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Investigation of plastic zone development in dynamic tear test specimens

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Investigation of Plastic Zone Development in Dynamic Tear Test Specimens

by

T.S. Koko[1], B.K. Gallant[1] and J.R. Matthews[2]

[1] Martec Limited, 400-1888 Brunswick Street, Halifax, NS, Canada, B3J 3J8
[2]Dockyard Laboratory Atlantic, Defence Research Establishment Atlantic, P.O. Box 99000, Stn Forces, Bldg D17, Halifax, N.S., B3K 5X5

Abstract

This paper presents on-going investigations on plastic zone development in dynamic tear (DT) type three-point bend specimens used to measure the fracture toughness of marine structural materials. The purpose of the study is to use finite element technology to provide an understanding of the plastic zone development, to determine the upper limit of temperature relative to full size transition curves where elastic plastic fracture becomes invalid. In earlier studies, the authors utilized 2-D finite element models to compute the ratio of crack tip blunting (stretch zone) to plastic zone size (radius) that is used to determine the elastic-plastic fracture toughness. Those studies established the feasibility, as well as limitations, of 2-D finite element modeling for computing the plastic zone development in DT specimens.

In the present study we present efforts geared towards improving the 2-D modeling, as well as investigations into the use of 3-D models to provide estimates of the shear lip size. The ABAQUS finite element software was used to model the elastic-plastic behavior of the specimens. The DT specimen was made of 350WT steel and the crack was induced by pressing the notch, followed by fatigue cracking at a limit load level of 40% of the specimen limit load. The specimen was loaded until fixed amounts of permanent deformation were recorded. Results were obtained in the form of plots, showing the progression of the plastic zone around the crack tip. For each case, the results provide the following: mid point plastic deflection, stretch zone width, plastic zone radius, and shear lip size. The finite element results obtained and how these compare to the experiments in elastic plastic testing are discussed.

ON PLASTIC ZONE DEVELOPMENT IN DYNAMIC TEAR-TYPE TEST SPECIMENS

BY

T.S. KOKO[1], B.K. GALLANT[1] and J.R. MATTHEWS[2]

[1]MARTEC LIMITED, HALIFAX, NS

[2]DREA, DOCKYARD LAB., P O BOX 99000, HALIFAX, NS

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NAVAL APPLICATIONS OF MATERIALS TECHNOLOGY
HALIFAX, NS, JUNE 7, 2001

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Outline

- BACKGROUND
- PROBLEM DESCRIPTION
- FINITE ELEMENT MODEL
- RESULTS
- SUMMARY AND CONCLUSIONS

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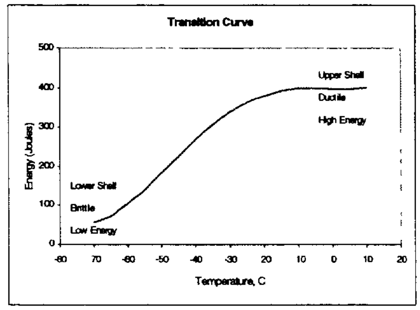
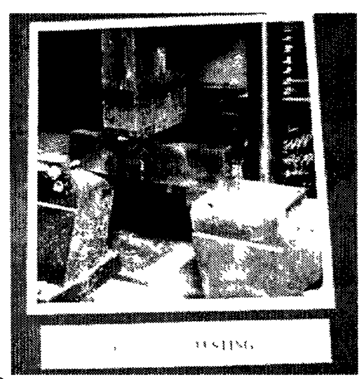
Background

- FRACTURE TESTS
  - Charpy V (C_v)
  - Plain strain fracture, K_{IC}
  - Dynamic tear (DT)
  - Elastic-plastic fracture toughness (J-integral)



Background

- J-INTEGRAL
  - An elastic-plastic fracture criterion that permits measurement of fracture toughness of a specimen that has been fractured after general yielding
  - Assumes that onset of fracture is due to a critical level of stress or strain being reached at or near the crack tip
  - Measured using 3-point bend specimens, such as DT specimens



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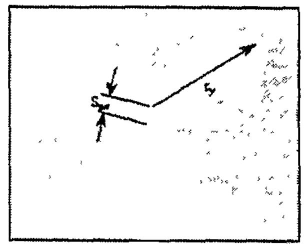
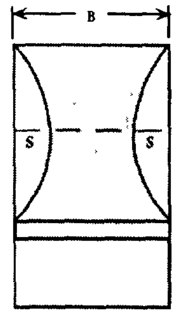
Background

Definitions:

r_y=Plastic zone radius
Szw = stretch zone width
s = shear lip size





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Background

- Definitions:
  - Stretch Zone Width (*SZW*): Distance from crack tip to interface of yield zone with side of crack

    $$Szw = J/(2\sigma_{flow})$$

  - Plastic Zone Radius (*PR*): Maximum extent of plastic zone
  - Ratio: $\beta = r_y / Szw$
  - Shear-lip size: Distance from the yield surface to original surface on side of specimen (s). Assumed to be equal to the critical r_y.

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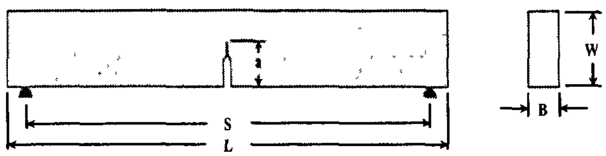
Background

- THEORY FOR UPPER LIMIT OF J-INTEGRAL
  - Standard validity criterion:

$$a, b, B \geq \alpha(J / \sigma_{flow})$$

$\alpha =$ Non-dimensional parameter (25-50)

$\sigma_{flow} =$ Flow stress



Background

Let $\alpha = 50$

Then by standard validity criterion:

$$B \geq 100 * S_{ZW}$$

or $$B \geq 100(r_y / \beta)$$

or $$B \geq 100 s / \beta$$

- Focus of study is to identify the ratio $\beta = r_y / S_{ZW}$
  - » Finite Element Method

Objectives

- Investigate The Plastic Zone Development in DT Test Specimens
  - To provide an understanding of the ratio of the plastic zone size (radius) to crack tip blunting (stretch zone)
  - To determine the upper limit where elastic plastic fracture becomes invalid

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Objectives

- Scope of this presentation
  - Influence of material models
  - Specimen geometry
  - Influence of mesh configuration
  - 3-D modeling

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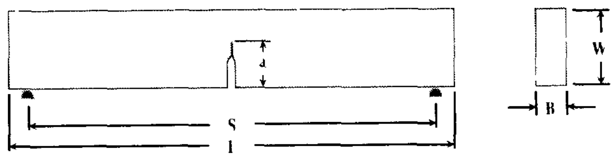
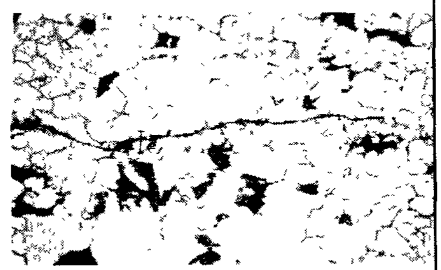
Problem Description

Specimen geometry





Crack tip shape

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Problem Description

Dimensions	Specimen		
	Standard DT	Non-Standard	DT with 1" x 2" Bar
Beam Length, L (mm)	181 00	125 00	225 00
Beam Span, S (mm)	164 00	100 00	200 00
Crack Length, a (mm)	14 00*	12 50**	14 00*
Beam Width, W (mm)	41 00	25 00	50 00
Beam Thickness, B (mm)	8 00	12 50	25 00

- Standard DT and non-standard specimens under quasi-static loading
- 350WT and 304 stainless steel materials
- Crack tip shape is that of a fatigue crack, followed by a blunted fatigue crack
- Require plastic zone development using FE analysis

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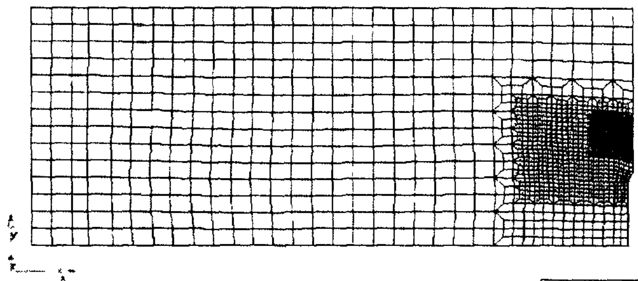
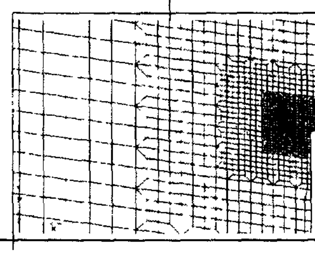
Finite Element Model



Typical FE Mesh for half of beam



Detailed mesh the around crack tip

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Finite Element Model

- Highlights of FE Model:
  - Assumes symmetry
  - Geometry of crack carefully modeled
  - Mesh consists of 4000 quad elements (2-D model)
  - Smallest element size approx. 0.1×10^{-3} mm near crack tip
  - ABAQUS FE code utilized
  - Large displacement, large strain, elastic-plastic formulations
  - Load applied as displacement at center of beam
  - Incremental analysis procedure (> 5000 increments typical)

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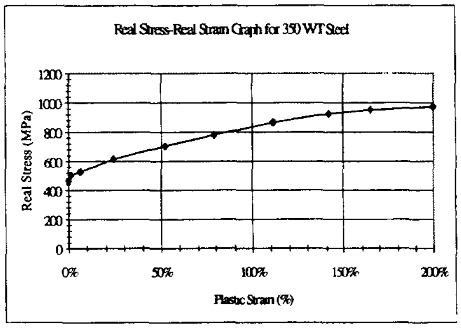
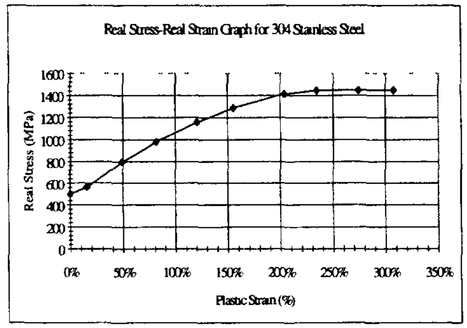
Finite Element Model

- Material Models for 350WT and 304SS





Constitutive Relations are input
as Cauchy stress-logarithmic strain
pairs in ABAQUS program

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Results

- Response Parameters
  - Mid-span deflection
  - Development of plastic zone
  - Plastic zone radius (r_y)
  - Stretch zone width (S_{ZW})
  - Ratio of r_y/S_{ZW}

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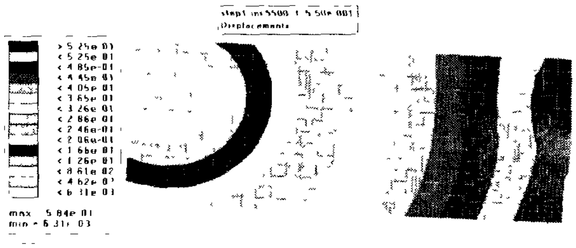
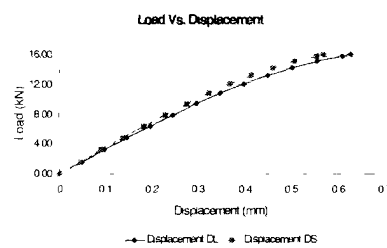
Deformation Response



Displacement contours



Load-Displacement Response

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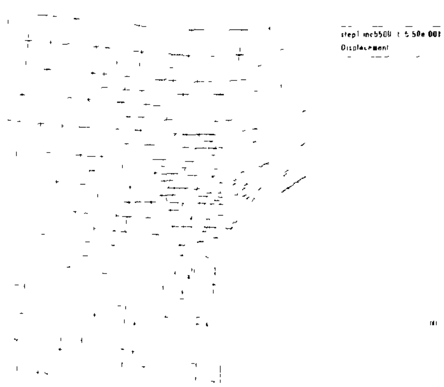
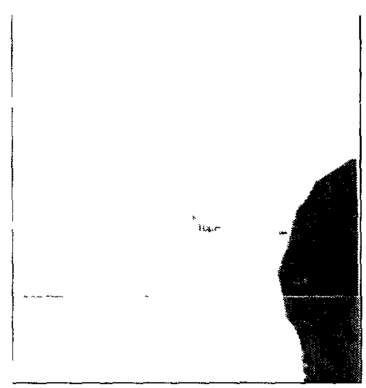
Deformation Response

Deformation Around Crack Tip:





FE Analysis

Experimental

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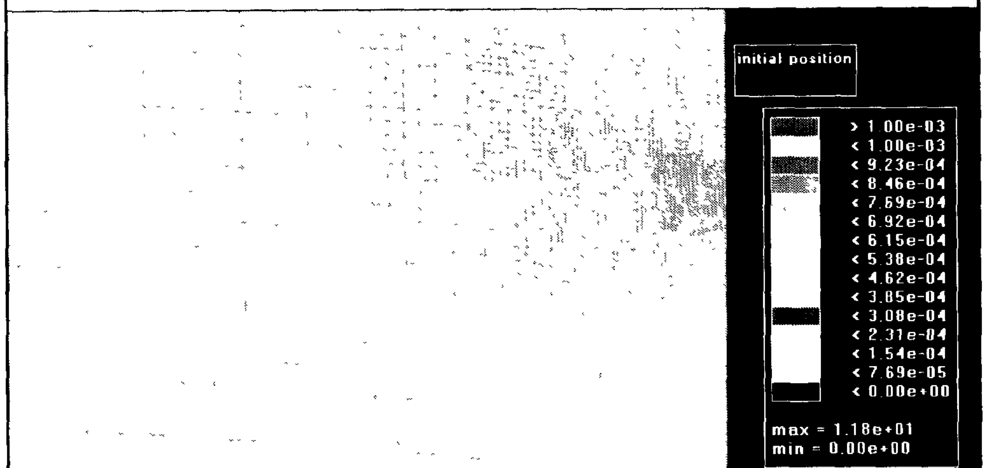
Plastic Zone Development



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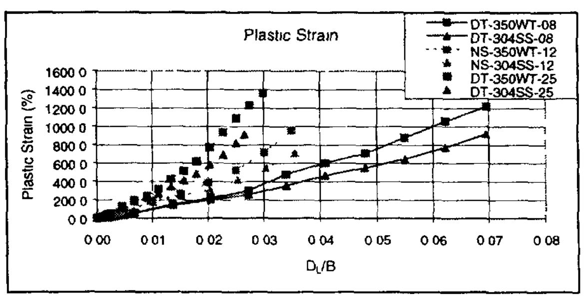
Plastic Strain



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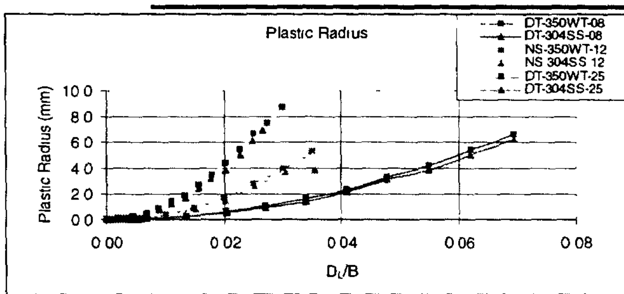
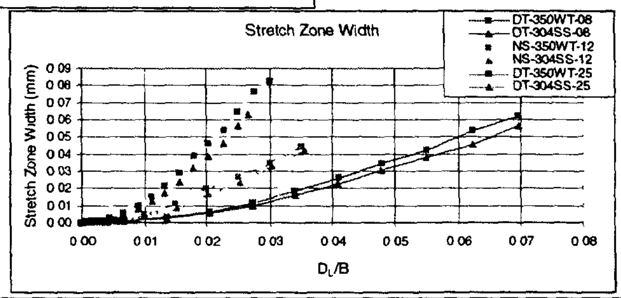
Plastic Zone Radius/SZW



Variation of Plastic Radius with Load



Variation of Stretch Zone Width with Load

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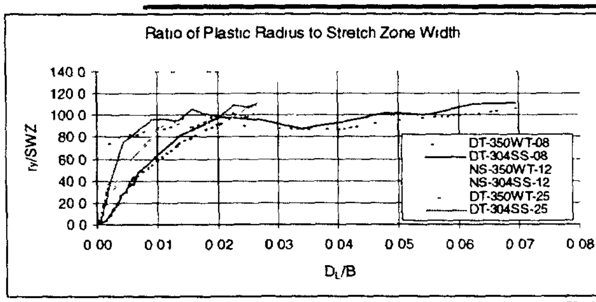
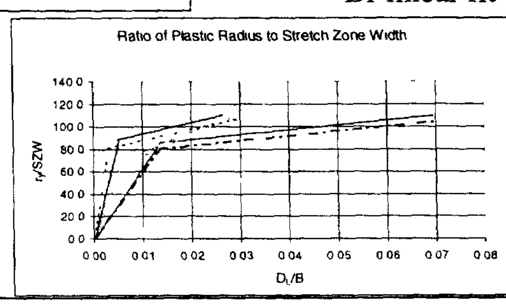
Plastic Zone Radius/SZW



Raw results

Bi-linear fit



Ratio of Plastic Radius (PR) to Stretch Zone Width (SZW)

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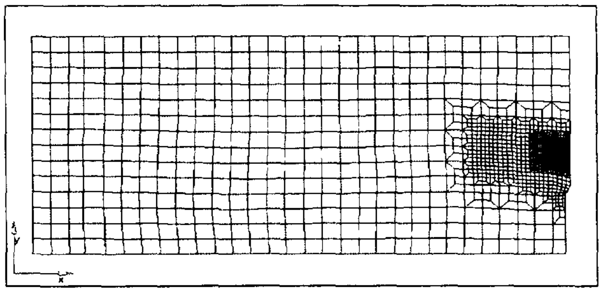
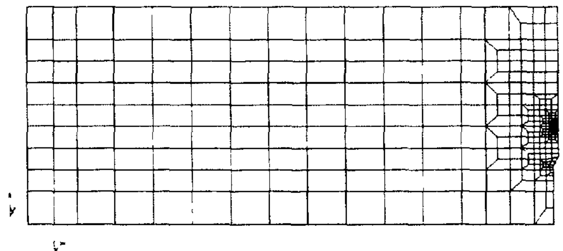
Influence of Mesh Configuration



Refined Model



Coarse Model

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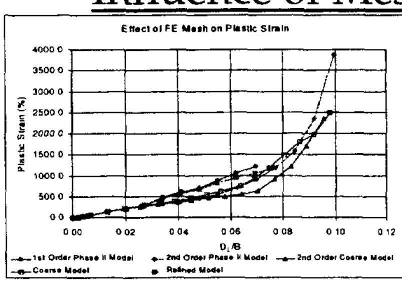
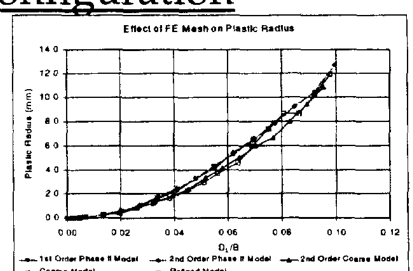
Influence of Mesh Configuration



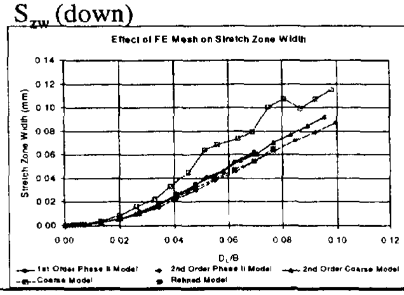


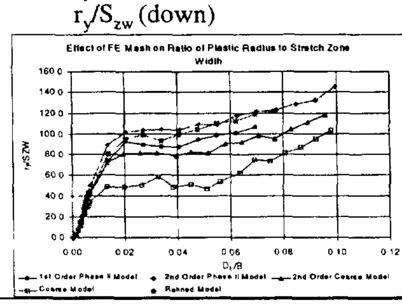
Plastic strain (up)

S_{zw} (down)

r_y (up)

r_y/S_{zw} (down)





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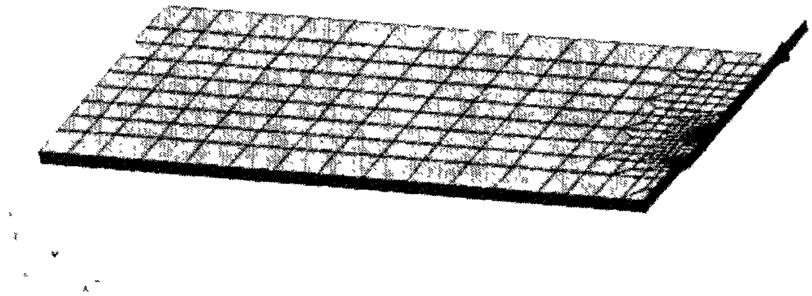
3-D Modeling



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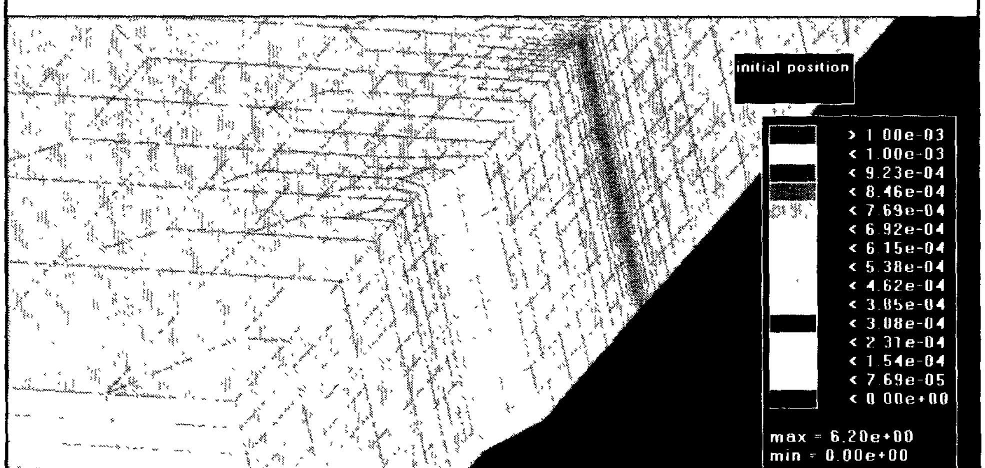
3-D Modeling



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Summary & Conclusions

- Presented FE analysis of development of plastic zone in DT test specimens (350WT and 304 SS materials)
- Maximum plastic strain, plastic zone radius (r_y) and S_{ZW} increase parabolically with load
- Maximum plastic strain, r_y and S_{ZW} increase with specimen thickness (for given D_L/B)
- Ratio r_y/SZW increases with plasticity and exhibit bilinear behaviour

Summary & Conclusions

- Ratio r_y/SZW
  - increases with plasticity and exhibit bilinear behaviour
  - is affected by mesh configuration

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