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Tuned Mass Dampers in the Design of Light-Weight Structures

Theory, Numerical Simulation, Application

Lecture 01
Introduction

Structural Mechanics and Numerical Methods
Bergische Universität Wuppertal

Static Problems

Roman aqueduct

Scottish stone bridge

historical buildings: compact design philosophy

Dynamic Problems

Lighter structures are vulnerable to dynamic excitation

Dynamic Vulnerability

In general: structures become vulnerable to dynamic effects if their eigenfrequencies are low.

Eigenfrequencies are determined by the ratio of stiffness to mass. They are low if a small stiffness is combined with a relatively large mass. Flexible structures can easily be excited.

Typical Vulnerable Structures

- large-span bridges, e.g. the projected Messina Bridge
- light foot bridge, e.g. the Millennium Bridge London
- bell towers, especially with heavy bells inside
- high (guyed) masts
- light roofs, e.g. stadium roofs
- substructures, e.g. the cables and hangers in cable-stayed and suspension bridges
- floors in industrial buildings where heavy machines are working
- grandstands in stadia

Typical Excitations

- wind excitation:
  - buffeting
  - vortex shedding
  - aeroelastic self-excited forces, e.g. flutter
- human excitation:
  - pedestrian excitation: walking, jogging, running
  - crowd excitation: dancing, jumping
- harmonic and periodic excitations:
  - bells ringing
  - rotating machines

The Phenomenon of Resonance

Resonance can occur for harmonic loads:

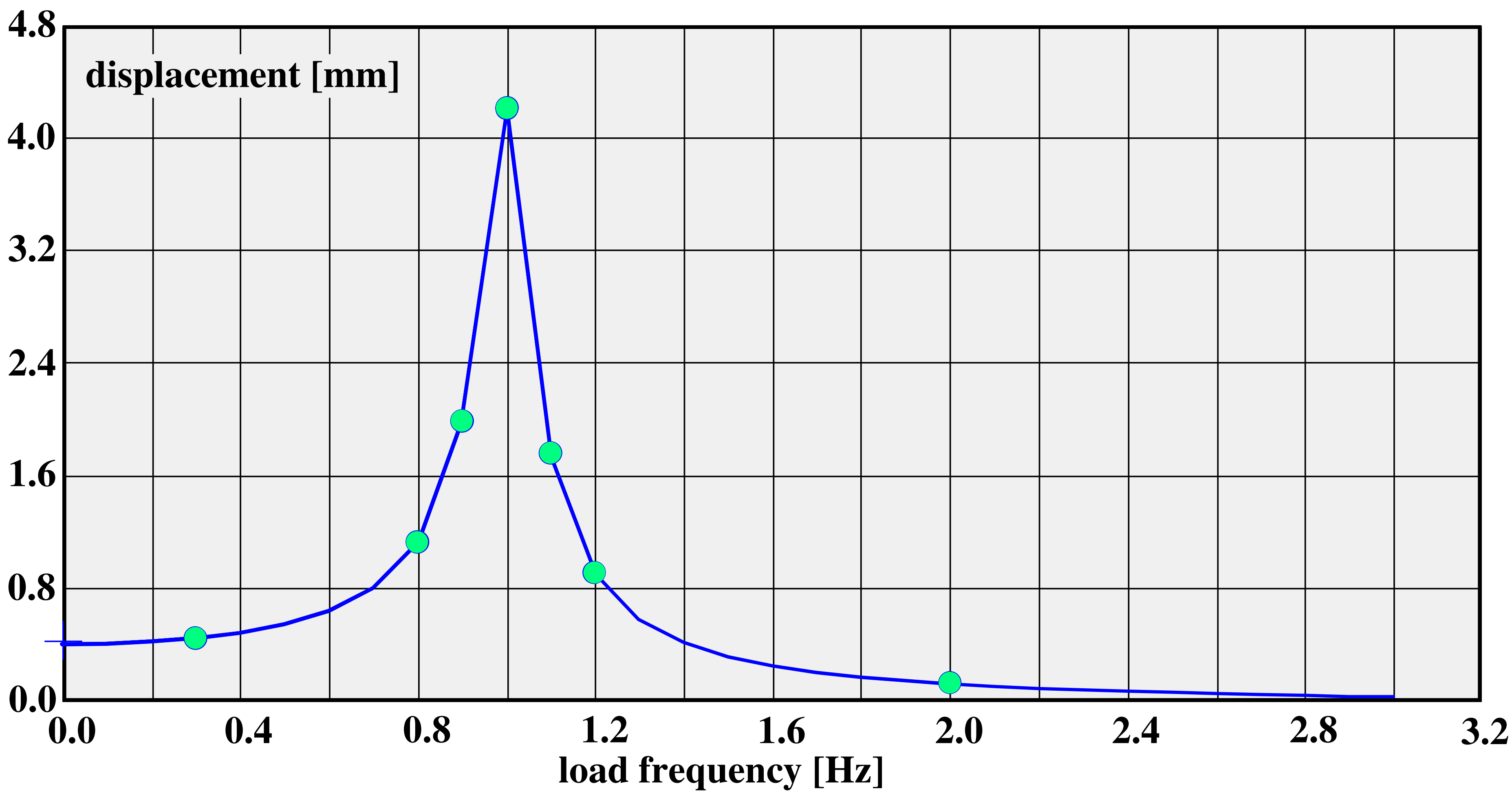
- The structure has an eigenfrequency ω,
- The load has a load load frequency Ω.

The dynamic amplification depends on the ratio between Ω and ω. Non-harmonic loads do not have a single load frequency, so strictly speaking there is no true resonance. Any load history can, however, be synthesized in a Fourier series (periodic) or a Fourier transform (non-periodic), so that a load history can be said to contain harmonics with different frequencies. Any harmonic can then be resonant with an eigenfrequency.

Resonance Spectrum

F in [Hz]

F = 0.3; F = 0.8; F = 0.9; F = 1.0; F = 1.1; F = 1.2; F = 2.0



Resonance: Consequences

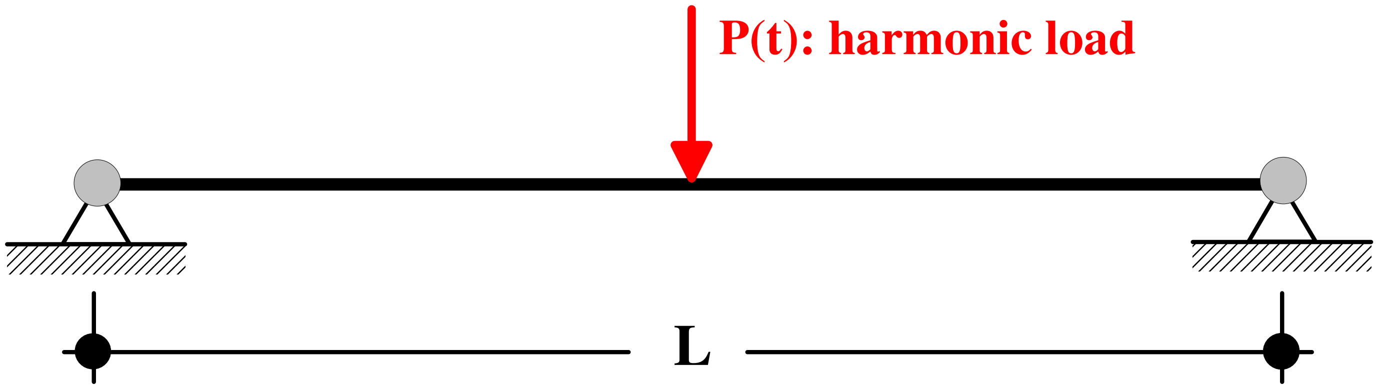
Many (not all) problems in structural dynamics are caused by *resonance*. The dynamic amplification can be very large (especially in cases of low damping) so that a sufficient strengthening of the structure is impossible.

What to do?

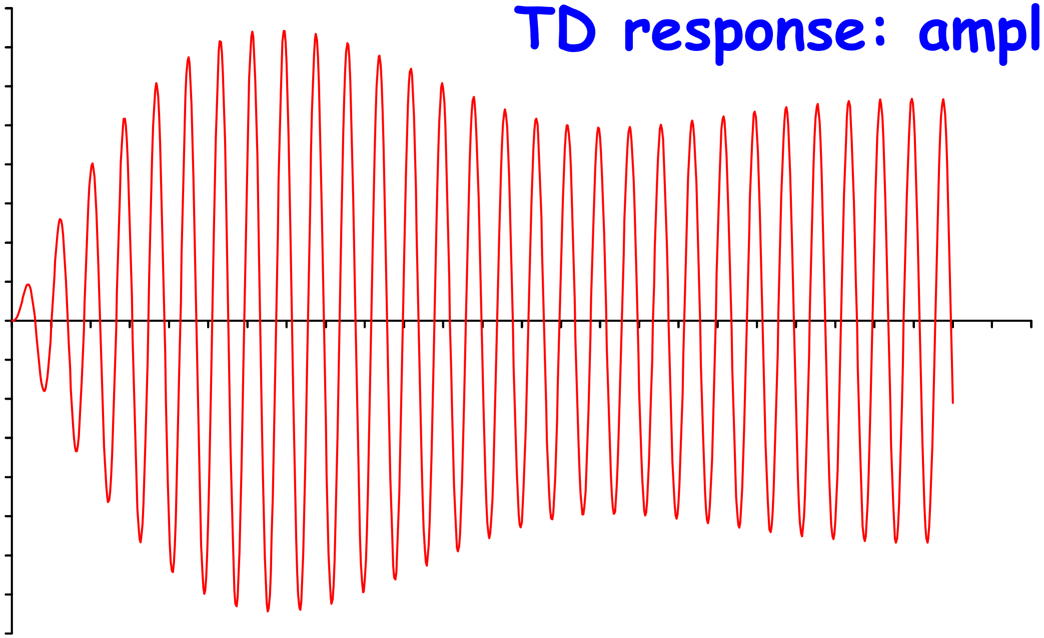
- **Avoid resonance by a design that is not primarily concerned with stresses but with the eigenfrequencies.**
- **Isolate structure or excitation from each other.**
- **Reduce the amplitudes by the installation of TMDs**
  Tuned Mass Dampers

Example: Simple Footbridge Model

beam (footbridge) under near-resonant harmonic load



TD response: amplitudes too large!

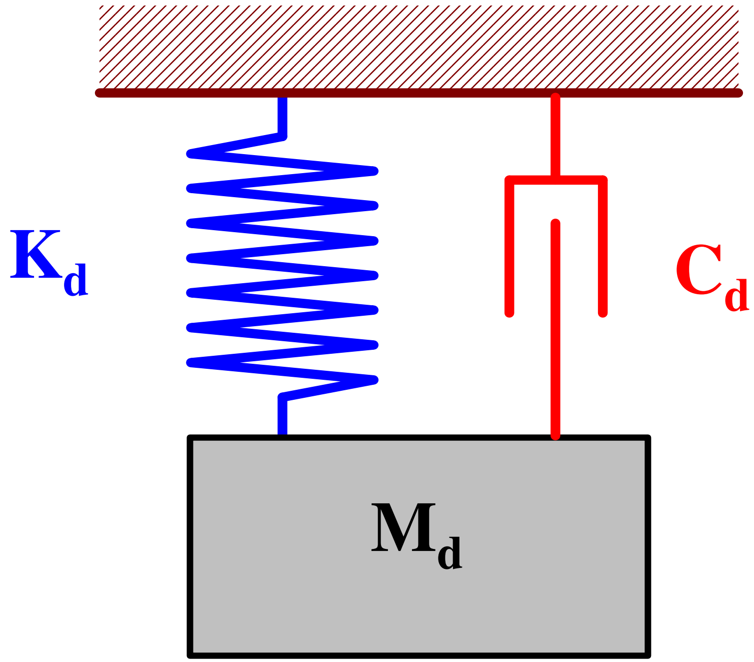


Attempt to reduce vibrations by introducing a TMD with 5% modal mass. The TMD contains no damping element.

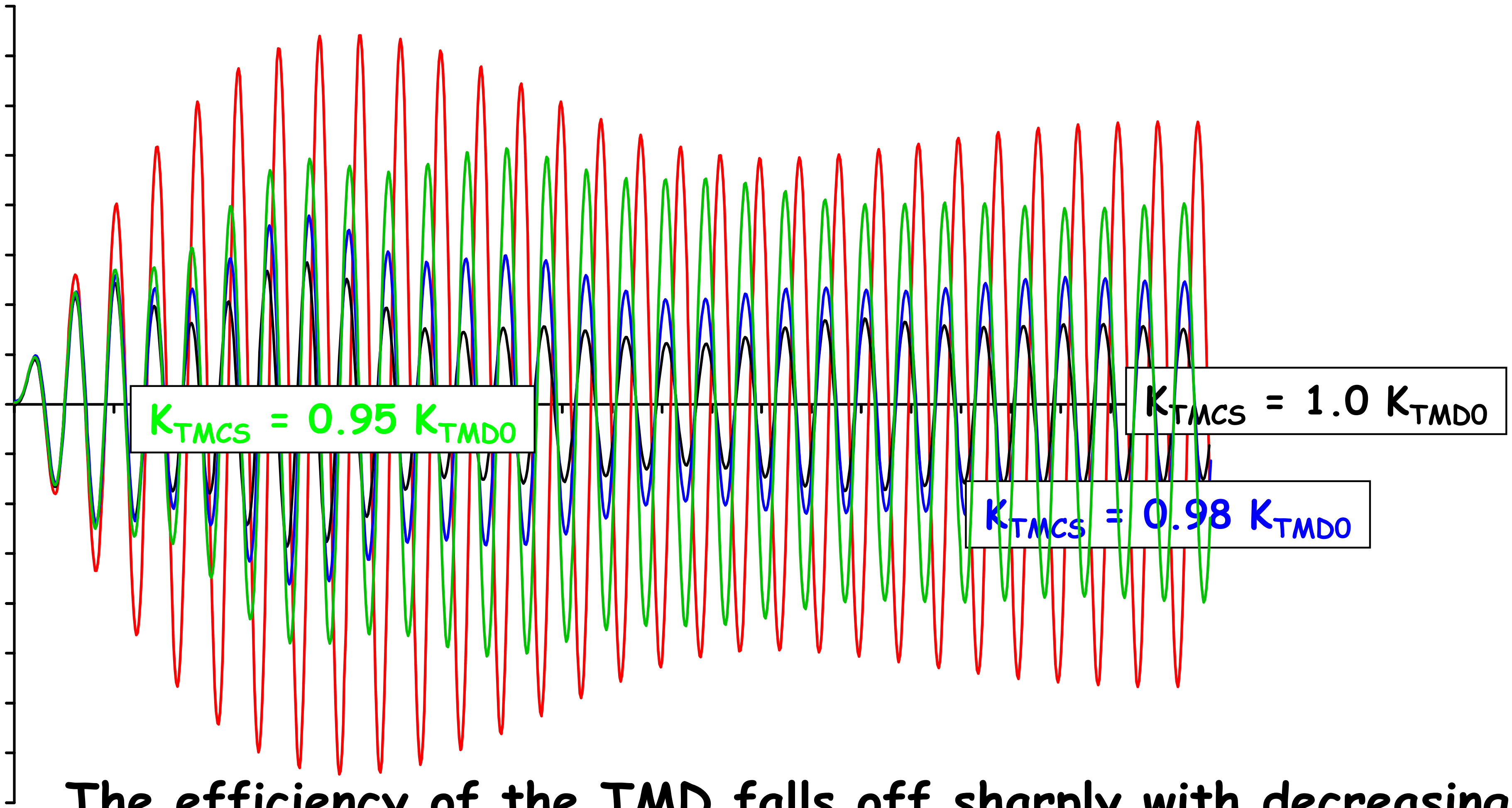
What is an TMD?

A (small) mass is elastically coupled to the structure. The stiffness of the spring is chosen such that the eigenfrequency of the TMD coincides closely with the eigenfrequency of the mode to be damped out.

The effective range of the damper can be broadened by adding a viscous element.

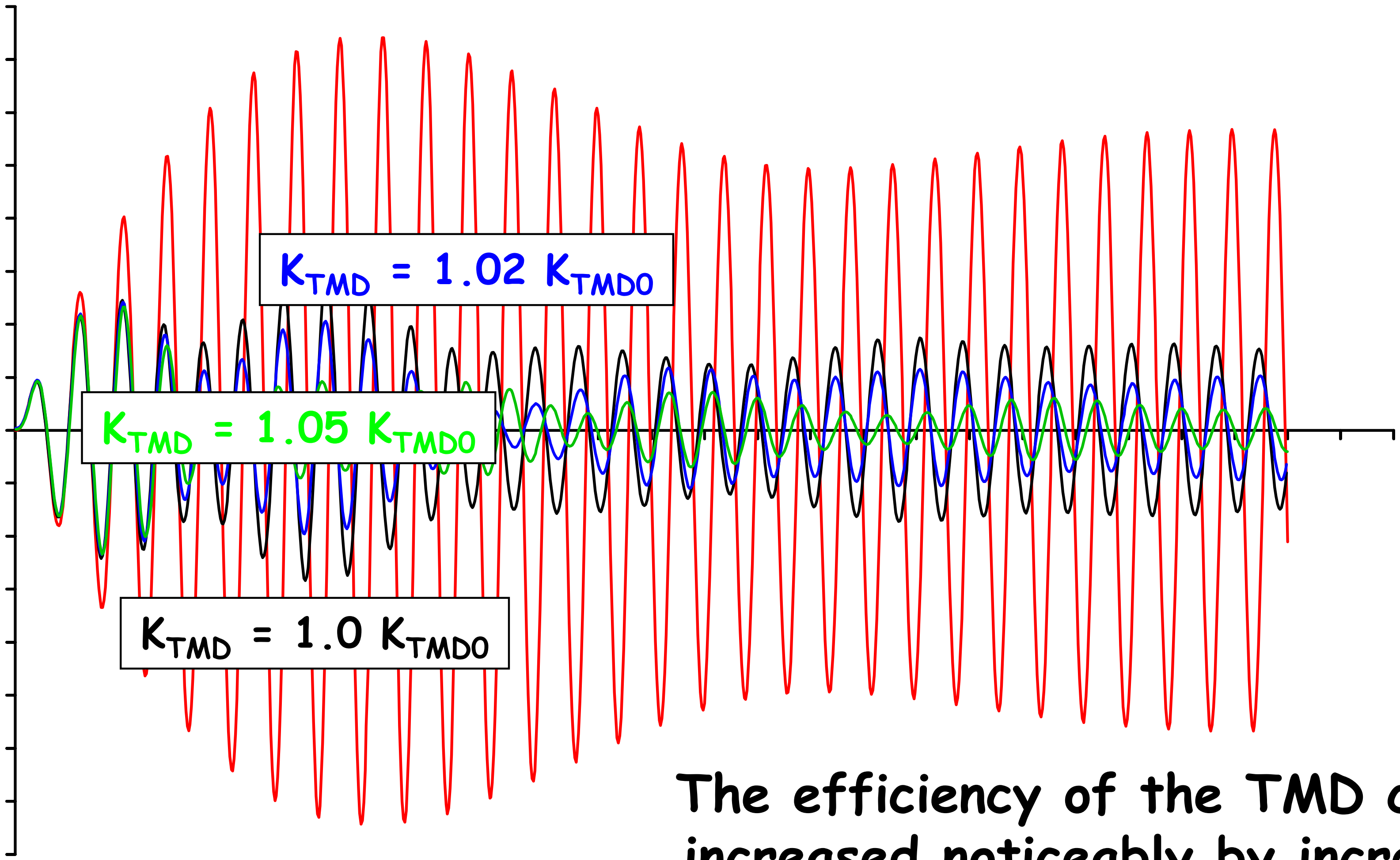


Tuning by Softening the TMD



The efficiency of the TMD falls off sharply with decreasing TMD eigenfrequncy

Tuning by Stiffening the TMD



The efficiency of the TMD can be increased noticeably by increasing its eigenfrequency.

Design of TMDs

We have observed by a numerical experiment that a small mass coupled to a structure can reduce the vibrations of the structure considerably.

We have also seen by experimenting with the TMD stiffness that the efficiency depends on the tuning of the TMD.

What we don't know now is a rational method of designing the TMD that gives the largest possible amplitude reduction while at the same being robust and safe with respect to fuzzy structural and load parameters.

That will be covered in the following.