



EXAMINATION PAPER

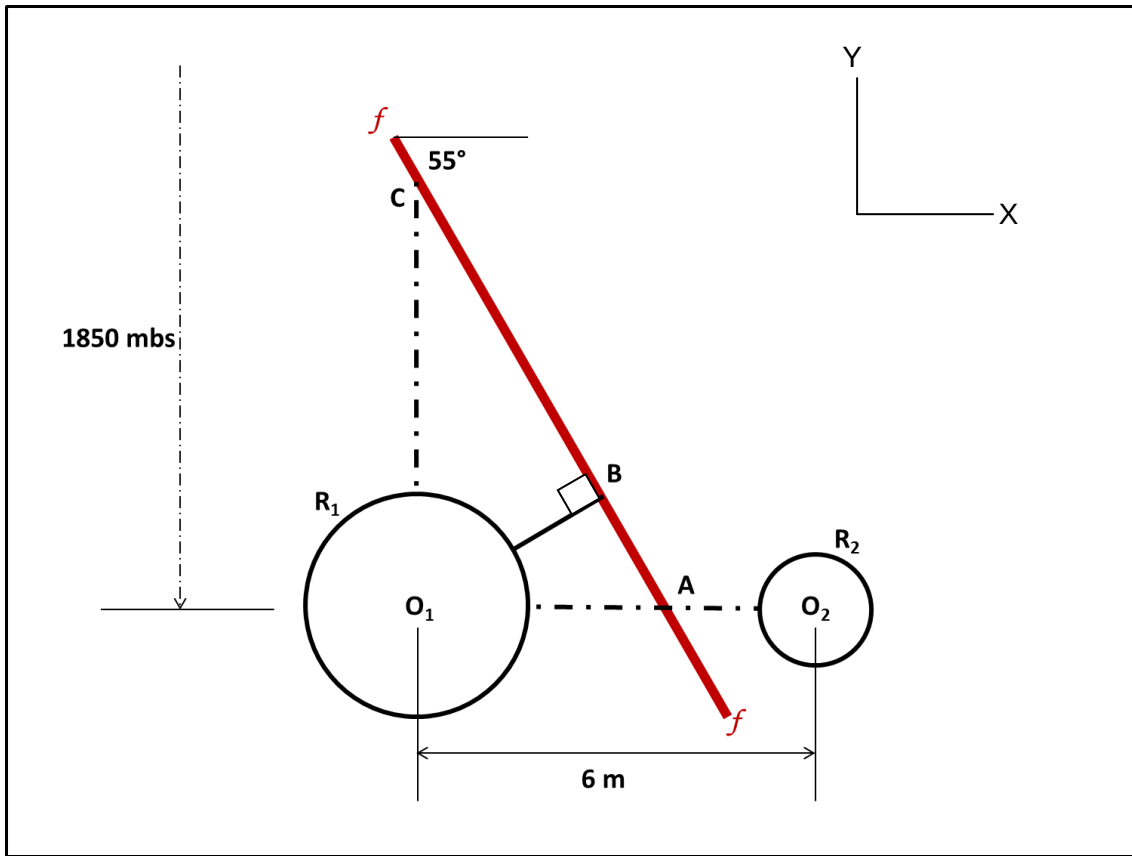
SUBJECT: ROCK MECHANICS CERTIFICATE PART 1: THEORY SUBJECT CODE: COMRMC1 EXAMINATION DATE: MAY 2013 TIME: 3 Hours	EXAMINER: JA MARITZ MODERATOR: DF MALAN TOTAL MARKS: 100 PASS MARK: 60%
--	--

NUMBER OF PAGES:12 (*including Cover and Formulae Sheets*)

SPECIAL REQUIREMENTS:

- 1. Answer All Questions.**
 - 2. Values given in question are not necessary answers calculated in previous questions.**
 3. All Questions are based on the given mining scenario.
 4. Start each question on a new page.
 5. References other than those provided are not permitted.
 6. Hand-held electronic calculators may be used.
 7. Write your **ID number** on the outside cover of each book used and on any graph paper or other loose sheets handed in.
- NB: your name must not appear on any answer book or loose sheets.**
- 8. Write in ink on the RIGHT HAND SIDE of the paper only (only the right hand pages will be marked).**
 9. Show all calculations on which your answers are based.
 10. Illustrate your answers by sketches or diagrams wherever possible.
 11. In answering these questions, full advantage should be taken wherever necessary of your practical experience as well as of the data given.
 12. Answers must be given to an accuracy that is typical of practical conditions.

GIVEN MINING SCENARIO



A fault is dipping at 55° and traverse the rock mass between to circular excavations which are 6 m apart (measured centre-to-centre). These excavations form part of an intense ventilation arrangement needed to supply air to the workings 1850 m below surface. The main tunnel (O_1) is 4 m in diameter with the secondary tunnel (O_2) being 2 m in diameter. Drilling a horizontal hole in the sidewalls of O_1 depicted the fault position as being 2 m into the sidewall.

Given:

$s = e^{\left(\frac{RMR - 100}{9}\right)}$	
$m = m_i e^{\left(\frac{RMR - 100}{28}\right)}$	
m_i	25
Relative Density	2.8
RMR	68
E	65 GPa
ν	0.27
UCS _{fault material}	55 MPa
ϕ _{fault plane}	26°
C_o _{fault plane}	1.5 MPa
k-ratio	0.5

$$\sigma_{rr} = \frac{1}{2}q(1+k)\left(1 - \frac{R^2}{r^2}\right) - \frac{1}{2}q(1-k)\left(1 - \frac{4R^2}{r^2} + \frac{3R^4}{r^4}\right)\cos 2\theta$$

$$\sigma_{\theta\theta} = \frac{1}{2}q(1+k)\left(1 + \frac{R^2}{r^2}\right) + \frac{1}{2}q(1-k)\left(1 + \frac{3R^4}{r^4}\right)\cos 2\theta$$

$$\tau_{r\theta} = \frac{1}{2}q(1-k)\left(1 + \frac{2R^2}{r^2} - \frac{3R^4}{r^4}\right)\sin 2\theta$$

QUESTION 1 – STRESS IN ROCK & ROCKMASSES

(20)

- 1.1. Determine the stress state for the polar coordinates at points A, B and C for the given mining scenario by using the Kirch equations assuming only the development of the main tunnel (O_1). (10)
- 1.2. Considering the secondary tunnel together with the main tunnel, what would be the stress state at point A? (4)
- 1.3. What would be the expected virgin stress levels at the 1850 mbs when calculated with:
- 1.3.1. Heim's rule (2)
 - 1.3.2. Rigid confinement theory (2)
 - 1.3.3. Kirch equations (2)

QUESTION 2 – STRESS AND STRAIN

(20)

- 2.1. Given the stress state at point B is represented by the matrix $\begin{bmatrix} 24 & 16 \\ 16 & 62 \end{bmatrix}$ MPa (X direction horizontal to the right and Y direction vertical up); determine the magnitude and direction of the principle stress conditions acting on the fault plane using Mohr's circle. (12)
- 2.2. Plot the schematic Mohr circles for the following conditions
- 2.2.1. Pure shear (2)
 - 2.2.2. Uniaxial tension (2)
 - 2.2.3. Hydrostatic stress field (2)
 - 2.2.4. Uniaxial compression (2)

QUESTION 3 – CONSTITUTION RELATIONSHIPS

(20)

- 3.1. Draw the Stress vs. Strain graphs comparing brittle and ductile rock formations. (4)
- 3.2. What is the major difference between brittle and ductile rocks (1)
- 3.3. In the given scenario, what strain would a rock sample experience when a force of 100 kN is applied to a 34 mm diameter sample. (3)
- 3.4. In which section along the Stress vs. Strain graph may one assume the Hooke's Law to be a valid? (1)
- 3.5. Assuming the following stress matrix, $\begin{bmatrix} 45 & 5 \\ 5 & 80 \end{bmatrix}$ MPa at an arbitrary location in the rock mass within the mining scenario, calculate all strain components by using the 2D representation of Hooke's Law and Modulus of Rigidity formulae. (5)
- 3.6. Define strain energy (1)
- 3.6.1. Based on your answers calculated in Question 3.5, calculate the amount of strain energy density stored in the rock mass at this point (3)
- 3.7. Define creep (2)

QUESTION 4 – ROCK PROPERTIES

(20)

- 4.1. When stability of a rock mass is tested, a specific failure criterion is used to base the assessment on. Name and discuss which criterion you would consider when the following conditions in the mining scenario are assessed: (10)
- 4.1.1. Assessment of fault plane stability.
- 4.1.2. Assessment of heavily jointed rock close to the contact.
- 4.2. Given the Hoek-Brown values for a rock mass $\text{RMR}=68$, while the fault material strength is 55 MPa, plot the yield curve for this infilling as well as the Point C stress state of $\begin{bmatrix} 39 & 0 \\ 0 & 36 \end{bmatrix}$ and comment whether the fault material should be stable or not. (10)

QUESTION 5 – ROCKMASS PROPERTIES& CLASSIFICATION

(20)

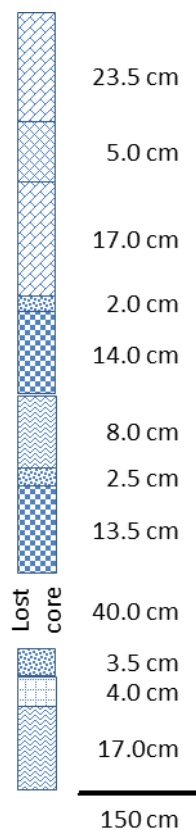
$$5.1. \alpha = \sqrt{\frac{E(1-\nu)}{(1+\nu)(1-2\nu)\rho}} \quad [\text{m/s}]$$

$$\beta = \sqrt{\frac{E}{2(1+2\nu)\rho}} \quad [\text{m/s}]$$

$$V_p \approx 3.5 + \text{Log}_{10} Q \quad [\text{km/s}]$$

Given the three equations showing the relationship between strength and seismic wave velocity in a rock mass, determine the Q rating of the given mining scenario and classify the rock accordingly (*Exceptionally poor to Exceptionally good*). (4)

5.2. Given the drill hole information as presented to the right, define and determine the following recovery values:



5.2.1. (SCR) Solid core recovery (2)

5.2.2. (%CR) Percentage core recovery (2)

5.2.3. (RQD) Rock Quality Designation as a percentage (2)

5.3. Terms and definitions: Define each of the following

- 5.3.1. Coefficient of friction (2)
- 5.3.2. Cohesion (2)
- 5.3.3. Compressive stress (2)
- 5.3.4. Plane strain (2)
- 5.3.5. Plane stress (2)

- END -

$$\sigma_{nn} = \sigma_{xx} \cos^2 \theta + 2\tau_{xy} \sin \theta \cos \theta + \sigma_{yy} \sin^2 \theta \quad \sigma'_{xx} = \sigma_{xx} \cos^2 \theta + 2\tau_{xy} \sin \theta \cos \theta + \sigma_{yy} \sin^2 \theta$$

$$\sigma_{mm} = \sigma_{xx} \sin^2 \theta - 2\tau_{xy} \sin \theta \cos \theta + \sigma_{yy} \cos^2 \theta \quad \sigma'_{yy} = \sigma_{xx} \sin^2 \theta - 2\tau_{xy} \sin \theta \cos \theta + \sigma_{yy} \cos^2 \theta$$

$$\tau_{nm} = \frac{1}{2}(\sigma_{yy} - \sigma_{xx}) \sin 2\theta + \tau_{xy} \cos 2\theta \quad \tau'_{xy} = \frac{1}{2}(\sigma_{yy} - \sigma_{xx}) \sin 2\theta + \tau_{xy} \cos 2\theta$$

$$\tan 2\theta = \frac{2\tau_{xy}}{\sigma_{xx} - \sigma_{yy}} \quad \sigma_1 + \sigma_2 = \sigma_{xx} + \sigma_{yy}$$

$$\sigma_1 = \frac{1}{2}(\sigma_{xx} + \sigma_{yy}) + \frac{1}{2}\sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4\tau_{xy}^2} \quad \sigma'_{xx} + \sigma'_{yy} = \sigma_{xx} + \sigma_{yy}$$

$$\sigma_2 = \frac{1}{2}(\sigma_{xx} + \sigma_{yy}) - \frac{1}{2}\sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4\tau_{xy}^2} \quad \tau_{\max} = \frac{1}{2}\sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4\tau_{xy}^2}$$

$$\sigma_{nn} = \sigma_1 \cos^2 \theta + \sigma_2 \sin^2 \theta \quad \tau_{\max} = \frac{1}{2}(\sigma_1 - \sigma_2)$$

$$\sigma_{mm} = \sigma_1 \sin^2 \theta + \sigma_2 \cos^2 \theta$$

$$\sigma_{nn} = \frac{1}{2}(\sigma_1 + \sigma_2) + \frac{1}{2}(\sigma_1 - \sigma_2) \cos 2\theta \quad \tau_{nm} = -\frac{1}{2}(\sigma_1 - \sigma_2) \sin 2\theta$$

$$\sigma_{mm} = \frac{1}{2}(\sigma_1 + \sigma_2) - \frac{1}{2}(\sigma_1 - \sigma_2) \cos 2\theta$$

$$\gamma_{xy} = \gamma_{yx} = 2\varepsilon_{xy} = 2\varepsilon_{yx}, \quad \gamma_{yz} = \gamma_{zy} = 2\varepsilon_{yz} = 2\varepsilon_{zy}, \quad \gamma_{zx} = \gamma_{xz} = 2\varepsilon_{zx} = 2\varepsilon_{xz}$$

$$\varepsilon_n = \varepsilon_{xx} \cos^2 \theta + \gamma_{xy} \sin \theta \cos \theta + \varepsilon_{yy} \sin^2 \theta \quad \varepsilon'_{xx} = \varepsilon_{xx} \cos^2 \theta + \gamma_{xy} \sin \theta \cos \theta + \varepsilon_{yy} \sin^2 \theta$$

$$\gamma_{nm} = (\varepsilon_{yy} - \varepsilon_{xx}) \sin 2\theta + \gamma_{xy} \cos 2\theta \quad \varepsilon'_{yy} = \varepsilon_{xx} \sin^2 \theta - \gamma_{xy} \sin \theta \cos \theta + \varepsilon_{yy} \cos^2 \theta$$

$$\tan 2\theta = \frac{\gamma_{xy}}{\varepsilon_{xx} - \varepsilon_{yy}} \quad \varepsilon_1 + \varepsilon_2 = \varepsilon_{xx} + \varepsilon_{yy} \quad \gamma'_{xy} = (\varepsilon_{yy} - \varepsilon_{xx}) \sin 2\theta + \gamma_{xy} \cos 2\theta$$

$$\varepsilon_1 = \frac{1}{2}(\varepsilon_{xx} + \varepsilon_{yy}) + \frac{1}{2}\sqrt{(\varepsilon_{xx} - \varepsilon_{yy})^2 + \gamma_{xy}^2} \quad \varepsilon'_{xx} + \varepsilon'_{yy} = \varepsilon_{xx} + \varepsilon_{yy}$$

$$\varepsilon_2 = \frac{1}{2}(\varepsilon_{xx} + \varepsilon_{yy}) - \frac{1}{2}\sqrt{(\varepsilon_{xx} - \varepsilon_{yy})^2 + \gamma_{xy}^2} \quad \gamma_{\max} = \sqrt{(\varepsilon_{xx} - \varepsilon_{yy})^2 + \gamma_{xy}^2}$$

$$\varepsilon_n = \varepsilon_1 \cos^2 \theta + \varepsilon_2 \sin^2 \theta \quad \gamma_{\max} = (\varepsilon_1 - \varepsilon_2)$$

$$\varepsilon_n = \frac{1}{2}(\varepsilon_1 + \varepsilon_2) + \frac{1}{2}(\varepsilon_1 - \varepsilon_2) \cos 2\theta \quad \varepsilon = \frac{\delta \ell}{\ell_o}$$

$$\gamma_{nm} = -(\varepsilon_1 - \varepsilon_2) \sin 2\theta$$

$$\sigma_{rr} = \sigma_{xx} \cos^2 \theta + 2\tau_{xy} \sin \theta \cos \theta + \sigma_{yy} \sin^2 \theta \quad \varepsilon_{rr} = \varepsilon_{xx} \cos^2 \theta + \gamma_{xy} \sin \theta \cos \theta + \varepsilon_{yy} \sin^2 \theta$$

$$\sigma_{\theta\theta} = \sigma_{xx} \sin^2 \theta - 2\tau_{xy} \sin \theta \cos \theta + \sigma_{yy} \cos^2 \theta \quad \varepsilon_{\theta\theta} = \varepsilon_{xx} \sin^2 \theta - \gamma_{xy} \sin \theta \cos \theta + \varepsilon_{yy} \cos^2 \theta$$

$$\tau_{r\theta} = \frac{1}{2}(\sigma_{yy} - \sigma_{xx}) \sin 2\theta + \tau_{xy} \cos 2\theta \quad \gamma_{r\theta\theta} = (\varepsilon_{yy} - \varepsilon_{xx}) \sin 2\theta + \gamma_{xy} \cos 2\theta$$

$$w = \frac{1}{2}(\sigma_1 \varepsilon_1 + \sigma_2 \varepsilon_2 + \sigma_3 \varepsilon_3) \quad w = \frac{1}{2}(\sigma_{xx} \varepsilon_{xx} + \sigma_{yy} \varepsilon_{yy} + \sigma_{zz} \varepsilon_{zz} + \tau_{xy} \gamma_{xy} + \tau_{yz} \gamma_{yz} + \tau_{zx} \gamma_{zx})$$

$$Q = wV$$

$$\begin{aligned}\varepsilon_{xx} &= \frac{1}{E} \{ \sigma_{xx} - \nu(\sigma_{yy} + \sigma_{zz}) \} \quad \gamma_{xy} = \frac{1}{G} \tau_{xy} \quad \varepsilon_{xy} = \frac{1}{2G} \tau_{xy} \quad G = \frac{E}{2(1+\nu)} \\ \varepsilon_{yy} &= \frac{1}{E} \{ \sigma_{yy} - \nu(\sigma_{xx} + \sigma_{zz}) \} \quad \gamma_{yz} = \frac{1}{G} \tau_{yz} \quad \varepsilon_{yz} = \frac{1}{2G} \tau_{yz} \quad K = \frac{E}{3(1-2\nu)} \\ \varepsilon_{zz} &= \frac{1}{E} \{ \sigma_{zz} - \nu(\sigma_{xx} + \sigma_{yy}) \} \quad \gamma_{zx} = \frac{1}{G} \tau_{zx} \quad \varepsilon_{zx} = \frac{1}{2G} \tau_{zx}\end{aligned}$$

$$\begin{aligned}\sigma_{xx} &= \lambda\Delta + 2G\varepsilon_{xx} \quad \tau_{xy} = G\gamma_{xy} \quad \tau_{xy} = 2G\varepsilon_{xy} \quad \Delta = \varepsilon_{xx} + \varepsilon_{yy} + \varepsilon_{zz} \\ \sigma_{yy} &= \lambda\Delta + 2G\varepsilon_{yy} \quad \tau_{yz} = G\gamma_{yz} \quad \tau_{yz} = 2G\varepsilon_{yz} \quad \lambda = \frac{E\nu}{(1+\nu)(1-2\nu)} \\ \sigma_{zz} &= \lambda\Delta + 2G\varepsilon_{zz} \quad \tau_{zx} = G\gamma_{zx} \quad \tau_{zx} = 2G\varepsilon_{zx}\end{aligned}$$

$$\begin{aligned}\sigma_{zz} &= 0 \quad \varepsilon_{zz} = -\frac{\nu}{E}(\sigma_{xx} + \sigma_{yy}) \\ \varepsilon_{xx} &= \frac{1}{E}(\sigma_{xx} - \nu\sigma_{yy}) \quad \gamma_{xy} = \frac{1}{G}\tau_{xy} \quad \sigma_{xx} = \frac{E}{1-\nu^2}(\varepsilon_{xx} + \nu\varepsilon_{yy}) \quad \tau_{xy} = G\gamma_{xy} \\ \varepsilon_{yy} &= \frac{1}{E}(\sigma_{yy} - \nu\sigma_{xx}) \quad \sigma_{yy} = \frac{E}{1-\nu^2}(\varepsilon_{yy} + \nu\varepsilon_{xx})\end{aligned}$$

$$\begin{aligned}\varepsilon_{zz} &= 0 \quad \sigma_{zz} = \nu(\sigma_{xx} + \sigma_{yy}) \\ \varepsilon_{xx} &= \frac{1}{E} \left\{ (1-\nu^2)\sigma_{xx} - \nu(1+\nu)\sigma_{yy} \right\} \\ \varepsilon_{yy} &= \frac{1}{E} \left\{ (1-\nu^2)\sigma_{yy} - \nu(1+\nu)\sigma_{xx} \right\}\end{aligned}$$

$$q = \rho g H \quad \sigma_v = q \quad \sigma_h = kq$$

$$\begin{aligned}\sigma_{rr} &= \frac{1}{2}q(1+k) \left(1 - \frac{R^2}{r^2} \right) - \frac{1}{2}q(1-k) \left(1 - \frac{4R^2}{r^2} + \frac{3R^4}{r^4} \right) \cos 2\theta \\ \sigma_{\theta\theta} &= \frac{1}{2}q(1+k) \left(1 + \frac{R^2}{r^2} \right) + \frac{1}{2}q(1-k) \left(1 + \frac{3R^4}{r^4} \right) \cos 2\theta \\ \tau_{r\theta} &= \frac{1}{2}q(1-k) \left(1 + \frac{2R^2}{r^2} - \frac{3R^4}{r^4} \right) \sin 2\theta\end{aligned}$$

$$\begin{aligned}\sigma_{rr} &= q \left(1 - \frac{R^2}{r^2} \right) \quad \sigma_{\theta\theta} = q \left(1 + \frac{R^2}{r^2} \right) \quad \tau_{r\theta} = 0 \quad \sigma_{zz} = 2\nu q \\ u &= \frac{(1+\nu)}{E} q \left\{ (1-2\nu)r + \frac{R^2}{r} \right\} \quad \nu = 0\end{aligned}$$

$$s_z = \frac{2(1-\nu)q}{G} \sqrt{\ell^2 - x^2}$$

$$\ell_c = \frac{s_m G}{2(1-\nu)q}$$

$$\ell < \ell_c \quad ERR = \frac{\Delta U_m}{\Delta A} = \frac{\pi(1-\nu)\ell q^2}{2G}$$

$$\ell = \ell_c \quad ERR = \frac{\Delta U_m}{\Delta A} = \frac{\pi}{4} s_m q$$

$$\ell > \ell_c \quad ERR = \frac{\Delta U_m}{\Delta A} = \frac{\pi}{4} s_m q \left(\frac{1 - (1 - \ell_c / \ell)^{1.27}}{\ell_c / \ell} \right)$$

$$\ell \rightarrow \infty \quad ERR = \frac{\Delta U_m}{\Delta A} = s_m q$$

$$\tau = c + \mu \sigma \quad \mu = \tan \phi \quad \sigma_1 = \sigma_c + \tan \psi \sigma_3$$

$$\tan \psi = \frac{1 + \sin \phi}{1 - \sin \phi} \quad \sigma_c = \frac{2c \cos \phi}{1 - \sin \phi} \quad \phi = \arcsin \left(\frac{\tan \psi - 1}{\tan \psi + 1} \right) \quad c = \frac{\sigma_c}{2 \sqrt{\tan \psi}}$$

$$Q = \frac{RQD}{J_n} \frac{J_r}{J_a} \frac{J_w}{SRF} \quad RMR = 9 \log_e Q + 44$$

$$\sigma_1 = \sigma_3 + \sigma_{ci} \left(m_b \frac{\sigma_3}{\sigma_{ci}} + s \right)^a \quad \sigma_1 = \sigma_3 + \sigma_{ci} \sqrt{m_i \frac{\sigma_3}{\sigma_{ci}} + 1}$$

$$GSI > 25 \quad GSI = RMR_{76} \quad GSI = RMR_{89} - 5$$

$$GSI < 25 \quad Q' = \frac{RQD}{J_n} \frac{J_r}{J_a} \quad GSI = 9 \log_e Q' + 44$$

$$m_b = m_i \exp \left(\frac{GSI - 100}{28} \right)$$

$$GSI > 25 \quad s = \exp \left(\frac{GSI - 100}{9} \right) \quad a = \frac{1}{2} \quad \sigma_1 = \sigma_3 + \sigma_{ci} \sqrt{m_b \frac{\sigma_3}{\sigma_{ci}} + s}$$

$$\sigma_{tm} = \frac{\sigma_{ci}}{2} \left(m_b - \sqrt{m_b^2 + 4s} \right) \quad \sigma_{cm} = \sigma_{ci} \sqrt{s}$$

$$GSI < 25 \quad s = 0 \quad a = 0.65 - \frac{GSI}{200} \quad \sigma_1 = \sigma_3 + \sigma_{ci} \left(m_b \frac{\sigma_3}{\sigma_{ci}} \right)^{0.65 - \frac{GSI}{200}}$$

$$\sigma_{tm} = 0 \quad \sigma_{cm} = 0$$

$$\sigma_{ci} > 100 \text{ MPa} \quad E_m \text{ (GPa)} = 10^{\left(\frac{GSI - 10}{40} \right)}$$

$$\sigma_{ci} < 100 \text{ MPa} \quad E_m \text{ (GPa)} = \sqrt{\frac{\sigma_{ci} \text{ (MPa)}}{100 \text{ (MPa)}}} 10^{\left(\frac{GSI - 10}{40} \right)}$$

$$\tau = \sigma_n \tan \left[\phi_a + JRC \log_{10} \left(\frac{JCS}{\sigma_n} \right) \right]$$

$$q = 0.025H \quad MPa \quad H[m] \quad \sigma_v = \rho gh \quad \sigma_h = k\sigma_v$$

$$e = 1 - \frac{w^2}{C^2} \quad C = w + B \quad r = \frac{h}{M} \left(1 - \frac{w^2}{C^2} \right) \quad h_e = h \left(1 - \frac{w^2}{C^2} \right) \quad h_e = he$$

$$\sigma_p = \frac{q}{1-e} \quad \sigma_p = 0.025H \frac{(w+B)^2}{w^2} \quad MPa \quad R = \frac{w}{h}$$

$$R < 5$$

$$\sigma_s = 7.2 \frac{w^{0.46}}{h^{0.66}} \quad MPa \quad Fs = \frac{\sigma_s}{\sigma_p} \quad Fs = 288 \frac{w^{2.46}}{Hh^{0.66}(w+B)^2}$$

$$R \geq 5$$

$$\sigma_s = 7.2 \frac{R_o^{0.5933}}{V^{0.0667}} \left\{ \frac{0.5933}{\varepsilon} \left[\left(\frac{R}{R_o} \right)^\varepsilon - 1 \right] + 1 \right\} \quad MPa$$

$$V = w^2 h \quad R_o = 5 \quad \varepsilon = 2.5$$

$$\sigma_s = \frac{0.07942}{(w^2 h)^{0.0667}} (R^{2.5} + 179.65) \quad MPa$$

$$Fs = \frac{\sigma_s}{\sigma_p} \quad Fs = \frac{3.1768w^{1.8666}}{H(w+B)^2 h^{0.0667}} \left\{ \left(\frac{w}{h} \right)^{2.5} + 179.65 \right\}$$

$$e = 1 - \frac{w_1 w_2}{C_1 C_2} \quad w_e = \frac{4w_1 w_2}{2w_1 + 2w_2}$$

$$\sigma_p = 0.025H \frac{C_1 C_2}{w_1 w_2} \quad MPa$$

$$R = \frac{E}{4(1-\nu^2)} \frac{s_m}{(\sigma_{cr} - q)} \quad R = 0.28 \frac{s_m}{\varepsilon_{cr}}$$

$$v_p = \sqrt{\frac{\lambda + 2G}{\rho}} \quad v_s = \sqrt{\frac{G}{\rho}}$$

$$ESS = |\tau| - [\sigma_n \tan(\theta) + C_0]$$

$$\sigma_1 = \sigma_3 + \sqrt{m\sigma_c\sigma_3 + s\sigma_c^2}$$

$$S_{m,he}=0.39h\left(\frac{W}{H}\right)^{0.32}$$

$$S_{m,pf}=0.1h_e\text{ , H}>80\text{m}$$

$$S_{m,pf}=0.8h_e\text{ , H}<80\text{m}$$

$$h_e=eh$$

$$\varepsilon_{m+}=4.2S_m+1.7$$

$$\varepsilon_{m-}=-9.1S_m-2.8$$

$$T_m=21.6S_m+7$$

$$L_c=2T\sqrt{k+\frac{\beta}{D}}+2(H-D)\tan\phi$$

$$\beta=\frac{1.53}{\gamma_m}-0.8$$

$$\gamma_m=0.025\frac{D-T}{D}+0.03\frac{T}{D}$$

$$\sigma_t=\frac{qB^2}{2t_s^2} \quad q=\rho g(t_s+t_w)$$

$$\sigma=\frac{3qL^2}{t^2}$$

$$\eta=\frac{qL^4}{32Et^3} \quad l_a=\frac{\gamma S_b^2t_w}{\pi d_h\tau}$$

$$w_e=\frac{4A}{c}$$

$$\sigma_{squat}=k\frac{R_o^b}{V^a}\left\{\frac{b}{\varepsilon}\left[\left(\frac{R}{R_o}\right)^{\varepsilon}-1\right]+1\right\}$$

$$Strength_{Squat}=\frac{0.0786}{V^{0,0667}}\left\{R^{2,5}+181,6\right\}$$

$$SF = \frac{Strength}{Load}$$

$$Strength = 7.2 \frac{w^{0.46}}{h^{0.66}}$$

$$SF_{CM} = SF \left(1 + \frac{0,6}{w} \right)^{2,46}$$

$$Load = \frac{[.025(H - T) + .030T] C_1 C_2}{w_1 w_2}$$

$$SF'' = SF \left(\frac{w - \Delta w}{w} \right)^{2,46}$$

$$SF' = SF \left(\frac{h}{h + \Delta h} \right)^{0,66}$$

$$e\% = \left[100 \frac{h_m}{h_s} \left(1 - \frac{w^2}{C^2} \right) \right] \frac{W}{W + P}$$

$$\sigma_t = \frac{qB^2}{2t_s^2}, \quad q = \rho g(t_s + t_w)$$

$$t_{sb} = \frac{Fk\rho gB^2}{2\sigma_t}$$

$$s = 1.414t_l \sqrt{\frac{\sigma_t}{Fq_c}}, \quad q_c = q_l + \frac{q_u E_l + q_l E_u}{E_l + E_u}$$

$$F_b = \frac{s}{\tan \phi} \left[\frac{3\rho g k B_s}{4} - \sigma_r d_h \right]$$

$$l_a = \frac{\rho g s^2 t_w + 0.05}{\pi d_h \tau_c}$$

$$l_a = \frac{Ft}{\pi d_h \tau_c}, \quad w_b = \rho g k t_{sb} s^2, \quad F_t = F_b + w_b$$

$$\sigma_{ts} = \frac{4w_b}{\pi d^2}, \quad w_b = \rho g s^2 t_w$$

$$\sigma_s = \frac{4F_t}{\pi d_s^2}$$