
$m_{rat} (m_T/m_R)$		0,5000
K_w	kN/m ²	10,00E6
vert. (1/2/3)		2,000
SV: e or OCR		0,7000
SV: is0 ₁₁		0,000
SV: is0 ₂₂		0,000
SV: is0 ₃₃		0,000
SV: is0 ₁₂		0,000
SV: is0 ₁₃		0,000
SV: is0 ₂₃		0,000
SV: sensit.		0,000

12 Next OK Cancel

Figure 4.3: Selecting clay hypoplasticity model in the "Parameters" tab sheet.

Chapter 5

EXAMPLES

5.1 Excavation in sand

The example of the excavation is taken over from PLAXIS manual; the problem is simulated with sand hypoplasticity model. Soil parameters of the sand correspond to the Hochstetten sand from Tab. 4.1; the intergranular strain parameters used are in Tab. 4.2. The sand is in a medium dense state with $e_0=0.85$.

Fig. 5.1 shows total displacements. Fig. 5.2 shows the normalised length of the intergranular strain tensor. The normalised length of the intergranular strain tensor varies between 0, which indicates the soil being inside the elastic range, and 1, corresponding to the state swept-out of the small-strain memory. In the case of the normalised length of the intergranular strain being equal to 1 the soil behaviour is governed by the basic hypoplastic model. Indeed, Fig. 5.2 shows that this is the case of an excavation, the soil below the bottom of the excavation and behind the wall is outside the small-strain-stiffness range. Fig. 5.3 shows mobilised friction angle, indicating emerging failure mechanism.

Input file for this example may be downloaded in Sec. 8.

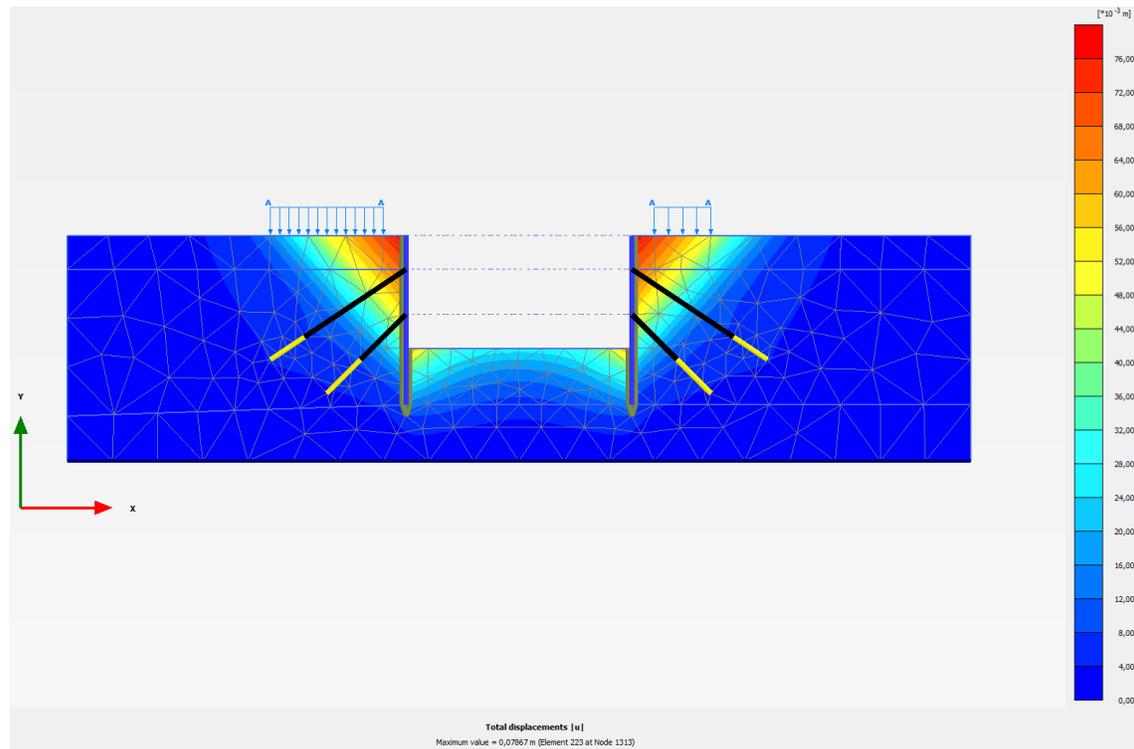


Figure 5.1: Excavation in sand - total displacement.

5.2 NATM tunnel in clay

In this example, an NATM tunnel excavated in stiff clay is simulated. The clay is simulated with London clay parameters (Tab. 4.3 for parameters of the basic model; Tab 4.5. for the intergranular strain parameters), with the initial value of void ratio equal to 0.7.

Figure 5.4 shows the displacement field predicted by the anisotropic stiffness model with $\alpha_G = 2$, whereas 5.5 shows the displacement field predicted by the model with $\alpha_G = 1$. Clearly, the anisotropic model predicts narrower and deeper surface settlement trough, which agrees better with monitored data. This is also clear from the settlement trough shown in Fig. 5.6. There, also predictions by the Mařín (2005) model [3] are included, which are close to the predictions by the isotropic model. Fig. 5.7 shows the normalised length of the intergranular strain tensor. The normalised length of the intergranular strain tensor in Fig. 5.7 demonstrates how the small-strain stiffness is activated in different parts of the modelled geometry.

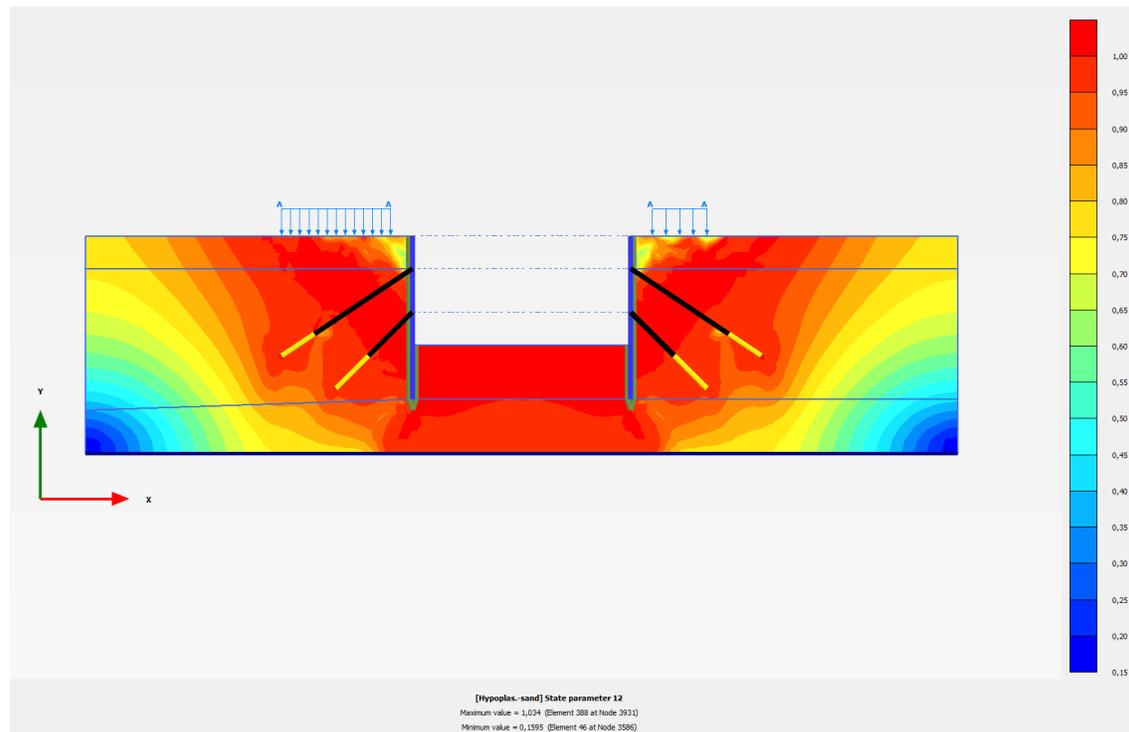


Figure 5.2: Excavation in sand - normalised length of the intergranular strain tensor.

5.3 Building subjected to an earthquake

This example demonstrates capabilities of a hypoplastic model in dynamic analysis of the earthquake impact on existing infrastructure. A real accelerogram of an earthquake recorded by USGS in 1989 is used for the analysis.

The building consists of 4 floors and a basement. It is 6 m wide and 25 m high. The subsoil consists of a sand with water level reaching the surface. The soil behaviour during the earthquake is considered as undrained. Two cases were simulated. In one case, the soil is in a loose state ($e_0 = e_{c0}$), in the second case the soil is in a dense state (e_0 is close to e_{d0}). Hypoplastic model parameters of the Hochstetten sand from Tab. 4.1 and the intergranular strain parameters from Tab. 4.2 are adopted.

Overall displacements of the top of the building are shown in Fig. 5.8. The soil response to the earthquake depends significantly on the soil state. The loose soil liquefies after 3-4 s of the earthquake, leading to the failure. The analysis cannot

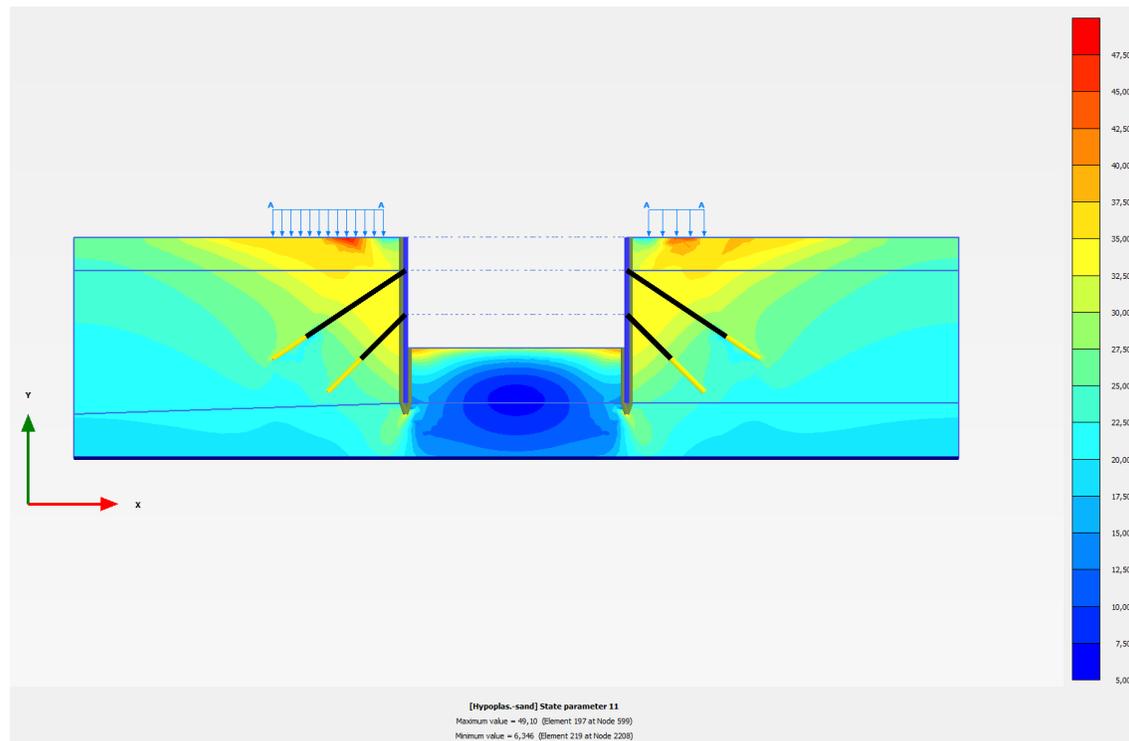


Figure 5.3: Excavation in sand - mobilised friction angle.

continue and fails. The displacements are much lower in the case of dense soil. Although some displacements occur also in this case, the soil retains some bearing capacity sufficient to overcome the failure.

Figure 5.9 shows total displacements after approx. 4 s of earthquake for the loose soil case, whereas Figure 5.10 shows the displacements at the same time (and in the same scale) for the dense soil. The figures indicate foundation failure for the loose soil case and relatively low displacements for the dense soil case.

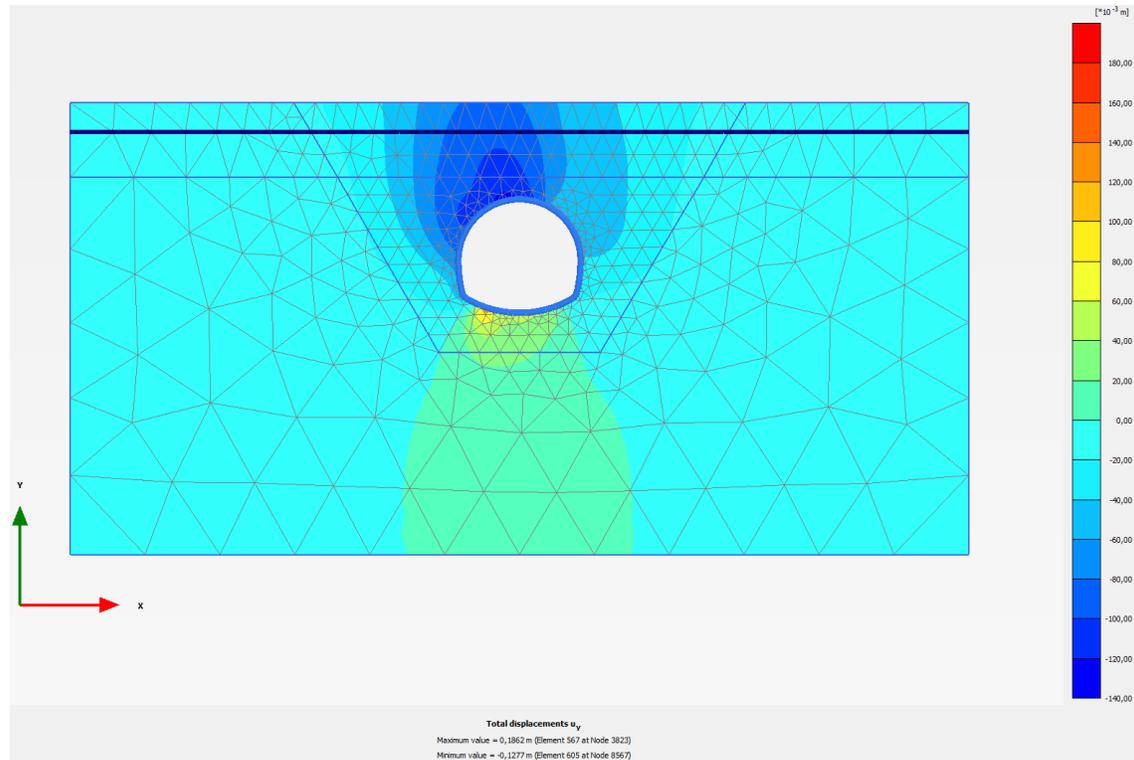


Figure 5.4: NATM tunnel construction - vertical displacement field predicted by the anisotropic model.

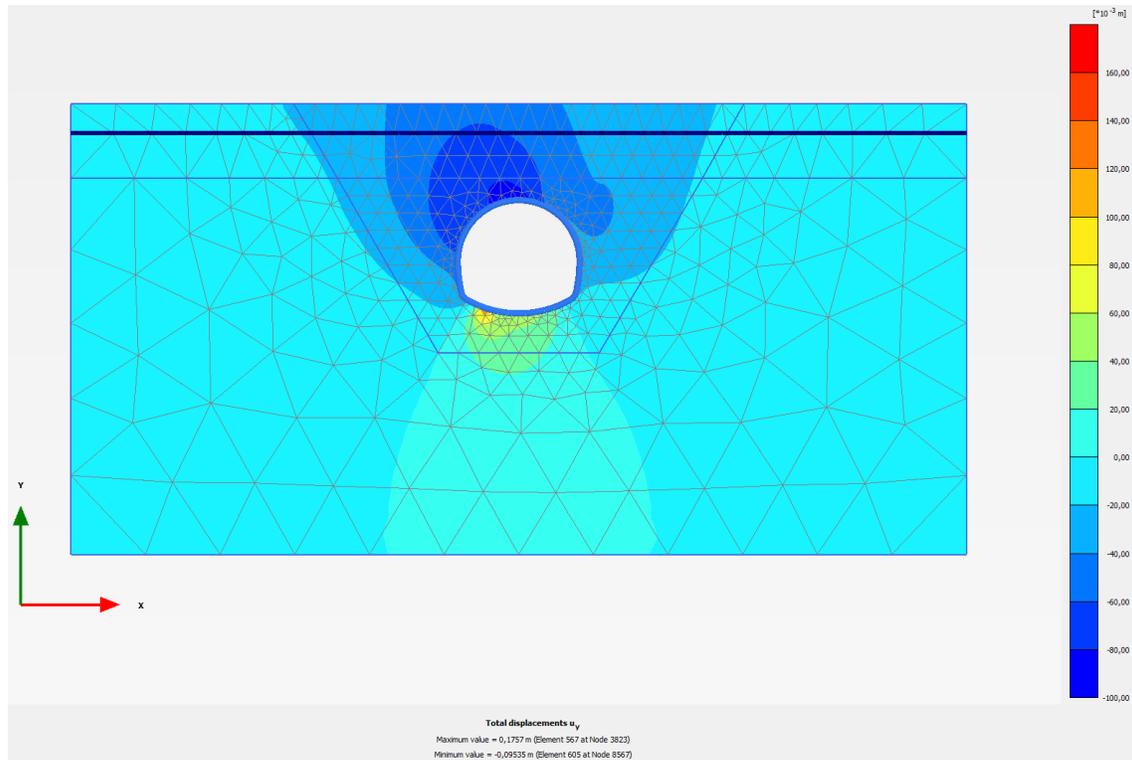


Figure 5.5: NATM tunnel construction - vertical displacement field predicted by the isotropic model.

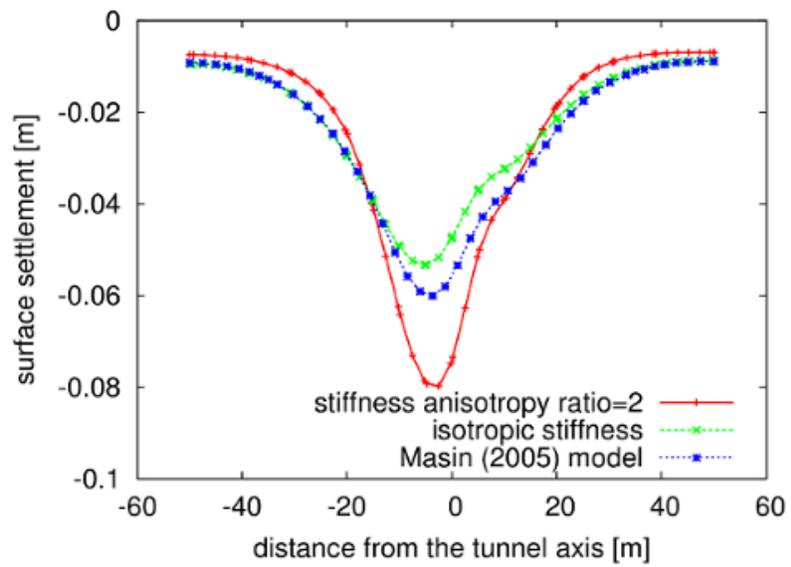


Figure 5.6: NATM tunnel construction - surface settlement troughs predicted by different models.

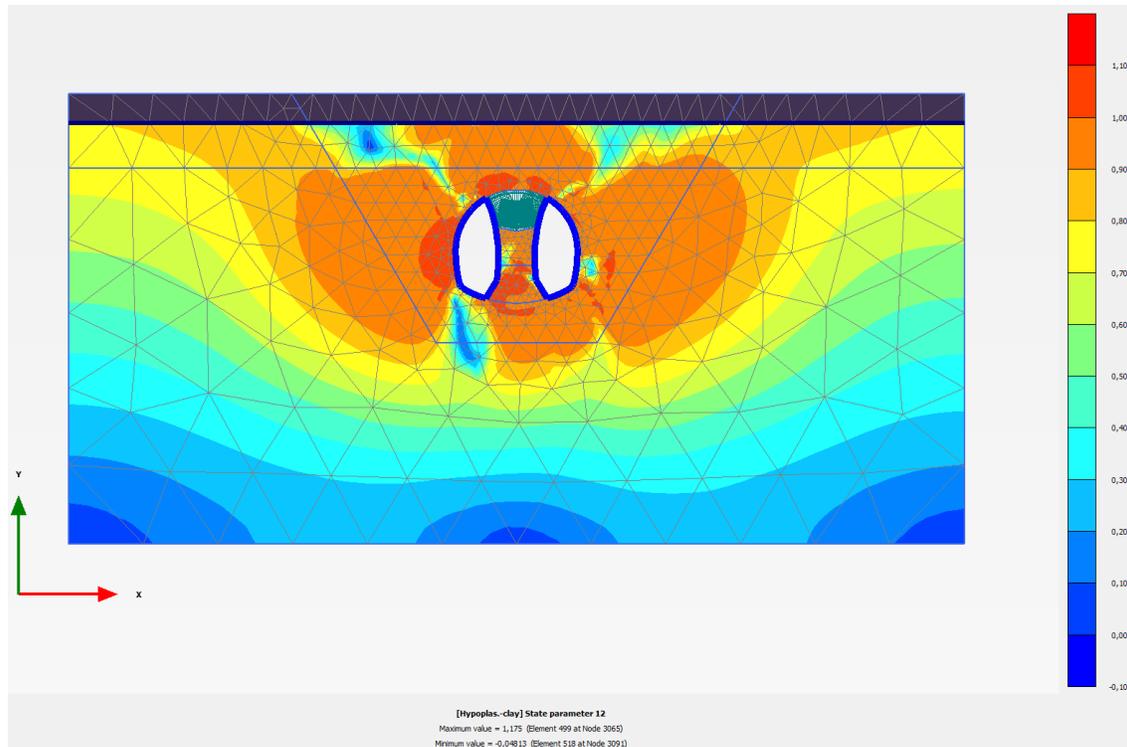


Figure 5.7: NATM tunnel construction - normalised length of the intergranular strain tensor.

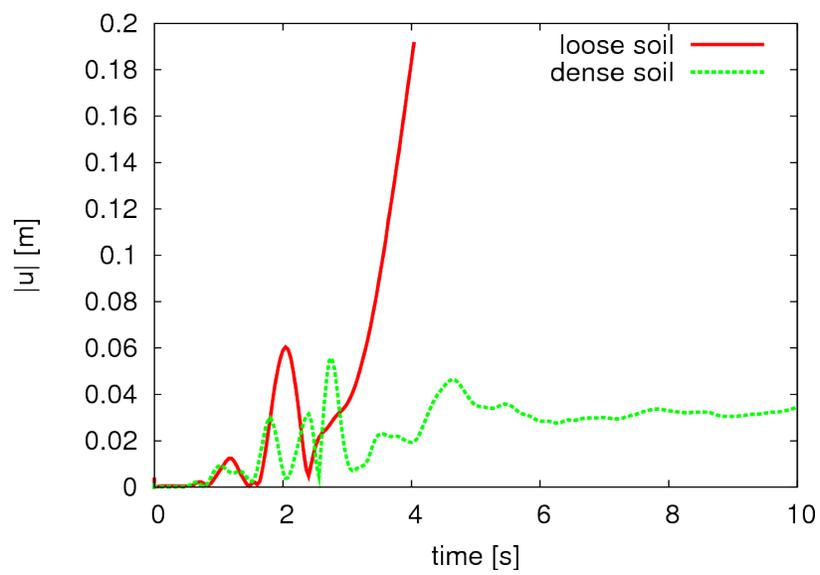


Figure 5.8: Displacement of the top of the building during the earthquake.

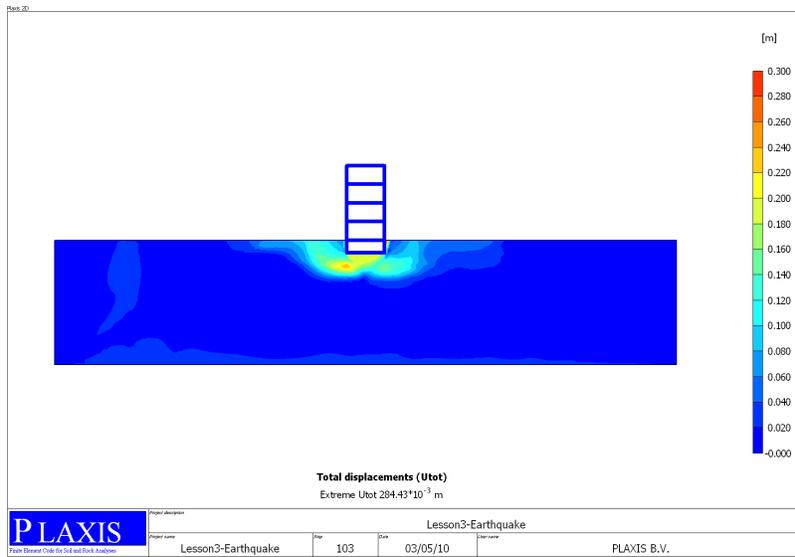


Figure 5.9: Total displacements after 4 s of earthquake - loose soil.

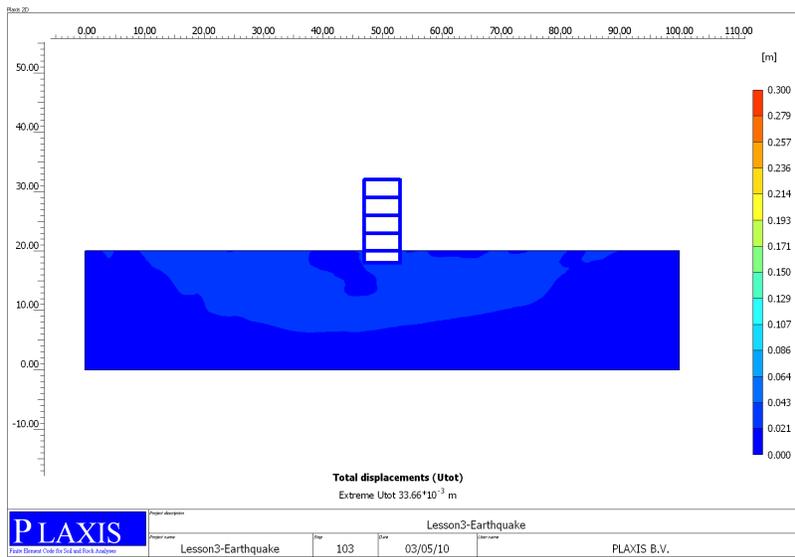


Figure 5.10: Total displacements after 4 s of earthquake - dense soil.

Chapter 6

TROUBLESHOOTING

Although the implementation has been tested to be accurate and robust, the hypoplastic models are highly non-linear which may cause problems during solving complex boundary value problems. When encountering problems, the following steps may help to improve the overall performance:

1. In the "Iterative procedure" settings under "Parameters" Tab sheet, set "Manual settings" and do not use the arc-length control.
2. Try to modify the iterative procedure by decreasing the "Desired minimum" and "Desired maximum" number of iterations (for example, 3 and 5 respectively).
3. The hypoplastic models are undefined in the tensile stress region, which can cause integration problems in the vicinity of the free surface and in the case of staged construction starting from the stress-free state. For this reason, artificial cohesion is introduced in the model implementation through the parameter p_t . The user can specify any p_t value; in the case $p_t=0$ kPa, the program replaces it by a default value $p_t=1$ kPa.
4. When used with interface elements, proper interface parameters must be input in the "Interface" Tab sheet under "Material models" window. Particularly, as some tensile stress is allowed for in the soil through the parameter p_t , the tensile stress should be allowed for also in the interface by increasing the cohesion value (e.g., 10 kPa). Convergence problems may also be caused by high interface stiffness. In the case PLAXIS keeps on iterating although the global error is below the tolerated value, or does not increase the step size although the

number of iterations is below the "desired minimum", problem is the most likely in interfaces.

Chapter 7

ACKNOWLEDGEMENT

The RKF-23 time integration scheme was programmed and kindly provided by Prof. C. Tamagnini and E. Sellari. The original *umat* - PLAXIS interface, which served as a basis for the present developments, was programmed and kindly provided by Dr. P.-A. von Wolffersdorff. The implementation was optimised during the stay of the author at Plaxis bv in March 2010. Plaxis support is greatly appreciated. Development of constitutive models was supported by the research grant **GACR 205/08/0732**. Software was developed under support of grant **TACR TA01031840**.

Bibliography

- [1] E. Bauer. Calibration of a comprehensive constitutive equation for granular materials. *Soils and Foundations*, 36(1):13–26, 1996.
- [2] I. Herle and G. Gudehus. Determination of parameters of a hypoplastic constitutive model from properties of grain assemblies. *Mechanics of Cohesive-Frictional Materials*, 4:461–486, 1999.
- [3] D. Mašín. A hypoplastic constitutive model for clays. *International Journal for Numerical and Analytical Methods in Geomechanics*, 29(4):311–336, 2005.
- [4] D. Mašín. A hypoplastic constitutive model for clays with meta-stable structure. *Canadian Geotechnical Journal*, 44(3):363–375, 2007.
- [5] D. Mašín. Clay hypoplasticity with explicitly defined asymptotic states. *Acta Geotechnica*, 8(5):481–496, 2013.
- [6] D. Mašín. Clay hypoplasticity model including stiffness anisotropy. *Géotechnique*, 64(3):232–238, 2014.
- [7] D. Mašín and J. Rott. Small strain stiffness anisotropy of natural sedimentary clays: review and a model. *Acta Geotechnica*, 9(2):299–312, 2014.
- [8] A. Niemunis and I. Herle. Hypoplastic model for cohesionless soils with elastic strain range. *Mechanics of Cohesive-Frictional Materials*, 2(4):279–299, 1997.
- [9] P. A. von Wolffersdorff. A hypoplastic relation for granular materials with a pre-defined limit state surface. *Mechanics of Cohesive-Frictional Materials*, 1(3):251–271, 1996.

Chapter 8

DOWNLOAD

Chapter 9

GNU GENERAL PUBLIC LICENSE

GNU GENERAL PUBLIC LICENSE Version 2, June 1991

Copyright (C) 1989, 1991 Free Software Foundation, Inc. 59 Temple Place, Suite 330, Boston, MA, 02111-1307, USA Everyone is permitted to copy and distribute verbatim copies of this license document, but changing it is not allowed.

Preamble

The licenses for most software are designed to take away your freedom to share and change it. By contrast, the GNU General Public License is intended to guarantee your freedom to share and change free software—to make sure the software is free for all its users. This General Public License applies to most of the Free Software Foundation’s software and to any other program whose authors commit to using it. (Some other Free Software Foundation software is covered by the GNU Library General Public License instead.) You can apply it to your programs, too.

When we speak of free software, we are referring to freedom, not price. Our General Public Licenses are designed to make sure that you have the freedom to distribute copies of free software (and charge for this service if you wish), that you receive source code or can get it if you want it, that you can change the software or use pieces of it in new free programs; and that you know you can do these things.

To protect your rights, we need to make restrictions that forbid anyone to deny you these rights or to ask you to surrender the rights. These restrictions translate to certain responsibilities for you if you distribute copies of the software, or if you modify it.

For example, if you distribute copies of such a program, whether gratis or for a fee, you must give the recipients all the rights that you have. You must make sure

that they, too, receive or can get the source code. And you must show them these terms so they know their rights.

We protect your rights with two steps: (1) copyright the software, and (2) offer you this license which gives you legal permission to copy, distribute and/or modify the software.

Also, for each author's protection and ours, we want to make certain that everyone understands that there is no warranty for this free software. If the software is modified by someone else and passed on, we want its recipients to know that what they have is not the original, so that any problems introduced by others will not reflect on the original authors' reputations.

Finally, any free program is threatened constantly by software patents. We wish to avoid the danger that redistributors of a free program will individually obtain patent licenses, in effect making the program proprietary. To prevent this, we have made it clear that any patent must be licensed for everyone's free use or not licensed at all.

The precise terms and conditions for copying, distribution and modification follow.

GNU GENERAL PUBLIC LICENSE TERMS AND CONDITIONS FOR COPYING, DISTRIBUTION AND MODIFICATION

0. This License applies to any program or other work which contains a notice placed by the copyright holder saying it may be distributed under the terms of this General Public License. The "Program", below, refers to any such program or work, and a "work based on the Program" means either the Program or any derivative work under copyright law: that is to say, a work containing the Program or a portion of it, either verbatim or with modifications and/or translated into another language. (Hereinafter, translation is included without limitation in the term "modification".) Each licensee is addressed as "you".

Activities other than copying, distribution and modification are not covered by this License; they are outside its scope. The act of running the Program is not restricted, and the output from the Program is covered only if its contents constitute a work based on the Program (independent of having been made by running the Program). Whether that is true depends on what the Program does.

1. You may copy and distribute verbatim copies of the Program's source code as you receive it, in any medium, provided that you conspicuously and appropriately publish on each copy an appropriate copyright notice and disclaimer of warranty; keep intact all the notices that refer to this License and to the absence of any warranty; and give any other recipients of the Program a copy of this License along with the Program.

You may charge a fee for the physical act of transferring a copy, and you may at your option offer warranty protection in exchange for a fee.

2. You may modify your copy or copies of the Program or any portion of it, thus forming a work based on the Program, and copy and distribute such modifications or work under the terms of Section 1 above, provided that you also meet all of these conditions:

a) You must cause the modified files to carry prominent notices stating that you changed the files and the date of any change.

b) You must cause any work that you distribute or publish, that in whole or in part contains or is derived from the Program or any part thereof, to be licensed as a whole at no charge to all third parties under the terms of this License.

c) If the modified program normally reads commands interactively when run, you must cause it, when started running for such interactive use in the most ordinary way, to print or display an announcement including an appropriate copyright notice and a notice that there is no warranty (or else, saying that you provide a warranty) and that users may redistribute the program under these conditions, and telling the user how to view a copy of this License. (Exception: if the Program itself is interactive but does not normally print such an announcement, your work based on the Program is not required to print an announcement.)

These requirements apply to the modified work as a whole. If identifiable sections of that work are not derived from the Program, and can be reasonably considered independent and separate works in themselves, then this License, and its terms, do not apply to those sections when you distribute them as separate works. But when you distribute the same sections as part of a whole which is a work based on the Program, the distribution of the whole must be on the terms of this License, whose permissions for other licensees extend to the entire whole, and thus to each and every part regardless of who wrote it.

Thus, it is not the intent of this section to claim rights or contest your rights to work written entirely by you; rather, the intent is to exercise the right to control the distribution of derivative or collective works based on the Program.

In addition, mere aggregation of another work not based on the Program with the Program (or with a work based on the Program) on a volume of a storage or distribution medium does not bring the other work under the scope of this License.

3. You may copy and distribute the Program (or a work based on it, under Section 2) in object code or executable form under the terms of Sections 1 and 2 above provided that you also do one of the following:

a) Accompany it with the complete corresponding machine-readable source code, which must be distributed under the terms of Sections 1 and 2 above on a medium

customarily used for software interchange; or,

b) Accompany it with a written offer, valid for at least three years, to give any third party, for a charge no more than your cost of physically performing source distribution, a complete machine-readable copy of the corresponding source code, to be distributed under the terms of Sections 1 and 2 above on a medium customarily used for software interchange; or,

c) Accompany it with the information you received as to the offer to distribute corresponding source code. (This alternative is allowed only for noncommercial distribution and only if you received the program in object code or executable form with such an offer, in accord with Subsection b above.)

The source code for a work means the preferred form of the work for making modifications to it. For an executable work, complete source code means all the source code for all modules it contains, plus any associated interface definition files, plus the scripts used to control compilation and installation of the executable. However, as a special exception, the source code distributed need not include anything that is normally distributed (in either source or binary form) with the major components (compiler, kernel, and so on) of the operating system on which the executable runs, unless that component itself accompanies the executable.

If distribution of executable or object code is made by offering access to copy from a designated place, then offering equivalent access to copy the source code from the same place counts as distribution of the source code, even though third parties are not compelled to copy the source along with the object code.

4. You may not copy, modify, sublicense, or distribute the Program except as expressly provided under this License. Any attempt otherwise to copy, modify, sublicense or distribute the Program is void, and will automatically terminate your rights under this License. However, parties who have received copies, or rights, from you under this License will not have their licenses terminated so long as such parties remain in full compliance.

5. You are not required to accept this License, since you have not signed it. However, nothing else grants you permission to modify or distribute the Program or its derivative works. These actions are prohibited by law if you do not accept this License. Therefore, by modifying or distributing the Program (or any work based on the Program), you indicate your acceptance of this License to do so, and all its terms and conditions for copying, distributing or modifying the Program or works based on it.

6. Each time you redistribute the Program (or any work based on the Program), the recipient automatically receives a license from the original licensor to copy, distribute or modify the Program subject to these terms and conditions. You may not

impose any further restrictions on the recipients' exercise of the rights granted herein. You are not responsible for enforcing compliance by third parties to this License.

7. If, as a consequence of a court judgment or allegation of patent infringement or for any other reason (not limited to patent issues), conditions are imposed on you (whether by court order, agreement or otherwise) that contradict the conditions of this License, they do not excuse you from the conditions of this License. If you cannot distribute so as to satisfy simultaneously your obligations under this License and any other pertinent obligations, then as a consequence you may not distribute the Program at all. For example, if a patent license would not permit royalty-free redistribution of the Program by all those who receive copies directly or indirectly through you, then the only way you could satisfy both it and this License would be to refrain entirely from distribution of the Program.

If any portion of this section is held invalid or unenforceable under any particular circumstance, the balance of the section is intended to apply and the section as a whole is intended to apply in other circumstances.

It is not the purpose of this section to induce you to infringe any patents or other property right claims or to contest validity of any such claims; this section has the sole purpose of protecting the integrity of the free software distribution system, which is implemented by public license practices. Many people have made generous contributions to the wide range of software distributed through that system in reliance on consistent application of that system; it is up to the author/donor to decide if he or she is willing to distribute software through any other system and a licensee cannot impose that choice.

This section is intended to make thoroughly clear what is believed to be a consequence of the rest of this License.

8. If the distribution and/or use of the Program is restricted in certain countries either by patents or by copyrighted interfaces, the original copyright holder who places the Program under this License may add an explicit geographical distribution limitation excluding those countries, so that distribution is permitted only in or among countries not thus excluded. In such case, this License incorporates the limitation as if written in the body of this License.

9. The Free Software Foundation may publish revised and/or new versions of the General Public License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns.

Each version is given a distinguishing version number. If the Program specifies a version number of this License which applies to it and "any later version", you have the option of following the terms and conditions either of that version or of any later version published by the Free Software Foundation. If the Program does not specify

a version number of this License, you may choose any version ever published by the Free Software Foundation.

10. If you wish to incorporate parts of the Program into other free programs whose distribution conditions are different, write to the author to ask for permission. For software which is copyrighted by the Free Software Foundation, write to the Free Software Foundation; we sometimes make exceptions for this. Our decision will be guided by the two goals of preserving the free status of all derivatives of our free software and of promoting the sharing and reuse of software generally.

NO WARRANTY

11. BECAUSE THE PROGRAM IS LICENSED FREE OF CHARGE, THERE IS NO WARRANTY FOR THE PROGRAM, TO THE EXTENT PERMITTED BY APPLICABLE LAW. EXCEPT WHEN OTHERWISE STATED IN WRITING THE COPYRIGHT HOLDERS AND/OR OTHER PARTIES PROVIDE THE PROGRAM "AS IS" WITHOUT WARRANTY OF ANY KIND, EITHER EXPRESSED OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. THE ENTIRE RISK AS TO THE QUALITY AND PERFORMANCE OF THE PROGRAM IS WITH YOU. SHOULD THE PROGRAM PROVE DEFECTIVE, YOU ASSUME THE COST OF ALL NECESSARY SERVICING, REPAIR OR CORRECTION.

12. IN NO EVENT UNLESS REQUIRED BY APPLICABLE LAW OR AGREED TO IN WRITING WILL ANY COPYRIGHT HOLDER, OR ANY OTHER PARTY WHO MAY MODIFY AND/OR REDISTRIBUTE THE PROGRAM AS PERMITTED ABOVE, BE LIABLE TO YOU FOR DAMAGES, INCLUDING ANY GENERAL, SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES ARISING OUT OF THE USE OR INABILITY TO USE THE PROGRAM (INCLUDING BUT NOT LIMITED TO LOSS OF DATA OR DATA BEING RENDERED INACCURATE OR LOSSES SUSTAINED BY YOU OR THIRD PARTIES OR A FAILURE OF THE PROGRAM TO OPERATE WITH ANY OTHER PROGRAMS), EVEN IF SUCH HOLDER OR OTHER PARTY HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

END OF TERMS AND CONDITIONS

Appendix: How to Apply These Terms to Your New Programs

If you develop a new program, and you want it to be of the greatest possible use to the public, the best way to achieve this is to make it free software which everyone can redistribute and change under these terms.

To do so, attach the following notices to the program. It is safest to attach them to the start of each source file to most effectively convey the exclusion of warranty;

and each file should have at least the "copyright" line and a pointer to where the full notice is found.

```
one line to give the program's name and a brief idea of what it does. Copyright
(C) 19yy ;name of author;
```

This program is free software; you can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation; either version 2 of the License, or (at your option) any later version.

This program is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU General Public License for more details.

You should have received a copy of the GNU General Public License along with this program; if not, write to the Free Software Foundation, Inc., 675 Mass Ave, Cambridge, MA 02139, USA.

Also add information on how to contact you by electronic and paper mail.

If the program is interactive, make it output a short notice like this when it starts in an interactive mode:

```
Gnomovision version 69, Copyright (C) 19yy name of author
Gnomovision comes with ABSOLUTELY NO WARRANTY; for details type 'show w'. This is free software,
and you are welcome to redistribute it under certain conditions; type 'show c' for details.
```

The hypothetical commands 'show w' and 'show c' should show the appropriate parts of the General Public License. Of course, the commands you use may be called something other than 'show w' and 'show c'; they could even be mouse-clicks or menu items—whatever suits your program.

You should also get your employer (if you work as a programmer) or your school, if any, to sign a "copyright disclaimer" for the program, if necessary. Here is a sample; alter the names:

```
Yoyodyne, Inc., hereby disclaims all copyright interest in the program 'Gnomovision'
(which makes passes at compilers) written by James Hacker.
```

```
signature of Ty Coon, 1 April 1989 Ty Coon, President of Vice
```

This General Public License does not permit incorporating your program into proprietary programs. If your program is a subroutine library, you may consider it more useful to permit linking proprietary applications with the library. If this is what you want to do, use the GNU Library General Public License instead of this License.