Tuned-mass damper

SAP2000 V14.2.4 models.zip

Tutorial

Name:	Tuned-mass damper
Description:	An overview of the tuned-mass damper and guidelines for modeling the device.
Program:	SAP2000
Version:	
Model ID:	na

A **tuned-mass damper** (TMD), also known as a pendulum damper, is not really a damper, but rather a pendulum or another gravity-based oscillator which is attached to the structure in such a way that it counteracts the vibration of one or more fundamental modes, thereby reducing the wind and/or seismic response of those modes.

Within SAP2000 or ETABS, a TMD may be modeled using a spring-mass system with damping. Guidelines for this subsystem are described as follows:

- **Spring** – Assign spring properties to a linear two-joint link object in which one joint is attached to the structure, and the other joint is free.
- **Mass** – Mass and weight are then assigned to the free joint.
- **Damping** – Within SAP2000, linear damping is included directly in the linear link property, while nonlinear damping is modeled using a viscous-damping link object in parallel with the linear link. Within ETABS, whether the system is linear or nonlinear, these damping objects are modeled in parallel.

Reference files

For reference, two SAP2000 models are attached, each identical except that Model 1 does not use a TMD, whereas Model 2 does. These models, also available in the Attachments section as a zipped file, are described as follows:

- **Model 1** – TestModel_Without TMD.SDB does not use a TMD, serves as the control system, and is used to determine the frequency of the structure.
- **Model 2** – TestModel_With TMD.SDB features a subsystem which simulates the effect of a pendulum damper.

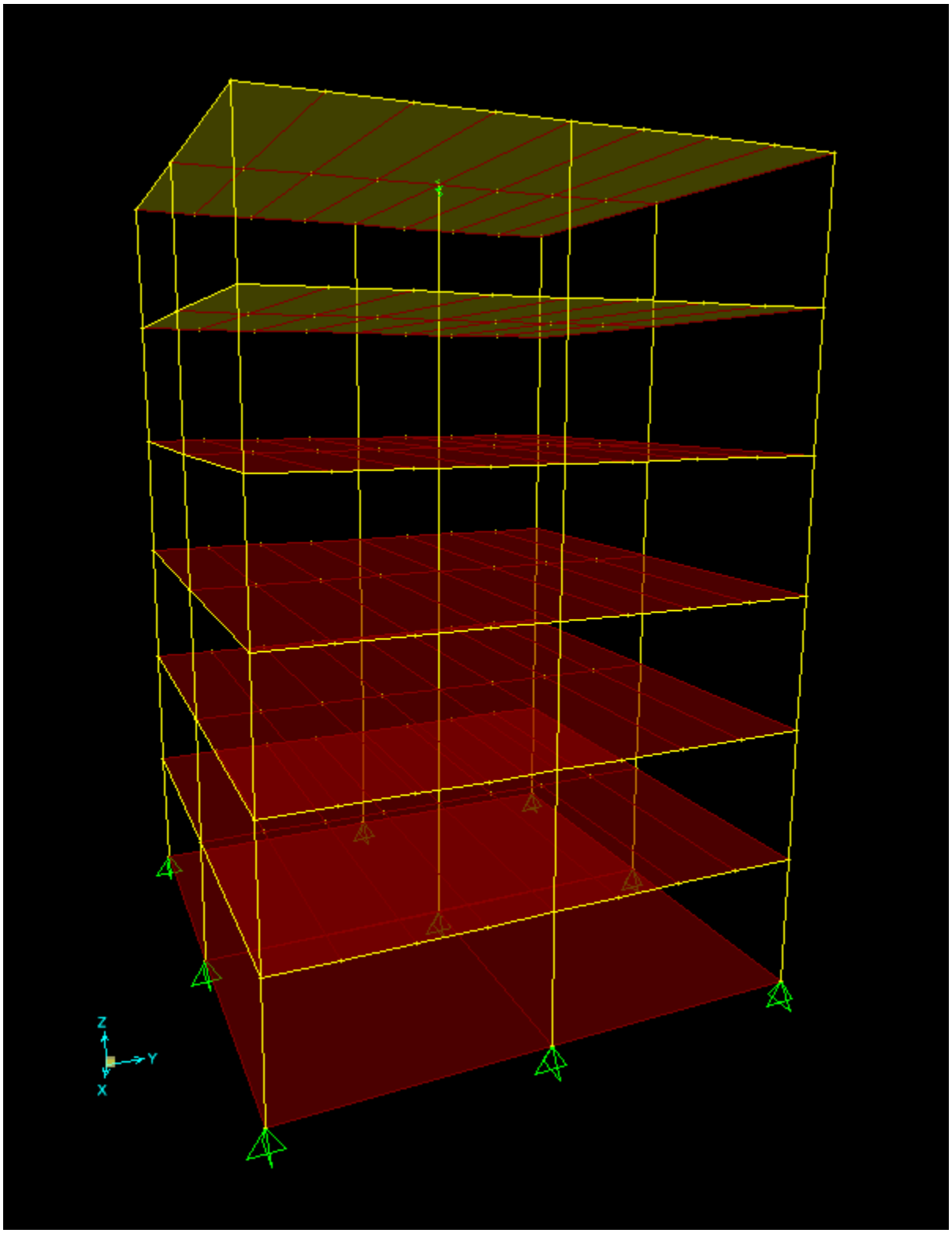


Figure 1 - Model 2 - Test model with TMD

Procedure

The general procedure for modeling a tuned-mass damper is given as follows:

1. Specify link properties

Any spring-mass system may represent the swinging pendulum in 2D. Here, spring constant is given as Mg/L, where M is mass, L is pendulum length, and g is gravity. It is slightly more challenging to model a pendulum which is free to translate in 3D. In this case, a linear link is created to represent the pendulum device. Select Define > Section Properties > Link/Support Properties, then define translational stiffnesses along U1, U2, and U3. The linear stiffness along U1 represents axial properties, and should be based on the EA/L value of the hangers, which is 1.0e6 kN/m in Model 2. The linear stiffness properties of U2 and U3 are chosen as Mg/L. In Model 2, the link is drawn at the top story. Link length is chosen as L = 0.1m, and mass is M = 10 kN-sec^2/m.

- **Length** – Pendulum length directly affects the period of the TMD. This is accounted for in the spring and mass properties used. However, the drawn length of the link object is arbitrary and may be chosen for convenience; it may even be zero. We recommend drawing the link such that the I-end (first joint) attaches to the structure, and the J-end (second joint) is free. In this case, within the linear link property, the shear distance from end J may be set to zero for the U2 and U3 DOF.
- **Mass** – Mass strongly affects how the TMD influences response. Changes to mass must be accounted for in the following locations:
    - Mass (M) should be assigned to the free joint (J-end of the link).
    - Weight (W = Mg) should be assigned to the free joint (J-end of the link) as a joint force load in the gravity direction in any self-weight load pattern.
    - Effective stiffness (Mg/L) of the U2 and U3 link properties.
- **Period** – Generally, the period (T) of the TMD is chosen to closely match the structural period to be counteracted, taken as the first period of vibration of control model. Note that, although the mass does not affect the period of the TMD, it does affect how strongly the TMD affects the rest of the structure, with larger masses typically having a larger effect. The period of the TMD is given by:

$$T = 2\Pi\sqrt{\frac{M}{K}} = 2\Pi\sqrt{\frac{M}{Mg/L}} = 2\Pi\sqrt{\frac{L}{g}}$$

  Once the period of the TMD is derived, TMD length is calculated from this value and gravity. This length, along with gravity and the arbitrary mass value, are then converted into the effective link stiffness of the U2 and U3 directions, given as Mg/L. This being the case, the length of the TMD in the real structure is not explicitly modeled, but is accounted for in the link property.
- **Damping** – Damping is defined as either a linear C coefficient or a nonlinear C value plus an exponent on the velocity term. Damping values should be chosen based on the physical characteristics of the TMD device. This damping source affects the TMD itself, but it is not the primary energy-dissipation mechanism for the structure as a whole. For a linear damper, an estimate of the fraction of critical damping () for the TMD is:

$$\xi = \frac{C}{2\sqrt{KM}} = \frac{C}{2\sqrt{M^2g/L}} = \frac{C}{2M\sqrt{g/L}}$$

2. Define the time-history analysis

Time-history analysis should be performed using either nonlinear modal (FNA) or direct-integration (linear or nonlinear) time-history load cases. These types of analyses correctly account for the coupling of the modes, an effect which may be caused by damping in the TMD device. If damping is small, it might be possible to obtain reasonable results using a linear modal time-history analysis, and possibly even response-spectrum analysis.

To provide overview for this procedure, the time-history load case of Model 2 is defined as follows:

- **TMD period** – Create a control model which does not have a TMD device. Run modal analysis and measure the fundamental period of the 1st mode. The TMD will be designed to counteract response which results from this mode.
- **Time function** – Select Define > Functions > Time History, then define a sine curve which has a period equal to that of the 1st mode of the control model. In this case, a period of 0.6 seconds is obtained.
- **Load case** – Add a nonlinear modal time-history load case which assumes 5% modal damping and uses 200 output steps, each 1/20th the size of the 1st time period.
- **Response** – Run analysis and review various response measures through Display > Show Plot Functions. As expected, response for the tuned-mass-damper model is found to be reduced.

Attachments

- **Model 1** – TestModel_Without TMD.SDB (SDB file)
- **Model 2** – TestModel_With TMD.SDB (SDB file)
- **Zipped File** – SAP2000 V14.2.4 models (zipped SDB files)