

TMD – Tuned Mass Damper

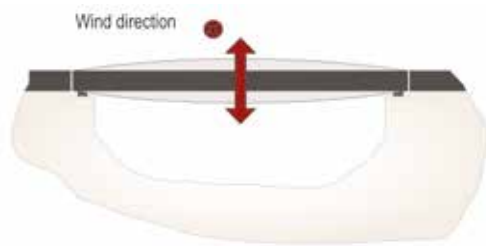
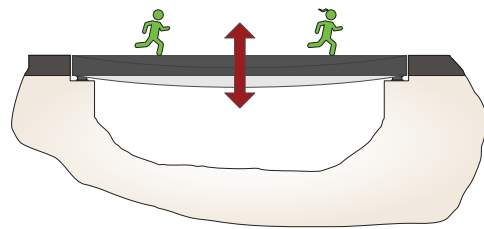


Bridge applications

In addition to static loads, bridges are also subjected to dynamic disturbances such as wind, traffic, and pedestrian loads. Particularly in slender and lightweight structures, these excitations may lead to structural vibrations. If displacement or acceleration limits are exceeded, user comfort may be impaired, material

fatigue may occur and, in extreme cases, structural damage may result.

To mitigate these effects, dedicated vibration control systems such as Tuned Mass Dampers (TMDs) are adopted.



Mumbai Trans Harbour Link

The Mumbai Trans Harbour Link is a 21.8 km long, six-lane expressway bridge connecting Mumbai with Navi Mumbai and is considered the longest sea bridge in India. To reduce vertical wind-induced vibrations, a special system of Tuned Mass Dampers (TMDs) was implemented in the structure. This includes 40 vertical TMDs, each with a mass of 4.8 t, supplied by MAURER and tuned to dampen the eigenfrequencies of the critical bending modes.



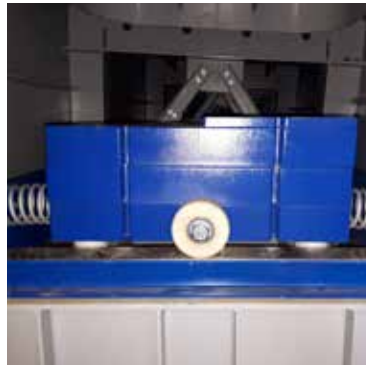
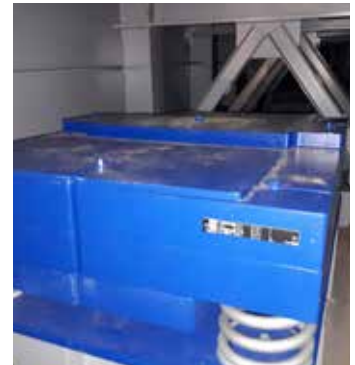
Hong Kong-Zhuhai-Macau Bridge

The Hong Kong–Zhuhai–Macau Bridge is a 55 km long bridge–tunnel system. It is both the longest sea crossing and the longest fixed link over open sea worldwide. It connects Hong Kong and Macau with Zhuhai. Using TMDs with masses ranging from 3.0 t to 6.25 t, bending modes with eigenfrequencies between 0.33 Hz and 0.8 Hz were mitigated.



Pedestrian Bridge Viaduct Parco di Luni

Slender pedestrian bridge located in the archaeological park of Luni, with high requirements regarding user comfort. To reduce pedestrian-induced vibrations, a total of six Tuned Mass Dampers (TMDs) were integrated: two vertical TMDs with a mass of 3,200 kg each, as well as four horizontal TMDs with masses of 1,000 kg and 2,200 kg, all tuned to the eigenfrequencies of 1.97 Hz, 2.34 Hz and 2.63 Hz of the critical bending modes.



Greenwich Design District Pedestrian Bridge

Slender pedestrian bridge within the Greenwich Design District, exhibiting increased susceptibility to vibration due to pedestrian-induced excitation. To improve user comfort, a Tuned Mass Damper (TMD) with a mass of 700 kg, tuned to the eigenfrequency of 2 Hz, was integrated into the handrail structure.



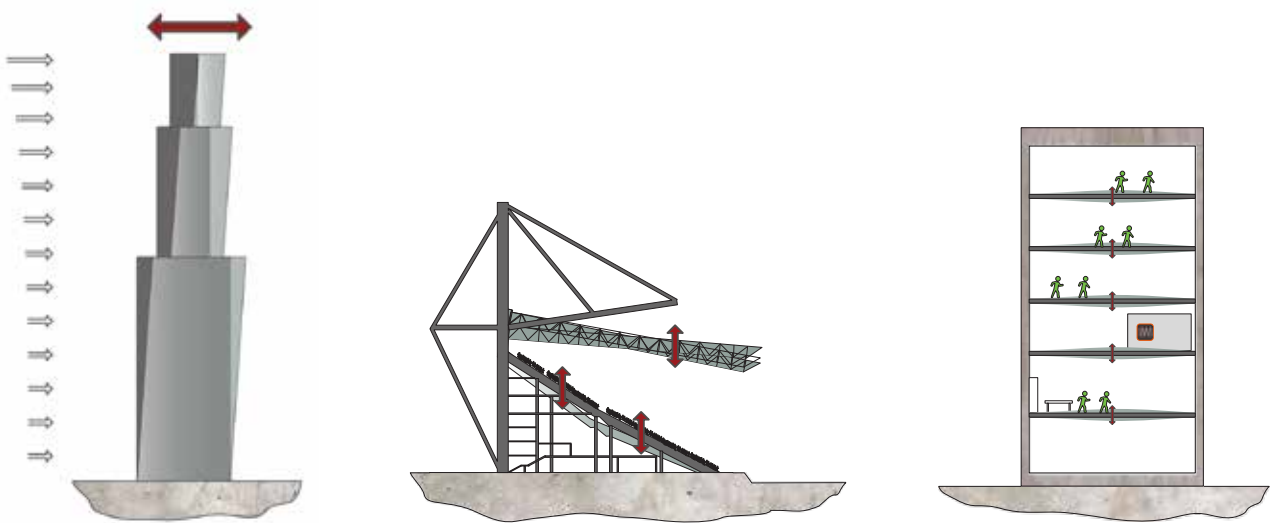
Building applications and industrial facilities

Buildings and industrial facilities are also subjected to dynamic actions such as wind and seismic loads. These can lead to noticeable structural vibrations and exceedance of acceptable accelerations and displacements, particularly in slender or tall structures.

The adoption of Tuned Mass Dampers effectively reduces structural accelerations and displacements. Typical applications include the mitigation of wind- and earth-

quake-induced vibrations in high-rise buildings, towers, and chimneys, as well as pedestrian-induced vibrations in grandstands, floors, and work platforms.

Further typical applications are found in industrial structures such as process and cooling towers, pipe racks, and machinery and plant platforms, where dynamic actions from wind, operation, or human activity occur.



SOCAR Tower in Baku, Azerbaijan

The 209 m tall SOCAR Tower is fitted with a high-performance Tuned Mass Damper system (TMD) for the control of wind- and earthquake-induced vibrations. The TMD with an approximate mass of 450 t is designed as folded pendulum to minimize the installation height. The TMD system is installed in the upper part of the building.

The folded pendulum TMD system was tuned to the eigenfrequencies of the bending modes in x- and y-directions, which are in the range between 0.16 Hz and 0.32 Hz. The TMD forms part of a multi-level protection concept and contributes not only to user comfort but also to the seismic performance of the high-rise building.



Baku Tower in Azerbaijan

The Baku Tower incorporates a large-scale Tuned Mass Damper (TMD) system to mitigate wind-induced structural vibrations at bending eigenfrequencies of 0.24 Hz in the x-direction and 0.27 Hz in the y-direction. Based on wind tunnel investigations, a pendulum TMD with a mass of approximately 400 t was installed in the upper part of the building. The system is designed to optimize serviceability and user comfort and reduces perceptible vibrations during frequently occurring wind events.



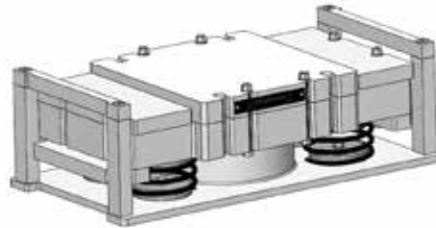
Roland Garros Tennis Stadium

At Court Philippe-Chatrier of the Roland Garros Tennis stadium, vertically acting Tuned Mass Dampers (TMDs) are used to control wind-induced vibrations of the slender, movable roof girders. Each of the steel box girders, which are over 100 m long, incorporates an individually tuned TMD with a mass of approximately 8 t, integrated directly into the girder. The TMD systems significantly reduce vibration amplitudes and ensure low-noise operation as well as enhanced fatigue resistance of the moveable roof structure, which allows opening and closing the roof within 15 minutes only.



Tuned Mass Damper MTMD

Slender and cantilevered structures may be prone to vibration, among other reasons, due to their low inherent damping of 0.5–1%. Without additional damping measures, large vibration amplitudes may occur, which reduce user comfort and lead to premature material fatigue.



Structural Safety

- Resonance avoidance to exclude structural damage
- Reduction of dynamic loads

Vibration Comfort

- Reduced accelerations
- Enhanced user comfort

Structural Durability

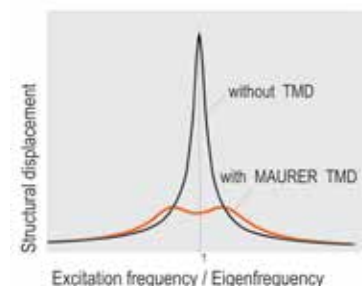
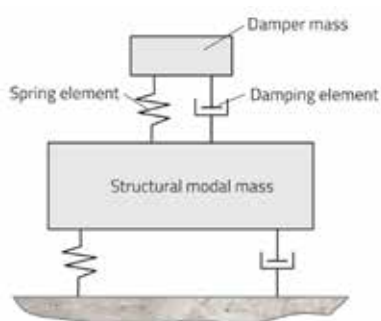
- Reduced fatigue
- Extended service life

MAURER tuned mass dampers are individually designed for each structure. The Tuned Mass Damper (TMD) is based on a spring-mass-system. The mass is designed in relation to the modal mass of the mode to be mitigated to guarantee the required supplemental damping. The natural frequency of the spring-mass-system is optimally tuned to the eigenfrequency of the critical mode by adjusting the spring stiffness and/or the mass.

The geometry of a TMD is adapted to the structure on a project-specific basis. Applications range from small TMDs in traffic guidance systems or bridges to large-scale applications in high-rise buildings.



Bigger ratio μ between TMD mass and modal mass of the critical structural mode enhances the vibration reduction, enlarges the bandwidth of the TMD with high efficiency and reduces the TMD relative motion. This also results in a lower damper mass amplitude.



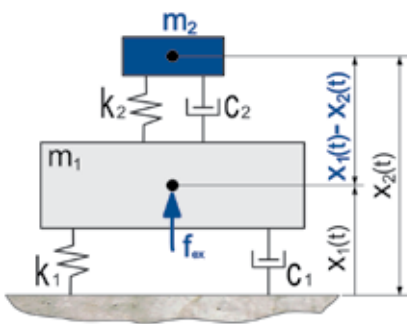
If possible the TMD is placed as close as possible at the position of greatest velocity (kinetic energy) of the critical mode. The optimal TMD frequency tuning ensures that the TMD mass oscillates at a phase angle of 90° relative to the structural displacement and thereby maximizes the structural vibration reduction. Depending on the mass ratio the reduction of structural displacements and accelerations is up to 90%.

Design

To minimize structural displacements and accelerations, the natural frequency f_2 and the damping ratio ζ_2 of the Tuned Mass Damper are optimized for the given eigenfrequency and modal mass of critical structural vibration mode.

The following parameters are required for the design of the Tuned Mass Damper:

- Eigenfrequency f_1 of the structural mode to be mitigated
- Corresponding modal mass m_1
- Maximum acceptable displacement and acceleration amplitudes of the structure
- Available installation space



- f_1 : eigenfrequency of the structural mode to be mitigated
- m_1 : modal mass
- k_1 : stiffness
- c_1 : viscous damping coefficient
- x_1 : displacement
- f_{ex} : excitation force
- m_2 : TMD mass
- k_2 : TMD stiffness
- c_2 : TMD viscous damping coefficient

For the selection and design of TMD, MAURER offers additional services:

- Vibration testing of the structure without TMD to assess the actual vibration amplitudes and eigenfrequencies
- Consulting for the design of the optimal Tuned Mass Damper
- Nonlinear time-history analysis (simulation) with wind, seismic and pedestrian excitations, without and with TMD
- Installation of the damper
- Stationary vibration tests and free decay tests, as a final functional verification
- Monitoring

Types of Tuned Mass Dampers

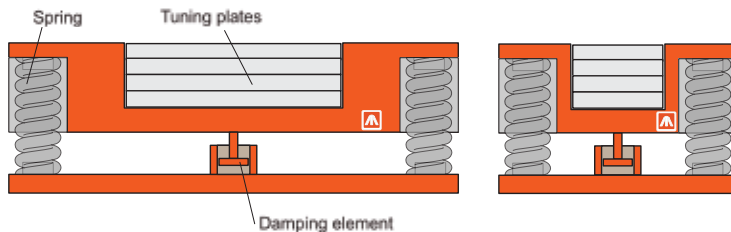
The TMDs are constructed such that the TMD mass oscillates in the same direction as the critical mode to be mitigated (MTMD-V, MTMD-H). The pendulum TMD (MTMD-P) can optimally dampen bending modes in both principal directions.

	Tuned Mass Damper		
Damping direction	Vertical	Horizontal	Horizontal pendulum
MAURER designation	MTMD-V	MTMD-H	MTMD-P

The geometrical dimensions are optimized to the given installation room dimensions.

Vertical Tuned Mass Dampers MTMD-V

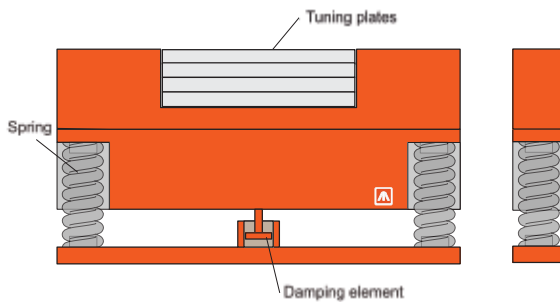
The MTMD-V consists of the vertically movable mass that is supported by steel helical springs. Parallel to the springs the damping element is positioned in the centre. With the use of tuning springs and tuning mass plates the TMD natural frequency can be fine-tuned on the construction site to the actual eigenfrequency of the critical mode.



These values are based on the assumption of vertical TMD relative motion of $\pm 40\text{mm}$.

Mass [kg]	Frequency [Hz]	Length [mm]	Width [mm]	Height [mm]
250	2,0	605	500	345
500		900	600	375
750		1200	650	385
1000		1000	765	385
1500		1680	900	410
2000		2000	1000	420
2500		2200	1130	420
3000		2400	1240	420
4000		2600	1510	430
5000		3000	1630	440
6000		3300	1810	440

The MTMD-V can also be realized in a slender configuration, as shown below.

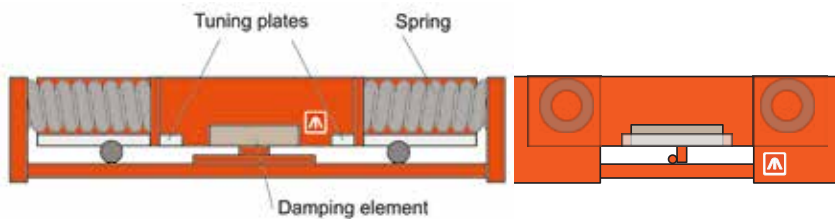


Mass [kg]	Frequency [Hz]	Length [mm]	Width [mm]	Height [mm]
250	2,0	800	200	610
500		900	200	895
750		1050	200	1030
1000		1220	200	1025
1500		1300	250	1045
2000		1620	250	1045
2500		1950	250	1055
3000		2270	250	1065
4000		2280	280	1205
5000		2460	280	1330
6000		2670	280	1335

The damping element is designed to produce the optimum TMD damping. The preliminary dimensions given above apply to the eigenfrequency of 2 Hz. The final dimensions depend on the precise eigenfrequency value and the available fixation options within the structure, as all MTMD-V units are individually tailored to the specific project requirements.

Horizontal Tuned Mass Dampers MTMD-H

The MTMD-H consists of a horizontally moveable guided mass supported between steel springs. The damping element is arranged perpendicular to the springs. The damper is designed to provide damping in one direction only. The TMD natural frequency can be fine-tuned on the construction site to the actual eigenfrequency of the critical mode by tuning springs and mass plates.



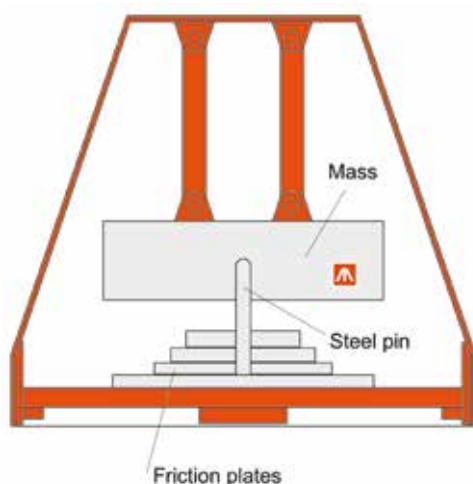
Mass [kg]	Frequency [Hz]	Length [mm]	Width [mm]	Height [mm]
250	1,0	600	640	270
500		950	640	280
750		1210	710	280
1000		1500	735	285
1500		2000	800	290
2000		2200	890	300
2500		2400	895	310
3000		2600	930	320
4000		3000	1000	330
5000		3200	1060	370
6000		3400	1090	400

These values are based on the assumption of horizontal TMD relative motion of +/-60mm.

The design has been optimized for minimum installation height. The dimensions are adapted on a project-specific basis.

The damping element is designed to produce the optimum TMD damping. The preliminary dimensions given above apply to the eigenfrequency in lateral direction of 1 Hz which is critical for footbridges. The final dimensions depend on the precise eigenfrequency value and the available fixation options within the structure, as all MTMD-H units are individually tailored to the specific project requirements.

Horizontal Pendulum Tuned Mass Dampers MTMD-P



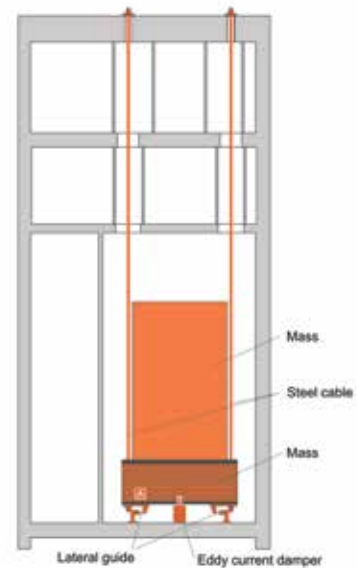
The MTMD-P consists of a mechanical pendulum with a suspended steel mass. The TMD natural frequency is adjusted by the length of the pendulum. The pendulum design provides effective damping in all horizontal directions.

The damping of the MTMD-P is either generated by several friction plates or a dash pot viscous damper. The fine-tuning of the TMD natural frequency is achieved with tuning springs.

Horizontal Pendulum Tuned Mass Dampers with Eddy Current Damper

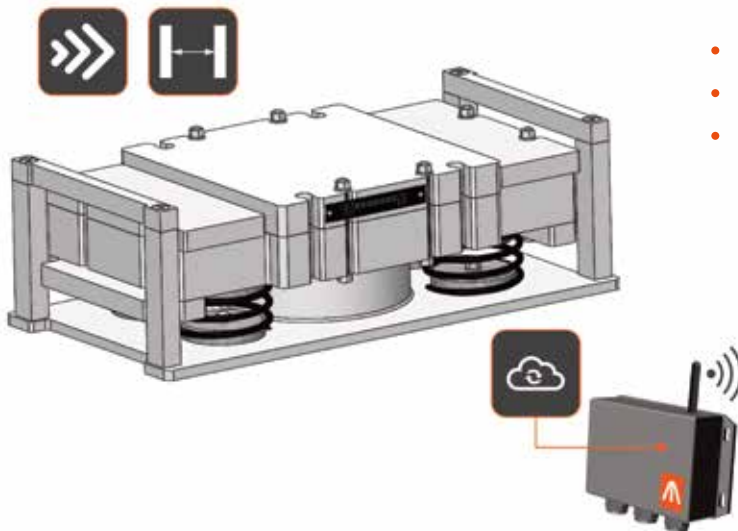
The MTMD-P equipped with an eddy current damper features:

- Zero friction => highly effective already at lowest structural accelerations
- No wearing or leaking up to more than 50 years of service
- Adaptive damping performance depending on TMD relative motion amplitude



Monitoring

MAURER offers a autarkic monitoring system for the following relevant parameters:



- Structural acceleration + frequency
- TMD displacement amplitude + frequency
- Additional project-specific parameters

Quality and Testing

A Tuned Mass Damper (TMD) is a structural component that is not governed by specific standards or guidelines besides the ones related to steel construction and spring design.

Each MAURER TMD is tested and documented prior to delivery to ensure compliance with the specific project requirements. Typically, this includes the checks of the smooth kinematics of the TMD mass, the TMD displacement capacity and TMD natural frequency.

The natural frequency of the TMD, or the pendulum mass,

respectively, is verified by exciting the TMD mass and fine-tuned if necessary.

At the installation site, final functional checks are carried out, including verifications of the smooth TMD kinematics and TMD natural frequency by means of free vibration testing of the TMD mass. If a monitoring system is required, the system is installed, configured and double-checked

Project-specific component testing can also be performed at accredited testing institutes.



Product Information**TMD Tuned Mass Damper**

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