CAStLE Continued K-Solutions Support

13 September 2023

US Air Force CAStLE

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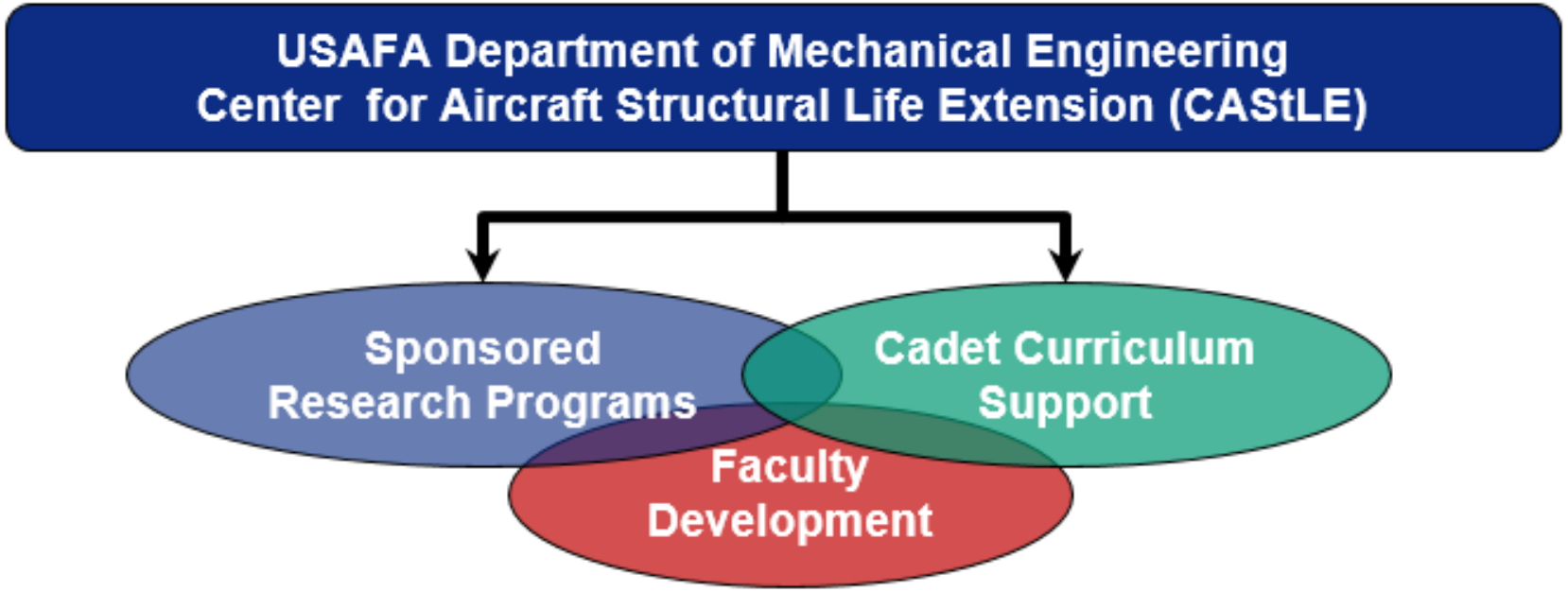
Overview

- **CAStLE**
- **Stress Intensity Factor Solution Milestones**
- **Related Research Activities**

CAStLE's Mission



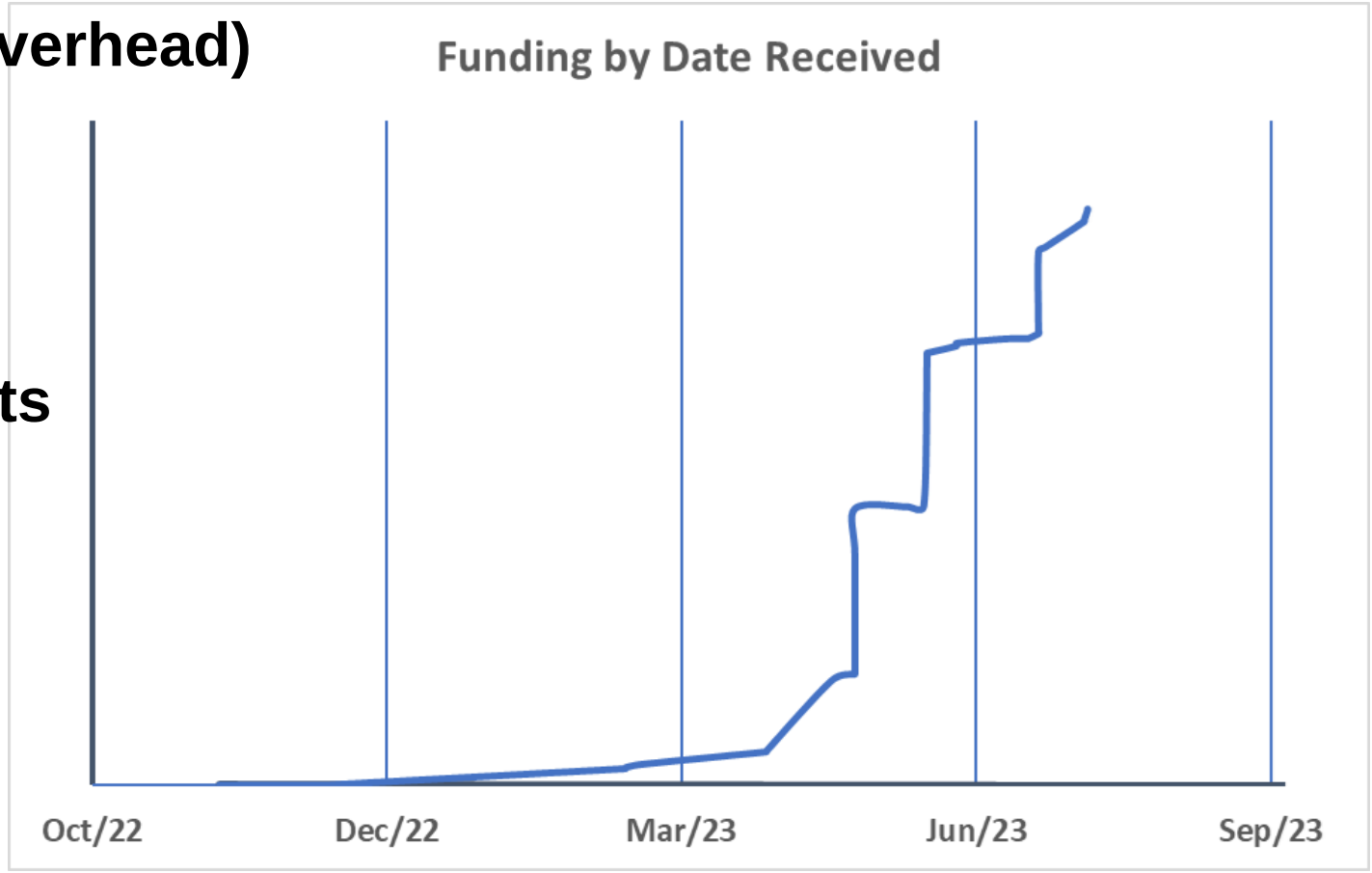
- **Efficiently execute sponsored research programs focused on delivered structural sustainment S&T solutions and products**
- **Provide world-class laboratory support to cadet engineering curriculum**
- **Integrate operationally relevant research into cadet curriculum and faculty development**

Research Task Personnel

- **Government—externally (soft money) funded**
  - **Strategic planning, tactical operations & contracting**
  - **Technical direction of all programs**
  - **Projects sometimes supplemented by faculty/cadets**
- **On-site (USAF Academy) contractors**
  - **Project technical expertise**
  - **Maintain the core competencies**
  - **Technical advice to cadets and faculty**
- **Off-site contractors and locations**
  - **Provide specialized capability that may not yet be economically efficient to have in-house (at USAFA)**
  - **Supplement labor capacity in large scale, CAStLE developed, processes**

Funding

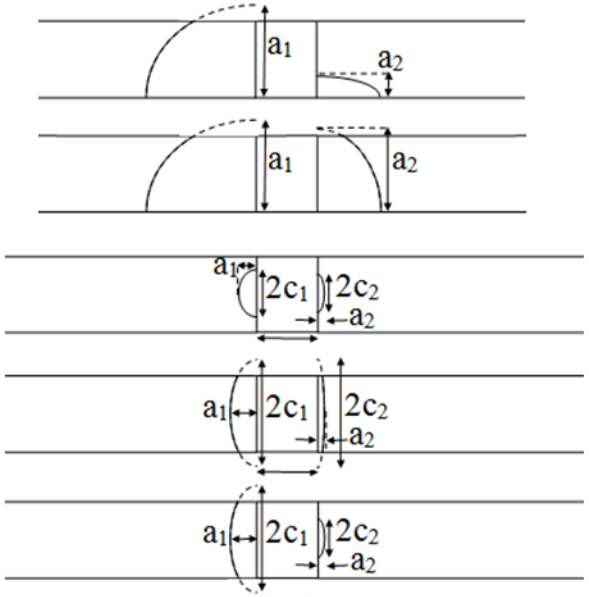
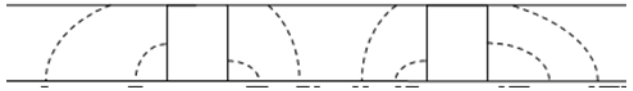
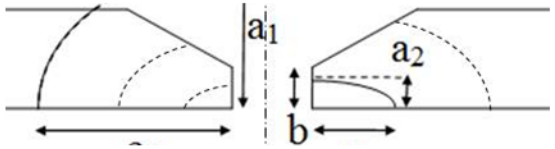
- External Funding
  - Direct Cite
    - Customer support contracts
  - Reimbursable (Institutional overhead)
    - CAStLE Civ Pay
    - Cadet curricular support
    - Travel requirements
    - CAStLE (unfunded) projects
    - Dean's unfunded projects



CAStLE Unfunded Project Example

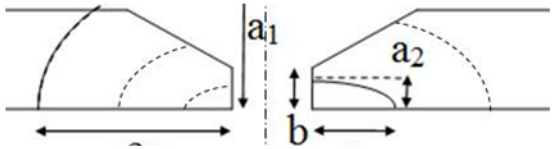
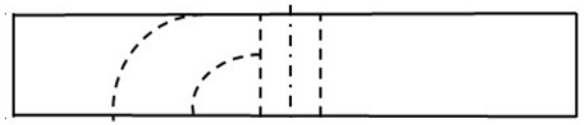
CONTINUED STRESS INSTENSITY FACTOR SOLUTION SUPPORT

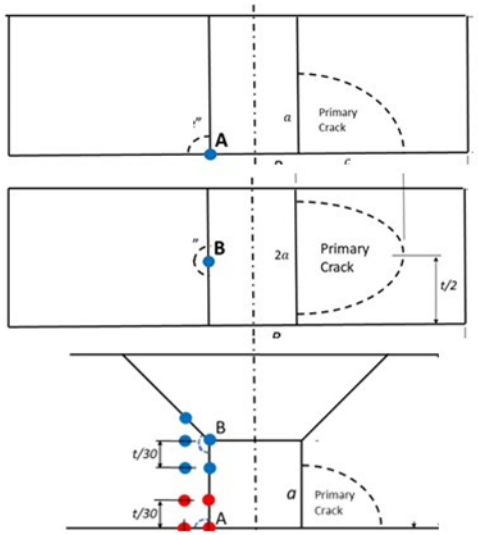
Milestones

	Crack Scenario	Note	$K_I(\phi)$-functions	Year
M1		*W/R*=200	5*M*	2005
M2		*W/R*=200	88M	2014-2017
M3			2000M	2010
M4		*W/R*=2.-40. *H/W*=1.0 *b/t*=0.5	35M	2019

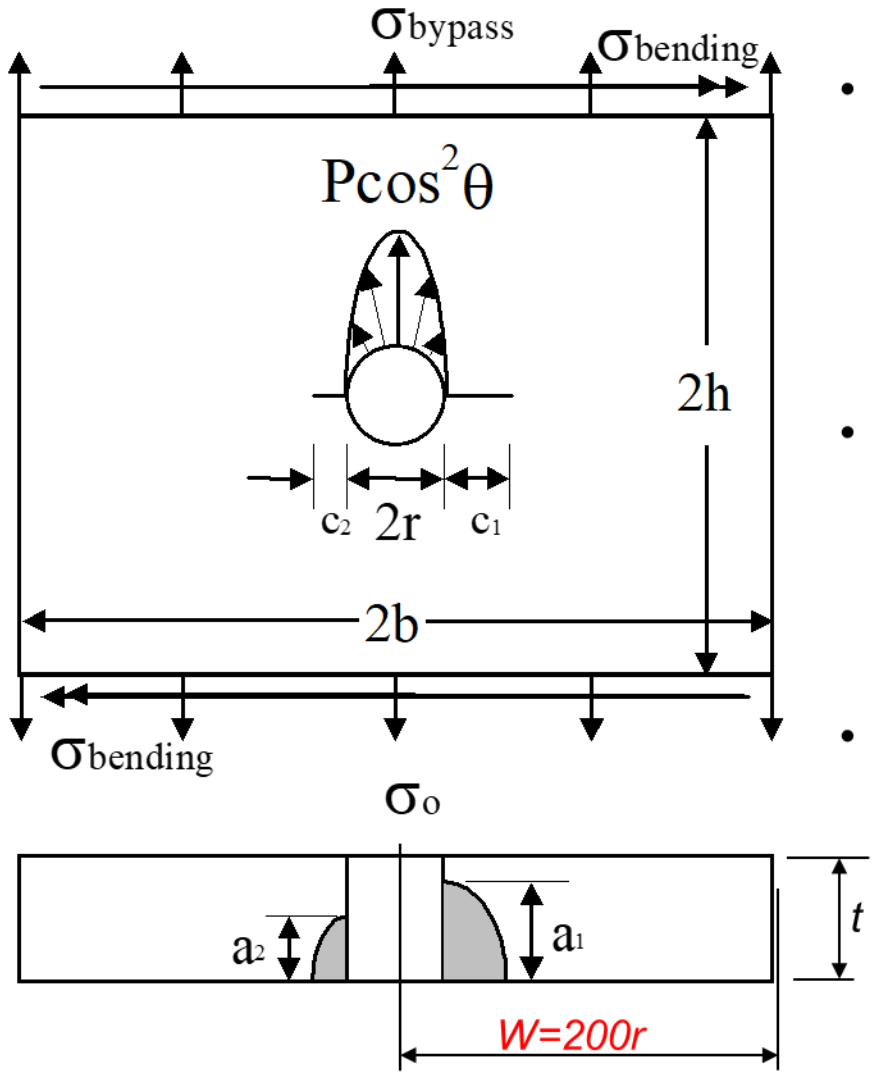
Milestones

USAF Academy Center for Aircraft Structural Life Extension (CAStLE)

	Crack Scenario	Note	$K_I(\phi)$-functions	Year
M5		*W/R*=2.-40. *H/W*=3.0 *b/t*=0.050	130*M*	2023
M6		*W/R*=2.-100. *H/W*=5.0	0.26M	2023

	Location of stress points	Note	Solutions	
M7		*W/R*=10 0. *W/R*=10 0. *W/R*=2.-40. *H/W*=1.0 *b/t*=0.50	18k 18k 32k	2022

Milestone 1: 2002/03 (Fawaz and Anderson), 4.9M solutions



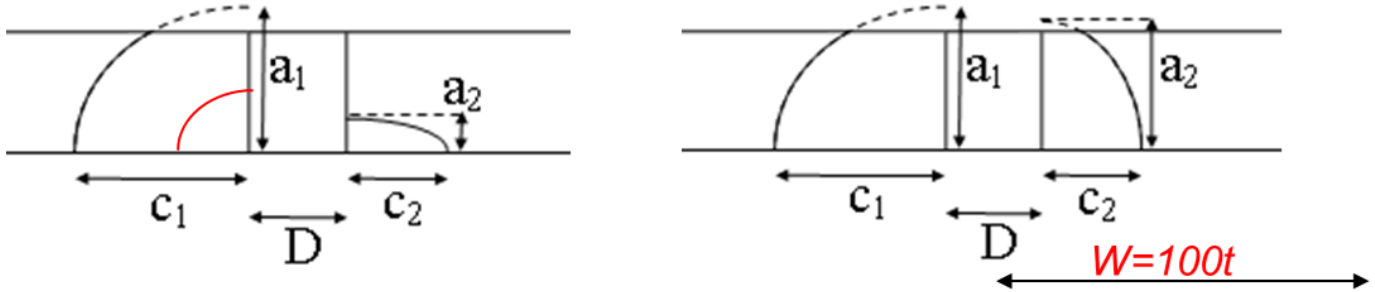
- Geometry
  - Centrally Located Straight Shank Hole
  - $0.1 \le r/t \le 10.0$ — 26 values
    - 0.1, 0.111, 0.125, 0.1428, 0.1667, 0.2, 0.25, 0.333, 0.5, 0.667, 0.75, 0.8, 1.0, 1.25, 1.333, 1.5, 1.667 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0
  - Finite Width/Height Plate
    - r/h = 0.0025
    - r/b = 0.0025
- Crack Shapes
  - $0.1 \le a/c \le 10.0$ — 25 values
    - 0.1, 0.111, 0.125, 0.1428, 0.1667, 0.2, 0.25, 0.333, 0.5, 0.667, 0.75, 0.8, 1.0, 1.25, 1.333, 1.5, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0
  - $0.1 \le a/t \le 0.99$ — 10 values
    - 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, 0.99
- Load Conditions — 3 cases
  - Tension
  - Bending*
  - Pin Loading (Bearing)

$$2x3x26x(25x10)^2 = 9.8\text{M}$$

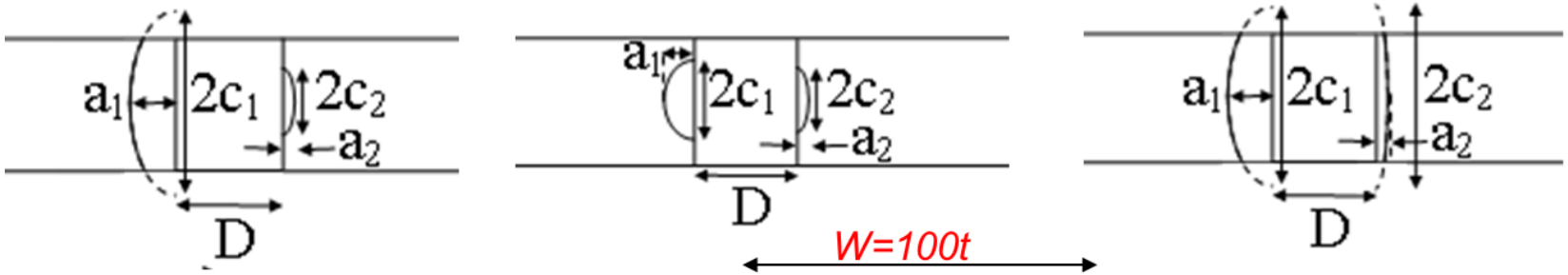
Remark: Solutions are valid for very wide plates. Accurate FW-correction needed.

Milestone 2: 2014/17, 88M solutions

A few solutions were corrected 2021 and the vertex accuracy was improved.



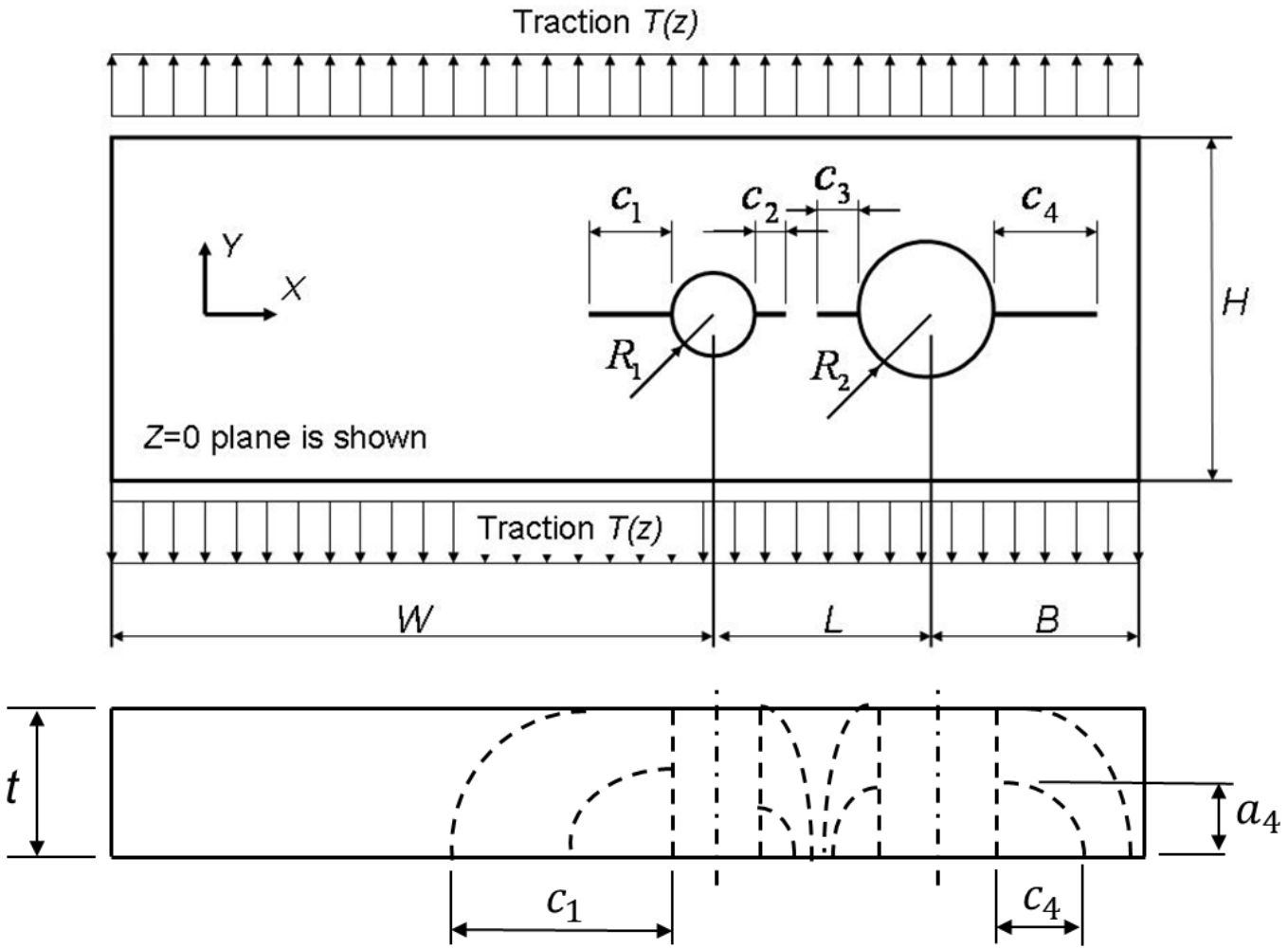
Cracks (through- and not-through-thickness) originating at the faying surface.



Cracks (through- and not-through-thickness) originating at half plate thickness.

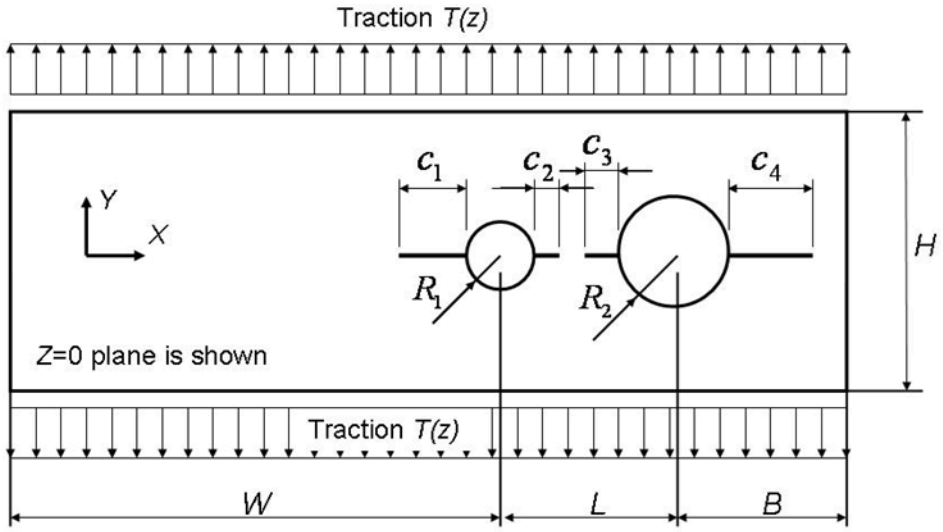
Remark: The not-through-thickness *K*-solutions for cracks originating at the faying surface verify the 2002/2003 years solutions (save for, correcting errors in 2003 years bending solutions for *R/t=7,8,9*).

Milestone 3: 2009/10, 1-4 crack scenarios, 2B solutions



Cracks (through- and not-through-thickness) originating at 1-4 locations at the faying surface.

MS 3 (cont): 2009/10, 1-4 crack scenarios, 2B solutions



Geometries: 384 different global geometries $\frac{R}{t}, L, B, \frac{R_1}{R_2}$.

r/t=0.075, 0.1, 0.2, 0.333, 0.5, 1.0, 2.0, 3.0, where $r = Min\{R_1, R_2\}$,

L=*1D,2D,3D,4D* where *D*= $Max\{2 \cdot R_1, 2 \cdot R_2\}$,

B=$1D_2, 2D_2, 3D_2, 4D_2$ where $D_2 = 2 \cdot R_2$,

$\frac{R_1}{R_2}$ =0.5, 1.0 and 2.0.

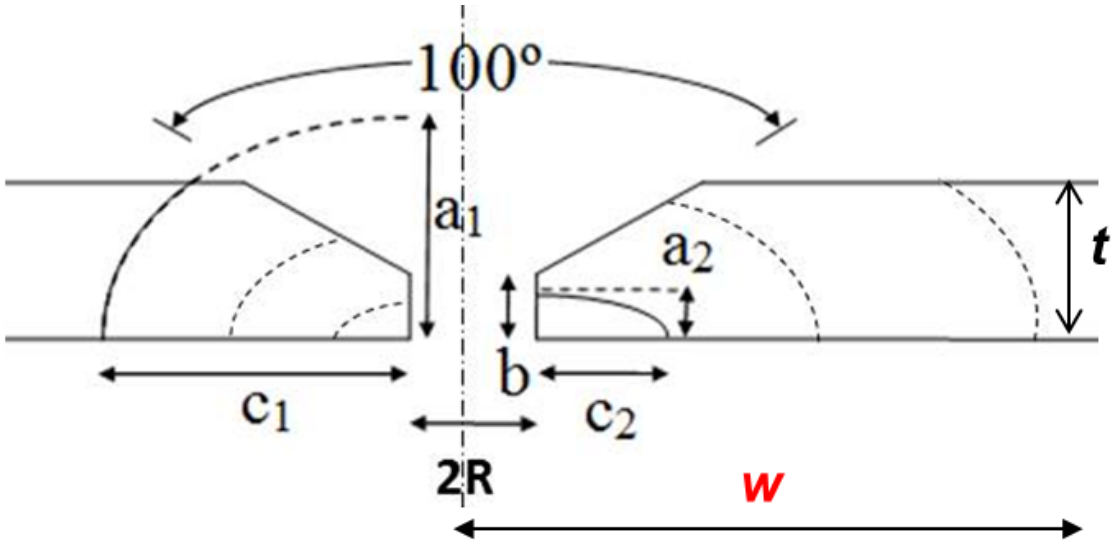
Crack Shapes: $0.1 \leq \frac{a}{c} \leq 10.0, 0.1 \leq \frac{a}{t} \leq 15.0,$

a/c=0.1, 0.111, 0.125, 0.1428, 0.1667, 0.2, 0.25, 0.333, 0.5, 0.667, 0.75, 0.8, 1.0, 1.25, 1.333, 1.5, 1.667, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0.

a/t=0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, 0.99, 1.05, 1.15, 1.25, 1.40, 1.65, 2.0, 2.5, 3.0, 4.0, 6.0, 9.0, 12.0, 15.0.

Load Conditions: Tension (only)

Milestone 4: 2019, First set for variable width W/R (H/W=1), 35M solutions



- Cracks initiating at the faying surface

c/a= 0.10,… 20 values…10.0

a/t= 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 0.975, 1.05, 1.15, 1.25, 1.50, 1.75, 2.00, 2.50, 3.00, 4.00. 5.00. 6.00, 8.00, 10.0, 12.0, 15.0, 20.0. 26 values

R/t= 0.20, 0.333, 0.5, 1.0, 1.5, 2.0, 3.0, 5.0. 8 values

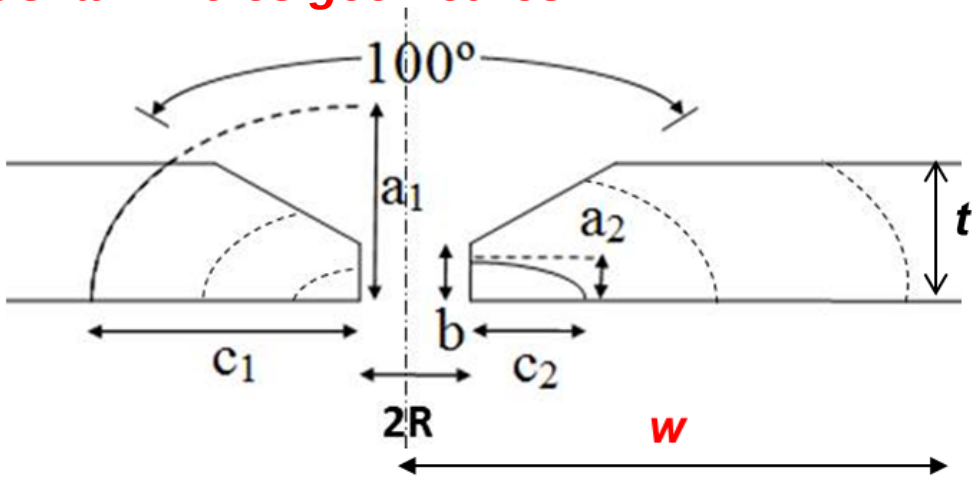
b/t= 0.50 1 value

W/R= 2.4, 2.6, 2.8, 3.2, …100.0 20 values

H/W= 1.0 1 value

Milestone 5: 2022/23, Ongoing Work, 130M solutions

In March 2021 it was decided that data for H/W=3.0 shall be created for countersunk and straight shank holes geometries.



Cracks initiating at the faying surface

Databases contain for *H/W*=3,b/t=0.05

- 0.8 million single crack solutions.
- 400 million double crack solutions.

Relative error in $K_I(\phi)$ is less than 0.05% along the entire crackfronts.

Expanded parameter space for *b/t*=0.05

c/a= 0.10,… 10.0. — 20 values

a/t= 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 0.975, 1.05, 1.15, 1.25, 1.50, 1.75, 2.00, 2.50, 3.00, 4.00. 5.00. 6.00. 8.00. 10.0, 12.0, 15.0, 20.0. — 26 values

R/t= 0.20, 0.25, 0.333, 0.4, 0.5, 0.567, 0.667, 0.8, 1.0, 1.25, 1.50, 1.75, 2.0, 2.5, 3.0, 4.0, 5.0. — 17 values

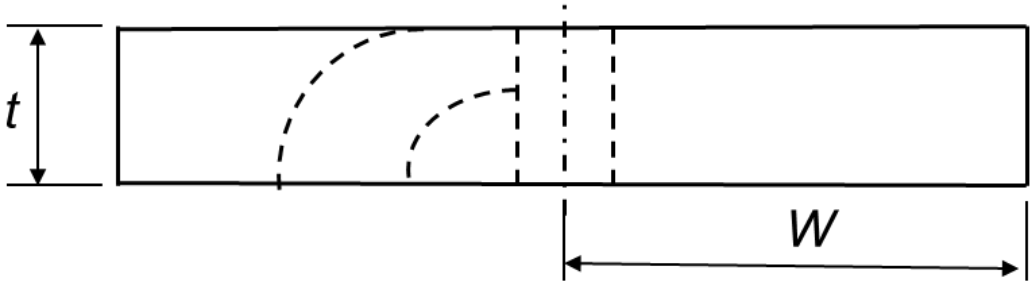
b/t= **0.05** — 1 value

W/R= 1.25, … 400.0 — 30 values

H/W= **3.0** — 1 value

Milestone 6: 2023, 260K solutions

Straight shank hole geometries with single cracks.



Single crack initiating at the faying surface

c/a= 0.10,… 20 values…10.0

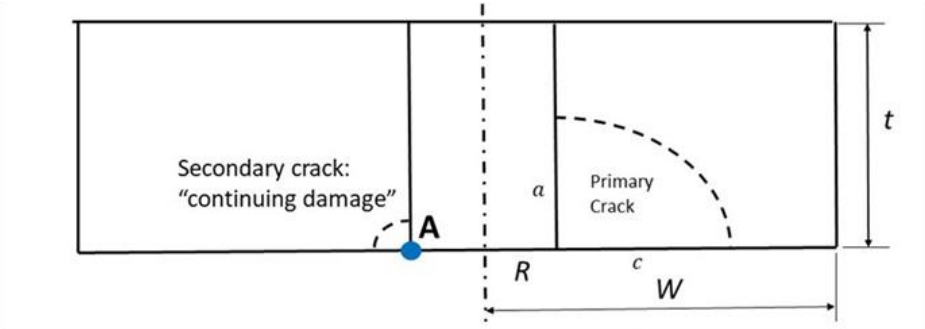
a/t= 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 0.975, 1.05, 1.15, 1.25, 1.50, 1.75, 2.00, 2.50, 3.00, 4.00. 5.00. 6.00, 8.00, 10.0, 12.0, 15.0, 20.0. 26 values

R/t= 0.20, 0.333, 0.5, 1.0, 1.5, 2.0, 3.0, 5.0. 8 values

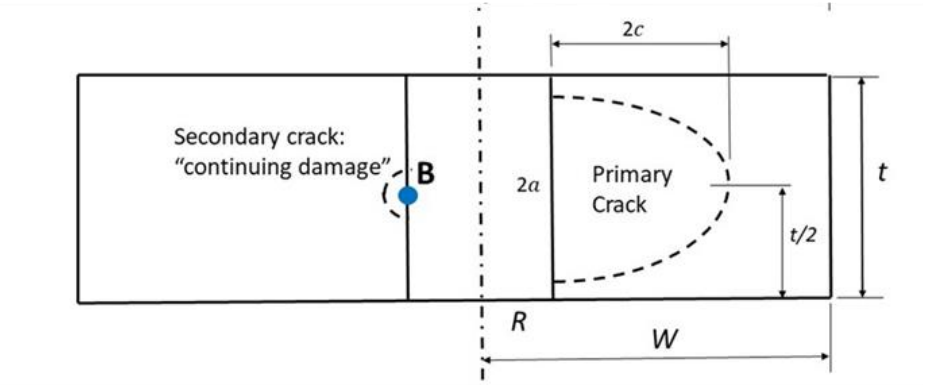
W/R= 2.4, 2.6, 2.8, 3.2, …100.0 20 values

H/W= **3.0** 1 value

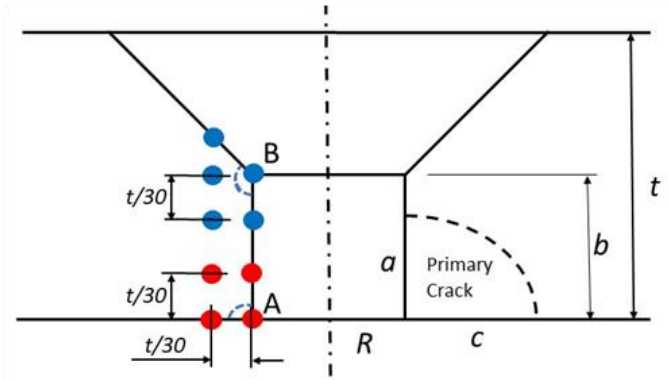
Milestone 7: 2019/20 “Continuing Damage” scenarios



Stress intensity factors are in 2017 years databases available for 25 *c/a* values, 23 *a/t*-values and 31 *R/t* values. *W/R*=100 and *H/W*=1. Totally 17825 analyzes for 3 load cases.

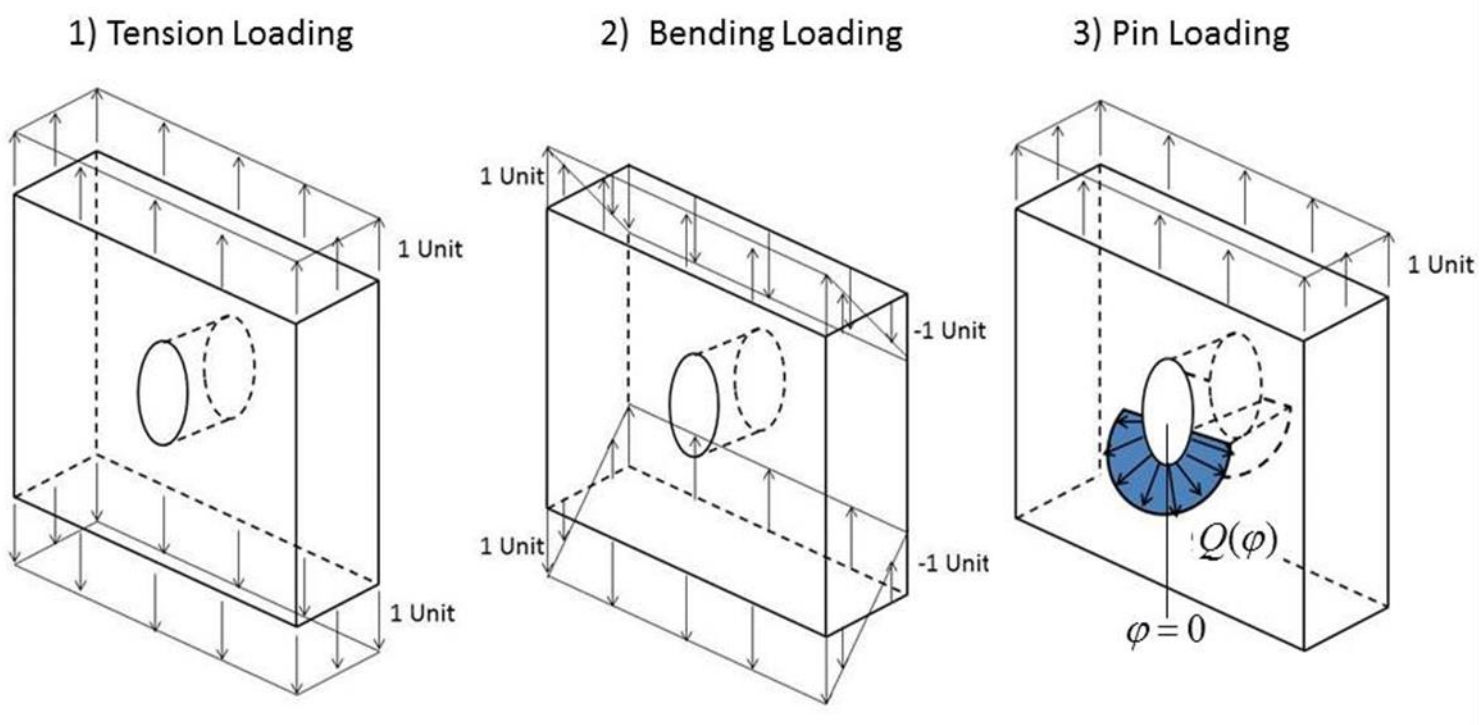


Stress intensity factors are in 2017 years databases available for 25 *c/a* values, 23 *a/t*-values and 31 *R/t* values. *W/R*=100 and *H/W*=1. Totally 17825 analyzes for 2 load cases (plate bending gives zero stress at point B).



Stress intensity factors are in 2019 years databases available for 20 *c/a* values, 10 *a/t*-values, 8 *R/t* values and 20 *W/R*-values. *H/W*=1 and *b/t*=0.50. Totally 32000 analyzes for 3 load cases.

The Three Load Cases



$$Q(\varphi) = \begin{cases} q \cdot \cos^2(\varphi) & \text{for} \quad -\pi/2 \le \varphi \le \pi/2 \\ 0 & \text{for} \quad |\varphi| > \pi/2 \end{cases} \qquad \text{(eq.1)}$$

$$2 \cdot W \cdot t \cdot 1 = q \cdot t \cdot \int_{-\pi/2}^{\pi/2} R \cdot \cos^2(\varphi) \cdot \cos(\varphi) \cdot d\varphi \qquad \text{(eq.2)}$$

Related Research Activities

- **Eliminating round-off errors in thin plates**
- **Developing a conservative pin load model**
- **Accurate calculations of K_I (Φ) arbitrarily close to verticies**

  where K_I (Φ) → ∞ or K_I (Φ) → 0

- **Developing high accuracy finite width correction equations**