ISP'7 (*)

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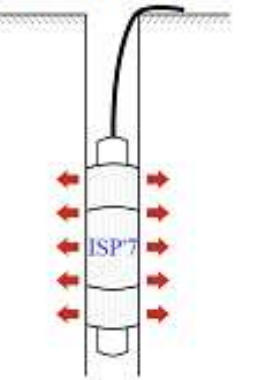

60 years of Pressuremeter
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Numerical modeling of cylindrical cavity expansion in rock mass based on the Hoek-Brown yield criterion

Sami Hamdi (Researcher - UCL)
Alain Holeyman (Professor - UCL)

Presented by Sami Hamdi (sami.hamdi@uclouvain.be)

UCL
Université catholique de Louvain

Outline

1. Rock masses Modeling

- Hoek-Brown (H-B) yield criterion
- Extended Drucker Prager (EDP) yield criterion
- Parameters for EDP yield criterion

2. Numerical axisymmetric modeling

- Triaxial tests and cylindrical cavity expansion
- Comparison with Lamé's solution

3. Experimental validation

- Comparison with pressuremeter tests
- Comparison with Pressiorama® chart

4. Conclusions

Rock masses Modeling

- Hoek-Brown yield criterion

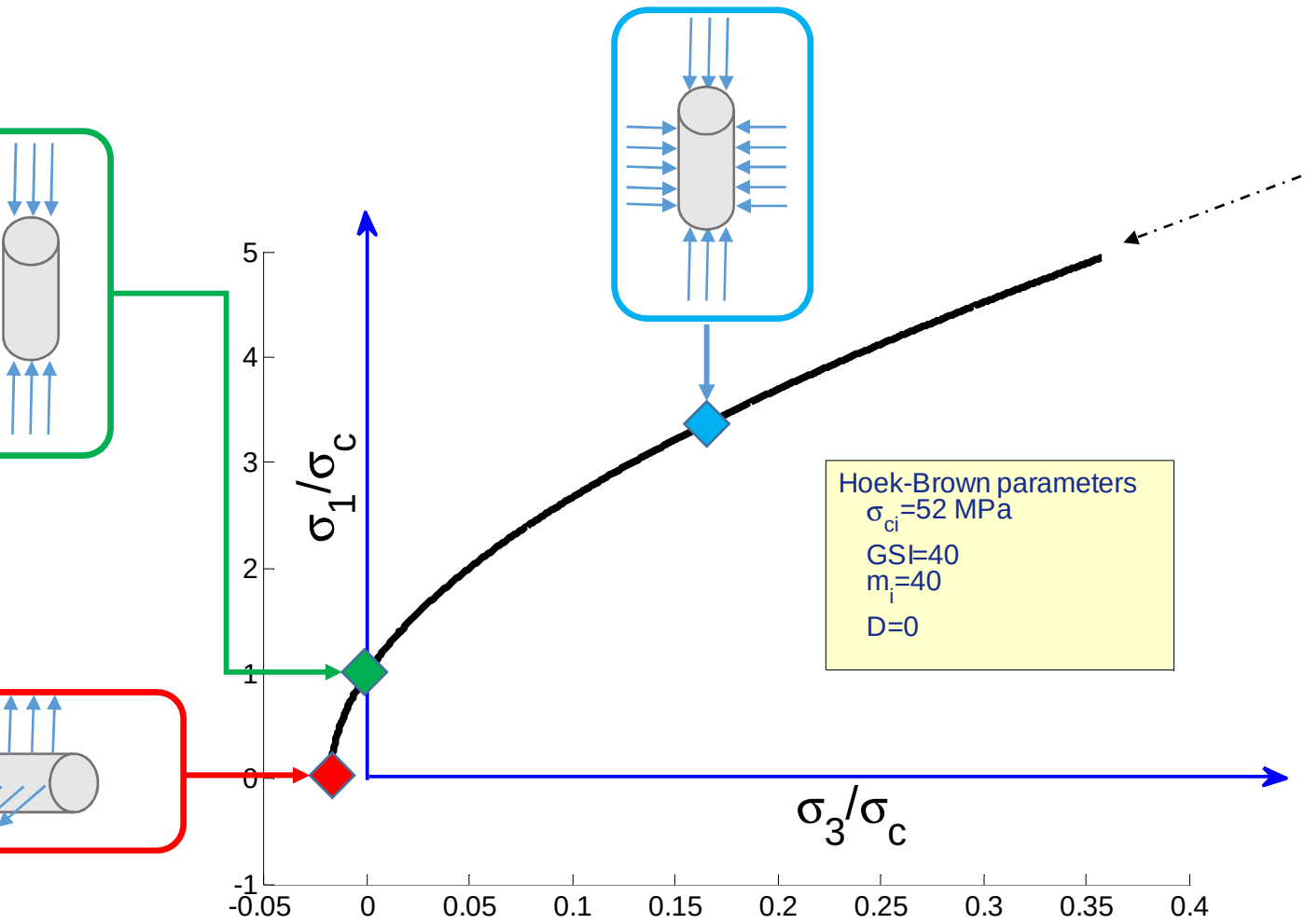


Figure.1 Hoek–Brown yield criterion

$$\sigma_1 = \sigma_3 + \sigma_{ci}\left(m_b \frac{\sigma_3}{\sigma_{ci}} + s\right)^{\alpha}$$

σ_1: major effective principal stress

σ_3 : minor effective principal stress

σ_{ci} : unconfined compressive strength of t
intact rock

m_b :reduced value of the material constar

m_i, α, s: material constants

Rock masses Modeling

- Extended Drucker-Prager yield criterion

$$F(p,q) = aq^b - p - p_t$$

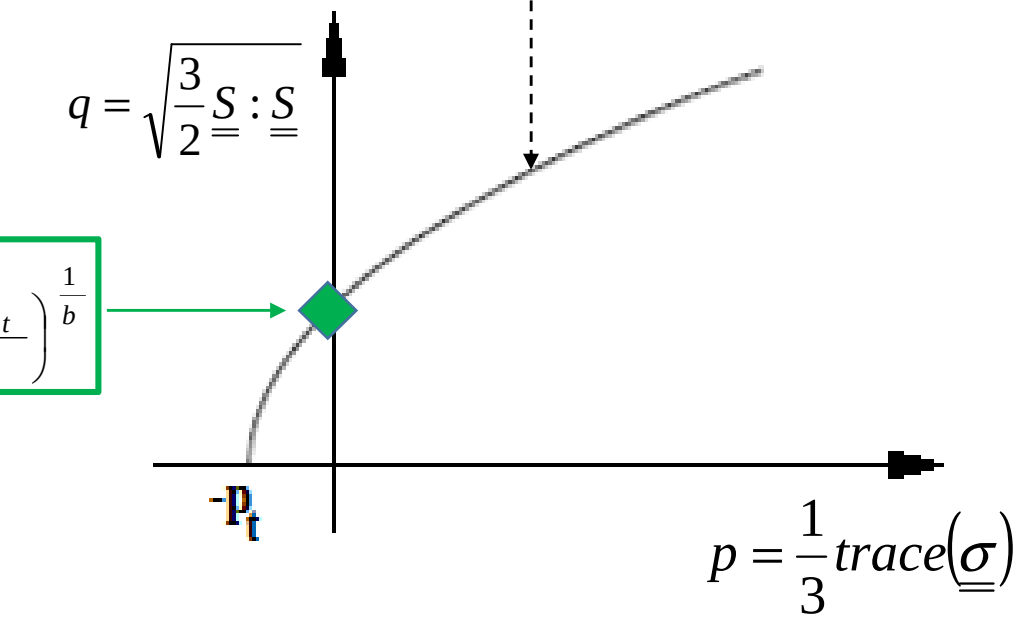


Figure.2 Extended Drucker-Prager yield criterion

$$\underline{\underline{\sigma}} = \begin{bmatrix} \sigma_3 & 0 & 0 \\ 0 & \sigma_3 & 0 \\ 0 & 0 & \sigma_1 \end{bmatrix} \qquad \underline{\underline{S}} = \frac{1}{3}\begin{bmatrix} \sigma_3 - \sigma_1 & 0 & \\ 0 & \sigma_3 - \sigma_1 & \\ 0 & 0 & 2\sigma_1 \end{bmatrix}$$

Triaxial conditions

$$\sigma_2 = \sigma_3$$

$$q = \sigma_1 - \sigma_3 \qquad p = \frac{1}{3}(\sigma_1 + 2\sigma_3)$$

Rock masses Modeling:

- Parameters calculation of the EDP yield criterion

H-B parameters

σ_{ci}

GSI

D=0

m_i

η_B

η_C

$$p = \frac{\sigma_{ci}}{6\eta^2}\left(m_b(3-\eta) + \sqrt{m_b^2(3-\eta)^2 + 36.s.\eta^2}\right)$$

$$q = \frac{\sigma_{ci}}{6\eta}\left(m_b(3-\eta) + \sqrt{m_b^2(3-\eta)^2 + 36.s.\eta^2}\right)$$

EDP paramete

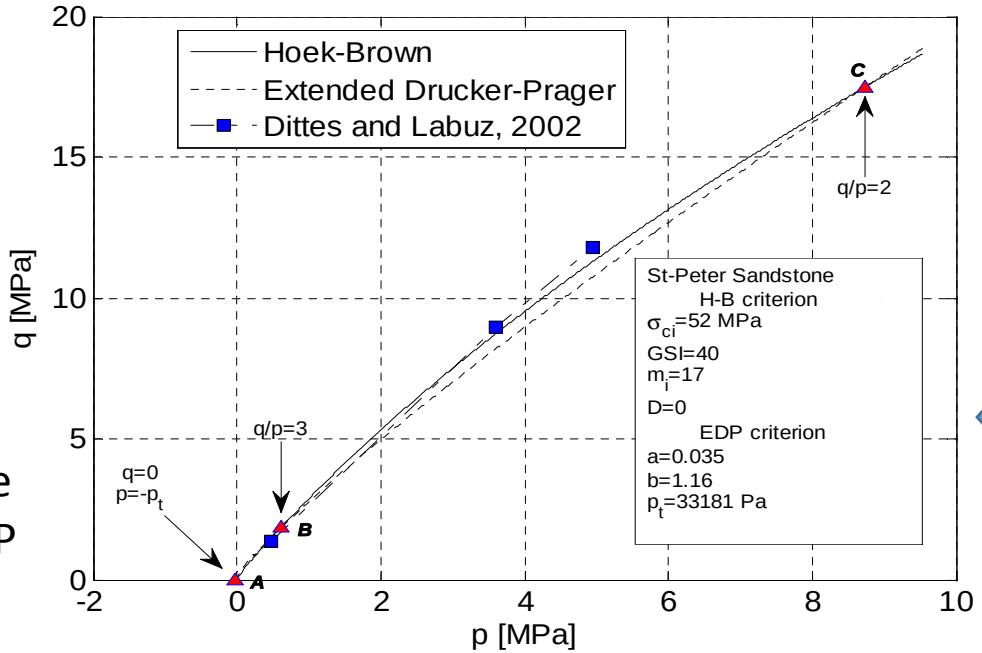
$$b = \frac{\ln\left(\frac{p_{\eta_B} + p}{p_{\eta_C} + p}\right.}{\ln\left(\frac{q_{\eta_B}}{q_{\eta_C}}\right)}$$

$$a = \frac{p_{\eta_B} + p}{q_{\eta_B}^{\ b}}$$

$$p_t = \frac{s\sigma_{ci}}{m_b}$$

$\eta_B = 3$

$\eta_B = 2$

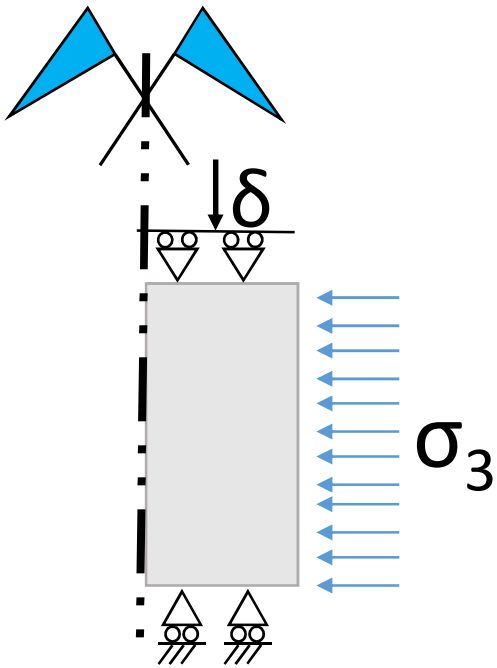


re. 3 Yield
on in p-q plane
th H-B and EDP

Rock masses Modeling

- Numerical triaxial tests

St-Peter sandstone parameters	
σ_{ci} = 52 MPa GSI = 40 m_i = 17 D=0	a = 0.035 b = 1.16 p_t =33 kPa E=4 GPa v=0.33
-B basic parameters	EDP parameters



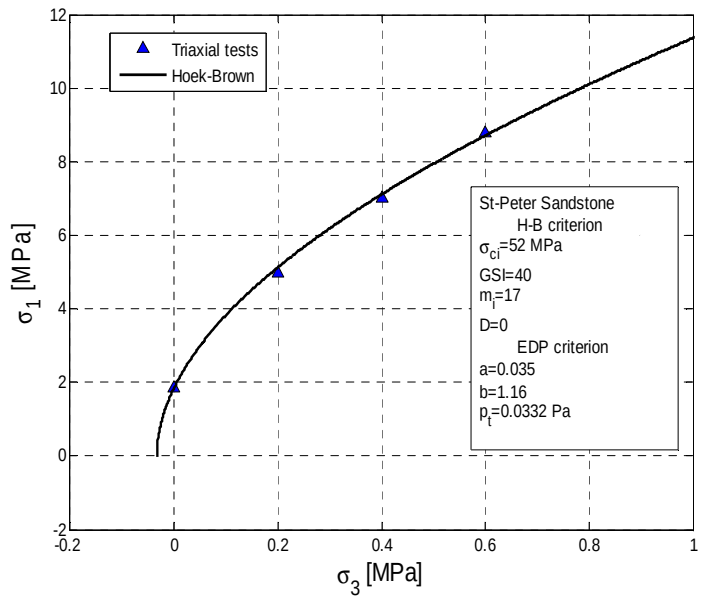


Figure. 4. Comparison between yield p
obtained by numerical triaxial compress
tests and the theoretical H-B yield criter

- Cylindrical cavity expansion

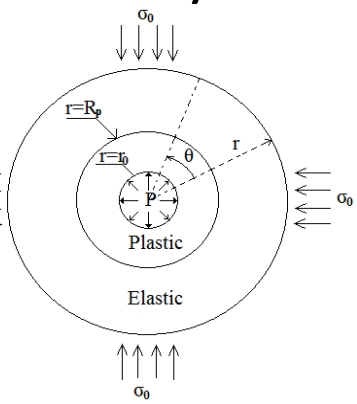


Figure. 5 Cylindrical cavity expansion in rock mass

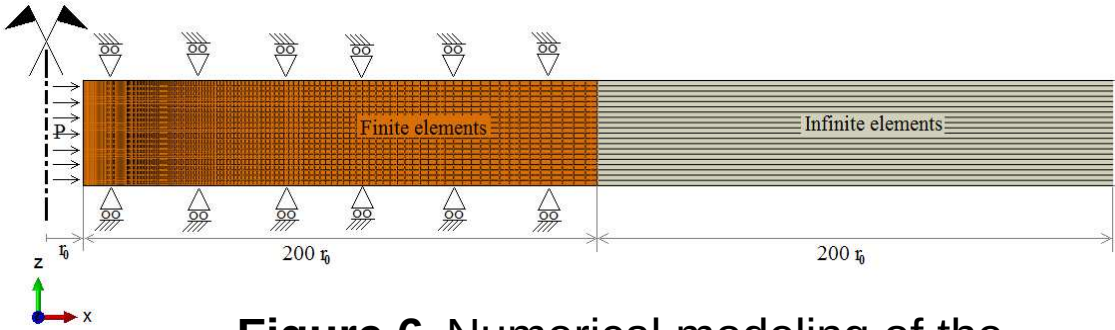


Figure.6. Numerical modeling of the cylindrical cavity expansion

Numerical axisymmetric modeling

- Comparison with Lamé's solution

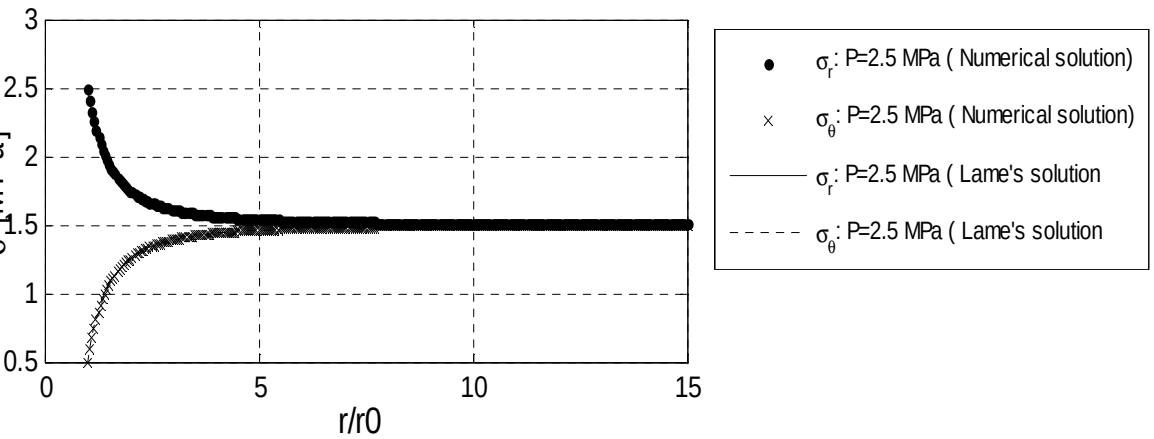
$$= \sigma_0 + (P - \sigma_0).\left(\frac{r_0}{r}\right)^2$$

$$= \sigma_0 - (P - \sigma_0).\left(\frac{r_0}{r}\right)^2$$

H-B yield criterion

Yielding pressure

$$P_{Yield} = \sigma_0 + \frac{\sigma_{ci}}{8}\left(-m_b + \sqrt{m_b^2 + 16s + 16m_b}\right.$$



gure. 7 Comparison of radial and circumferential esses with elastic analytical

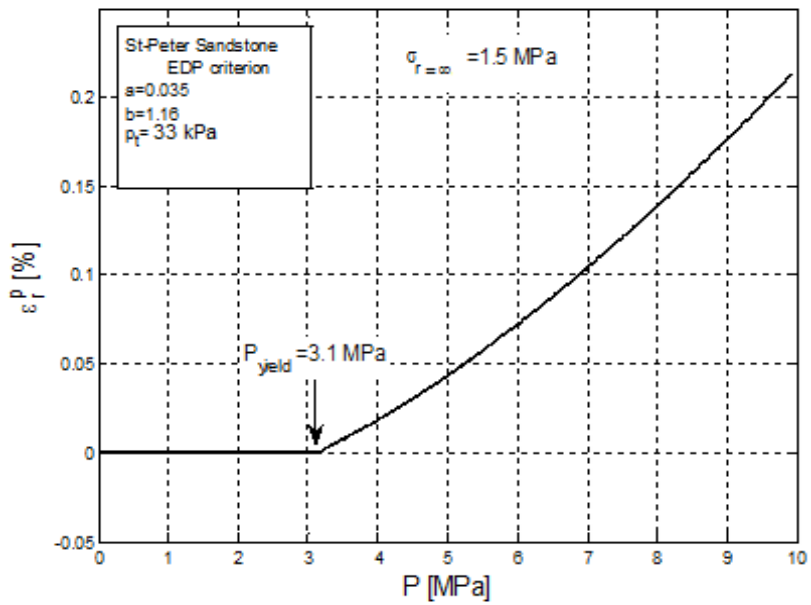


Figure. 8 Radial plastic strain at the cavity wall vs. applied pressure (ABAQUS)

St-P
sand

Experimental validation

- Comparison avec pressuremeter test performed in St-Peter sandstone

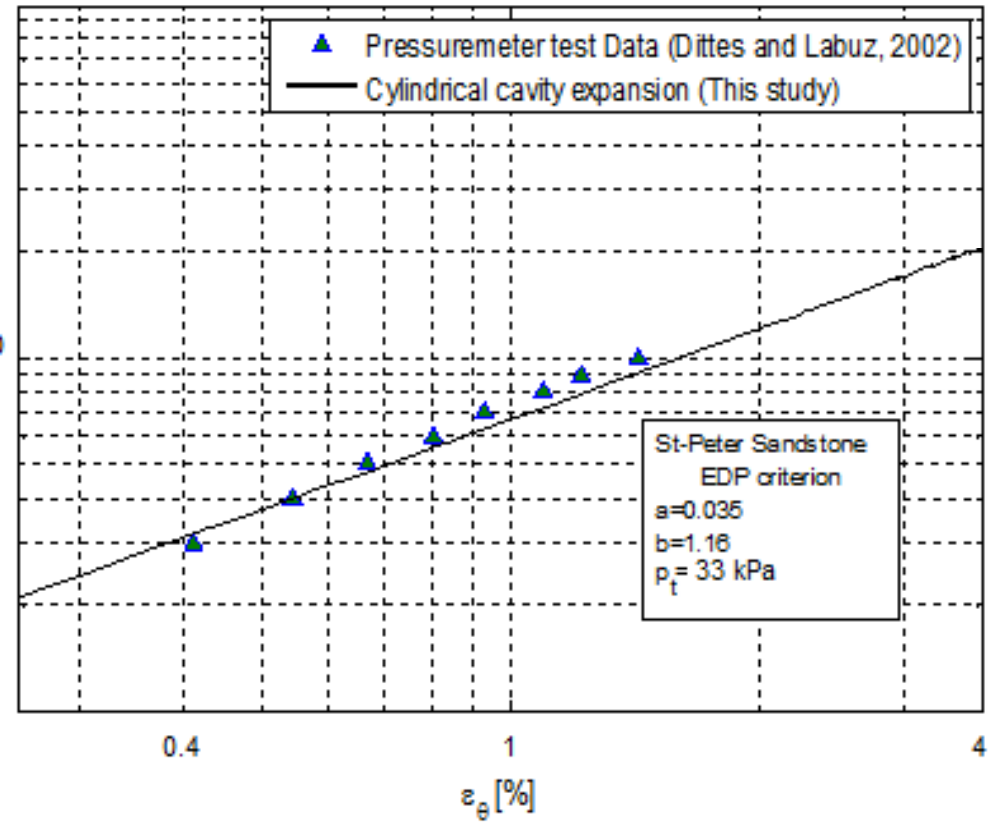


Figure. 9 Comparison between pressuremeter tests and present study

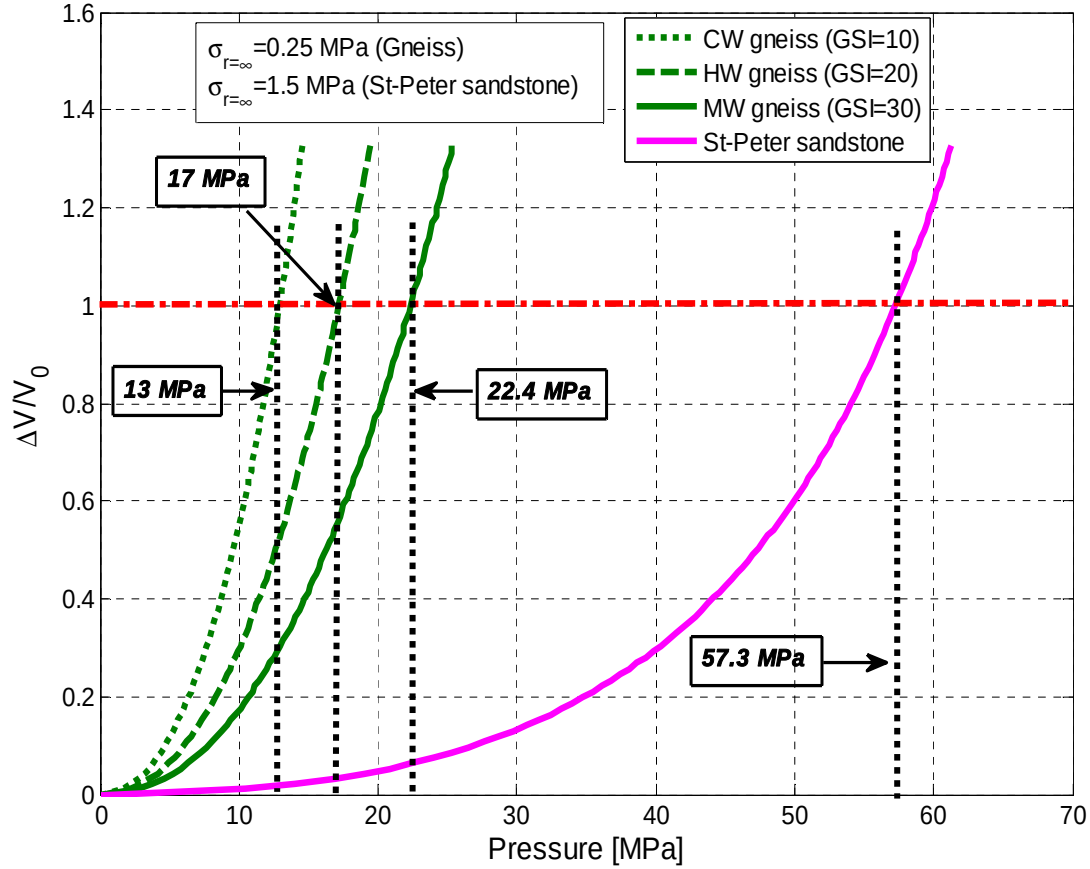


Figure. 10 Normalized probe volume variation as a function of the applied pressure for weathered gneiss and for St-Peter sandstone

Experimental validation

- Comparison with Pressiorama® chart (weathered gneiss)

- Moderately weathered Gneiss [GSI=30]
- Highly weathered Gneiss [GSI=20]
- Completely weathered Gneiss [GSI=10]
- St-Peter sandstone

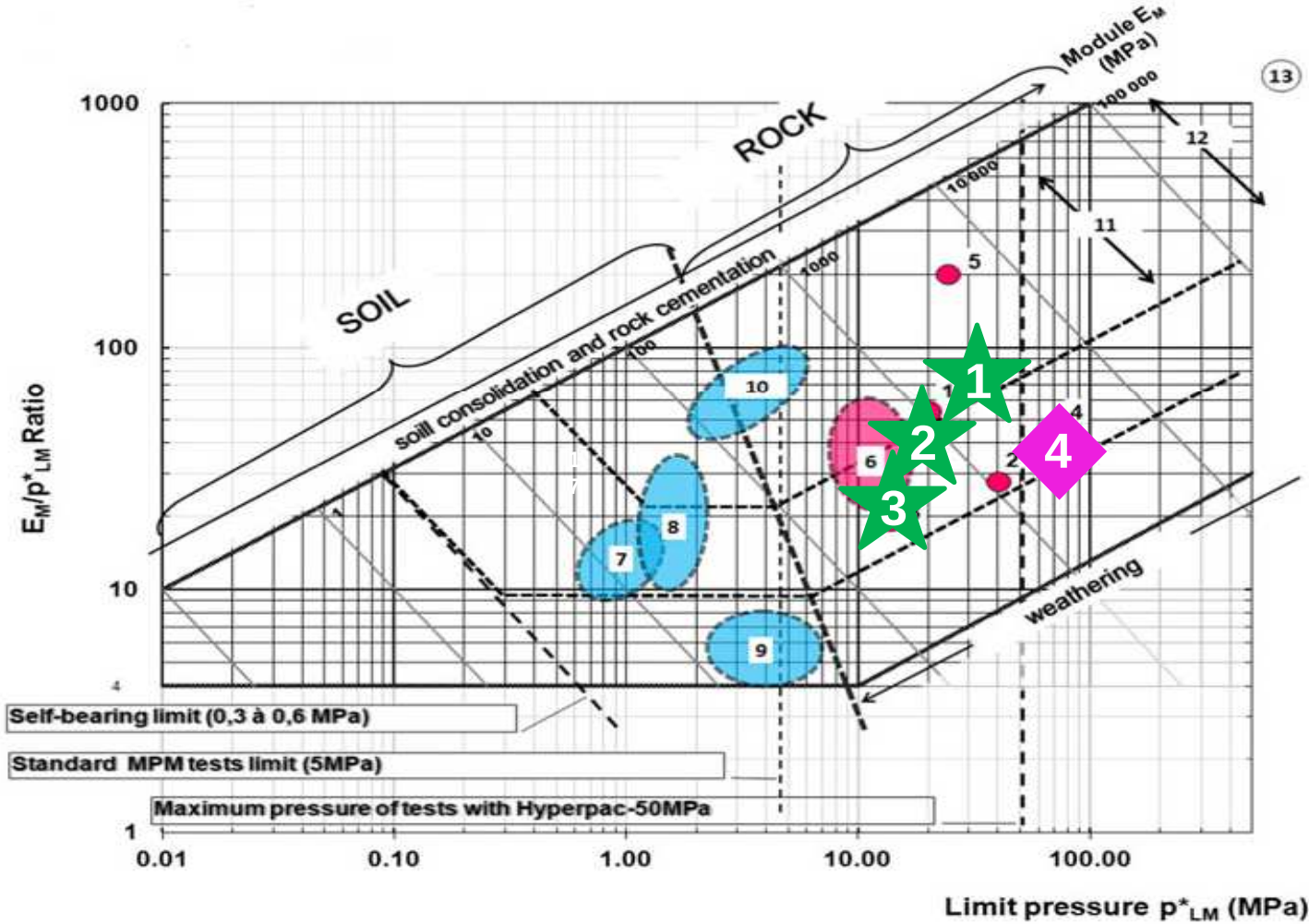


Figure. 11 Pressiorama® [E_m/P_{LM}, P_{LM}] "spectral" diagram ranging from soils to rocks (after Baud et Gambin 2013)

Conclusions

Extended Drucker-Prager (EDP) yield criterion allows a reasonable modeling of roc mass bahaviour based on the Hoek-Brown yield criterion Extended.

The proposed numerical model of cylindrical cavity expansion in rock mass gave good results compared to pressuremeter tests performed in St-Peter sandstone

Good agreement with Pressiorama® chart for weathered gneiss

During pressuremeter tests in rock masses, a small incremental pressure is needed i order to identify the yielding pressure.

The Limit pressure (P_L) is very high: revision of doubling of the probe volume criterion should be considered in the case of pressuremeter tests performed in rock masses