Approximate Modal Decomposition of Inelastic Dynamic of Wall Buildings

Advanced Vibration

Sudan Pandey

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Approximate Modal Decomposition of Inelastic Dynamic of Wall Buildings

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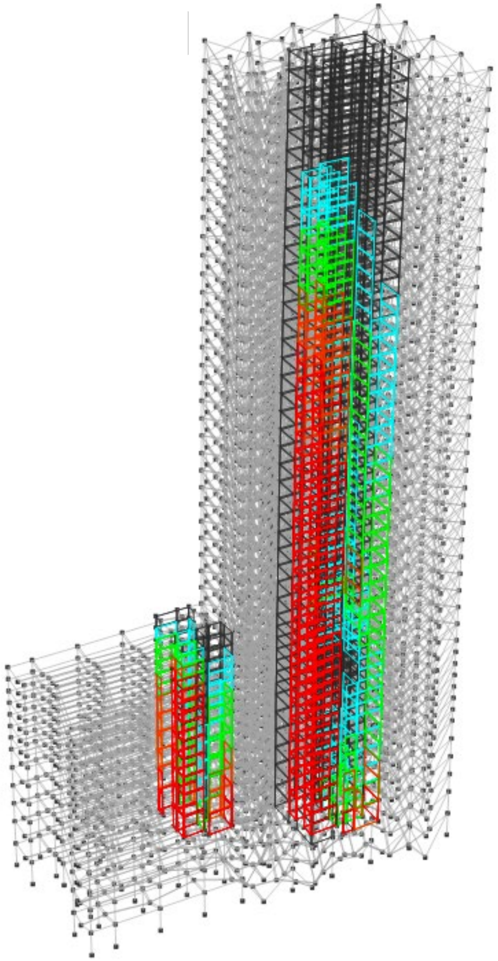

- *Most reliable and accurate*
- *Numerical step-by-step direct integration*
- *Required long computational time, expensive*
- *Require high expertise to interpret analysis results and implement them for design*
- *Difficult to gain physical understanding of complex nonlinear dynamic response*

$$[M](\ddot{x})+[C](\dot{x})+[K](x)=(F(t))$$ (Linear system)

$$[M](\ddot{u})+[C](\dot{u})+F_{sn}(u,\dot{u})=(f(t))$$ Non-Linear system

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Modal Analysis

Decoupled equations: $\ddot{q}_i + 2\zeta_i \omega_i \dot{q}_i + \omega_i^2 q_i = f_i(t)$ (Linear system)

Why Modal Coordinates are Important? [Ref: Lecture 1b]

- ***Vibration modes have intrinsic meaning. Modes and modal coordinates tell us something more understandable about structural response than do structural matrices***
- ***Modes, modal frequencies, and modal damping factors can be measured and compared with prediction.***
- ***The EOM in modal coordinates can be integrated independently***
- ***The total response can be obtained by summing the individual modal responses***

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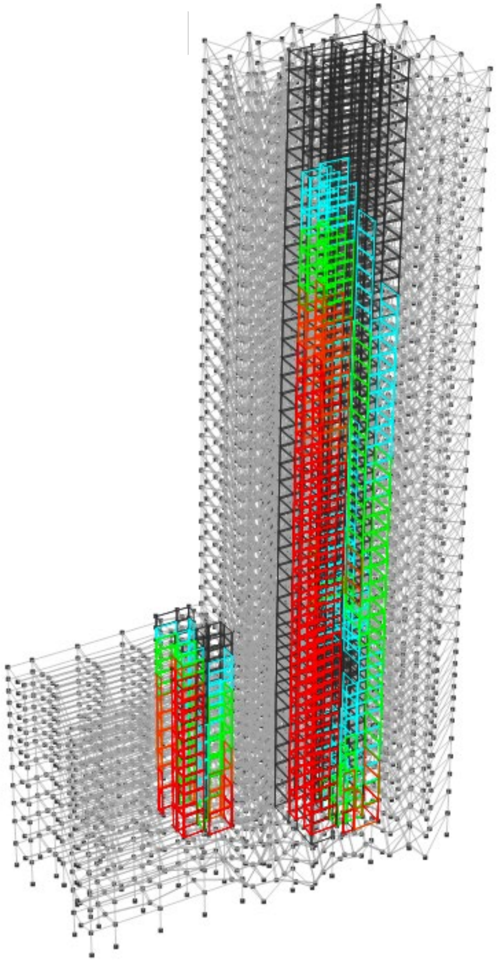
Dynamic Analysis Procedures

Uncoupled Modal Response History Analysis (UMRHA)



- *Developed by Chopra and Goel (2002)*
- *Extended version of the "Classical Modal Analysis" procedure*
- *Each vibration mode behaves like SDOF system and can be expressed as,*

$$\ddot{u}_n + 2\xi_n \omega_n \dot{u}_n + \frac{F_{sn}(u_n, \dot{u}_n)}{L_n} = -\ddot{u}_g(t)$$

- *Total response is determined by combining response of all significant modes*
- *Assumes that 'vibration modes' still exist even for the nonlinear responses*
- *Assumes principle of superposition remain valid for inelastic responses.*

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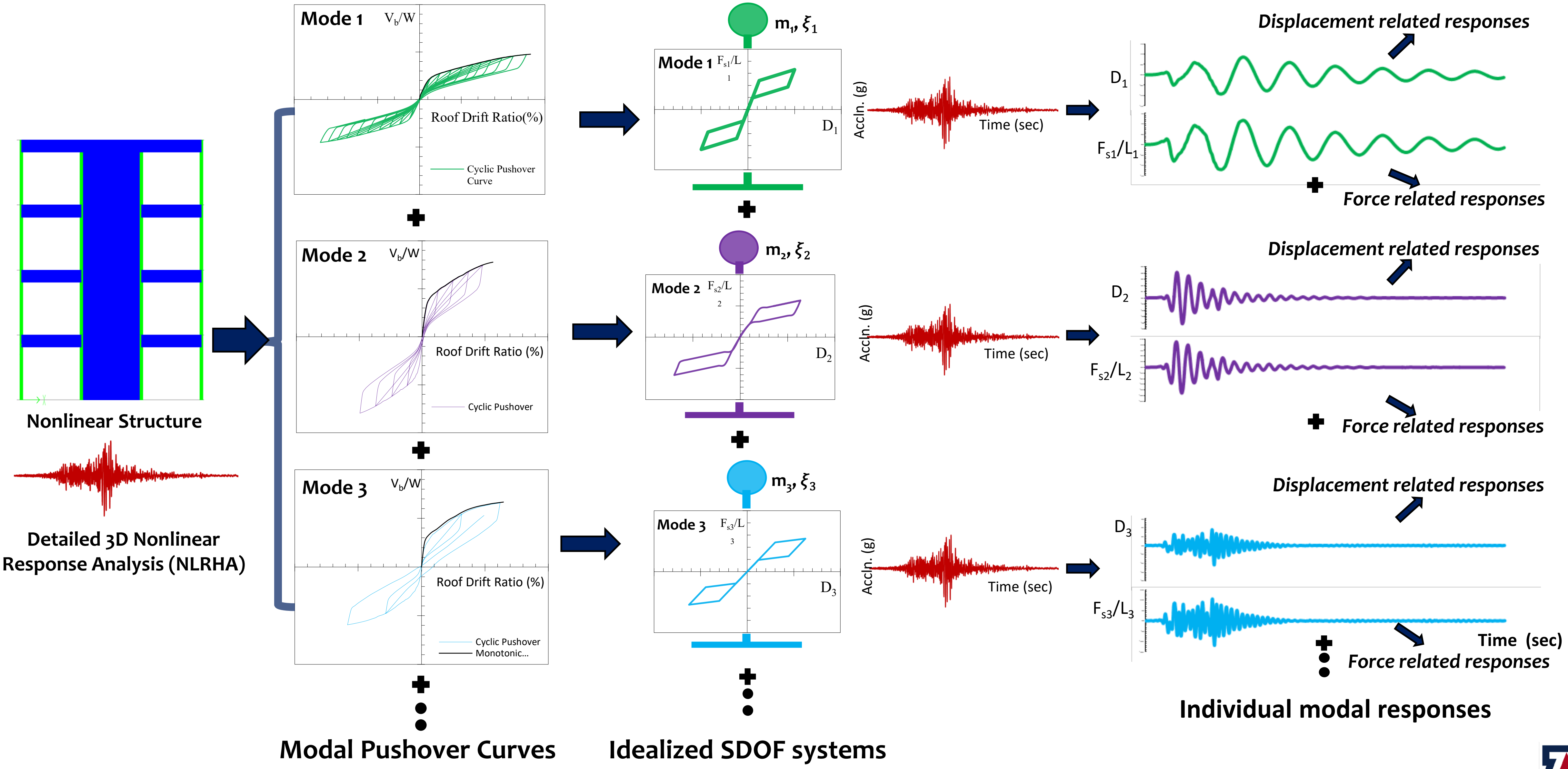
Uncoupled Modal Response History Analysis (UMRHA)



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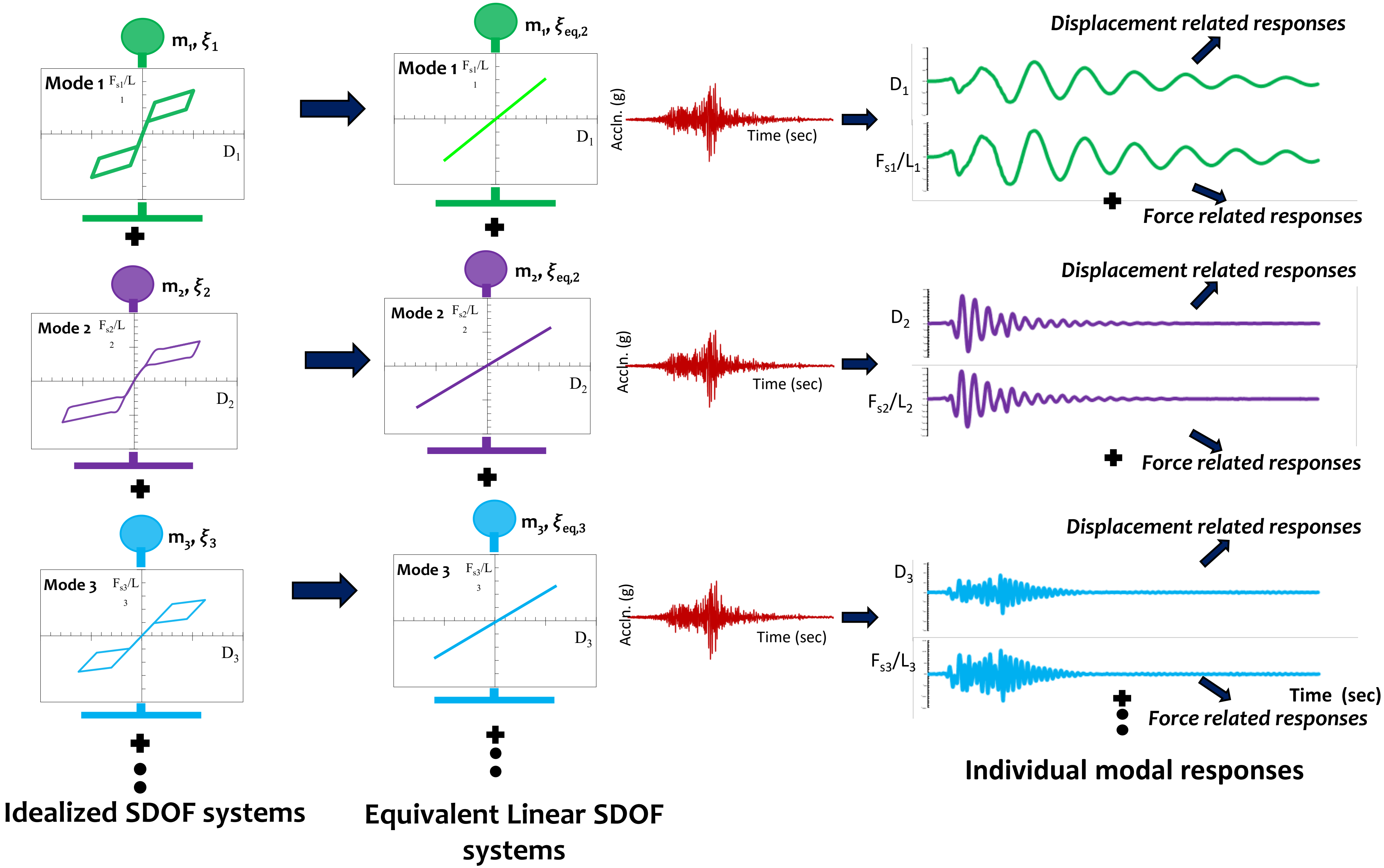
Approximate Modal Decomposition



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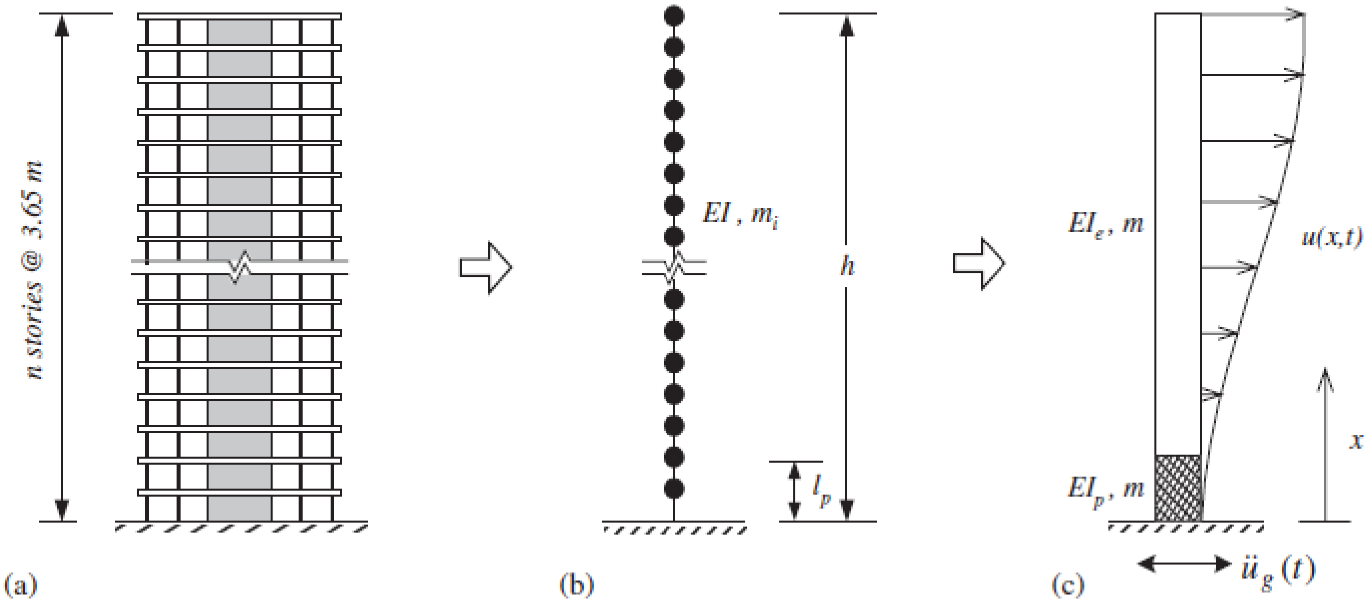

Figure 2. (a) Wall building of interest; (b) simplified inelastic wall model; and (c) equivalent linear wall model.

Case Study Building and Equivalent Linear Model

Salient Features:

- ***Building is modeled as vertical cantilever beam with lumped mass at floor level***
- ***Building heights selected for this study are 20, 25, 30, 35, and 40 stories.***
- ***The ratio of wall height to depth (aspect ratio) is set to 10.***
- ***A fully fixed base is assumed in all cases.***

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Direct Method

The response of each individual equivalent linear models can be directly evaluated from the corresponding best fit equivalent linear model.

- ## Orthogonal Filter Method

Complex modal coordinate $y_i(t)$ is first extracted from the available time histories of the bending moment and velocity.

$$y_i(t) = \frac{\int_0^h (EIu''(x,t)) \cdot \phi_i'' \, \mathrm{d}x - \lambda_i \int_0^h m(\dot{u}(x,t)) \cdot \phi_i \, \mathrm{d}x}{\int_0^h EI\phi_i''^2 \, \mathrm{d}x - \lambda_i^2 \int_0^h m\phi_i^2 \, \mathrm{d}x}$$

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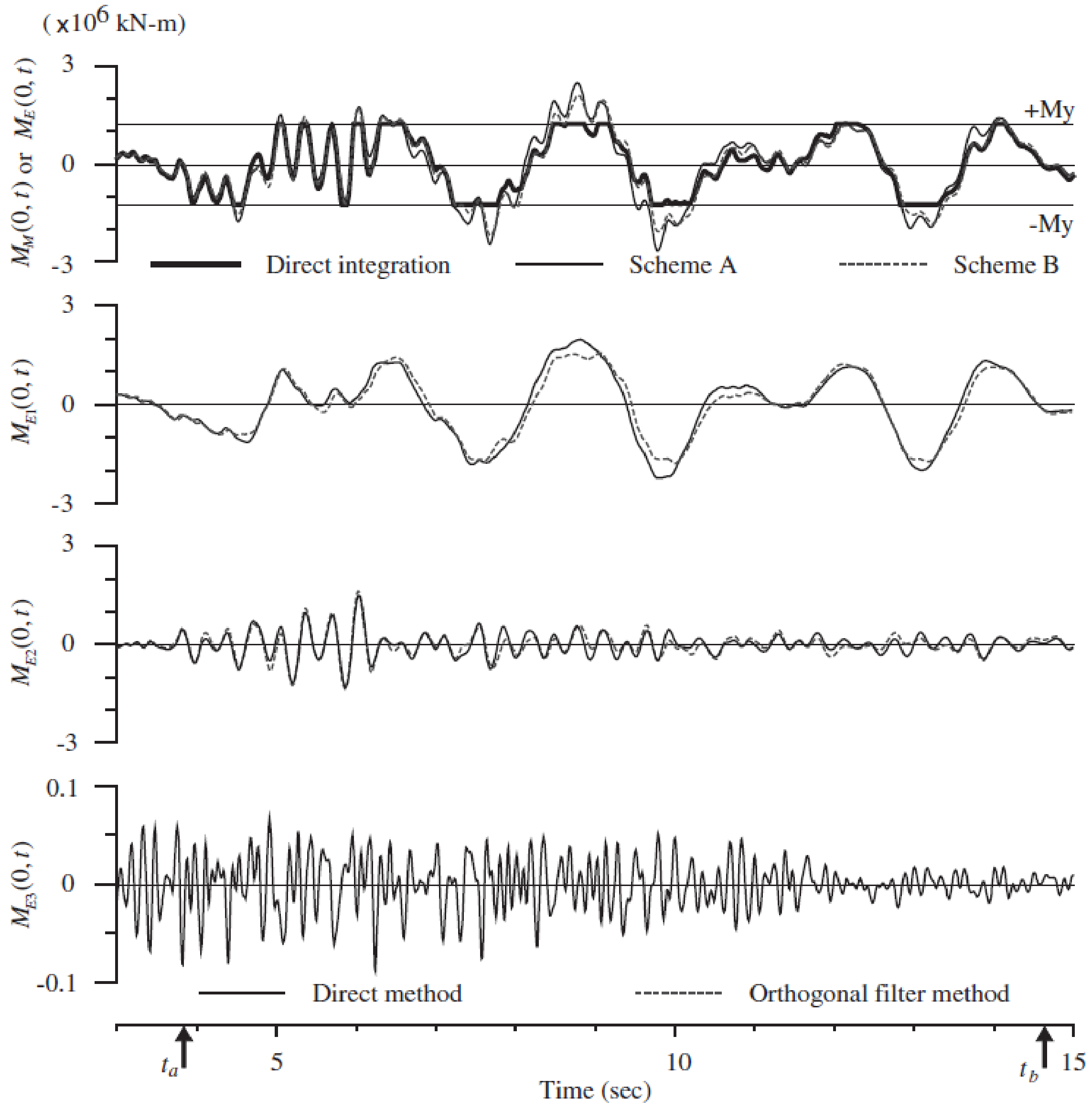

Decomposed modal base moment of 40-story wall building under the ANFS ground motion.

Both method; Direct method and Orthogonal Filter method gives close result

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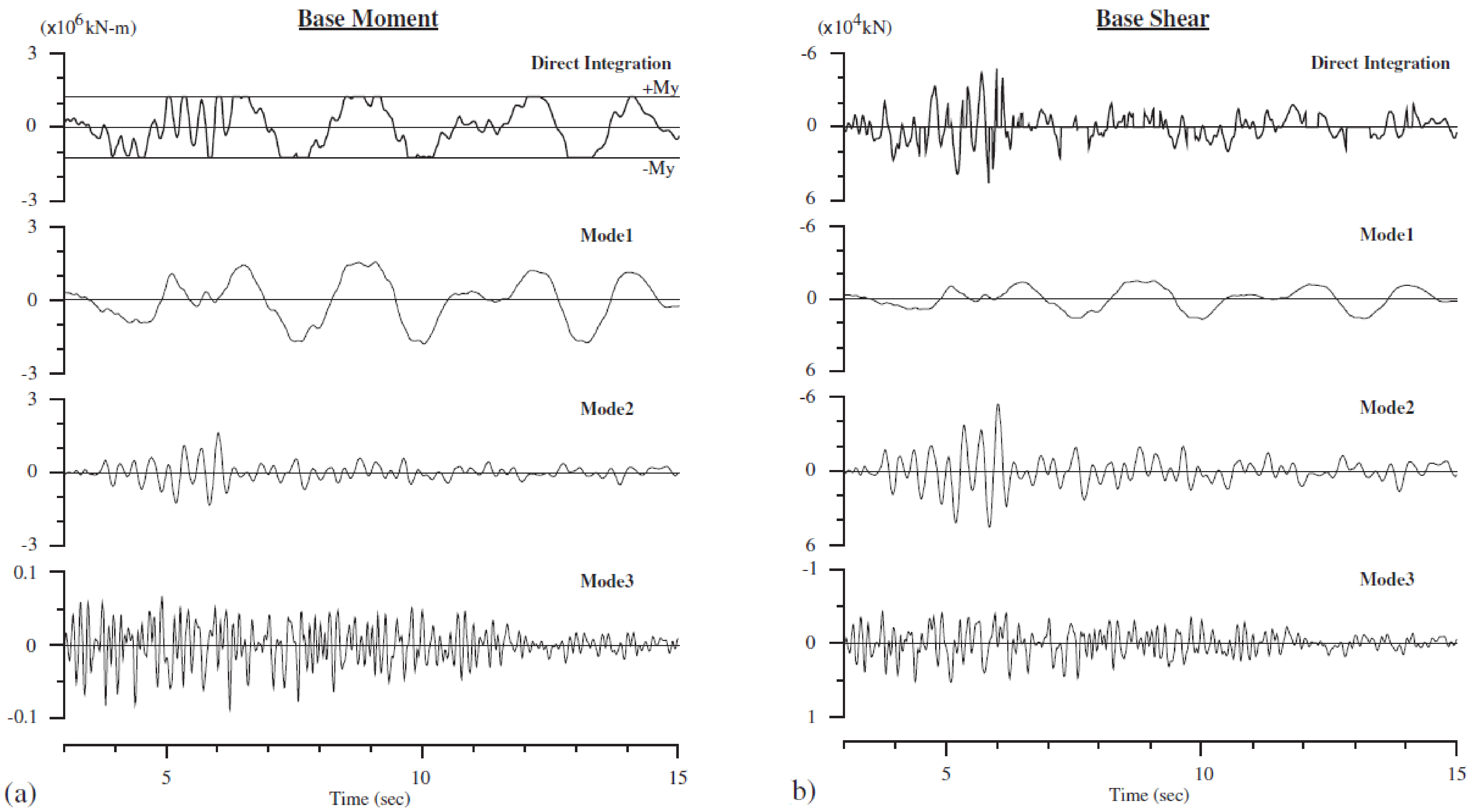

Figure 7. Modal decomposition results of 40-story wall building under the ANFS ground motion: (a) modal base moment; (b) modal base shear; (c) comparison of combined modal moment and DI moment; and (d) comparison of combined modal shear and DI shear.

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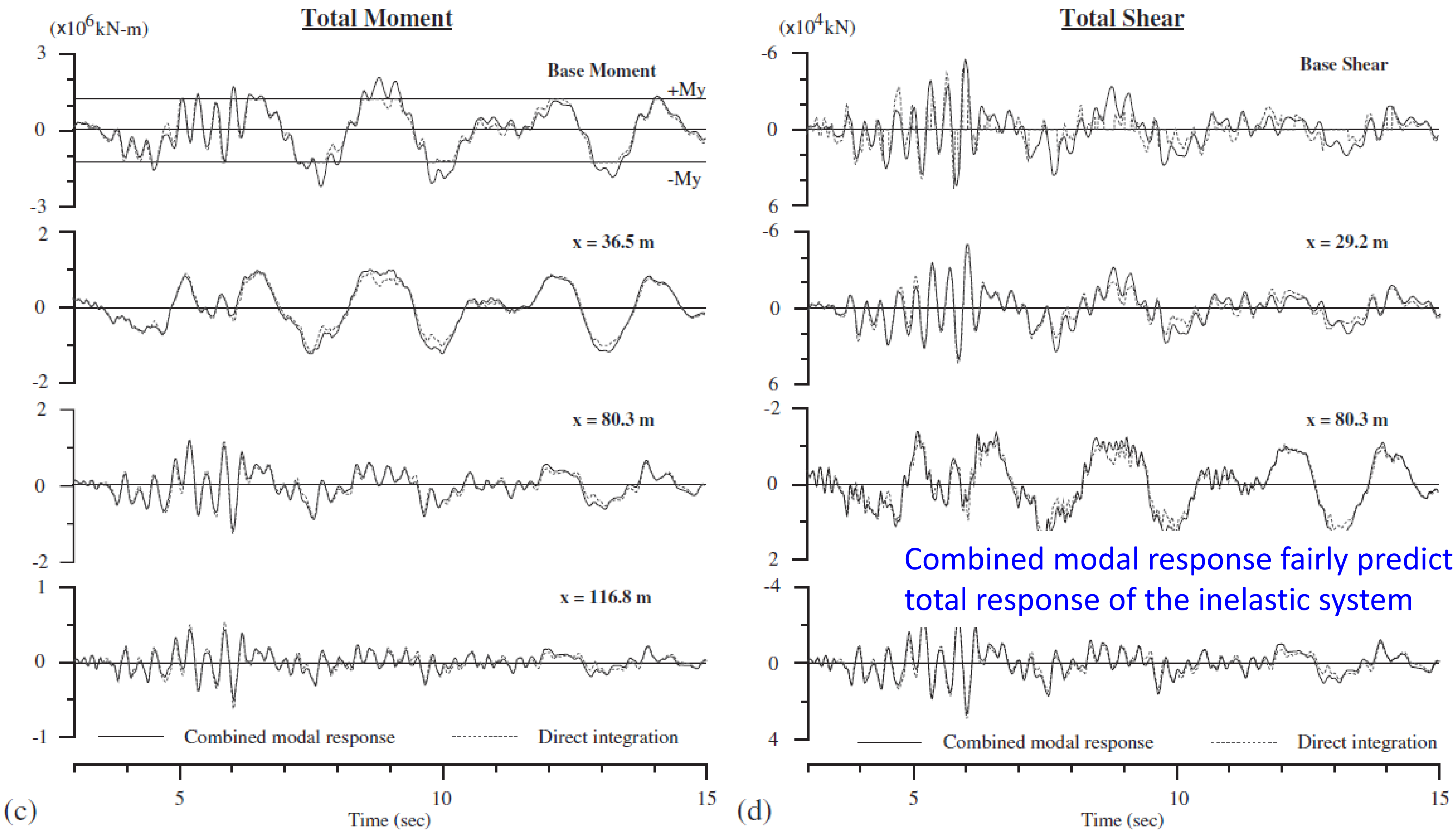

Combined modal response fairly predict the total response of the inelastic system

Figure 7. Modal decomposition results of 40-story wall building under the ANFS ground motion: (a) modal base moment; (b) modal base shear; (c) comparison of combined modal moment and DI moment; and (d) comparison of combined modal shear and DI shear.

Summary

- *Modal decomposition provides the physical insight into the complex response of the complex dynamic system*
- *Both direct method and orthogonal method fairly predict the total nonlinear response of the system*
- *This approximate method will be very useful in the development of different alternative method for the inelastic analysis of the complex system like high rise buildings*
- *Orthogonal filter can be used to extract the individual response from the total response of the system*
- *The accuracy of this approximate modal decomposition method depends on the accuracy of the equivalent linear system*

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Recommendation

- *Consideration of the effect of shear deformation*
- *Consideration of the effect of axial load effects*
- *Find a better way to model the equivalent linear model*

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1. Chopra, A. K. (2007) Dynamics of Structures: Theory and Applications to Earthquake Engineering, 3rd Edition, Pearson Prentice Hall: Upper Saddle River, NJ.

2. Sangarayakul, C., & Warnitchai, P. (2004). Approximate modal decomposition of inelastic dynamic responses of wall buildings. *Earthquake engineering & structural dynamics*, *33*(9), 999-1022..

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