MINERALS COUNCIL
SOUTH AFRICA

EXAMINATION PAPER

SUBJECT: CERTIFICATE IN ROCK MECHANICS PAPER 1 : THEORY	**EXAMINER:** H YILMAZ
SUBJECT CODE: COMRMC1	**MODERATOR:** G KOTZE
EXAMINATION DATE: 11 MAY 2021	**TOTAL MARKS:** [100]
TIME: 14:30 to 17:30 (3 HOURS)	**PASS MARK:** (60%)

NUMBER OF PAGES: 10

THIS IS NOT AN OPENBOOK EXAMINATION – ONLY REFERENCES PROVIDED ARE ALLOWED

SPECIAL REQUIREMENTS:

1. Answer **all four questions**. Answer the questions **legibly** in English.
2. 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.

3. Show all calculations **and check calculations on which the answers are based.**
4. **Only non-programmable basic scientific calculators** may be used for calculations.
5. Write **legibly** in ink on the **right hand page** only – **left hand pages will not be marked**.
6. Illustrate your answers by means of sketches or diagrams wherever possible.
7. **Final answers** must be given to an accuracy which is typical of practical conditions, However be careful not to use too few decimal places during your calculations, as rounding errors may result in incorrect answers

NB: Ensure that the correct unit of measure (SI unit) are recorded as marks will be deducted from answers if the incorrect unit is used even if the calculated value is correct.

8. In answering the questions, full advantage should be taken of your practical experience as well as data given.
9. Please note that you are not allowed to contact your examiner or moderator regarding this examination.
10. Cell phones and other smart devices e.g. smart-watches are **NOT** allowed in the examination room.

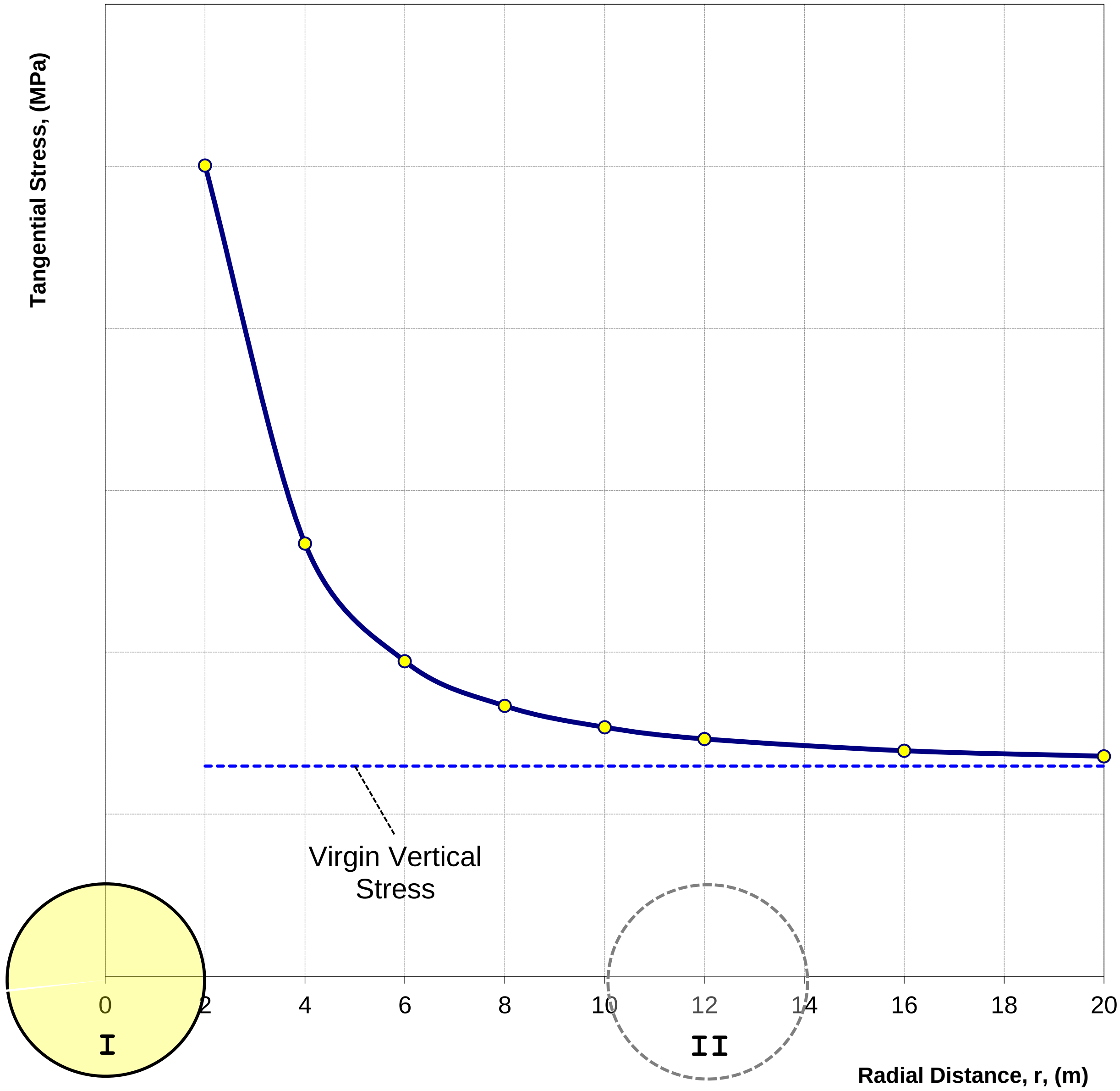
QUESTION 1 **[TOTAL: 25]**

1.1 Distribution of tangential stresses along a horizontal line on the side of a 2 m radius Tunnel I is provided as a solid line. Virgin vertical stress is indicated as a dotted line. Tunnel II with the same size is planned to be developed parallel to the Tunnel I, 8 m away skin to skin.

i) Plot the resultant tangential stresses between these two tunnels. Use the grid lines to ensure the answer is accurate on a relative basis. No calculations are required. Complete your solution on this sheet and attach it on the answer book. (5)

ii) Briefly describe how you obtained the solution in i). (3)

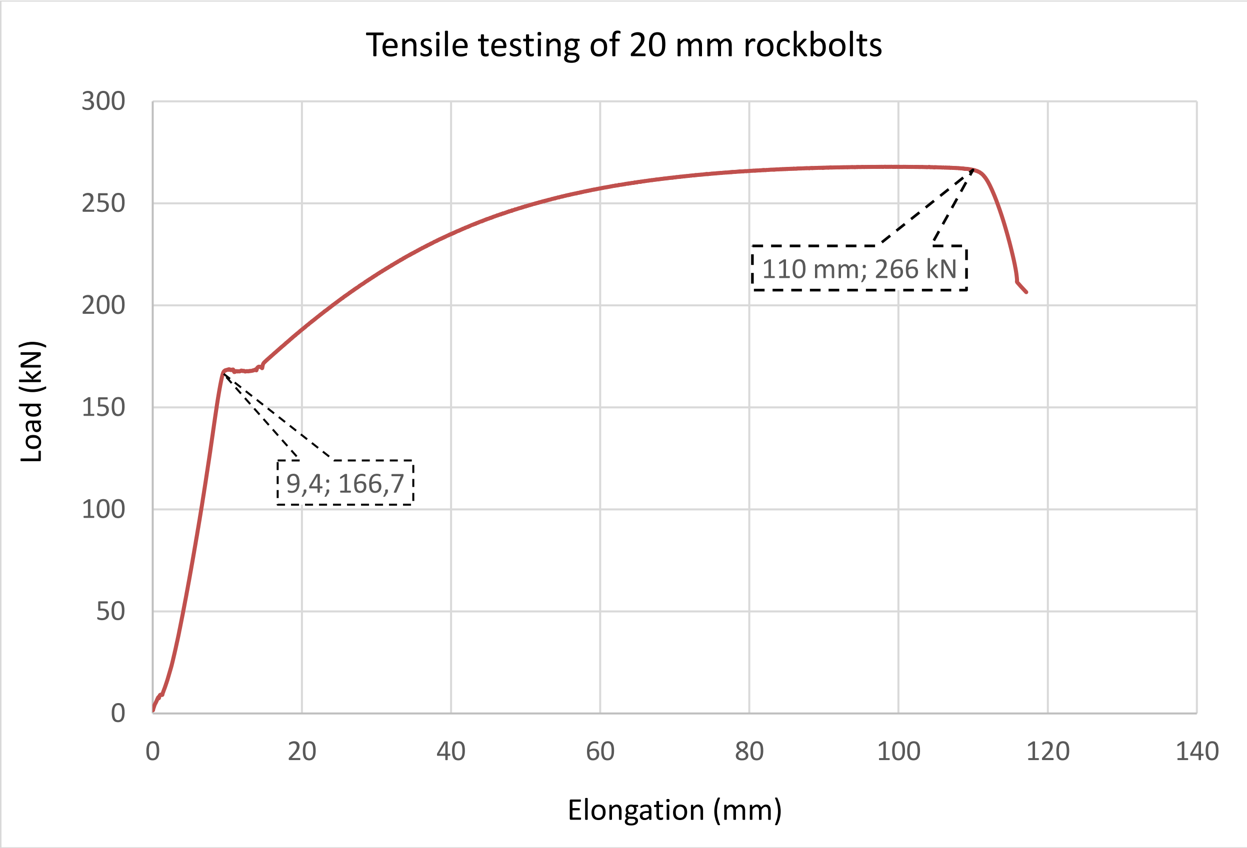
iii) What would be your recommendation for spacing between the two tunnels and justify your recommendation? (2)



1.2 A rebar with 900 mm length and 20 mm diameter is tensioned to failure. Force - Elongation behaviour and failure point are provided as a graph (*Note that tension and elongation are taken as absolute values*). Calculate the following;

- i) Tensile strength, (2)
- ii) Initial stiffness, (2)
- iii) Percentage elongation at peak load, (2)
- iv) Strain at peak load, (2)
- v) What would be the influence of testing a 25 mm rebar on failure load, tensile strength and initial stiffness? (3)

Note: Remember the importance of units for answers.



1.3 Multiple choices: (2 marks each)

i) Rocks having the same properties when tested in different directions across the material are called;

a) Uniform b) Homogenous c) Isotropic d) Non-Linear Elastic

e) Continuous e) Elastic

ii) When the stress is relieved at any position during a uniaxial compression test, the unloading follows a different path to loading with the resultant non-recoverable strain. This behaviour is called;

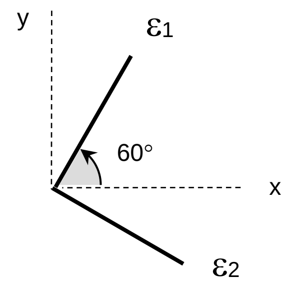
a) Strain Softening b) Cohesion loss c) Brittle-ductile transition

d) Residual strain e) Residual strength f) Hysteresis

QUESTION 2 **[TOTAL: 25]**

2.1 The magnitudes of principal strains are: $\varepsilon_1 = 3\times10^{-3}$, $\varepsilon_2 = -2\times10^{-3}$ as a result of a plane stress condition.

- i) Calculate the strain components along x-y coordinate position. (8)
- ii) Calculate the principal stresses if Elastic Modulus and Poisson's Ratio are 50 GPa and 0.2 respectively. Comment on the direction of the principal stresses and strains. (6)



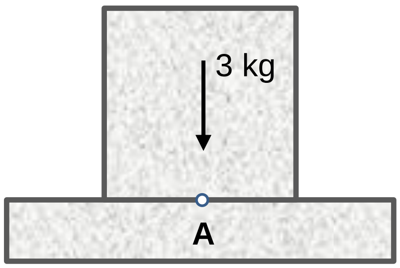
2.2 Draw the Mohr's circles for the following states of strains.
Use the same graph space for all the circles.
$\times10^{-3}$ applies to all strains. (11)

IMPORTANT: Use a compass to draw circles. Titles of the graph axis should clearly be indicated.

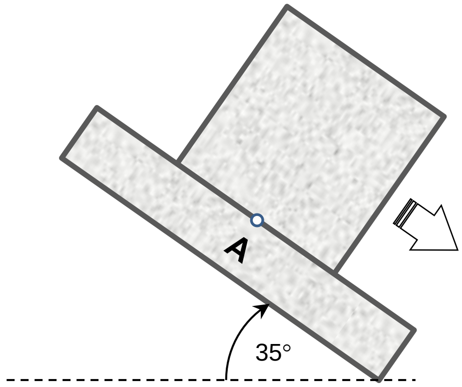
i)	$\varepsilon_x = 0$	$\varepsilon_y = -2$	and	$\gamma_{xy} = 0$
ii)	$\varepsilon_x = 0$	$\varepsilon_y = 0$	and	$\gamma_{xy} = 2$
iii)	$\varepsilon_x = 0,5$	$\varepsilon_y = -0,5$	and	$\gamma_{xy} = 0$
iv)	$\varepsilon_x = 2$	$\varepsilon_y = 2$	and	$\gamma_{xy} = 2$

QUESTION 3 **[TOTAL: 25]**

3.1 A 3 kg cubic rock specimen with smooth sides and a side length of 10 cm is resting on a smooth surface of the same rock type. The assembly is tilted and sliding of the top block takes place at 35°. (Take g = 10m/s^2 in calculations)



a)



b)

i) Calculate the density of the rock and the weight of the cubic rock specimen. (4)

ii) Calculate and illustrate the state of stress at Point A as vectors on the sliding plane for both cases a) and b). (9)

iii) Define Basic Friction Angle. (2)

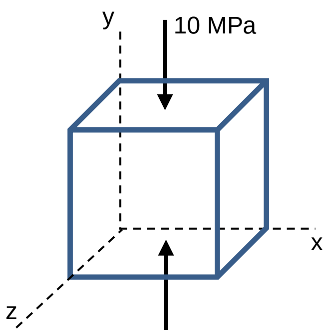
iv) What is the basic friction angle for the plane between the blocks? (1)

(Total 16)

3.2

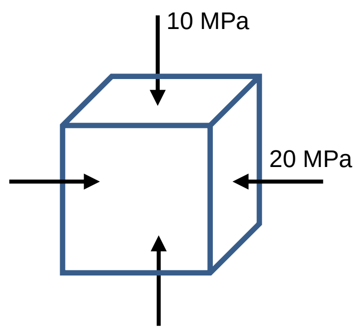
i) Calculate the strain along the x-direction for the three cases illustrated below if Elastic Modulus and Poisson's Ratio are 70 GPa and 0.3 respectively. (6)

ii) Name the loading condition for each case. (3)



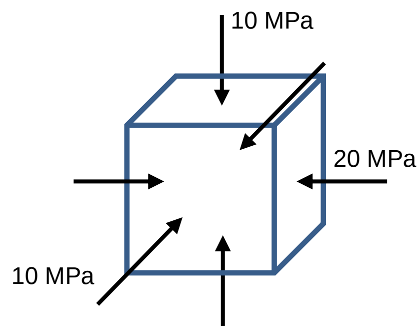
Case a)

σ_y = 10MPa, $\sigma_x = \sigma_z = 0$



Case b)

σ_y = 10MPa, σ_x = 20MPa $\sigma_z = 0$



Case c)

σ_y = 10MPa, σ_x = 20MPa σ_z = 10MPa

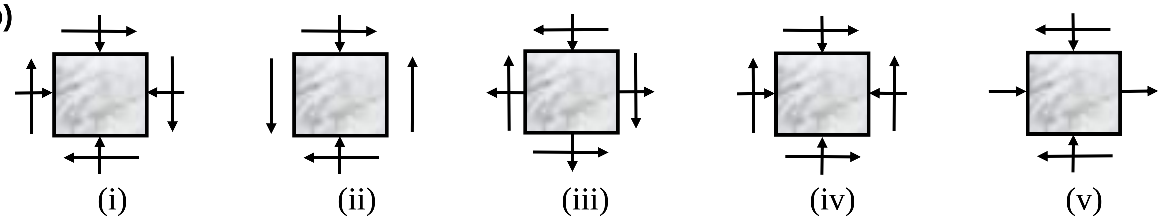
QUESTION 4 **[TOTAL: 25]**

Multiple Choice Questions
Only one answer per question No credit will be given for any working shown.

a) A rock core is subjected to uniaxial compression, therefore, its volume in the elastic region
- (i) increases and then decreases
- (ii) decreases and then increases
- (iii) decreases
- (iv) does not change
- (v) increases

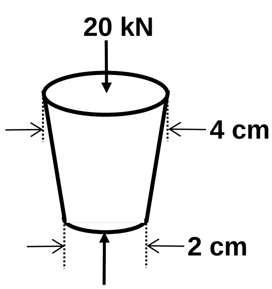
(**2 Marks**)

b)



Which of the above state of stresses on a square element is correct? Note that moment and force equilibrium exist, and $\sigma_x \neq \sigma_y \neq \tau_{xy}$. (**2 Marks**)

c) A cone shaped rock core is subjected to compression. The magnitude of the maximum stress on this specimen is;



- (i) 63,7 MPa
- (ii) 15,9 MPa
- (iii) 4,0 MPa
- (iv) 3,14 MPa
- (v) 1,8 MPa

(**2 Marks**)

d) Calculate the magnitude of minor principal stress for the following state of stress.
$\sigma_x = 6$ MPa, $\sigma_y = 6$ MPa, τ_{xy} = Non-zero unknown, $\sigma_1 = 9$ MPa, $\sigma_2 = ?$

- (i) Cannot be calculated if τ_{xy} is unknown
- (ii) 3 MPa
- (iii) 6 MPa
- (iv) 12 MPa
- (v) 21 MPa

(**2 Marks**)

e)

- Elastic modulus (E)
- Shear modulus (G)
- Poisson's Ratio (v)

The only constants defining the characteristics of an elastic material are

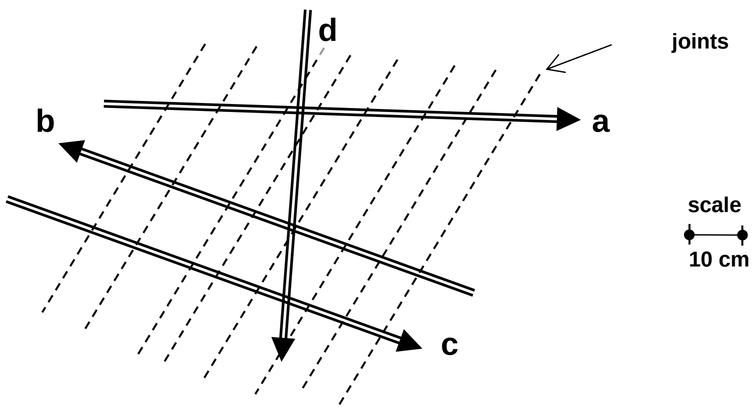
(i) E and G (ii) v (iii) E and v (iv) E, G and v (v) G and v

(**2 Marks**)

f) Vertical component of virgin stresses depends on

i) Elastic modulus
ii) Poisson's Ratio
iii) Depth below surface
iv) Shear modulus
v) Volumetric strain (**2 Marks**)

g) Which borehole orientation in the following sketch would result in the highest RQD?



(i) a (ii) b (iii) c (iv) d (v) b and c (vi) all the same

(**2 Marks**)

h) Which of the following parameters is <u>not</u> used to classify a rock mass using the *RMR* system:

i) Rock Quality Designation (*RQD*)
ii) Stress reduction factor
iii) Spacing of discontinuities
iv) Groundwater conditions
v) UCS of rock material (**2 Marks**)

i) Which of the following statements is <u>wrong</u>?

"The shear strength of discontinuities can be reduced when;

i) Normal stress (σ_n) is reduced
ii) Part or the entire discontinuity surface is not in intimate contact.
iii) Water pressure is present in a rock mass.
iv) In-situ roughness profile (scale) decreases.
v) A significant thickness of clay or gouge fillings occurs." (**2 Marks**)

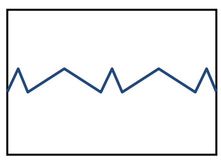
j) For linearly elastic, isotropic behaviour, stress and strain are related by _____?_____ ;

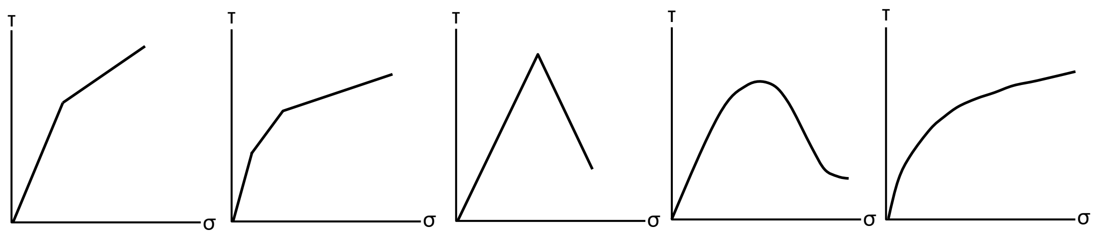
(i) Hoek-Brown failure criterion,
(ii) Newton's second law of motion,
(iii) Bieniawski's law,
(iv) Hooke's law,
(v) Mohr-Coulomb criterion, (**2 marks**)

k) Displacements in elastic modelling programs, such as Examine2D, are not influenced by;

(i) Tunnel span,
(ii) Mining depth
(iii) Tunnel orientation on plan,
(iv) Elastic modulus of rock,
(v) Poisson's ratio, (**2 marks**)

l) Which of the following graphs is the likely outcome of Patton's shear test with the following saw tooth configuration?





(i) (ii) (iii) (iv) (v)

(**3 Marks**)

FORMULAE SHEET

1. F = mg $\qquad\qquad$ σ = F/A
2. $q_v = \rho g h$
3. $\beta_o = \frac{(1+\sin\varphi_i)}{(1-\sin\varphi_i)}$
4. RQD = 115 – 3.3 Jv
5. $\tau = C_o + \mu\sigma_n$
6. $\sigma_1 = \sigma_c + \beta_o\sigma_3$
7. $\mu = tan\varphi_i$
8. $\mathbf{s} = \mathbf{e}^{\frac{(\mathbf{RMR}-\mathbf{100})}{\mathbf{9}}}$
9. $\mathbf{m} = \mathbf{m_i}\,\mathbf{e}^{\frac{(\mathbf{RMR}-\mathbf{100})}{\mathbf{28}}}$
10. $\sigma_1 = \sigma_3 + \sqrt{}(s\sigma_c^2 + m\sigma_c\sigma_3)$
11. $k = \frac{v}{1-v}$
12. $K = \frac{E}{3(1-2v)}$
13. W = ½ σε
14. $Q = \frac{1}{2}\sigma\varepsilon \times \text{Volume}$
15. $\varepsilon = \Delta\ell / \ell_o$ $\qquad$ $E = \sigma/\varepsilon$ $\qquad$ $\varepsilon_r = -v\varepsilon_a$
16. $\sigma_{xx} = \left[\frac{E}{(1+v)(1-2v)}\right]\left[(1-v)\varepsilon_{xx} + v\left(\varepsilon_{yy} + \varepsilon_{zz}\right)\right]$
17. $\sigma_{yy} = \left[\frac{E}{(1+v)(1-2v)}\right]\left[(1-v)\varepsilon_{yy} + v(\varepsilon_{xx} + \varepsilon_{zz})\right]$
18. $\sigma_{zz} = \left[\frac{E}{(1+v)(1-2v)}\right]\left[(1-v)\varepsilon_{zz} + v\left(\varepsilon_{xx} + \varepsilon_{yy}\right)\right]$
19. $\sigma_x = \frac{E}{1-\nu^2}(\varepsilon_x + \nu\varepsilon_y)$ $\qquad$ $\sigma_y = \frac{E}{1-\nu^2}(\varepsilon_y + \nu\varepsilon_x)$
20. $\sigma_1 = \frac{E}{1-\nu^2}(\varepsilon_1 + \nu\varepsilon_2)$ $\qquad$ $\sigma_2 = \frac{E}{1-\nu^2}(\varepsilon_2 + \nu\varepsilon_1)$
21. $\sigma_n = \sigma_1 cos^2\theta + \sigma_2 sin^2\theta$ $\qquad$ $\tau_{nm} = -\frac{1}{2}(\sigma_1 - \sigma_2)sin2\theta$
22. $\sigma_1 = \frac{1}{2}\left(\sigma_x + \sigma_y\right) + \frac{1}{2}\sqrt{}\left[\left(\sigma_x - \sigma_y\right)^2 + 4\tau_{xy}^2\right]$
23. $\sigma_2 = \frac{1}{2}\left(\sigma_x + \sigma_y\right) - \frac{1}{2}\sqrt{}\left[\left(\sigma_x - \sigma_y\right)^2 + 4\tau_{xy}^2\right]$
24. $\theta = \frac{1}{2}arc\tan\left[2\tau_{xy}/\left(\sigma_x - \sigma_y\right)\right]$

25. $\tau_{max} = \frac{1}{2}(\sigma_1 - \sigma_2)$

26. $\sigma_{x\prime} = \sigma_x cos^2\theta + 2\tau_{xy} \sin\theta \cos\theta + \sigma_y sin^2\theta$

27. $\sigma_{y\prime} = \sigma_x sin^2\theta - 2\tau_{xy} \sin\theta \cos\theta + \sigma_y cos^2\theta$

28. $\tau_{x\prime y\prime} = \frac{1}{2}\left(\sigma_y - \sigma_x\right) \sin 2\theta + \tau_{xy} \cos 2\theta$

29. $\varepsilon_{x'} = \varepsilon_x \cos^2\theta + \gamma_{xy} \sin\theta\cos\theta + \varepsilon_y \sin^2\theta$

30. $\varepsilon_{y'} = \varepsilon_x \sin^2\theta - \gamma_{xy} \sin\theta\cos\theta + \varepsilon_y \cos^2\theta$

31. $\gamma_{x'y'} = (\varepsilon_y - \varepsilon_x) \sin 2\theta + \gamma_{xy} \cos 2\theta$

32. $\varepsilon_{x'} = \varepsilon_x \cos^2\theta + \gamma_{xy} \sin\theta\cos\theta + \varepsilon_y \sin^2\theta$

$$\varepsilon_1 + \varepsilon_2 = \frac{2}{3}(\varepsilon_{0°} + \varepsilon_{60°} + \varepsilon_{120°}),$$

33. $$(\varepsilon_1 - \varepsilon_2)^2 = \frac{4}{3}(\varepsilon_{60°} - \varepsilon_{120°})^2 + \frac{4}{9}(2\,\varepsilon_{0°} - \varepsilon_{60°} - \varepsilon_{120°})^2$$

$$\tan 2\theta = \frac{\sqrt{3}(\varepsilon_{60°} - \varepsilon_{120°})}{2\,\varepsilon_{0°} - \varepsilon_{60°} - \varepsilon_{120°}}$$

34. $\varepsilon_x = \frac{1}{E}\,[\sigma_x - \nu(\sigma_y + \sigma_z)]$ $\quad\gamma_{xy} = \frac{1}{G}\tau_{xy}$ $\quad G = \frac{E}{2(1+\nu)}$

$\varepsilon_y = \frac{1}{E}\,[\sigma_y - \nu(\sigma_x + \sigma_z)]$ $\quad\gamma_{yz} = \frac{1}{G}\tau_{yz}$

$\varepsilon_z = \frac{1}{E}\,[\sigma_z - \nu(\sigma_x + \sigma_y)]$ $\quad\gamma_{zx} = \frac{1}{G}\tau_{zx}$

35. $\varepsilon_1 = \frac{1}{2}\left(\varepsilon_x + \varepsilon_y\right) + \frac{1}{2}\sqrt{\left[\left(\varepsilon_x - \varepsilon_y\right)^2 + \gamma_{xy}^2\right]}$

36. $\varepsilon_2 = \frac{1}{2}\left(\varepsilon_x + \varepsilon_y\right) - \frac{1}{2}\sqrt{\left[\left(\varepsilon_x - \varepsilon_y\right)^2 + \gamma_{xy}^2\right]}$

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

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

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

$\sigma_z^t = \sigma_z^v + \nu\,(\sigma_r^i + \sigma_\theta^i)$