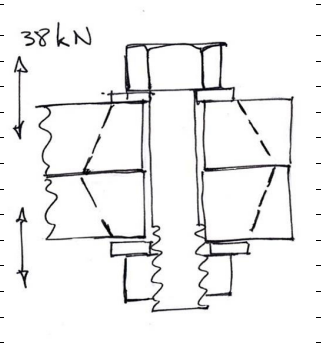
Example Bolt Analysis

example bolt Gerber AL 2018 25d.doc

Problem Statement:

It is recommended that 2 bolts of grade 8.8, M12, 30 grip length, bolts be used to support a fluctuating load of 38kN. Initially you are required to check if this recommendation is acceptable. You must then consider if a safer connection should be made, also, investigate if a lighter, but equally safe connection can be made.

It is required that a service life of 10^7 cycles, with less than 5% chance of failure.



Problem as given

Upon re-analysing this design, using a smaller cone agle of 25 degrees in place of the 30 given in texts, and examining the effect of a lower Young's modulus E. the following observations are made: The smaller cone angle has increased the alternating stress by about 15%, making the use of even 2 M12 precarious. Varying E had little effect on the bolt stresses provided it applied to the bolts equally to the flange anf bolt material.

The advice is now that at least 2 M16 8.8 bolts be used in which case the failure of one would maintain a safe joint.

Executive summary:

It was established that two M16 8.8 grade bolts would be safe. It is nevertheless proposed that three M12 bolts be used. Should one fail or be improperly installed the remaining two would safely carry the load.

number of M12 bolts	***condition***
1	unsafe
2	safe if there is no single bolt failure
3	safe even if any one of three bolts fails

Yet a lighter, equally safe bolted connection could be made using three M10, grade 8.8 bolts

Properties of proposed bolt grade:

It is proposed that M12 bolts be initially investigated expecting that 2 or more bolts should be used From the lecture notes and from Shigley the Su, Sy, Se and Sp for grade 8.8 bolts are tabled below and theses values are plotted in the fatigue diagram for these bolts.

description	***value***	***units***	***symbol***	***expression***	Table 1
Ultimate tensile strength	830	N/mm2	**Su**		***lecture notes***
Proof strength	564.4	"	**Sp**	Su*0.8*0.85	
reliability factor	0.868	no	rel	95% reliability for each bolt	***required life***
Endurance limit	111.7		**Se**	0.155*Su*rel	***expectancy***

You should use material properties of bolts that meet the ASTM standard A574M, provided that can be substantiated.

Develop the fatigue diagrams representing these bolts subjected to the stated alternating load

Calculate sufficient points to drawn the Proof, Goodman lines and Gerber parabola

The Proof line is straight and joins value Sp on the mean stress axis to Sp on fatigue axis

The proof strength is taken to be 85% of the yield strength

For high strength steel components a proof line represents a safe limit for mean tensile stress, Beyond the proof stress permanent deformation may take place

Proof line				
sa	***sm***			
0	564.4			***Eq 24***
120	444.4	(1-I55/Sp)*Sp		***Lecture notes***
564.4	0			

Calculate coordinated of points on the Goodman line

The Goodman line is straight and joins (0,Se) to (Su,0) on the fatigue diagram

Goodman line			
sa	***sm***		***Eq 26***
0	830	(1-H15/Se)*Su	***Lecture notes***
111.67	0		

Calculate Gerber parabola:

The Gerber line is a parabola given by eq 25 in lecture notes.
For an FS of 1 the Gerber line represents a resonable mean fit through the data, indicating a 50% likelyhood of fatigue failure over the no of cycles or which the fatigue strength Se has been evaluated

Gerber line			
sa	***sm***		***Norton p338***
0	830	(SQRT(1-sa/Se))*(Su)	
30	710		***Eq 25***
80	442	"	***Lecture notes***
Se = 111.7	0		

Note that a parabola requires only 3 points to describe it, a fourth point can be used to establish correctness, ie there is no need for more than 4 points.

Calculate safe Gerber parabola:

A margin of 10% is allowed on the 38 kN alternating load. This appears as Factor of Safety

Eq 25
Lecture notes

The 'safe' Gerber parabola is proportional to the original line but its intercepts at both axis are reduced by the factor FS. A Factor of Safety > 1 is to be nominated. The selected value is to be entered at the relevant cell below, currently set at 1.1

Safe Gerber line			
sa	***sm***		***FS=1.1***
0	755	(SQRT(1-FS*sa/Se))	
30	633		
80	347	"	
Se/FS = 101.5	0		

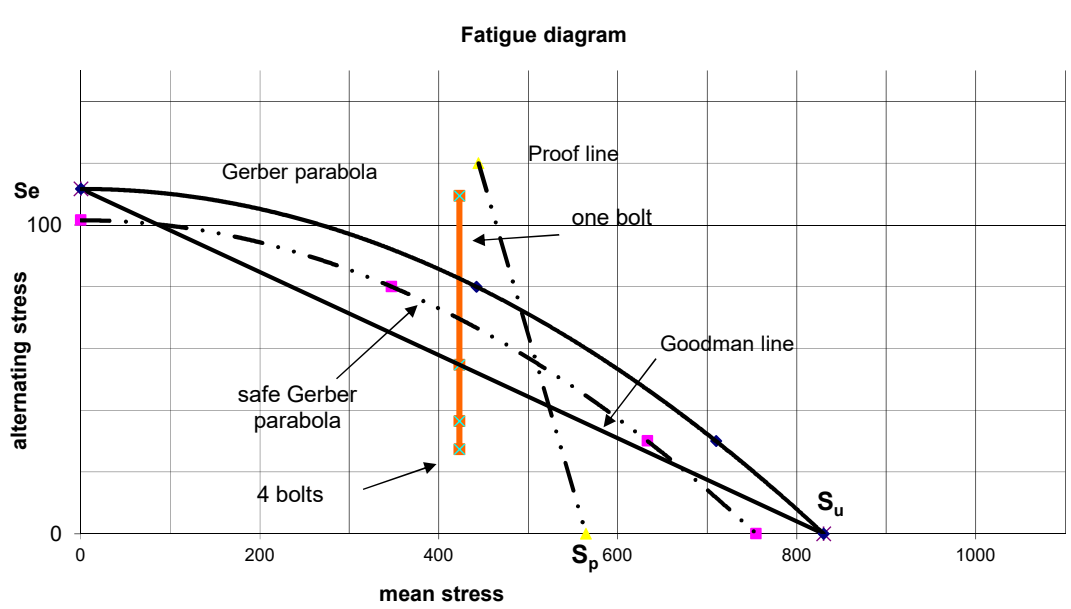
Selection of margin against probability of failure:

Shigley p333

The safety of this bolt design will primarely relie on the use of statistic to predict a low likelyhood of failure and the use of more than 1bolt such that the remaining bolts can take the load should one fail. From the tables provided by the references we will use a reliabilty factor that predicts 5% or less for any one bolt to fail.

Norton p334
rel=0.868

Plots of above Gerber and safe Gerber parabola, Goodman and proof lines:



A spreadsheet with just calculations cannot by itself used be used as a report. A spreadsheet can be used as a report only if sufficient comments are added to make it easily understandable, as has been attempted in this example. The onus is on the writer to make their work comprehensible

Given information:

	description	*value*	*units*	*symbol*	*expression*	
						Problem
	external force	38000	N	P		***as given***
	Young's modulud	195000	N/mm^2	E		
data for chosen M12 fine pitch threads:						***M12 to be***
	major diameter	12.00	mm	M		***tried***
	washer dia	18.00	"	dw	M*1.5	
	area of stem	113.10	mm^2	Ab	M*M*(PI()/4)	
	estimated stress area at threads	90.48	"	As	Ab*0.80	***Fig 12***
	grip length	30.00	mm^2	l		***lect notes***

Chosen variables to suit this installation:

preload	0.75	no	pr		
integer no of bolts	4.00	int	lnb		
Factor of safety	1.10	no	FS		

(a FS of 1.1 is nominated but may be reconsidered. It is likely that a practical combination of bolt diameter and number will have to be chosen that will result in a very safe bolted joint)

Calculate ratio of external load transmitted to bolt, using 25 degree cone angles:

stiffness of bolt	735133	N/mm	kb	Ab*E/l	***Eq 15 notes***
stiffness of flanges	2087746	"	km	(0.466*PI()*E*M)/(2*LN(5*((0.466*l+0.5*M)/	
	`			(0.466*l+2.5*M))))	
ratio of extenal load	0.260	no	rat	kb/(kb+km)	

(the variable 'rat' represents the ratio of the externally applied load ie 'P' that will be transmitted to the bolt)

NOTE that varying Young's modulus for the flanges has no effect on the division of load between flanges and bolts, but the cone angle does, increasing rat from 0.238 to 0.260

Calculate mean and alternating stresses:

preload force	38299	N	Fi	Sp*As*pr	
max force per bolt	40773	"	Fmax	Fi+P*rat/lnb	
min force per bolt	35825	"	Fmin	Fi-P*rat/lnb	
max bolt stress	450.6	N/mm^2	smax	Fmax/As	
min bolt stress	396.0	"	smin	Fmin/As	
mean bolt stress	423.3	"	smn	(smax+Smin)/2	
alt bolt stress	27.3	"	salt	(smax-Smin)/2	

(mean and alternating bolt load and stresses can be calculated directly and unmistakebly from the max and min bolt loads

Allowance for FS:

given mean bolt stress, calc alt stress at safe Gerber line

point on safe Gerber line at smn	69.6	"	saFS	(1-((FS*smn/Su)^2))*(Se/FS)	
point on Gerber line at smn	82.6	"		((1-(smn/Su)^2)*Se)	

(the safe Gerber parabola can be calculated by reducing the Gerber curve by the FS)

Further considerations: these are some other options available

we have not taken into account how much of the original clamping force is left after the external load is applied. That requires an additional factor of safety

Plot on fatigue graph the alt and mean stresses for increasing number of bolts:

									25d	**30d**
	nb	**M**	**salt**	**smn**				**E**	207000	207000
	1	12	109.4	423	unsafe				109.4	94.1
	2	"	54.7	423	marginally safe				54.7	47.05
	3	"	36.5	423	safe even if one bolt fails				36.5	31.4
	4	"	27.3	423	safe even if half of the bolts fails				27.3	23.5
								rat	0.26	0.238

Alternatively we could select the number of bolts and use the solver to determine the diameter that would place them on the safe Gerber curve

point on safe Gerber line at smn				69.6	"	saFS	
Excess fatigue strength				42.2	"	eSf	(1-((FS*smn/Su)^2))*(Se/FS)
							saFS-salt

nb	**M**	**salt**	**smn**	
1	15.83	69.6	423.3	**less than 5% probability than any one bolt will fail**
2	10.31	"	"	"
3	7.93	"	"	"
4	6.53	"	"	"

It is proposed then that one more bolt be used for each of the above combinations

nb	**M**	
2	16	safe even if one bolt fails
3	12	"
4	8	"
5	7	"