Rock Properties

Eurock 2018

24 May 2018

Ian Gray

ian@sigra.com.au www.sigra.com.au

Rock mechanics analysis

Based on limit state design

– sliding – toppling etc

Based on elastic analysis – with allowance for failure

Most analysis is by numerical models

- these require real rock propeties

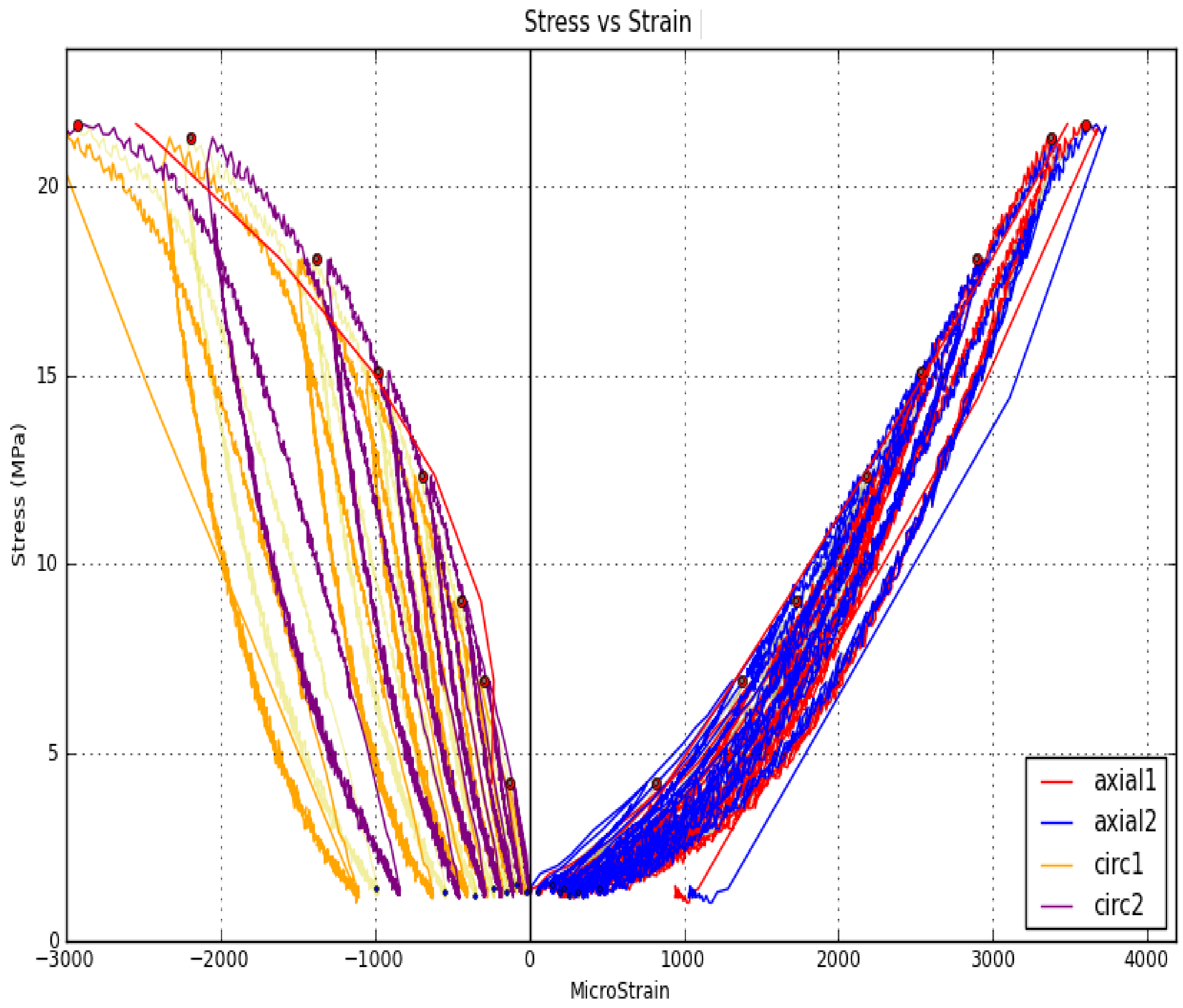
What rock properties are generally used in numerical models?

- Isotropic
- Linearly elastic
- Failure by Mohr-Coulomb or Hoek-Brown failure criteria
- Frictional sliding when failure has occurred

Cyclic uniaxial test for a typical weaker sandstone

nonlinear

exhibits permanent deformation



Real rocks have complex characters

- The IDEAL model is designed to suit hard crystalline rocks

- Many rocks exhibit far more complex behaviour
- Elastic nonlinearity
- Anisotropy
- Progressive loss of cohesion as failure takes place
- Progressive development of cohesion if strain ceases
- Fluid pressure effects which may be poroelastic or fracture related
- Shrinkage or swelling with loss/adsorption of water or gas

General equation of deformation of an elastic body

- $\left\{\varepsilon_{ij}\right\} = \left[C_{ijkl}\right]\{\sigma_{kl}\}$

- C_{ijkl} - 36 Terms of the compliance matrix

- These reduce to 21 because of symmetry

- model such behaviour as dilation or compaction – albeit by a series of linear elastic steps

- It is however very difficult to measure 21 parameters x multiple stress states

Orthotropic simplification of material behaviour – symmetric matrix 9 unknowns

- $$\begin{Bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ \gamma_{23} \\ \gamma_{31} \\ \gamma_{12} \end{Bmatrix} = \begin{bmatrix} \frac{1}{E_1} & -\frac{\nu_{21}}{E_2} & -\frac{\nu_{31}}{E_3} & 0 & 0 & 0 \\ -\frac{\nu_{12}}{E_1} & \frac{1}{E_2} & -\frac{\nu_{32}}{E_3} & 0 & 0 & 0 \\ -\frac{\nu_{13}}{E_1} & -\frac{\nu_{23}}{E_2} & \frac{1}{E_3} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{23}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{31}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{12}} \end{bmatrix} \begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \tau_{23} \\ \tau_{31} \\ \tau_{12} \end{Bmatrix}$$

Assumptions and observations to be able to solve for unknown compliance matrix terms

- Look at the sample and find an axis of symmetry
- Ensure

- $\frac{v_{ij}}{E_i} = \frac{v_{ji}}{E_j}$ - From symmetry -
- $v_{ij}v_{ji} = v_a^2$
- $v_{ji} = \sqrt{\frac{E_j}{E_i}}v_a$

Solving for the orthotropic elastic behaviour

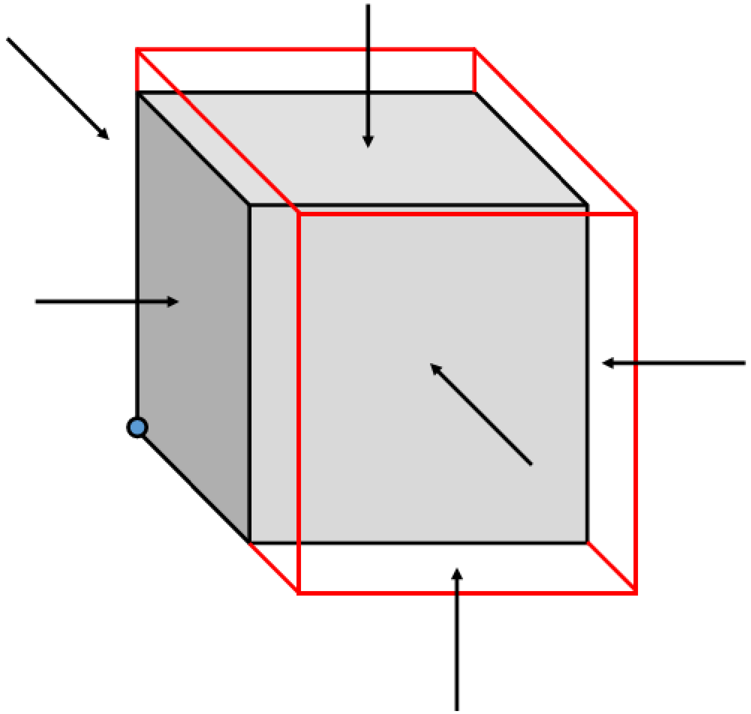
- $\Delta\varepsilon_{ii} = \frac{1}{E_i}\Delta\sigma_{ii} - \frac{v_{ji}}{E_j}\Delta\sigma_{jj} - \frac{v_{ki}}{E_k}\Delta\sigma_{kk}$

- $E_i = \frac{1}{\Delta\varepsilon_{ii}}(\Delta\sigma_{ii} - v_{ij}\Delta\sigma_{ji} - v_{ik}\Delta\sigma_{kk})$

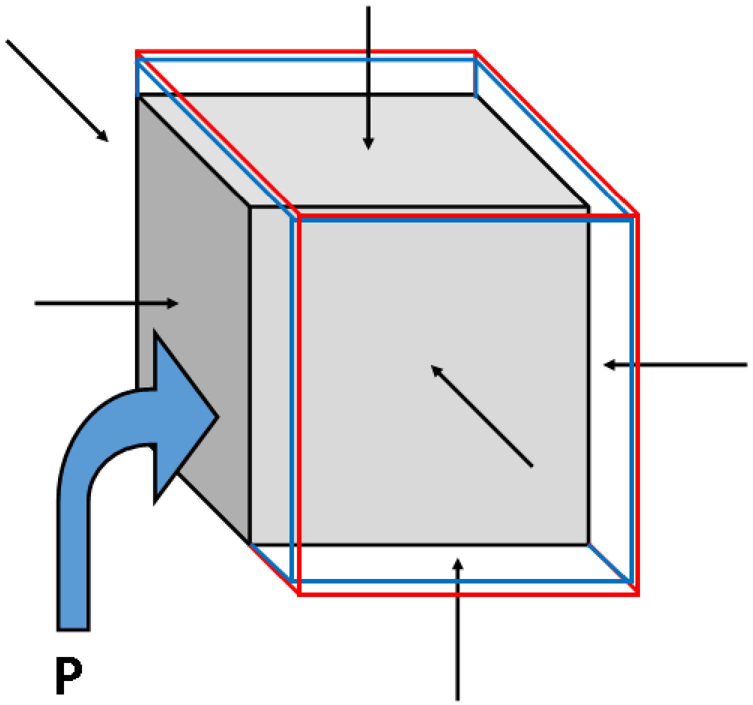
- $residual = fn(E_i) = \frac{1}{\Delta\varepsilon_{ii}}\left(\Delta\sigma_{ii} - \sqrt{\frac{E_i}{E_j}}v_a\Delta\sigma_{jj} - \sqrt{\frac{E_i}{E_k}}v_a\Delta\sigma_{kk}\right) - E_i$

Sigra

Deformation under a unit stress



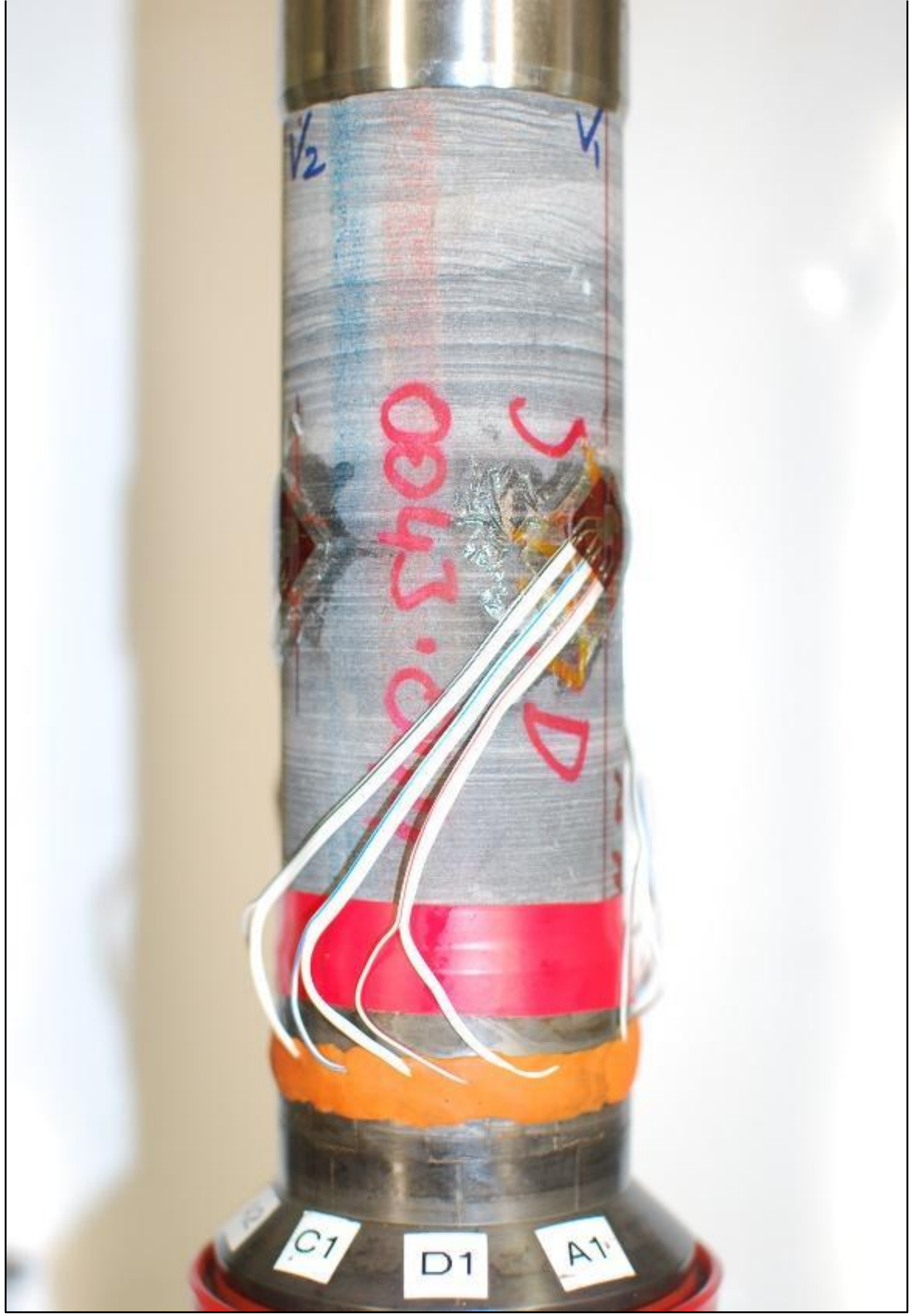
Recovery under unit fluid pressure
Poroelastic behaviour



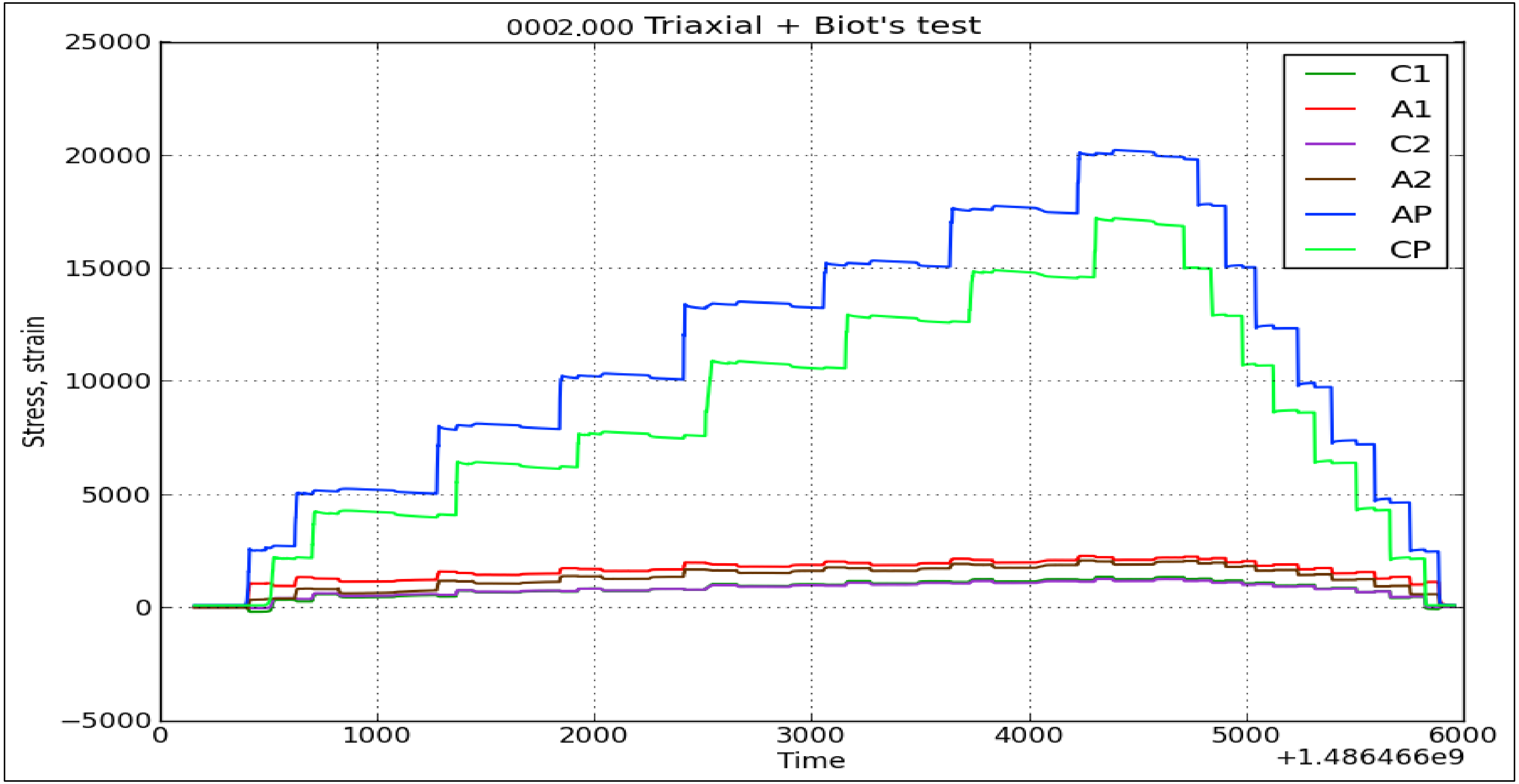
Solving for poroelastic behaviour

- $$\begin{bmatrix} \frac{1}{E_1} & -\frac{v_{21}}{E_2} & -\frac{v_{31}}{E_3} \\ -\frac{v_{12}}{E_1} & \frac{1}{E_2} & -\frac{v_{32}}{E_3} \\ -\frac{v_{13}}{E_1} & -\frac{v_{23}}{E_2} & \frac{1}{E_3} \end{bmatrix} \begin{Bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{Bmatrix} = \begin{Bmatrix} \left(\frac{1}{E_1}\Delta\sigma_{11} - \frac{v_{21}}{E_2}\Delta\sigma_{22} - \frac{v_{31}}{E_3}\Delta\sigma_{33} - \Delta\varepsilon_{11} \right)/\Delta P \\ \left(-\frac{v_{12}}{E_1}\Delta\sigma_{11} + \frac{1}{E_2}\Delta\sigma_{22} - \frac{v_{32}}{E_3}\Delta\sigma_{33} - \Delta\varepsilon_{22} \right)/\Delta P \\ \left(-\frac{v_{13}}{E_1}\Delta\sigma_{11} - \frac{v_{23}}{E_2}\Delta\sigma_{22} + \frac{1}{E_3}\Delta\sigma_{33} - \Delta\varepsilon_{33} \right)/\Delta P \end{Bmatrix}$$

Fine grained silty sandstone to be triaxially tested



Axial and confining loading sequence with strains and gas pressurisation cycles



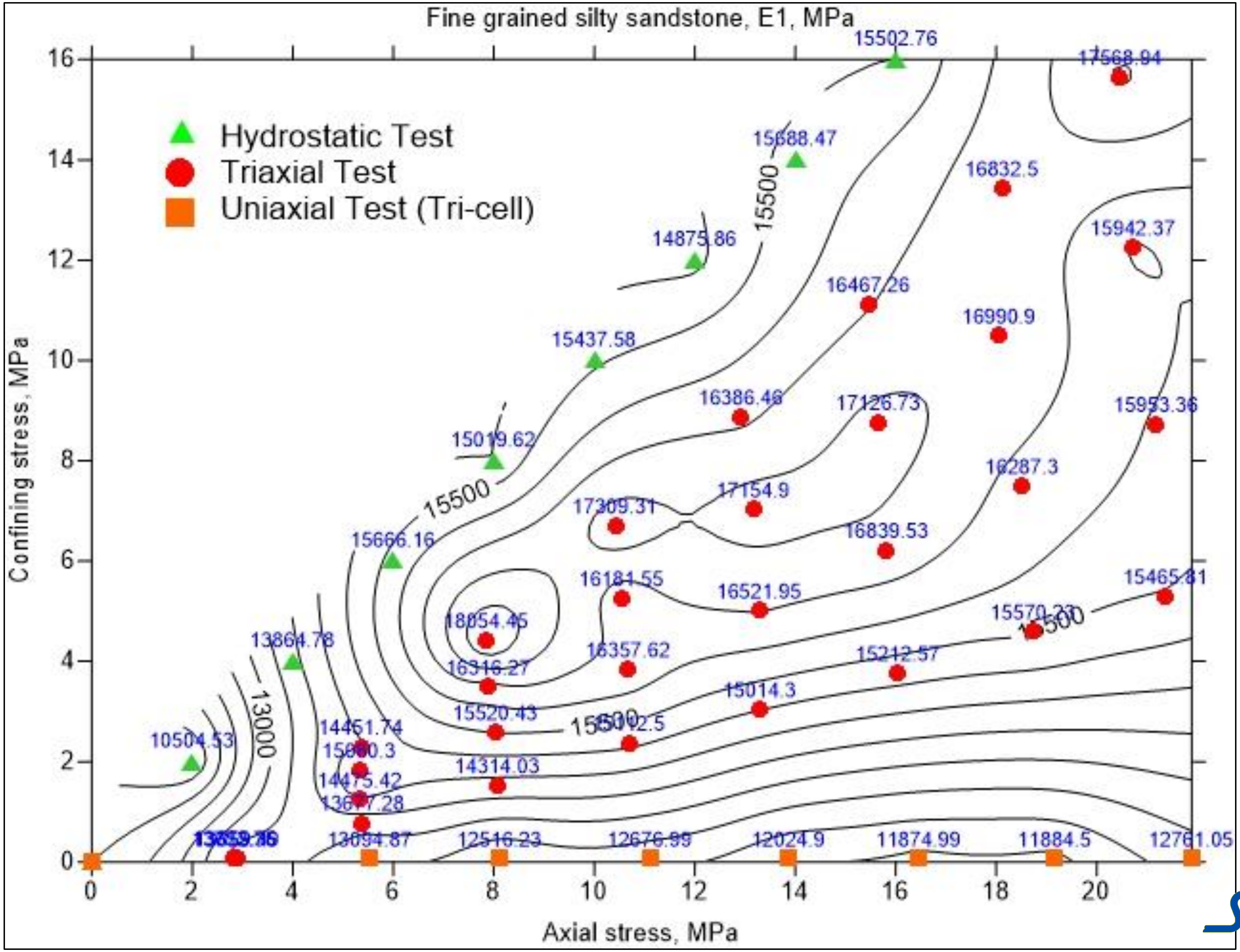
Sigra

Hydrostatic test phyllite sample in silicone resin

Sigra

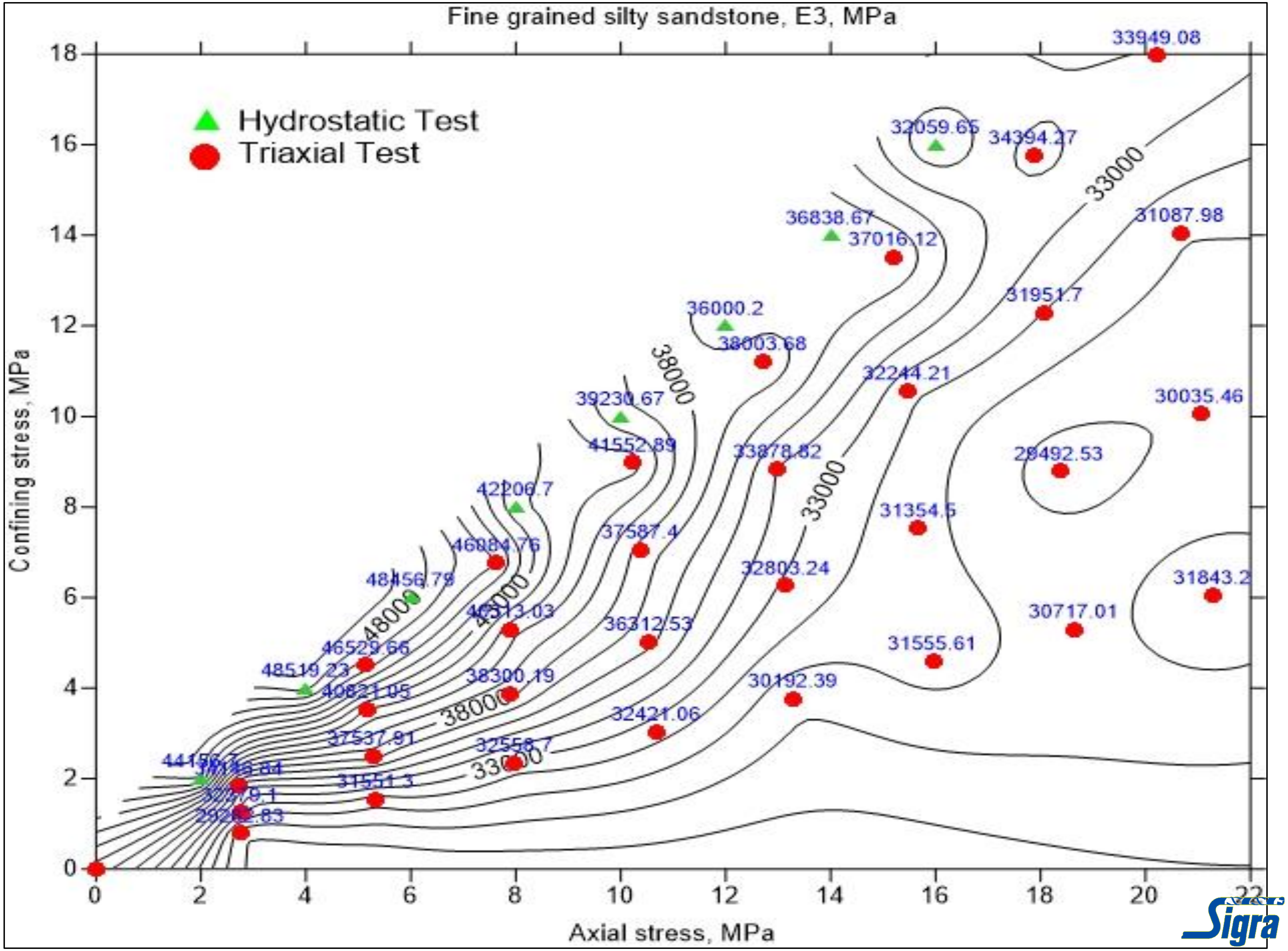
Fine grained silty sandstone

E_1



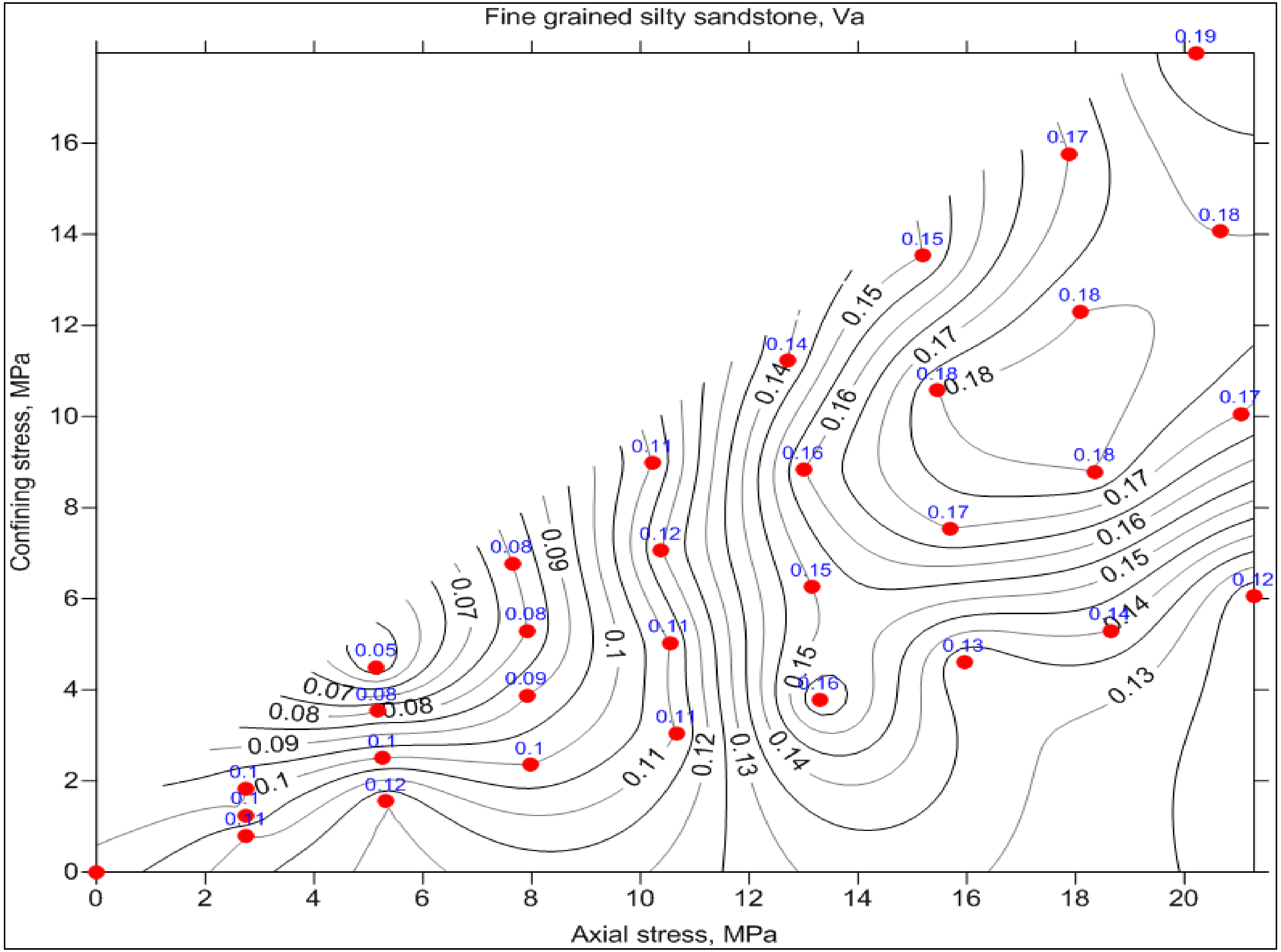
Fine grained silty sandstone

E_3



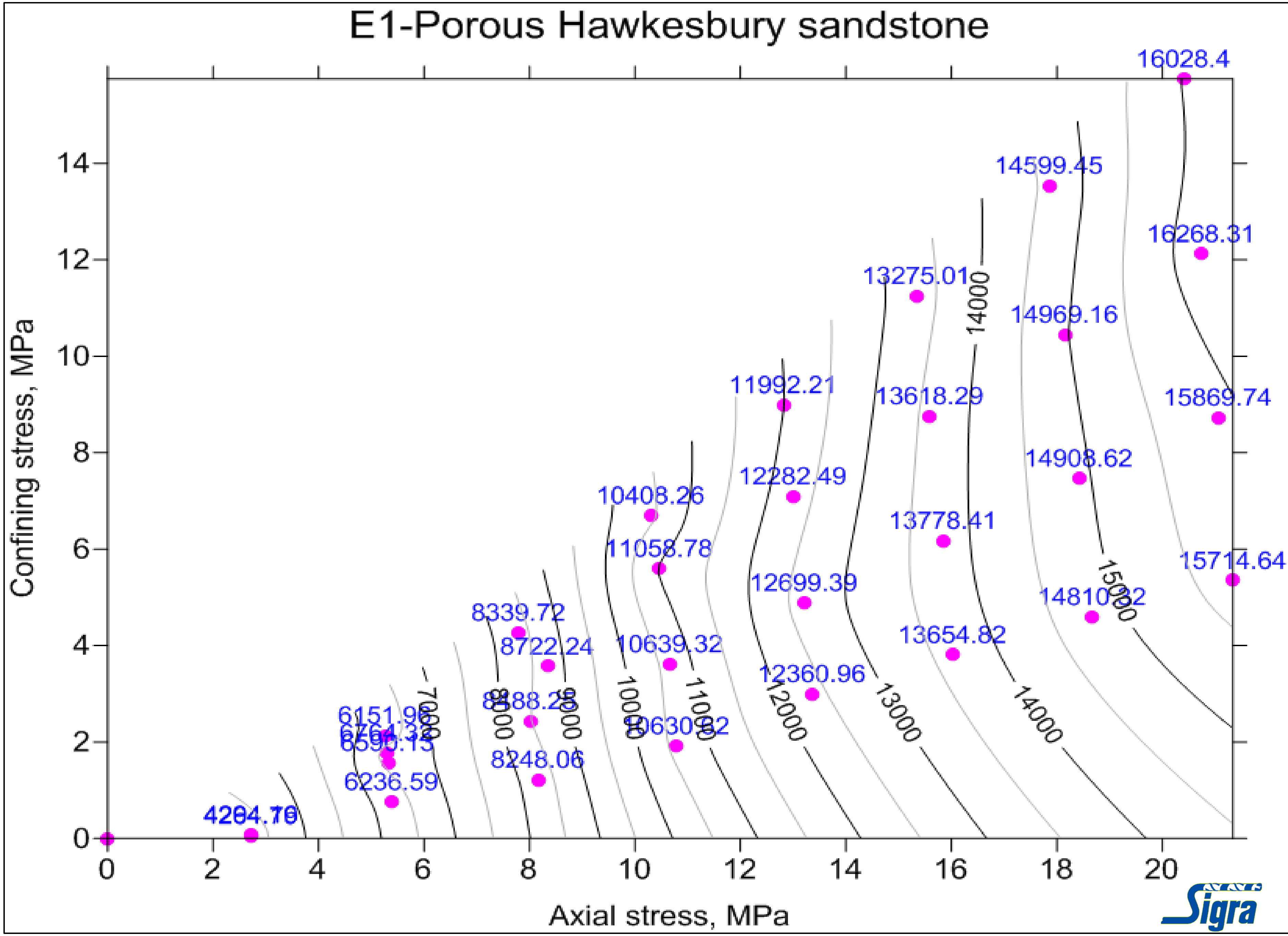
Fine grained silty sandstone

v_a



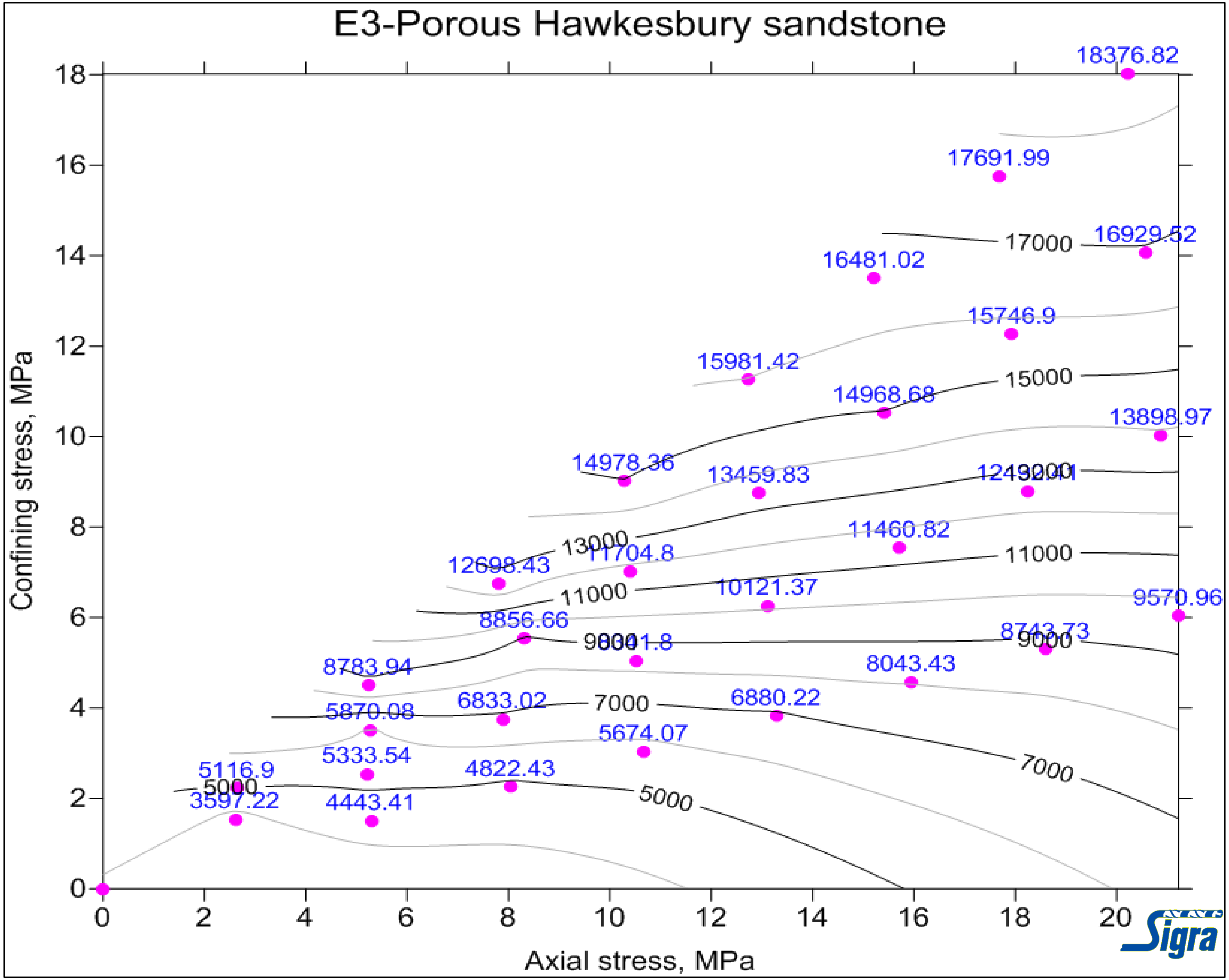
Porous Hawkesbury sandstone

E_1



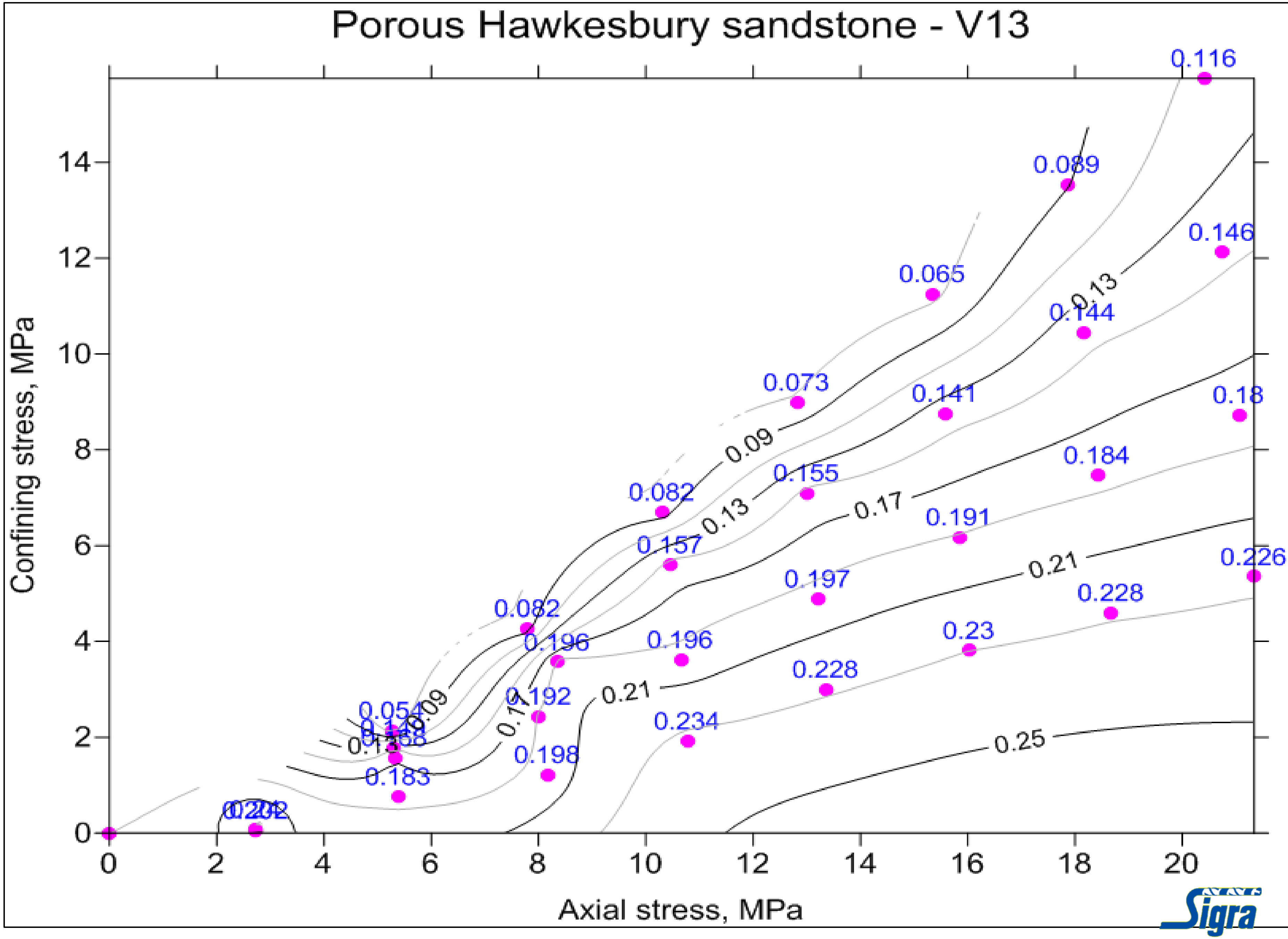
Porous Hawkesbury sandstone

E_3



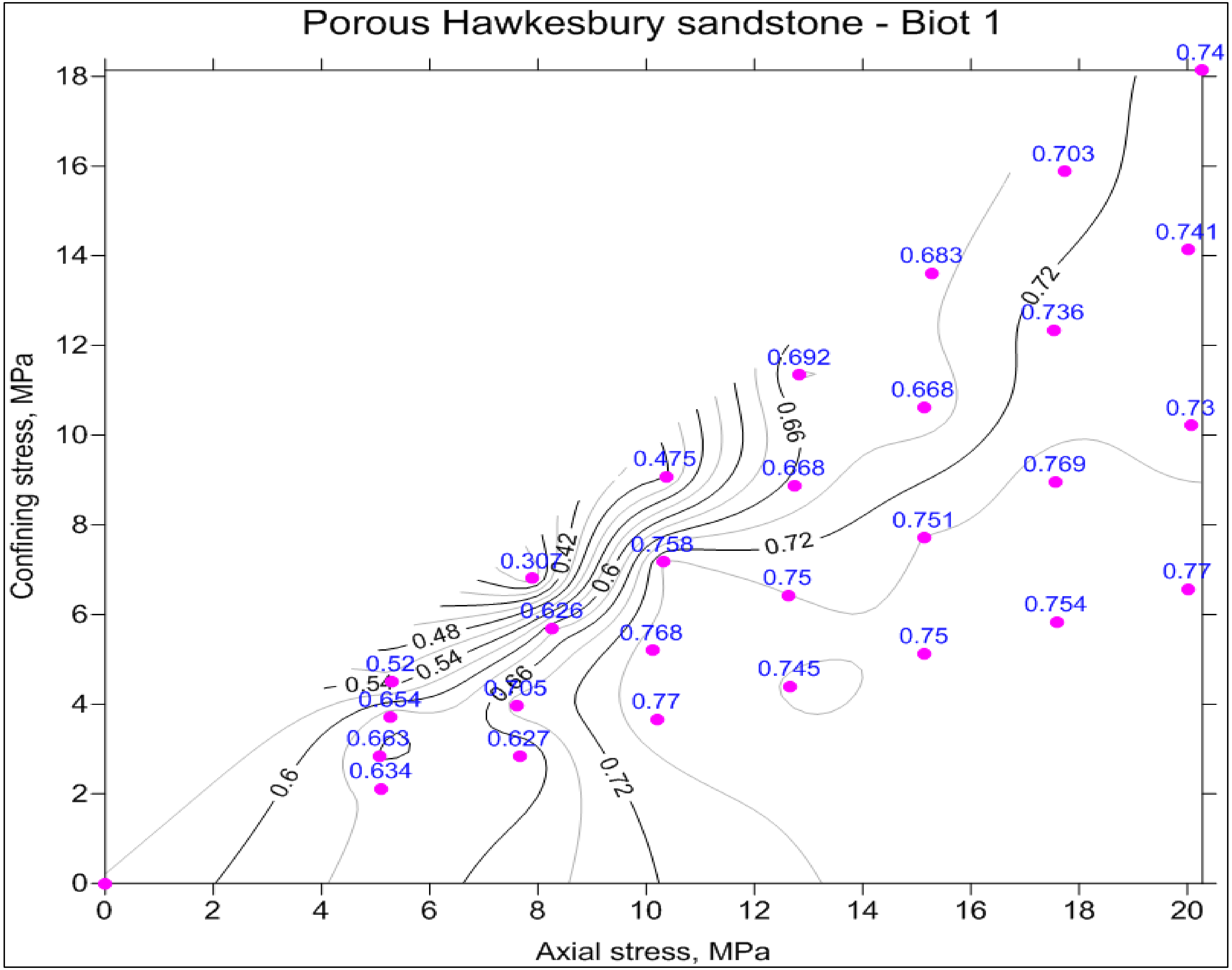
Porous Hawkesbury sandstone

Poisson's ratio ν_{13}



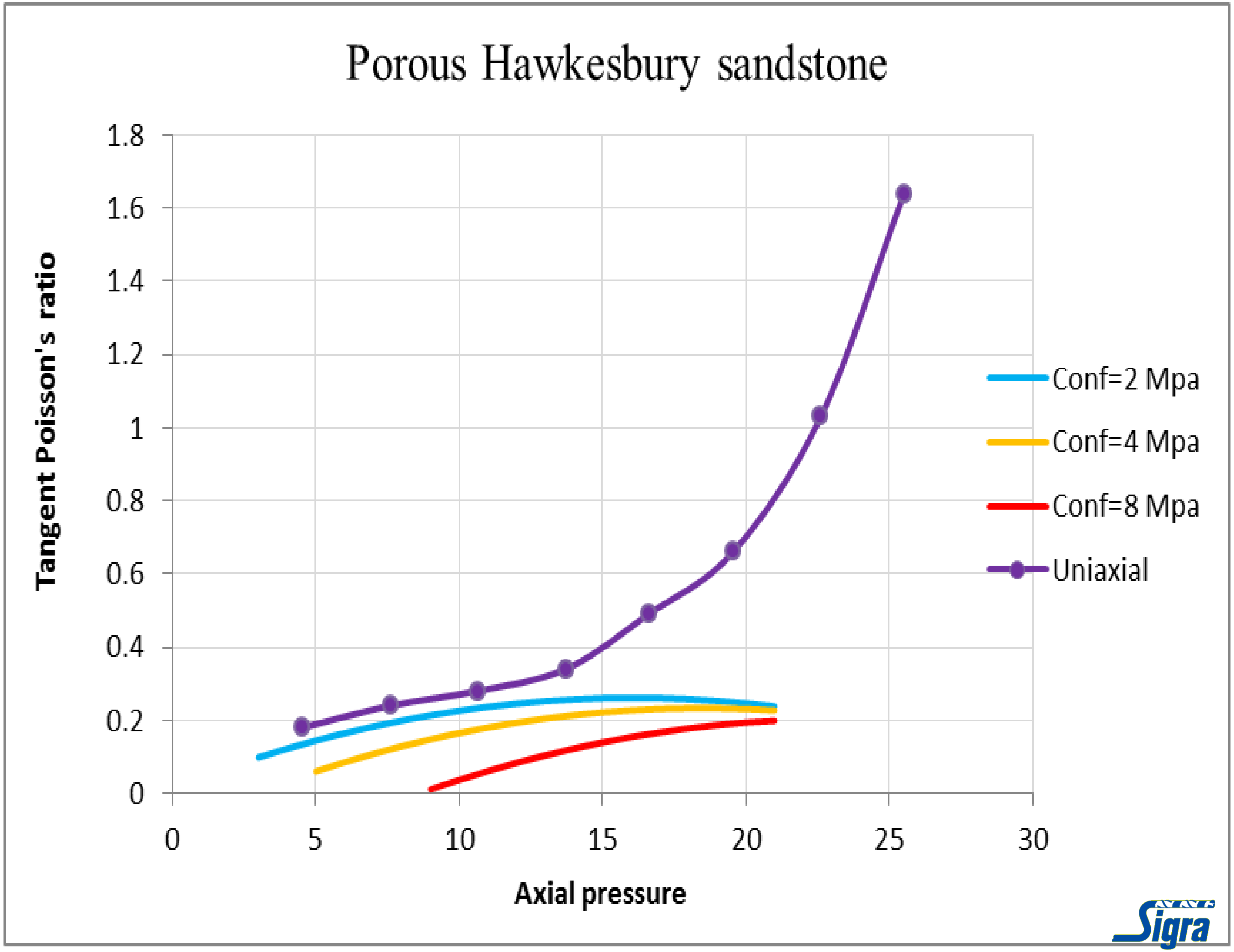
Porous Hawkesbury sandstone

Poroelastic coefficient α_1

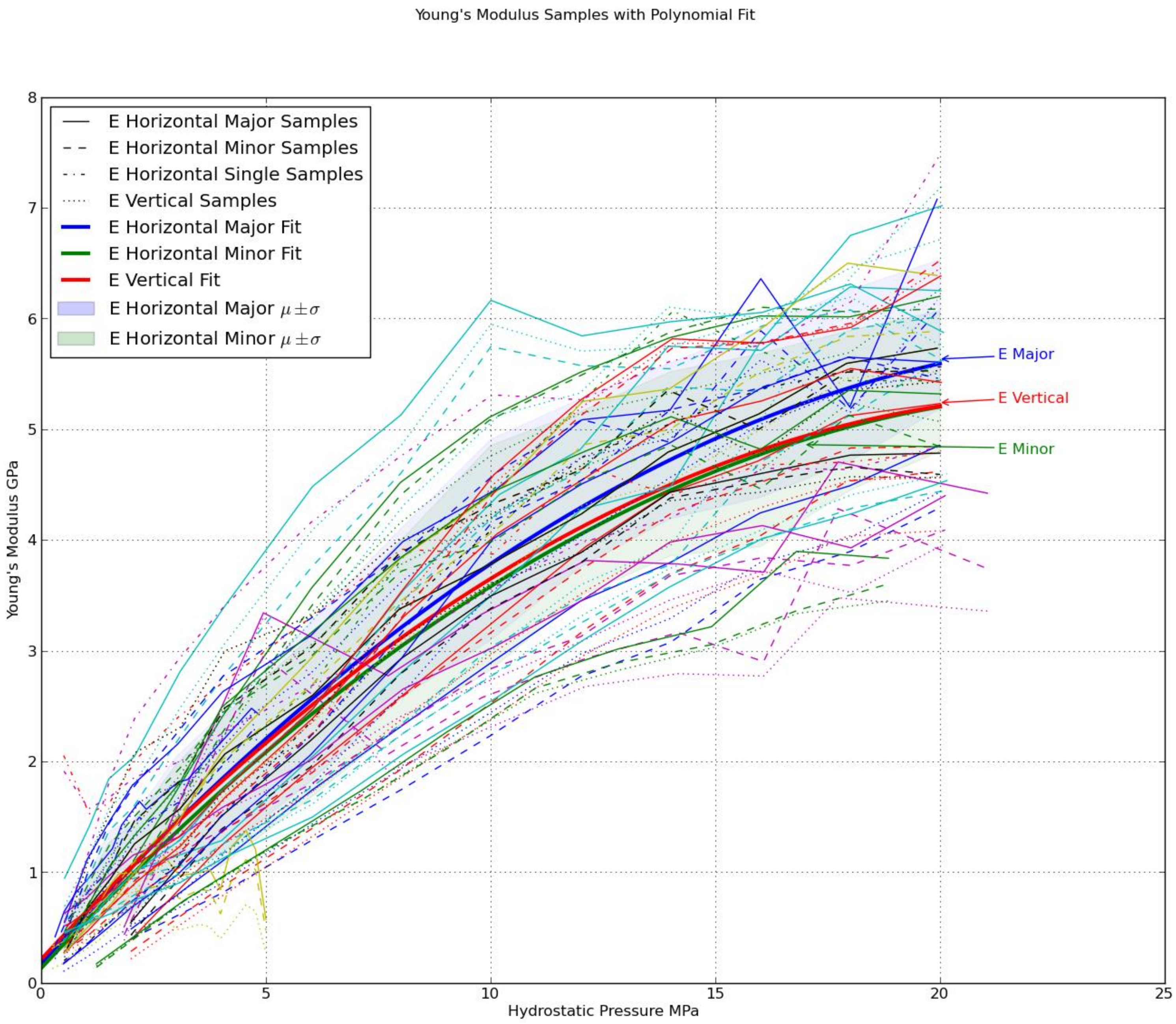


Porous Hawkesbury sandstone

Influence of confinement on Poisson's ratio v_{12}

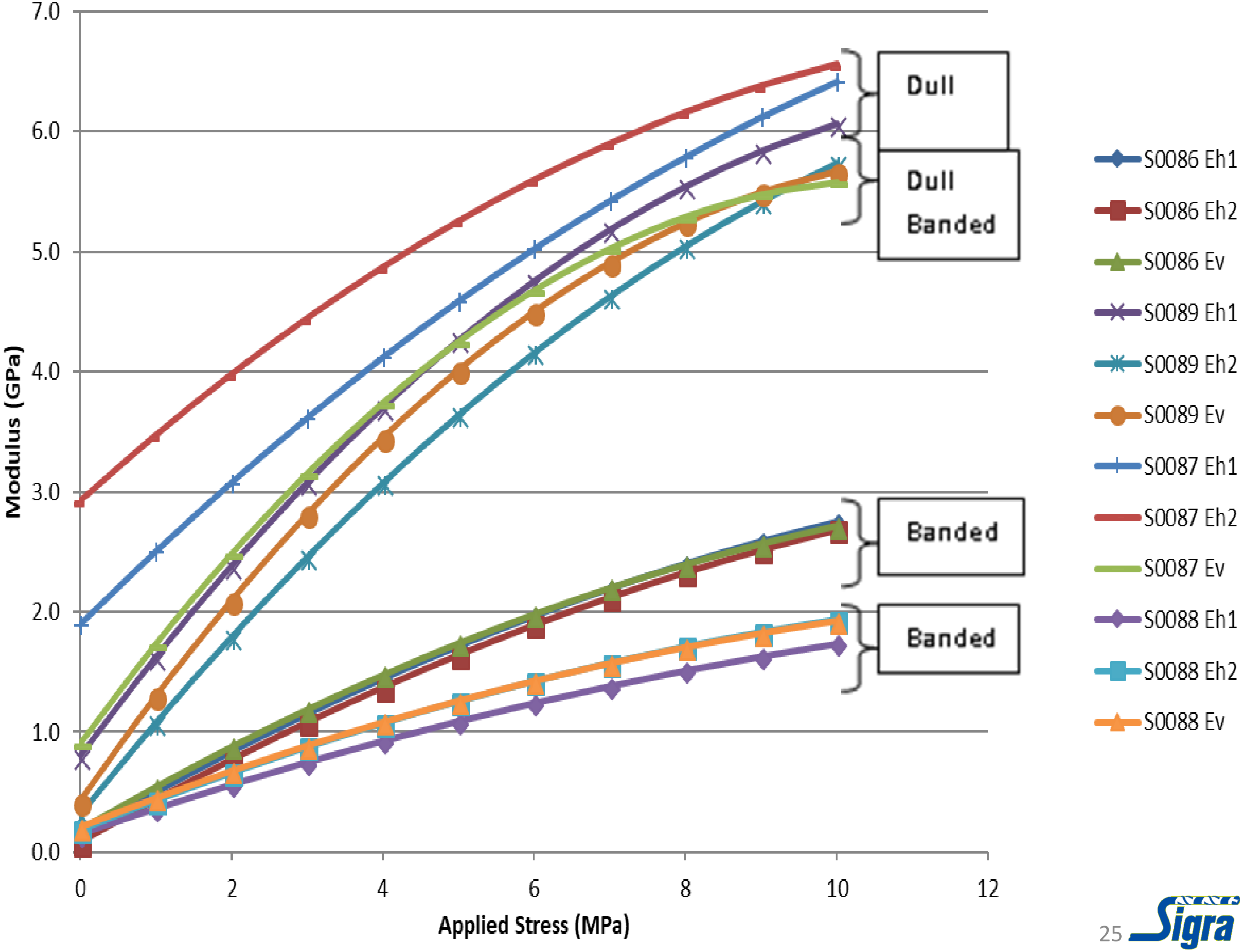


Young's modulus of coal fragments



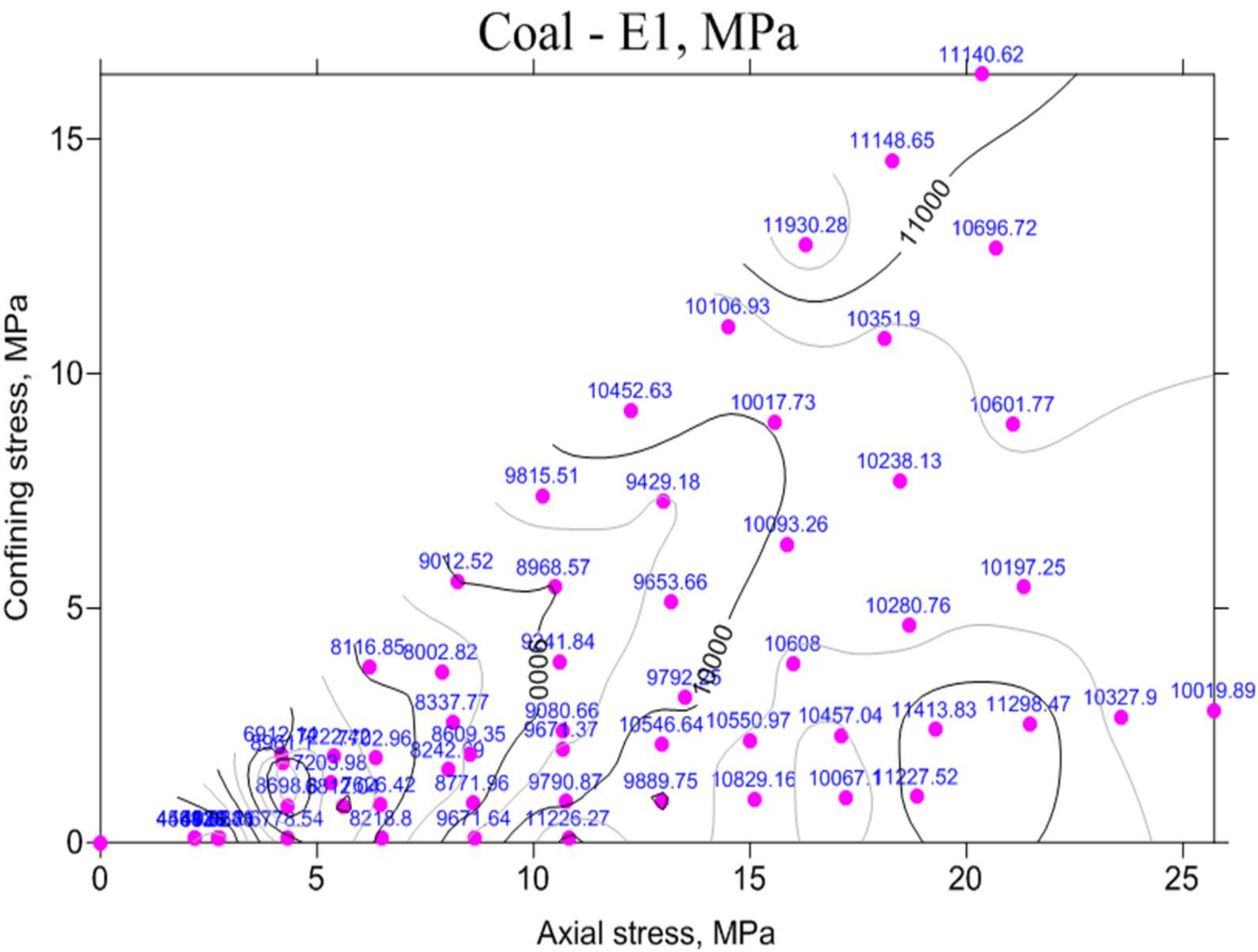
Variations in stiffness of different coals

Hydrostatic testing



An apparently weak (soft) coal

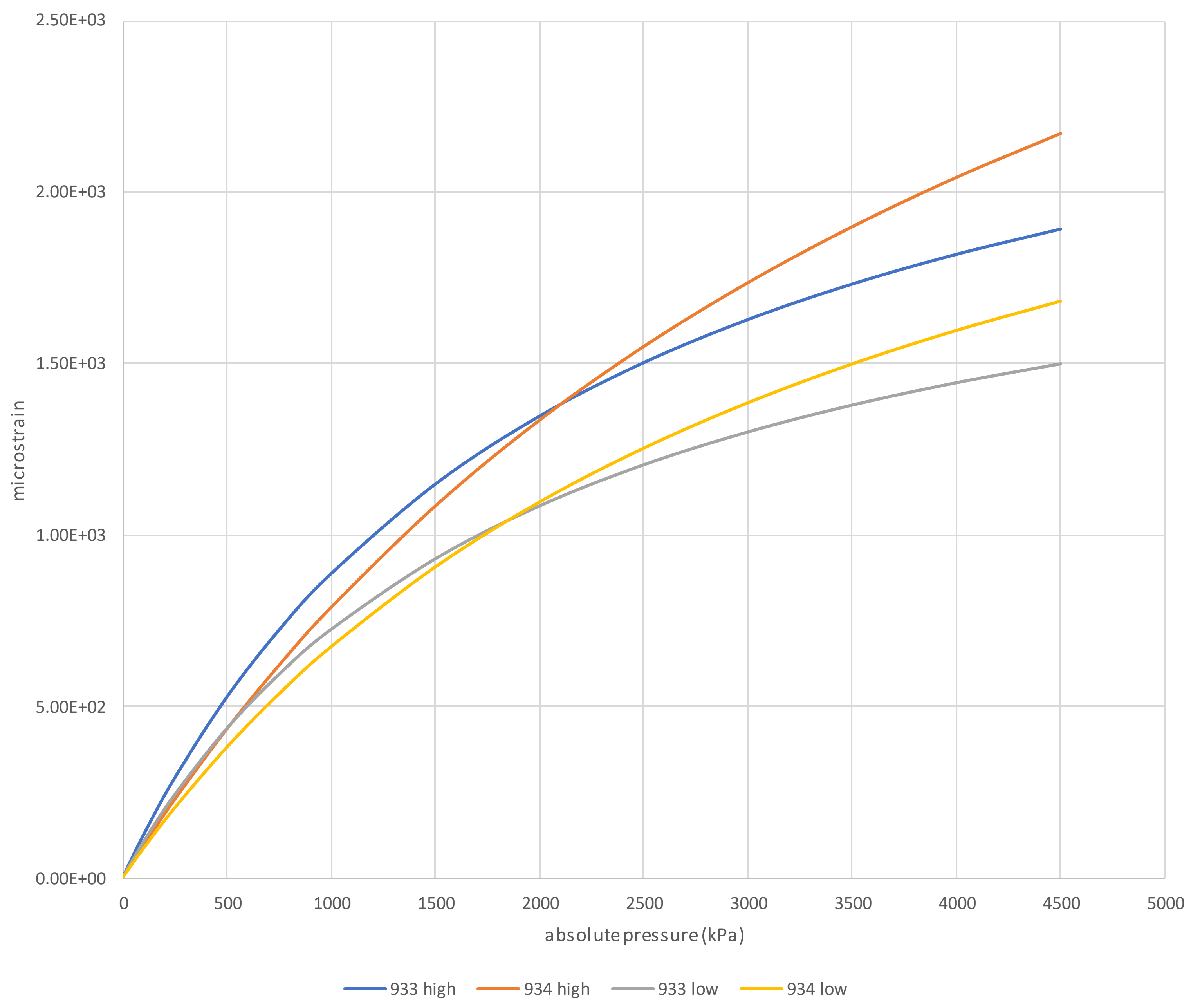
E_1 perpendicular to bedding



Shrinkage and swelling type behaviour

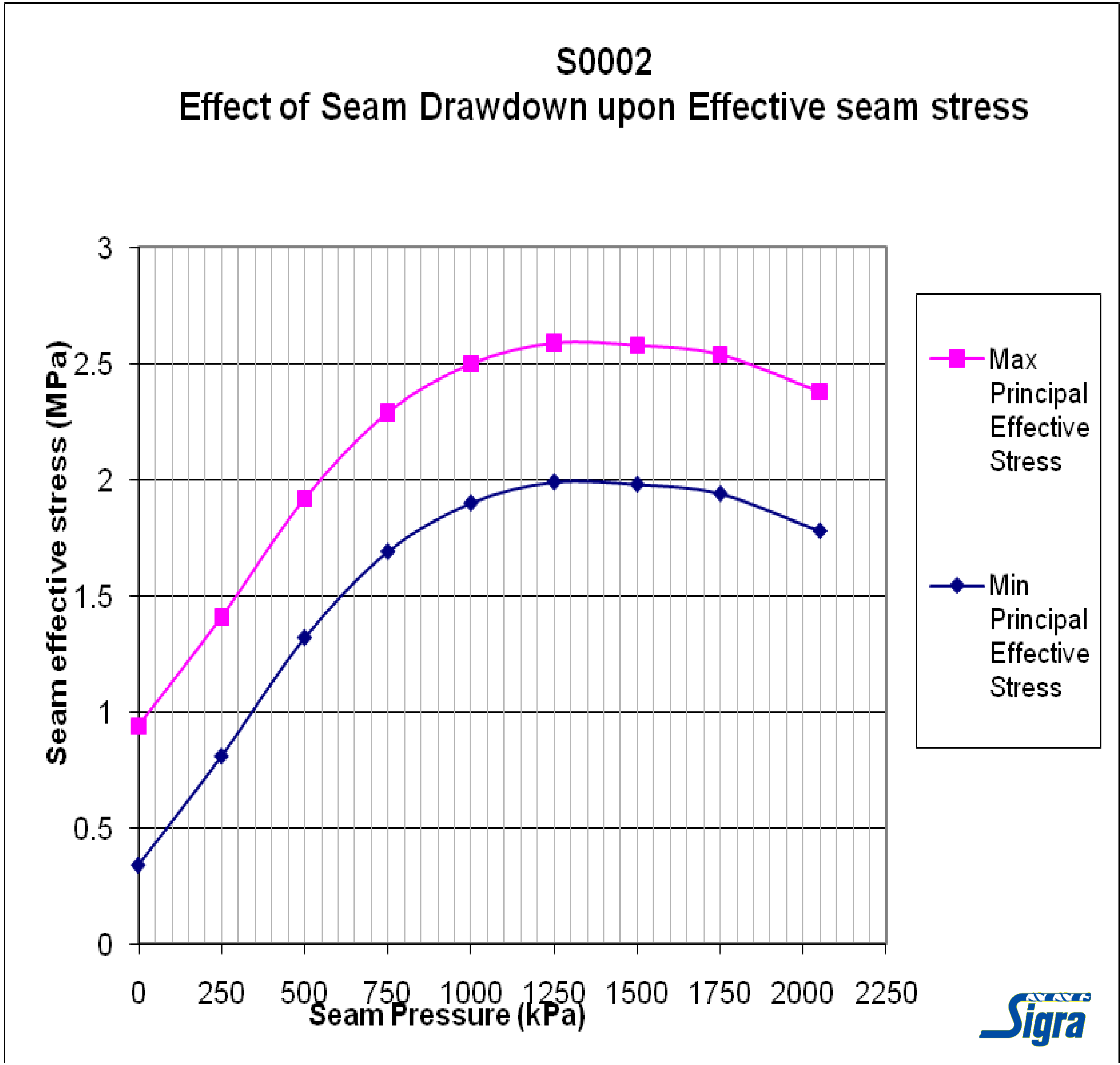
- Most commonly recognised in coals that shrink with gas desorption
- Affects carbonaceous shales to a lesser extent
- Affects some clayey rocks which shrink with water loss
- The associated stress changes may be very significant depending on the stiffness of the rock

Shrinkage strains in coal with methane as the seam gas



Stress Path

- Effective stress changes with the drainage of water and gas from a coal seam



Sigra

Rock Joints

- Need to consider their behaviour prior to failure
- How does fluid act within them?
- Probable sudden transition from a filled joint without any fluid pressure effects to one that suddenly has fluid within it.

Thank You

This is part of what we do.

Sigra Pty Ltd

93 Colebard St West, Acacia Ridge, Brisbane Queensland 4110, Australia

Tel: +61 (7) 3216 6344 Fax: +61 (7) 3216 6988

http://www.sigra.com.au info@sigra.com.au