Optimization of Tuned Mass Damper parameters based on numerical optimization and model reduction

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1. Context

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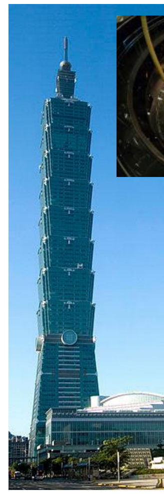
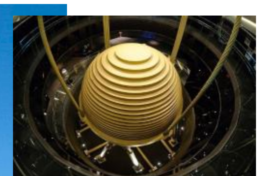
Mechanical tuned vibration absorbers


Mass-spring
Tuned Mass Damper
(TMD)

Pendulum
Tuned Mass Damper
(PTMD)

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2. Question

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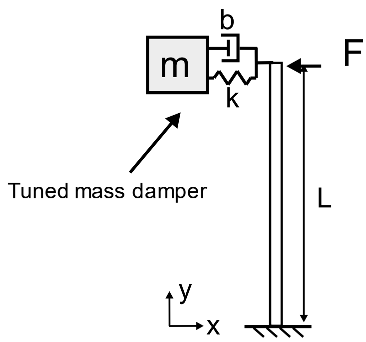
Design and optimization of TMDs



m,k,b ?

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3. Method

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3.1 Current approach

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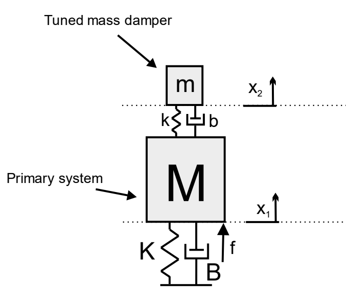
Basic theory of TMDs



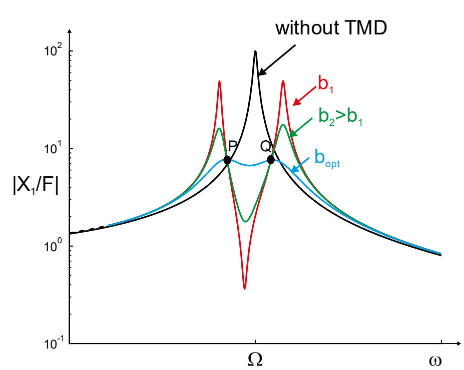
$$\omega_n = \sqrt{\frac{k}{m}}, \quad \Omega = \sqrt{\frac{K}{M}}$$

$$\nu = \frac{\omega_n}{\Omega}, \quad \mu = \frac{m}{M}$$

$$\nu = \frac{1}{1+\mu}$$

$$\xi = \sqrt{\frac{3\mu}{8(1+\mu)}} = \frac{b}{2\sqrt{km}}$$

[Den Hartog, 1956]



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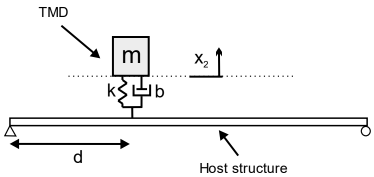
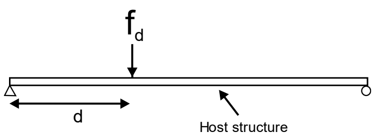
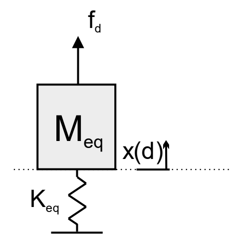
Analytical approach for complex structures





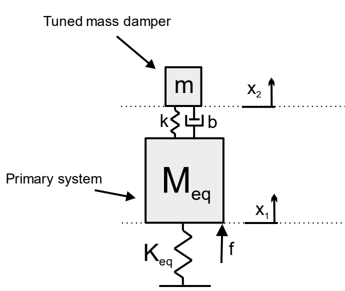
Single mode approximation

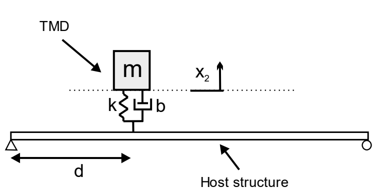
$$M_{eq}\ddot{x}(d) + K_{eq}x(d) = f_d$$



$$M_{eq} = \frac{\mu_j}{\psi_j^2(d)}, \quad K_{eq} = \frac{\mu_j \omega_j^2}{\psi_j^2(d)}$$

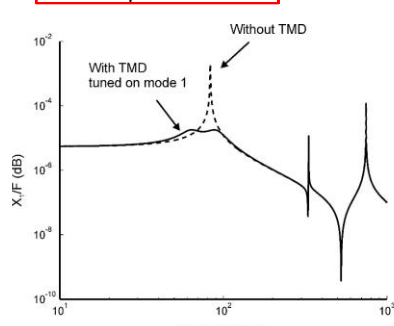
Analytical approach for complex structures





$$\nu = \frac{1}{1+\mu}$$

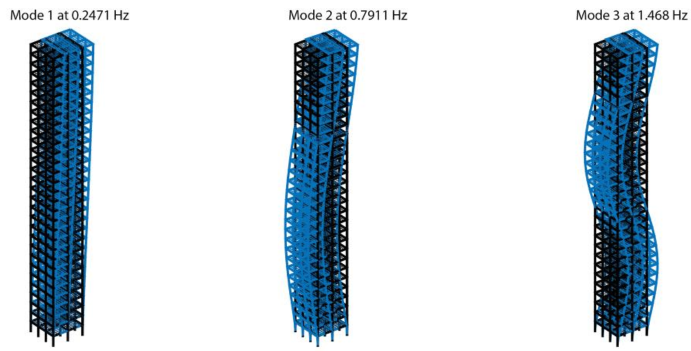
$$\xi = \sqrt{\frac{3\mu}{8(1+\mu)}}$$



Analytical approach for complex structures

$$M_{eq} = \frac{\mu_j}{\psi_j^2(d)}, \quad K_{eq} = \frac{\mu_j \omega_j^2}{\psi_j^2(d)}$$

Requires to compute the first mode shapes of the structure



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3.2 New approach

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Problems associated with the analytical approach

Reduction of the main system to a one dof system :
- Introduces errors leading to sub-optimal solution
- Is not possible in the case of base (earthquake) excitation

Optimized quantities are limited to:
- Harmonic force excitations
- White noise random excitations

Alternative numerical approach

Equations of motion in the frequency domain (host structure + TMD)

$$(K - \omega^2 M + j\omega B)X = F \quad (1)$$

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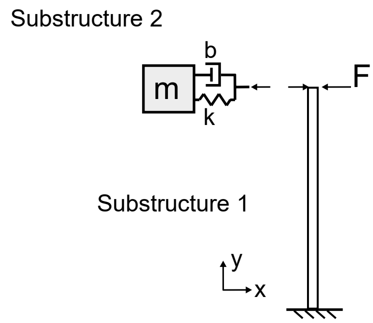
Definition of a cost function :

$$\text{maximum of } |X/F| \text{ in a frequency band around } \omega_j$$

Use of Matlab *fminsearch* function to find *k,b* which minimize the cost function

Typically, this requires to solve 100 000 times eq (1) when 2000 frequency lines are used

Ingredients for efficient model reduction



- Substructuring
- Reducing host structure using Mac-Neal with adequate static corrections
- Pre-assemble and reduce host structure and TMD matrices separately

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4. Results

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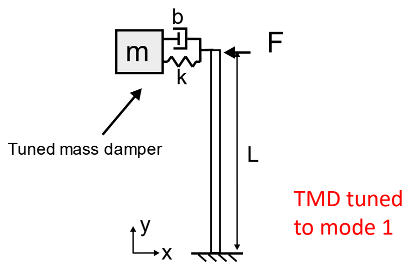
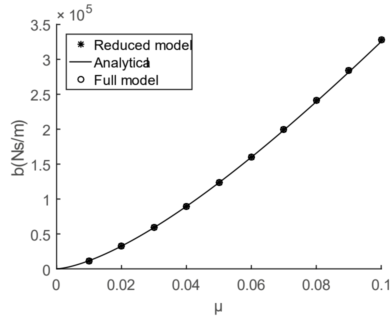
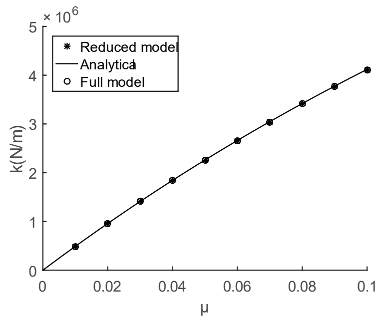
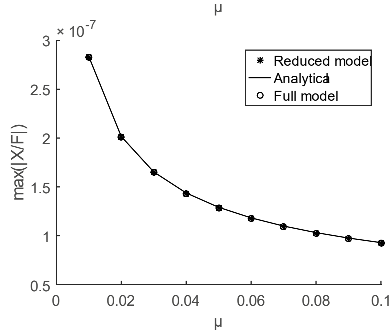
Example of a cantilever beam









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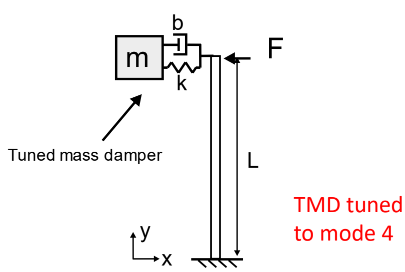
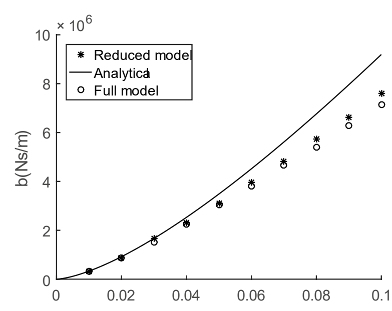
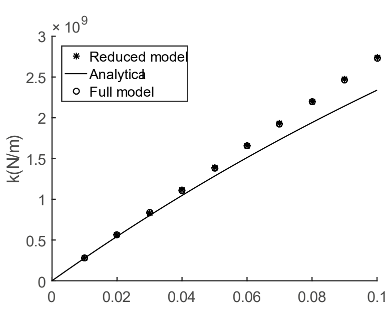
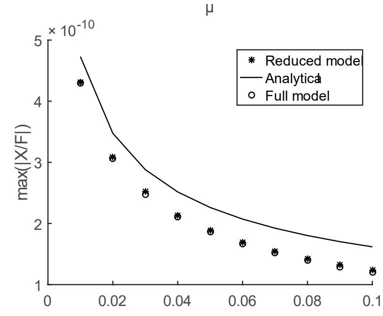
Example of a cantilever beam









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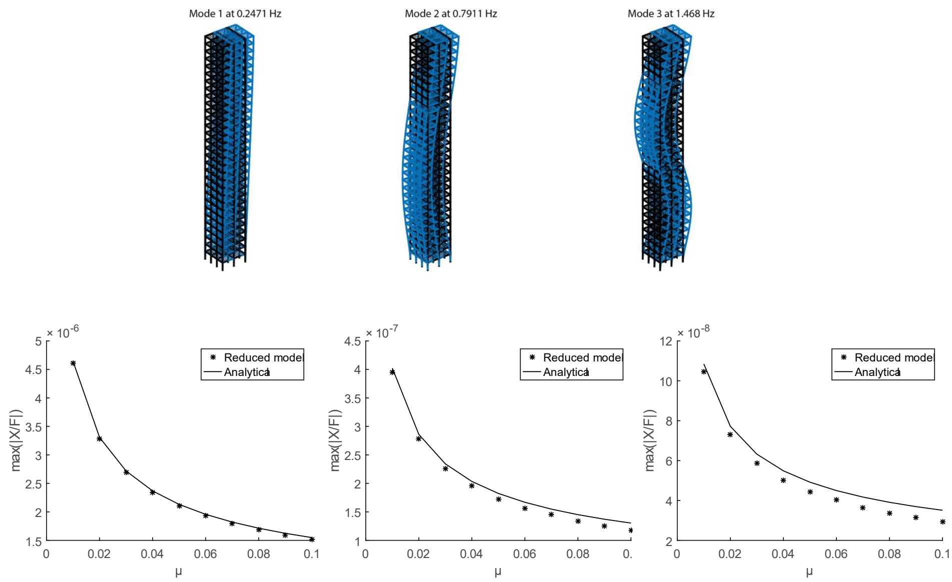
Application to a large finite element model of a building



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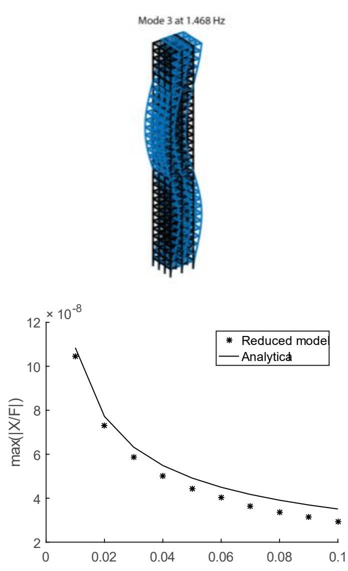
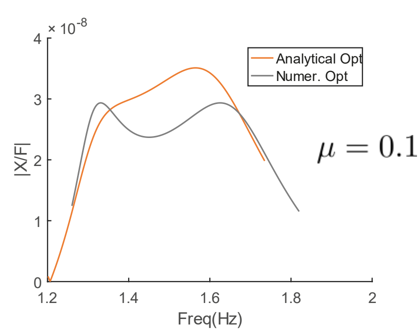
Zoom on mode 3 detuning





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5. Information

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Conclusion

- Limitations of the analytical approach
  - SDOF approximation
  - Base excitation problem
  - Harmonic or white noise excitation
- Limitations of the numerical approach
  - Computational costs

-> Introduction of efficient model reduction techniques

- Illustration on a 55 000 DOFs model with harmonic force excitation
  - Leads to true optimal solutions compared to full model
  - Model reduction cost = 1 min / Optimization cost = 3sec
  - Full model optimization cost = 2 days

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6. Future

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Perspectives

- Extension to other load/output cases to treat realistic cases of
  - Wind excitation (prescribed power spectrum)
  - Earthquake excitation (base excitation + given spectrum)

  where no analytical solution can be derived

- Extension to include uncertainties/variations in host structure/TMD mechanical characteristics

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