Plastic Energy Dissipation for Steel Building with BRBs

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Outline

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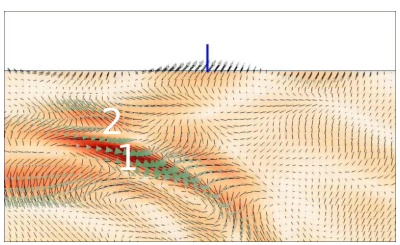
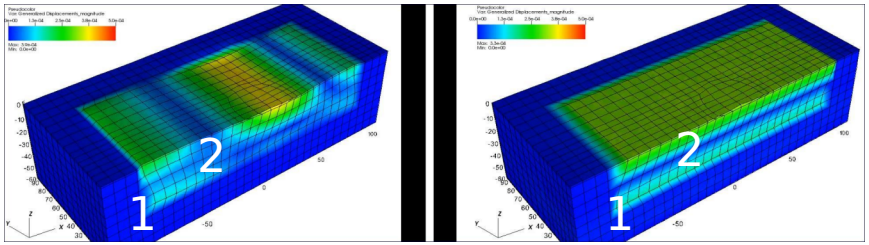
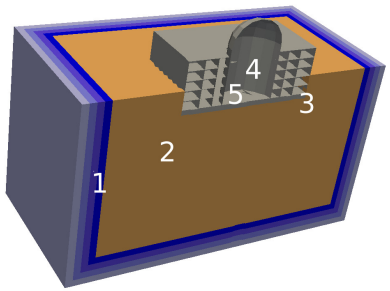
Motivation

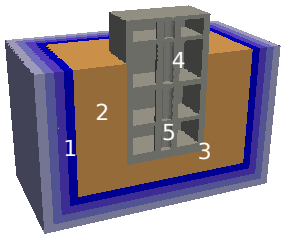
- Safety and economy of infrastructure
- Design, build and maintain sustainable infrastructure
- Responsible Engineer, with Executive Powers
- Engineer with versatile, quality assured analysis tool to
  - Explore design concepts
  - Assess infrastructure performance
- Engineering Analysis to Predict and Inform

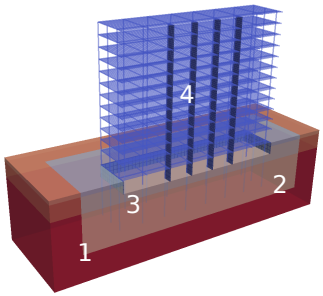
Civil Engineering Analysis Challenges

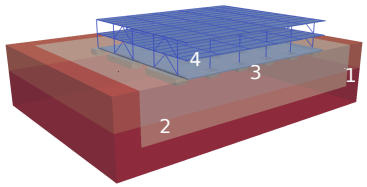


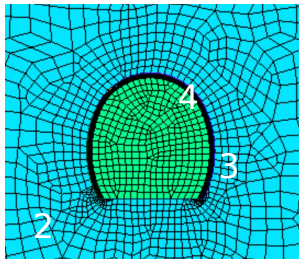


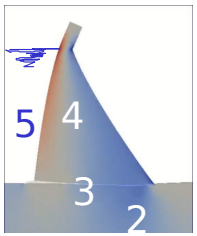


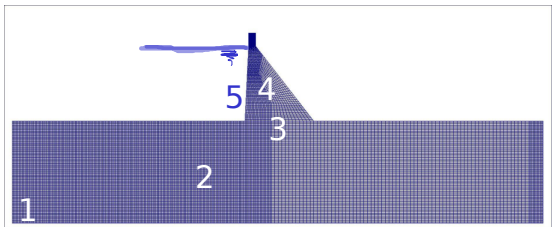


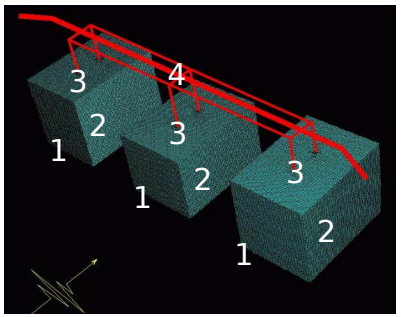








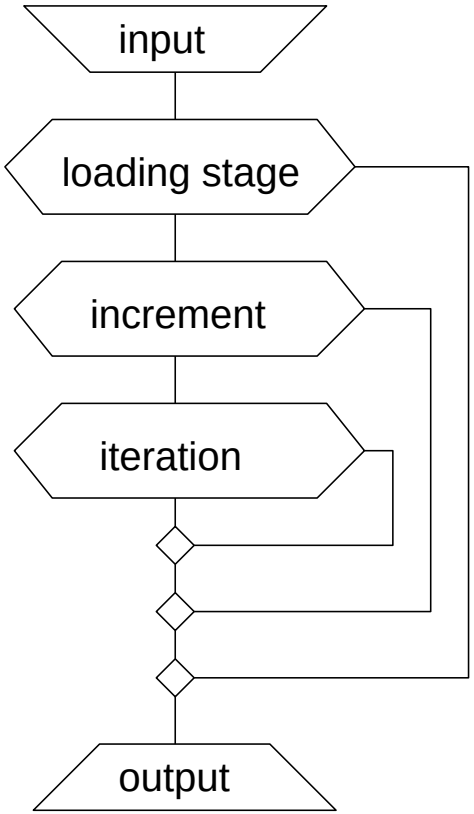




Outline

Real-ESSI Engineering Analysis System

- Statics and dynamics of rock, soil, structures, fluids...
- Linear, Nonlinear, Inelastic
- Deterministic and Probabilistic
- High Performance Computing, HPC
- Reduction of Modeling Uncertainty
- Propagation of Parametric Uncertainty
- QA: Verification and Validation
- Infrastructure safety and economy
- `http://real-essi.us/`



FEM for ESSI Analysis

- Single Phase FEM: $M_{AacB}\,\ddot{\bar{u}}_{Bc} + K_{AacB}\,\bar{u}_{Bc} = F_{Aa}$

- Two phase FEM, u-p-U:

$$\begin{bmatrix} (M_s)_{KijL} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & (M_f)_{KijL} \end{bmatrix} \begin{bmatrix} \ddot{\bar{u}}_{Lj} \\ \ddot{\bar{p}}_N \\ \ddot{\bar{U}}_{Lj} \end{bmatrix} + \begin{bmatrix} (C_1)_{KijL} & 0 & -(C_2)_{KijL} \\ 0 & 0 & 0 \\ -(C_2)_{LjiK} & 0 & (C_3)_{KijL} \end{bmatrix} \begin{bmatrix} \dot{\bar{u}}_{Lj} \\ \dot{\bar{p}}_N \\ \dot{\bar{U}}_{Lj} \end{bmatrix}$$

$$+ \begin{bmatrix} (K^{EP})_{KijL} & -(G_1)_{KiM} & 0 \\ -(G_1)_{LjM} & -P_{MN} & -(G_2)_{LjM} \\ 0 & -(G_2)_{KiL} & 0 \end{bmatrix} \begin{bmatrix} \bar{u}_{Lj} \\ \bar{p}_M \\ \bar{U}_{Lj} \end{bmatrix} = \begin{bmatrix} \bar{f}^{solid}_{Ki} \\ 0 \\ \bar{f}^{fluid}_{Ki} \end{bmatrix}$$

- Equilibrium: $R = F_{external} - F_{internal}$

Energy Input and Dissipation in ESSI System

Energy input, forces/loads, static/dynamic

Energy dissipation outside SSI domain:

- SSI system oscillation radiation
- Reflected waves radiation

Energy dissipation/conversion inside SSI domain:

- Inelasticity of soil, interfaces, structure, dissipators
- Viscous coupling with internal/pore and external fluids
- Energy deflectors, meta-materials

Numerical energy dissipation/production

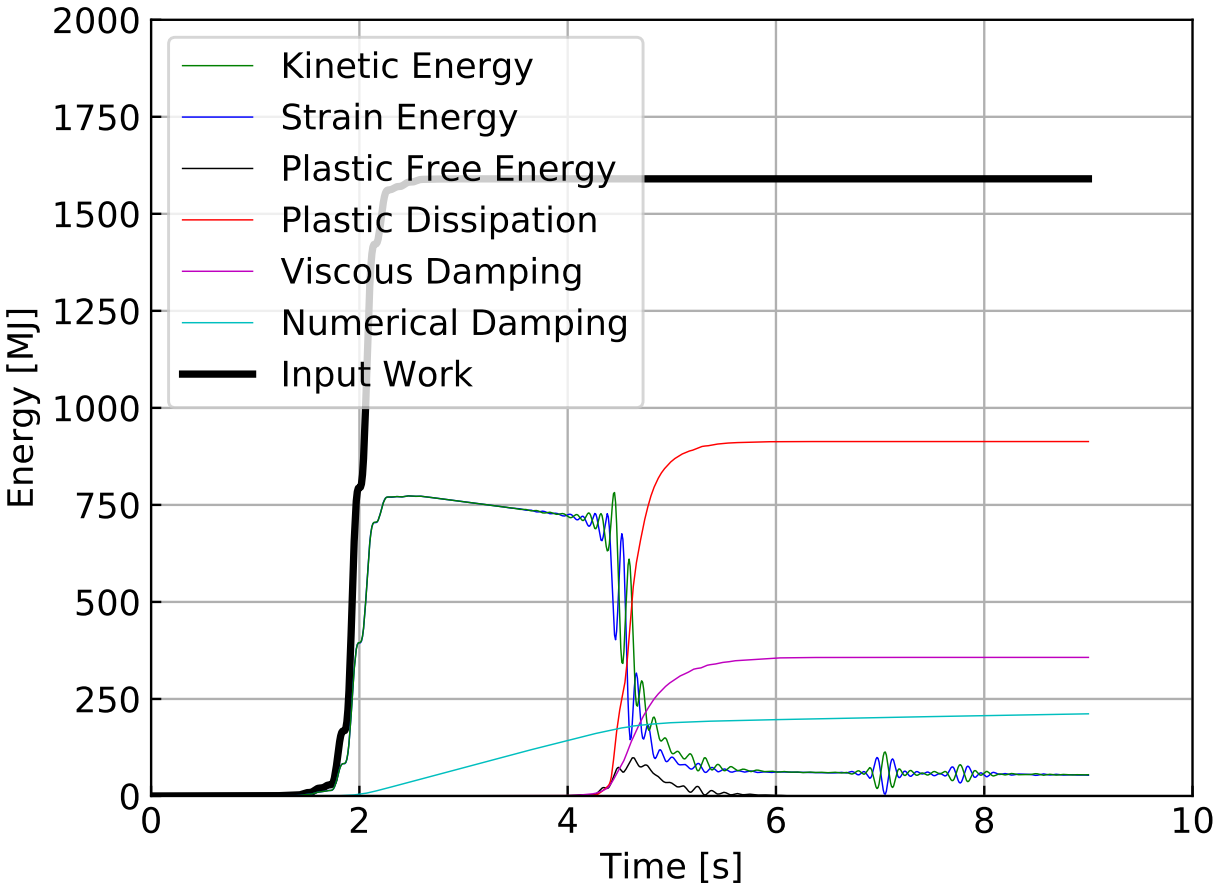
Energy Dissipation within ESSI System

- Plastic energy dissipation:
  $\Delta\Phi = \sigma_{ij}\Delta\epsilon_{ij} - \sigma_{ij}\Delta\epsilon_{ij}^{el} - \Delta\psi_{pl} \geq 0$

- Viscous energy dissipation/damping:
  $\Delta D_V = C_{ij}\dot{u}_j\Delta u_i$

- Algorithmic, numerical energy dissipation/production:
  Newmark, Hilber-Hughes-Taylor, Houbolt, Bathe, Wilson...

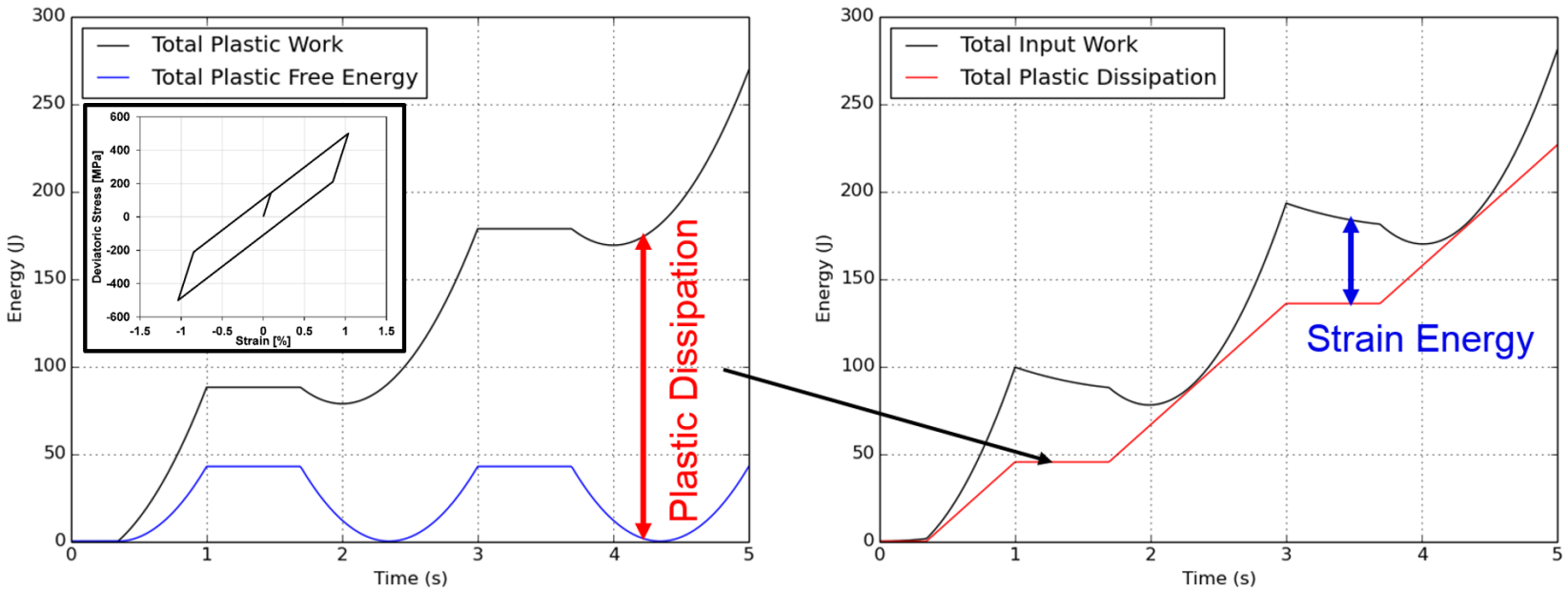
Energy Dissipation Control



Plastic Energy Dissipation

Plastic work is NOT plastic dissipation !

Surface area of $F - \Delta$ or $\sigma - \epsilon$ is NOT plastic dissipation !



Plastic Energy Dissipation

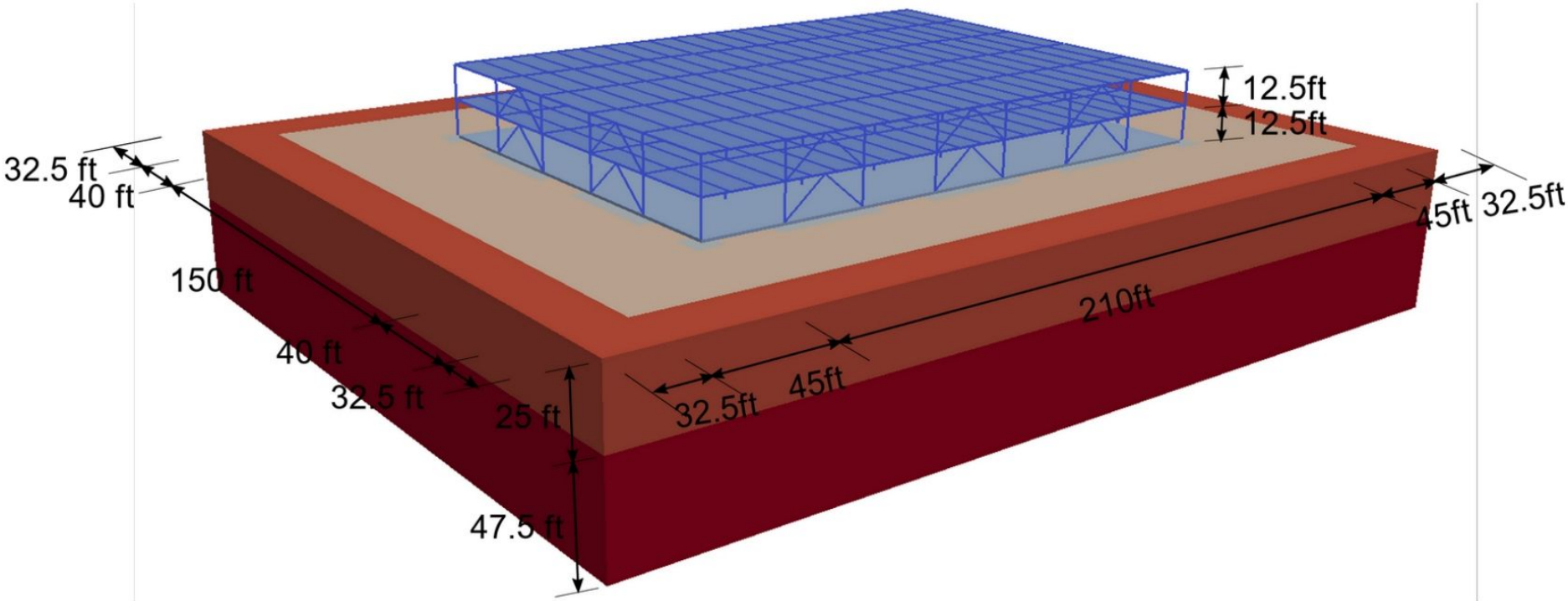
Increment of plastic energy dissipation:
$\Delta\Phi = \sigma_{ij}\Delta\epsilon_{ij}^{pl} - \Delta\psi_{pl} \geq 0$

Plastic Free Energy $\Delta\psi_{pl}$

- 3D Drucker-Prager EI=PI, Armstrong Frederick (soil)
  $\Delta\psi_{pl} = \left((3/(2h_a))\alpha_{ij}\Delta\alpha_{ij} - m_{ij}^{vol}\Delta\lambda\right)(-\sigma_{kk}/3)$

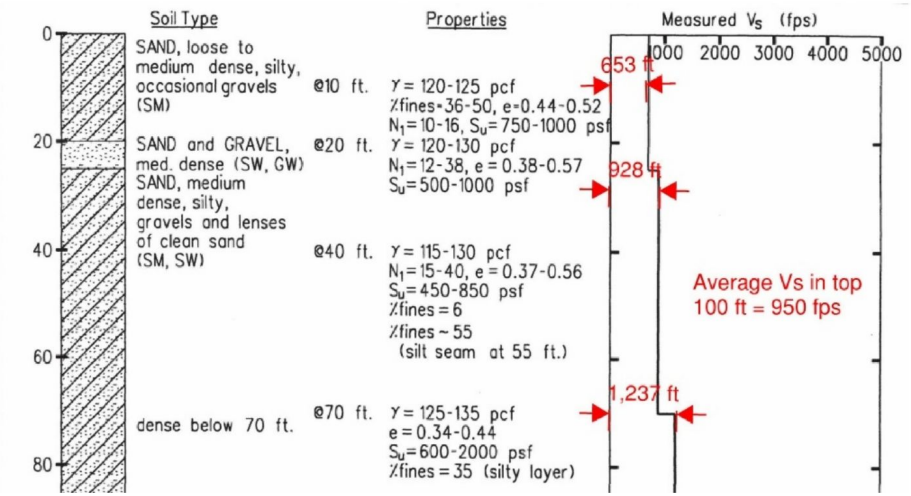
- 1D steel fiber (BRB)
  $\Delta\psi_{pl} = \frac{1}{2}\left((\sigma + \sigma^r)\Delta\epsilon\right) + (\epsilon^{pl} - \epsilon^r)\Delta\sigma\big)$

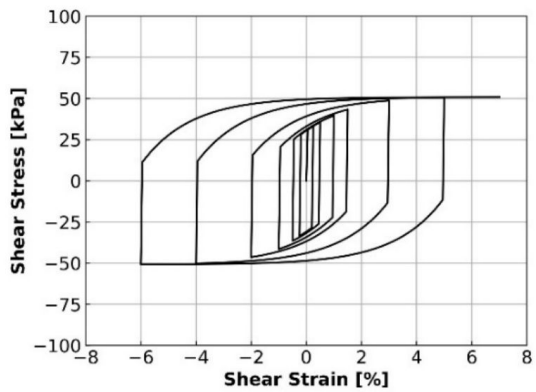
ASCE-7, Steel Building with BRBs

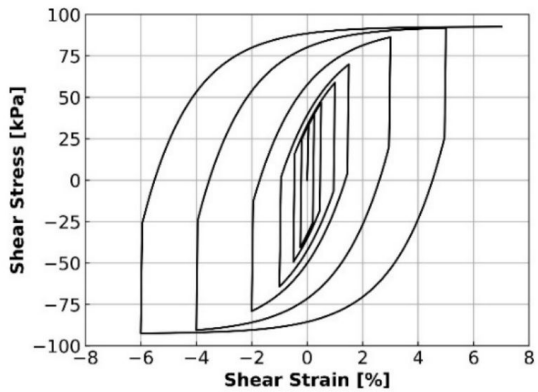


ASCE-7, Steel Building with BRBs, Soil

Parabolic Drucker-Prager with Armstong-Frederick rotational kinematic hardening

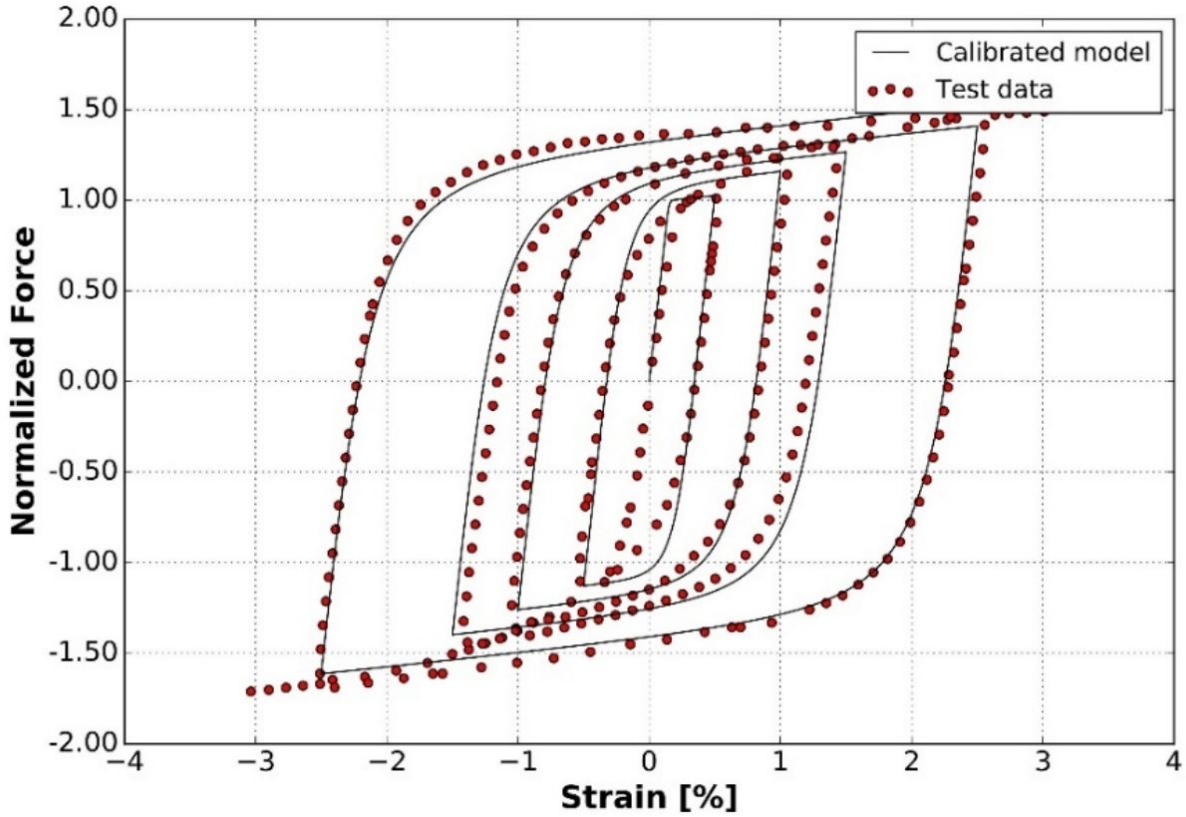




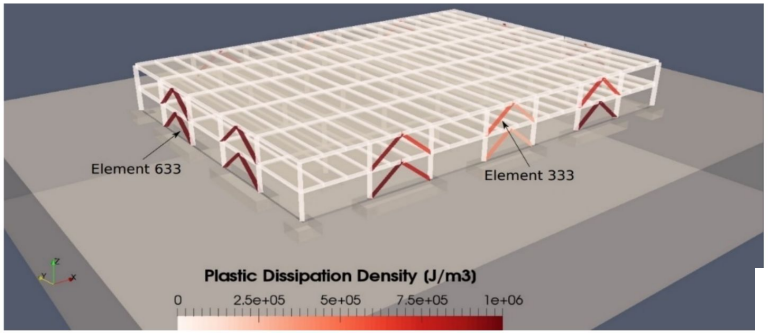


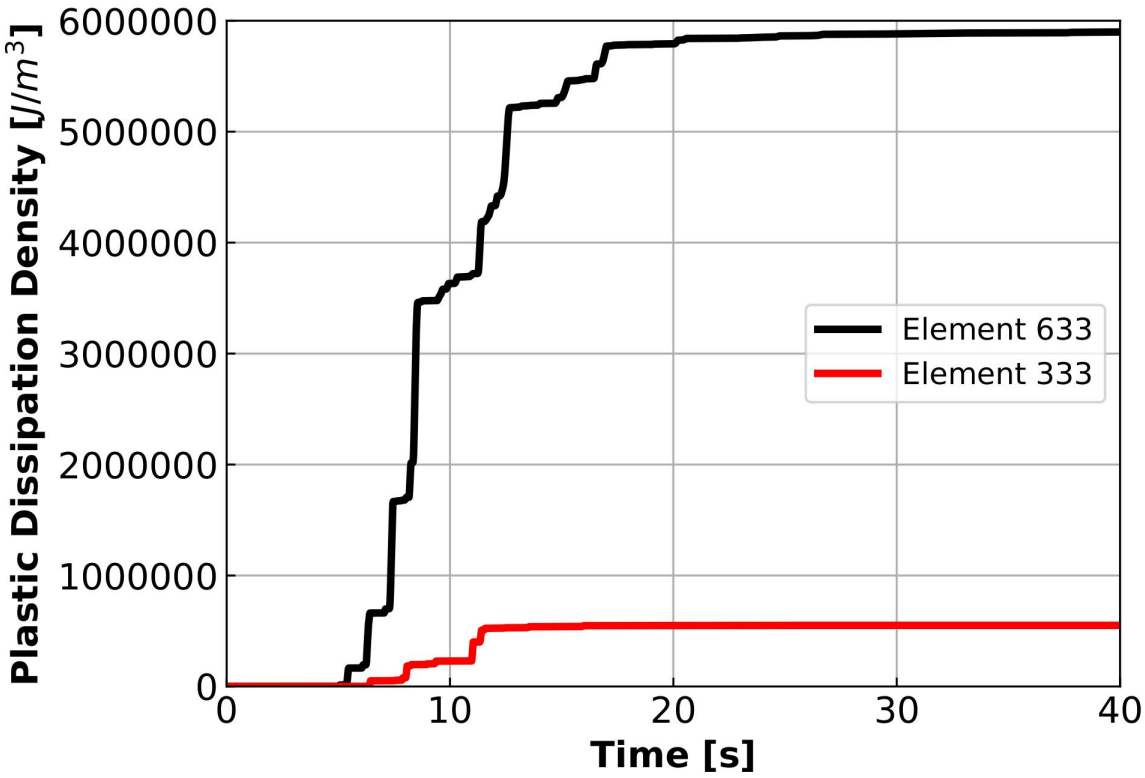
ASCE-7, Steel Building with BRBs, Steel

Giuffré-Menegotto-Pinto 1D Fiber steel model

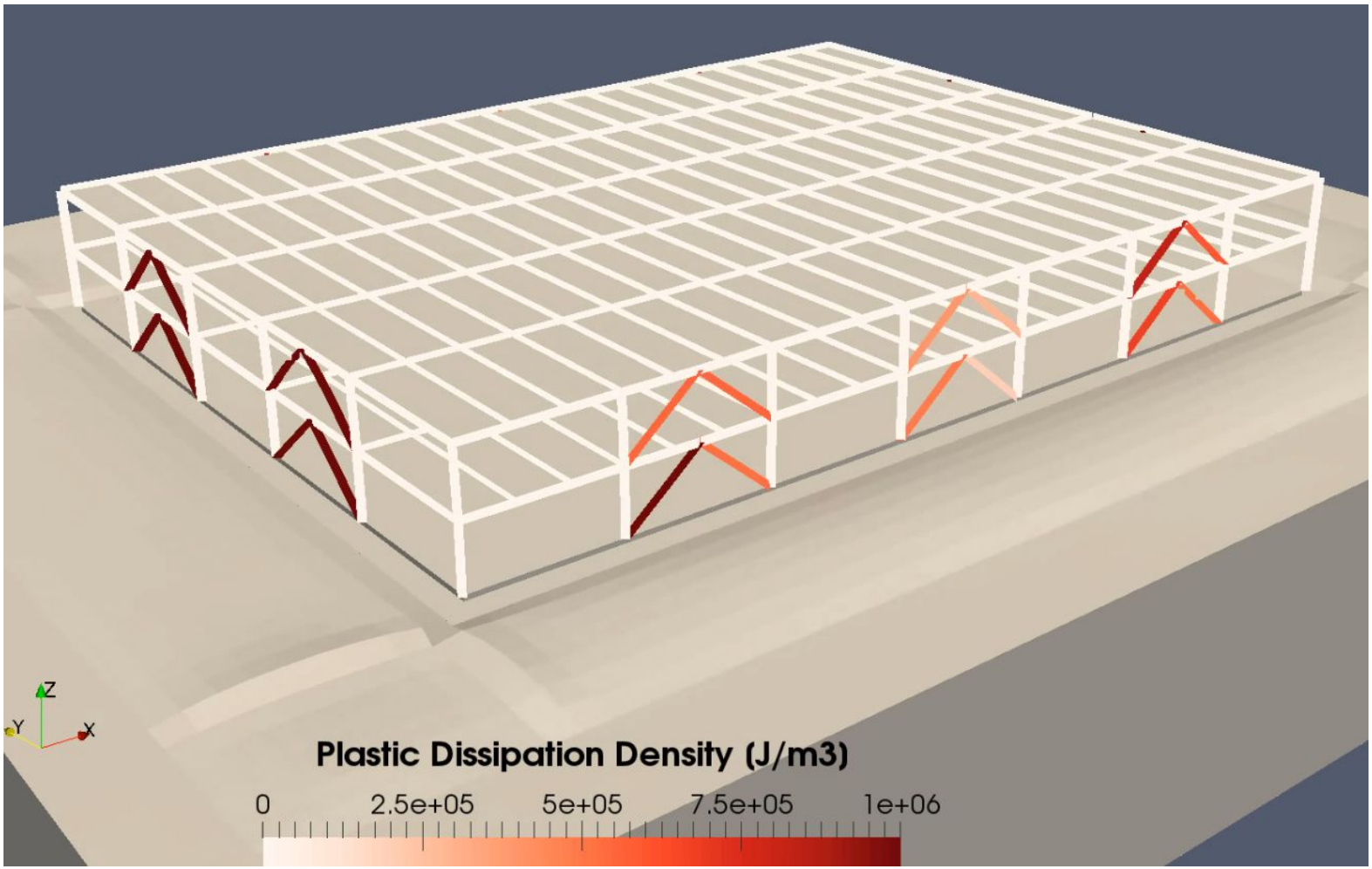


Buckling Restrained Braces (BRB) Energy Dissipation





ASCE-7-21, Steel Building Energy Dissipation



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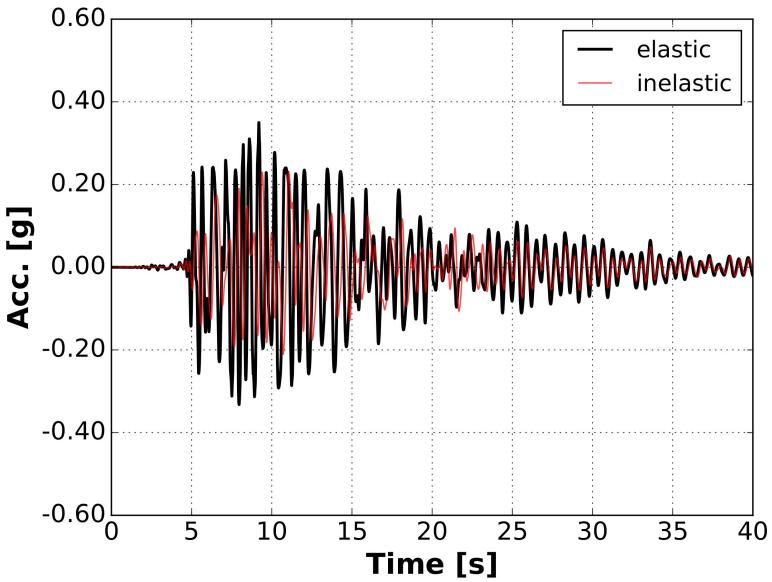
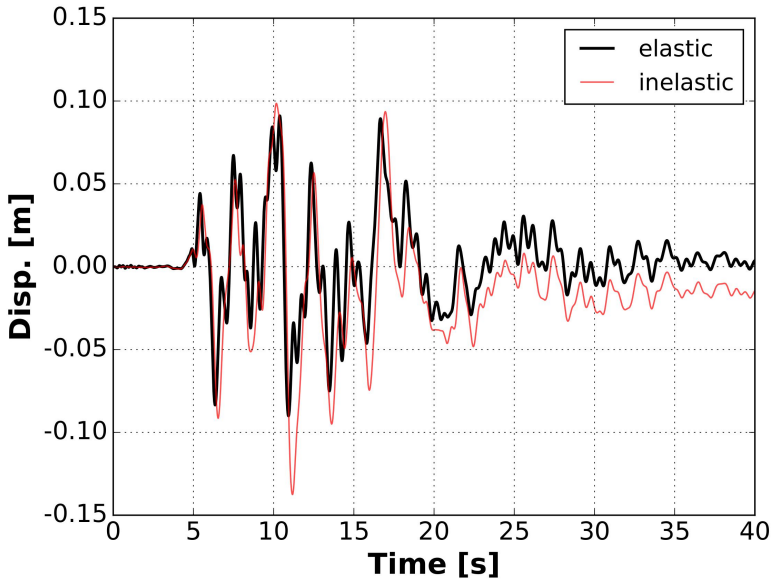
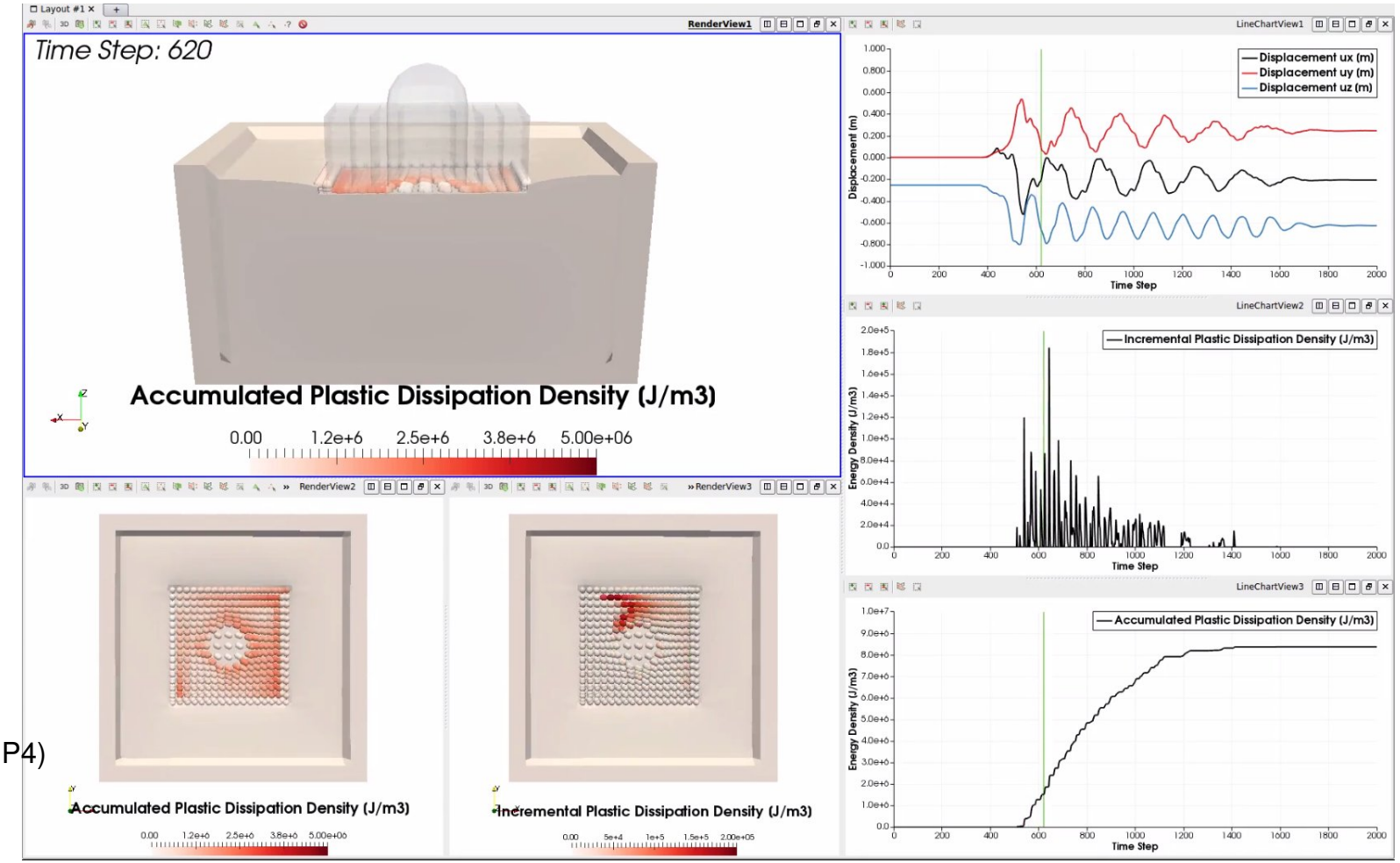
Building Seismic Response





Important Infrastructure, Energy Dissipation



(MP4)

Outline

Summary

- Engineering analysis to predict and inform
- Engineer needs to know !
- Mechanical energy dissipation for design and assessment
- Education and Training is the Key