Determination of bearing stress equivalent width

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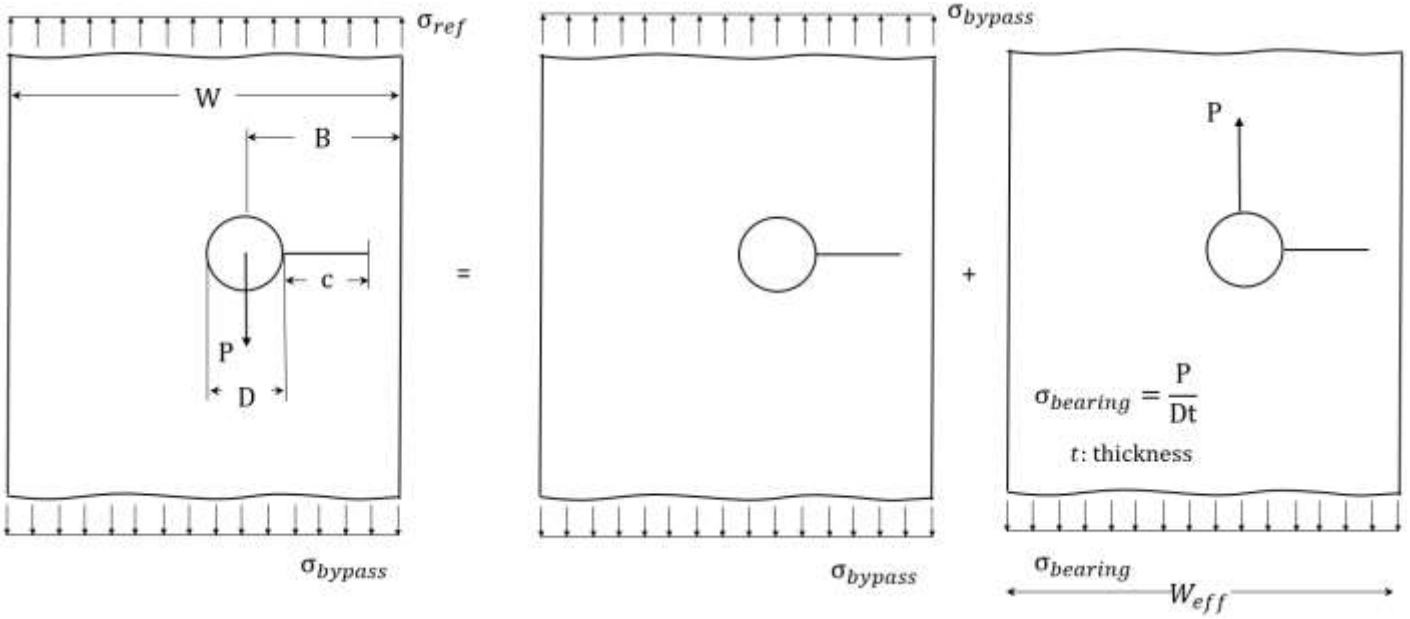
Background

- SIF calculation with combined tensile and bearing loading

$$K_I = \beta_{total}\sigma_{ref}\sqrt{\pi c}$$

$$ASF = \frac{\sigma_{bypass}}{\sigma_{ref}} \qquad BSF = \frac{\sigma_{bearing}}{\sigma_{ref}}$$

$$\beta_{total} = \beta_{tension}\, ASF + \beta_{bearing}\, BSF$$



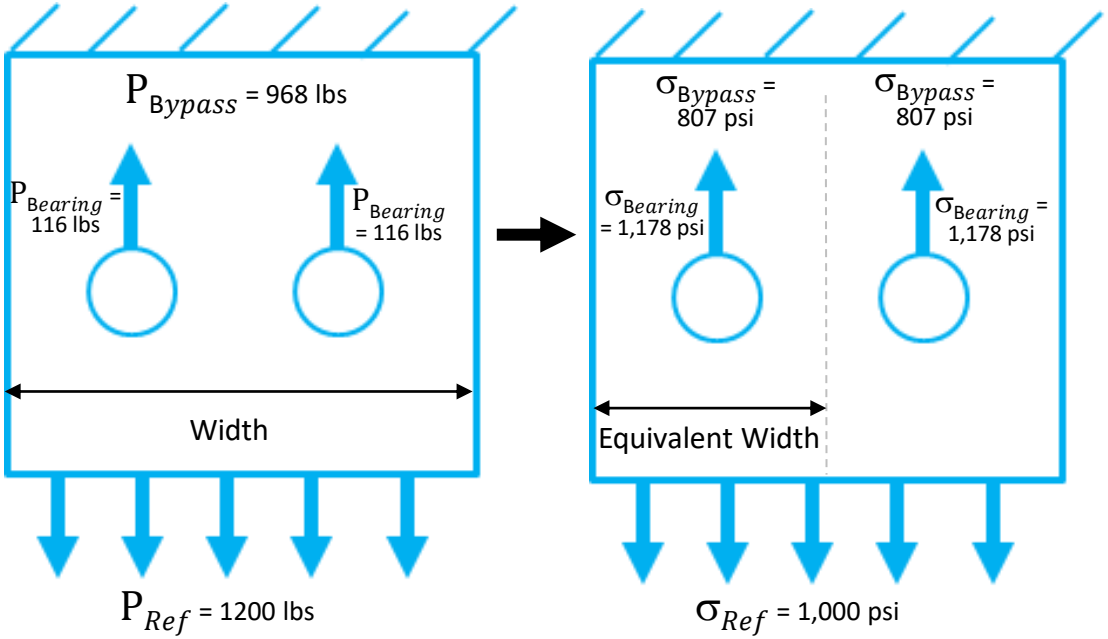
Background

- SIF calculation with combined tensile and bearing loading

$$ASF = \frac{\sigma_{bypass}}{\sigma_{ref}} \qquad BSF = \frac{\sigma_{bearing}}{\sigma_{ref}}$$

$$ASF = 1 - BSF\left(D/W_{eff}\right)$$

$$\beta_{total} = \beta_{tension}\,\mathrm{ASF} + \beta_{bearing}\,\mathrm{BSF}$$

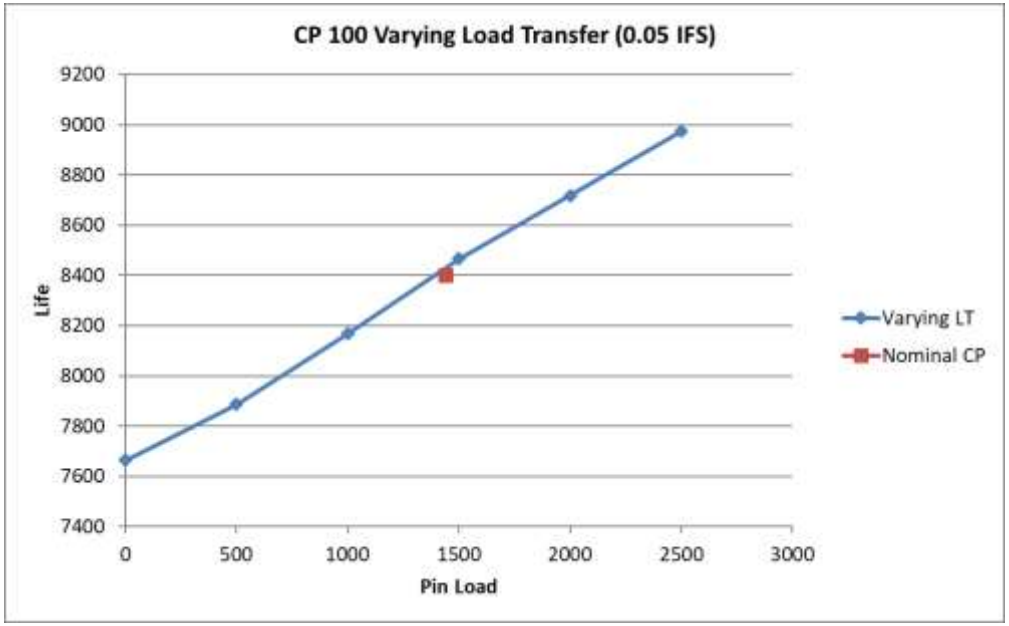


$$\mathrm{ASF} = \frac{\sigma_{Bypass}}{\sigma_{\text{Ref (Far field)}}} = \frac{807\ \text{psi}}{1{,}000\ \text{psi}} = \mathbf{.807}$$

$$\mathrm{BSF} = \frac{\sigma_{Bearing}}{\sigma_{\text{Ref (Far field)}}} = \frac{1{,}178\ \text{psi}}{1{,}000\ \text{psi}} = \mathbf{1.178}$$

Background

- Counterintuitive results found for some geometries
  - Increasing load transfer led to increased life



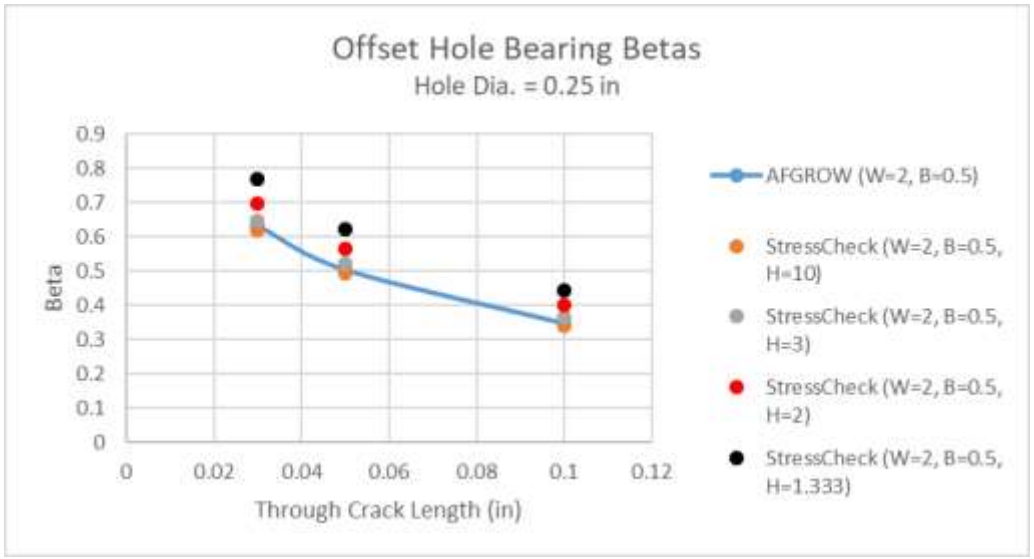
  - Unexpected because increased concentration of stress near crack should cause a net increase in short crack SIFs

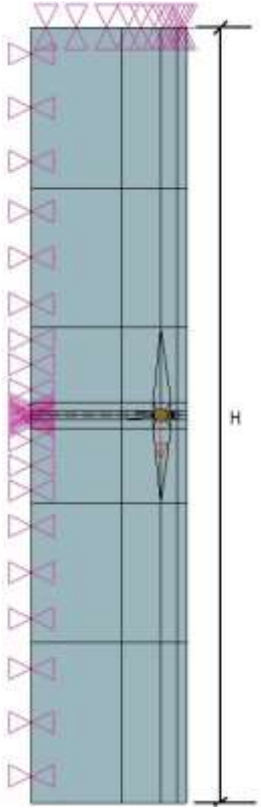
Background

- Counterintuitive results found for some geometries

  Further study

  – Harter 2017: Focused on finite width/offset hole corrections





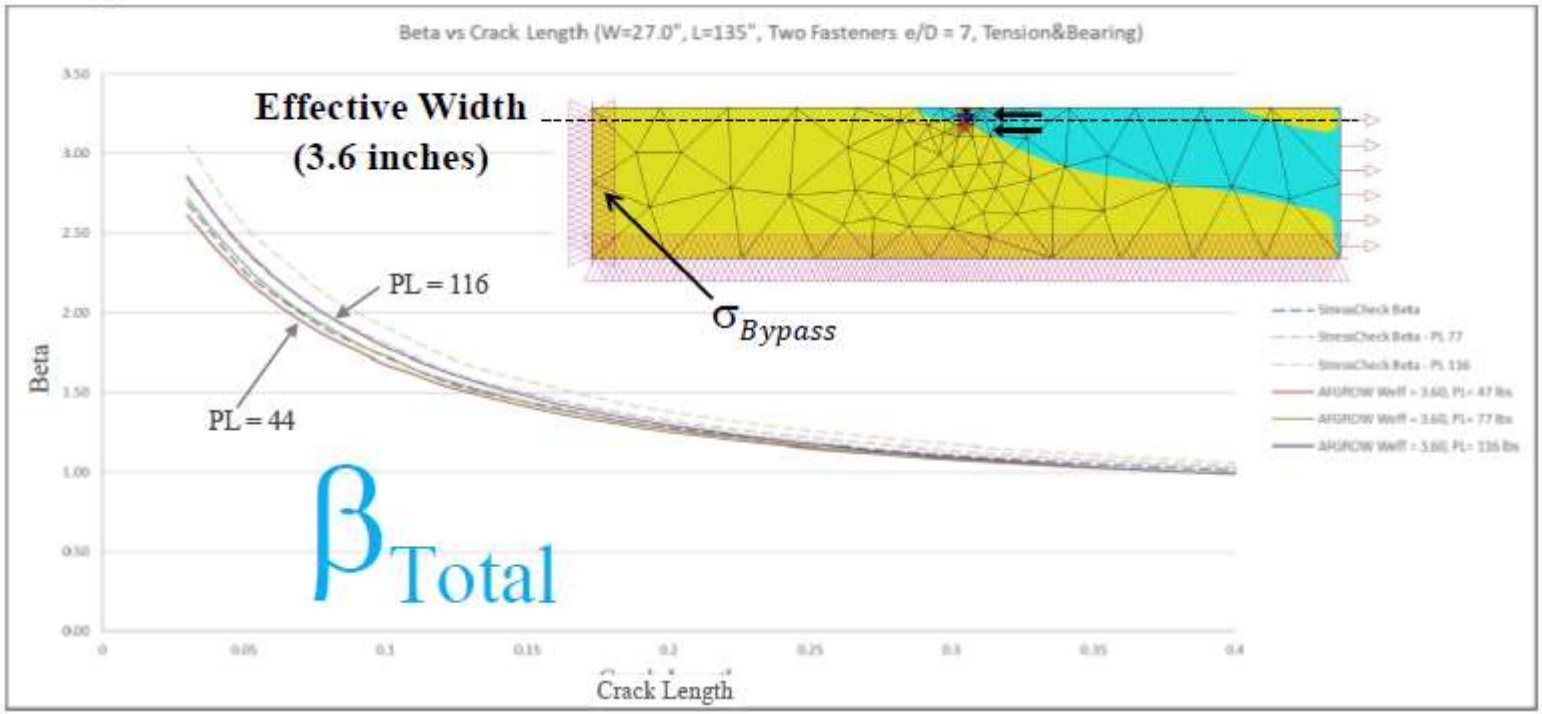
  ➢ "When modeling wide/offset plates with combined loads, it is… recommended to adjust the panel width so that the hole is not more than 6D from either edge."

Background

- Counterintuitive results found for some geometries

  Further study

  – Anderson 2020: Focused on effective width assumption



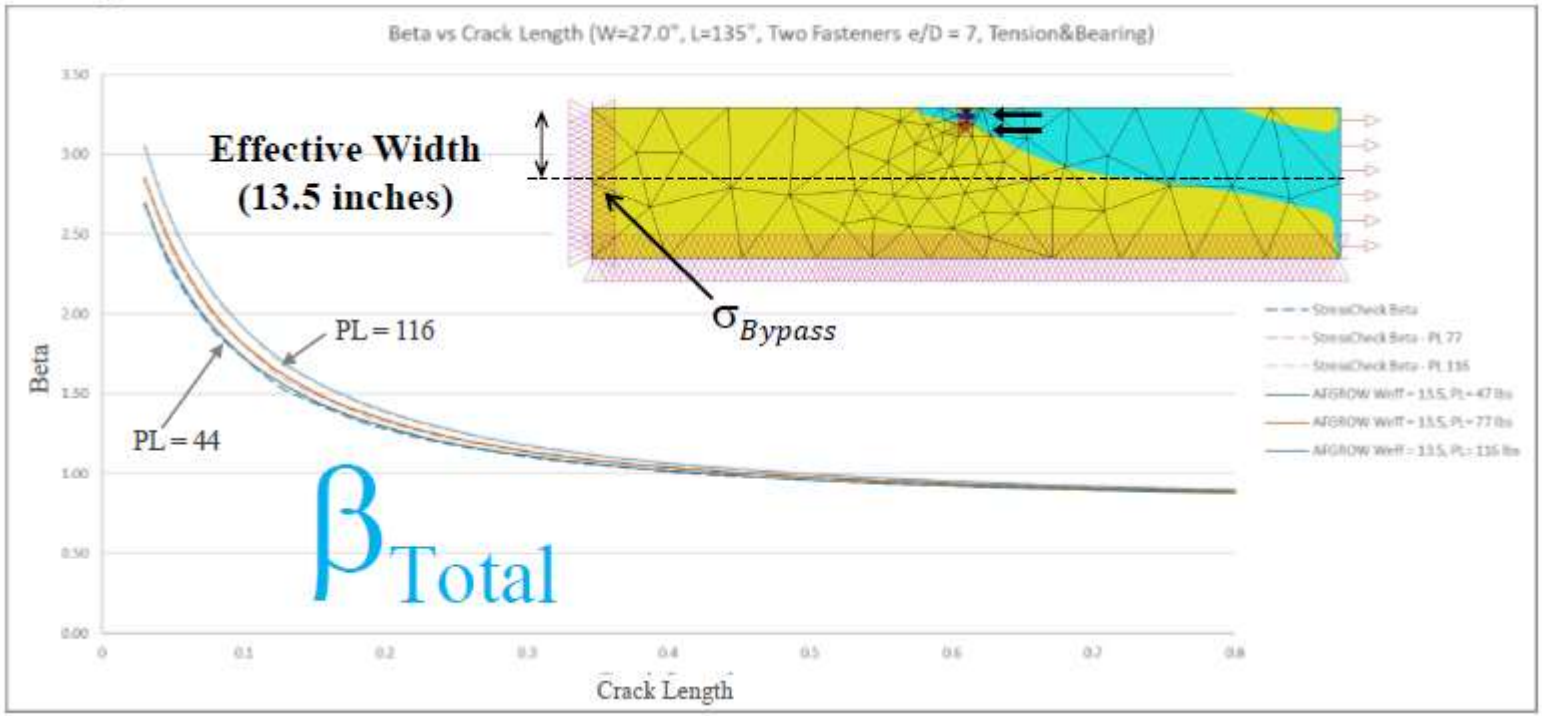
- Mismatch found when using effective width from analysis ground rules

Background

- Counterintuitive results found for some geometries

  Further study

  – Anderson 2020: Focused on effective width assumption



➢ Recommendation: Investigate more geometries and loading combinations

Calculation of effective widths

- Solution space

BSF = $\sigma_{bearing}/\sigma_{ref}$ = [0.5,1,1.5,2,4,8,15,20]

D/2B = [0.02, 0.05, 0.1, 0.3]

c/(B-D/2) = [0.05, 0.1, 0.3, 0.5, 0.9, 0.95]

Single fastener geometries:

B/W = [0.25, 0.35, 0.5]

Double fastener geometries:

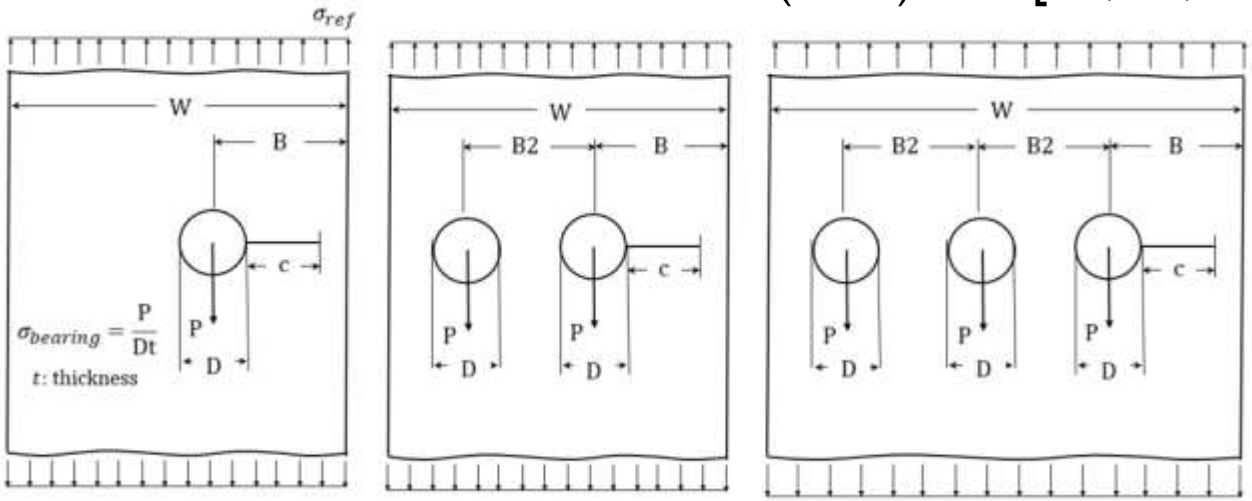
B2/D = [2,4,8]

(B+0.5 B2)/W = [0.1, 0.3, 0.5]

Triple fastener geometries:

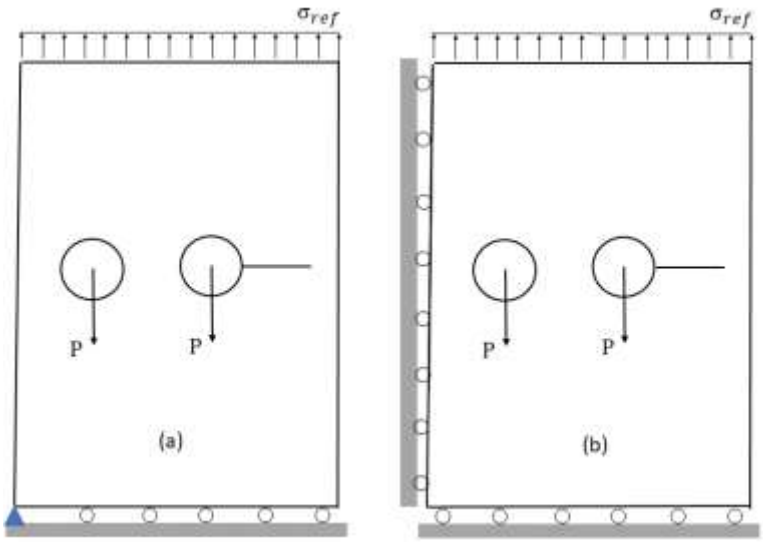
B2/D = [2,4,8]

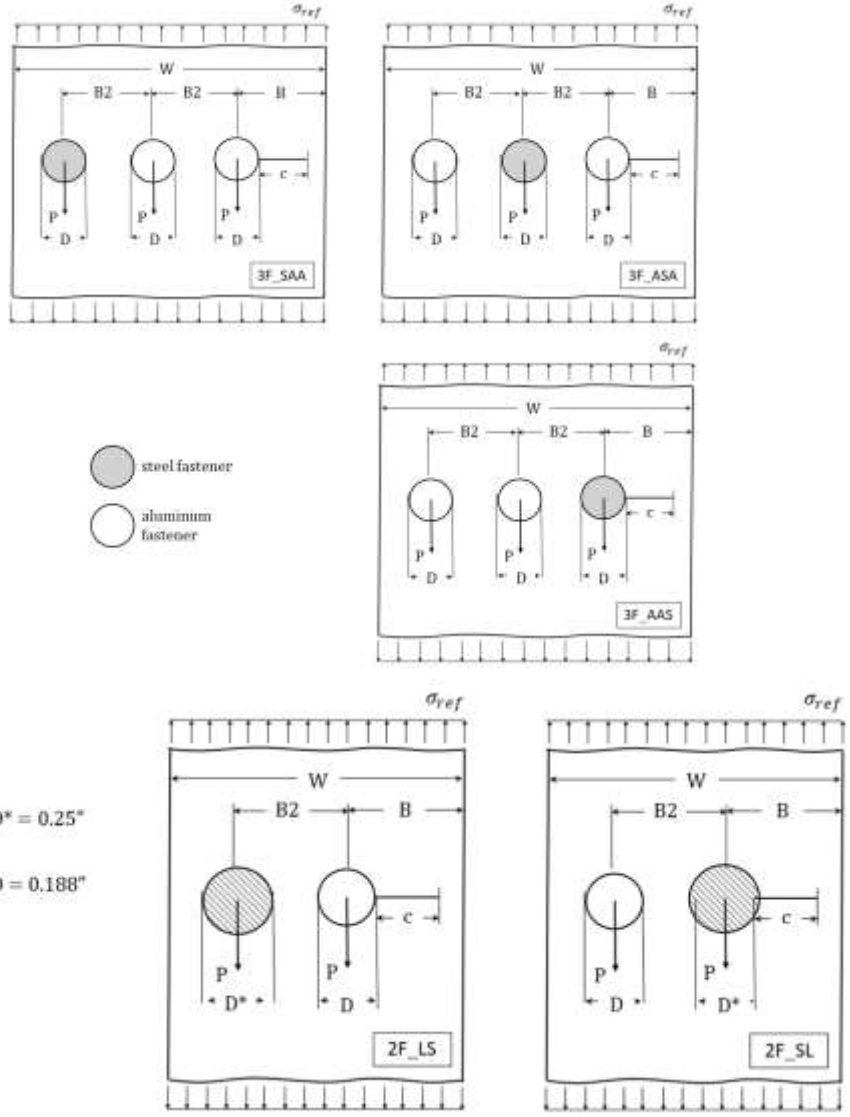
(B+B2)/W = [0.1, 0.3, 0.5]



Calculation of effective widths

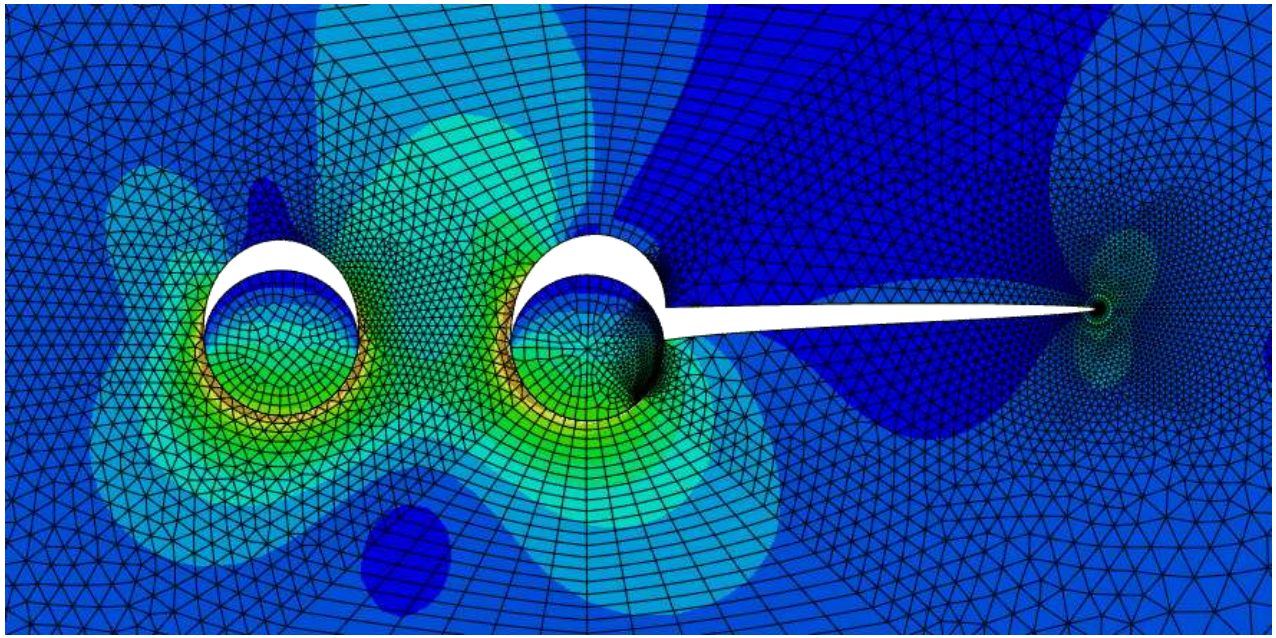
- Configurations
  - Models with no bending restraint
    - Identical fasteners
  - Models with bending restraint
    - Identical fasteners
    - Fastener stiffnesses varied
    - Fastener diameters varied





Calculation of effective widths

- ABAQUS model details
  - Quadratic elements with refined crack tip and fastener regions
  - SIFs extracted using contour integrals
  - Contact surface with friction coefficient = 0.3
  - Height/width = 6

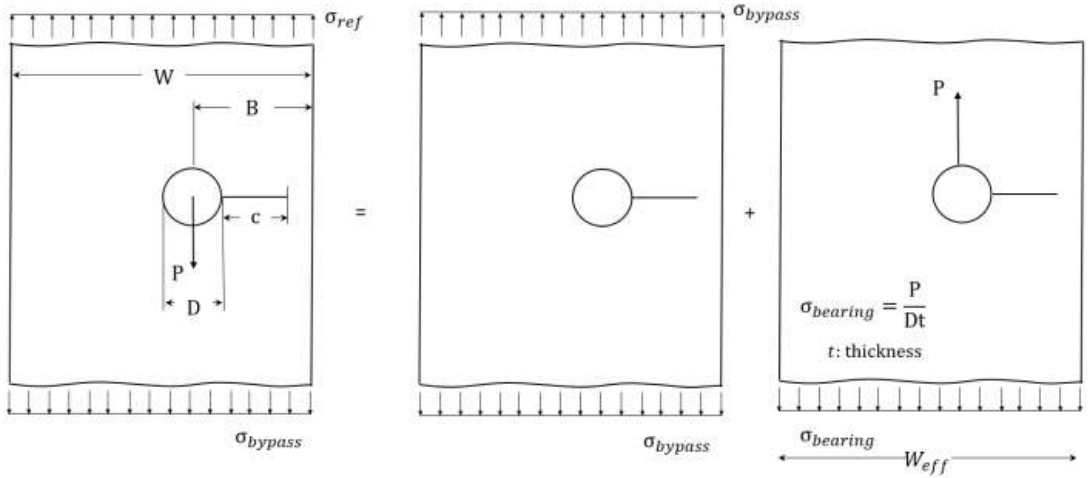


Calculation of effective widths

- Calculation procedure
  - Three models run for each geometry:
    - Tension only to find $\beta_{tension}$
    - Bearing only to find $\beta_{bearing}$
    - Combined loading to find β_{total}
  - BSF calculated from bearing load and geometry

$$ASF = \frac{\beta_{total} - \beta_{bearing}\, BSF}{\beta_{tension}}$$

$$W_{eff} = \frac{D * BSF}{1 - ASF}$$



Calculation of effective widths

- Results: Models with no bending restraint
  - Increasing D: W_{eff}/W increases
  - Increasing BSF: W_{eff}/W increases
  - Increasing offset: W_{eff}/W decreases
  - For offset holes, increasing fastener pitch: W_{eff}/W increases
  - Increasing c
    - With low BSF, W_{eff}/W initially increases, then decreases
    - With higher BSF, W_{eff}/W always decreases
  - For centered holes, W_{eff}/W stays constant
  - W_{eff}/W is very sensitive to BSF for short cracks

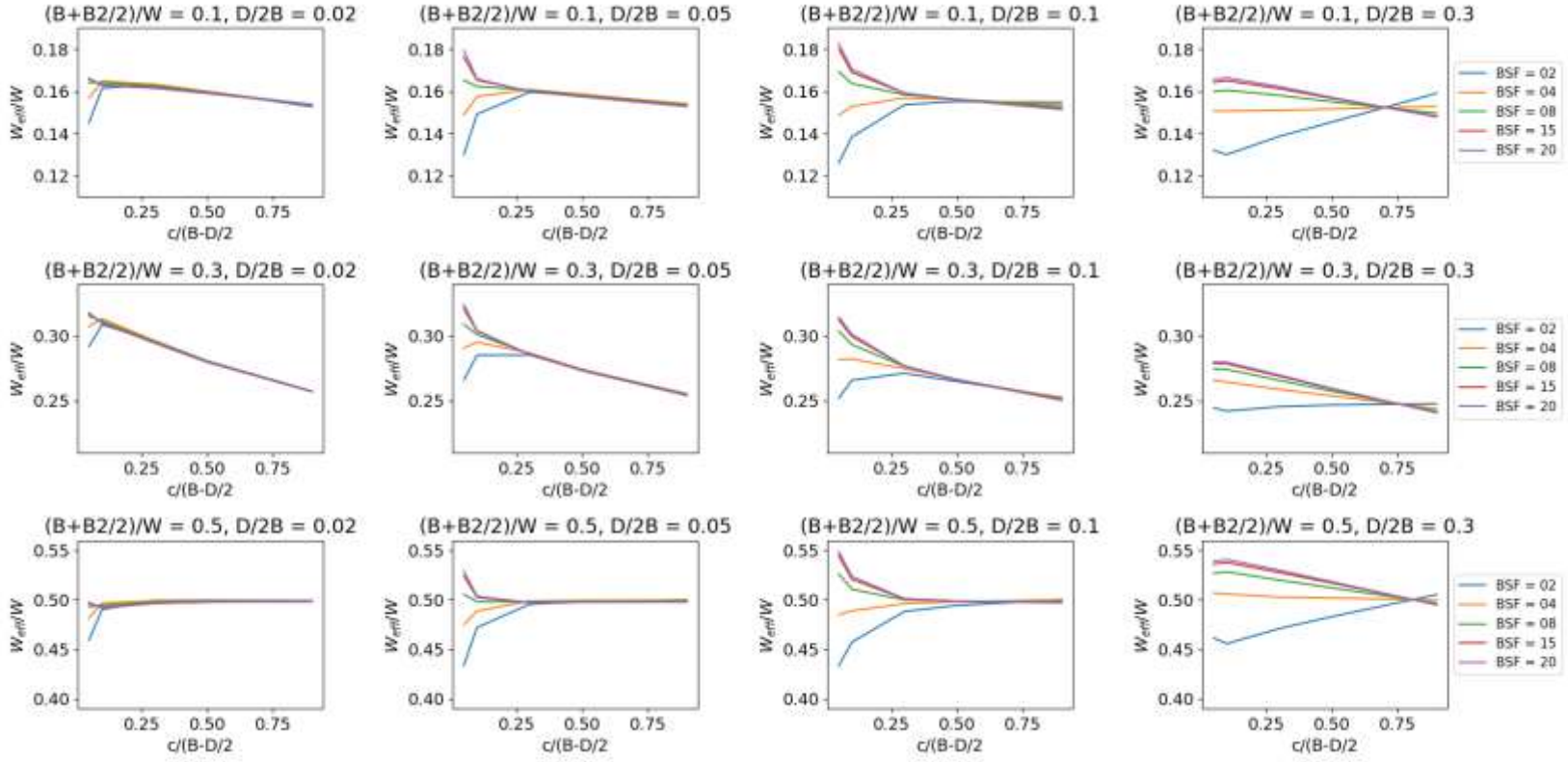
➢ Results heavily influenced by in-plane bending

Calculation of effective widths

- Results: Models with no bending restraint

Increasing diameter

Increasing offset



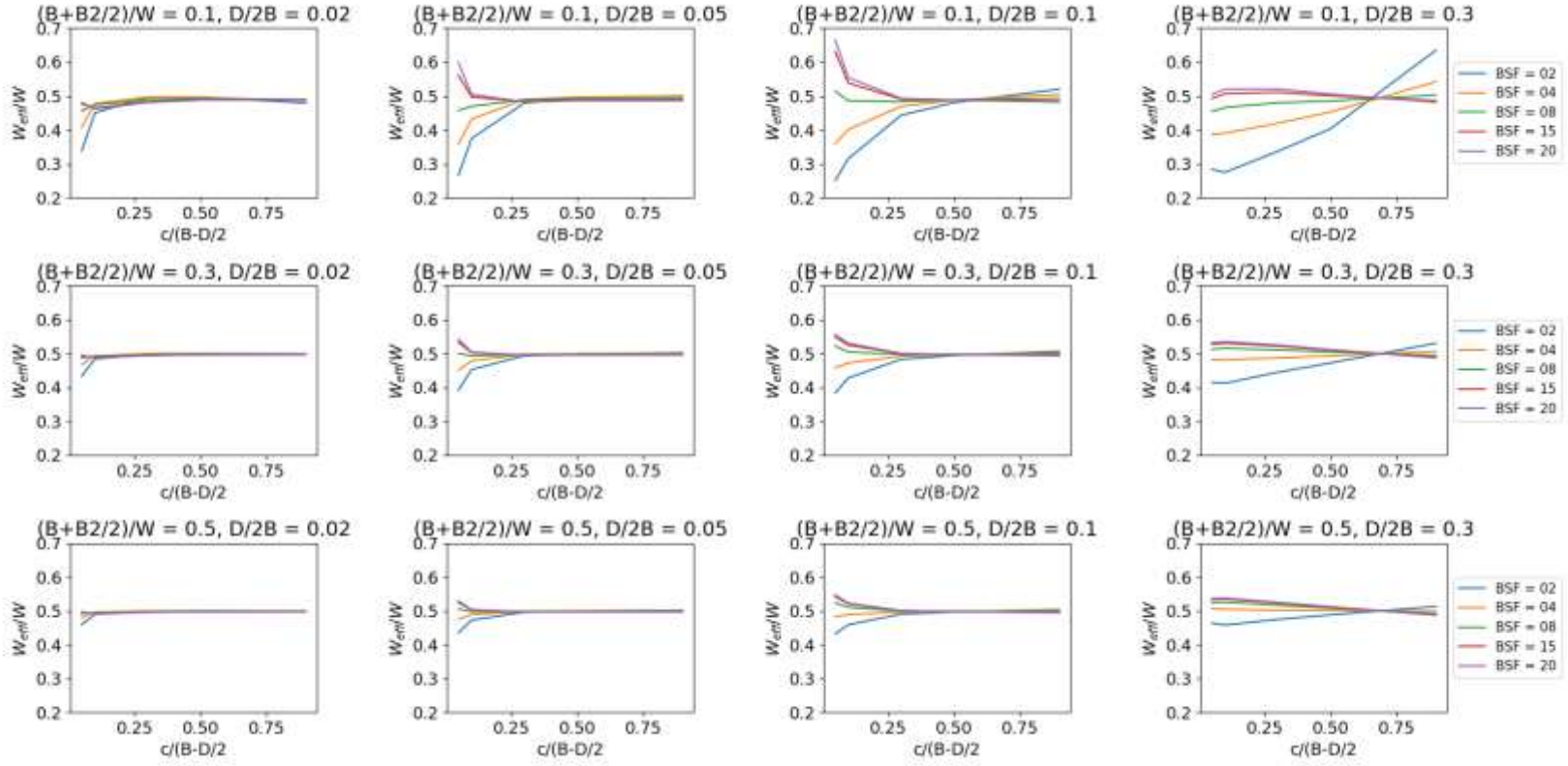
All examples shown: 2 fasteners, fastener pitch = 4D

Calculation of effective widths

- Results: Models with bending restraint

Increasing diameter

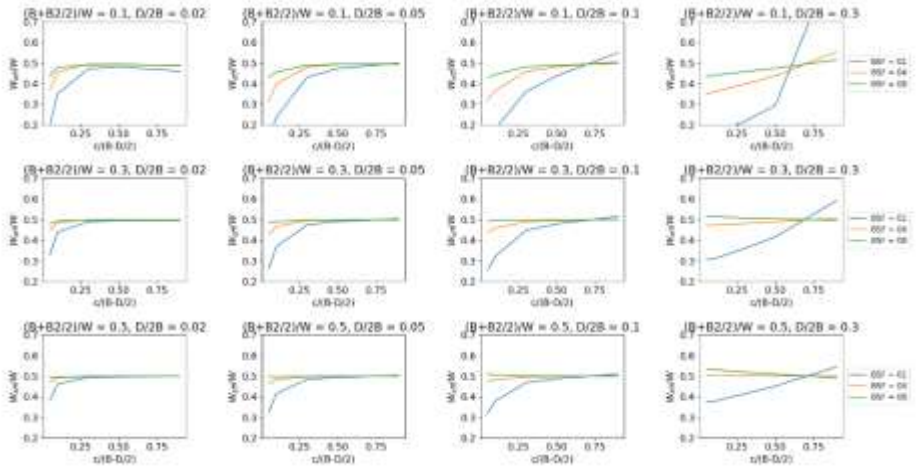
Increasing offset



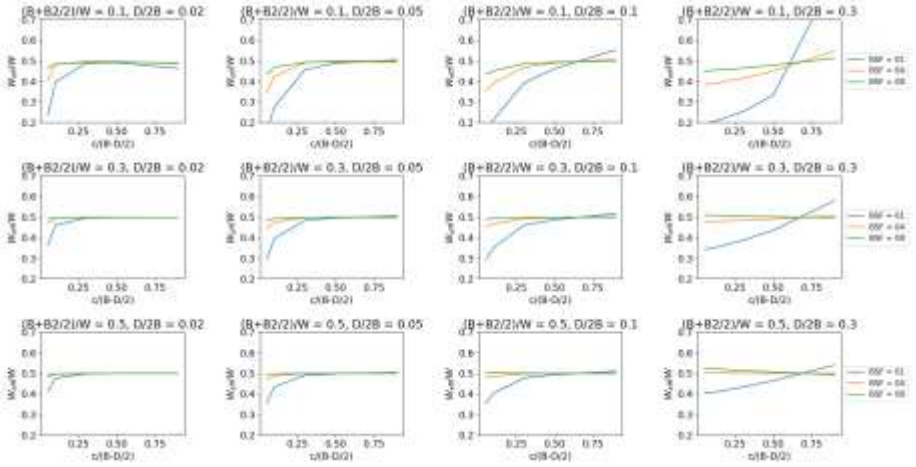
$$W_{eff}/W = \frac{1}{no\ of\ fasteners}$$

Calculation of effective widths

- Results: Varying fastener stiffness



Crack at aluminum fastener



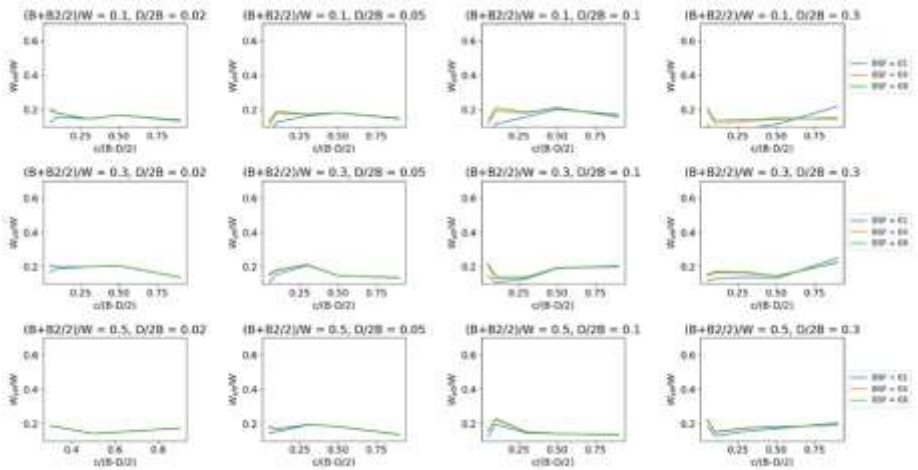
Crack at steel fastener

  - Variability at small c, large offset, large D, and low BSF
  - Placement of stiffer fastener has limited impact

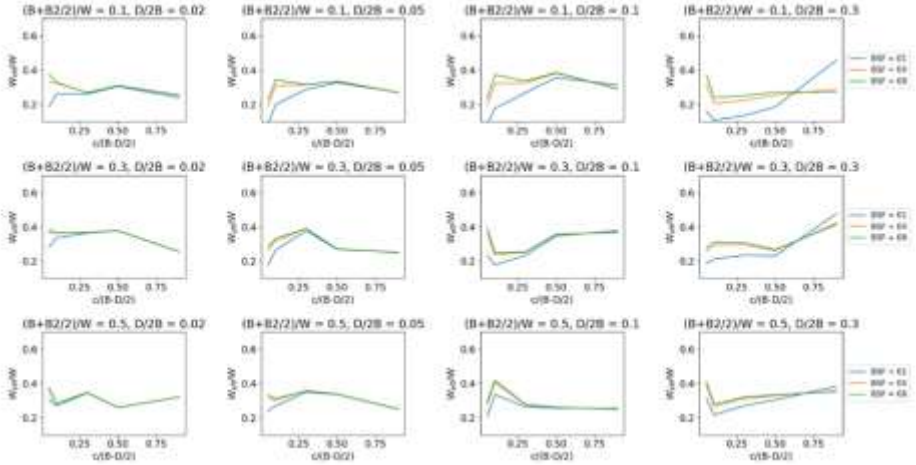
$$W_{eff}/W = \frac{1}{no\ of\ fasteners}$$

Calculation of effective widths

- Results: Varying fastener diameters (two fasteners)



Crack at smaller fastener (0.188”)

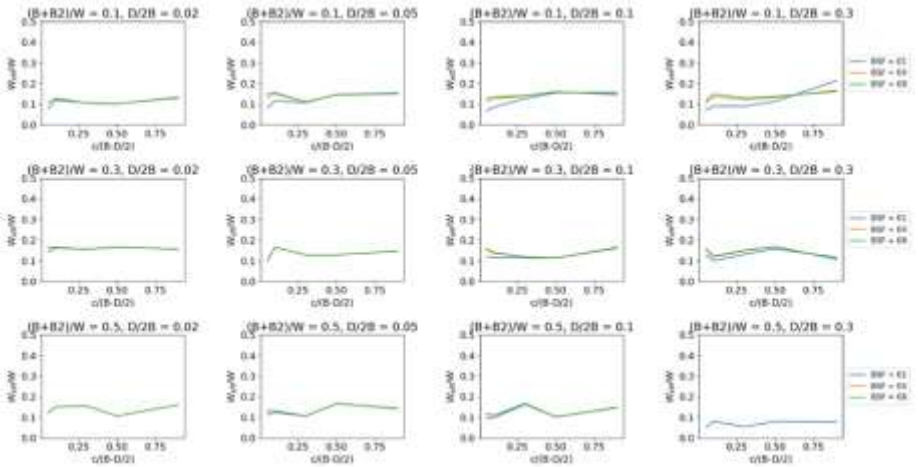


Crack at larger fastener (0.250”)

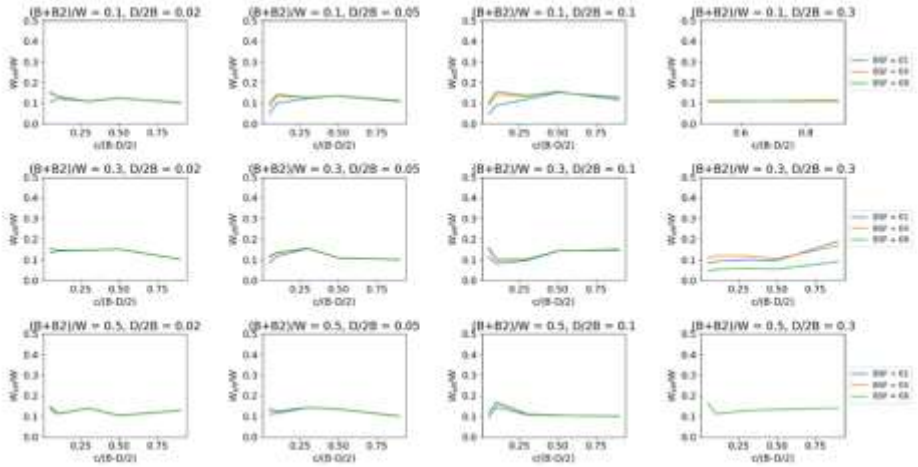
  - Clear impact of bending effects as larger fastener pulls more load, reducing W_{eff}, especially when crack is growing from smaller fastener

Calculation of effective widths

- Results: Varying fastener diameters (three fasteners)



Large fastener farthest from crack



Large fastener in middle

– Assuming $W_{eff}/W = \frac{1}{no\ of\ fasteners}$ should always be conservative

Remaining questions

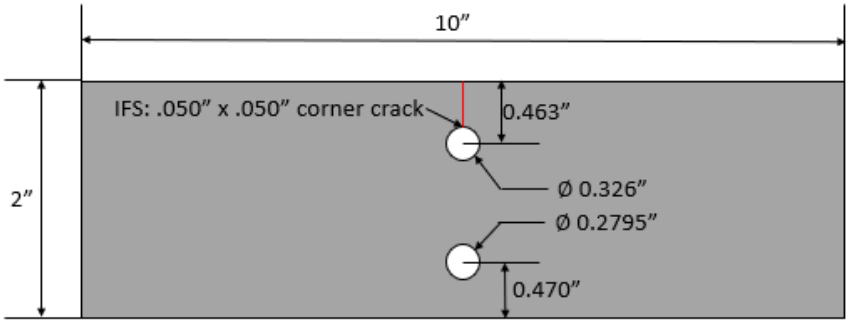
- Refinement of recommendations for fastener rows with different size fasteners
  - Results don't lead to clear recommendation

- Investigation of non-flat geometries
  - Is it still valid to assume $W_{eff}/W = \frac{1}{no\ of\ fasteners}$?

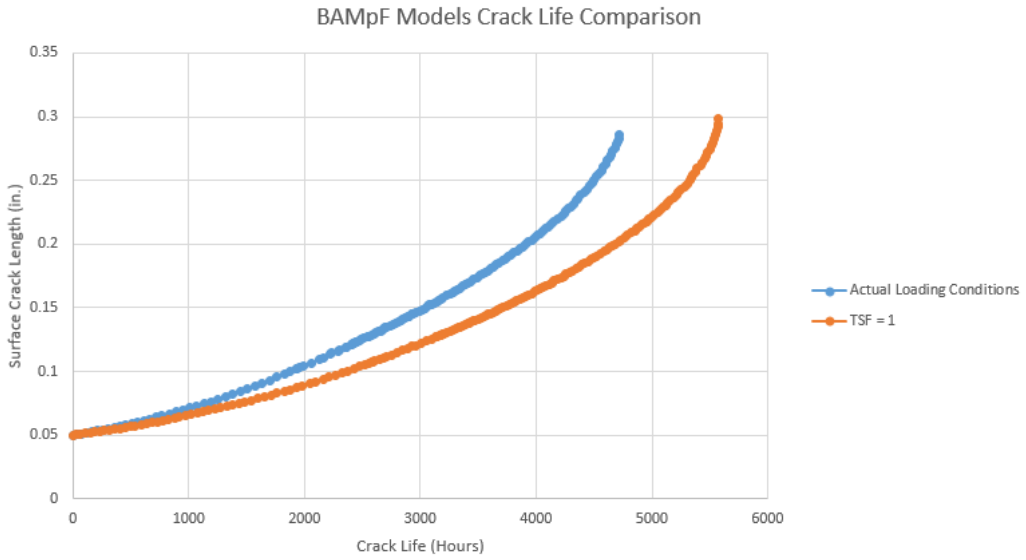
- Why do we still see lower betas for higher pin loading in some geometries?
  - Not entirely caused by effective width assumption

Remaining questions

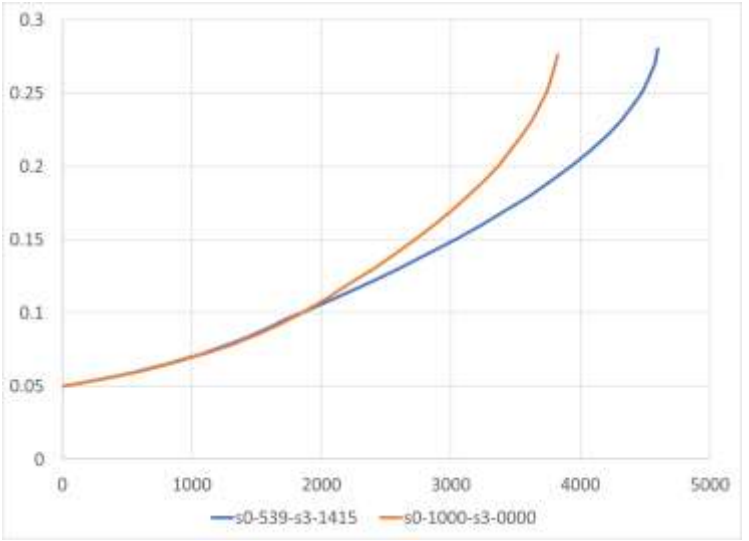
- Lower betas for higher pin loading?



BAMpF analysis by Connor Hood (USAF)

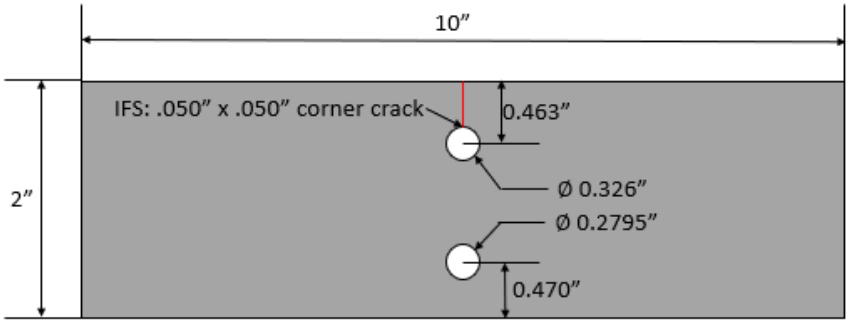


AFGROW analysis

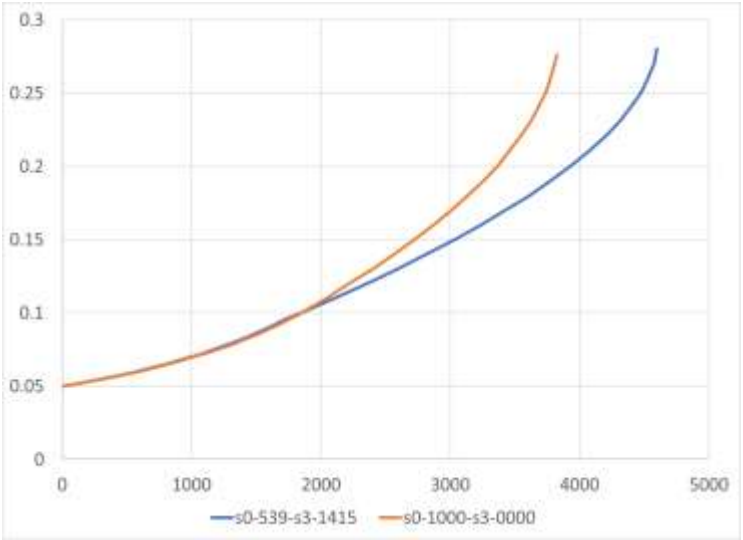


Remaining questions

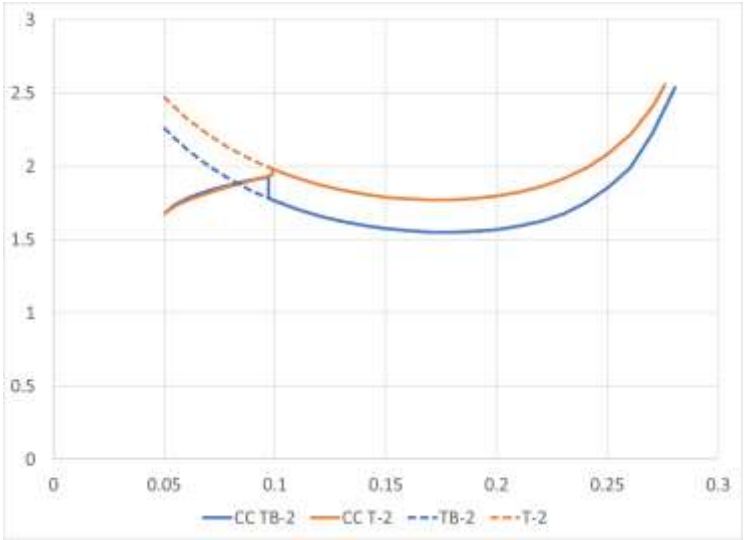
- Lower betas for higher pin loading?



Life

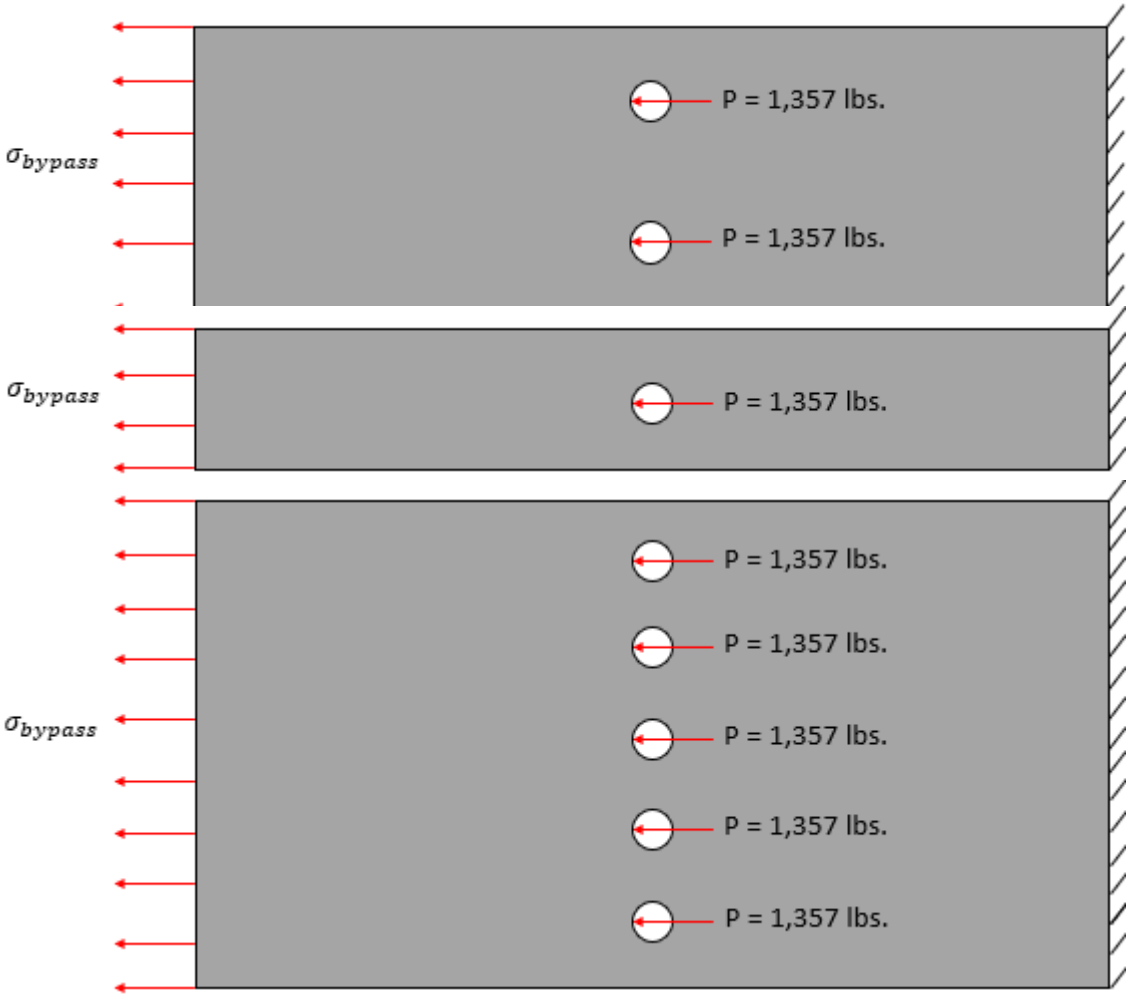


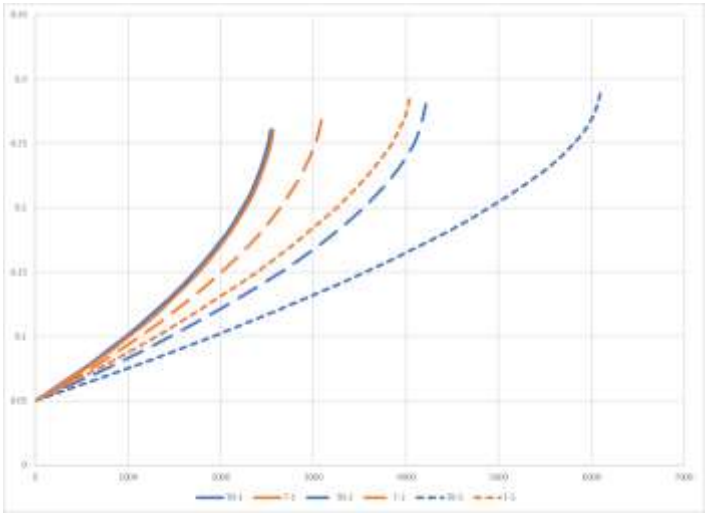
Beta

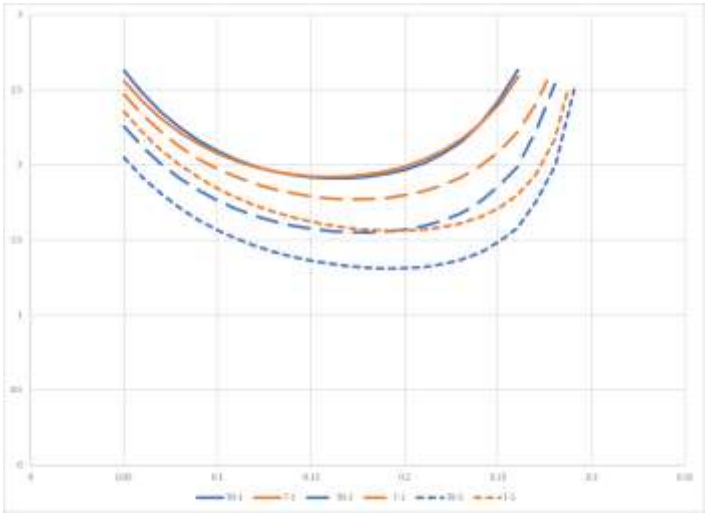


Remaining questions

- Lower betas for higher pin loading?

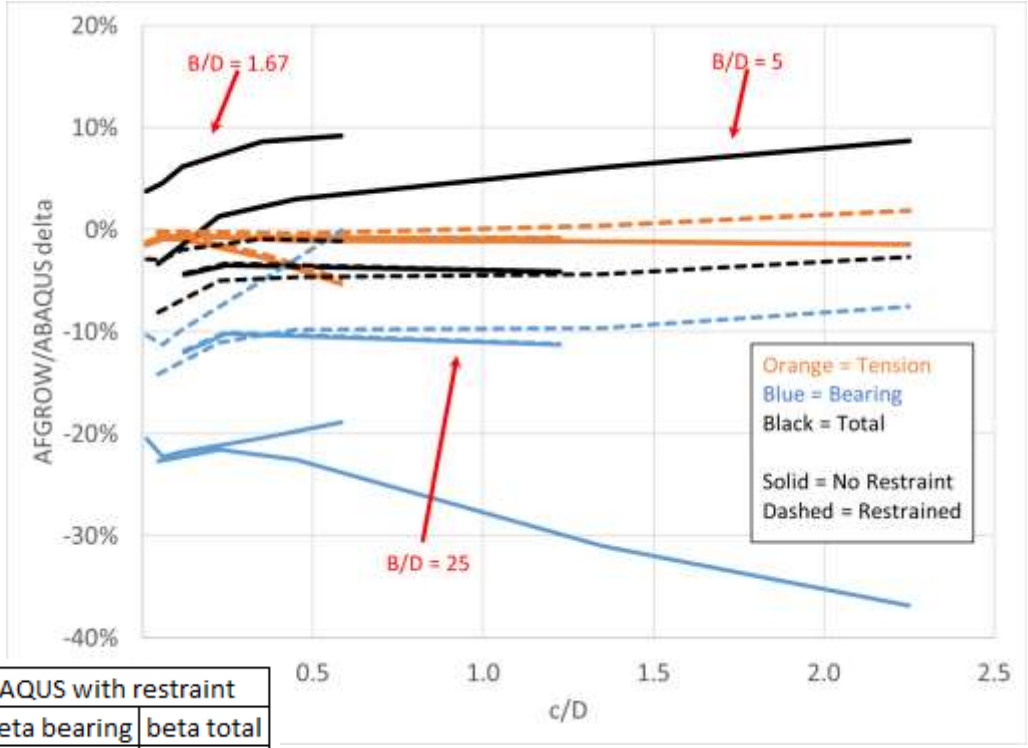






Remaining questions

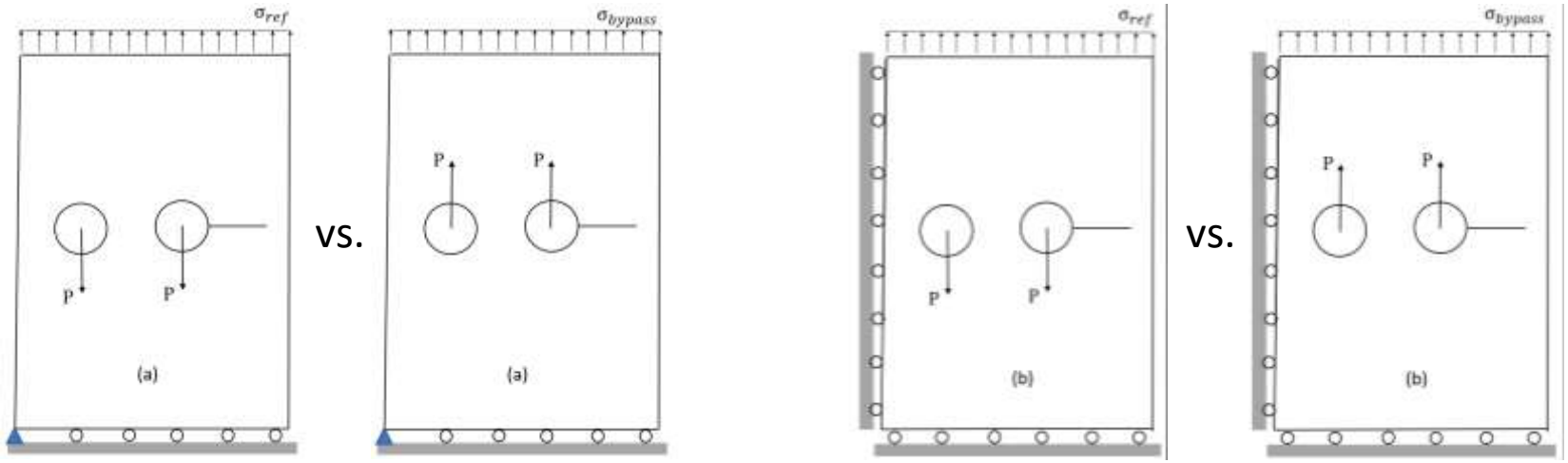
- Lower betas for higher pin loading?
  - AFGROW/ABAQUS betas compared for a mix of geometries
    - 1, 2, and 3 fasteners
    - Varying edge distances
    - Small to large cracks



	AFGROW/ABAQUS no restraint			AFGROW/ABAQUS with restraint		
Fasteners	beta tension	beta bearing	beta total	beta tension	beta bearing	beta total
1	0.1%	-10.3%	8.2%	0.8%	2.2%	3.2%
2	-3.0%	-27.6%	-1.4%	-2.3%	-16.4%	-8.1%
3	-1.2%	-24.9%	1.6%	-0.8%	-13.8%	-5.7%

Remaining questions

- Lower betas for higher pin loading?
  - AFGROW/ABAQUS betas compared for a mix of geometries
    - ➢ $\beta_{tension}$ compare well
    - ➢ $\beta_{bearing}$ low, but explainable
      - ➢ Single vs. multiple fastener loading
    - ➢ *ASF* and W_{eff} assumptions bring β_{total} close to ABAQUS calculations
      - ➢ Modeling decisions lead to differences that muddy superposition assumptions



Conclusions and summary

- For most configurations, $W_{eff} = \frac{W}{no\ of\ fasteners}$
- Guidance for fastener rows with different size fasteners can be refined
- Non-flat geometries still need investigation
  - Bending restraint will have large impact
- Lower betas for higher pin loading?
  - Current assumptions of causes:
    1. Differences in offset hole correction for tension vs. bearing
       - More offset -> lower $\beta_{tension} / \beta_{total}$
    2. Restraint assumptions in model development
    3. $\beta_{tension}$ conservatively assumes open hole, and increasing pin loading reduces this conservatism