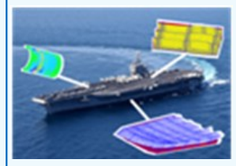
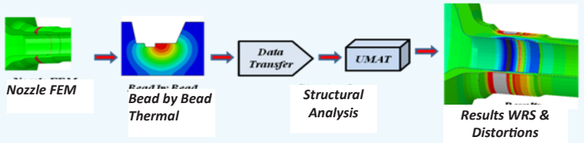
Reliability of Fabricated Structures

Fabrication (including welding) residual stress can be a key contributor to weld cracking in both construction and service. Emc^2 has developed proprietary computer codes to accurately simulate residual stress build-up in construction and repair welds. These have been applied to nozzles in pressure vessels, girth welds, and repair welds. Distortion control is also predicted to optimize construction procedures for large welded structures, which allows for more economic production in heavy construction equipment, ships, offshore platforms and rigs, and other large equipment.



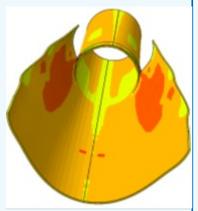
Ship distortion control

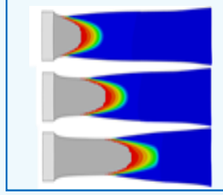
We are specialists in a new discipline now referred to as Residual Stress Engineering. Our VFT® (Virtual Fabrication Technology) software is now tied to the open source code WARP3D and is available on a cloud system.

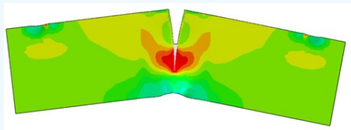


3D Cohesive Zone Model

3D cohesive-zone modeling (CZM) technique is employed to simulate quasi-static and dynamic ductile crack growth in pipes and lab specimens.

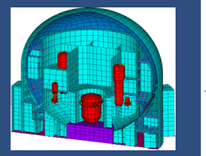


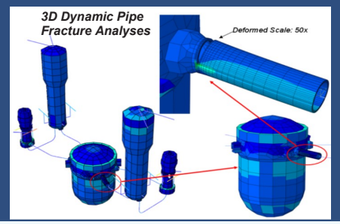




3D Dynamic Pipe Fracture Analyses

In the nuclear industry, there are regulatory requirements for assessing plant piping subjected to loads from seismic or other dynamic events. We have pioneered the development and validation of a special cracked-pipe element to determine crack initiation and amount of crack growth that can be expected for plant piping subjected to seismic and/or water- hammer loads.



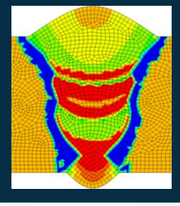


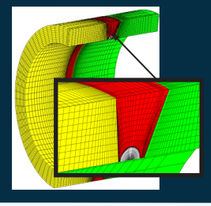
general COMPUTATIONAL Capabilities

- Stress analysis – detailed finite element analyses (static and dynamic)
- Computational fracture mechanics
  - ◊ Fracture parameter calculations and development of estimation schemes
  - ◊ Natural crack growth using Advanced Finite Element Analysis
  - ◊ Crack propagation simulation using damage mechanics models (e.g., Gurson, Cohesive-Zone Models)
  - ◊ 3D dynamic pipe fracture analyses
  - ◊ XFEM
- Computational weld modeling – VFT® software
  - ◊ Reliability of welded structures
  - ◊ Distortion control
  - ◊ Microstructure control
- Probabilistic and reliability analyses
  - ◊ Probabilistic load modeling
  - ◊ Damage tolerance analysis
  - ◊ Structural integrity of composite structures
  - ◊ Probabilistic mechanics analyses of nuclear piping systems
- LBB Analyses for Nuclear Power Plants
- Viscoelastic and viscoplastic modeling of polymers
- Thermoplastic process modeling

SPECIAL SOFTWARE DEVELOPMENT

- ***VFT®***– weld modeling software for weld residual stress and distortion control now tied to open source code WARP3D and available on a cloud system
- ***ALT3D*** – determines crack-driving force for arbitrary crack in any 3D geometry using only the initial uncracked component stress analysis
- ***PipeFracCAE©***– special purpose FE mesh generator and automated GUI to calculate arbitrarily-shaped stress-corrosion crack growth
- ***Emc2PDFA©***– Software for ductile fracture propagation/ arrest predictions

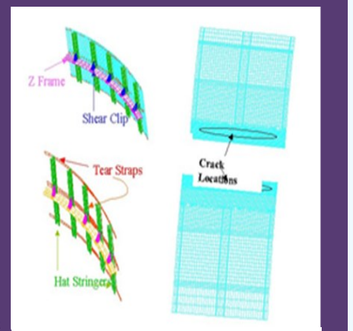




Probabilistic Fracture Mechanics

Emc^2 staff have developed and applied probabilistic methods for risk quantification for over a quarter of a century. We developed the methodology for probabilistic load modeling of the space shuttle main engines, radionuclide transport during severe accidents, and structural risk assessment of the vehicle to return Martian soil to earth. Emc^2 staff, under contract to NASA, performed the first probabilistic damage tolerant analysis of a commercial aircraft. Based on the successful conclusion of this program the FAA funded efforts to develop a probabilistic damage tolerant code for commercial aircraft, TRACLIFE. Additionally, Emc^2 staff have led programs on:

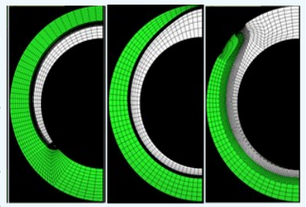
- Risk characterization of Large Performance Assessment for Radioactive Waste Management.
- The French Radioactive Waste program (for ANDRA)
- Yucca Mountain Project - the risk approach
- Development and application of adaptive importance sampling - Emc^2 developed code PROMETHEUS
- Development of the probabilistic analysis computer code for US-NRC xLPR program

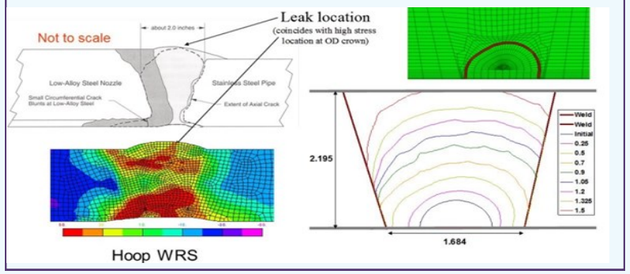


Probabilistic Damage Tolerant Analysis based on full 3D model

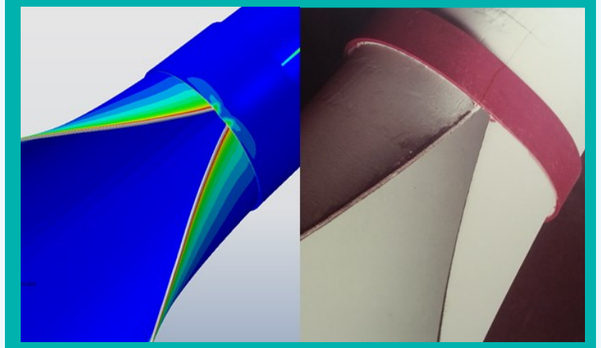
AFEA: Natural Crack Growth Modeling

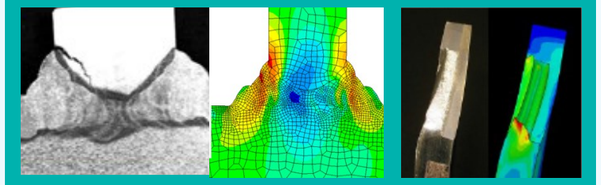
Advanced Finite Element Analysis (AFEA) is used to simulate 'natural' crack growth using PipeFracCAE© which incorporates an automated FE mesh generator developed by Emc^2 and can be used as direct input for the commercial FE code ABAQUS. This method has been used where subcritical crack growth is sensitive to weld residual stresses as well as other normal operating stresses, including thermal loads. AFEA has been extended to axial crack





"We provide materials, structural integrity, and reliability solutions through innovative engineering"





MISSION

Engineering Mechanics Corporation of Columbus (Emc^2) is an employee owned engineering research and development consulting company focused on materials, structural integrity and reliability of complex systems. We provide high quality engineering services and products that are innovative and responsive to our clients' schedule and budgetary requirements. Emc^2 nurtures creativity, continually invests in staff development and new technologies, and collaborates with our clients to assemble the best combination of experts to solve critical problems for the commercial and governmental communities we serve.

Since our founding in the last century, Emc^2 has always taken pride in our leadership role on various Codes and Standards setting committees. We remain committed to our mission to provide experimental, computational, reliability and analytical solutions to client needs while also supporting societal goals of insuring safe operations of systems of all sizes and complexity.

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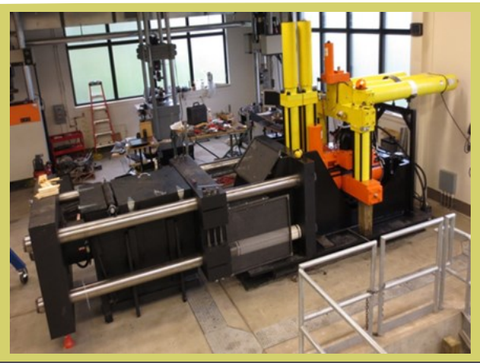


BEAST

DROP-WEIGHT-TEAR TESTS OF THICK SPECIMEN

BEAST is a one-of-a-kind, Emc^2 designed, 4-post/450 kip pneumatic assisted servo-hydraulic test machine with impact speeds up to 35fps (for quasi-static and seismic rates). The maximum stored energy in the gas accumulators is 2,500,000 ft-lb and is capable of testing DWTT specimen up to 3 inch thick and under 8' length.

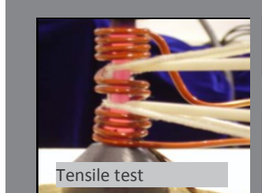
GENERAL CAPABILITIES: EXPERIMENTAL

- ◊ 7000 sq-ft lab with 1, 25, 50, 110, and 220 kip machines with state-of-the-art MTS digital controllers
- ◊ Pit for hydraulic pipe burst tests with axial flaws
- ◊ Creep testing of plastic or metallic specimens
- ◊ High-speed digital video camera at 20,000 fps

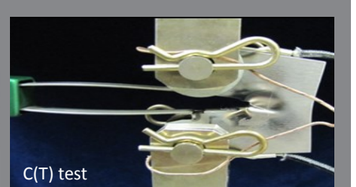
Laboratory Specimen Testing

- TENSILE TESTS
- DWTT TESTS
- CHARPY TESTS
- C(T) TEST
- SENT TESTS
- FPBT
- CTOD,CTOA
- J-R curves
- Fracture speed
- Failure stress
- Constraint frac. parameter

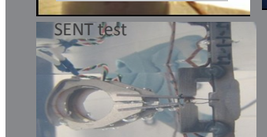
- Specialized SENT tests
  - ◊ Mode-I and Mode-II behavior of SENT specimen with notch in HAZ
  - ◊ SENT specimen with weld containing natural cross-sectional geometry



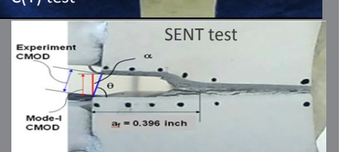
Tensile test



C(T) test



SENT test



SENT test

Moderate to High Energy

Full-Scale Pipe Burst Tests

We review/develop fracture-control plans for large-diameter pipeline projects throughout the world. Our high-energy pipe test site located in Mojave Desert 125 miles northwest of Los Angeles, California is used for conducting full-scale all-gas burst tests under controlled temperature and pressure conditions. Emc^2 has a patent for "Soft Crack Arrestors" which is a ductile composite material that will not produce ring-off failure at the arrestor like fiberglass composite arrestors.

Moderate energy burst test is an economical alternative, especially for lower temperature operation which can capture the real – full scale fracture behavior with a confirmation on brittle-to-ductile transition temperature on modern pipeline steel. Recently a modified burst test was designed to immediately achieve steady-state fracture behavior on newer linepipe steel (high Charpy energy steel above 250J).

Moderate energy vessel burst test

High energy full-scale burst test

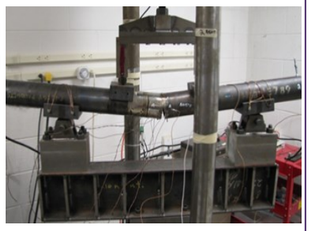
High Speed video of Emc^2 developed Crack Arrestor test

HYDROSTATIC Pipe Burst Tests

Hydrostatic pipe fracture tests are conducted to validate existing fracture initiation prediction models for high-strength linepipe materials (axial through-wall and surface cracked pipes).

Four-Point Bending Pipe Tests

Fully instrumented full-scale flawed or unflawed pipe (3-8" OD) bend tests at RT and high temperature with and without internal pressure. Crack growth, ovalization measurement system



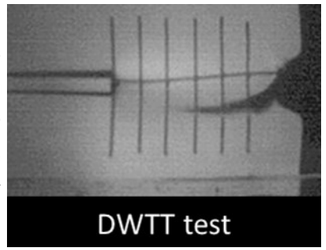
Metallic and Polymeric Charpy test

We have an Instron DYNATUP 9250GV testing machine (max capacity of 1,100 ft-lb) to conduct Charpy tests on metal and plastic specimens that can record load-displacement data. We have a unique capability of capturing impact using high speed camera.

High Speed Video

Emc^2 has equipment and staff for making high-speed digital video recording of dynamic tests and events at 20,000 frame per second but can record as high as 210,00 fps at reduced resolution. The equipment has been used in dynamic specimen fracture testing, full-scale pipe tests, mechanical damage simulation etc.

Charpy Test on HDPE



DWTT test

Plastic & Polymer Composites

Emc^2 has unique expertise in the area of plastics and polymeric matrix composites in structural applications. We have led the ASTM standards activities for the use of thermoplastic matrix composite materials in construction and infrastructure uses. Emc^2 developed breakthrough patented technology in the area of natural fiber reinforced composites that can replace fiber glass reinforcement in many applications.

Emc^2 is the primary technical adviser to the US NRC on reviewing the application of high density polyethylene (HDPE) pipe for safety-related service water applications at nuclear power plants. Emc^2 actively participates in the ASME Boiler and Pressure Vessel Code meetings that develop industry consensus standards for HDPE piping in critical applications for the nuclear industry.

Emc^2 is also a technical advisor to US NRC on reviewing application of Carbon Fiber Composite repair of in service pipe

Hydrostatic plastic pipe burst

Training & Courses

Emc^2 has years of experience across multiple fields of mechanics. We provide training for organizations on an as requested basis on a variety of topics either tailored to the particular organization or 'off the shelf.' Training is conducted on topics such as

- ◊ Leak-Before-Break methods
- ◊ Structural Integrity of HDPE
- ◊ Weld Modeling, WRS and Distortion control
- ◊ Composites in Linepipe Applications
- ◊ ASME code
- ◊ Structural Reliability
- ◊ Probabilistic Mechanics and Fracture
- ◊ Fracture Mechanics
- ◊ DWTT and Ductile fracture in Gas Linepipe and fatigue

Contact us and we can provide training at your site or in our office.

Code Compliance Assessment

Our staff members are experts in application of a number of industry codes for piping systems. We have been involved with development and implementation of these codes and standards, including:

- ASME Section XI Code on pressure vessel and piping inspection and flaw evaluation rules for nuclear power plants,
- U.S. Nuclear Regulatory Commission Standard Review Plans and Regulatory Guides for the integrity of piping systems in nuclear power plants,
- American Petroleum Institute (API) 579 fitness-for-service assessment techniques for pressurized equipment in the refinery and chemical industry,
- American Society of Mechanical Engineers (ASME) Post-Construction Standards for non-nuclear plants (under development),
- API and CSA (Canadian Standards Association) codes for crack arrest and defect assessment of girth welds in gas/and oil transmission pipelines,
- BS 7910 assessment for various welded joints
- Application of DNV Offshore Standard OSF101 "Submarine Pipeline Systems."
- Various ASTM standards for material testing requirements.

Non-Code Structural Integrity Assessment

Emc^2 has unique capabilities in assessing certain structural integrity issues that are not covered by existing codes and standards including:

- Structural integrity of welds that fall outside accepted minimum requirements in existing codes and standards, such as unique geometry, highly brittle microstructure, complex-load conditions, multiple flaw interactions, etc.
- Girth weld defect acceptance criteria under large displacement controlled conditions, including mine subsidence, seismic activities, slope instabilities, and thawing in discontinuous permafrost.
- Girth weld defect acceptance criteria in reeled pipes.
- Reliability-based (limit states) design.
- Probabilistic structural integrity analyses
- Toughness testing specification for unique applications.
- Application of constraint-sensitive fracture mechanics in quantifying realistic material toughness.
- Structural integrity of non-traditional welded joints that involve very low strain-hardening materials and under-matching welds.
- Cracking and thinning in elbows, tees, and branch connections.