

HW-3D: CALCULATING LEAST PRINCIPAL STRESSES

CALCULATING HORIZONTAL STRESSES FROM OVERBURDEN

The goal of this exercise is to demonstrate the methods most commonly used to calculate the horizontal stresses in a basin, assuming the overburden is known. Most of these methods can be divided into 2 categories:

- a) Use of a constant ratio between vertical and horizontal effective stresses
- b) Use of a ratio between vertical and horizontal effective stresses that varies with depth

GENERAL INPUT:

- Consider that the sediments have an overburden gradient of 20 MPa/km and that the pore water has a gradient of 10 MPa/km
- Assume that the basin is overpressured with a pressure gradient of 15 MPa/km (i.e. the pore pressure at a depth of 5 km is 75 MPa).
- Poisson's ratio $\nu=0.25$
- Consider a Basin with a depth of 5 Km

A) CONSTANT RATIO

1. Eaton (1969) calculated the ratio of horizontal to vertical stresses using concepts of the elastic theory:

$$\sigma_h = \left[\frac{\nu}{1-\nu} \right] (\sigma_v - u) + u \quad \text{Equation A.1}$$

where σ'_h is the effective horizontal stress, σ'_v the effective vertical stress and u the pore pressure.

Adopting Eaton's approach, calculate the vertical and horizontal effective and total stresses and plot the stress profiles in the axes provided below (Figure A). Identify the least principal stress.

2. Zoback & Healy (1984) proposed a ratio of minor to major principal effective stresses based on the assumption that stresses in the Earth cannot exceed the frictional strength of pre-existing faults:

$$\sigma_3 = \left[\frac{1 - \sin\phi}{1 + \sin\phi} \right] (\sigma_1 - u) + u \quad \text{Equation A.2}$$

Where ϕ is the friction angle ($\mu = \tan(\phi)$), σ_1 the maximum principal stress and σ_3 the minimum principal stress.

Calculate the vertical and horizontal effective and total stresses using the Zoback & Healy approach, using a friction coefficient $\mu = 0.578$ ($\phi = 30$). Plot the stress profiles on Figure A and identify the least principal stress. How do the stresses compare with Eaton's approach?

B) STRESS RATIO VARYING WITH DEPTH

Various authors have proposed empirical curves that relate the stress ratio with depth (e.g. Eaton (1969), Matthews & Kelly (1967)).

Table B provides values for the stress ratio K_i based on the empirical relation proposed by Matthews & Kelly (1967) from the Louisiana Gulf Coast.

Depth (km)	K_i	σ_v (MPa)	u (MPa)	σ_h (MPa)	σ'_h (MPa)
1	0.43	20	15		
2	0.56	40	30		
3	0.67	60	45		
4	0.78	80	60		
5	0.85	100	75		

Table B: Stress ratio K_i with depth from Matthews & Kelly (1967)

Using these values calculate the stresses at the given depths by filling in the rest of the Table B. Plot the stresses in the axes provided (Figure B) and interpolate the variation of the horizontal stress with depth.

C) APPLICATION: STRESSES AT A THRUST BELT

Using the approach proposed by Zoback & Healy (1984) (Equation A.2) calculate the vertical and horizontal effective and total stresses at a thrust belt setting and plot the stress profiles on the axes provided at Figure C. Use the same friction angle as in A2 ($\phi = 30^\circ$). Remember that at a thrust belt setting, the horizontal stress is higher than the vertical stress.

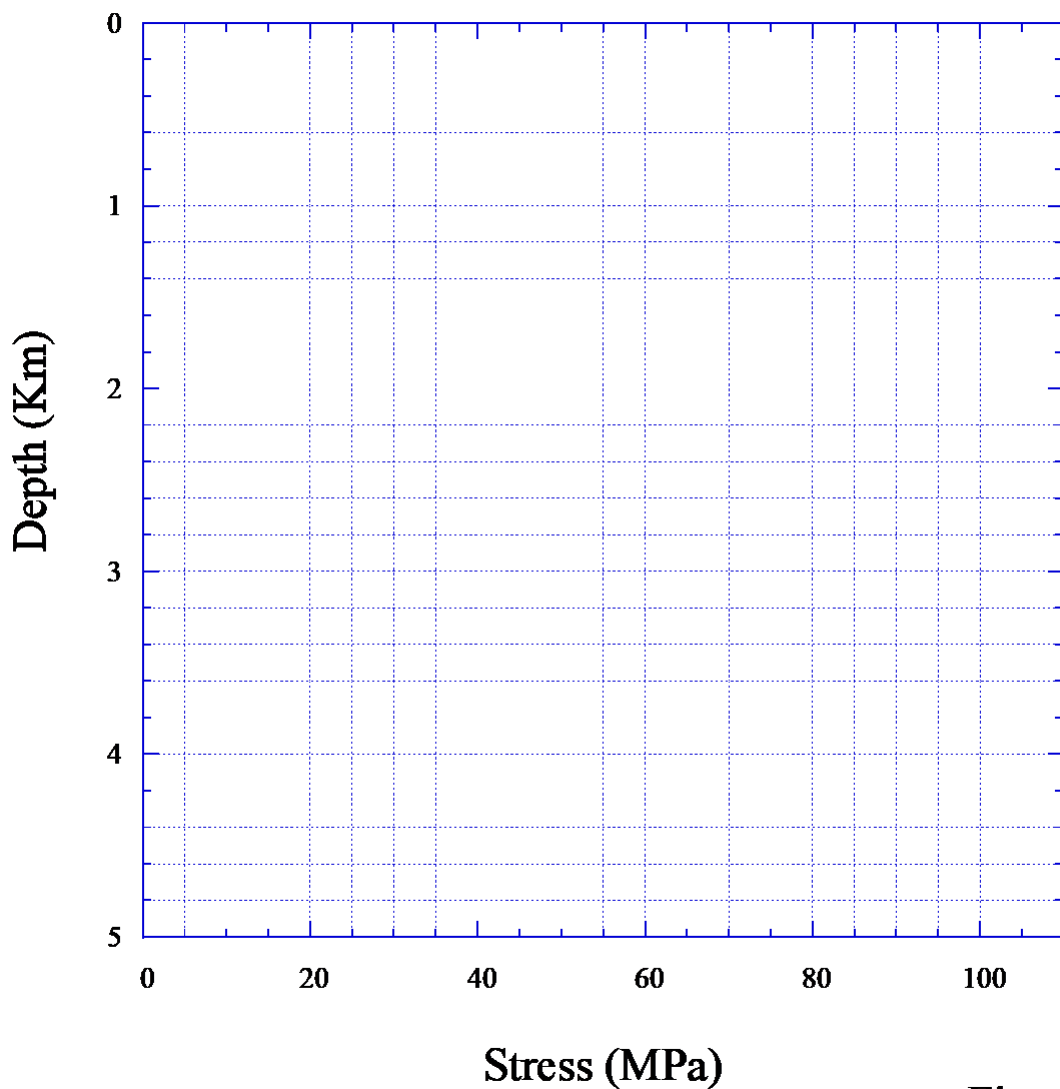


Figure A

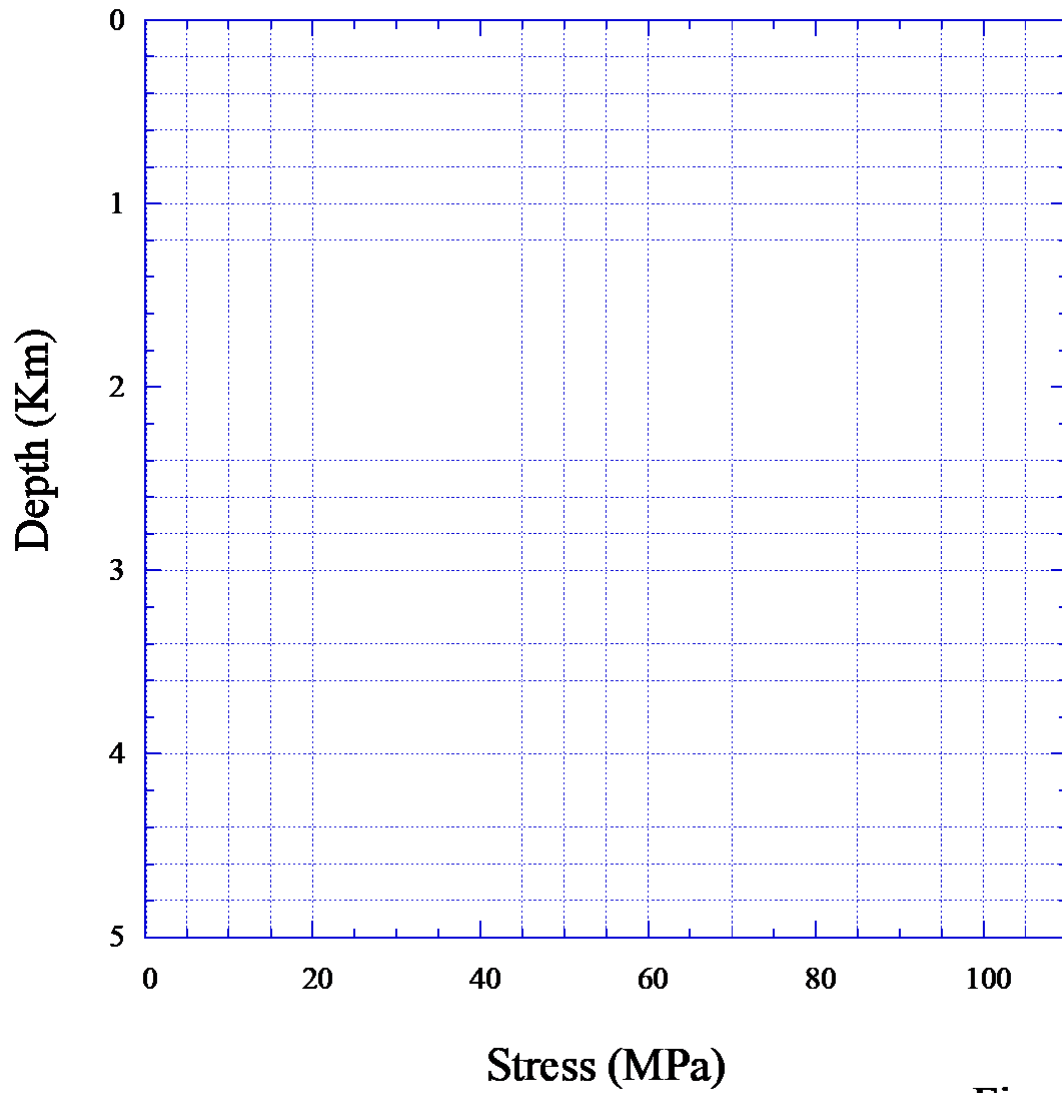


Figure B

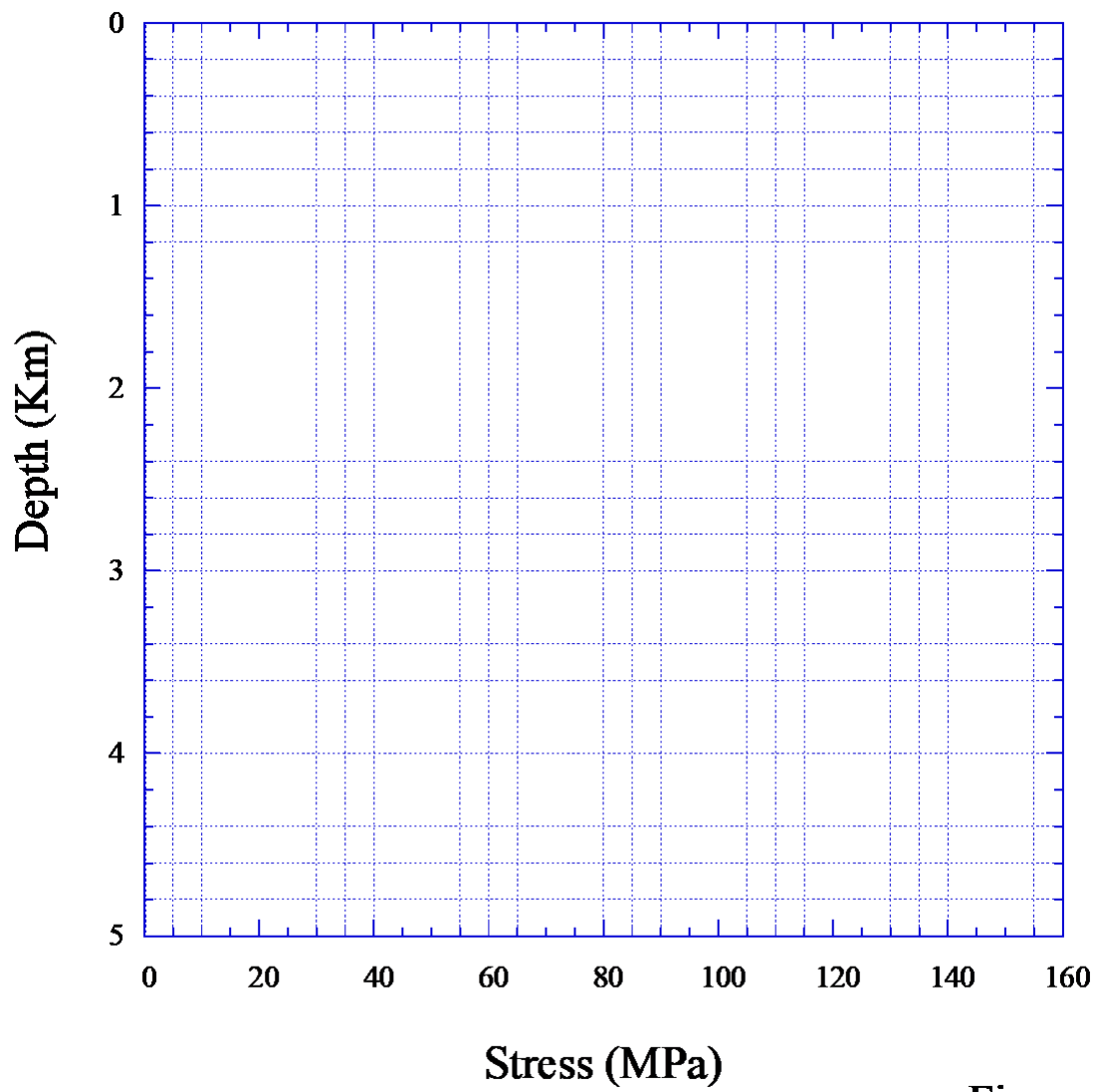


Figure C