MEC-E8006 Fatigue of Structures

Remote Exam 10.12.2019

Exam includes four problems. Each problem is of equal value. Answers may be written in English or Finnish. You can use a calculator. Books and all supporting material is allowed.

Answer to exam questions using method most suitable to you and exam submission (e.g. handwriting, Word, Mathcad, CAD, etc.). Remember that reasoning, calculation steps, results, and discussions should be clearly visible like traditional exam.

After the exam, you have 15 minutes time to create single pdf document and deliver it deliver it using MyCourses submission folder.

Problem 1

Give a short and clear explanation for the following term and concepts

a) Fatigue assessment using linear elastic fracture mechanics

b) Cyclic hardening and cyclic softening

c) Effective notch stress method

d) Proportional and non-proportional loading

e) Residual stress

f) Endurance limit

Problem 2

An un-notched component (fabricated from RQC-100 steel) is subjected to the load history shown below.

a) Perform a rainflow count of the load history.

b) Estimate the number of cycles and repetitions to failure. Use Goodman mean stress correction.

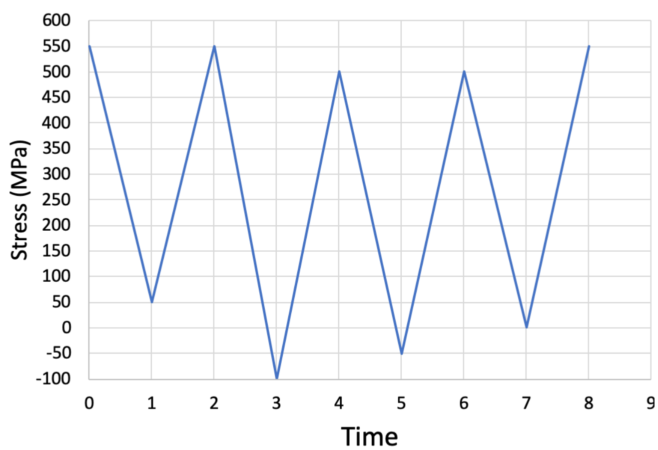
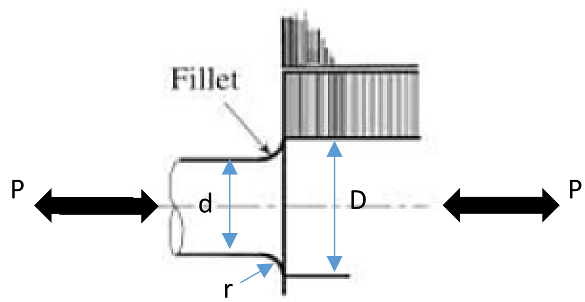


Figure 1: Load history for one repetition.

Problem 3

The notched component depicted in the picture below is axially loaded with constant amplitude loading with zero mean stress. The component is fabricated from SAE 1045 steel. The diameters of shaft are D=200mm and d=100mm. The radius r is 2.5 mm. Ultimate strength of the material is given in the table.



a) Determine stress concentration and fatigue notch factor for the component by using Neuber's and Peterson's rule. Compare and briefly comment the results. Table for stress concentrations are provided.

b) Give an estimation of the fatigue limit and compute the allowable stress amplitude that can be applied for $4*10^5$ load cycles (notched component, use K_f of Peterson, m'=0.9, $K_f'=K_f$).

c) If RQC-100 steel is used instead of SAE 1045 steel, does one can assume without any calculations that this increases the fatigue life? What is the physical reasoning for this?

Problem 4

A notched component has k_t=3. The component is loaded until nominal stress S=200 MPa, and unloaded to a nominal stress of S=0. Strain-life properties of the material are:

E=100 GPa; σ_f'=1000 MPa; ε_f'=1.0; b=-0.08; c=-0.60

a) Determine the local stress and local strain at the notch at S=200MPa (Neuber's rule)

b) Determine the residual local stress and local strain at the notch at S=0 MPa (Neuber's rule)

c) Estimate the fatigue life of the component; use the modified Morrow equation to consider the mean stress correction

d) **Bonus question:** What results would you expect by using ESED Glinka's rule?

TABLES

Material	Yield Strength	Ultimate Strength	True Fracture Strength	$\sigma_a = \sigma_f'(2N_f)^b = AN_f^B$		
	σ_o	σ_u	$\tilde{\sigma}_{fB}$	σ_f'	A	$b = B$
(a) Steels						
AISI 1015 (normalized)	227 (33)	415 (60.2)	725 (105)	976 (142)	886 (128)	−0.14
Man-Ten (hot rolled)	322 (46.7)	557 (80.8)	990 (144)	1089 (158)	1006 (146)	−0.115
RQC-100 (roller Q & T)	683 (99.0)	758 (110)	1186 (172)	938 (136)	897 (131)	−0.0648

Table 10.2 Estimates of the *S-N* Curve Point at 10^3 Cycles

Juvinall (2006)[1]	$m' = 0.9,\ k_f' = k_f$ (bending; torsion with τ_u replacing σ_u)
	$m' = 0.75,\ k_f' = k_f$ (axial)
Budynas (2011)[2]	$m' = 0.90$ ($\sigma_u <$ 483 MPa)
(steel only)	$m' = 0.2824x^2 - 1.918x + 4.012$, $x = \log \sigma_u$ ($\sigma_u \geq$ 483 MPa)
	$k_f' = k_f$

Notes: [1]Use the estimate $\tau_u \approx 0.8\sigma_u$ for steel, and $\tau_u \approx 0.7\sigma_u$ for other ductile metals. [2] The equation for m' is a fit to the curve given in Budynas (2011).

Table 10.1 Parameters for Estimating Fatigue Limits

Parameter	Applicability	Juvinall (2006)	Budynas (2011)
Bending fatigue limit factor: m_e	Steels, $\sigma_u \leq 1400\,\text{MPa}$[1]	0.5	0.5
	High-strength steels	≤ 0.5	$\sigma_{erb} = 700\,\text{MPa}$
	Cast irons; Al alloys if $\sigma_u \leq 328\,\text{MPa}$	0.4	—
	Higher strength Al	$\sigma_{erb} = 131\,\text{MPa}$	—
	Magnesium alloys	0.35	—
Load type factor: m_t	Bending	1.0	1.0
	Axial	1.0	0.85
	Torsion	0.58	0.59
Size (stress gradient) factor: m_d	Bending or torsion[2,3,4]	1.0 ($d < 10\,\text{mm}$) 0.9 ($10 \leq d < 50$)	$1.24d^{-0.107}$ ($3 \leq d \leq 51\,\text{mm}$)
	Axial[2,3]	0.7 to 0.9 ($d < 50$)[5]	1.0
Surface finish factor: m_s	Polished	1.0	1.0
	Ground[6]	See Fig. 10.10	$1.58\sigma_u^{-0.085}$
	Machined[6]	See Fig. 10.10	$4.51\sigma_u^{-0.265}$
Life for fatigue limit point: N_e, cycles	Steels, cast irons	10^6	10^6
	Aluminum alloys	5×10^8	—
	Magnesium alloys	10^8	—

Notes:[1] Juvinall specifically gives a hardness limit, $HB \leq 400$. [2]Diameter d is in mm units. [3]For Juvinall, for $50 \leq d < 100\,\text{mm}$, decrease the values of m_d by 0.1 relative to the values for $d < 50\,\text{mm}$, and for $100 \leq d < 150\,\text{mm}$ decrease by 0.2. [4]For Budynas, use $1.51d^{-0.157}$ for $51 < d \leq 254\,\text{mm}$, and for nonrotating bending, replace d with $d_e = 0.37d$ for round sections, and with $d_e = 0.808\sqrt{ht}$ for rectangular sections (Fig. A.2). [5]Use 0.9 for accurately concentric loading, and a lower value otherwise. [6]For Budynas, substitute σ_u in MPa.

Table 14.1 Cyclic Stress–Strain and Strain–Life Constants for Selected Engineering Metals.[1]

		Tensile Properties				Cyclic σ-ε Curve			Strain–Life Curve			
Material	Source	σ_o	σ_u	$\tilde{\sigma}_{fB}$	$\% RA$	E	H'	n'	σ'_f	b	ε'_f	c
(a) Steels												
SAE 1015	(8)	228	415	726	68	207,000	1349	0.282	1020	−0.138	0.439	−0.513
(normalized)		(33.0)	(60.2)	(105)		(30,000)	(196)		(148)			
Man-Ten[2]	(7)	322	557	990	67	203,000	1096	0.187	1089	−0.115	0.912	−0.606
(hot rolled)		(46.7)	(80.8)	(144)		(29,500)	(159)		(158)			
RQC-100	(2)	683	758	1186	64	200,000	903	0.0905	938	−0.0648	1.38	−0.704
(roller Q & T)		(99.0)	(110)	(172)		(29,000)	(131)		(136)			
SAE 1045	(6)	382	621	985	51	202,000	1258	0.208	948	−0.092	0.260	−0.445
(HR & norm.)		(55.4)	(90.1)	(143)		(29,400)	(182)		(137)			
SAE 4142	(1)	1619	2450	2580	6	200,000	2810	0.040	2550	−0.0778	0.0032	−0.436
(As Q, 670 HB)		(235)	(355)	(375)		(29,000)	(407)		(370)			
SAE 4142	(1)	1688	2240	2650	27	207,000	4140	0.126	3410	−0.121	0.0732	−0.805
(Q & T, 560 HB)		(245)	(325)	(385)		(30,000)	(600)		(494)			
SAE 4142	(1)	1584	1757	1998	42	207,000	2080	0.093	1937	−0.0762	0.706	−0.869
(Q & T, 450 HB)		(230)	(255)	(290)		(30,000)	(302)		(281)			
SAE 4142	(1)	1378	1413	1826	48	207,000	2210	0.133	2140	−0.0944	0.637	−0.761
(Q & T, 380 HB)		(200)	(205)	(265)		(30,000)	(321)		(311)			
AISI 4340[2]	(3)	1103	1172	1634	56	207,000	1655	0.131	1758	−0.0977	2.12	−0.774
(Aircraft Qual.)		(160)	(170)	(237)		(30,000)	(240)		(255)			
AISI 4340	(1)	1371	1468	1557	38	200,000	1910	0.123	1879	−0.0859	0.640	−0.636
(409 HB)		(199)	(213)	(226)		(29,000)	(277)		(273)			
Ausformed H-11	(1)	2030	2580	3170	33	207,000	3475	0.059	3810	−0.0928	0.0743	−0.7144
(660 HB)		(295)	(375)	(460)		(30,000)	(504)		(553)			
(b) Other Metals												
2024-T351 Al	(1)	379	469	558	25	73,100	662	0.070	927	−0.113	0.409	−0.713
		(55.0)	(68.0)	(81.0)		(10,600)	(96.0)		(134)			
2024-T4 Al[3]	(4)	303	476	631	35	73,100	738	0.080	1294	−0.142	0.327	−0.645
(Prestrained)		(44.0)	(69.0)	(91.5)		(10,600)	(107)		(188)			
7075-T6 Al	(5)	469	578	744	33	71,000	977	0.106	1466	−0.143	0.262	−0.619
		(68.0)	(84)	(108)		(10,300)	(142)		(213)			
Ti-6Al-4V	(1)	1185	1233	1717	41	117,000	1772	0.106	2030	−0.104	0.841	−0.688
(soln. tr. & age)		(172)	(179)	(249)		(17,000)	(257)		(295)			
Inconel X	(1)	703	1213	1309	20	214,000	1855	0.120	2255	−0.117	1.16	−0.749
(Ni base, annl.)		(102)	(176)	(190)		(31,000)	(269)		(327)			

Notes: [1]The tabulated values either have units of MPa (ksi), or they are dimensionless. [2]Test specimens prestrained, except at short lives, also periodically overstrained at long lives. [3]For nonprestrained tests, use same constants, except $\sigma'_f = 900(131)$ and $b = -0.102$.

Sources: Data in (1) [Conle 84]; (2) author's data on the ASTM Committee E9 material; (3) [Dowling 73]; (4) [Dowling 89] and [Topper 70]; (5) [Endo 69] and [Raske 72]; (6) [Leese 85]; (7) [Wetzel 77] pp. 41 and 66; (8) [Keshavan 67] and [Smith 70].

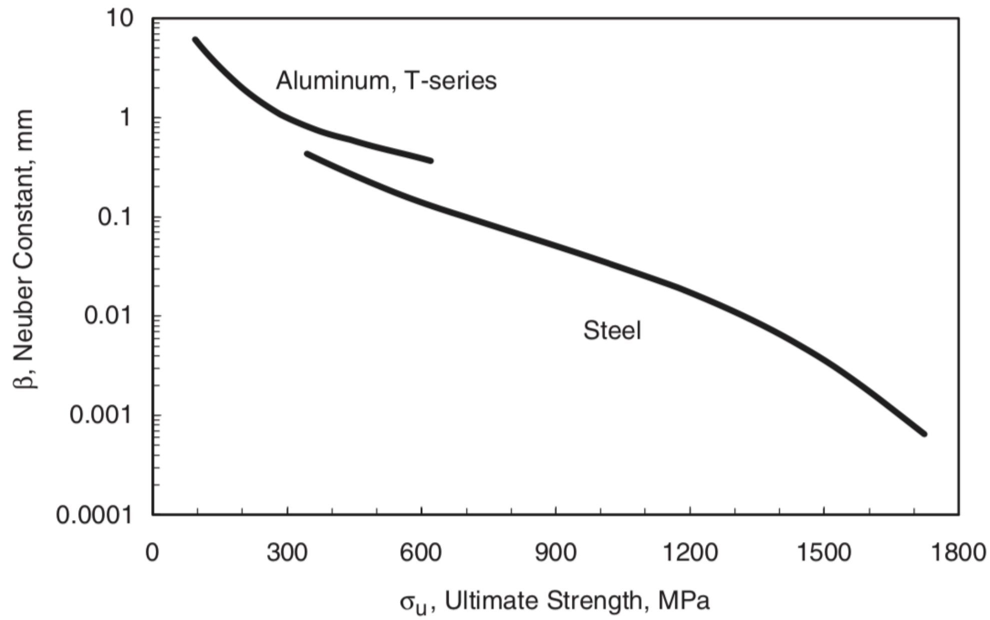


Figure 10.8 Neuber constant β as a function of ultimate tensile strength for carbon and low-alloy steels and for solution treated and aged (T-series) aluminum alloys. Curves from [Kuhn 52] and [Kuhn 62] are replotted.

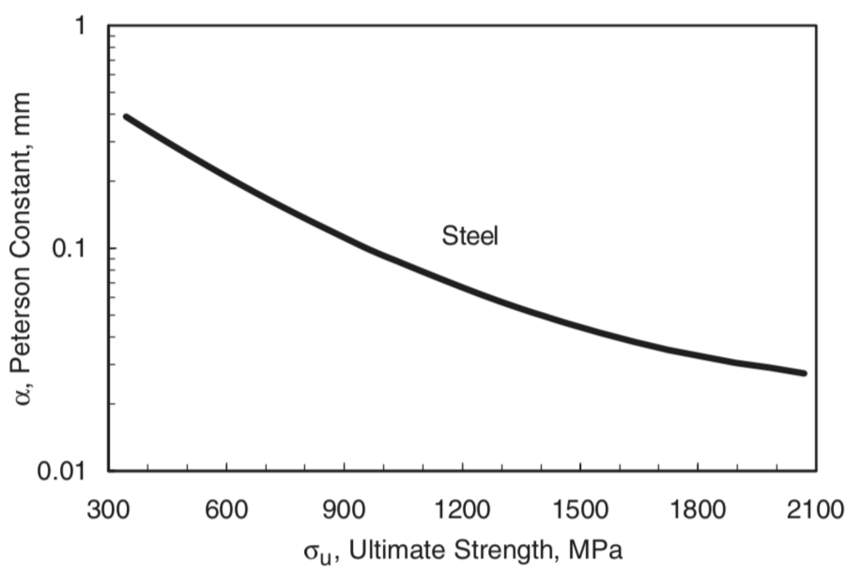


Figure 10.7 Peterson constant α as a function of ultimate tensile strength for carbon and low-alloy steels. Typical values from [Peterson 59] closely fit the curve shown.

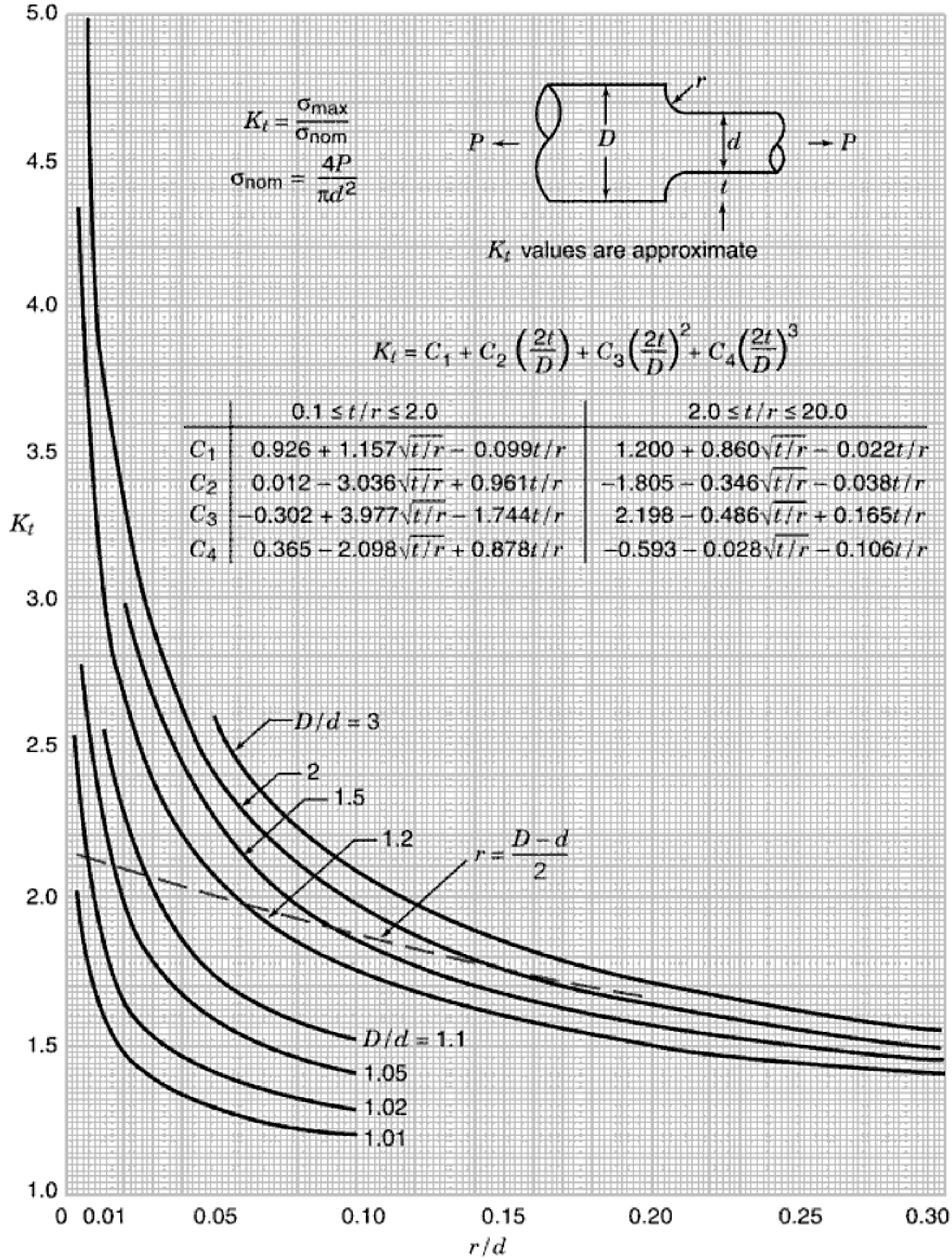


Chart 3.4 Stress concentration factors K_t for a stepped tension bar of circular cross section with shoulder fillet.