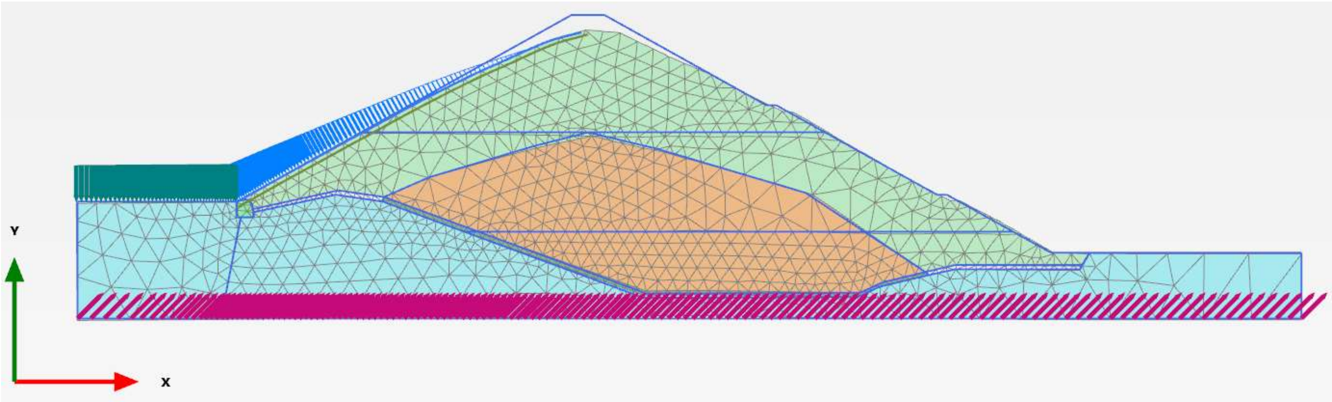
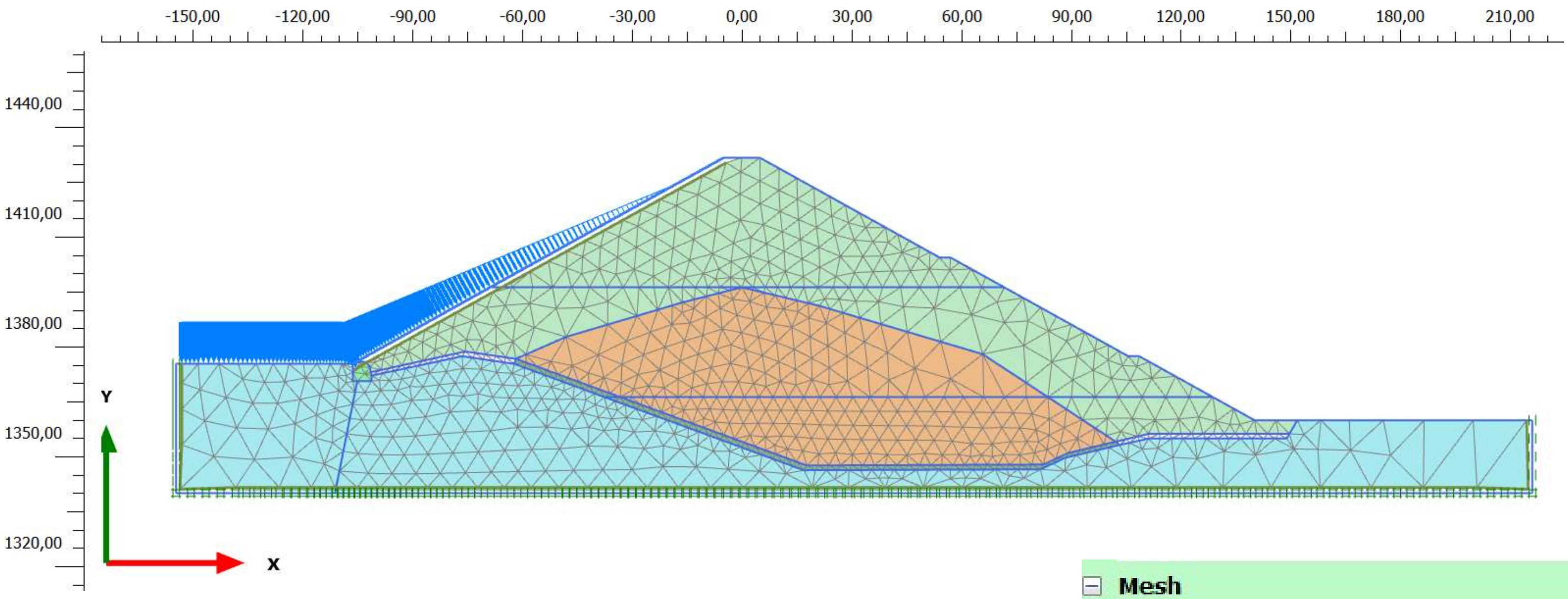
15th ICOLD benchmark workshop on Numerical analysis of Dams Theme B

Nonlinear Dynamic Analyses for Menta Embankment Dam with Plaxis HS-small (Hardening Small Strain) Model



Hui Lu, Multiconsult, Norway

Model overview

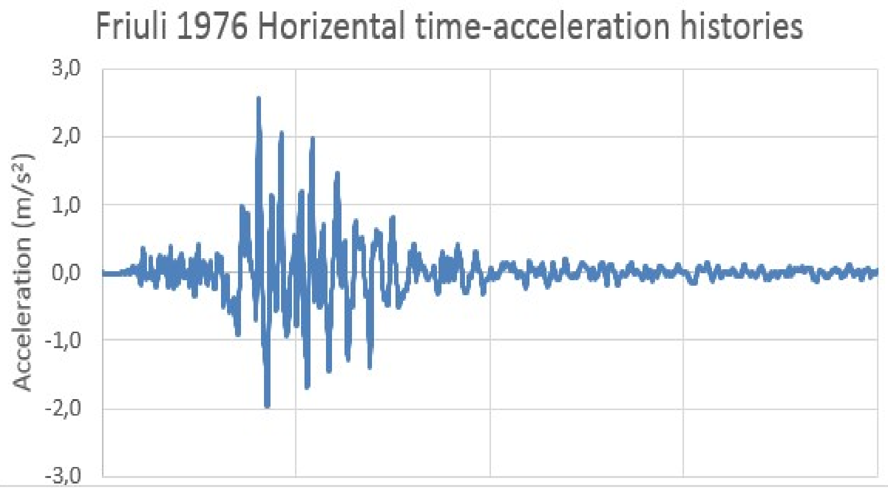


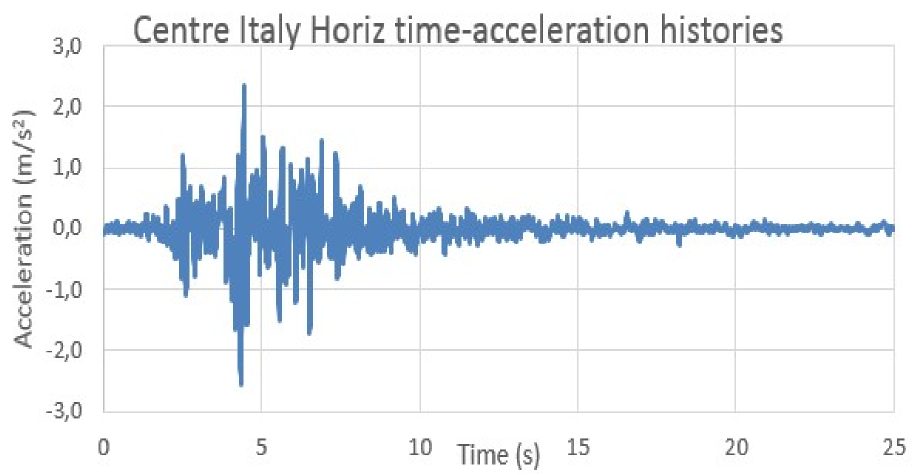
$$AverageElementSize \leq \frac{\lambda}{8} = \frac{V_{s,min}}{8 f_{max}}$$

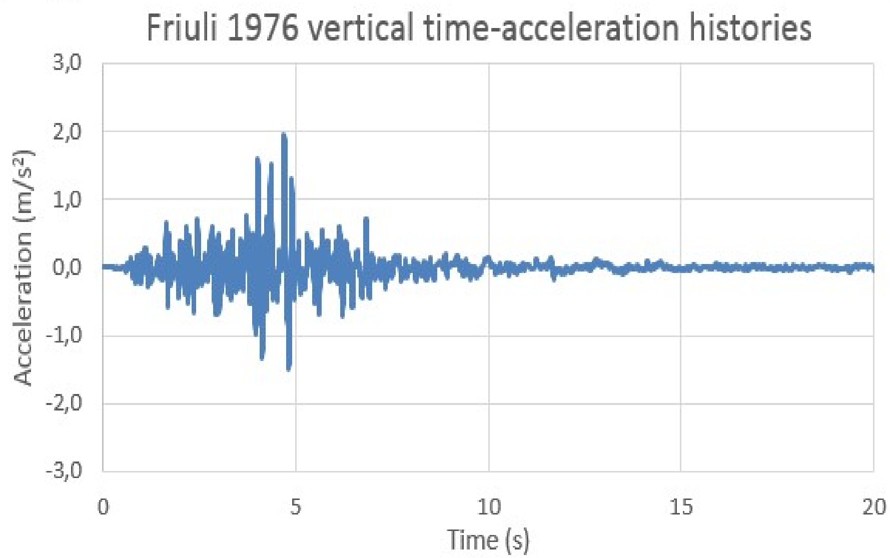
Estimated $V_{s,min}$=400m/s, f_{max}=5Hz
Average element size ≤ 10m

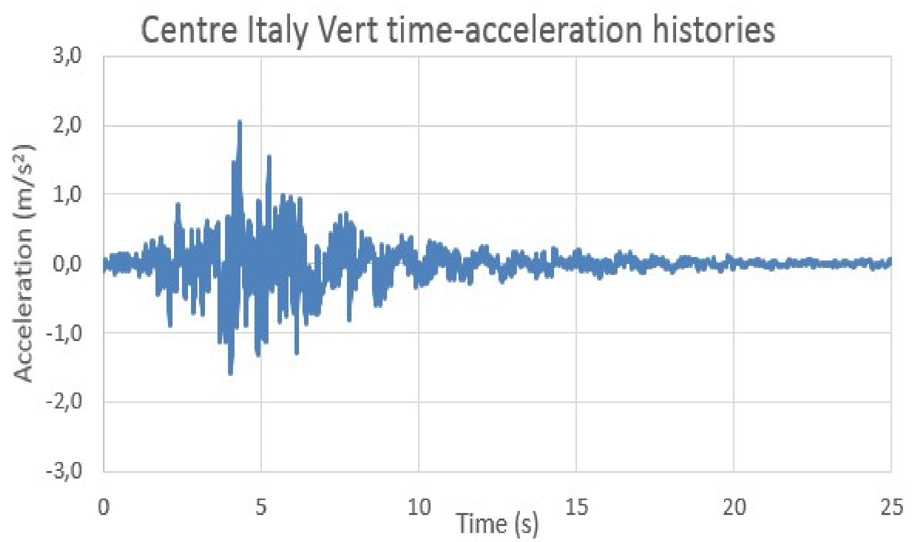
Mesh	
Nr of soil elements	1604
Nr of nodes	13333
Average element size	4,841 m
Maximum element size	24,99 m
Minimum element size	0,7255 m

Dynamic acceleration inputs (scaled to PGA_h=0.26g)



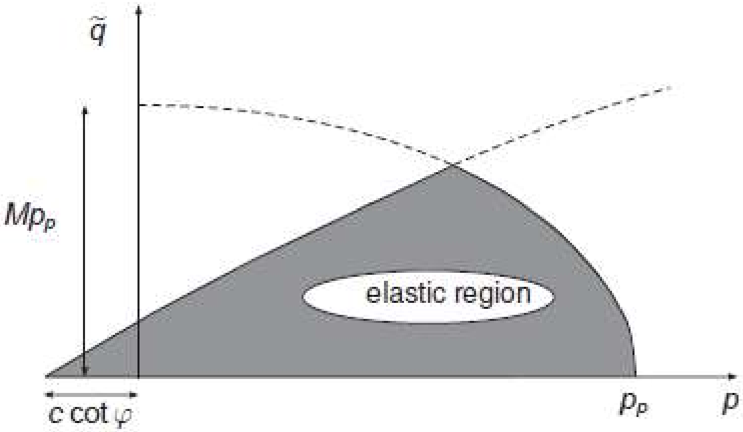


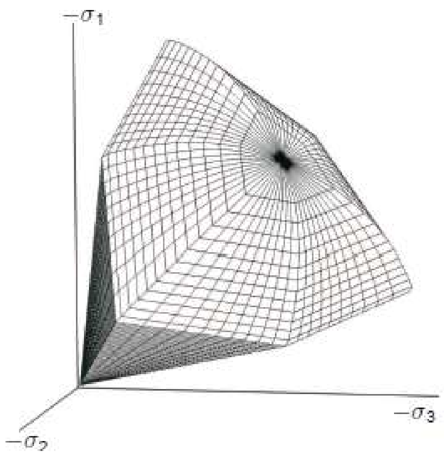


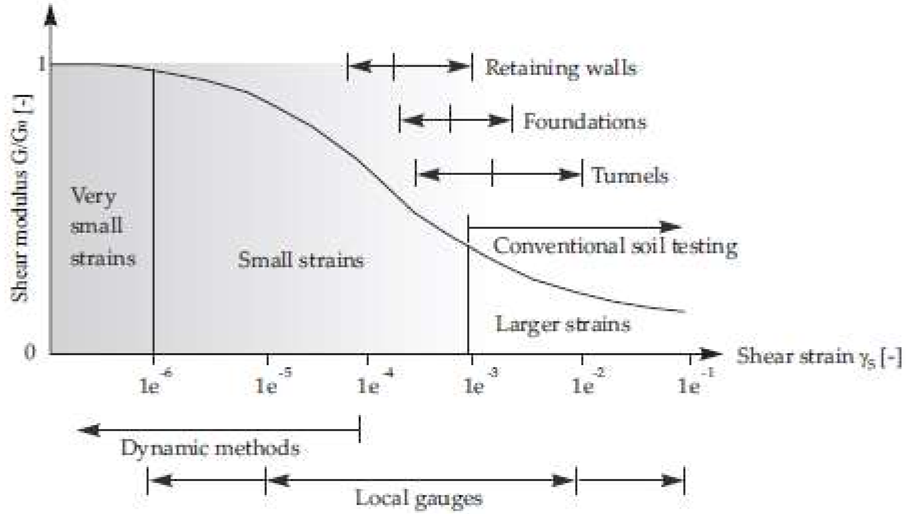


Material model: HS-small (Hardening Small Strain) model

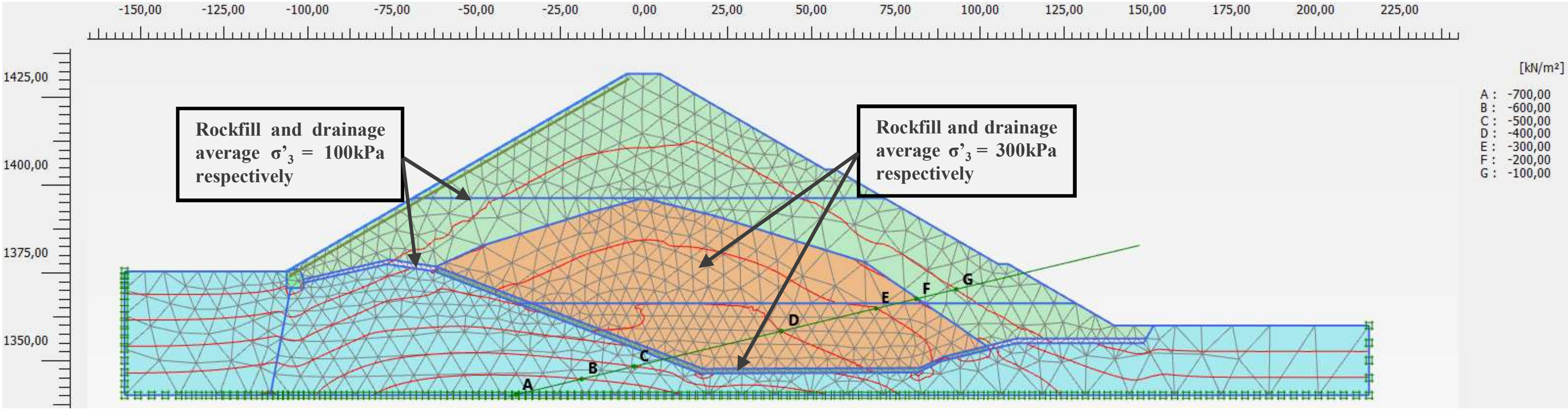
HS-small = Ordinary elastic-perfectly-plastic with M-C criterion + Cap Yielding (hardening) + small strain depending stiffness







Rockfill and drainage layer for the Menta is divided into two different materials

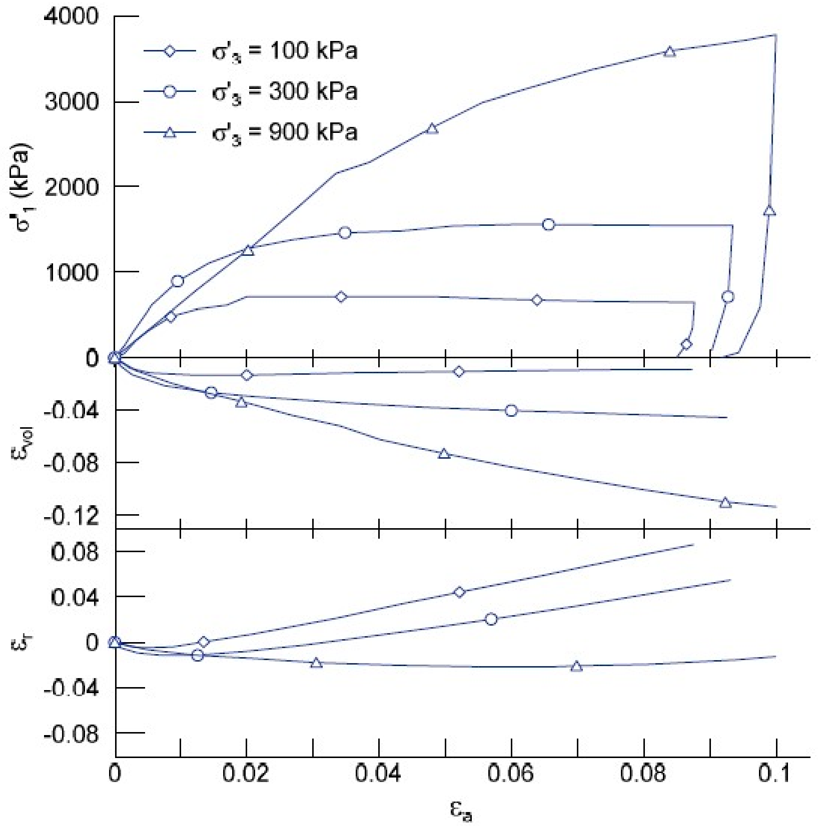


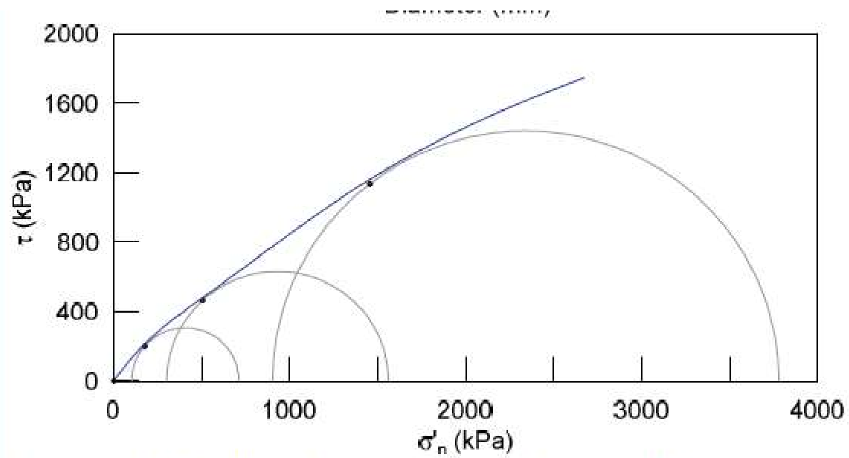
- HS-small model are applied to the rockfill and drainage material
- Different permeability is given for the rockfill (10^{-5} m/s) and drainage (10^{-4} m/s) material
- Both Rockfill and drainage material is divided into two material due to average normal stress. The reason is because the friction angle is normal stress depending.

Detail inputs 1

Parameters	Rock mass	Concrete gallery	Rockfill/drainage average σ'$_{3c}$=100kPa	Rockfill/drainage average σ'$_{3c}$=300kPa
Material type	Linear-Elastic	Linear-Elastic	HS-small, drained	HS-small, drained
Unit weight γ	27 kN/m^3	24 kN/m^3	23 kN/m^3	23 kN/m^3
Permeability k	1E-07 m/s	1E-10 m/s	1E-05 m/s (rockfill) 1E-04 m/s (drainage)	1E-05 m/s (rockfill 1E-04 m/s(drainage
Elastic modulus E	1E+06 kPa	30E+06 kPa	-	-
Poisson's ratio ν	0.25	0.2	-	-
Cohesion c'	-	-	1 kPa	1 kPa
Friction φ'	-	-	48.8°	42.6°
Dilation angle ψ	-	-	2°	2°
Interface permeability	-	-	Impermeable	Impermeable
Interface strength friction reduction factor R_{inter}	-	-	0.5	0.5
Rayleigh damping coefficient α			0.124	0.124
Rayleigh damping coefficient β			0.003152	0.003152

Detail HS-small model input parameters	Rockfill/drainage average Material 1: σ$_{3c}$=100kPa	Rockfill/drainage average Material 2: σ$_{3c}$=300kPa
E_{50}^{ref}	100E+03 kPa	86.92E+03 kPa
E_{ode}^{ref}	80E+03 kPa	69.53E+03 kPa
E_{ur}^{ref}	300E+03 kPa	260.74E+03 kPa
m	0.5	0.5
ν_{ur}	0.2	0.2
G_0^{ref}	375E+03 kPa	446.5E+03 kPa
$\gamma_{0.7}$	0.000223	0.0002783





Results of TXCD-K0 laboratory test (K_0 = 0.4)

Detail inputs 1

Detail HS-small model input parameters
E_{50}^{ref}
E_{ode}^{ref}
E_{ur}^{ref}
m
ν_{ur}
G_0^{ref}
$\gamma_{0.7}$

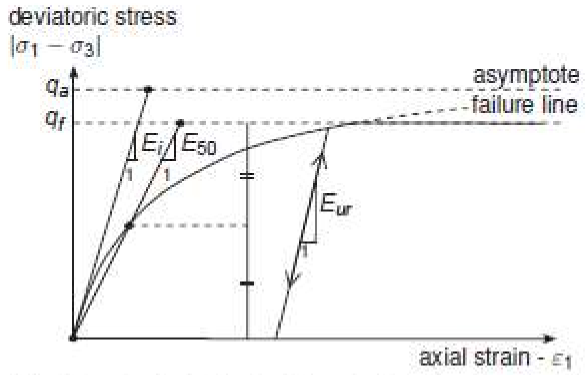


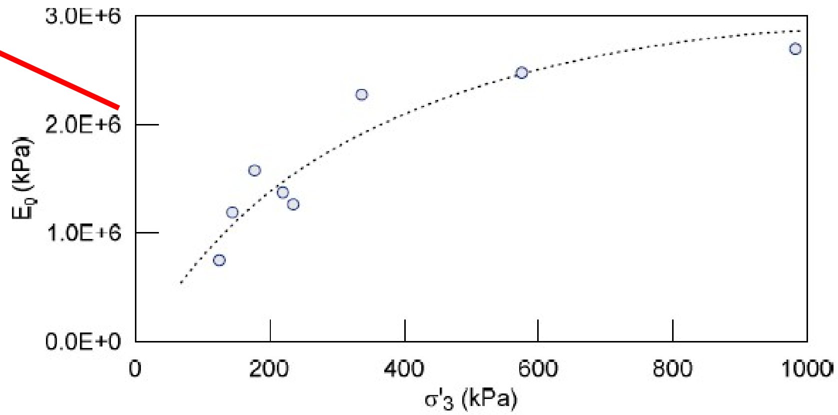
Figure 6.1 Hyperbolic stress-strain relation in primary loading for a standard drained triaxial test

$$E_{50} = E_{50}^{ref}\left(\frac{c\cos\varphi - \sigma'_3\sin\varphi}{c\cos\varphi + p^{ref}\sin\varphi}\right)^m$$

E_{ode}^{ref} is estimated as $0.8 \times E_{50}^{ref}$

E_{ur}^{ref} is estimated as $3 \times E_{50}^{ref}$

G_0



$$\tau = G_s\gamma = \frac{G_0\gamma}{1 + 0.385\frac{\gamma}{\gamma_{0.7}}}$$

Model and inputs 2

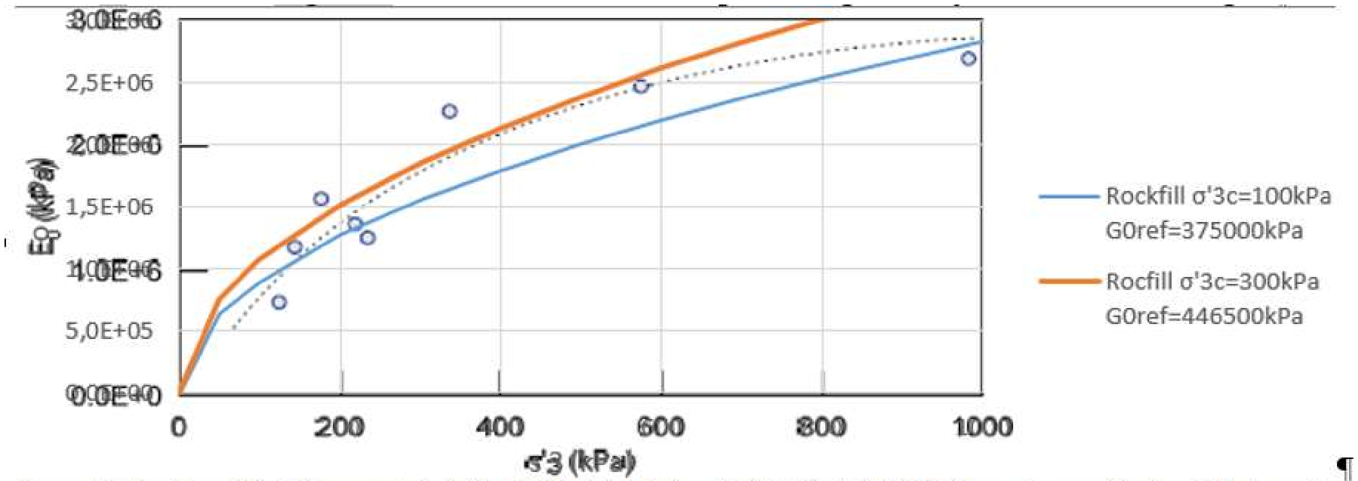


Figure 5 Selection of G_0^{ref} for materials 1 (G_0^{ref}=375000 kPa) and 2 (G_0^{ref}=446500 kPa) based on cyclic triaxial test results; m=0.5.

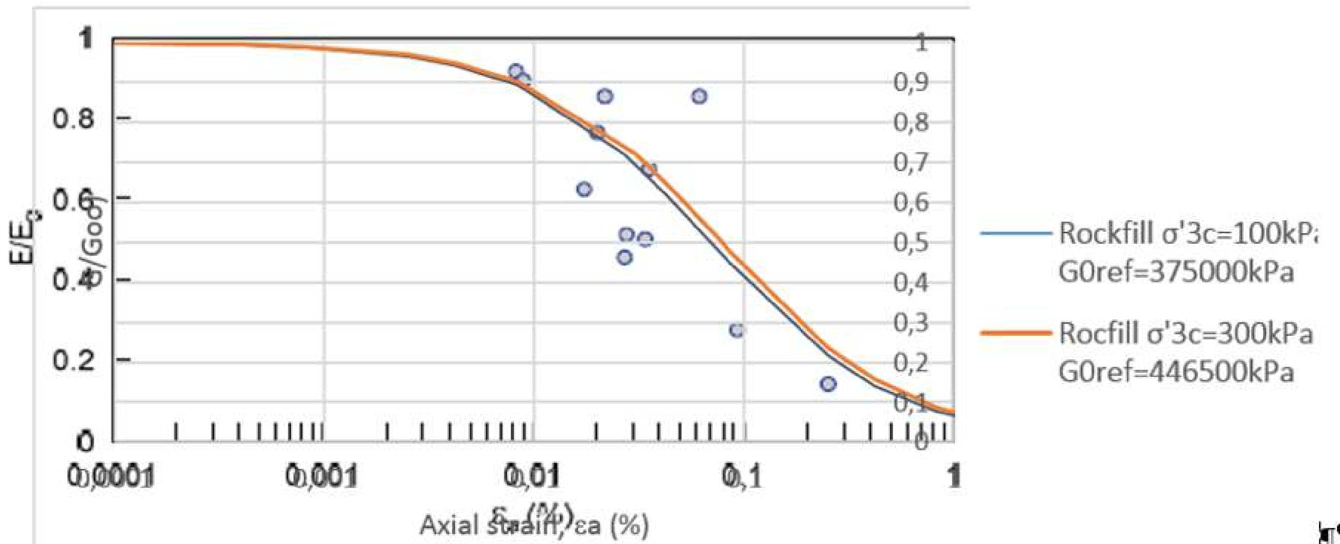
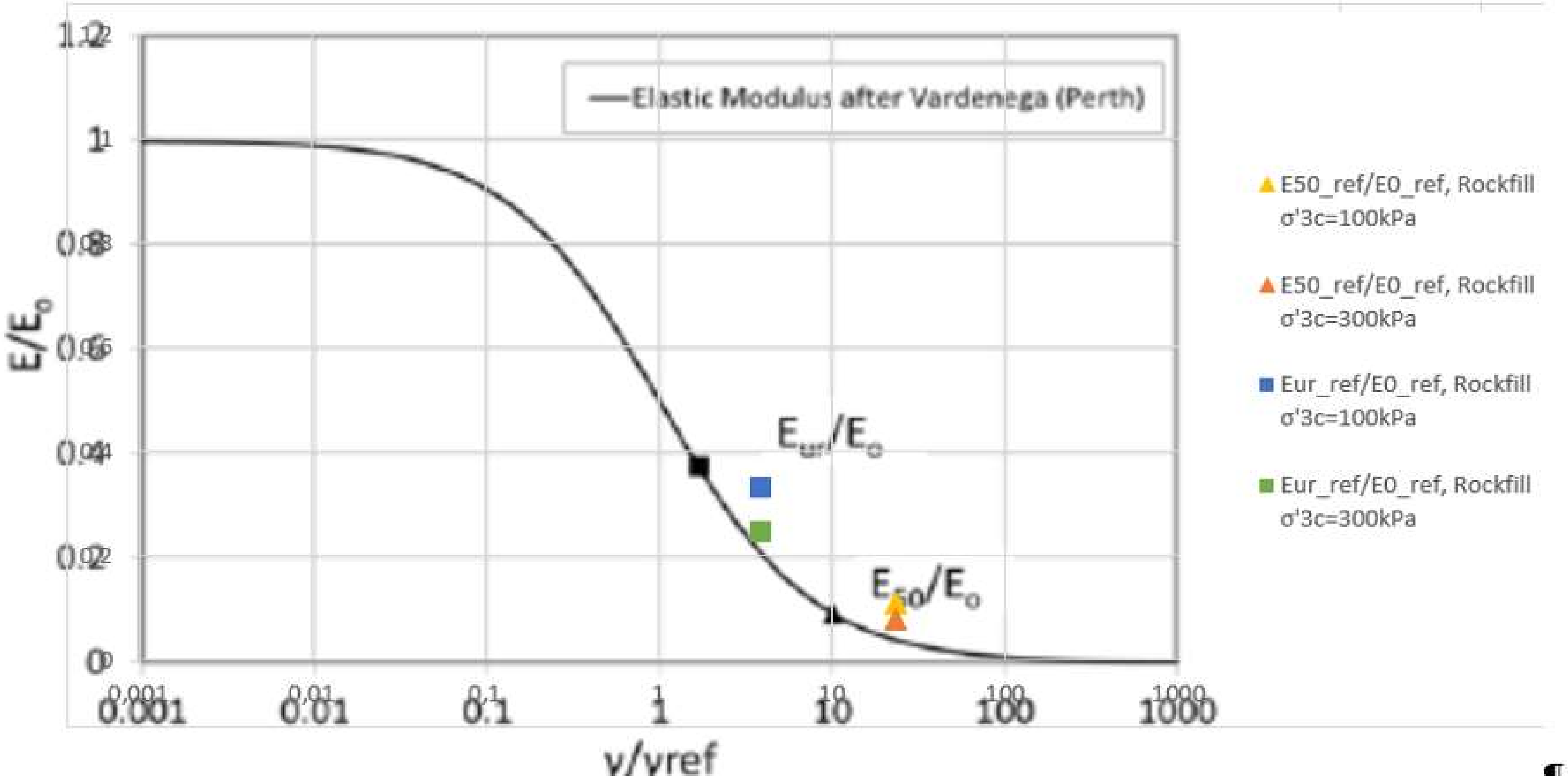


Figure 6 Normalised E/E0 functions obtained from Plaxis HS-small model from the corresponding input parameters as Table 2 comparing with the given cyclic triaxial test results.

Model and inputs 3



E_0^{ref}, E_{50}^{ref} and E_{ur}^{ref} is verified with the Stiff clay, cohesion less, high relative density soil According to Plaxis Mannual, Vermmer and Cox & Mayne

[6] Vermeer, P- (2001) - On single anchor retaining wall. PLAXIS Bulletin No 10.

[7] Cox, C. and P. Mayne (2015) – Soil Soil stiffness constitutive model parameters for geotechnical problems: A dilatometer testing approach. Proceedings DMT-2015.

Model and inputs 4

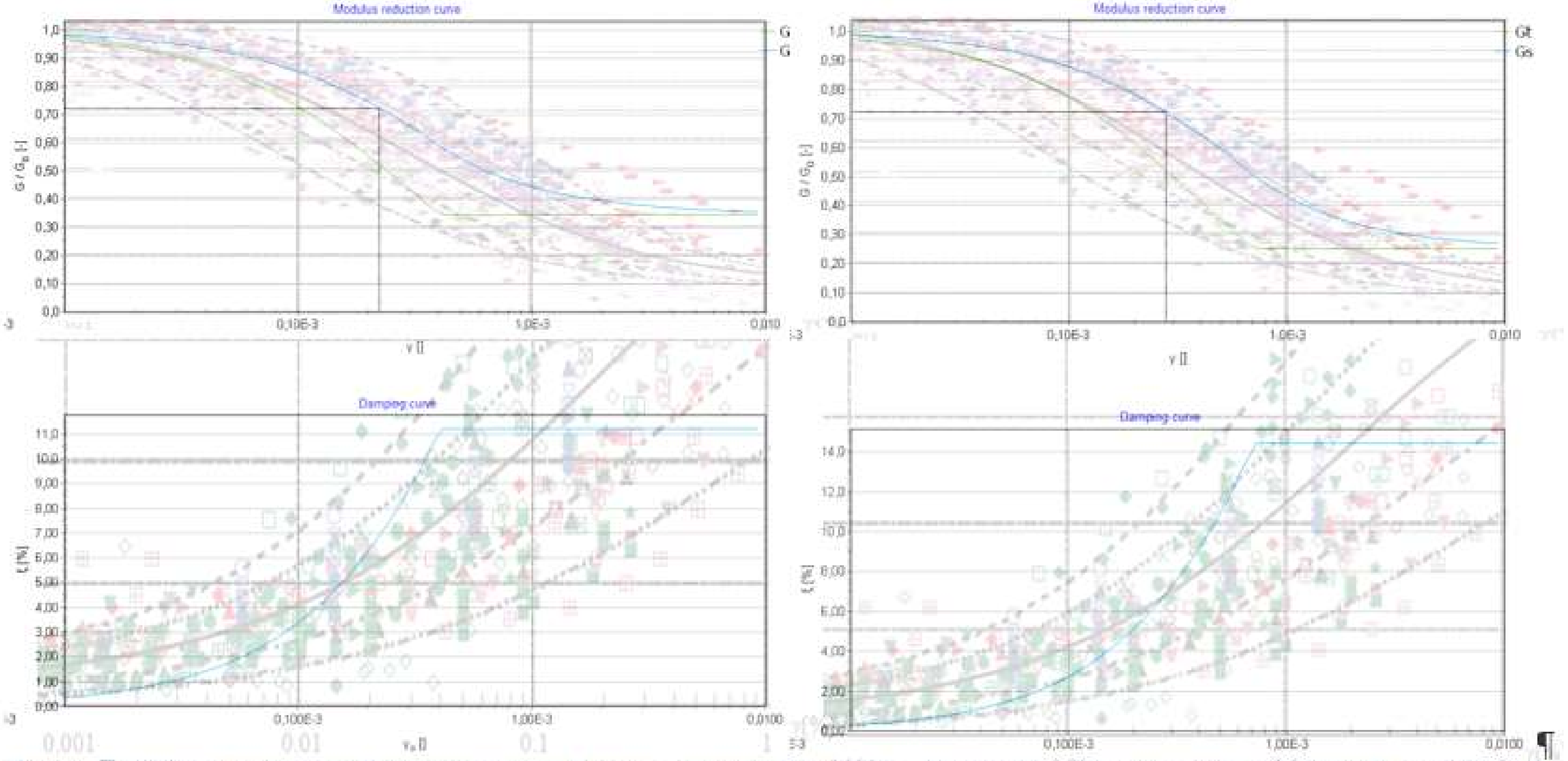
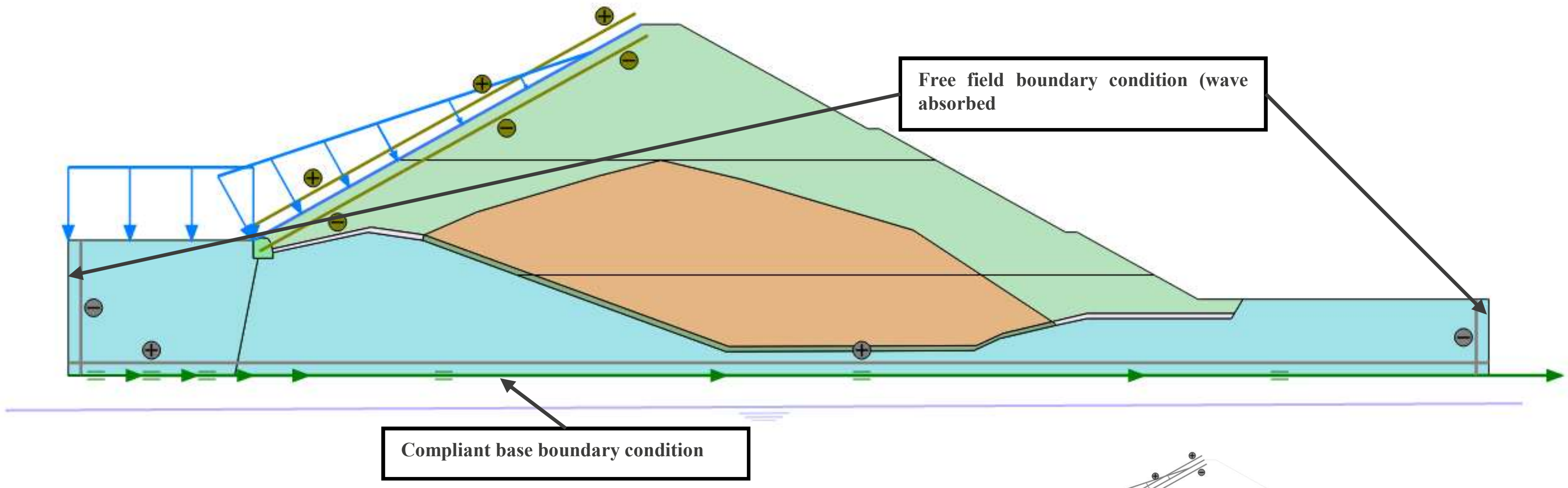


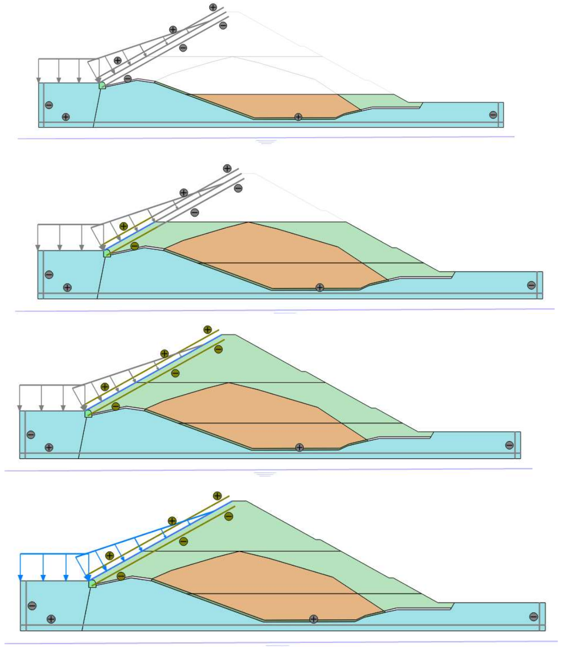
Figure 7 G/G₀ functions and damping ratio function obtained from the HS-small model (Rockfill σ'₁=100kPa on the left, Rockfill σ'₁=300kPa on the right). They are compared with cyclic triaxial test results of rockfill from 35 large rockfill dams from China [5].

[5] Yu Feng. Jia. Shi Chun. Chi (2012). Application of rockfill dynamical characteristic statistic curve in mid-small scale concrete face dam dynamic analysis

Boundary condition and construction stage

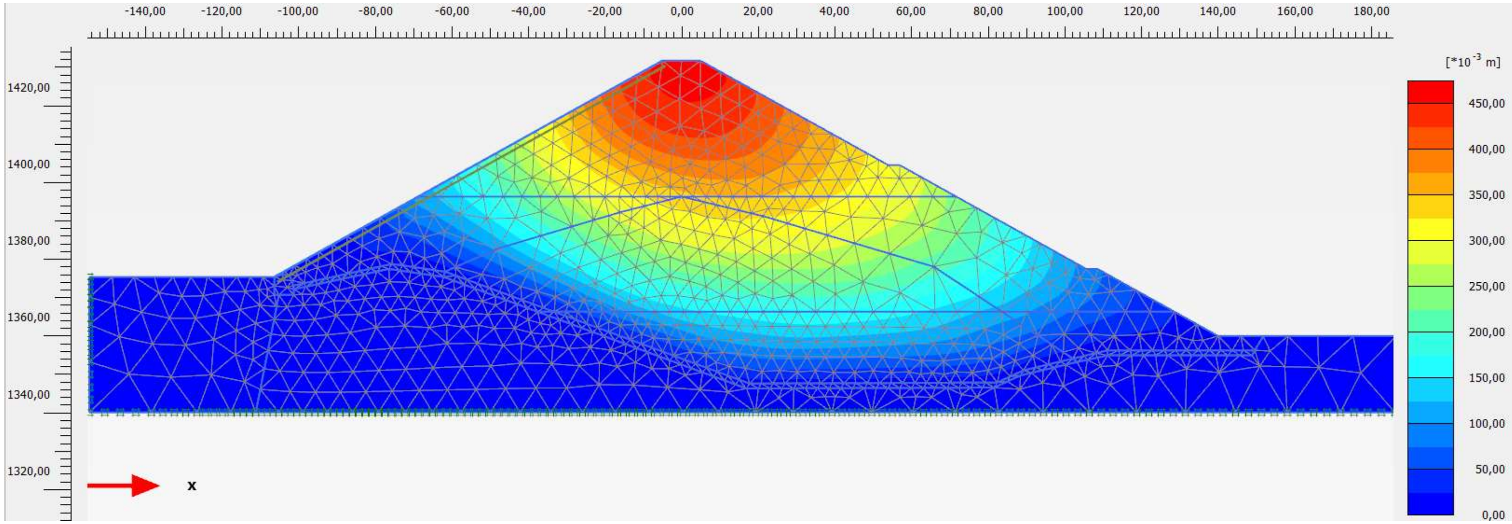


- Initial phase [InitialPhase]
- 01 Construction Stage-1 [Phase_1]
- 02 Construction Stage-2 [Phase_2]
- 03 Construction Stage-3 [Phase_3]
  - 04 Reservior EL 1424,5 masl [Phase_4]
    - **04-1 Dynamic 1deg Bitumonous [Phase_5]**
    - 04-2 Dyanmic 28deg Bitumonous [Phase_7]
  - 03-1 Dynam Empty reservior [Phase_6]

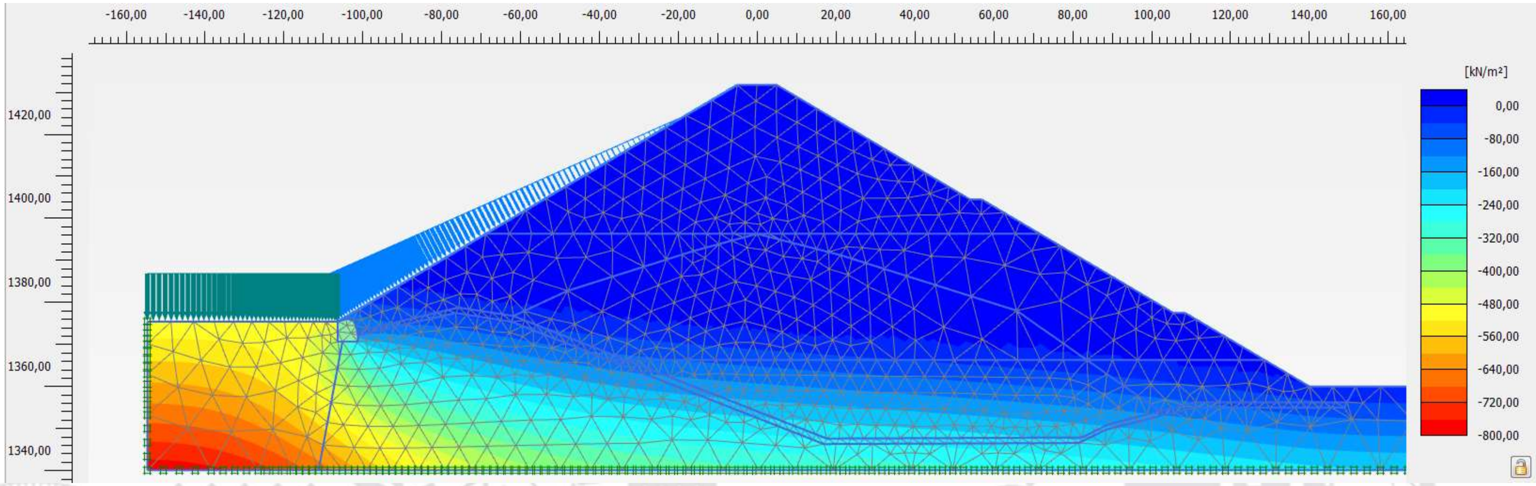


Results-Static

Total settlement after construction 0.46m



Pore pressure after impounding

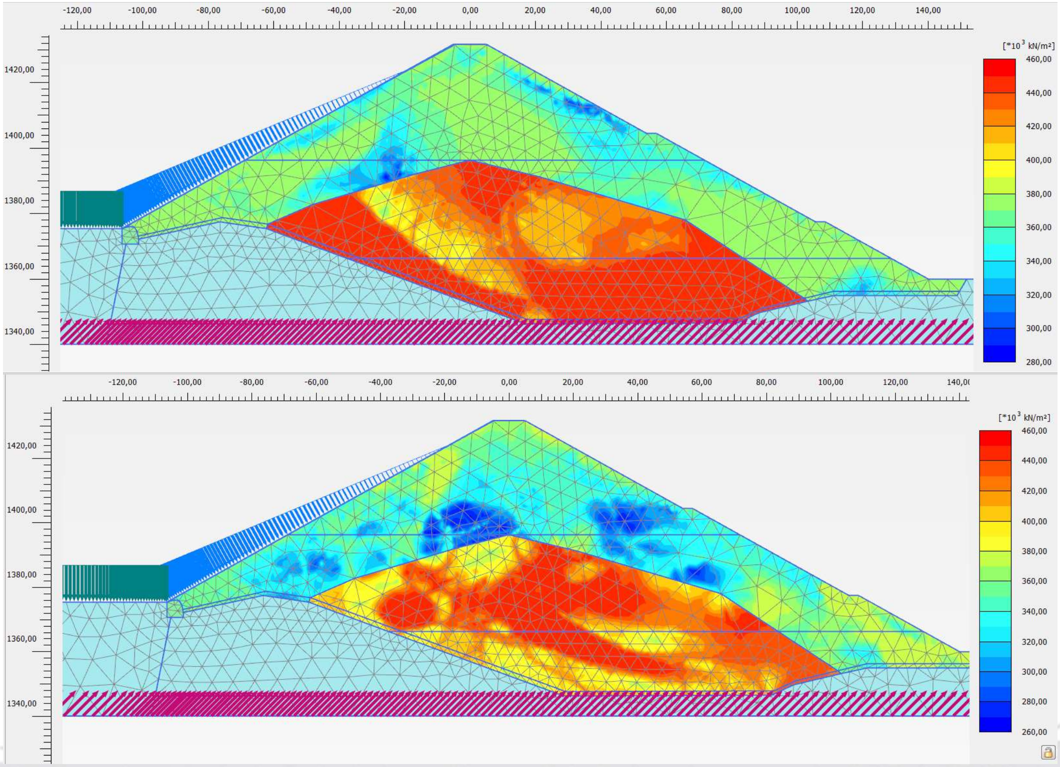


Results dynamic – fundamental frequency

EQ Friuli: 2.00 Hz
EQ Central Italy: 0.72 Hz

acceleration time histories are required as seismic evaluation parameters. Embankment dams have fundamental periods of vibration that often range between 0.5 and 1.5 second and, for use

Verification after the hand calculation (Lambe, T.W., Whitman (1976) summarised in Kramer's book 7.62). Dam fundamental frequency is about 1.6-1.92 Hz



Gazetas (1982) ... where the shear modulus increases as a po... ...cording to $G(z) = G_b(z/H)^m$, where G_b is the average shear modulus at the base of the dam. For such conditions, the nth natural circular frequency (assuming $h/H = 1$) is given by

$$\omega_n = \frac{\bar{v}_{ss}}{H}\frac{\beta_n}{8}(4+m)(2-m) \tag{7.62}$$

where $\bar{v}_{ss}$ is the average shear wave velocity of the soil in the dam and β_n is the nth root of a period relation (Dakoulas and Gazetas, 1985) tabulated in Table 7-2 for the first five modes of vibration.

Table 7-2 Values of β_n for First Five Modes of Vibration of an Earth Dam

	n				
m	1	2	3	4	5
0	2.404	5.520	8.654	11.792	14.931
$\frac{1}{2}$	2.903	6.033	9.171	12.310	15.451
$\frac{4}{7}$	2.999	6.133	9.273	12.413	15.544
$\frac{2}{3}$	3.142	6.283	9.525	12.566	15.708
1	3.382	7.106	10.174	13.324	16.471

Compacted clay
$v_s = 1200$ ft/sec

Figure E7.6

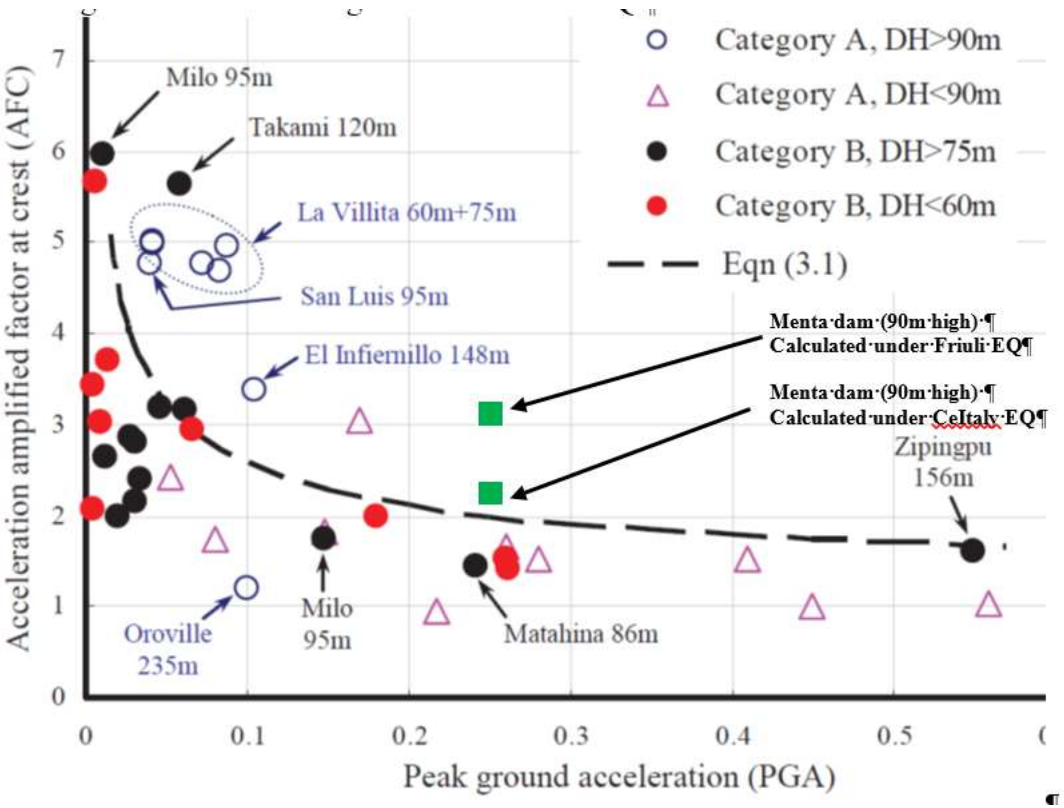
Equation (7.62) produces a fundamental period of

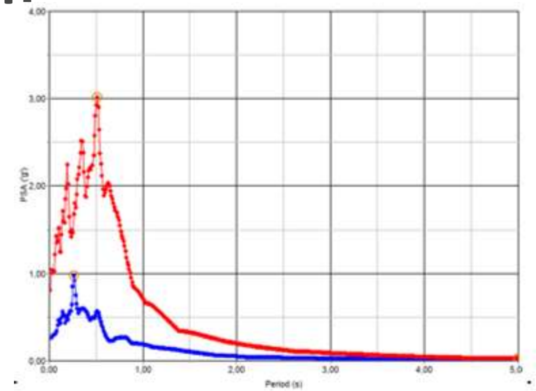
$$T_1 = \frac{16\pi}{(4+m)(2-m)\beta_1}\frac{H}{\bar{v}_{ss}} \tag{7.63}$$

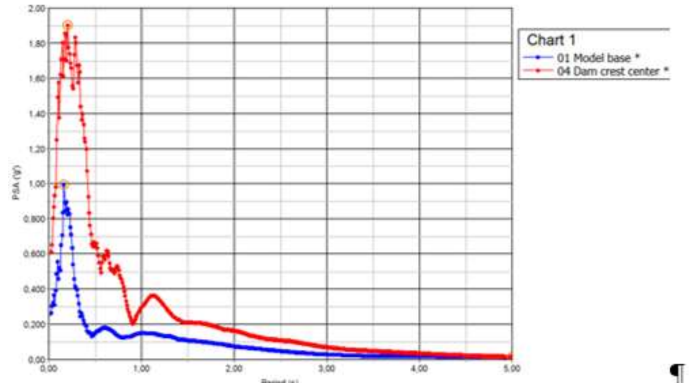
Example 7.6

Results dynamic – Crest to base amplification

EQ Friuli: 3.11
EQ Central Italy: 2.33 Hz



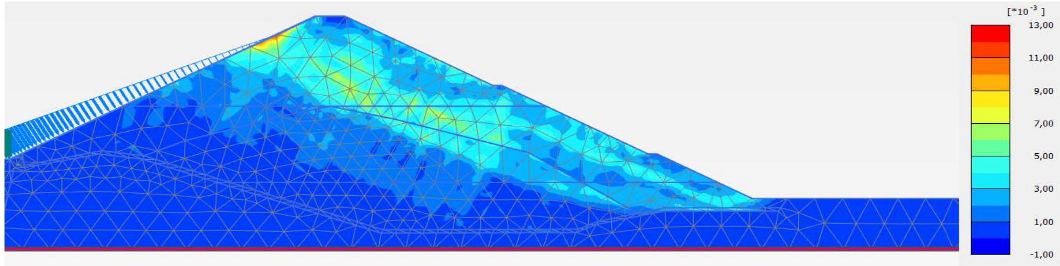




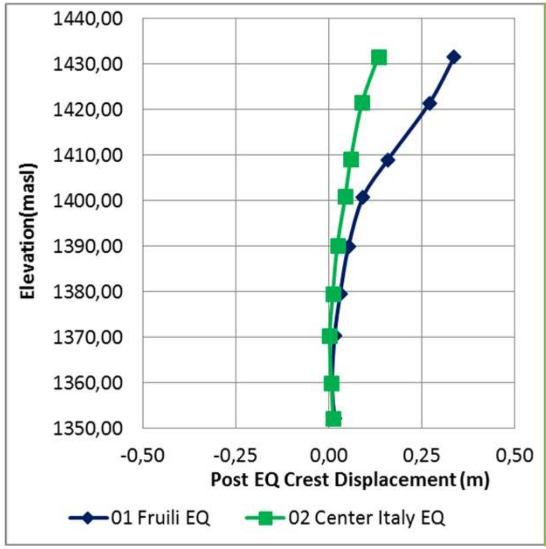
[8] Yu, L., Kong, X., Xu, B. (2012). Seismic Response Characteristics of Earth and Rockfill Dams, Proc. 15th World Conference on Earthquake Engineering, Lisbon

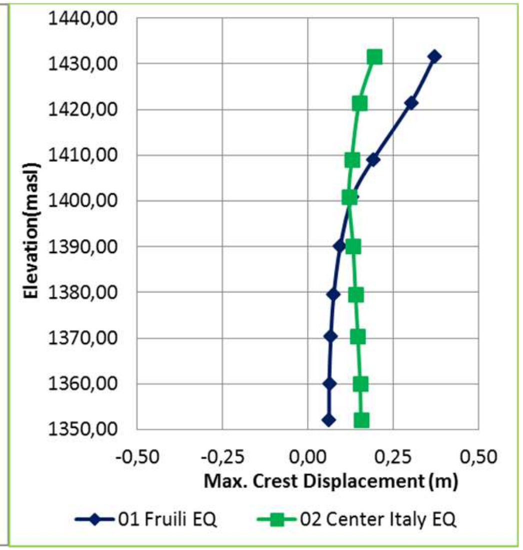
Results dynamic – γ_{max}, max. centre line deflection, post-EQ settlement

γ_{max}:
- EQ Friuli: 1.3%
- EQ Central Italy: 0.8 %



Max. centre line deflection:
- EQ Friuli: 0.37m
- EQ Central Italy: 0.19m





Post EQ settlement:
- EQ Friuli: 0.21m
- EQ Central Italy: 0.16m

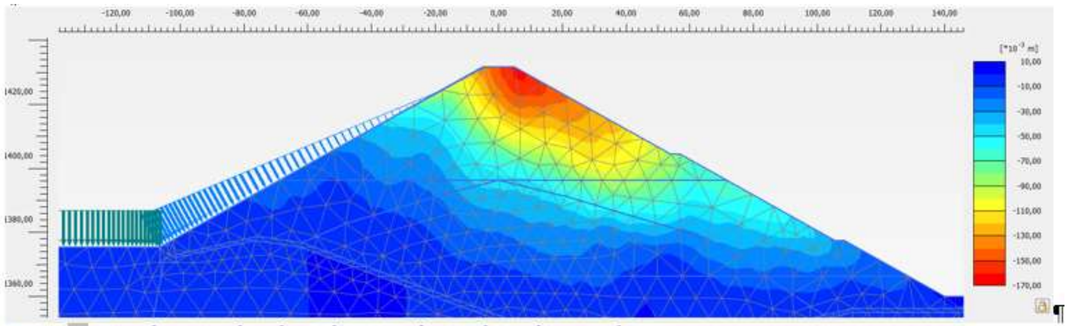
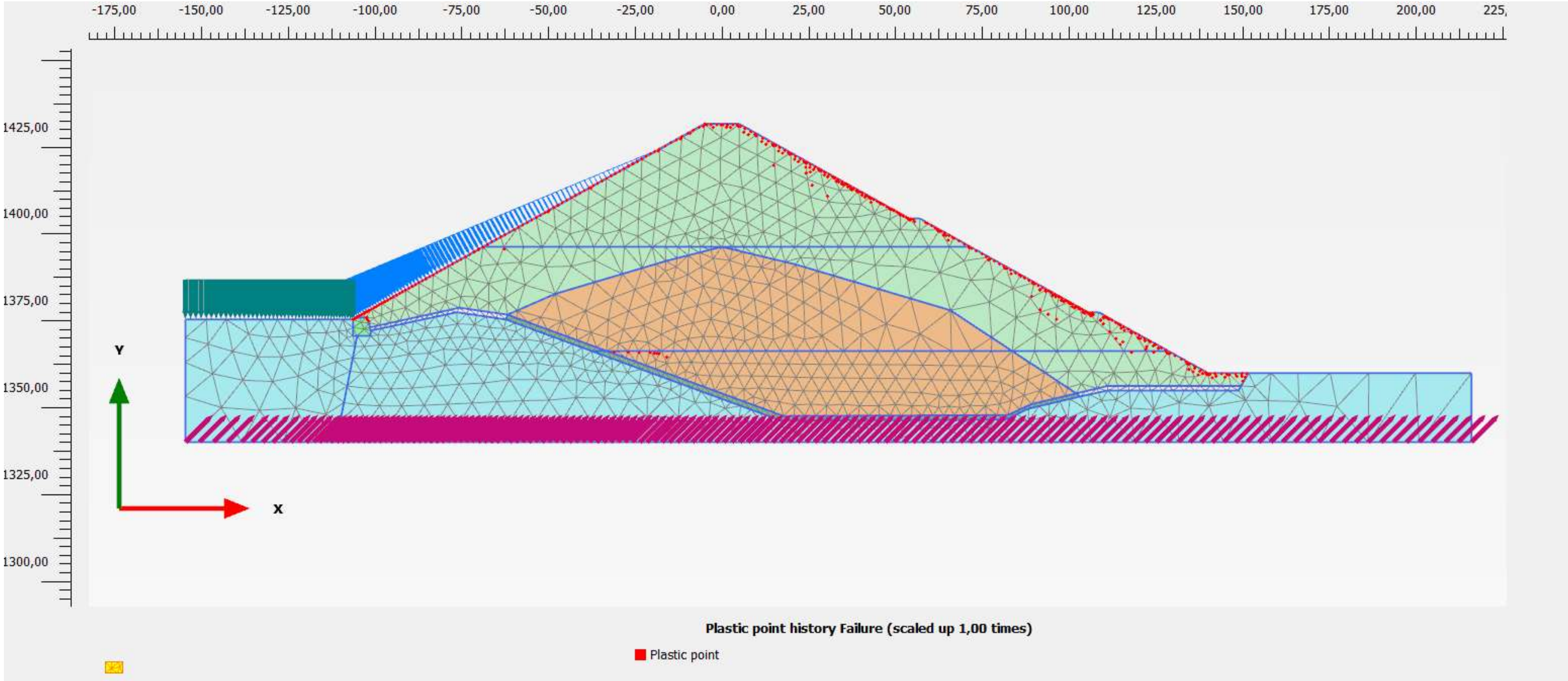


Figure 14 Typical post-earthquake settlement under Friuli EQ for example

Results dynamic – historical plasitc points during the earthquake



Results dynamic – Bituminous facing

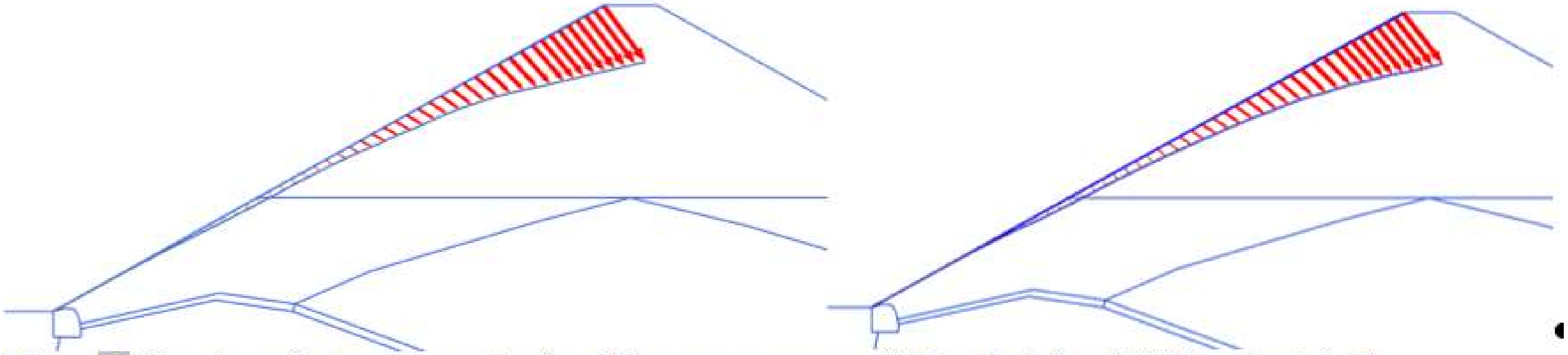


Figure 17 bituminous facing deformation for different temperatures (1°C at the left and 28°C at the right)

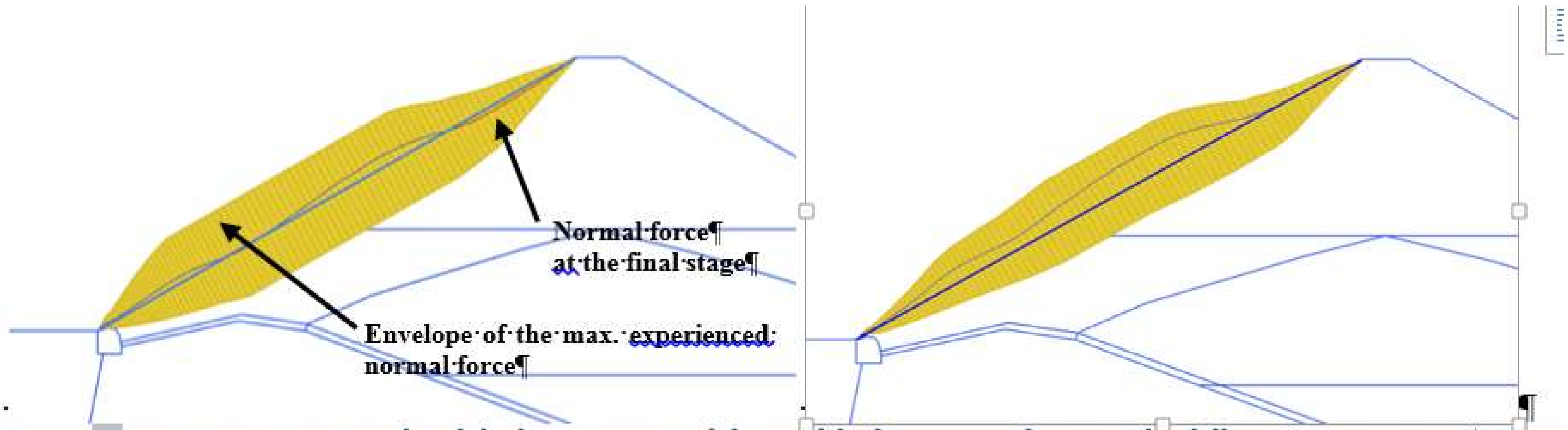


Figure 18 maximum experienced and the last step normal force of the bituminous facing at the different temperatures (1°C at the left and 28°C at the right)

Thank you for your attention ☺