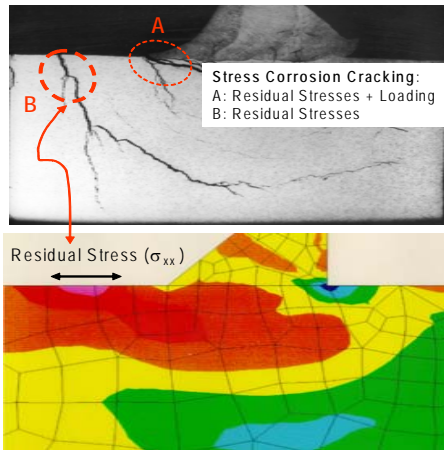


*A Battelle Training Course on*

# **Residual Stresses and Distortions in Welded Structures: Modeling, Analysis, and Mitigation**

Jan. 22nd – Jan 23rd, 2007  
Battelle, Columbus, OH



Example: Root Cause Analysis for a Real-World Stress Corrosion Cracking

## About the Course

This unique course is designed to:

- provide a critical assessment of the current “state of art” residual modeling, analysis, and measurement techniques
- demonstrate effective modeling and analysis procedures for various industrial applications
- identify critical controlling parameters governing residual stress and distortion developments in typical engineering structures
- train participants to define and solve day to day residual stress and distortion problems, e.g., how to effectively:
  - obtain reasonable solutions using existing commercially available analysis techniques
  - mitigate residual stresses
  - control welding-induced distortions
  - incorporate residual stresses in fracture and fatigue assessment procedures

A bound volume of all course notes will be provided to all registered participants.

## Course Instructor

The course will be taught by Dr. Pingsha Dong, who has published over 180 peer-reviewed papers in archive journals and major conference proceedings. He has lectured internationally as a keynote speaker on fatigue/fracture of welded structures and advanced process computational modeling techniques for welding/joining processes. He has received numerous prestigious awards/recognitions, including *R&D Magazine*’s 100 Award (2006), *TIME Magazine*’s Math Innovator (2005), *Aviation Week and Space Technology*’s Aerospace Laurels Award (2004), AWS’s R.D. Thomas (2004) and Dr. R. Wasserman Awards (1998), SAE’s Henry Ford II Distinguished Award for Excellence in Automotive Engineering (2003), ASME G.E.O Widener Literature Award (2002).

## Course Content

**Mon, Jan. 22 8am – 5pm**

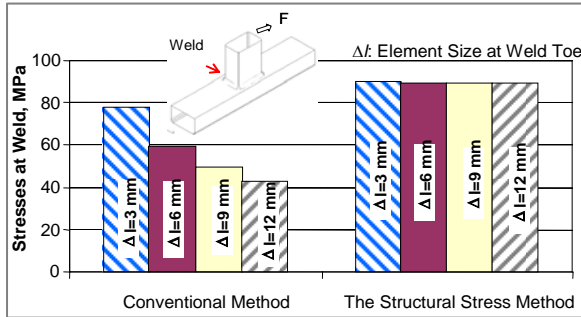
- The importance of understanding welding-induced residual stresses and distortion:
  - Weldability
  - Structural manufacturability
  - Structural integrity
- Residual stress/distortion development mechanisms
  - Necessary and sufficient conditions
    - Thermal stress
    - Simple thermo-plasticity descriptions for welding processes
  - A graphic solution technique for a simple 1D, but important residual stress problem
  - Limitations of existing commercial FEA packages
- Modeling requirements and procedures
  - Time and length scale considerations
  - What needs to be modeled?
  - What can be modeled today?
  - How to validate modeling results?
  - Proven effective modeling procedures for engineering applications
  - Welding heat flow analysis procedure
    - 2D versus 3D simulation
    - The most common mistake in 2D analysis
    - The challenges in 3D analysis and simple solutions
  - High temperature material behavior
    - Proper constitutive model descriptions
    - What need to be considered?
    - What can be ignored?
  - Modeling requirements for welding-induced distortions
    - Differences and similarities comparing with residual stress analysis
    - Stable distortions
    - Unstable or buckling distortions

- Some proven modeling procedures
    - Numerical implementation and validations
    - How to deal with deficiencies in FEA packages
  - Residual stresses in weld repairs
  - Residual stress measurements
    - Available techniques
    - Assumptions and limitations
    - Why measurements can be wrong!
    - How to interpret measurement results
    - How to devise an effective measurement plan
    - Examples on residual stress measurements
  - Residual stresses from typical welding processes
    - Conventional fusion welding processes
    - High energy beam processes (EB, Laser, etc)
    - Solid state processes, e.g., RSW, brazing, friction/inertia welding, friction stir welding, etc
- Tues, Jan. 23 8am – noon**
- Principles for mitigating residual stresses and distortions
    - In-process techniques, e.g., thermal and/or mechanical conditioning techniques, weld sequencing planning, fixturing, etc.
    - Post-process techniques, e.g., thermal and/or mechanical based stress improvement techniques (e.g., local peening, rolling, ...) and conventional stress relief treatment (PWHT, Local PWHT, mechanical over loading)
  - Some well-documented real-world examples on residual stresses and distortions, and mitigation techniques
    - Aerospace and automotive
    - Petrochemical/power generation
    - Heavy equipment and offshore/marine structures
  - Fracture mechanics treatment of residual stresses for fracture and fatigue assessment
    - Load- versus displacement-controlled conditions
    - The problem with J-integral calculation
    - Residual stress decomposition technique
    - Through-thickness residual stress characterization
    - A generalized parametric description
    - K solution techniques: brute force methods, an engineering estimation scheme using Battelle’s mesh-insensitive structural stress method
    - Residual stress induced tri-axiality
    - Fitness for service assessment using the master S-N curve method
    - An effective fatigue assessment procedure incorporating residual stresses
    - Some application examples: residual stress and PWHT induced creep damage; stress corrosion cracking evaluation; novel stress improvement techniques
  - Summary

*A Battelle SS JIP Training Course on*

# *The Mesh-Insensitive Structural Stress Method for Fatigue Evaluation of Welded Structures*

*Jan. 23rd – Jan 24th, 2007  
Battelle, Columbus, OH*



## Battelle Structural Stress JIP\*

A Battelle Joint Industry Project (JIP) was launched in 2001 to further refine and validate Battelle's mesh-insensitive structural stress method (its commercial version is also referred to as the Verity™ method) for various industrial applications. Since then, the structural stress method has not only been proven mesh-insensitive and robust, but also demonstrated its effectiveness in collapsing thousands of well-documented fatigue tests in the literature into a single narrow band, referred to as the master S-N curve. To further expand its use for a broad range of industrial applications and facilitate adoptions by national and international Codes and Standards organizations, The Phase II of the JIP (JIP II) is currently on-going. In conjunction with JIP II, an entry-level training course on the Battelle structural stress methodology will be offered a few times a year for both JIP II sponsors (free of charge for up to five representatives per sponsor) and non-JIP participants.

## About the Course

This course will provide a unique opportunity for attendees to learn the details of the mesh-insensitive structural stress method for fatigue evaluation of welded structures, from its mechanics basis, numerical implementation to S-N data correlations and

life predictions. Through this training course, participants will become familiar with some of the most important issues associated with fatigue of welded joints and existing design and analysis methods. Participants, with hands-on experiences gained during the training course, should be able to:

- Solve basic fatigue design problems
- Effectively interpret fatigue test data
- Perform computer-based fatigue life estimations for small-scale fatigue problems

A demo version of an automated structural stress post-processor and a bound volume of all course notes will be provided to all registered participants. It is desirable to have a laptop for effective participation in the hands-on exercises.

## Course Instructor

The course will be taught by Dr. P. Dong, the lead developer of the mesh-insensitive structural stress method. He has published over 180 peer-reviewed papers in archive journals and major conference proceedings and lectured internationally as a keynote speaker on fatigue/fracture of welded structures and advanced computational modeling techniques for welding/joining processes. Dr. Dong has received numerous prestigious awards/recognitions, including *R&D Magazine's* 100 Award (2006), *TIME Magazine's* Math Innovator (2005), *Aviation Week and Space Technology's* Aerospace Laurels Award (2004), AWS's R.D. Thomas (2004) and Dr. R. Wasserman Awards (1998), SAE's Henry Ford II Distinguished Award for Excellence in Automotive Engineering (2003), ASME G.E.O Widener Literature Award (2002).

## Course Content

**Tues, Jan. 23, 2007, 1pm-5pm:**

### 1. Fundamental aspects of weld fatigue

- Some relevant terminologies and definitions
- Unique fatigue features associated with welded joints
  - Material heterogeneity
  - Residual stresses
  - Geometric discontinuities
  - Distinct fatigue modes
- Conventional fatigue evaluation procedures
  - Key assumptions
  - Stress definitions and calculation procedures
  - Code-recommended S-N curves and assumptions
  - Unresolved critical issues

### 2. The Structural Stress (SS) Method – Part I

- Requirements for an effective fatigue parameter
- The structural stress definition
  - Mechanics basis
  - Numerical implementation
- Simple calculation procedures

- Shell/plate models
- 2D and axisymmetric solid models
- Edge details
- SS measurement techniques and validations
- Comparison with other stress definitions
  - ASME linearization method
  - Hot spot stress method, etc.
- Demo: spreadsheet-based SS calculations on pre-prepared examples

**Weds, Jan. 24 2007, 8am-5pm**

### 3. The Structural Stress Method – Part II

- Needs for a generalized SS procedure
- SS procedure for arbitrarily curved weld in space
- Formulation and numerical implementation
- Mesh-insensitivity validations
- Treatment of multi-axial stress state
- Structural stress post-processor
  - Input requirements
  - Calculation examples
  - Weld representation considerations
- Demo of SS Post-Processors
- Hands-on session by course participants with pre-prepared examples run on their laptop

### 4. The Master S-N Curve Approach

- How to consider thickness and load mode effects?
  - Fracture mechanics consideration
  - SS-based K solution techniques
  - Two-stage crack growth model and validations
- Formulation of the master S-N curve
- Validations using a large amount of S-N data
- Implications on fatigue testing and data interpretation
  - Failure definitions
  - Load-controlled versus displacement-controlled
  - Why lots of test data are useless?

### 5. SS Modeling and Fatigue Prediction Procedures

- How to use the master S-N curve
- Structural stress calculations – do's and don'ts
- Weld representation and weld line definitions
- Other weld types, e.g., spot welds, friction stir welds, etc
- Life prediction examples
- Fatigue-resistant joint design examples
- Demo of Verity™ in fe-safe™

### 6. Additional Applications

- Multi-axial and non-proportional loading
- Low cycle fatigue
- Thermal loading and residual stresses
- Solder fatigue in electronic packaging

### 7. Summary

\* For information on Battelle's Structural Stress JIP, please contact Dr. P. Dong at [dongp@battelle.org](mailto:dongp@battelle.org) or call at 614 424 4908

## Registration Form for Battelle Training Courses Battelle, Columbus, OH

1. Residual Stresses and Distortions in Welded Structures: *Modeling, Analysis, and Mitigation*, January 22-23, 2007
2. The Mesh-Insensitive Structural Stress Method for Fatigue Evaluation of Welded Structures, January 23-24, 2007

*Please remit via fax or mail to:*

Attendee's Name: \_\_\_\_\_

Attendee's Title: \_\_\_\_\_

Company Name: \_\_\_\_\_ Citizenship: \_\_\_\_\_

Street Address/P.O. Box \_\_\_\_\_ City: \_\_\_\_\_ State: \_\_\_\_\_

Zip/Postal Code: \_\_\_\_\_ Country: \_\_\_\_\_ Office Phone: \_\_\_\_\_

Office Fax: \_\_\_\_\_ E-mail address: \_\_\_\_\_

*Ms. Bonnie Bailey  
Battelle, 505 King Avenue  
Columbus, OH 43201-2693  
Phone: 614-424-4388  
Fax: 614-458-4388  
Email: Baileyb@battelle.org*

*Make Checks payable to:* Battelle Memorial Institute

<b>Course Selection</b> (Please mark those as appropriate)	<b>Registration Fee (USD) *</b>			
	<b>Prior to January 5, 2007</b>		<b>After January 5, 2007</b>	
	<b>On-Going Battelle Structural Stress JIP Participant?</b>			
	Yes	No	Yes	No
<b>Course 1 only</b>	\$1,000	\$1,500	\$1,500	\$2,000
<b>Course 2 only</b>	Free	\$1,500	Free	\$2,000
<b>Registration for Both</b>	\$1,000	<b>\$2,500</b>	\$1,500	<b>\$3,300</b>
<b>TOTAL</b>				

Amount: \_\_\_\_\_ (US Currency)

Charge by Credit Card: Charge to:     VISA     MasterCard     American Express

Account Number \_\_\_\_\_

Exp. Date \_\_\_\_\_

\_\_\_\_\_  
Signature

\_\_\_\_\_  
Date

**LOCAL AREA HOTELS**

**ADDRESS**

**SERVICES**

**PARKING**

**Blackwell Inn**

**2110 Tuttle Park Place  
Columbus, OH  
(614) 247-4000**

**24 Hour  
rm serv.  
Restaurant**

**\$10 per day  
Shuttle to Battelle/arpt**

**University Plaza**

**3110 Olentangy River Rd  
Columbus, OH  
(614) 267-7461**

**Breakfast Incl.  
Use of Spa**

**Free parking, shuttle to Battelle**

\* 100% of the course fee will be charged for cancellations received after January 5, 2007. Battelle reserves the right to limit admission