TOPOLOGY OPTIMIZATION OF ROCKING BRACED FRAMES FOR NONLINEAR EARTHQUAKE RESPONSE

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1. Introduction

Topology optimization is a computational tool that enables the development of efficient and elegant structures. Application of topology optimization for earthquake resistant design is challenging due to the complexity of nonlinear dynamic response under random ground motions. Since inelasticity is concentrated at energy-dissipating elements, modified modal analyses can approximately capture the nonlinear earthquake response using equivalent linear structural properties. Based on these simplified analyses, topology optimization can be extended for nonlinear seismic response of structural systems, such as rocking braced frames, by taking into account the nonlinear response of the rocking base and the frequency characteristic of the design earthquake.

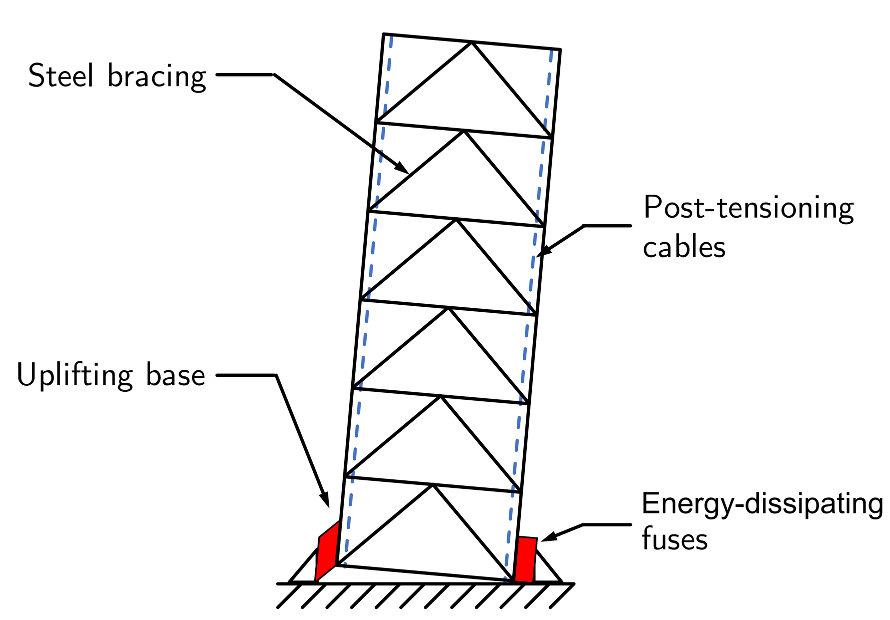

Figure 1. Rocking braced frame

2. Methodology

The extended topology optimization problem, using surrogate modes, for nonlinear earthquake response is detailed below. The load cases for the rocking braced frame are shown in Figure 2.

$$
\begin{aligned}
&\text{mininimize} && C_T(\boldsymbol{\rho}) = \sum_{i=1}^{m} w_i \boldsymbol{F}_i^T \boldsymbol{u}_i && (1)\\
&\text{subject to} && \int_{\Omega} \rho dV - \bar{V} \leq 0 &&\\
& && 0 \leq \rho_e \leq 1, && \forall e \in \Omega\\
&\text{with} && \boldsymbol{u}_i = K_{eq}^{-1} \boldsymbol{F}_i\,, && \text{for } i = 1, \dots, m\\
& && \boldsymbol{F}_i = \frac{\Gamma_i M \boldsymbol{\phi}_i Sa(T_i)}{R_i} && \text{for } i = 1, \dots, m\\
& && \left[K_{eq} - \omega_i^2 M\right] \boldsymbol{\phi}_i = \boldsymbol{0}\,, && \text{for } i = 1, \dots, m\\
& && \boldsymbol{\phi}_i^T M \boldsymbol{\phi}_j = \delta_{ij}, && \text{for } i, j = 1, \dots, m
\end{aligned}
$$

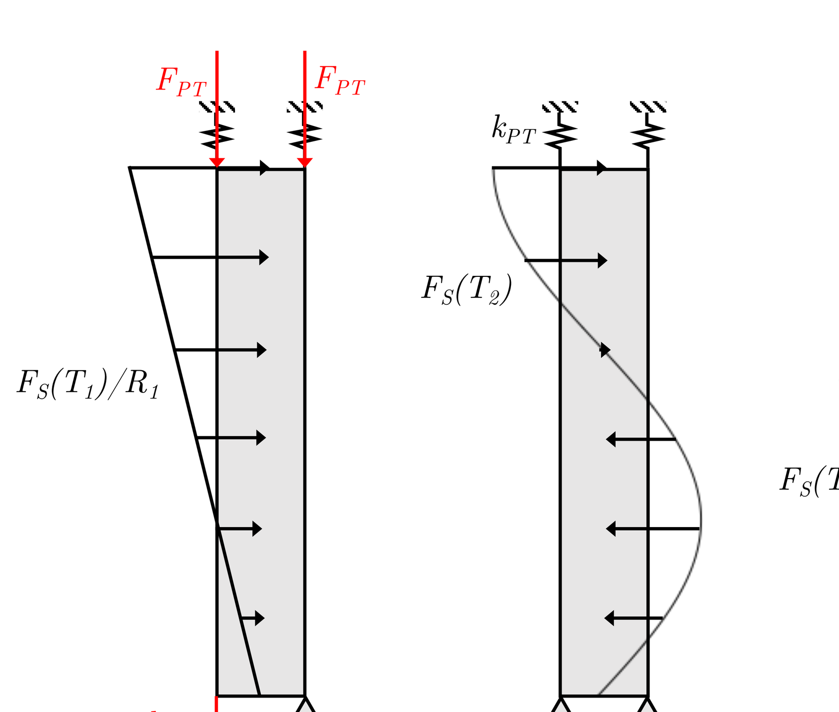

Figure 2. Multiple load cases for topology optimization

3. Topology Optimization Results

The methodology is applied to a single rocking braced frame to determine the location of the steel bracing members in the elastic rocking spine. Figure 3 shows the (a) design domain, (b) resulting optimized topology, (c) the Von Mises stress distribution along with the convergence history.

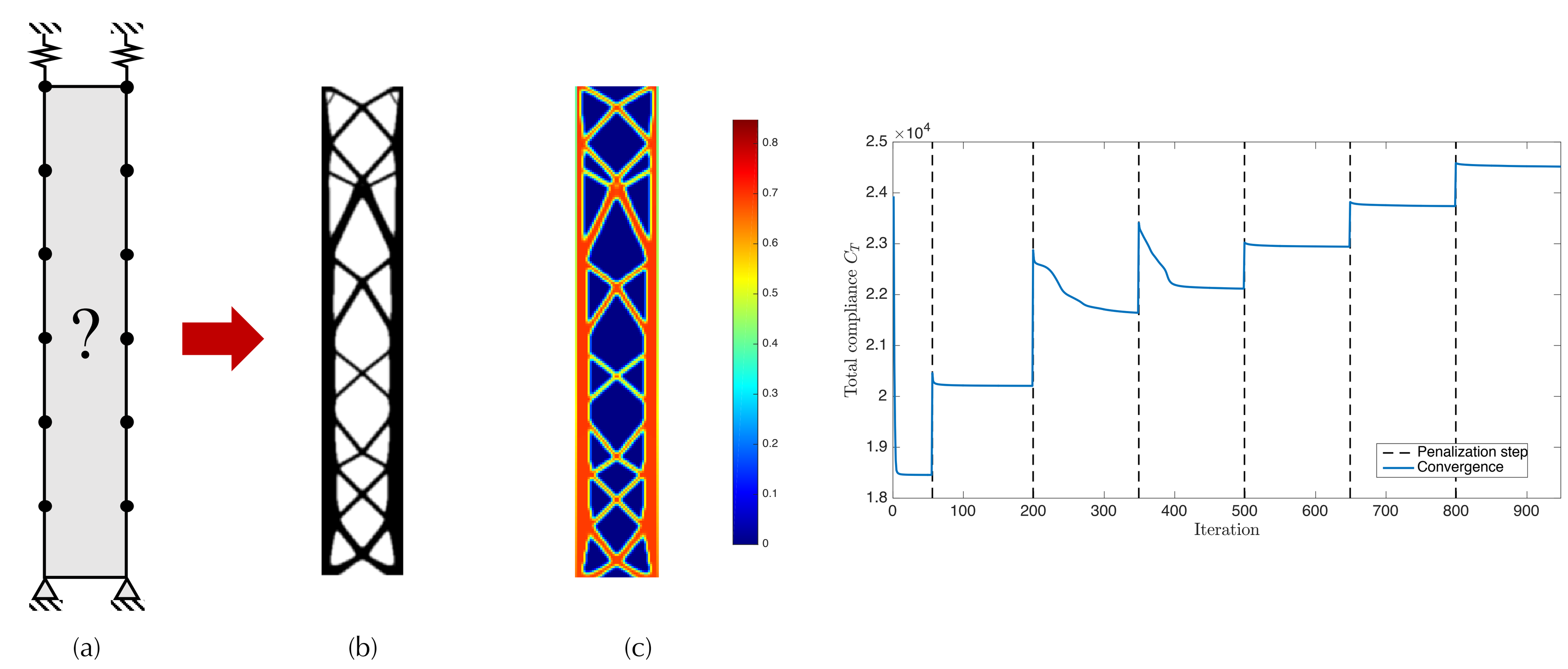

Figure 3. Topology optimization results

The decoupled optimization results for each modal load case demonstrate the influence of higher modes, especially the second mode, on the distribution of bracing along the height of the spine. The story shear forces correlate with a high density of bracing and vice-versa (Figure 4).

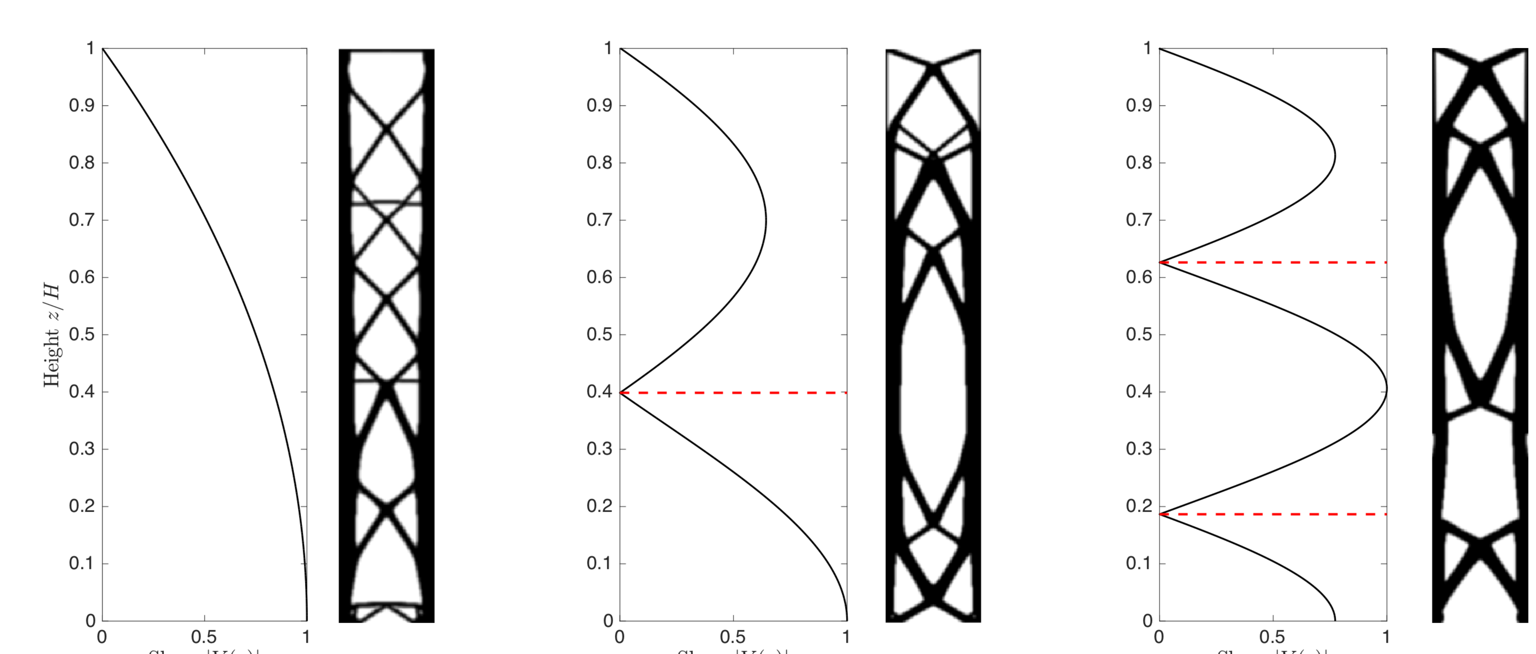

Figure 4. Topology optimization modal results and modal story shear forces

4. Conclusion

- A methodology to extend topology optimization for nonlinear earthquake response is presented using surrogate modal load cases
- The method is applied to rocking braced frames and the numerical results demonstrate important conceptual design considerations, especially the contribution of higher modes

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