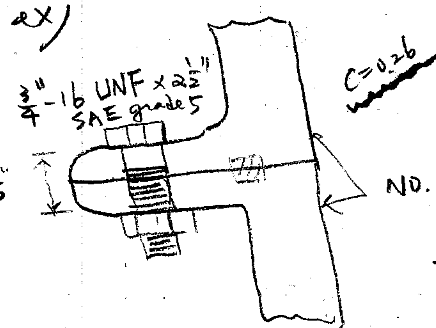
ex)



loaded by an axial tensile force of 4000 lb, ~~permanent~~ load

① determine n_y, n_s

② torque to be applied to tighten the bolt

Sol: → $F = 4000$ lb

$g = 1.5"$ (grip)

→ $d = 0.75"$ (major diameter)

$p = \frac{1}{16} = 0.0625"$

$L = 2.5"$ (total length)

→ $S_p = 85$ ksi } table ~~8.9~~ 8.9

$S_y = 92$ ksi

~~$E_b = 30\times10^6$ Mpsi~~ ~~table E-5~~ carbon steel

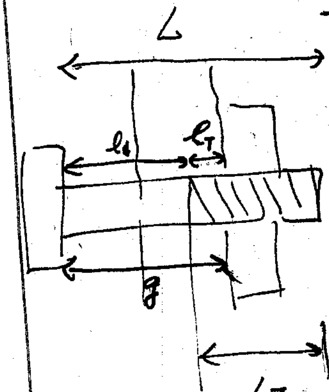
$E_m = 16\times10^6$ ksi

Threaded length $L_T = 2d + \frac{1}{4} = 1.75$ (eq. 8-13)

thread length of a bolt

$L_T = \begin{cases} 2D + \frac{1}{4} & L \le 6\text{in} \\ 2D + \frac{1}{2} & L > 6\text{in} \end{cases}$

$= \begin{cases} 2D + 6\ \text{mm} & L \le 125 \\ 2D + 12 & 125 < L \le 200 \\ 2D + 25 & L > 200 \end{cases}$



→ $A_t = 0.373$ — table 8.2

→ $A_d = \frac{\pi}{4}d^2 = 0.4418\ \text{in}^2$

$l_d = L - L_T = 2.5 - 1.75 = 0.75"$ (unthreaded portion)

$l_T = g - l_d = 1.5 - 0.75 = 0.75"$ (threaded portion of grip)

$k_b = \dfrac{A_d A_t E_b}{A_d l_T + A_t l_d} = 8.1\times10^6$ lb/in

$\sigma = E\epsilon$

$\frac{F}{A} = E\cdot\frac{\delta}{L}$

$\frac{F}{\delta} = \frac{AE}{L}$

$k_m = \dfrac{A_m E_m}{L} = \dfrac{\frac{\pi}{4}\left[(3d)^2 - d^2\right]\cdot 16\times10^6}{2.5} = 22.6\times10^6$ psi

$C = \dfrac{k_b}{k_b + k_m} = \dfrac{8.1\times10^6}{8.1\times10^6 + 22.6\times10^6} = 0.26$

→ $F_i = 0.9\, A_t S_p = 0.9\times0.373\times85\times10^3 = 28.53\times10^3$ lb

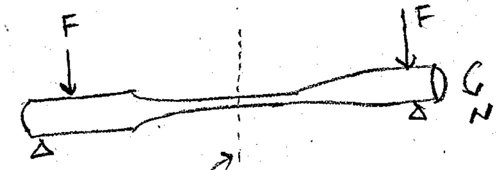
→ $n_y = \dfrac{S_p\cdot A_t - F_i}{CP} = 3.05$

→ $n_s = \dfrac{F_i}{P(1-C)} = 9.64$

→ T = tightening torque $= KF_i d$

Empirical fatigue data

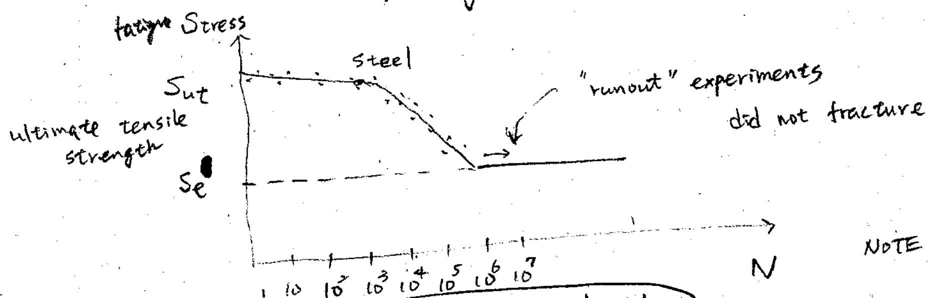
R.R. Moore rotating-beam fatigue testing machine



section is in pure bending (no shear force)

time t   time $t + \frac{1}{2}$ cycle

completely reversed bending stress



NOTE: both axes are log scale

S_e = endurance limit

S_e' = "unmodified" endurance limit

if $S < S_e'$ → specimen never fracture even as $N \to \infty$

relationship of S_e' and S_{ut}

empirically: $S_e' = \begin{cases} \frac{1}{2} S_{ut} & \text{if } S_{ut} < 212 \text{ kpsi} \\ 107 \text{ kpsi} & \text{if } S_{ut} > 212 \text{ kpsi} \end{cases}$ (0.506; 740 MPa; 1460 MPa)

NOTE, existence of an endurance limit is specific to ferrous materials (containing iron)

(e.g. aluminum will fracture at ANY S (however low) — if we run for sufficiently large N)

3 regions.

low cycle $(0 < N \leq 10^3)$: use static failure theory
at $N = 10^3$, fractures at $S \approx 0.9\, S_{ut}$ (usually less than S_y)

infinite life $(N > 10^6)$: if specimen survive, must be $S < S_e'$ → it will survive indefinitely

finite life $(10^3 < N \leq 10^6)$
characterize by a power law: $S_f(N) = aN^b$

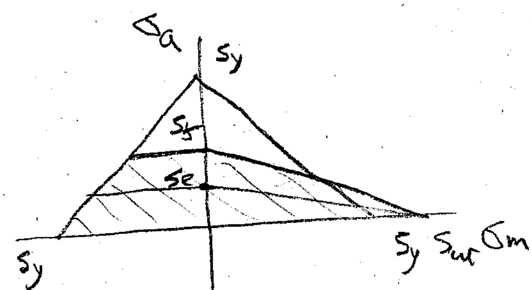
- Safe (σ_a, σ_m) region for a particular life (N cycles)

  → compute fatigue strength

  $$S_f = aN^b$$

  → draw regions defined by

  $$\begin{cases} \sigma_m > 0, & \dfrac{\sigma_a}{S_f} + \dfrac{\sigma_m}{S_{ut}} < 1 \\ \sigma_m < 0, & \dfrac{\sigma_a}{S_f} < 1 \end{cases}$$



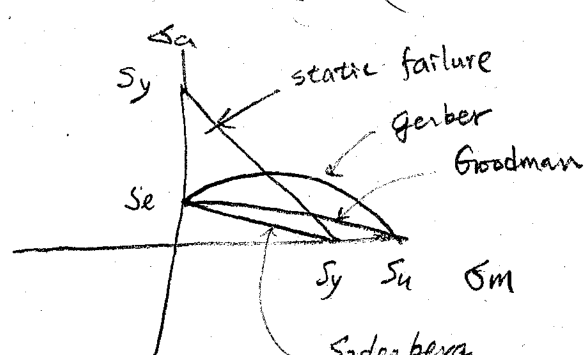
- Some alternative to Goodman line:

  Soderberg line — uses S_y instead of S_{ut}

  $$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_y} < 1$$

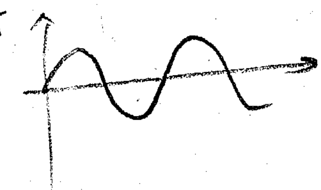
  Gerber parabola — assumes quadratic dependence on σ_m

  $$\frac{\sigma_a}{S_e} + \left(\frac{\sigma_m}{S_{ut}}\right)^2 < 1$$

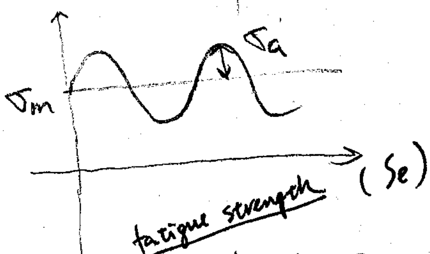


- Fatigue Under non-zero mean Stress

R.R. Moore → zero mean stress



non zero mean stress



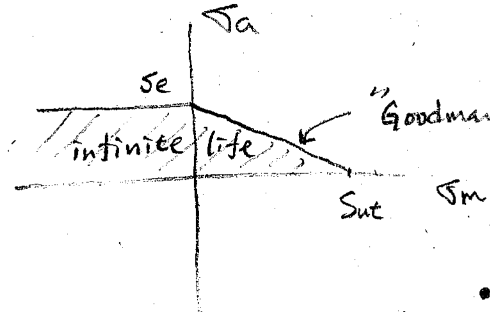
(S_e) fatigue strength

emperical resules

if $\sigma_m < 0$ (compressive), S_f is the same as RR Moore ~~test~~

if $\sigma_m > 0$ (tensile), S_f is <u>less</u> than R.R. Moore test

Safe region on plot of σ_a v.s. σ_m



σ_a always >0

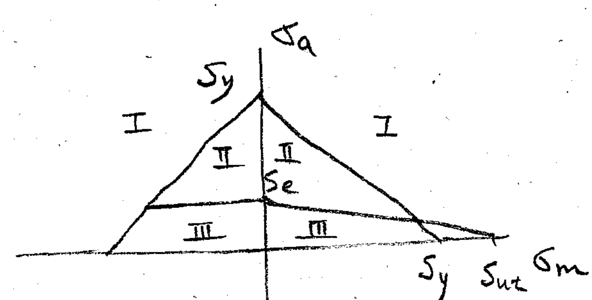
"Goodman line"

$$\begin{cases} \sigma_m > 0 & \dfrac{\sigma_a}{S_e} + \dfrac{\sigma_m}{S_{ut}} < 1 \\ \sigma_m < 0 & \sigma_a < S_e \end{cases}$$

- If also want to guard against yielding

must have $\sigma_a + |\sigma_m| < S_y$

or $\dfrac{\sigma_a + |\sigma_m|}{S_y} < 1$ (both $\sigma_m > 0$ or $\sigma_m < 0$)



region I : immediate failure
region II : finite life
region III : infinite life