AE 737: Mechanics of Damage Tolerance

Lecture 10 - Residual Strength

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February 20, 2020

schedule

- 20 Feb - Residual Strength, Homework 4 Due
- 25 Feb - Multiple Site Damage, Mixed-Mode Fracture
- 27 Feb - Exam Review, Homework 5 Due
- 3 Mar - Exam 1

outline

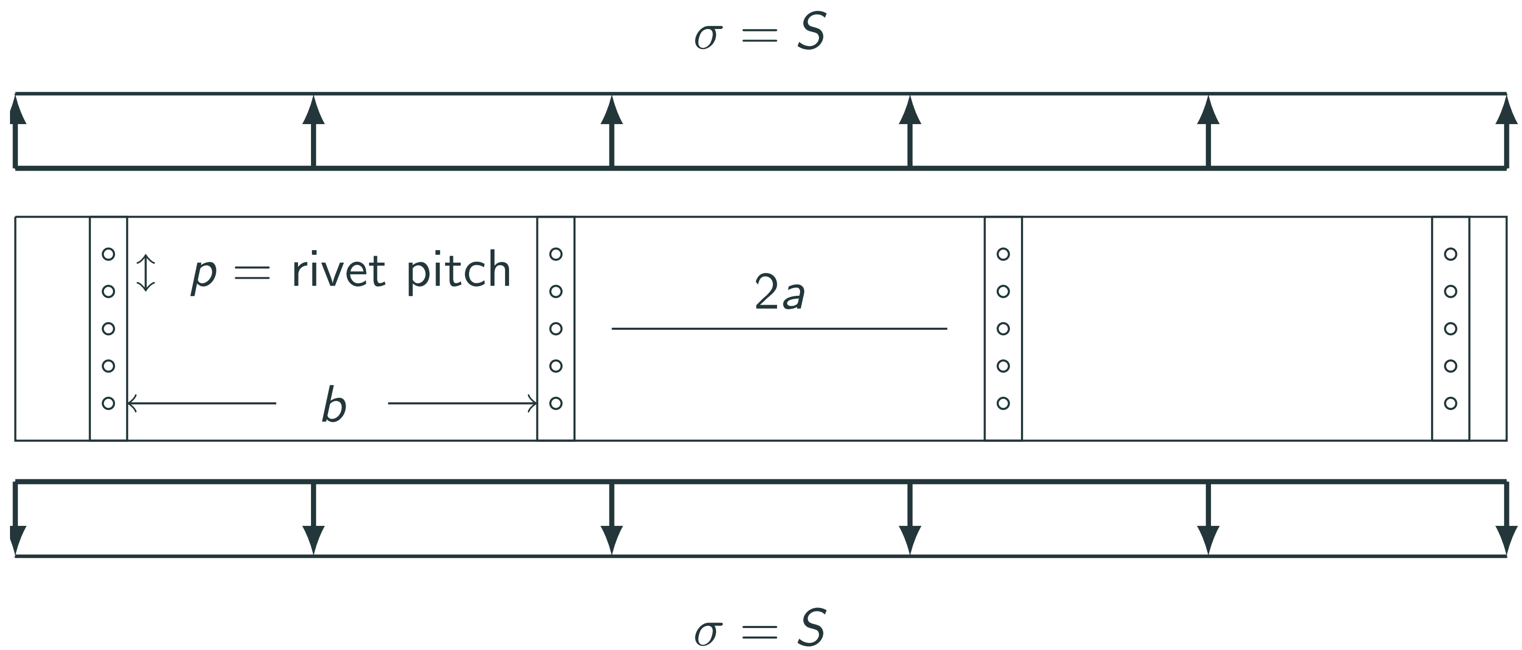
- stiffeners
- severed stiffeners
- crack stoppers

stiffeners

stiffened panels

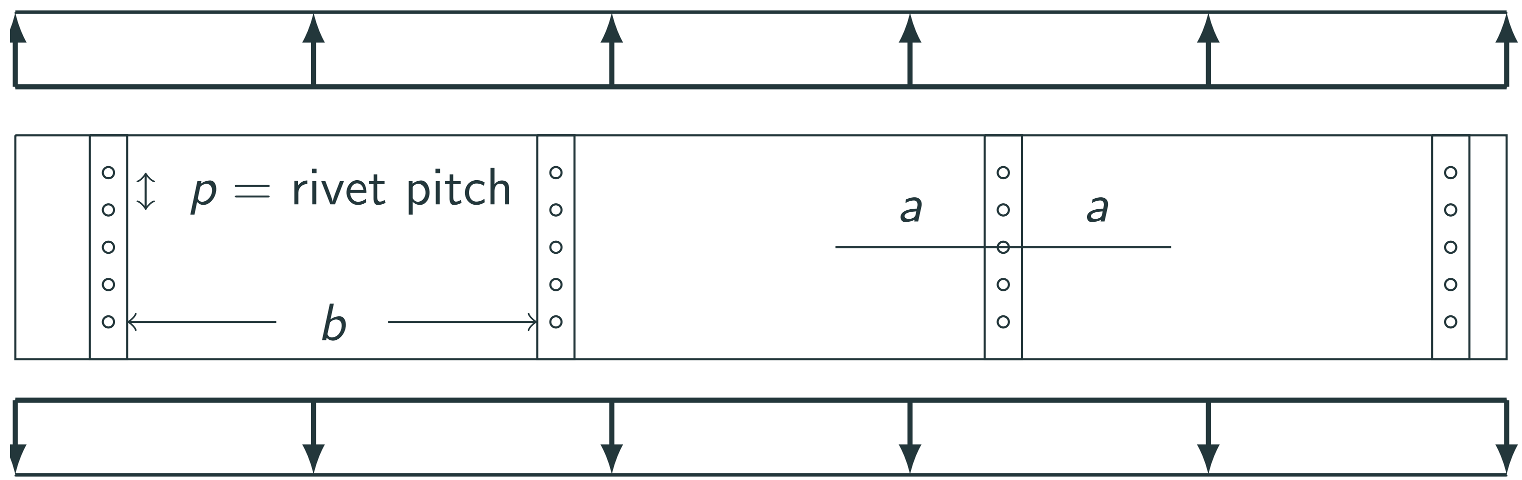
- In aircraft the skin/stringer system provides many benefits (resistance to buckling)
- Stringers also act as stiffeners to resist crack propagation in the skin
- Panels in these configurations are generally very wide relative to expected crack dimensions
- Cracks are generally modeled either as centered between stiffeners or centered under a stiffener
- We need to consider the residual strength of the panel, the stiffener, and the rivets

centered between stiffeners



centered under stiffener

$\sigma = S$



$\sigma = S$

remote stress

- For displacement continuity, we know that

$$\left(\frac{PL}{AE}\right)_{Skin} = \left(\frac{PL}{AE}\right)_{Stiffener}$$

- Since L is the same, we find

$$\frac{S}{E} = \frac{S_S}{E_S}$$

- Where the subscript $_S$ indicates stiffener values, we can express the remote stress in the stiffener as

$$S_S = S\frac{E_S}{E}$$

skin

- The critical stress in the skin is determined the same way as it was in the residual strength chapter
- The only exception is that the stiffener contributes to β

$$S_C = \frac{K_C}{\sqrt{\pi a}\beta}$$

stiffener

- The maximum stress in a stiffener will be increased near a crack
- We represent the ratio of maximum force in stiffener to remote force with the Stiffener Load Factor, L

stiffener

$$
\begin{aligned}
L &= \frac{\text{max force in stiffener}}{\text{remote force applied to stiffener}} \\
&= \frac{S_{S,max} A_S}{S_S A_S} \\
&= \frac{S_{S,max}}{S \frac{E_S}{E}} \\
LS \frac{E_S}{E} &= S_{S,max} \\
LS \frac{E_S}{E} &= \sigma_{YS} \\
S_C &= \frac{\sigma_{YS} E}{L E_S}
\end{aligned}
$$

rivet

- We can define a similar rivet load factor to relate maximum stress in the rivet to remote stress in the skin

$$L_R = \frac{\tau_{max} A_R}{Sbt}$$

$$L_R = \frac{\tau_{YS} A_R}{Sbt}$$

$$S_c = \frac{\tau_{YS} A_R}{L_R bt}$$

finite element analysis

- CC Poe found that panels could be related by a parameter he defines as μ

$$\mu = \frac{A_S E_S}{A_S E_S + AE}$$

- Where A_S is the cross-sectional area of a stiffener, E_S is stiffener modulus
- A is the skin cross-sectional area (per stiffener) A=bt and E is the modulus of the skin

finite element analysis

- pp 167 - 178 give β, L and L_R for various skin/stiffener configurations
- These values were determined using a finite element model

examples

- quantitative example (p. 179-180)
- qualitative notes on behavior (p. 181-182)
- worked (http://nbviewer.jupyter.org/github/ndaman/damagetolerance/blob/master/examples/stiffener%20example.ipynb)

severed stiffeners

failure in stiffener

- Sometimes the stiffeners fail before the panel
- T. Swift conducted some parametric studies on panels with a severed stiffener
- When the crack is short (and near the severed stiffener) the residual strength is lower due to the broken stiffener
- As the crack nears the next stiffener, residual strength is very similar to a panel with all stiffeners intact

failure in stiffener

- Swift considers the difference in stress at different points in the stiffener
- Instead of one general load factor (L), he uses *SCFO* and *SCFI*
- We can find the critical value of remote stress at the outer flange as

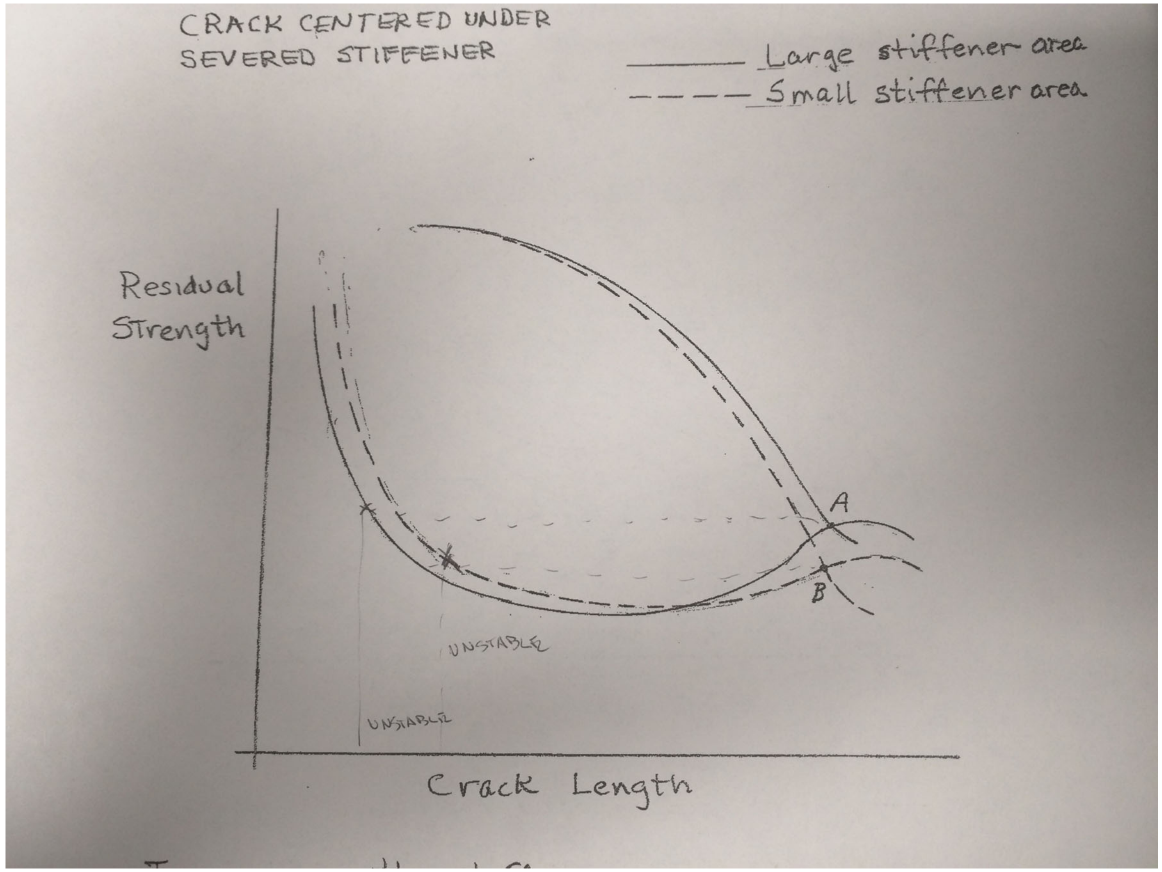
$$\sigma_C = \frac{\sigma_U}{SCFO}$$

- And similarly at the inner flange

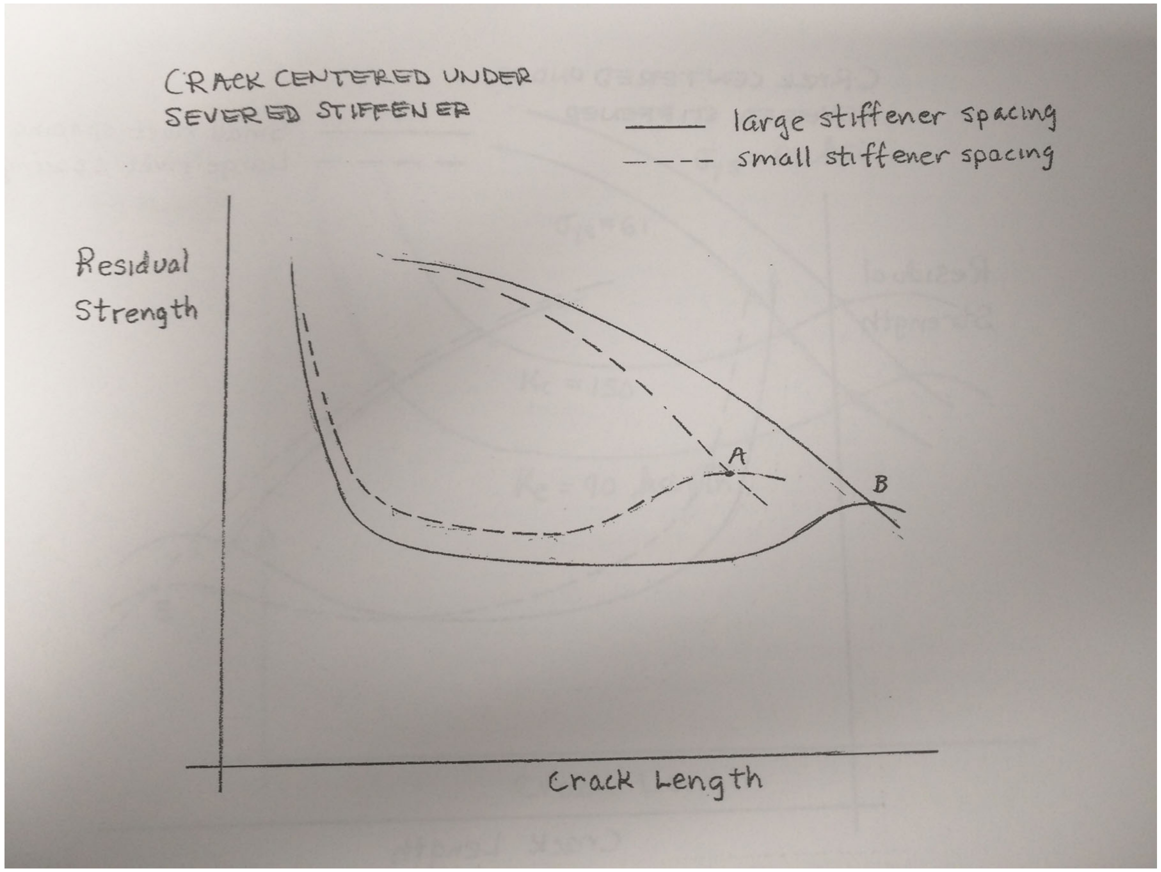
$$\sigma_C = \frac{\sigma_U}{SCFI}$$

- Swift's parametric study did not consider rivet failure

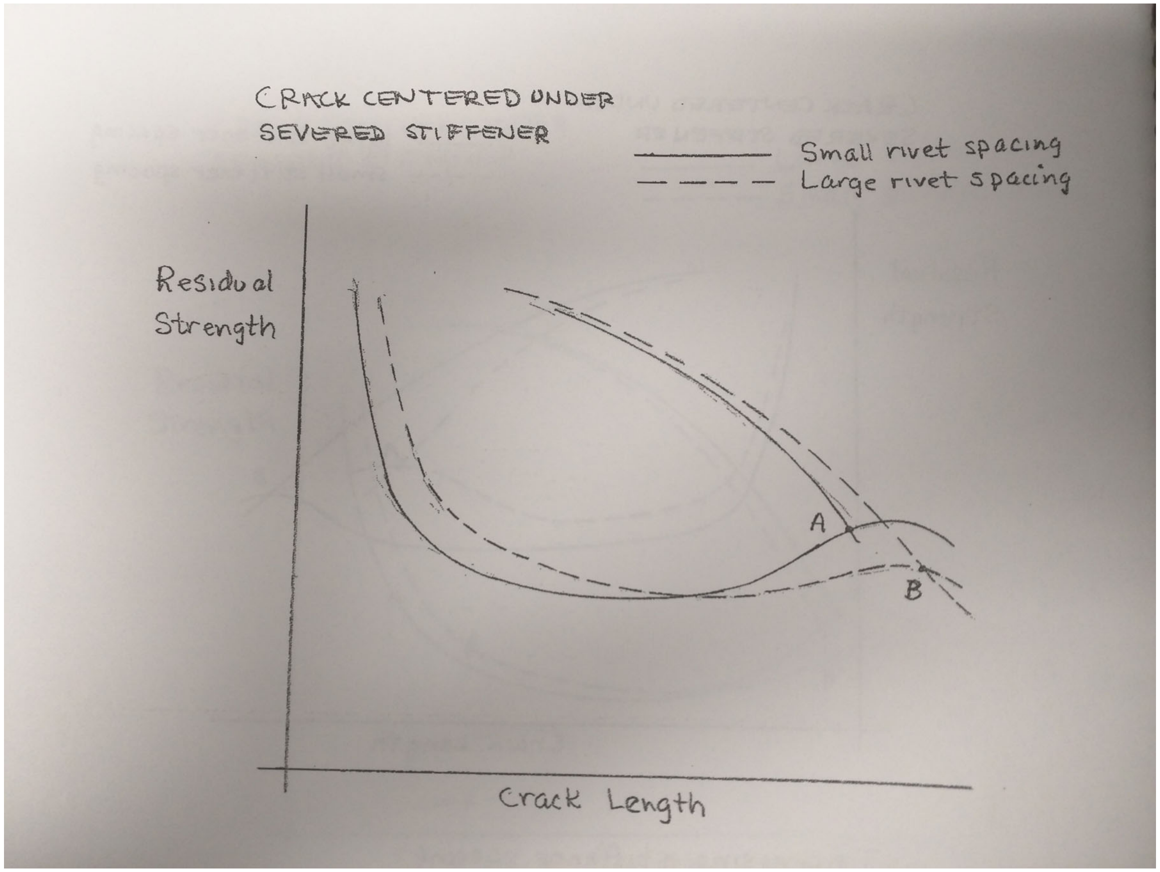
stiffener area



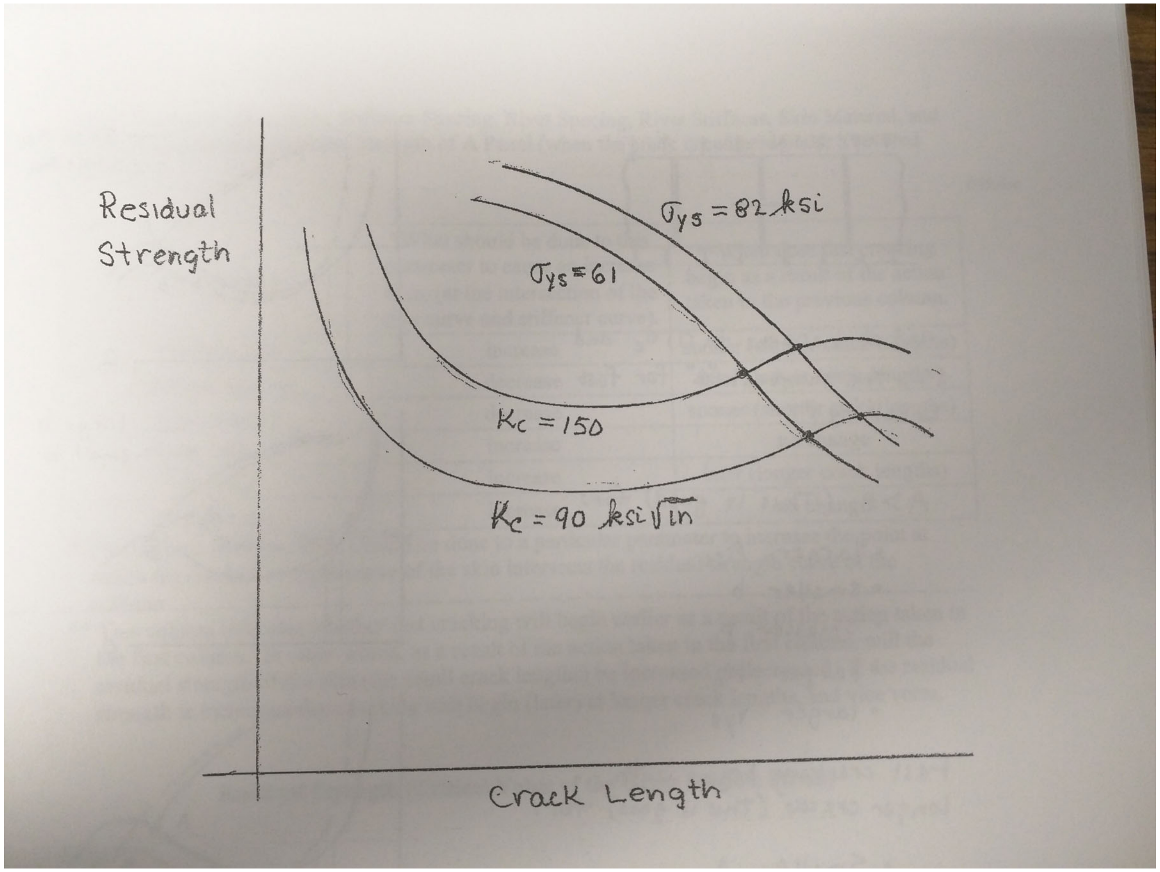
stiffener spacing



rivet spacing



strength and toughness increase



example

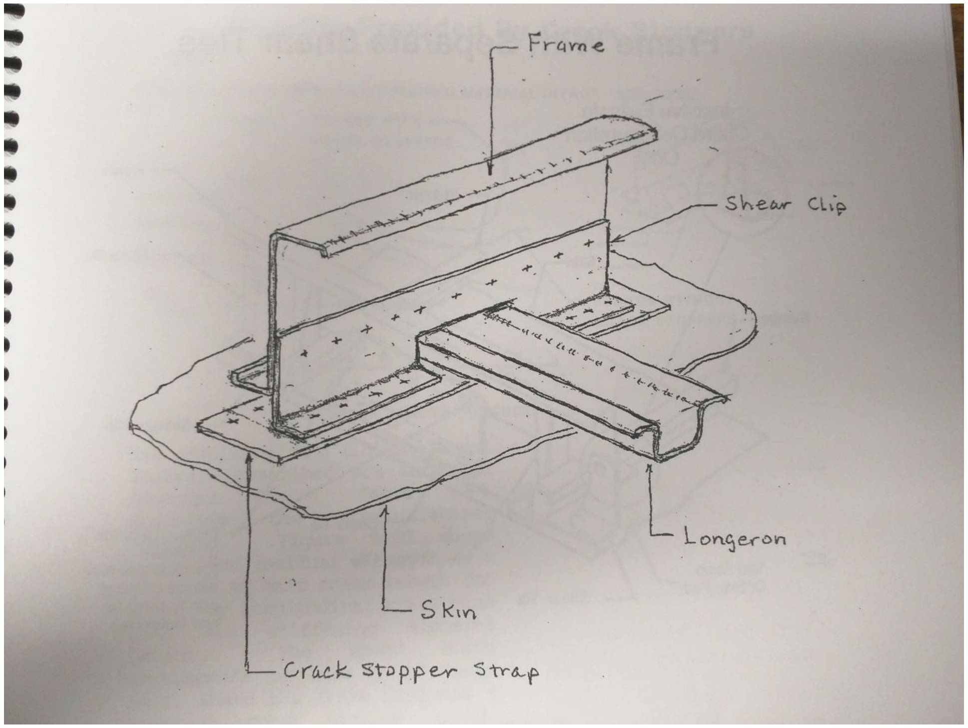
- If we consider the case from Swift's data most similar to our previous example:

$$P = 1.0 \text{ in}$$
$$A_{st} = 0.2538 \text{ in}^2$$
$$b = 10.0 \text{ in}$$

- So we use the tables for Case 10

crack stoppers

crack stopper



optimal crack stopper

- Swift found that the ideal crack stopper has a cross-sectional area approximately equal to 1/4 the stiffener area
- The ideal material was titanium (as opposed to steel or aluminum).
- Aluminum did not transfer enough load to the stiffeners, steel transferred too much

example

- Compare cases 1, 3, and 5