Controlling Harmful Vibrations in a Building with a Passive Tuned Mass Damper

Engineering Practicum Report

ME395

by

Farhaan Alam (2001ME25)
Kritish Kumar (2001ME36)
Nischal Jain (2001ME41)
Shivam Yadav (2001ME70)

Department of Mechanical Engineering
Indian Institute of Technology Patna

Abstract

In a time where buildings are growing bigger to accommodate the large influx and growth of population in metropolitan cities, prevention of catastrophic failure of the structure due to vibrations induced by environmental factors, like dynamic winds or seismic loads, near the natural frequency of the building structure, is essential while designing the building itself. An efficient method of reducing the effects of these vibrations is designing a damper which damps these vibrations and thus reduces the loads on the building

A pendulum style damper is a simple and elegant damper which has also been used in a professional capacity in the Taipei 101 tower. Using a pendulum, we can control (or rather, in our case, dampen) the vibrations in a structure.

In our scale model made of flat steel rods and plywood, we use a pendulum-style mass damper.

Introduction

In the late 19th and early 20th century, most large civil structures were built using rather conservative design processes resulting in stiff structures. As the sizes of the structures increased over time due to the rapid growth in human population, trade and business, there was a need for lighter materials to construct these structures.

This resulted in the development of lighter, more slender structures, which proved far more susceptible to large deflections resulting from dynamic wind or seismic loads caused when the dominant frequency in the loading or driving function neared the natural frequency of the structure. This undesirable condition (for typical infrastructure facilities) is resonance or near-resonance.

The use of dampers can remove energy from physical systems, but damping it too much can increase the structure's stiffness. Using a passive Tuned Mass damper (TMD), engineers can reduce the large displacements associated with the structure's resonance. Simply put, the energy that would have led to large displacements of the structure is now being diverted to drive the mass in the damper in the opposite direction of the displacement of the structure.

An excellent example of a TMD is in the Taipei 101 tower, which uses a 2 - DOF pendulum-type damper to keep the building steady on the typhoon and earthquake-prone Taiwan island.

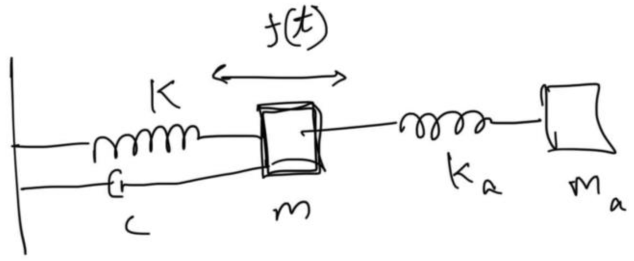
In our scale model, we use a similar pendulum-style damper, but we induce oscillations in only one DOF, using a 1-DOF damper for damping.

In our MATLAB simulations, we have estimated the damping coefficient and stiffness of the structure and modeled the effects of oscillations with and without the damper and compared both in a single graph.

Methodology and Theory

To explain our model, we considered the building-TMD system to be a two-degree-of-freedom coupled oscillator, with the building being damped and the pendulum (the mass damper) being undamped.

The building-TMD system can roughly be approximated as follows:



Considering a damped single-degree-of-freedom oscillator (with mass m, stiffness k and damping c driven by a sinusoidal force $f(t) = \underline{f}\ cos\ cos\ (\omega t)$) with an attached undamped and unforced SDOF oscillator, (with mass m_a and stiffness k_a), the coupled equations of motion are:

$$m\ddot{r}(t) + c\dot{r}(t) + kr(t) - k_a\big(r_a(t) - t(t)\big) = f(t)$$

$$m_a\ddot{r}_a(t) + k_a\big(r_a(t) - t(t)\big) = 0$$

Now, using complex-exponential notation for the responses in the two equations, i.e., $r(t) = \underline{r}e^{i\omega t}$ and $r_a(t) = \underline{r_a}e^{i\omega t}$ and the forcing function $f(t) = \underline{f}(t)e^{i\omega t}$, we obtain:

$$(-\omega^2 m + i\omega c + k + k_a)\underline{r} - k_a\underline{r_a} = \underline{f}$$

$$-k_a\underline{r} + (-\omega^2 m_a + k_a)\underline{r_a} = 0$$

and the frequency response function from forcing to the displacement response of the primary system mass, *m:*

$$H(\omega) = \frac{\underline{r}}{\frac{\underline{f}}{k}} = \frac{-\omega^2 m_a + k_a}{\left(\frac{1}{k}\right)(-\omega^2 m + i\omega c + k + k_a)(-\omega^2 m_a + k_a) - k_a^2}$$

In order to control the oscillations of the primary mass (i.e., the building), the frequency response of the primary system must be made zero at the forcing frequency. From the above equation, we observe that this is possible when the numerator becomes zero, i.e.

$$-\omega^2 m_a + k_a = 0$$

Or, the forcing frequency equals the natural frequency of the mass damper.

The parameters k, k_a can be taken as

$$k = 4 \times \frac{3EI}{L^3}$$

$$k_a = \frac{m_a g}{l}$$

Where

E = elastic modulus of the pillars used for the model building.

I = area moment of inertia about the neutral axis of the cross-section of the pillars.

L = length of the said pillars,

l = length of the pendulum,

g = acceleration due to gravity

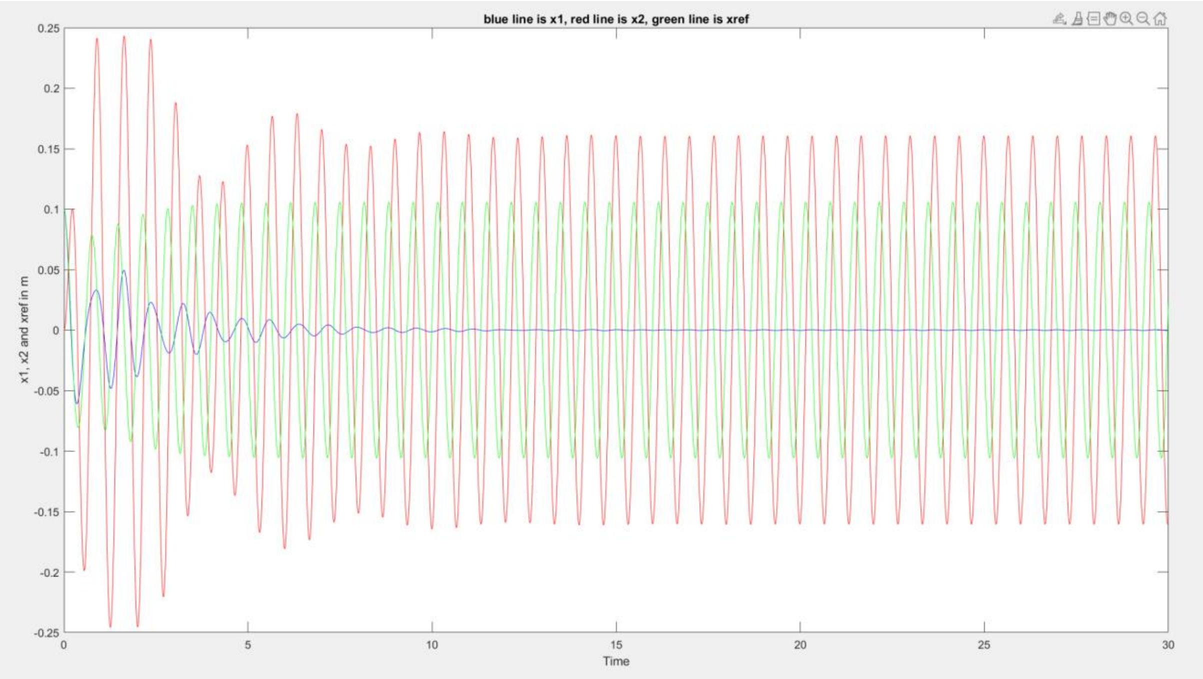
The MATLAB code for an optimized model for this project is uploaded here:

https://drive.google.com/drive/folders/1srBvzkSsylBhbH8ib1JTYHhPdcYhXj3r?usp=sharing

Active tuned mass dampers, meanwhile, are designed such that they may work for a wide range of forcing frequencies, as natural calamities such as earthquakes do not occur with predefined oscillating frequencies.

One way in which it may be designed is to dynamically vary the natural frequency of the pendulum by changing its length.

Results:



MATLAB code run for an optimized building model, run at a forcing frequency close to the resonance frequency of the building. Building's oscillations are shown in green while the building + TMD system is shown in blue. Notice the way the blue line stabilizes.

Conclusion:

In our practicum, a TMD was built to control the oscillation of the primary mass (i.e., building). However, due to our building ending up being too stiff, the pendulum length needs to be smaller than we anticipated to maintain natural frequency close to that of the building. Practically, this means that it will be difficult to get the observations we obtained from our simulations.

We have mentioned the results we got from the MATLAB simulations which theoretically shows the damping effect of pendulum.

Next task:

We have to improve the model with more flexible pillars so that we can better control its vibrations using the TMD.

Work on the active tuned mass damper and compare the results between active and passive tuned mass dampers so that we can understand the drawbacks of Passive TMD over Active TMD.