UNISA university of south africa

EXAMINATION PAPER

SUBJECT: ROCK MECHANICS CERTIFICATE PART 1: THEORY	EXAMINER: JA MARITZ
SUBJECT CODE: COMRMC1	MODERATOR: M HANDLEY
EXAMINATION DATE: 16 MAY 2011	TOTAL MARKS: [100]
TIME: 14:30 – 17:00	PASS MARK: 60%

NUMBER OF PAGES: 14

SPECIAL REQUIREMENTS:

1. **Answer ALL 4 Questions.**
2. Start each question on a new page.
3. References other than those provided are not permitted.
4. Hand-held electronic calculators may be used.
5. Write your **examination number** on the outside cover of each book used and on any graph paper or other loose sheets handed in.

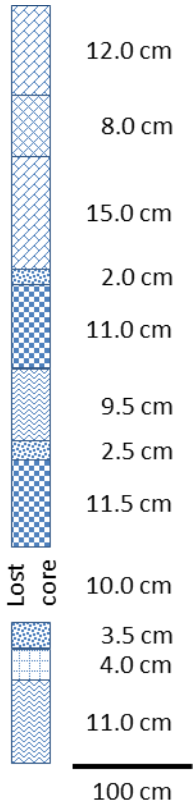
NB: your name must not appear on any answer book or loose sheets.

6. **Write in ink on the RIGHT HAND SIDE of the paper only (only the right hand pages will be marked).**
7. Show all calculations on which your answers are based.
8. Illustrate your answers by sketches or diagrams wherever possible.
9. In answering these questions, full advantage should be taken wherever necessary of your practical experience as well as of the data given.
10. Answers must be given to an accuracy that is typical of practical conditions.

Question 1 – Rock mass classifications and strength

1.1 Rock Quality Designation is generally used in rock mass classification. Define RQD and supply the equation used. (2)

1.2 A 1.0m (or part of) core sample has been recovered during a project exploration phase. Determine the RQD from the recovered core as presented below. (3)



1.3 Name and indicate how the different factors from the Barton's Rock Tunnelling Quality Index (Q) could influence the rock quality (4)

1.4 Barton and Choubey developed an equation to calculate shear strength on a plane.

i) Provide this equation and define each of the four parameters required as input: (3)

ii) Given the following: $\Phi_b = 28^{O}$, JRC = 17 and JCS = 110 MPa, calculate the shear strength of the plane when σ_n = 0.5 MPa and σ_n = 3.0 MPa respectively. (2)

iii) What significance is there with an increasing σ_n? (1)

1.5 Two rock samples were tested in a triaxial shear strength test machine and failed at the following principle stress values;

Test 1: σ_1 = 210kPa σ_3 = -10kPa

Test 2: σ_1 = 390kPa σ_3 = 144kPa

i) Explain by means of a sketch how the triaxial shear strength test machine works. (5)

ii) Draw the Mohr circles that represent the two tests. (2)

iii) Determine the material cohesion (1)

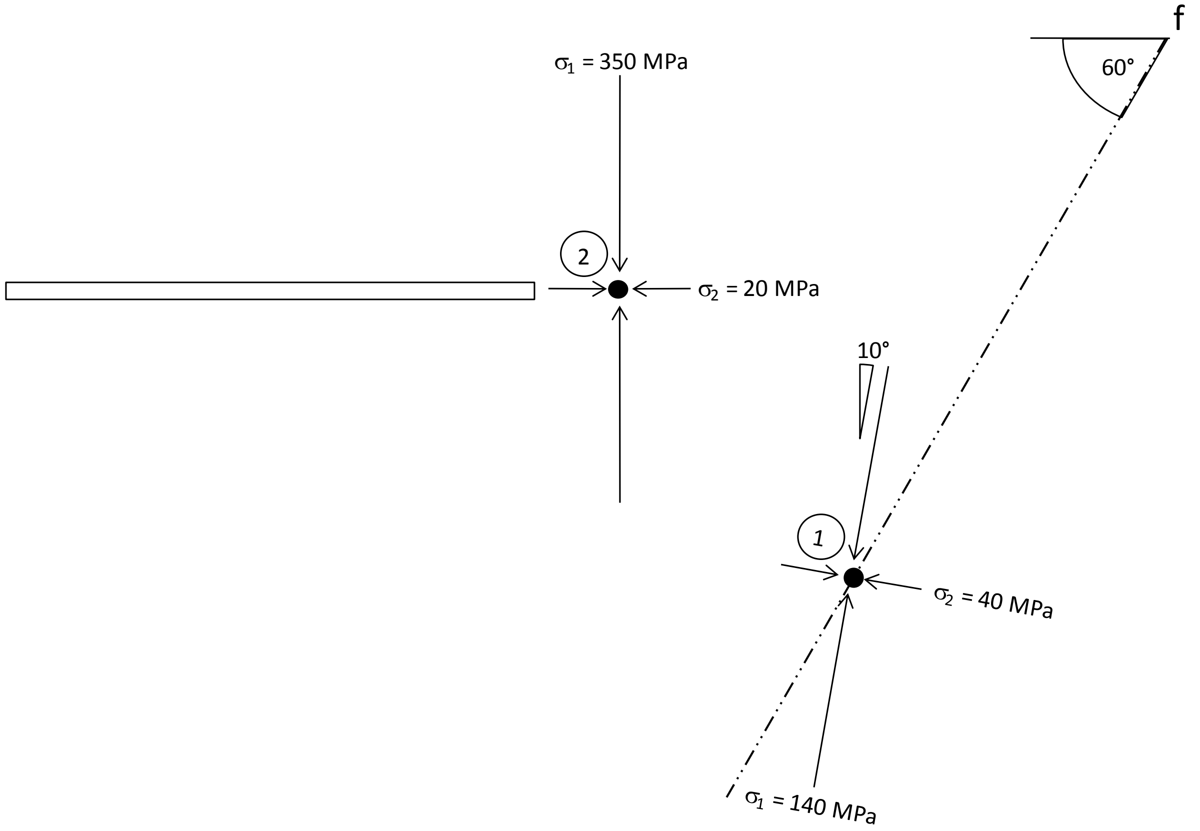
iv) Determine the material friction angle (1)

v) Determine the shear strength of the material if a normal stress of 300kPa is applied across the joint. (1)

[25]

QUESTION 2 – ROCK STRESS

The two dimensional stress state at two points in a homogeneous rockmass are shown below where lithostatic stress conditions does not necessary exist.



2.1 Define the following rock engineering parameters and provide symbols and SI units where applicable (make use of a sketch where possible). (5)

2.1.1 Normal stress

2.1.2 Shear stress

2.1.3 Homogeneous rockmass

2.1.4 Lithostatic stress conditions

2.1.5 Poisson's ratio

2.2 If the fault has a friction angle of 30° and cohesion of 2.0 MPa, comment on its stability at Point 1. Show all calculations. (10)

2.3 The rock mass has Hoek-Brown values of m = 15 and s = 0.1, while σ_c = 240 MPa. Plot the yield curve for this rockmass as well as the stress state at Point 2 and comment whether the rockmass should be in a state of failure or not. (10)

[25]

QUESTION 3 – STRESS IN ROCK AND ROCKMASSES

Two circular excavations are to be bored in an elastic, homogeneous and isotropic rockmass.

3.1 As the acting rock engineer on the mine, name the equation or theory you would apply to determine the distance between the excavations to avoid stress interaction between the two excavations. (1)

3.2 The radial and tangential stress regime around a tunnel is defined by the Kirsch equation. The respective equations are:

$$\sigma_\theta = \frac{1}{2}q(1+k)\left(1+\frac{R^2}{r^2}\right)+\frac{1}{2}q(1-k)\left(1+\frac{3R^4}{r^4}\right)Cos2\theta$$

and

$$\sigma_r = \frac{1}{2}q(1+k)\left(1-\frac{R^2}{r^2}\right)-\frac{1}{2}q(1-k)\left(1-\frac{4R^2}{r^2}+\frac{3R^4}{r^4}\right)Cos2\theta$$

The input parameters for the calculation include k, q, R, r and θ. Explain these input parameters by means of a sketch. (5)

3.3 The tunnel to be bored is 5 m in diameter. Determine the tangential and radial stresses in the sidewall at 1000 m below surface. The rock has a uniaxial strength of 180 MPa and a relative density of 2.76. Assume gravitational acceleration as 9.81 m/s^2. The calculated k ratio in this area of the mine is 1.6. Reproduce and complete the table below. (4)

Distance into Sidewall	σ_θ	σ_r
0.0	37.91	
0.5		8.07
1.0	38.69	
1.5		20.60
2.0	35.62	
5.0		36.10
10.0	28.44	
15.0		41.95

3.3.1 Plot the stress in relation to the distance into the sidewall for both the radial and tangential stresses. In addition to these two stresses, also indicate the value of the vertical and horizontal stresses when applying Heim's Rule. (6)

3.3.2 On viewing the results from your graph, express your opinion with regards to the validity of the rule of thumb that suggests the skin to skin spacing of two excavations should not be less than three time the combined width of the excavations. (2)

3.3.3 Explain how you would determine the principle stresses at 1000 m depth and then calculate the principle stresses. (5)

3.3.4 Calculate the tangential and radial stresses on the edge of the excavation in hangingwall. (2)

[25]

QUESTION 4 – ROCK ENGINEERING THEORY

4.1 Explain each of the following terms by utilising sketches and formulae (where appropriate) and give examples of how and where they can impact on rock engineering design.

4.1.1 Elastic modulus (3)

4.1.2 Principal stress (3)

4.1.3 Shear stress (3)

4.1.4 Elasto-plastic behaviour (2)

4.2 Explain the following concepts, listing the limitations and areas of appropriate application in each case (provide sketches, examples and where appropriate, formulae or equations).

4.2.1 RCF (4)

4.2.2 ERR (4)

4.2.3 ESS (3)

4.2.4 RMR (3)

[25]

TOTAL MARKS : 100

Useful Formulae

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$Q = wV$$

$$\varepsilon_{xx} = \frac{1}{E}\left\{\sigma_{xx} - \nu(\sigma_{yy} + \sigma_{zz})\right\} \quad \gamma_{xy} = \frac{1}{G}\tau_{xy} \quad \varepsilon_{xy} = \frac{1}{2G}\tau_{xy} \quad G = \frac{E}{2(1+\nu)}$$

$$\varepsilon_{yy} = \frac{1}{E}\left\{\sigma_{yy} - \nu(\sigma_{xx} + \sigma_{zz})\right\} \quad \gamma_{yz} = \frac{1}{G}\tau_{yz} \quad \varepsilon_{yz} = \frac{1}{2G}\tau_{yz} \quad K = \frac{E}{3(1 - 2\nu)}$$

$$\varepsilon_{zz} = \frac{1}{E}\left\{\sigma_{zz} - \nu(\sigma_{xx} + \sigma_{yy})\right\} \quad \gamma_{zx} = \frac{1}{G}\tau_{zx} \quad \varepsilon_{zx} = \frac{1}{2G}\tau_{zx}$$

$$\sigma_{xx} = \lambda\Delta + 2G\varepsilon_{xx} \quad \tau_{xy} = G\gamma_{xy} \quad \tau_{xy} = 2G\varepsilon_{xy} \quad \Delta = \varepsilon_{xx} + \varepsilon_{yy} + \varepsilon_{zz}$$

$$\sigma_{yy} = \lambda\Delta + 2G\varepsilon_{yy} \quad \tau_{yz} = G\gamma_{yz} \quad \tau_{yz} = 2G\varepsilon_{yz} \quad \lambda = \frac{E\nu}{(1+\nu)(1-2\nu)}$$

$$\sigma_{zz} = \lambda\Delta + 2G\varepsilon_{zz} \quad \tau_{zx} = G\gamma_{zx} \quad \tau_{zx} = 2G\varepsilon_{zx}$$

$$\sigma_{zz} = 0 \quad \varepsilon_{zz} = -\frac{\nu}{E}(\sigma_{xx} + \sigma_{yy})$$

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

$$\varepsilon_{yy} = \frac{1}{E}(\sigma_{yy} - \nu\sigma_{xx}) \quad \sigma_{yy} = \frac{E}{1-\nu^2}(\varepsilon_{yy} + \nu\varepsilon_{xx})$$

$$\varepsilon_{zz} = 0 \quad \sigma_{zz} = \nu(\sigma_{xx} + \sigma_{yy})$$

$$\varepsilon_{xx} = \frac{1}{E}\left\{ (1-\nu^2)\sigma_{xx} - \nu(1+\nu)\sigma_{yy}\right\}$$

$$\varepsilon_{yy} = \frac{1}{E}\left\{ (1-\nu^2)\sigma_{yy} - \nu(1+\nu)\sigma_{xx}\right\}$$

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

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

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

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

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

$$u = \frac{(1+\nu)}{E}q\left\{(1-2\nu)r + \frac{R^2}{r}\right\} \quad v = 0$$

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

$$\ell < \ell_c \quad ERR = \frac{\Delta U_m}{\Delta A} = \frac{\pi(1-\nu)\ell q^2}{2G} \qquad \ell = \ell_c \quad ERR = \frac{\Delta U_m}{\Delta A} = \frac{\pi}{4} s_m q$$

$$\ell > \ell_c \quad ERR = \frac{\Delta U_m}{\Delta A} = \frac{\pi}{4} s_m q\left(\frac{1-(1-\ell_c/\ell)^{1,27}}{\ell_c/\ell}\right) \qquad \ell \to \infty \quad ERR = \frac{\Delta U_m}{\Delta A} = s_m q$$

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

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

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

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

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

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

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

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

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

$$GSI < 25 \quad s = 0 \qquad a = 0.65 - \frac{GSI}{200} \qquad \sigma_1 = \sigma_3 + \sigma_{ci}\left(m_b\frac{\sigma_3}{\sigma_{ci}}\right)^{0,65-\frac{GSI}{200}}$$

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

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

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

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

$$q = 0.025H \quad MPa \quad H[m] \qquad \sigma_v = \rho g h \quad \sigma_h = k\sigma_v$$

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

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

$R < 5$

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

$R \geq 5$

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

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

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

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

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

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

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

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

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

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

$S_{m,he} = 0.39h\left(\frac{W}{H}\right)^{0.32}$ $S_{m,pf} = 0.1h_e$, H>80m $S_{m,pf} = 0.8h_e$, H<80m

$h_e = eh$

$\varepsilon_{m+} = 4.2S_m + 1.7$ $\varepsilon_{m-} = -9.1S_m - 2.8$ $T_m = 21.6S_m + 7$

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

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

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

$\sigma_t = \frac{qB^2}{2t_s^{\ 2}}$ $q = \rho g(t_s + t_w)$ $\sigma = \frac{3qL^2}{t^2}$ $\eta = \frac{qL^4}{32Et^3}$ $l_a = \frac{\gamma S_b^2 t_w}{\pi d_h \tau}$

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

$\sigma_{squat} = k\frac{R_o^b}{V^a}\left\{\frac{b}{\varepsilon}\left[\left(\frac{R}{R_o}\right)^{\varepsilon} - 1\right] + 1\right\}$ $Strength_{Squat} = \frac{0.0786}{V^{0,0667}}\left\{R^{2,5} + 181,6\right\}$

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

$$SF_{CM} = SF\left(1 + \frac{0,6}{w}\right)^{2,46} \qquad Load = \frac{\left[.025\left(H - T\right) + .030T\right]C_1C_2}{w_1w_2}$$

$$SF^{//} = SF\left(\frac{w - \Delta w}{w}\right)^{2,46} \qquad SF^{/} = SF\left(\frac{h}{h + \Delta h}\right)^{0,66}$$

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

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

$$s = 1.414t_l\sqrt{\frac{\sigma_t}{Fq_c}}, \quad q_c = q_l + \frac{q_uE_l + q_lE_u}{E_l + E_u} \qquad F_b = \frac{s}{\tan\phi}\left[\frac{3\rho gkB_s}{4} - \sigma_r d_h\right]$$

$$l_a = \frac{\rho gs^2t_w + 0.05}{\pi d_h\tau_c} \qquad l_a = \frac{Ft}{\pi d_h\tau_c}, \quad w_b = \rho gkt_{sb}s^2, \quad F_t = F_b + w_b$$

$$\sigma_{ts} = \frac{4w_b}{\pi d^2}, \quad w_b = \rho gs^2t_w \qquad \sigma_s = \frac{4F_t}{\pi d_s^2}$$