UNIVERSITY OF BOLTON

OFF CAMPUS DIVISION

BACHELOR OF ENGINEERING (HONOURS) IN MECHANICAL ENGINEERING

MALAYSIA – KTG

SEMESTER 1 EXAMINATION 2018/2019

ADVANCED MATERIALS AND STRUCTURES

MODULE NO: AME 6002

Date: Tuesday 8th January 2019 **Time: 2.5 Hours**

INSTRUCTIONS TO CANDIDATES:

There are FOUR questions.

Answer ALL questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

This examination paper carries a total of 100 marks.

All working must be shown. A numerical solution to a question obtained by programming an electronic calculator will not be accepted.

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Q1. (a) Part of a cold water cooling system as a vessel subjected to a following direct stresses in the x, y, and z directions: 160 MPa, −60 MPa, 120 MPa, respectively. Due to the connection of a flange at the position of interest, two shear stresses are present, one related to xy with a value of 60 MPa and another related to yz with a value of 30 MPa.

(i) Draw the elemental cube showing the stresses acting. (4 marks)

(ii) Using this information given above and knowing that one of the Principal stresses is 110 MPa, calculate the other two principal stresses. (8 marks)

(iii) Evaluate the three angles (α, β, and γ) which describe the direction of the maximum principal stress relative to xyz co-ordinate system. Produce also a sketch showing this principal stress relative the elemental cube. (7 marks)

(b) If the yield strength of the material in tension is 380 MPa and the material follows the von Mises yield criterion, estimate the factor of safety associated with this point in vessel. (6 marks)

Total 25 marks

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Q2. (a) A 300 mm internal diameter pipeline used in a chemical plant is pressurised to 3 MPa and has a blanking cover as shown schematically in Figure Q2. If it is assumed that the cover is manufactured from steel with $E = 210$ GPa and $\nu = 0.31$ and can be modelled as a thin flat circular plate. Hence show that:

$$\frac{\delta w}{\delta r} = \frac{\frac{pr^3}{16} + C_1\frac{r}{2} + C_2\frac{1}{r}}{D}$$

where C_1 and C_2 are constant, p is the internal pressure, r is the radial distance from the centre of the plate, w is the normal displacement at position r and $D = Et^3/12(1-\nu^2)$. (9 marks)

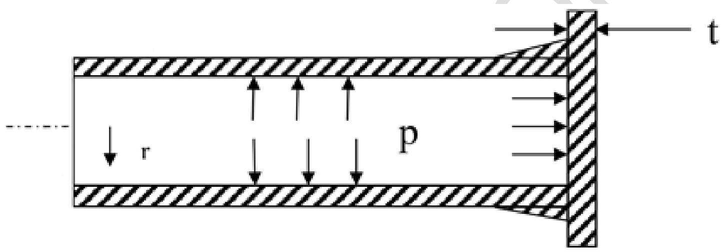

Figure Q2

(b) Evaluate the necessary thickness t of the cover assuming that the design stress is limited to 250 MPa. (9 marks)

(c) Does the thickness calculated justify the assumption? State the reason for your answer. (2 marks)

(d) If in the actual cover it is secured by a ring of bolts, describe how this will change the stress value and the deflected shape under the load. (5 marks)

Total 25 marks

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Q3. (a) Boiler plate steel is used to fabricate a cylindrical pressure vessel with a diameter $2r$ of 5 m and a wall thickness t of 8 mm with a fracture toughness of 34 MPa $m^{1/2}$. Inspection reveals a crack of 20 mm length running in the circumference direction.

(i) What is the maximum internal pressure P allowable, assuming a safety factor of 4? Given the hoop stress is P_r/t and longitudinal stress is $P_r/2t$. (6 marks)

(ii) Consider how the allowable maximum internal pressure would be affected if the inspection showed the crack running in the axial direction. (4 marks)

(iii) If the internal pressure varies between 0.8 MPa to 1.6 MPa every 40 s, how many cycles are required to extend the crack to 30 mm in the circumferential direction and how long will this take? Assume $C = 10^{-31}$, $Y = 1.12$, and $m = 3.5$. (7 marks)

(b)

(i) Explain the relationship between the stress intensity factor K and the fracture toughness K_c of a material. (2 marks)

(ii) Name two factors that K is dependent upon. (2 marks)

(c) Sketch the graph of fatigue-crack growth rates da/dN, as a function of the applied stress intensity range K in metallic materials, identifying the key elements of the graph? (4 marks)

Total 25 marks

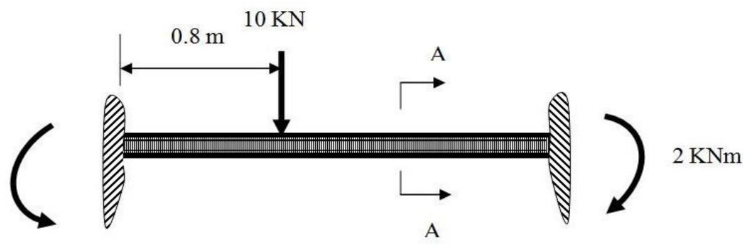
Please turn the page

Q4. (a) An endurance racing car floor panel support beam is to be fabricated from a carbon fibre reinforced polymer composite (CFRC) skins with a honeycomb core and a fibre volume fraction of 78%.

The beam is 2.3 m long and is assumed to be fully built-in. The core is limited to a thickness of 82 mm. The loads under a worst case scenario are given in Figure Q4. Using the above information and that in Table Q4, design a suitable lay-up for the skins. Also make a simple sketch of your lay-up and state any assumptions you have used. (12 marks)

(b) Estimate the percentage weight saving if the skins had been manufactured from an aluminium alloy with a design stress of 102 MPa, an elastic modulus of 77 GPa and a relative density of 3.86. (8 marks)

(c) If after tests in service the 10 kN load is observed to act 0.8 mm off left end from the y-y axis, explain how you would model this situation and how the lay-up would change. (4 marks)



Section on A-A
Beam Cross-Section

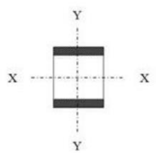


Figure Q4

Question 4 continued over the page.
Please turn the page

Question 4 cont'd…

Table Q4

Material	**Property**	
Carbon Fibre	Elastic Modulus E (GPa)	350
	Design Strain (%)	0.5
	In Plane Shear Strength (MPa)	45
	Inter-Laminar Shear Strength (MPa)	20
	Relative Density	1.68
	Laminate Surface Bond Strength (MPa)	30
Epoxy Resin	Relative Density	1.25
	Elastic Modulus E (GPa)	3.5

Total 25 marks

END OF QUESTIONS

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Formula Sheet

1. Elasticity – finding the direction vectors

$$\begin{bmatrix} S_x \\ S_y \\ S_z \end{bmatrix} = (\text{Stress tensor}) \begin{pmatrix} l \\ m \\ n \end{pmatrix}$$

$$k = \frac{1}{\sqrt{a^2 + b^2 + c^2}}$$

where a, b, and c are the co-factors of the eigenvalue stress tensor.

$$l = ak \qquad l = \cos\alpha$$

$$m = bk \qquad m = \cos\theta$$

$$n = ck \qquad n = \cos\varphi$$

2. Yield criterion

Von Mises:

$$\sigma_{vm} = \frac{1}{\sqrt{2}}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]^{1/2}$$

Tresca:

$$\sigma_3 \geq \sigma_2 \geq \sigma_1$$

$$\sigma_{tr} = 2\tau_{max}$$

$$\tau_{max} = \max\left(\frac{|\sigma_1 - \sigma_2|}{2}; \frac{|\sigma_1 - \sigma_3|}{2}; \frac{|\sigma_3 - \sigma_2|}{2}\right)$$

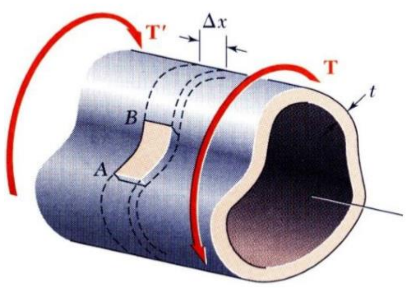
$$\frac{\sigma_{vm}}{\sigma_{tr}} = \frac{\sqrt{3}}{2}$$

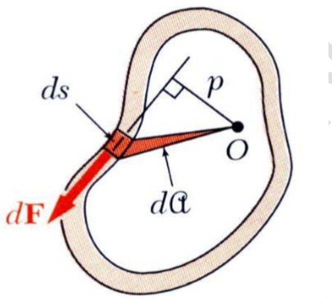
3. Strain gauges

Transform from x to x' through angle ϑ is given by:

$$\varepsilon_{x\prime} = \frac{1}{2}(\varepsilon_x + \varepsilon_y) + \frac{1}{2}(\varepsilon_x - \varepsilon_y)\cos 2\theta + \frac{\gamma_{xy}}{2}\sin 2\theta$$
$$\varepsilon_{y\prime} = \frac{1}{2}(\varepsilon_x + \varepsilon_y) - \frac{1}{2}(\varepsilon_x - \varepsilon_y)\cos 2\theta - \frac{\gamma_{xy}}{2}\sin 2\theta$$
$$\gamma_{x\prime y\prime} = -(\varepsilon_x - \varepsilon_y)\sin 2\theta + \gamma_{xy}\cos 2\theta$$

4. Torsion in closed thin wall cross section (CTW)

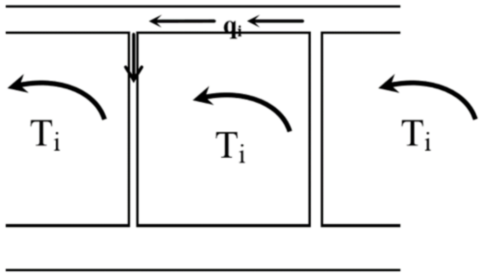




- Shear stress τ varies inversely with thickness t
  $\tau = \frac{T}{2tA}$
- Shear flow
  $q = \tau t$
- Applied torque T
  $T = 2qA$
- Angle of twist
  $\phi = \frac{TL}{4A^2G}\oint \frac{ds}{t}$

5. Torsion in multi-cells thin wall cross-section

- Section considered as an assembly of N tubular sub-sections (compartments), each subjected to torque T_i as shown on the figure below:



$$T = \sum_{i=1}^{n} T_i = 2\sum_{i=1}^{n} q_i A_i$$

- Common angle of twist for all compartment:

$$\theta = \frac{L}{2GA_i}\oint \frac{q_i - q'}{t(s)} ds$$

where q is the shear flow of the main compartment, q' is the shear flow due to torque in adjacent compartments, A_i is the area of cross-section i, t is the thickness of the cross-section and s is the circumference of the compartment.

6. Torsion in open thin wall cross-section (OTW)

If $b/t \geq 10$, then $\alpha = \beta = 1/3$

and

$$J_\alpha = J_\beta = J = \sum_{i=1}^{n} \frac{1}{3} b_i t_i^3$$

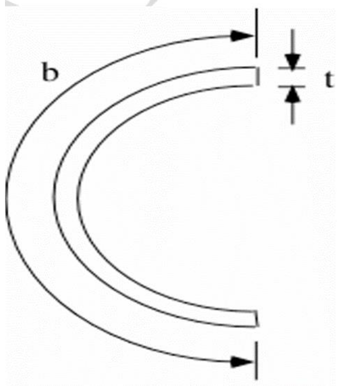
Shear stress

$$\tau_{max} = \frac{T t_{max}}{J}$$

Twist angle

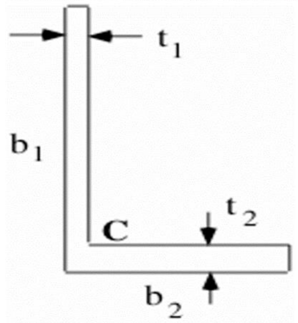
$$\phi = \frac{LT}{GJ}$$

(a)



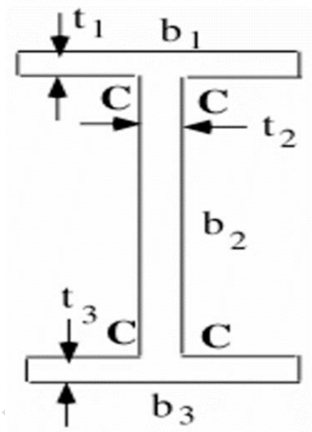
$$J = \frac{1}{3} b t^3$$

(b)



$$J = \frac{1}{3} b_1 t_1^3 + \frac{1}{3} b_2 t_2^3$$

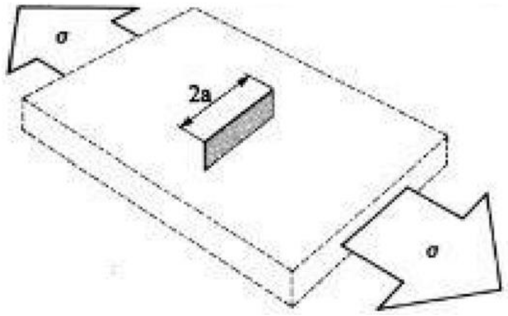
(c)



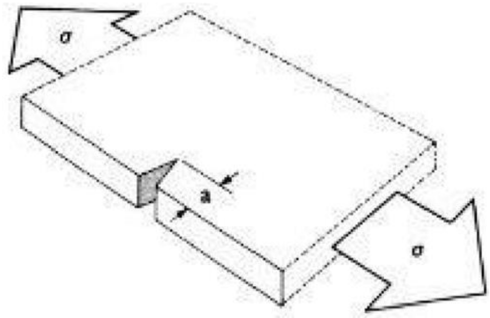
$$J = \frac{1}{3} b_1 t_1^3 + \frac{1}{3} b_2 t_2^3 + \frac{1}{3} b_3 t_3^3$$

7. Fracture mechanics

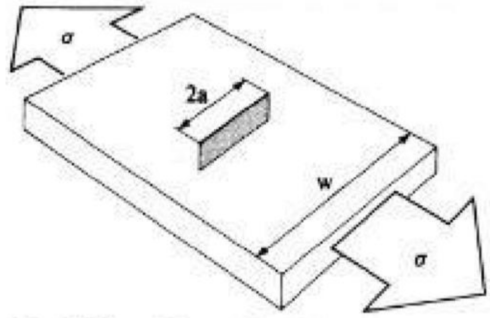
Y values for plates loaded in tension



(1) Through crack of length $2a$ in an infinite plate $Y = 1$.

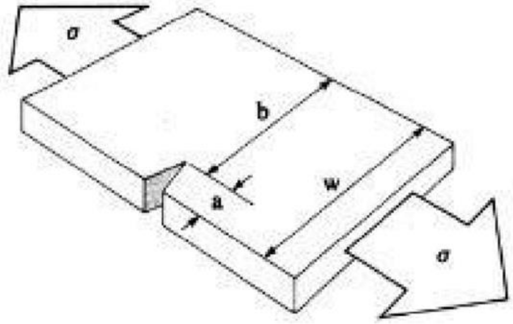


(2) Edge crack of length a in an *indefinite plate* $Y = 1.12$.
Because plane strain and plane stress have identical stress fields, this calibration is also for an edge scratch of depth a on a large body carrying tensile stress σ.



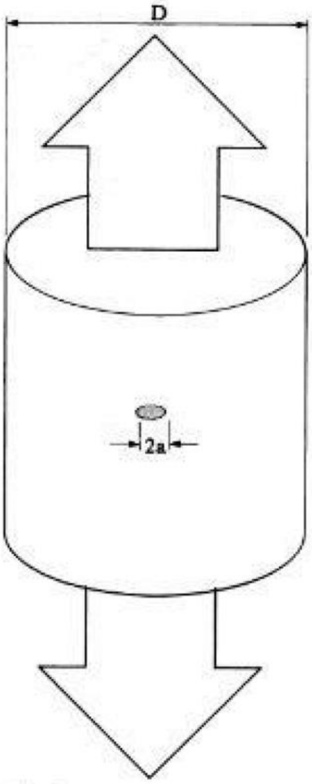
(3) Through crack of length $2a$ in a plate of width w.

$$Y = \left(\sec\frac{\pi a}{w}\right)^{1/2}, \ \frac{2a}{w} \leq 0.7$$



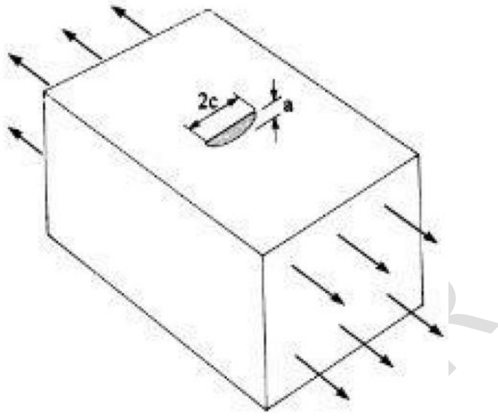
(4) Edge crack of length a in a plate of width w.

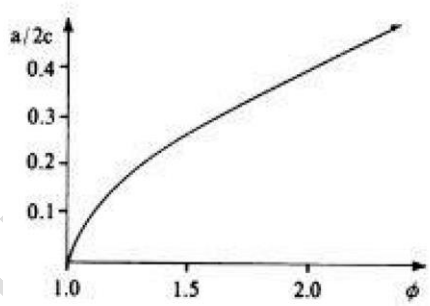
$$Y = 0.265\left(\frac{b}{4}\right)^4 + \frac{0.875 + 0.265\,a/w}{(a/w)^{3/2}}$$



(5) Through crack of length $2a$ in a plate of width w.

$$Y = \frac{2}{\pi},\ a \ll D$$

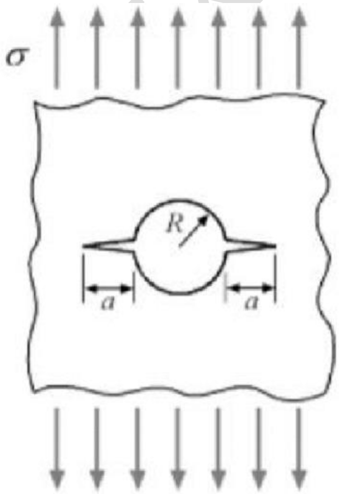




(6) Semi-elliptical surface flow.

$$Y = \frac{1.12}{\phi^{1/2}}$$

Infinite plate with a hole and symmetric double through cracks under tension.



$$K_I = \sigma\sqrt{\pi a}\left[1 + 2.365\left(\frac{R}{R+a}\right)^{2.4}\right]$$

8. Life calculations

$$\frac{da}{dN} = C(\Delta K)^m$$

$$N = \frac{1}{CY^m \sigma_a^m \pi^{\frac{m}{2}}} \int_{a_0}^{a_1} \frac{da}{a^{\frac{m}{2}}}$$

9. Circular plates

$$\frac{d}{dr}\left[\frac{1}{r}\frac{d}{dr}\left(r\frac{dw}{dr}\right)\right] = -\frac{Q_r}{D}$$

Hooke's law is expressed in terms of w as follows:

$$\sigma_r = \frac{E}{1-\nu^2}(\varepsilon_r + \nu\varepsilon_\theta) = -\frac{E_z}{1-\nu^2}\left(\frac{d^2w}{dr^2} + \frac{\nu}{r}\frac{dw}{dr}\right)$$

$$\sigma_\theta = \frac{E}{1-\nu^2}(\varepsilon_\theta + \nu\varepsilon_r) = -\frac{E_z}{1-\nu^2}\left(\frac{1}{r}\frac{dw}{dr} + \nu\frac{d^2w}{dr^2}\right)$$

Bending moment and shear force:

$$M_r = -D\left(\frac{d^2w}{dr^2} + \frac{\nu}{r}\frac{dw}{dr}\right),\ D = \frac{Et^3}{12(1-\nu^2)}$$

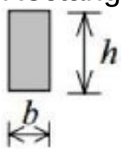
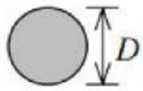
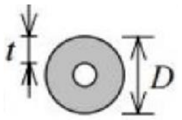
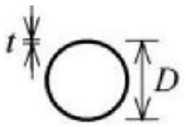
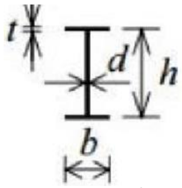
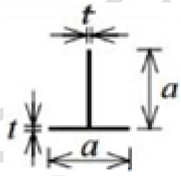
$$M_\theta = -D\left(\frac{1}{r}\frac{dw}{dr} + \nu\frac{d^2w}{dr^2}\right)$$

$$Q_r = -\frac{1}{2\pi r}\int_0^{2\pi}\int_b^r qr\,dr\,d\theta = -\frac{1}{r}\int_b^r qr\,dr$$

Governing equation:

$$\nabla^4 w = \left(\frac{d^2}{dr^2} + \frac{1}{r}\frac{d}{dr}\right)\left(\frac{d^2}{dr^2} + \frac{1}{r}\frac{d}{dr}\right)w = \frac{q}{D}$$

10. Plastic sections

Section	Elastic modulus	Plastic modulus	Shape factor
Rectangle 	$\frac{1}{6}bh^2$	$\frac{1}{4}bh^2$	1.50
Circle 	$\frac{\pi}{32}D^3$	$\frac{1}{6}D^3$	1.70
Thick-walled tube 	$\frac{\pi}{32}D^3\left[1-\left(1-\frac{2t}{D}\right)^4\right]$	$\frac{1}{6}D^3\left[1-\left(1-\frac{2t}{D}\right)^3\right]$	$\pm$1.50
Thin-walled tube 	$\frac{\pi}{4}tD^2$	tD^2	1.27
I-section 	$bht+\frac{1}{6}dh^2$	$bht+\frac{1}{4}dh^2$	$\pm$1.15
T-section 	$\frac{5}{18}ta^2$	$\frac{1}{2}ta^2$	1.80

11. Composite Materials

$$E_{composite} = E_{fibre}V_{fibre} + E_{matrix}(1 - V_{fibre})$$

12. Fracture toughness of some engineering materials

Material	K_{IC} (MN m$^{-3/2}$)	E (GN/m^2)	$\mathcal{G}_{IC}$ (kJ/m^2)
Plain carbon steels	140-200	200	100
High strength steels	30-150	200	5-110
Low to medium strength steels	10-100	200	0.5-50
Titanium alloys	30-120	120	7-120
Aluminium alloys	22-33	70	7-16
Glass	0.3-0.6	70	0.002-0.008
Polycrystalline alumina	5	300	0.08
Teak-crack moves across the grain	8	10	6
Concrete	0.4	16	1
PMMA (Perspex)	1.2	4	0.4
Polystyrene	1.7	3	0.01
Polycarbonate (ductile)	1.1	0.02	54
Polycarbonate (brittle)	0.4	0.02	6.7
Epoxy resin	0.8	3	0.2
Fibreglass laminate	10	20	5
Aligned glass fibre composite – crack across fibres	10	35	3
Aligned glass fibre composite – crack down fibres	0.3	10	0.0001
Aligned carbon fibre composite – crack across fibres	20	185	2

13. Formulas for values of the maximum principal stresses and maximum deflection in circular plates as obtained by theory of flexure of plates

Support and loading	Principal stress $\boldsymbol{\sigma_{max}}$	Point of maximum stress	Maximum deflection $\boldsymbol{w_{max}}$
Edge simply supported; load uniform ($r_0 = a$)	$\frac{3}{8}(3+\nu)P\frac{a^2}{h^2}$	Centre	$\frac{3}{16}(1-\nu)(5+\nu)\frac{pa^4}{Eh^3}$
Edge fixed; load uniform ($r_0 = a$)	$\frac{3}{4}P\frac{a^2}{h^2}$	Edge[a]	$\frac{3}{16}(1-\nu^2)\frac{pa^4}{Eh^3}$
Edge simply supported; load at centre $P = \pi r_0^2 \rho$, $r_0 \to 0$, but $r_0 > 0$	$\frac{3(1+\nu)}{2\pi h^2}P\left(\frac{1}{\nu+1} + \ln\frac{a}{r_0} - \frac{1-\nu}{1+\nu}\frac{r_0^2}{4a^2}\right)$	Centre	$\frac{3(1-\nu)(5+\nu)Pa^2}{4\pi E h^3}$
Fixed edge; load at centre $P = \pi r_0^2 p$, $r_0 \to 0$	$\frac{3(1+\nu)}{2\pi h^2}P\left(\ln\frac{a}{r_0} + \frac{r_0^2}{4a^2}\right)$ a must be $> 1.7r_0$	Centre	$\frac{3(1-\nu)Pa^2}{4\pi E h^3}$

a = radius of plate; r_0 = radius of centre loaded area; h = thickness of plate; p = uniform load per unit area; ν = Poisson's ratio

[a]For thicker plates ($h/r > 0.1$), the deflection is $w_{max} = C(3/16)\left(1-\nu^2\right)\left[\rho a^4/Eh^3\right]$, where the constant C depends on the ratio h/a as follow: $C = 1 + 5.72(h/a)^7$.

14. Related mathematics

Cubic equations-general form

$\sigma^3 + F_1\sigma^2 + F_2\sigma + F_3 = 0$

where F_1, F_2, and F_3 are constants then the solution has three roots, say a, b, and c giving:

$$(\sigma - a)\cdot(\sigma - b)\cdot(\sigma - c) = 0$$

Hence,

$$\sigma^3 + F_1\sigma^2 + F_2\sigma + F_3 = 0$$

as a general form.

If either a, b, or c is known a simple quadratic equation based upon the other two unknowns can derived and solved.

Position of the Maximum moment of a propped cantilever length L is given by:

$(\sqrt{2} - 1)L$ from the prop end.

Finding determinants using cofactors:

Sign of cofactor

$$\begin{bmatrix} + & - & + \\ - & + & - \\ + & - & + \end{bmatrix}$$

$$A = \begin{pmatrix} 2 & 4 & -3 \\ 1 & 0 & 4 \\ 2 & -1 & 2 \end{pmatrix}$$

$$A = \begin{pmatrix} 2 & 4 & -3 \\ 1 & 0 & 4 \\ 2 & -1 & 2 \end{pmatrix}$$

$$A = \begin{pmatrix} 2 & 4 & -3 \\ 1 & 0 & 4 \\ 2 & -1 & 2 \end{pmatrix}$$

Find determinants:

$$2\begin{vmatrix} 0 & 4 \\ -1 & 2 \end{vmatrix} - 4\begin{vmatrix} 1 & 4 \\ 2 & 2 \end{vmatrix} - 3\begin{vmatrix} 1 & 0 \\ 2 & -1 \end{vmatrix}$$

$= 2[(0)(2) - (-1)(4)] - 4[(1)(2) - (2)(4)] - 3[(1)(-1) - (0)(2)]$

$= 8 + 24 + 3$

$= 35$