Mercury;

An Integrated Finite Element Solver for Earthquake Engineering Hybrid Simulation

Developed by

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Mercury:

- Streamlined, yet powerful, nonlinear transient finite-element simulation tool designed explicitly for earthquake engineering hybrid simulation.
- Not intended to be a general purpose finite element code nor designed to perform geographically distributed test.
- Does not require any intermediary "broker" or facilitator to communicate with actuators.
- Seeks to provide experimentalists with the most commonly used features of a general purpose finite element code for their hybrid simulation.
- Designed to efficiently perform slow (pseudo-dynamic), fast and hard real-time hybrid simulation.

Releases

- ✓ MATLAB (development and education)
- ✓ c++ (hybrid simulation or large scale computation)
  - ✓ LabVIEW & Real Time LabVIEW
  - ✓ Simulink & xPC
  - ✓ Windows
  - ✓ Linux, (real time Linux)

Simulations

- ✓ Static push-over analyses
- ✓ Static reversed-cyclic analyses
- ✓ Dynamic time-series analyses
- ✓ Uniform-support excitation
- ✓ Multi-support excitation

Element Library 2D truss and beam-column elements

- ✓ Force (with and without element iterations) and displacement based elements
- ✓ Zero length and zero section elements

Sections

- ✓ Elastic
- ✓ Layer or fiber

Constitutive models

- ✓ Steel
  - ✓ Hardening model with isotropic and kinematic hardening
  - ✓ Bilinear model with isotropic hardening
  - ✓ Giuffre-Menegotto-Pinto-Filippou
- ✓ Concrete
  - ✓ Modified Kent and Park
  - ✓ Anisotropic Damage Models

Solution Algorithms

- ✓ Linear
- ✓ Initial stiffness
- ✓ Newton-Raphson
- ✓ Modified Newton Raphson

Integrators

- ✓ Static: Load control, displacement control, Arc Length
- ✓ Transient: Newmark β, Hilber-Hughes-Taylor α; Shing (IS, NR or MNR)

Convergence Criteria

- ✓ Displacement norm
- ✓ Force norm
- ✓ Energy norm

Hybrid Capabilities

- ✓ Truss & Beam-Column
- ✓ Multiple elements and multiple DOF
- ✓ Available as LabView/Simulink signals
- ✓ Read/Write hybrid components to/from SCRAMNet (Shared Common Random Access Memory Network)

*Work in progress

- ✓ I Correction for actuator errors
- ✓ Embedded Kalman Filter for inertia force correction*

Analysis Commands

- ✓ Static analysis
- ✓ Transient analysis
- ✓ Generalized eigenmodes ($\mathbf{K} - \lambda\mathbf{M}$

Scripting Interface

- ✓ Embedded Lua
- ✓ MATLAB like syntax
- ✓ Functions & variables

Output

- ✓ Recorders for nodal quantities
- ✓ Real time graphical display of physical and hybrid deformed shapes (based on TK)

Documentation

- ✓ Doxygen
- ✓ Regression Tests run weekly
- ✓ Over 30 test/valiadation problems
- ✓ Technical (over 300 pages) & User Manual

Special features

- ✓ MATLAB version ideal for educational/prototyping. Has a hybrid element, and can connect through TCP/IP with another module.
- ✓ Optimized for speed in element computation and matrix solver for
  - ✓ Shared memory computer: multithreaded with INTEL MKL
  - ✓ Distributed memory computers: MPI
- ✓ User controlled mixed solution algorithms: possible to change solution algorithm(NR, MNR and IS) automatically if convergence problem exists in a time step at both the structure and element level.
- ✓ Refinements of the Shing integration scheme:
  - ✓ Allows $10n$ iterations per time increment of 0.01 sec.
  - ✓ Continuously updated stiffness matrix on a separate CPU.
- ✓ Pushover analysis: allows application of imposed displacements on multiple free degrees of freedom.
- ✓ Concrete model: newly developed anisotropic damage model (by LMT/Cachan) with residual displacement and hysterisis damping for improved reliability of prediction.
- ✓ **"Battle tested" on the real time hybrid simulation of the highly nonlinear reinforced concrete frame shown below (with over 400 degrees of freedom, and 136 elements). Results compared favorably with shake table test of similar frame**, see below.
- ✓ Funding: NEESinc and The State of Colorado.