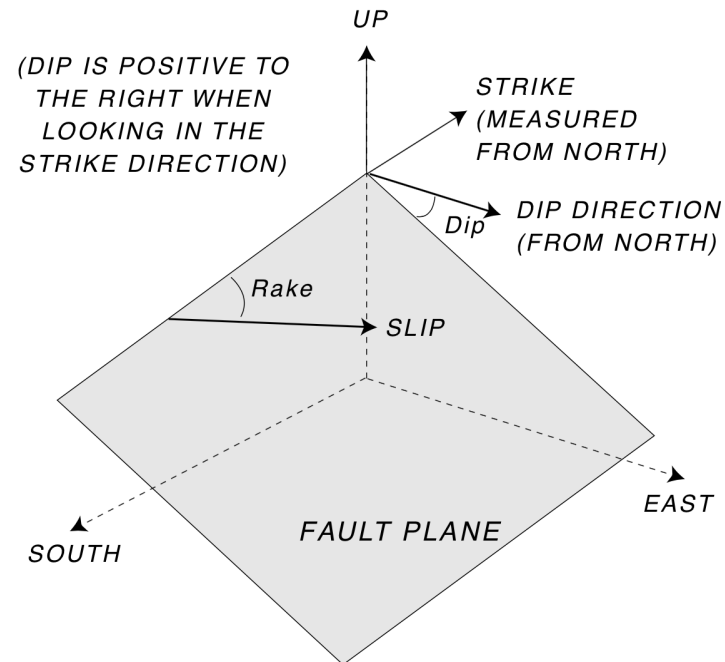
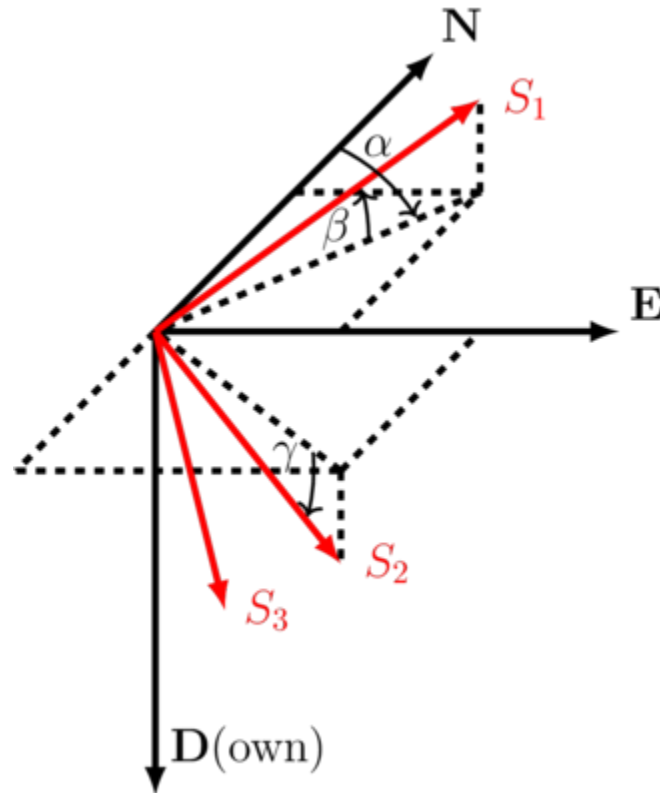


Faults and fractures at depth



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Geographical coordinate system



$$\mathbf{R}_G = \begin{bmatrix} \cos \alpha \cos \beta & \sin \alpha \cos \beta & -\sin \beta \\ \cos \alpha \sin \beta \sin \gamma - \sin \alpha \cos \gamma & \sin \alpha \sin \beta \sin \gamma + \cos \alpha \cos \gamma & \cos \beta \sin \gamma \\ \cos \alpha \sin \beta \cos \gamma + \sin \alpha \sin \gamma & \sin \alpha \sin \beta \cos \gamma - \cos \alpha \sin \gamma & \cos \beta \cos \gamma \end{bmatrix}$$

Stress in geographical coordinate system

$$\mathbf{S}_G = \mathbf{R}_G^T \mathbf{S} \mathbf{R}_G$$

Example: Strike-slip faulting

$$\mathbf{S} = \begin{bmatrix} 30 & 0 & 0 \\ 0 & 25 & 0 \\ 0 & 0 & 20 \end{bmatrix}$$

$$\alpha = 0^\circ$$

$$\beta = 0^\circ$$

$$\gamma = 90^\circ$$

Azimuth of S_{Hmax}

$$S_1 = S_{Hmax}$$

$$S_2 = S_v$$

$$\mathbf{R}_G = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & -1 & 0 \end{bmatrix}$$

$$\mathbf{S}_G = \begin{bmatrix} 30 & 0 & 0 \\ 0 & 20 & 0 \\ 0 & 0 & 25 \end{bmatrix}$$

Example: Normal faulting

$$\mathbf{S} = \begin{bmatrix} 30 & 0 & 0 \\ 0 & 25 & 0 \\ 0 & 0 & 20 \end{bmatrix}$$

$$\alpha = 0^\circ$$

$$\beta = -90^\circ$$

$$\gamma = 0^\circ$$

Azimuth of S_{hmin}

$$S_1 = S_v$$

$$\mathbf{R}_G = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ -1 & 0 & 0 \end{bmatrix}$$

$$\mathbf{S}_G = \begin{bmatrix} 20 & 0 & 0 \\ 0 & 25 & 0 \\ 0 & 0 & 30 \end{bmatrix}$$

Example: Reverse faulting

$$\mathbf{S} = \begin{bmatrix} 30 & 0 & 0 \\ 0 & 25 & 0 \\ 0 & 0 & 20 \end{bmatrix}$$

$$\alpha = 90^\circ$$

$$\beta = 0^\circ$$

$$\gamma = 0^\circ$$

Azimuth of S_{Hmax}

$$S_1 = S_{Hmax}$$

$$S_2 = S_{hmin}$$

$$\mathbf{R}_G = \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{S}_G = \begin{bmatrix} 25 & 0 & 0 \\ 0 & 30 & 0 \\ 0 & 0 & 20 \end{bmatrix}$$

Example: Strike-slip faulting

$$\mathbf{S} = \begin{bmatrix} 60 & 0 & 0 \\ 0 & 40 & 0 \\ 0 & 0 & 35 \end{bmatrix}$$

$$\alpha = 135^\circ$$

$$\beta = 0^\circ$$

$$\gamma = 90^\circ$$

Azimuth of S_{Hmax}

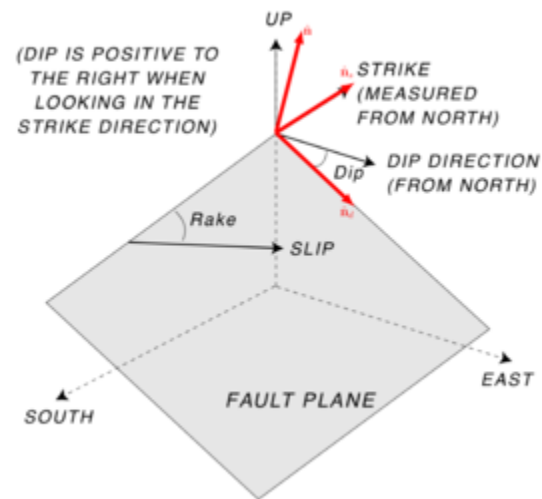
$$S_1 = S_{Hmax}$$

$$S_2 = S_v$$

$$\mathbf{R}_G = \begin{bmatrix} -\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 \\ 0 & 0 & 1 \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 \end{bmatrix}$$

$$\mathbf{S}_G = \begin{bmatrix} 47.5 & -12.5 & 0 \\ -12.5 & 47.5 & 0 \\ 0 & 0 & 40 \end{bmatrix}$$

Fault orientation



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Fault traction and stress

Traction on fault plane

$$\vec{t} = \mathbf{S}_G \cdot \hat{\mathbf{n}}$$

Normal stress to plane

$$S_n = \vec{t}^\top \cdot \hat{\mathbf{n}}$$

Shear stress in dip direction

$$\tau_d = \vec{t}^\top \cdot \hat{\mathbf{n}}_d$$

Shear stress in strike direction

$$\tau_s = \vec{t}^\top \cdot \hat{\mathbf{n}}_s$$

Example: Strike-slip faulting

$$\mathbf{S}_G = \begin{bmatrix} 30 & -8.66 & 0 \\ -8.66 & 40 & 0 \\ 0 & 0 & 30 \end{bmatrix}$$

$$\begin{aligned} \text{strike} &= 60^\circ \\ \text{dip} &= 90^\circ \end{aligned}$$

$$\hat{\mathbf{n}} = \begin{bmatrix} -0.866 \\ 0.5 \\ 0 \end{bmatrix} \quad \hat{\mathbf{n}}_s = \begin{bmatrix} 0.5 \\ 0.866 \\ 0 \end{bmatrix} \quad \hat{\mathbf{n}}_d = \begin{bmatrix} 0 \\ 0 \\ 1.0 \end{bmatrix}$$

$$S_n = 40 \quad \tau_d = 0 \quad \tau_s = 8.66$$

Example: Normal faulting

$$\mathbf{S}_G = \begin{bmatrix} 4000 & 0 & 0 \\ 0 & 3000 & 0 \\ 0 & 0 & 5000 \end{bmatrix}$$

$$\begin{aligned} \text{strike} &= 45^\circ \\ \text{dip} &= 60^\circ \end{aligned}$$

$$\hat{\mathbf{n}} = \begin{bmatrix} -0.612 \\ 0.612 \\ -0.5 \end{bmatrix} \quad \hat{\mathbf{n}}_s = \begin{bmatrix} 0.707 \\ 0.707 \\ 0 \end{bmatrix} \quad \hat{\mathbf{n}}_d = \begin{bmatrix} -0.3535 \\ 0.3535 \\ 0.866 \end{bmatrix}$$

$$S_n = 3875 \quad \tau_d = -650 \quad \tau_s = -433$$

Example: Normal faulting

$$\mathbf{S}_G = \begin{bmatrix} 5000 & 0 & 0 \\ 0 & 4000 & 0 \\ 0 & 0 & 3000 \end{bmatrix}$$

$$\begin{aligned} \text{strike} &= 225^\circ \\ \text{dip} &= 60^\circ \end{aligned}$$

$$\hat{\mathbf{n}} = \begin{bmatrix} 0.612 \\ -0.612 \\ -0.5 \end{bmatrix} \quad \hat{\mathbf{n}}_s = \begin{bmatrix} -0.707 \\ -0.707 \\ 0 \end{bmatrix} \quad \hat{\mathbf{n}}_d = \begin{bmatrix} 0.3535 \\ -0.3535 \\ 0.866 \end{bmatrix}$$

$$S_n = 4125 \quad \tau_d = -650 \quad \tau_s = -433$$

Example: Reverse faulting

$$\mathbf{S}_G = \begin{bmatrix} 2100 & -520 & 0 \\ -520 & 1500 & 0 \\ 0 & 0 & 1000 \end{bmatrix} \quad \begin{array}{l} \text{strike} = 120^\circ \\ \text{dip} = 70^\circ \end{array}$$

$$\hat{\mathbf{n}} = \begin{bmatrix} -0.814 \\ -0.470 \\ -0.342 \end{bmatrix} \quad \hat{\mathbf{n}}_s = \begin{bmatrix} -0.5 \\ 0.866 \\ 0 \end{bmatrix} \quad \hat{\mathbf{n}}_d = \begin{bmatrix} 0.2961 \\ -0.1710 \\ 0.9396 \end{bmatrix}$$

$$S_n = 1441 \quad \tau_d = 161 \quad \tau_s = 488$$