UNIVERSITI SAINS MALAYSIA

First Semester Examination
Academic Session 2016/2017

December 2016/ January 2017

EMM 331 – Solid Mechanics
[Mekanik Pepejal]

Duration : 3 hours
Masa : 3 jam

Please check that this paper contains **EIGHT(8)** printed pages, **TWO(2)** page Appendix and **FIVE(5)** questions before you begin the examination.

*[Sila pastikan bahawa kertas soalan ini mengandungi **LAPAN(8)** mukasurat beserta **DUA(2)** Lampiran bercetak dan **LIMA(5)** soalan sebelum anda memulakan peperiksaan.]*

Appendix/*Lampiran*:

1. Selected formulas for solid mechanics [**1 page**/*mukasurat*]

2. Stress concentration factors for fillets in circular shafts [**1 page**/*mukasurat*]

INSTRUCTIONS : Answer **ALL** questions.

*[**ARAHAN** : Jawab **SEMUA** soalan.]*

Answer questions in English OR Bahasa Malaysia.
[Jawab soalan dalam Bahasa Inggeris ATAU Bahasa Malaysia.]

Answer to each question must begin from a new page.
[Jawapan bagi setiap soalan mestilah dimulakan pada mukasurat yang baru.]

In the event of any discrepancies, the English version shall be used.
[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai.]

Q1. [a] With the help of sketches, provide answers to the following questions:
Dengan bantuan lakaran, berikan jawapan bagi soalan di bawah:

(i) Define strain energy density and show it in stress-strain graph.
Takrifkan ketumpatan tenaga terikan dan tunjukkannya pada graf tegasan-terikan.

(ii) Explain the benefit of plotting a stress-strain graph instead of a load-displacement graph.
Terangkan manfaat dalam memplot graf tegasan-terikan berbanding graf beban-anjakan.

(iii) Define virtual work method and state its benefit in predicting structural deflection.
Takrifkan kaedah kerja maya dan nyatakan manfaatnya dalam menjangka lenturan struktur.

(**30 marks**/*markah*)

[b] A circular section rod of diameter 20 mm has the shape of a quadrant of a circle of radius 300 mm as shown in Figure Q1[b]. If a vertical force 100 N is applied at the free end, determine the deflection in the direction of the applied force. The Young's modulus is 208 GPa and the shear modulus is 80 GPa.

Sebuah rod sebahagian bulatan dengan diameter 20 mm mempunyai bentuk sukuan bulatan dengan radius 300 mm seperti ditunjukkan pada Rajah S1[b]. Sekiranya daya menegak 100 N dikenakan pada penghujung bebas, tentukan lenturan pada arah daya yang dikenakan. Rod berkenaan mempunyai modulus Young 208 GPa dan modulus ricih 80 GPa.

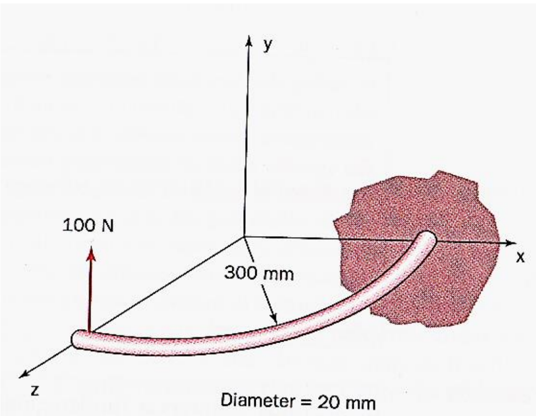

Figure Q1[b]
Rajah S1[b]

(**70marks**/*markah*)

Q2. [a] A steel has Young's modulus E of 30 GPa and elastic limit σ_y of 300 MPa. Figure Q2[a] shows strain inputs of cyclic test with the values of stresses at bottom and peak of the cycle are -500MPa and 500MPa respectively. With the aid of stress (MPa) vs strain (%) graphs as the responses for the strain inputs, sketch the response of the steel under cyclic compression-tension loading using elastic-nonlinear hardening deformation model. Please state the values of stress-strain at the intervals between elastic and plastic deformation.

Suatu keluli mempunyai modulus Young E = 30 GPa dan takat elastik σ_y = 300 MPa. Rajah S2[a] menunjukkan input terikan bagi ujian berkitar dengan nilai tegasan pada bawah dan puncak kitaran masing-masing sebanyak -500 MPa dan 500 MPa. Dengan bantuan graf tegasan (MPa) melawan terikan (%) sebagai respon kepada input terikan, lakarkan respon bagi keluli berkenaan di bawahbeban mampatan-tegangan berkitar menggunakan model ubahbentuk elastik-pengerasan nonlinear. Nyatakan nilai-nilai tegasan-terikan pada perubahan antara ubahbentuk elastik dan plastik.

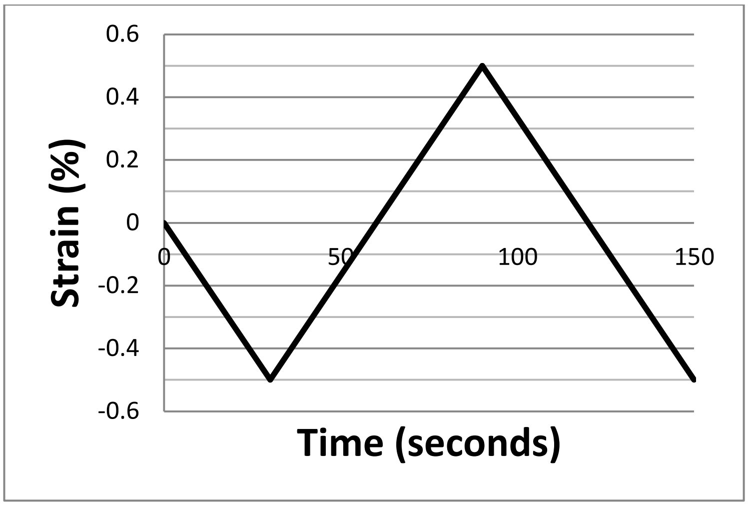

Figure Q2[a]
Rajah S2[a]

(**35 marks**/*markah*)

[b] Consider the stress-strain data in Table Q2[b] for a steel. Obtain values of the constants for a stress-strain curve by using either the elastic-power hardening relationship or the Ramberg-Osgood relationship that fits these data. Add your fitted curve to the plot of the data and comment on how well it fits the data.

Pertimbangkan data tegasan-terikan pada Jadual S2[b] bagi suatu keluli. Dapatkan nilai-nilai pekali bagi lengkuk tegasan-terikan dengan menggunakan persamaan elastik-pengerasan kuasa atau persamaan Ramberg-Osgood yang *sepadan dengan data berkenaan. Plotkan lengkuk graf berdasarkan persamaan yang diperolehi dan berikan komen tentang kesepadanan antara kedua-dua data.*

Table Q2[b]
Jadual S2[b]

σ (MPa)	ε(%)	σ (MPa)	ε(%)
0	0	270	0.70
50	0.07	290	1.05
100	0.14	300	1.50
150	0.21	310	2.30
200	0.28	313	3.00
240	0.45	315	3.50

(**65 marks**/*markah*)

Q3. [a] (i) With the help of sketches, give two real examples of failures in engineering field and explain their relationship with stress concentration effect.

Dengan bantuan lakaran, berikan dua contoh sebenar kegagalan dalam bidang kejuruteraan dan terangkan hubungannya dengan kesan penumpuan tegasan.

(**20 marks**/*markah*)

(ii) A stepped shaft shown in Figure Q3[a] is to rotate at 900 rpm as it transmits power from a turbine to a generator. The grade of steel specified in the design has an allowable shearing stress of 55 MPa. Determine the maximum power that can be transmitted.
(Power, P = $2\pi f$T).

Sebuah aci berlangkah seperti Rajah S3[a] berputar pada 900 rpm untuk menghantar kuasa dari turbin ke penjana. Gred keluli yang dinyatakan dalam rekabentuk mempunyai tegasan ricih yang dibenarkan sebanyak 55 MPa. Tentukan kuasa maksimum yang boleh dihantar. (Kuasa, P = $2\pi f T$).

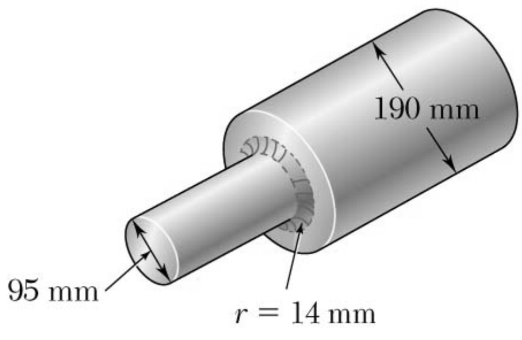

Figure Q3[a]
Rajah S3[a]

(**30 marks**/*markah*)

…5/-

[b] **A structural beam under high temperature has failed due to creep rupture. Develop a suitable relationship to describe creep stress relationship for a beam under pure bending using these criteria:**

(i) **Strain in pure bending: $\boldsymbol{\varepsilon = y/R}$**
(ii) **Creep in the secondary stage : $\boldsymbol{d\varepsilon/dt = B\sigma^n}$**

A constant bending moment is applied to the structural beam with a cross section as shown in Figure Q3[b], around the neutral axis XX.

Suatu alur di bawah suhu tinggi telah mengalami kegagalan akibat rayapan pecah. Bina satu persamaan untuk mengaitkan tegasan rayapan di bawah lenturan asli menggunakan criteria ini:

(i) *Terikan dalam lenturan asli:* $\boldsymbol{\varepsilon = y/R}$
(ii) *Rayapan pada peringkat kedua :* $\boldsymbol{d\varepsilon/dt = B\sigma^n}$

Suatu momen lenturan malar dikenakan pada alur yang mempunyai keratan rentas seperti pada Rajah S3[b], pada paksi neutral XX.

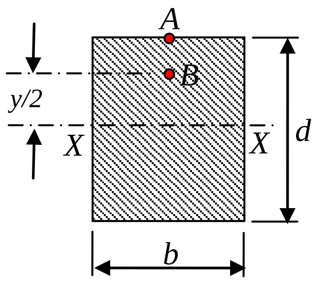

Figure Q3[b]
Rajah S3[b]

If the beam follows a creep law of the form $\boldsymbol{d\varepsilon/dt = B\sigma^n}$, demonstrate that the creep stress at point A is similar to the creep stress at point B. Assume $\boldsymbol{n}$ = 10 and the second moment of area is $\boldsymbol{I_x = bd^3/12}$.

Jika alur menuruti hukum rayapan $\boldsymbol{d\varepsilon/dt = B\sigma^n}$, *tunjukkan tegasan rayapan pada titik A adalah sama pada rayapan pada titik B. Anggapkan* n = *10 dan momen luas kedua adalah* $\boldsymbol{I_x = bd^3/12}$.

(**50 marks**/*markah*)

Q4. [a] The energetics of crack advance, G, and the stress intensity factor, K, are the founding concepts in fracture mechanics theory. Demonstrate that the relationship of G_C and K_C for a thin plate is approximated by:

Kaedah tenaga perambatan retak, G, dan faktor keamatan tegasan, K, adalah konsep asas dalam teori mekanik kepatahan. Tunjukkan perkaitan G_C dan K_C bagi plat nipis dianggarkan oleh:

$$K_C^2 = EG_C$$

where E is the modulus of elasticity.
yang mana E adalah modulus kekenyalan.

(40 marks/*markah*)

[b] A wide sheet of aluminium alloy has a central crack 25 mm long. If the fracture stress for the sheet is 200 MN/m^2 and the yield stress of the material is 400 MN/m^2, calculate the fracture toughness of the material

Suatu keping aloi aluminium menpunyai retak sepanjang 25 mm. Jika tegasan retak adalah 200 MN/m^2 dan tegasan alah adalah 400 MN/m^2, tentukan keliatan patah bahan tersebut

(i) Using Linear Elastic Fracture Mechanics (LEFM) and
Menggunakan Mekanik Kepatahan Linar Elastik (LEFM) dan

(ii) Using the Irwin's plastic zone correction.
Menggunakan pembetulan zon plastik Irwin.

Under LEFM conditions, to qualify the fracture toughness measurement of a fracture test, the following conditions have to be satisfied:

Di bawah keadaan LEFM, untuk melayakkan pengukuran keliatan patah dalam sesuatu ujian kepatahan, keadaan di bawah ini perlu dipenuhi:

$$B, a \geq 2.5\left(\frac{K_Q}{\sigma_Y}\right)^2 \qquad 0.45 < \frac{a}{W} < 0.55 \qquad F_Q \leq 1.1F_Y$$

If the size of the crack length is the same as above, propose the minimum size of a compact tension test specimen in terms of the important dimensions of crack length, a, ligament length, W, and thickness, B, for a valid LEFM testing. Construct a drawing to represent a suitable compact tension specimen.

Jika saiz retak adalah sama seperti di atas, cadangkan saiz minima bagi spesimen tegangan kompak mengikut dimensi utamanya seperti panjang retak, a, panjang ligament, W dan ketebalan, B untuk ujian LEFM yang sah. Hasilkan lukisan untuk mewakili specimen tegangan kompak yang bersesuaian.

(60 marks/*markah*)

Q5. **The blades of a turbine rotor are fitted into aluminium alloy discs as shown in Figure Q5. Take these crack growth data below for aluminium alloy:**

Suatu bilah rotor turbin dipasangkan kepada cakera aloi aluminium seperti di Rajah S5. Gunakan data perambatan retak di bawah untuk aloi aluminium:

$$C = 4 \times 10^{-11}$$
$$m = 3.54$$
$$K_{IC} = 35\ MN/m^{-3/2}$$

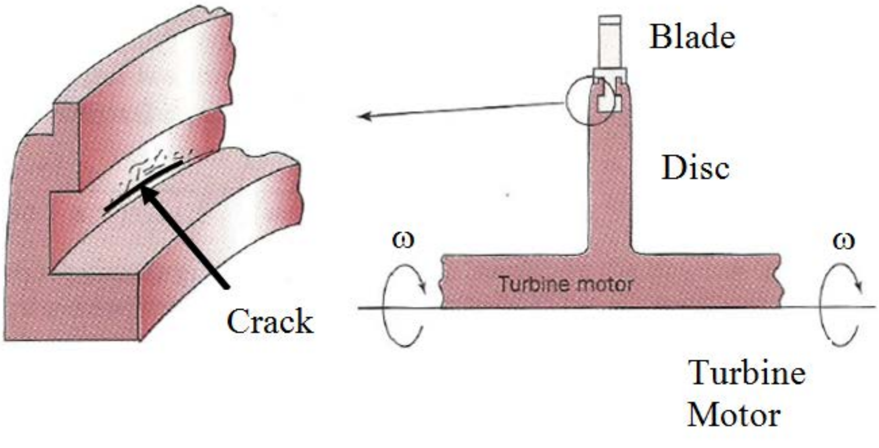

Figure Q5
Rajah S5

If during the assembly of the system, a 0.1 mm deep crack is made in the surface of the disc as indicated above:

Jika semasa pemasangan, suatu retak sedalam 0.1 mm telah dihasilkan pada permukaan cakera seperti ditunjukkan di atas:

(i) **Use the Paris's Law to derive the number of stress cycles under fatigue due to the crack.**

Gunakan hukum Paris untuk menerbitkan persamaan bagi kitar tegasan di bawah kelesuan disebabkan oleh retak itu.

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

Demonstrate how many stress cycles the disc can withstand before fatigue failure occurs.

Tunjukkan berapa kitaran tegasan cakera itu dapat alami sebelum kegagalan kelesuan berlaku.

(**40 marks**/*markah*)

(ii) **If the rotor is required to undergo at least 2000 cycles in service, by what factor should the rotation speed be increased in a test to verify that any cracks in the disc are too small to grow to a critical size in service?**

The rotation of the turbine causes a stress of 350 MN/m^2 at the plane of the crack.

Jika rotor dikehendaki beroperasi sekurang-kurangnya sebanyak 2000 kitar dalam perkhidmatannya, apakah faktor yang perlu untuk ujian kelajuan pusingan rotor untuk menentukan retak atau calar di dalam cakera adalah kecil untuk merambat menjadi saiz yang kritikal dalam perkhidmatan turbin?

Pusingan turbin menghasilkan tegasan sebanyak 350 MN/m^2 pada satah retak.

(**60 marks**/*markah*)

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APPENDIX 1
LAMPIRAN 1

Selected formulas

Selected theories of failure

Tresca: $\sigma_1 - \sigma_3 = \sigma_Y$

von Mises: $(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 2\sigma_Y^2$

Basic strain energy formulas

Load category	General Expression for strain energy	Particular case for constant load and geometry	Strain Energy per unit volume
Tension	$\int \frac{F^2}{2AE} dx$	$\frac{F^2 L}{2AE}$	$\frac{\sigma^2}{2E}$
Simple shear	$\int \frac{Q^2}{2AG} dx$	$\frac{Q^2 L}{2AG}$	$\frac{\tau^2}{2G}$
Torsion	$\int \frac{T^2}{2GJ} dx$	$\frac{T^2 L}{2GJ}$	$\frac{\tau_m^2}{4G}$ for circular section
Bending	$\int \frac{M^2}{2EI} dx$	$\frac{M^2 L}{2EI}$	$\frac{\sigma_m^2}{6E}$ for rectangular section

Selected trigonometric applications

Selected Trigonometric identities	Selected Trigonometric integrals
$\sin^2\theta = \frac{1}{2}(1 - \cos 2\theta)$	$\int \sin x \, dx = -\cos x + c$
$\cos^2\theta = \frac{1}{2}(1 + \cos 2\theta)$	$\int \cos x \, dx = \sin x + c$
$\sin\theta \cos\theta = \frac{1}{2} \sin 2\theta$	

Selected formulas for stresses for pressurized systems

Hoop stress:	$\sigma_H = \frac{pr}{t}$	for relatively thin wall vessel
Longitudinal stress:	$\sigma_L = \frac{pr}{2t}$	for relatively thin wall vessel
Hoop and Longitudinal stress	$\sigma_H = \sigma_L = \frac{pr}{t}$	for relatively thin spherical vessel

APPENDIX 2
LAMPIRAN 2

Stress concentration factors for fillets in circular shafts

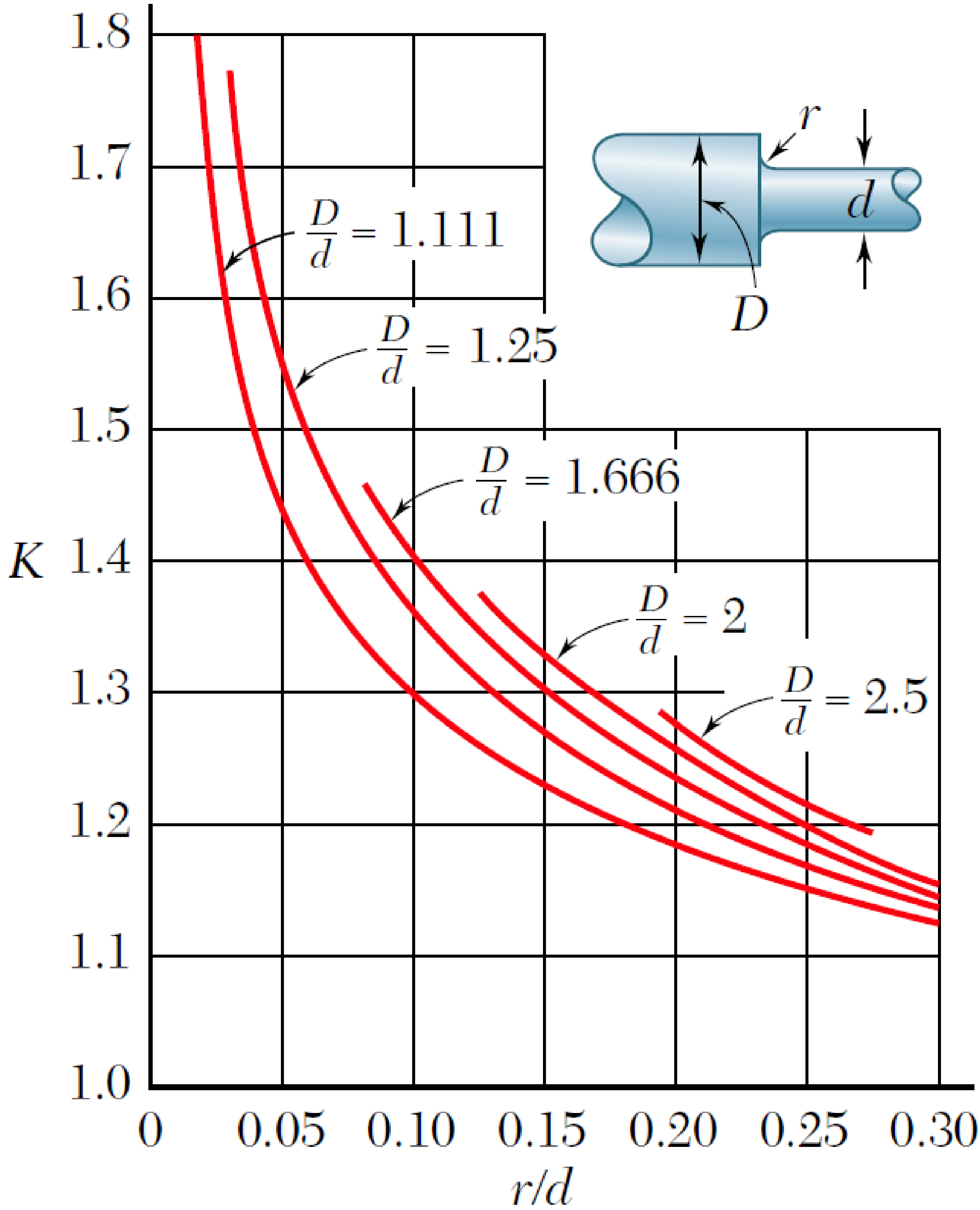

Figure A2: Stress Concentration factors for fillets in circular shafts.