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UNIVERSITI SAINS MALAYSIA

First Semester Examination  
Academic Session 2008  
*Peperiksaan Semester Pertama  
Sidang Akademik 2008*

November 2008  
*November 2008*

**EMM 331/3 – Solid Mechanics**  
***Mekanik Pepejal***

Duration : 3 hours  
*Masa : 3 jam*

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**INSTRUCTIONS TO CANDIDATE:**

**ARAHAN KEPADA CALON:**

Please check that this paper contains **NINE (9)** printed pages, **FIVE (5)** pages appendix and **SIX (6)** questions before you begin the examination.

*Sila pastikan bahawa kertas soalan ini mengandungi **SEMBILAN (9)** mukasurat bercetak, **LIMA (5)** mukasurat lampiran dan **ENAM (6)** soalan sebelum anda memulakan peperiksaan.*

Answer **FIVE (5)** questions.

Jawab **LIMA (5)** soalan.

Answer all questions in **English** OR **Bahasa Malaysia** .

*Calon boleh menjawab semua soalan dalam **Bahasa Malaysia** ATAU **Bahasa Inggeris***

**Appendix/Lampiran:**

- |                                      |                     |
|--------------------------------------|---------------------|
| 1. Formula untuk Mekanik Pepejal     | [1 page/mukasurat]  |
| 2. Beam Deflection Formulas          | [1 page/mukasurat]  |
| 3. Stress concentration factors      | [2 pages/mukasurat] |
| 4. Properties of Rolled-Steel Shapes | [1 page/mukasurat]  |

Each question must begin from a new page.

*Setiap soalan mestilah dimulakan pada mukasurat yang baru.*

**Q1. [a]** The prismatic beam AB of length  $L$  is loaded with  $P$  at  $D$  as shown in Figure 1[a]. This beam is made of rolled-steel with the properties as shown in the appendix.

- (i) Taking into account only the effect of normal stresses due to bending, determine the strain energy of the beam.
- (ii) Calculate the strain energy, knowing that the beam is W250 x 67,  $P = 180$  kN,  $L = 3.8$  m,  $b = 2.6$  m, and  $E = 200$  GPa.

*Sebuah rasuk bersegi empat AB yang mempunyai panjang  $L$  dikenakan dengan beban  $P$  pada  $D$  seperti yang ditunjukkan dalam Rajah S1[a]. Rasuk ini diperbuat daripada keluli guling dengan ciri-ciri seperti yang terdapat di dalam lampiran*

- (i) Dengan cuma mengambil kira kesan tegasan normal disebabkan lenturan, tentukan tenaga terikan rasuk tersebut.
- (ii) Kirakan tenaga terikan jika parameter rasuk seperti berikut: W250 x 67,  $P = 180$  kN,  $L = 3.8$  m,  $b = 2.6$  m, dan  $E = 200$  GPa.

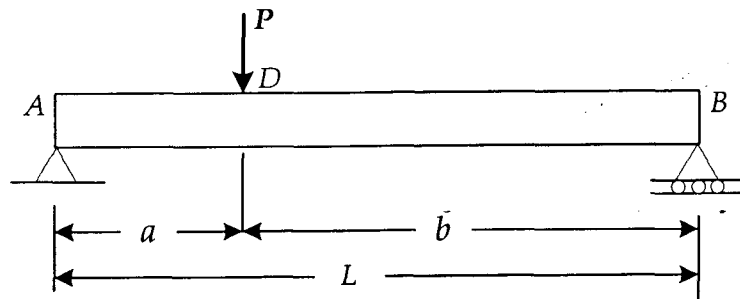


Figure Q1[a]  
Rajah S1[a]

(40 marks/markah)

**[b]** The three bar truss shown in Figure Q1[b] is made of steel and has the cross-sectional area shown. Using  $E = 200$  GPa, determine:

- (i) Vertical deflection of joint C
- (ii) Horizontal deflection of joint C.

*Tiga ahli kekuda yang ditunjukkan dalam Rajah S1[b] diperbuat daripada keluli dan mempunyai luas keratan rentas seperti yang ditunjukkan. Dengan menggunakan  $E = 200$  GPa, tentukan:*

- (i) Lenturan menegak pada sambungan C
- (ii) Lenturan melintang pada sambungan C.

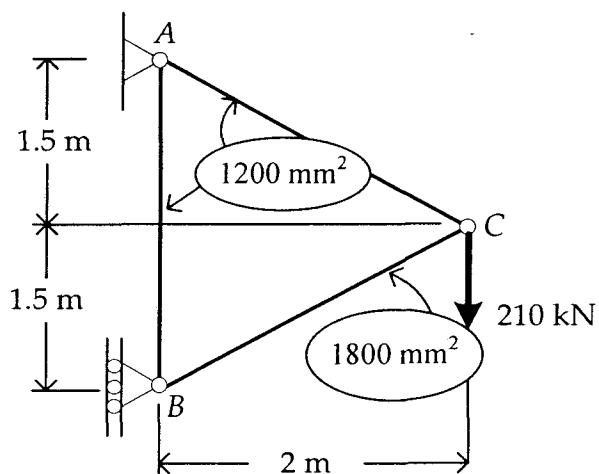


Figure Q1[b]  
Rajah S1[b]

(60 marks/markah)

- Q2. [a] Using  $E = 200 \text{ GPa}$ , determine the strain energy of the steel rod ABC when  $P = 35 \text{ kN}$ .

Dengan menggunakan  $E = 200 \text{ GPa}$ , tentukan tenaga terikan rod keluli ABC apabila  $P = 35 \text{ kN}$

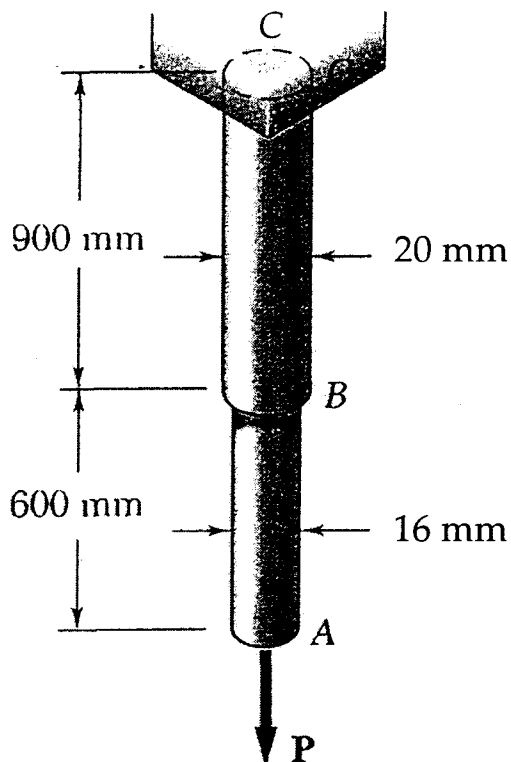


Figure Q2[a]  
Rajah S2[a]

(40 marks/markah)

- [b] The following creep rupture data was recorded for an alloy steel when it was tested at a range of stresses and temperatures:

*Data kemusnahan rayapan berikut telah direkodkan untuk keluli aloi apabila ianya diuji pada berbagai tegasan dan suhu:*

Temperature (°C)	Stress (MN/m <sup>2</sup> )	Time to failure (hr)
500	300	4724
600	200	570
700	100	297
800	60	95.3
1000	30	8.6

If a component made from this material is required to last at least 15 000 hours at a stress of 230 MN/m<sup>2</sup>, what is its maximum permissible service temperature? The constant “a” in the Larsen-Miller parameter for the alloy is 20.

*Jika komponen daripada bahan ini diperlukan untuk bertahan sekurang-kurangnya 15 000 jam pada tegasan 230 MN/m<sup>2</sup>, apakah suhu servis yang maksimum? Angkatap “a” dalam parameter Larsen-Miller untuk aloi ialah 20.*

(60 marks/markah)

- Q3. [a] The state of plane stress shown in Figure Q3[a] occurs at a critical point of a steel machine component. As a result of a several tensile tests, it has been found that the tensile yield strength is  $\sigma_Y = 200$  MPa.

- (i) Determine the factor of safety with respect to yield, using Tresca criterion and Von Mises criterion.
- (ii) Briefly explain the given state of stress associated with Tresca and Von Mises on the plane stress. Use sketch if necessary.

*Keadaan tegasan satah yang ditunjukkan dalam Rajah S3[a] berlaku pada titik kritikal komponen mesin keluli. Berdasarkan keputusan daripada beberapa ujian tegangan, kekuatan alah untuk keluli tersebut ialah  $\sigma_Y = 200$  MPa.*

- (i) *Tentukan faktor keselamatan berdasarkan alah, dengan menggunakan kriteria Tresca dan kriteria Von Mises*
- (ii) *Terangkan dengan ringkas keadaan tegasan yang diberikan dengan merujuk kepada Tresca dan Von Mises. Gunakan lakaran jika perlu.*

-5-

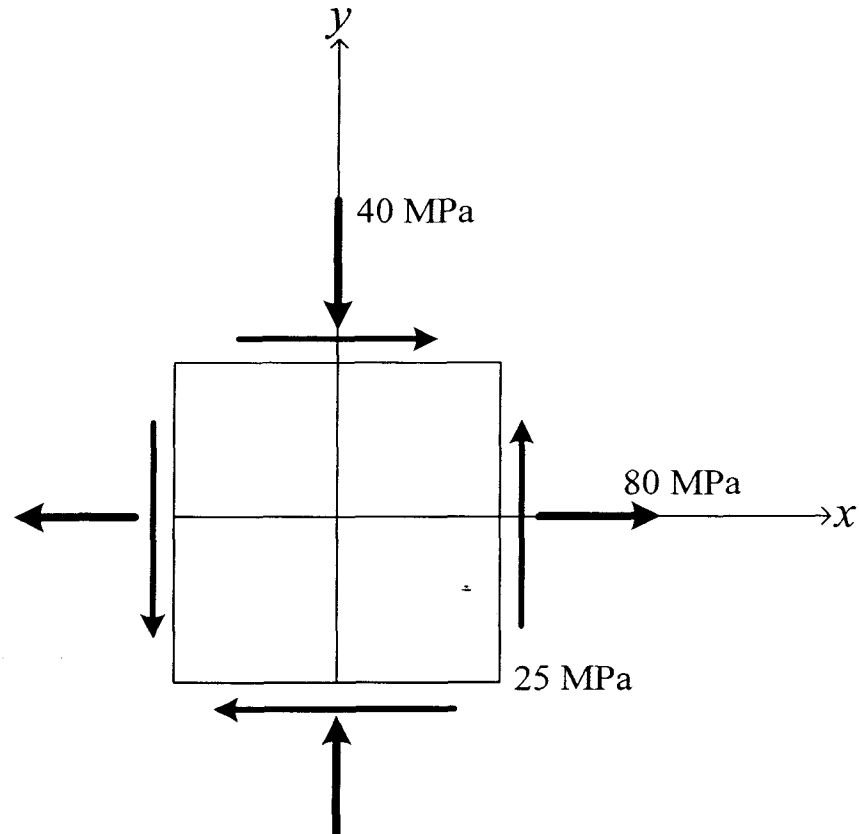


Figure Q3[a]  
Rajah S3[a]

(50 marks/markah)

- [b] A mild steel shaft of 50 mm diameter is subjected to a bending moment of 2.0 kNm. If the yield point of the steel in simple tension is 200 MPa, find the maximum torque that can also be applied according to : (i) Tresca criterion (ii) Von Mises criterion.

*Satu aci keluli berdiameter 50 mm dikenakan momen lentur 2.0 kNm. Jika titik alah keluli ini dalam tegangan ialah 200 MPa, cari kilasan maksima yang boleh dikenakan mengikut : (i) kriteria Tresca (ii) kriteria Von Mises*

(50 marks/markah)

- Q4. [a] Use appendix for Question 4.

Knowing that the hole has a diameter of 10 mm as shown in Figure Q4[a], determine

- (i) the radius  $r_f$  of the fillets for which the same maximum stress occurs at the hole A and at the fillets
- (ii) the corresponding maximum allowable load P if the allowable stress is 103 MPa.

Guna lampiran untuk menjawab Soalan 4.

Dengan mengetahui diameter lubang ialah 10 mm seperti yang ditunjukkan dalam Rajah S4[a], tentukan

- (i) jejari  $r_f$  kambi dimana tegasan maksimum berlaku pada lubang A dan pada kambi
- (ii) beban maksimum yang dibenarkan  $P$  jika tegasan maksima ialah 103 MPa.

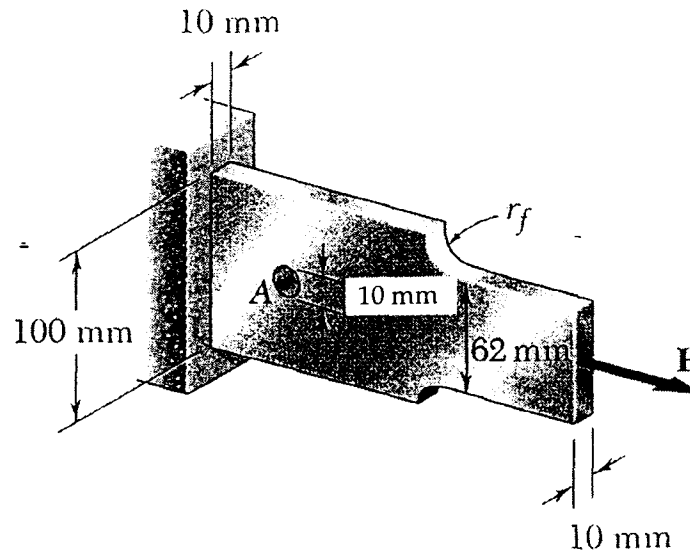


Figure Q4[a]  
Rajah S4[a]

(50 marks/markah)

- [b] The stepped shaft shown in Figure Q4[b] 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.
- (i) For the preliminary design shown, determine the maximum power that can be transmitted.
  - (ii) If in the final design the radius of the fillet is increased so that  $r = 24$  mm, what will be the percent change in power transmitted relative to the preliminary design.

Aci bertingkat seperti yang ditunjukkan dalam Rajah S4[b] akan berputar pada 900 rpm semasa ia menghantar kuasa daripada turbin ke janakuasa. Spesifikasi gred keluli dalam rekaan tersebut mempunyai tegasan ricih 55 MPa.

- (i) Untuk rekaan awal yang ditunjukkan, tentukan kuasa maksima yang boleh dihantarkan.
- (ii) Jika dalam rekaan akhir jejari kambi dinaikkan kepada  $r = 24$  mm, apakah peratus perbezaan dalam kuasa yang boleh dihantarkan relatif kepada rekaan awal.

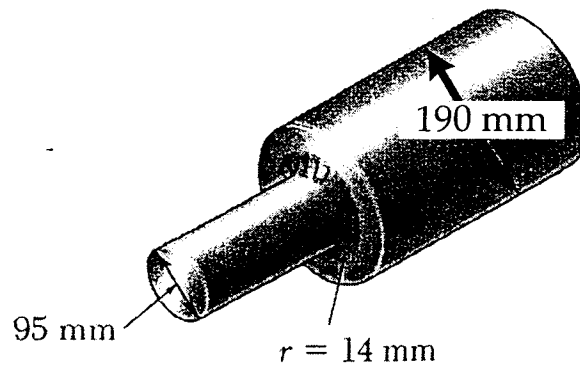


Figure Q4[b]  
Rajah S4[b]

(50 marks/markah)

Q5. [a] Briefly describe the following terms as applied in fatigue:

- (i) Endurance Limit
- (ii) Fatigue Strength
- (iii) Mean Stress
- (iv) Alternating Stress

Terangkan dengan ringkas perkara-perkara di bawah yang diaplikasikan dalam lesu.

- (i) Had Kekuatan
- (ii) Kekuatan Lesu
- (iii) Tegasan Purata
- (iv) Tegasan ulang alik

(40 marks/markah)

- [b] A shaft of circular cross-section is subjected to a steady bending moment of 1500 Nm and simultaneously to an alternating bending moment of 1000 Nm at the same place (so that the total moment fluctuates between 2500 Nm and 500 Nm). By using Gerber rule, calculate the diameter of the shaft if the factor of safety is to be 3.0. The yield stress of the material is 210 MPa, the ultimate stress is 250 MPa and the fatigue limit in reversed bending is 170 MPa.

*Sebatang aci yang berkeratan rentas bulat dikenakan momen lentur tidak berubah sebanyak 1500 Nm dan pada masa yang sama dikenakan dengan momen rasuk berubah-ubah sebanyak 1000 Nm pada tempat yang sama (jadi jumlah momen berubah di antara 2500 Nm dan 500 Nm). Dengan menggunakan aturan Gerber, kirakan garis pusat aci jika faktor keselamatan ialah 3.0. Tegasan alah untuk bahan ini ialah 210 MPa, tegasan muktamad ialah 250 MPa dan had lesu dalam lentur timbal balik ialah 170 MPa.*

(60 marks/markah)

- Q6. [a] A steel pressure vessel fractured in a brittle manner when an internal pressure of 20 MN/m<sup>2</sup> was applied. The vessel had a longitudinal surface crack 10 mm long and 4 mm deep. A subsequent fracture mechanics test on a sample of the steel showed that it had a  $K_{IC}$  value of 65 MN m<sup>-3/2</sup>. If the vessel diameter was 1 m and its wall thickness was 10 mm, determine whether the data was consistent with the observed failure. Given the formula for semi-elliptical surface flaw,  $K = \sigma(\pi a^{1/2})(1.12/\sqrt{\theta})$  as shown in Figure Q6[a].

*Bekas tekanan yang diperbuat daripada besi keluli telah patah rapuh bila dikenakan tekanan dalaman sebanyak 20 MN/m<sup>2</sup>. Keretakan membujur yang berlaku pada bekas ini sepanjang 10 mm dan dalamnya ialah 4 mm. Ujian makmal yang dijalankan mendapati nilai  $K_{IC} = 65 \text{ MN m}^{-3/2}$ . Jika diameter bekas ialah 1 m dan tebal dindingnya ialah 10 mm, tentukan sama ada data yang diperolehi sepadan dengan kegagalan yang dilihat. Diberi formula untuk menentukan kecacatan permukaan semi-ellips,  $K = \sigma(\pi a^{1/2})(1.12/\sqrt{\theta})$  seperti yang ditunjukkan dalam Rajah S6(a).*

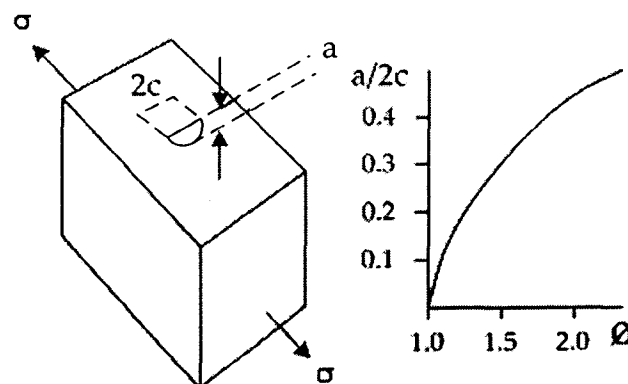


Figure Q6[a] Elliptical Surface crack  
Rajah S6[a] Rekahan permukaan berbentuk elips

(30 marks/markah)



- [b] **Briefly explain why the theory of stress concentration can not be used in developing the theory of fracture mechanics? Use the sketch if necessary.**

*Terangkan dengan ringkas kenapa teori penumpuan tegasan tidak boleh digunakan dalam menerbitkan teori mekanik patah? Gunakan lakaran jika perlu.*

**(20 marks/markah)**

- [c] **Three fracture toughness samples of an aluminium alloy have identical external dimensions and a thickness of 25 mm. During three tests on the samples the following information was obtained:**

*Tiga sampel kekuatan alah untuk aluminium aloi mempunyai ukuran luaran yang sama dan mempunyai ketebalan 25 mm. Semasa tiga ujian dijalankan ke atas sampel tersebut, maklumat berikut telah didapatkan:*

Test	Sample crack length (mm)	Applied load (kN)	Sample elongation (mm)
1	20	185	Sample fractured
2	19.5	120	0.26
3	20.5	120	0.263

**If the Young's modulus and Poisson's ratio values for the aluminium are  $70 \text{ GN/m}^2$  and 0.3 respectively, calculate fracture toughness of the material.**

*Jika modulus Young dan nisbah Poisson untuk aluminium ialah masing-masing  $70 \text{ GN/m}^2$  dan 0.3, kirakan kekuatan patah untuk bahan tersebut.*

**(50 marks/markah)**

## Formula untuk Mekanik Pepejal

Theories of failures:

Tresca:  $\sigma_1 - \sigma_3 = \sigma_Y$       Von-Mises:  $(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 2\sigma^2_Y$

Fatigue:

$$N_f = \frac{2}{C(Y.S_R)^m \pi^{\frac{m}{2}} (2-m)} \left( a_f^{1-\frac{m}{2}} - a_0^{1-\frac{m}{2}} \right) \quad \Delta K = Y.S_R \sqrt{\pi a} \quad \frac{da}{dN} = C [Y.S_R \sqrt{\pi a}]^m$$

Goodman:  $S_a = S_D \left( 1 - \frac{S_m}{S_u} \right)$       Gerber:  $S_a = S_D \left[ 1 - \left( \frac{S_m}{S_u} \right)^2 \right]$

Soderberg:  $S_a = S_D \left( 1 - \frac{S_m}{S_Y} \right)$

Unsymmetrical and curved bending

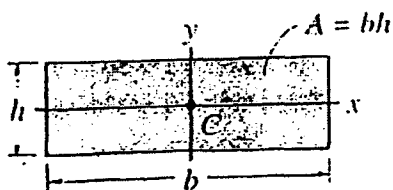
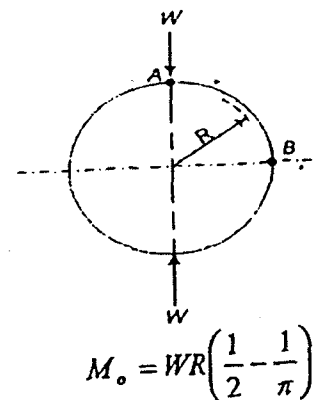
Rectangular section:  $n = R' - \frac{d}{\log_e \left[ \frac{(R'+d/2)}{(R'-d/2)} \right]}$

Circular section:  $n = R' - \frac{d}{2 \left[ R' - (R'^2 - r^2)^{1/2} \right]}$

$$\frac{\sigma}{y} = \frac{M}{nA(R_1 + y)} \quad \frac{y}{z} = \frac{I_z}{I_y} \tan \theta = \tan \phi$$

$$\sigma_x = \frac{yE}{R_y} + \frac{zE}{R_z}$$

$$= \frac{y(M_z I_y - M_y I_{yz}) + z(M_y I_z - M_z I_{yz})}{I_y I_z - I_{yz}^2}$$



Rectangular area

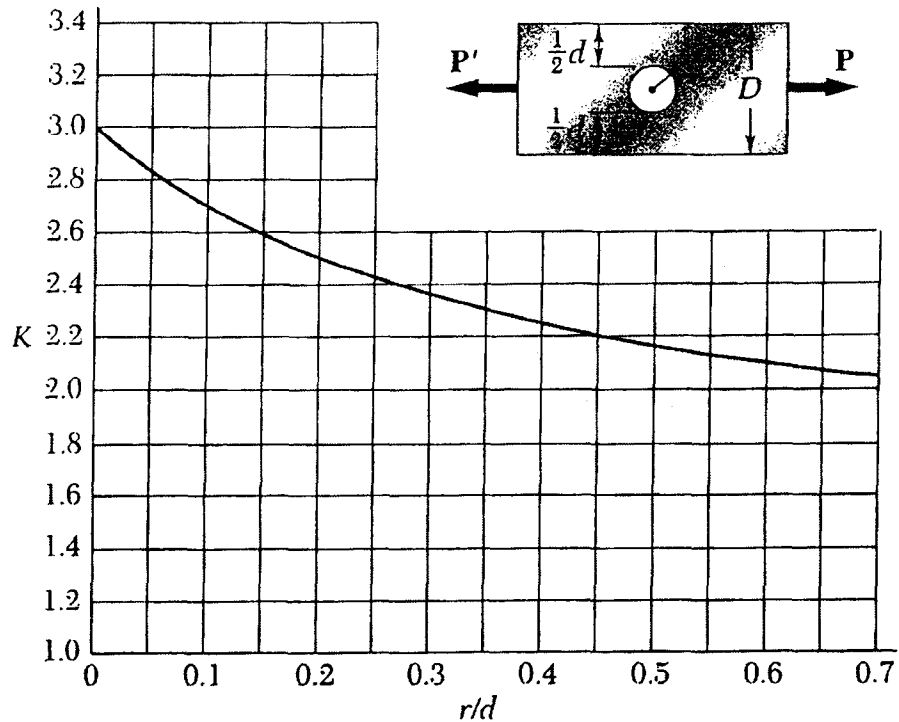
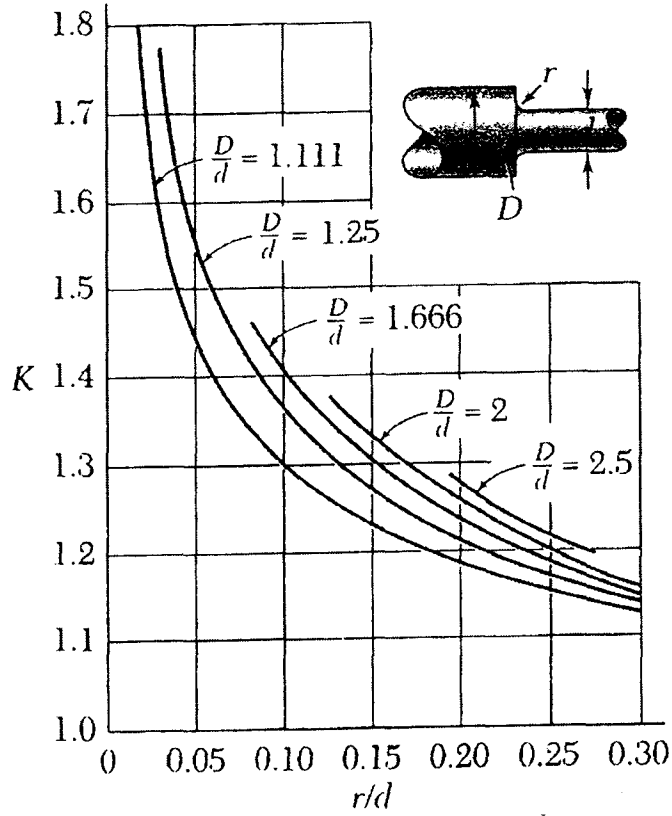
$$I_x = \frac{1}{12} b h^3$$

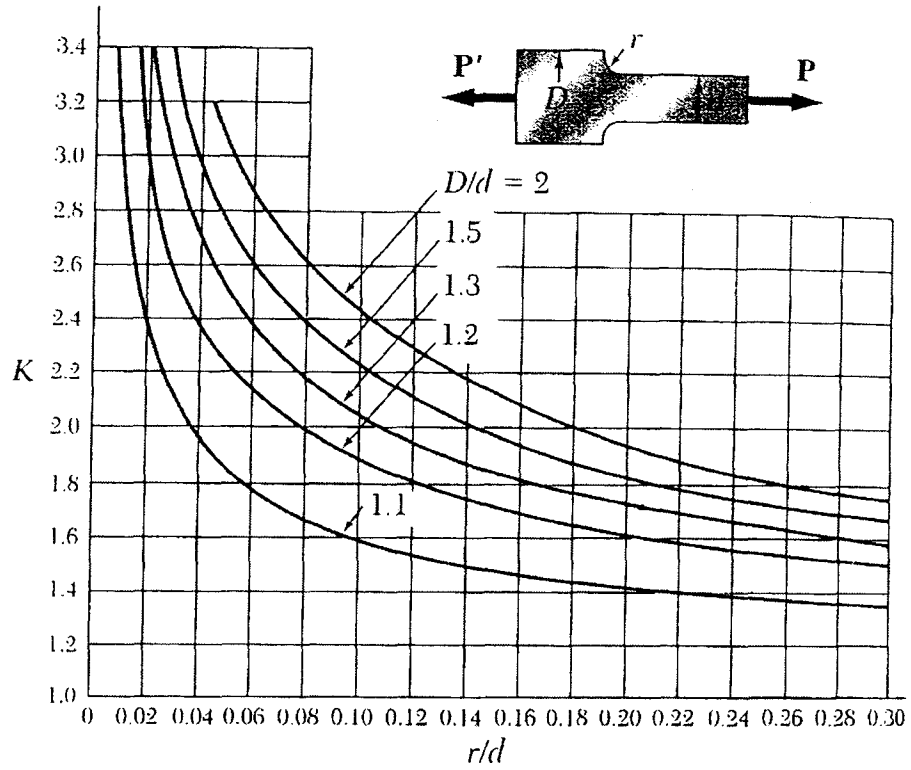
$$I_y = \frac{1}{12} h b^3$$

**Beam Deflection Formulas**

Beam Loading and Deflection	Maximum Deflection	Slope at End(s)	Deflection Equations
	$\delta_{\max} = \frac{PL^3}{3EI}$	$\theta_B = \frac{PL^2}{2EI}$	$\delta = \frac{Px^2}{6EI}(3L - x)$
	$\delta_{\max} = \frac{Pa^2}{6EI}(3L - \alpha)$	$\theta_B = \frac{Pa^2}{2EI}$	$\delta_{AC} = \frac{Px^2}{6EI}(3\alpha - x)$ $\delta_{CB} = \frac{Pa^2}{6EI}(3x - \alpha)$
	$\delta_{\max} = \frac{wL^4}{8EI}$	$\theta_B = \frac{wL^3}{6EI}$	$\delta = \frac{wx^2}{24EI}(x^2 - 4Lx + 6L^2)$
	$\delta_{\max} = \frac{ML^2}{2EI}$	$\theta_B = \frac{ML}{EI}$	$\delta = \frac{Mx^2}{2EI}$
	$\delta_{\max} = \frac{PL^3}{48EI}$	$\theta_A = \theta_B = \frac{PL^2}{16EI}$	$\delta_{AC} = \frac{Px}{48EI}(3L^2 - 4x^2)$
	<p>For <math>a &gt; b</math>:</p> $\delta_{\max} = \frac{Pb(L^2 - b^2)^{3/2}}{9\sqrt{3}EI}$ at $x_m = \sqrt{\frac{L^2 - b^2}{3}}$	$\theta_A = \frac{Pb(L^2 - b^2)}{6EIL}$ $\theta_B = \frac{Pa(L^2 - a^2)}{6EIL}$	$\delta_{AC} = \frac{Pbx}{6EIL}(L^2 - x^2 - b^2)$ $\delta_{CB} = \frac{Pb}{6EIL} \left[ \frac{L}{b}(x - \alpha)^3 + (L^2 - b^2)x - x^3 \right]$
	$\delta_{\max} = \frac{5wL^4}{384EI}$	$\theta_A = \theta_B = \frac{wL^3}{24EI}$	$\delta = \frac{wx}{24EI}(L^3 + x^3 - 2Lx^2)$
	$\delta_{\max} = \frac{ML^2}{9\sqrt{3}EI}$ at $x_m = \frac{L}{\sqrt{3}}$	$\theta_A = \frac{ML}{6EI}$ $\theta_B = \frac{ML}{3EI}$	$\delta = \frac{Mx}{6EI}(L^2 - x^2)$

**Stress concentration factors**





## Properties of Rolled-Steel Shapes

Designation†	Area A, mm <sup>2</sup>	Depth d, mm	Flange		Web Thick- ness t <sub>w</sub> , mm	Axis X-X			Axis Y-Y		
			Width b <sub>f</sub> , mm	Thick- ness t <sub>f</sub> , mm		t <sub>x</sub> 10 <sup>3</sup> mm <sup>4</sup>	S <sub>x</sub> 10 <sup>3</sup> mm <sup>3</sup>	r <sub>x</sub> mm	I <sub>y</sub> 10 <sup>6</sup> mm <sup>4</sup>	S <sub>y</sub> 10 <sup>3</sup> mm <sup>3</sup>	r <sub>y</sub> mm
W310 × 143	18200	323	309	22.9	14.0	348	2150	138	113	731	78.8
	107 13600	311	306	17.0	10.9	248	1590	135	81.2	531	77.3
	74 9480	310	205	16.3	9.4	165	1060	132	23.4	228	49.7
	60 7590	303	203	13.1	7.5	129	851	130	18.3	180	49.1
	52 6670	318	167	13.2	7.6	119	748	134	10.3	123	39.3
	44.5 5690	313	166	11.2	6.6	99.2	634	132	8.55	103	38.8
	38.7 4940	310	165	9.7	5.8	85.1	549	131	7.27	88.1	38.4
	32.7 4180	313	102	10.8	6.6	65.0	415	125	1.92	37.6	21.4
	23.8 3040	305	101	6.7	5.6	42.7	280	119	1.16	23.0	19.5
W250 × 167	21300	289	265	31.8	19.2	300	2080	119	98.8	746	68.1
	101 12900	264	257	19.6	11.9	164	1240	113	55.5	432	65.6
	80 10200	256	255	15.6	9.4	126	984	111	43.1	338	65.0
	67 8580	257	204	15.7	8.9	104	809	110	22.2	218	51.0
	58 7420	252	203	13.5	8.0	87.3	693	108	18.8	185	50.3
	49.1 6250	247	202	11.0	7.4	70.6	572	106	15.1	150	49.2
	44.8 5720	266	148	13.0	7.6	71.1	535	111	7.03	95.0	35.1
	32.7 4180	258	146	9.1	6.1	48.9	379	108	4.73	64.8	33.7
	28.4 3630	260	102	10.0	6.4	40.0	308	105	1.78	34.9	22.1
22.3 2850	254	102	6.9	5.8	28.9	228	101	1.23	24.1	20.8	
W200 × 86	11000	222	209	20.6	13.0	94.7	853	92.4	31.4	300	53.2
	71 9100	216	206	17.4	10.2	76.6	709	91.7	25.4	247	52.8
	59 7560	210	205	14.2	9.1	61.1	582	89.9	20.4	199	51.9
	52 6660	206	204	12.6	7.9	52.7	512	89.0	17.8	175	51.7
	46.1 5860	203	203	11.0	7.2	45.5	448	87.9	15.3	151	51.1
	41.7 5310	205	166	11.8	7.2	40.9	399	87.8	9.01	109	41.2
	35.9 4580	201	165	10.2	6.2	34.4	342	86.7	7.64	92.6	40.8
	31.3 4000	210	134	10.2	6.4	31.4	299	88.6	4.1	61.2	32.0
	26.6 3390	207	133	8.4	5.8	25.8	249	87.2	3.3	49.6	31.2
	22.5 2860	206	102	8.0	6.2	20.0	194	83.6	1.42	27.8	22.3
	19.3 2480	203	102	6.5	5.8	16.6	164	81.8	1.15	22.5	21.5
	W150 × 37.1	4730	162	154	11.6	8.1	22.2	274	68.5	7.07	91.8
29.8 3790		157	153	9.3	6.6	17.2	219	67.4	5.56	72.7	38.3
24.0 3060		160	102	10.3	6.6	13.4	168	66.2	1.83	35.9	24.5
18.0 2290		153	102	7.1	5.8	9.17	120	63.3	1.26	24.7	23.5
13.5 1730		150	100	5.5	4.3	6.87	91.6	63.0	0.918	18.4	23.0
W130 × 28.1	3580	131	128	10.9	6.9	10.9	166	55.2	3.81	59.5	32.6
	23.8 3010	127	127	9.1	6.1	8.80	139	54.1	3.11	49.0	32.1
W100 × 19.3	2480	106	103	8.8	7.1	4.77	90.0	43.9	1.61	31.3	25.5

†A wide-flange shape is designated by the letter W followed by the nominal depth in millimeters and the mass in kilograms per meter.