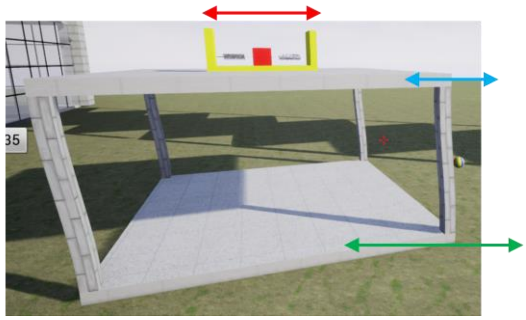
Worksheet 5
Tuned Mass Dampers

The activities here are presented with minimal guidance. They are merely suggestions to get you started, plus a little theoretical background which should help. You are free to plan and execute any investigation(s) you like. Remember to talk with other folk. You can choose to focus on a single-storey building, or multi-storey building. The level contains some prepared buildings of various stories, plus an experimental building where you can change the number of stories during run-time.



1.1 Basic Idea of a TMD

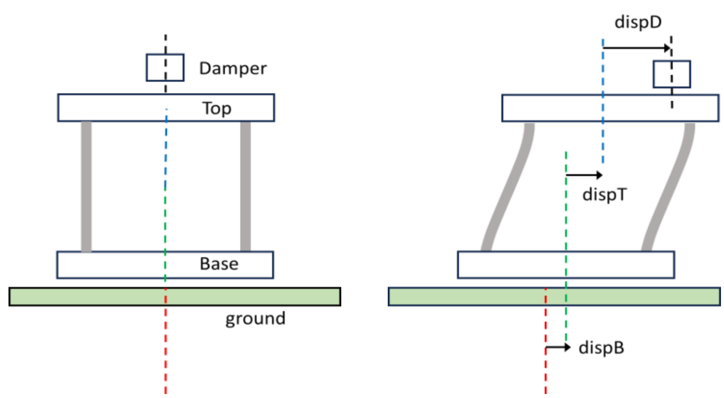
To keep things simple, let's work first with a single-storey building as shown on the right. During an earthquake the ground vibrates and causes the building **base** (green arrow) to vibrate. The **top** floor starts to vibrate (blue arrows) due to forces transmitted by the columns. You know that if the frequency of ground vibrations is right, then the amplitude of the top floor can become large, so the columns will bend and eventually fail. We therefore need to reduce the top-floor amplitude (blue arrows).

The TMD is an additional mass coupled to the top floor with springs and damping (yellow and red). The mass (red) starts oscillating (red arrows) and extracts power from the top floor, and through damping, converts this to heat. Since power is absorbed, the top floor vibrations are reduced and the building becomes safe.

New buildings can be designed with a TMD in place, but TMDs can be *retro-fitted* to existing buildings. Their mass is typically 1-2% of the building mass.

It's important to understand the output variables from the simulation. The computation generates a displacement of the building base, **dispB** relative to the ground. It then computes the displacement of the top floor **dispT** relative to the building base, and the displacement of the damper **dispD** relative to the top floor.

These *relative* displacements are useful; if you are in the building standing on the base, then you are interested in the relative displacement of the ceiling (top floor) above you since that's what you see. Similarly, it is the relative displacement between damper and top floor which determines how much power the damper absorbs. The diagram below should help.

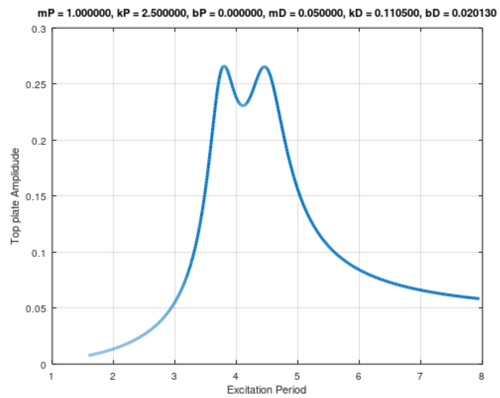


On the left is the equilibrium situation before the earthquake. The colored dotted lines indicate the starting location of the building components, all are aligned, there are no displacements. On the right is the situation during an earthquake; the building base is displaced relative to the ground; the top floor is displaced relative to the base and the damper is displaced relative to the top.

Of course, it is useful to know the *absolute* displacements of the top floor and the damper. These can be obtained by adding in the displacement of the base.

1.2 Designing the TMD

The mass, stiffness and damping of the TMD are design parameters which must be chosen. As mentioned above the mass is typically 1-2% of the building mass. That leaves stiffness and damping as two remaining free parameters. Theory shows how to set stiffness and damping to obtain the *optimal* removal of power.



The amplitude response of an optimally tuned TMD is shown on the right, note the horizontal axis is *period* (1 divided by frequency). There are two peaks, since there are two oscillating masses (top floor and TMD mass), remember the Multi-PIE system.

Let's first appreciate why there are optimal values of stiffness and damping.

(a) Run the Octave script **TMD_Response_Theoretical** which will plot this curve. When asked to input **bD** (damping of the TMD mass) enter **0.02013**, the optimal value.

(b) Repeat for **bD = 0.1** and **bD = 0.3** and compare all three plots.

(c) Looking at the plots, can you see why the value of **0.02013** is optimal?

1.3 Run the Simulation

Find the single storey building labelled **BendyBuilding,** select it and press **P** to grab its default parameters.

(a) The default parameters are the optimal ones mentioned above. Run the simulation and observe.

(b) Now ***plan an investigation***. But to do this, you must understand what the various parameters mean, their possible effect, and more importantly, which ones you should not change. Here we go to help with the ***planning***.

Param	Meaning	Could be changed?
kP	stiffness of columns	No. Defined by the building design.
mP	mass of the floor	No. Defined by the building design.
bP	damping by columns	Maybe; changing the concrete!
kD	damper stiffness	Yes. Free variable
mD	damper mass	Yes. Free variable
bD	damper damping	Yes. Free variable

Remember our task which is to remove vibration from the building. It's *damping* which is key here.

(c) Now conduct your (planned) ***investigation***. You need to choose a parameter to change (independent variable) and something to measure (dependent variable(s). Then, perhaps choose another and so on.

1.4 Multi-storey buildings

You could choose to investigate multi-storey buildings. Several pre-defined buildings are available, and there is even an option where you can define **N** the number of floors.

But a note of caution. As the number of floors increases, the *time to obtain a stable solution* will increase, and so the stable solution may be *intractable*. So you may end up investigating the vibration *transients* which is fine.

One possibility is to investigate the structures *without* the TMD, just to see how they behave. To do this you should set the parameters **kD = 0**, **bD = 0** which should decouple the TMD from the building.

So, what remaining parameter could you change? Well, I think there are two, **kP** and **bP** the stiffness and damping of the columns. These parameters follow from the engineering of the columns (made from reinforced concrete, a composite of steel bars and concrete glue); more steel means a higher stiffness, a different concrete mix could influence the damping.