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MAURER
Tuned Mass and Viscous Dampers

Technical Information and Products

MAURER SÖHNE
forces in motion
Since 1876

MAURER – Tuned Mass and Viscous Dampers

Contents Page

MAURER – Tuned Mass and Viscous Dampers

1. Introduction for TMDs and viscous dampers

1.1 Why are TMDs or/and viscous dampers necessary?

Many tall and flexible structures are susceptible to vibrations. Mostly these are structures with low natural damping in combination with mostly rather low natural frequencies.

In case such vibrations are not going to be damped

- a normal service or walking on these structures is not possible,
- resonance phenomenon can occur and structural collapse could happen,
- fatigue phenomenon with crack in the structure can occur, which can lead finally to the structural collapse, too.

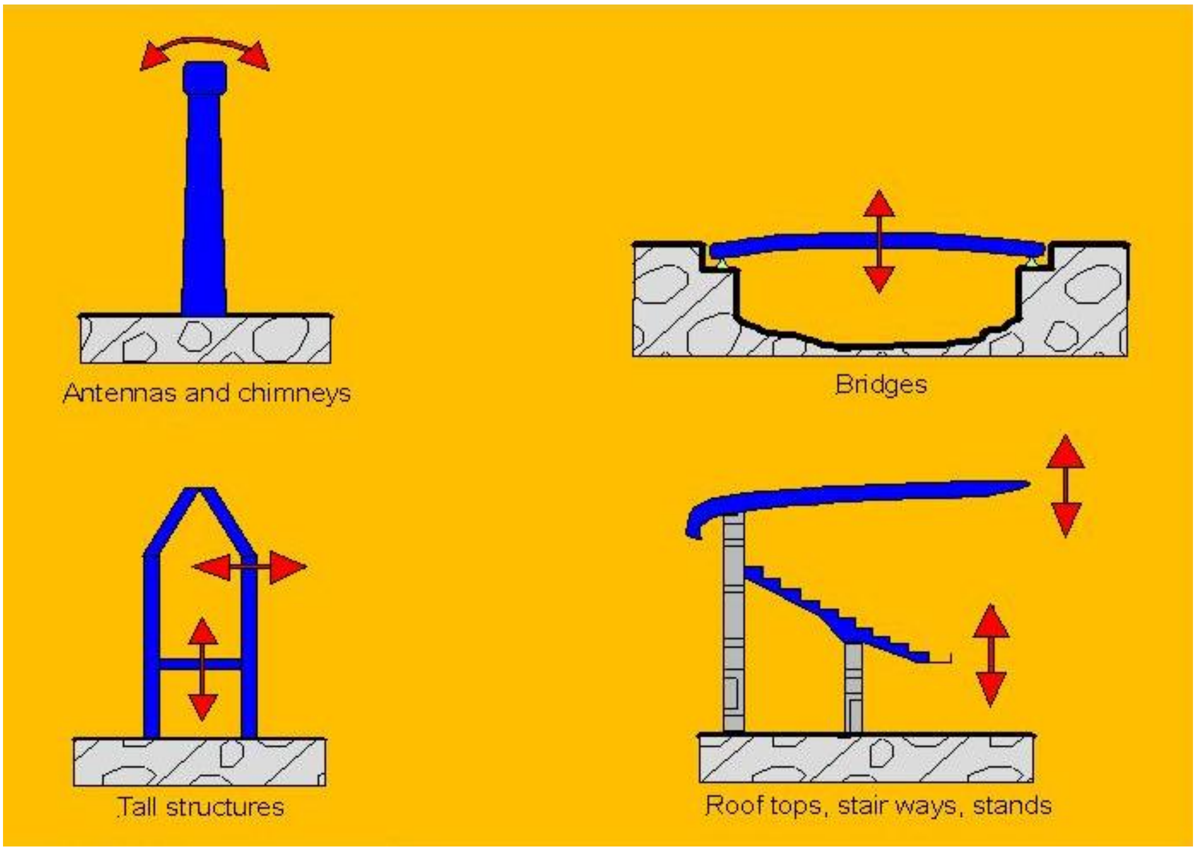


Fig. 1: Samples for vibration sensitive structures

For best possible reduction of structural vibrations Maurer TMDs or viscous dampers are individually adapted to the structural requirements and characteristics. From there almost any kind of shape and size - up to 30,000 kg or even more for TMDs and 6000 kN or even more force response for viscous dampers - can be realised, as every TMD or viscous damper will be individually calculated and designed according to:

- critical structural natural frequency,
- kinetic equivalent structural mass, and
- appearing vibrations with regards to direction, admissible vibration amplitude and acceleration.

1.2 Functions of a TMD and a viscous damper

A TMD or a viscous damper is connected to the structure (bridge, chimney, etc.) at the location where a significant or the biggest vibration is occurring. The TMD-device is consisting of a moving mass, springs and a damping element. The below sketches describe the principle of horizontal and vertical vibrations. The TMD should be placed at the location of the greatest vibration amplitude, as then the efficiency is granted to be highest possible with lowest effort. **The application of viscous dampers is shown in chapter 6.**

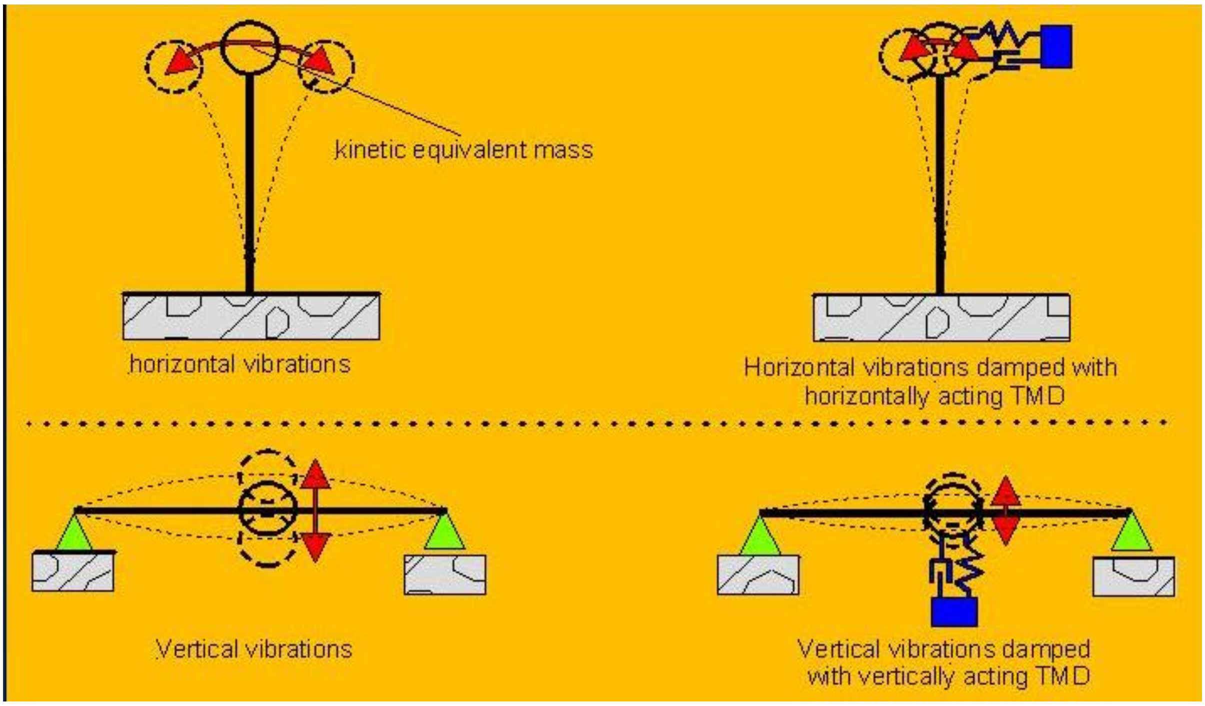


Fig. 2: Principle of system and location for TMDs

For instance in case the main system (Index H) with certain characteristics (mass = m_H, stiffness = k_H, natural damping = d_H) will vibrate under certain circumstances, a TMD with certain characteristics (mass = m_D, stiffness = k_D, natural damping = d_D) will be firmly set onto this main system. Between main system and the TMD mass a spring element and a damping element is arranged to adapt the TMD in a way, that it is mitigating and partially accommodating the vibrations of the main system.

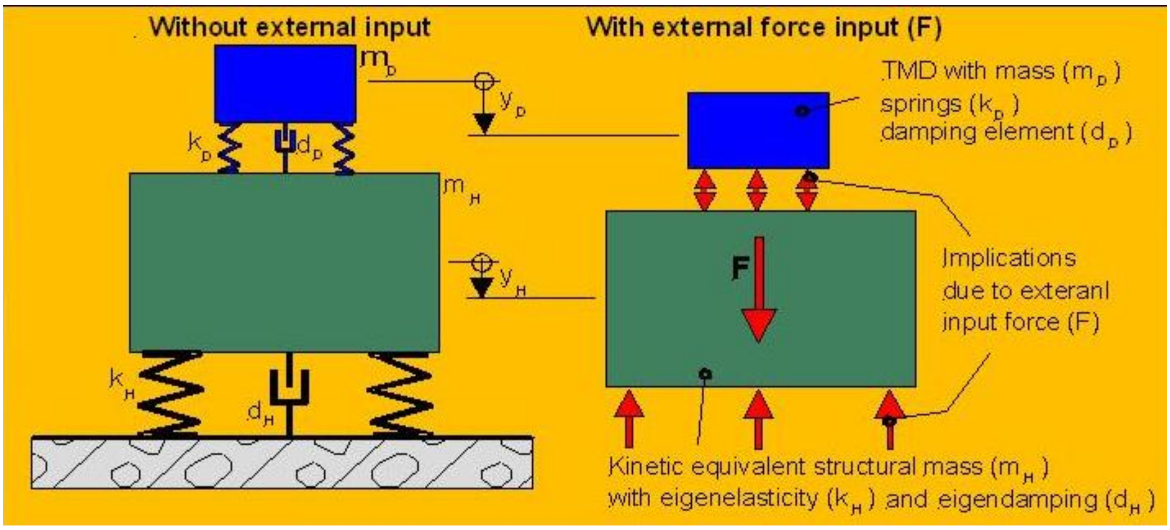


Fig. 3: Working principle of TMD

Introduction of the above physical values:

- Main system: m_H = kinetic equivalent mass of structure [kg]
  k_H = stiffness coefficient [N/m]
  d_H = damping coefficient [N/m/s=Ns/m]
  $y_H = y_H$ (t) displacement of m_H [m]
  F = F(t) = external influence force acting onto m_H

- TMD: m_D = moving/swinging mass of TMD [kg]
  K_D = stiffness coefficient [N/m]
  d_D = damping coefficient [N/m/s=Ns/m]
  $y_D = y_D$ (t) displacement of m_D [m]

  The absolute displacement y_D of the TMD mass is of less practical interest compared to the relative displacement of m_D to m_H:
  $z_D = y_D - y_H$

The main system will react with a harmonic vibration – after a short transient phase - if an external harmonic force F = F (t) = F · sinΩt is acting and the main system is vibrating stationary with the natural frequency Ω. In case the main system is not fitted with a TMD, it is reacting with severe vibrations if the exiting frequency of the external force is correlating with the structural natural frequency, which is called resonance.

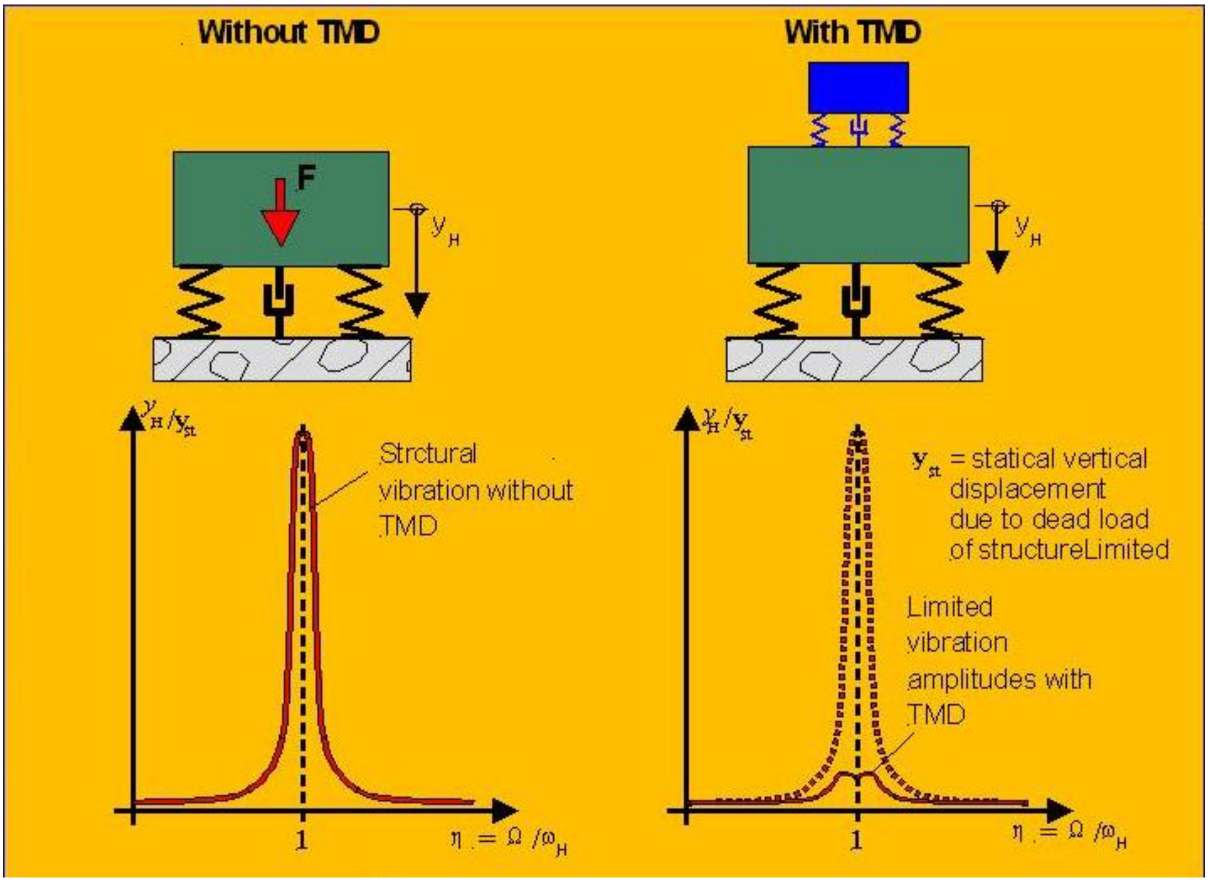


Fig.4: Dynamic response of the main system with and without TMD

The coupling of a TMD to a main system with a mass m_D, while considering certain rules for the optimal TMD dimensioning – spring stiffness (k_D) and damping (d_D) – results in much less reactions of the main system (see Fig. 4). The mitigation of the vibration of the main system results of counteracting displacements of the damper mass (m_D), the frequency adaptation of the springs and the simultaneous damping supplied by the special TMD-damping element.

2. Adaptation of the TMD to the main system (structure)

2.1 Adaptation criteria

For a optimal efficiency of the TMD an accurate adaptation with respect to following issues is necessary:

- **Mass:** The mass ratio (μ) of the TMD mass to the kinetic equivalent structural mass has to be sufficient. For small ratios ($\mu \leq 0.025$) big vibration amplitudes of the TMD mass relatively to the structure are resulting. This can create a space problem for proper integration of the TMD into the available structural gap, but also the TMD gets usually much more expensive due to more and bigger springs.
  In addition a small mass ratio is decreasing the effective range of the TMD (Fig. 5). The TMD mass movements are significantly smaller for bigger ratios ($\mu > 0.025$) and the effective range for a 100% TMD efficiency around the resonance frequency is greater, too.

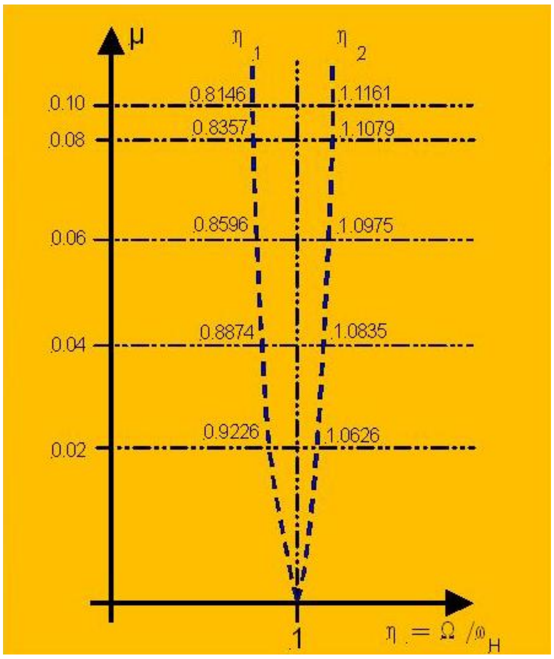


Fig. 5: Frequency range with respect to μ

- **Frequency:** To achieve the best possible mitigation of the main system vibration, the natural frequency of the TMD has to be calculated in a certain ratio to the natural frequency of the main system, means both frequencies must not be identical. The ratio between them is called deviation κ or to be out of tune respectively (Fig. 6).

$$\kappa_{opt} = \frac{f_D}{f_H}$$

with κ_{opt} = optimal deviation
f_D = natural frequency of TMD
f_H = natural frequency of main system

and according to DEN HARTOG it is valid for harmonic excitation:

$$\kappa_{opt} = \frac{1}{1+\mu} < 1$$

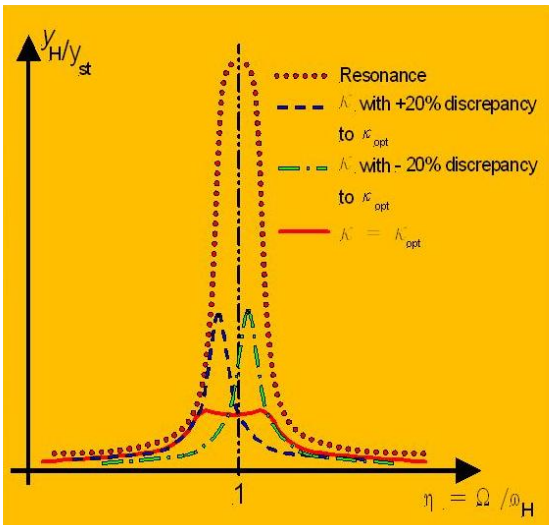


Fig. 6: Behaviour of main system if deviation varies

- **Damping:** The necessary optimal damping $\zeta_{D,opt}$ of the TMD has to be adapted to the chosen mass ratio μ, while following equation is valid:

$$\zeta_{D,opt} = \sqrt{\frac{3\mu}{8 \times (1+\mu)^3}}$$

2.2. Consequences of a wrong or bad adaptation of a TMD

- **Too less mass ratio µ:**
  For small mass ratios (ca. $\mu < 0.04$) the effective range of the TMD is limited. This means, that in case of environmental temperature changes, structural fatigue, etc.. the natural frequency of the structure is changing, the efficiency of the TMD with a µ less than 4% is influenced and decreased more than for bigger mass ratio values (see Fig. 5).

  In addition small µ-values result in bigger TMD-mass amplitudes (Fig. 4), which can often not be realised due to a lack of available space within the structure.
  Example: The maximum relative displacement of the tuned mass for $\mu = 0.02$ is by the factor 5.36 bigger than the maximum displacement of the structure itself. For $\mu = 0.1$ this factor is 2.53 only.

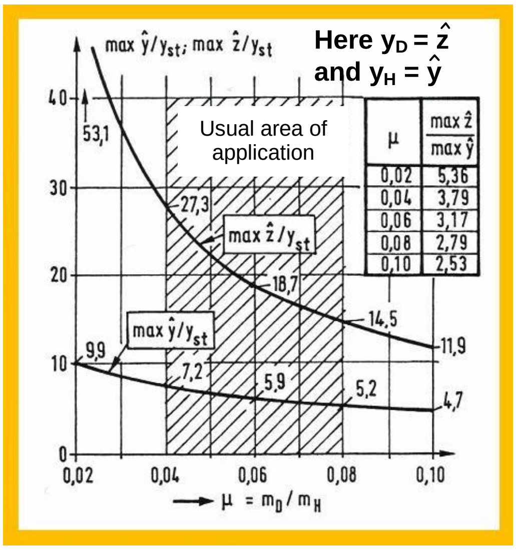


Fig. 7: Relative displacements of the TMD compared with the structure itself and usual area for mass ratios

- **Deviation of the optimal „out of tune“ value:**
  The optimal natural frequency of the TMD is not identical with the natural frequency of the structure! The TMD frequency is out of tune to the structural frequency by a well defined value, which is the deviation with a big influence on the final efficiency of the TMD (chapter 2.1). Therefore the structural natural frequency and the kinetic equivalent structural mass has to be known. Due to the complexity of structures and the lack of knowledge of stiffness values (soil, bearings, etc.), it is usually difficult to determine exactly the natural frequency of the structure to be damped. This is valid also for the kinetic equivalent mass. In the upper part a) of Fig. 8 the value max y/y_{st} for the three different mass ratios 0.04, 0.06 und 0.08 is shown along the relation κ/κ_{opt} (on horizontal axis).
  Example: In case of a value of 0.8 for the relation κ/κ_{opt} – the deviation κ is 20% less than the optimal value – the maximum related amplitude for $\mu = 0.04$ with 29 is by factor 4 (= 29/7,2) bigger compared to the optimal deviation.

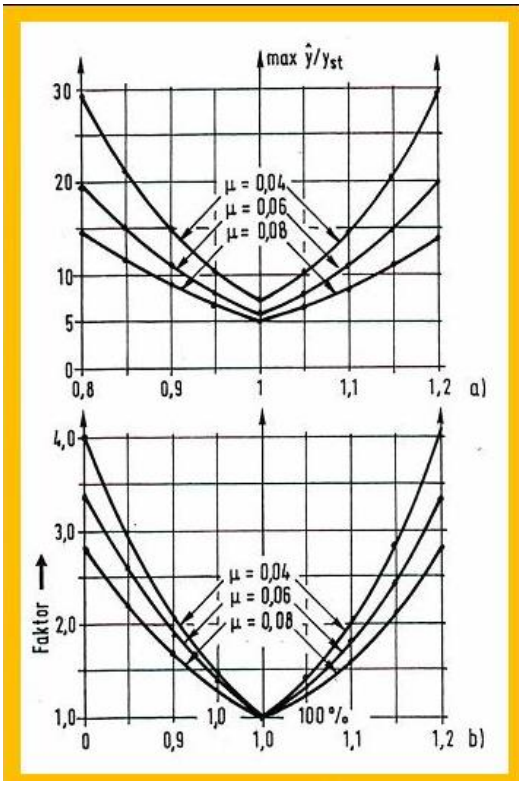


Fig. 8: Amplitude amplification factor in case the optimal deviation does not fit

- **Deviation to optimal damping:** The correctly adapted damping for the TMD mass is helping to provide best possible efficiency of the unit also. The deviation to the optimal damping has got less influence than the deviation to the optimal TMD frequency.
  Example: In case the deviation of damping is within the range of ±25% to the optimal values (see area marked in red in Fig. 9), there is minor influence on the overall efficiency of the TMD! In Fig. 9 consequences of damping deviation factor on horizontal axis) on the vibration amplitudes of the structure (index y; lower curve) and on the TMD (index z; upper curve) are shown. In general significant changes in amplitudes of the main structure will result due to deviations greater than ±50%. Therefore damping is important, but the structure will react not such sensitive to deviations to the optimal damping values.

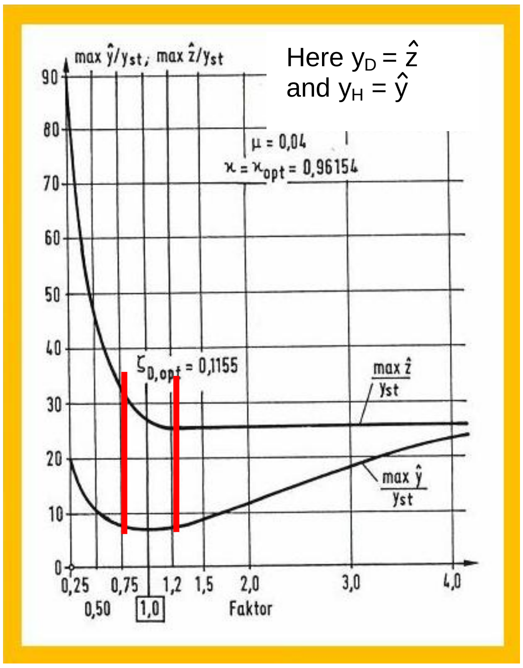


Fig. 9: Deviation of damping with resulting changes of structure and TMD amplitudes for μ = 0,04

2.3. Assessment of the three main adaptation criteria for a TMD

1) The most important criteria is the optimal deviation (Fig. 10) from the structural natural frequency. In case the TMD frequency including the defined value for the deviation is not optimally fitting to the structure, already small frequency deviations can result in major efficiency loss of the TMD (Fig. 8).

2) An important criteria is an effective mass ratio value granting a wide-banded range of optimal operation (Fig. 7).

3) The damping is less important than the above two criteria, as there the biggest deviations are acceptable without creating a significant loss in efficiency (Fig. 9).

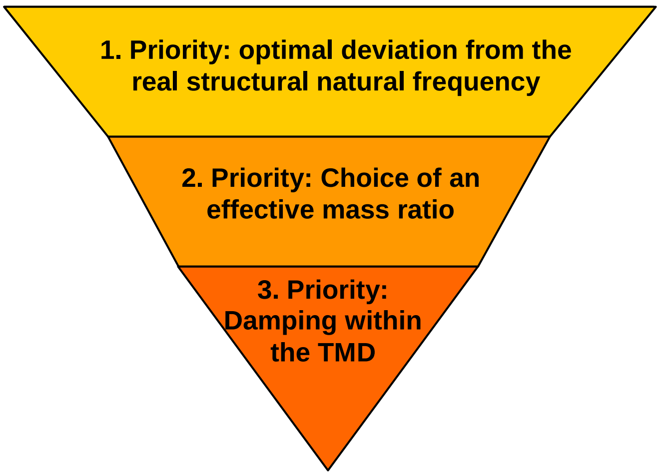


Fig. 10: Priorities of three main adaptation criteria

3. Necessary technical data for the design of a TMD

For the dimensioning and the design of TMDs following input data are required:

- **Kinetic equivalent bridge mass, which is the participating mass of the structure in the vibration for the various sensitive modes or alternatively the mass ratio is already supplied.**

- **Natural frequency of the structure.**

- **Optional: Space requirements for the TMD.**

- **Optional: Degree of damping for the damping element of the TMD.**

The data of the first two issues have to be known, as otherwise a TMD cannot be designed. The two last data are not essentially necessary. In case these data are not specified, the design is done according to economical considerations.

4. Optimal procedure for a TMD dimensioning

- Determination of critical natural values or frequencies respectively and the kinetic equivalent structural mass.
- Evaluation of TMD type and TMD-design (number, mass, location, etc.) and design of necessary structural fixation brackets.
- Vibration test by MAURER or an University or other specialists after finished construction works on the structure and recording of the real frequencies.
- Final TMD design based on vibration tests and manufacture of TMD.
- Installation of TMD.
- Possibly a second vibration test to verify the efficiency of the TMD.

5. Different types of MAURER-TMDs (MTMD)

MAURER-TMDs are always individually adapted to the structure with regard to mass, frequency, damping and available space.

The below listed types are showing up the design principles only, which are finally adapted individually to the structure.

Different MTMD types:

5.1 MTMD-V: Vertically acting tuned mass dampers
5.2 MTMD-H: Horizontally acting tuned mass damper
5.3 MTMD-P: Pendulum tuned mass damper
5.4 ATMD: Adaptive tuned mass damper

5.1. MTMD-V: Vertically acting tuned mass damper

5.1.1 Technical description of MTMD-V

Principle of function:
The MTMD-V is placed at the structure´s location with the corresponding maximum of the vibration amplitude of the vertical natural frequency.
The fixation to the structure is provided usually by bolt connections to girders or structural brackets.
The MTMD-V is consisting of a vertically moving and guided mass, which is set onto steel springs. In parallel to the springs a damping element is arranged.

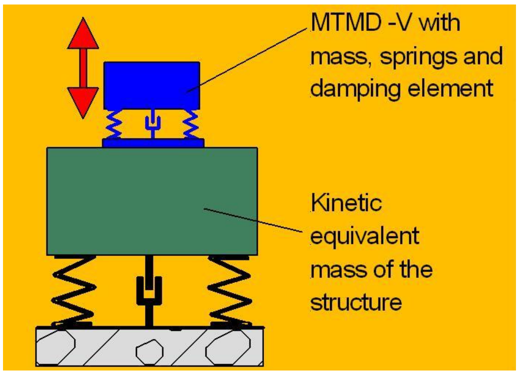


Fig. 11: Principle of function of MTMD-V

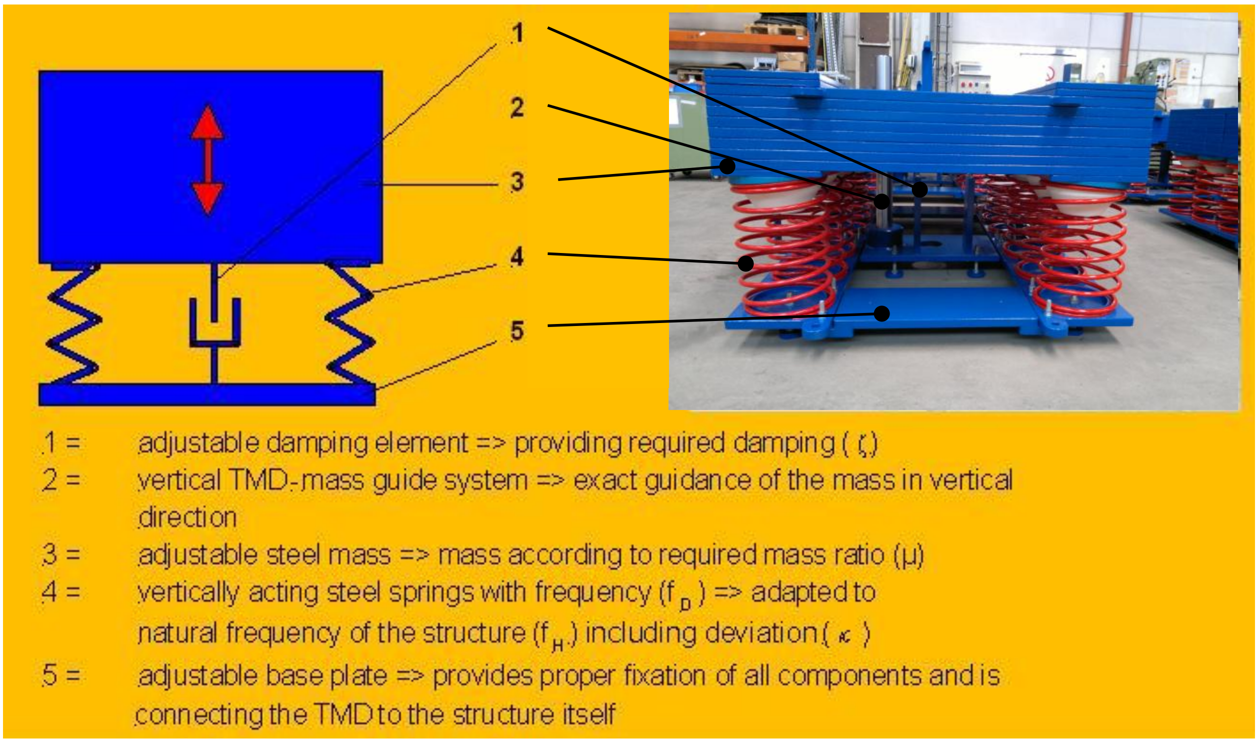


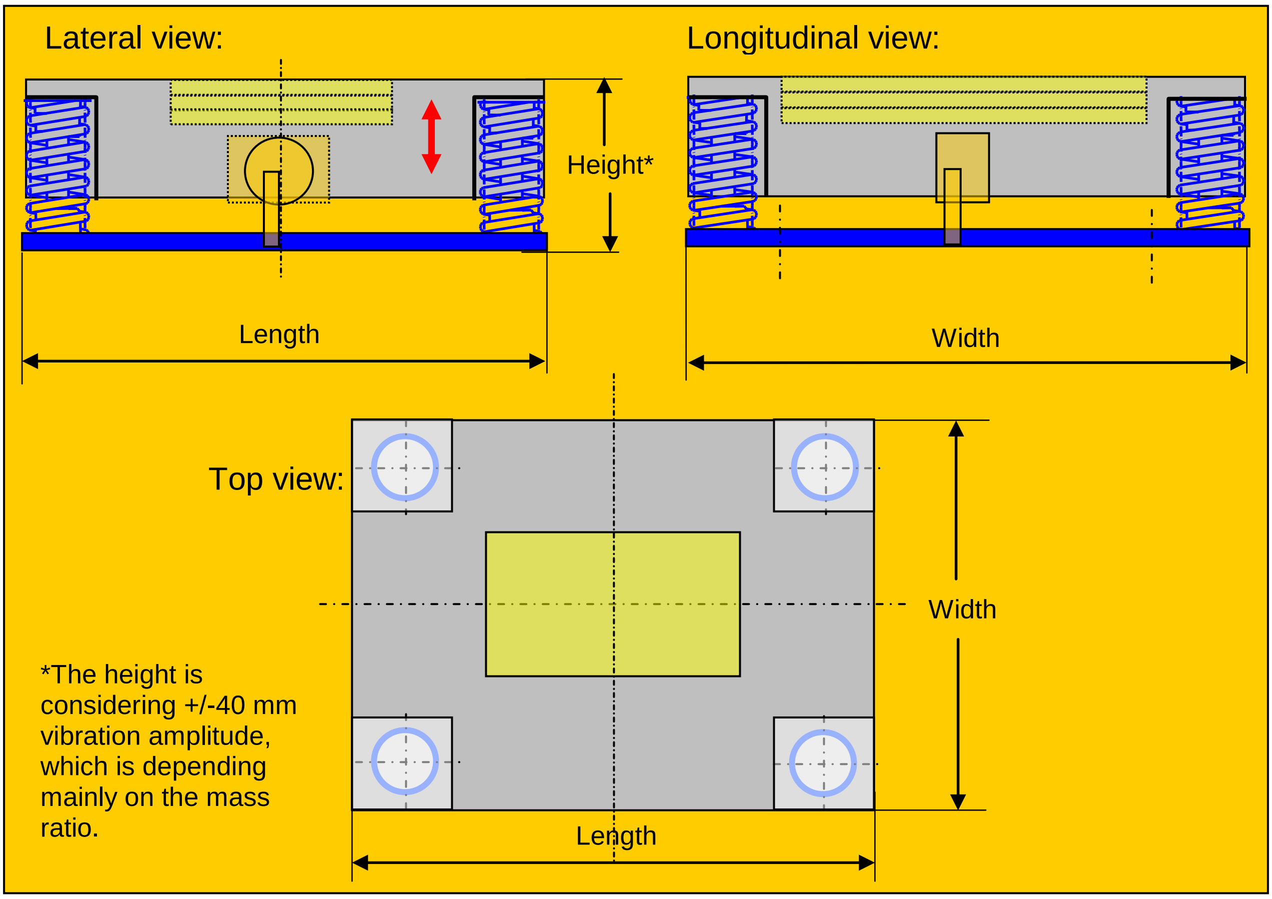
Fig. 12: Description of MTMD-V

The MTMD-V is individually adapted to the structure in co-operation with the contractor and the designer. It is available in all sizes (30,000 kg or even more), shapes (flat, tall, etc.) and adjustment versions (frequency, damping, etc.).

Sizes of MTMD-V for first project phase

Depending on the individual structure the MTMD-V dimensions are adapted by MAURER to the special request! **The below mentioned values are just for orientation to get a first idea of possible sizes.**

Version 1: MTMD-V-flat (none scale)



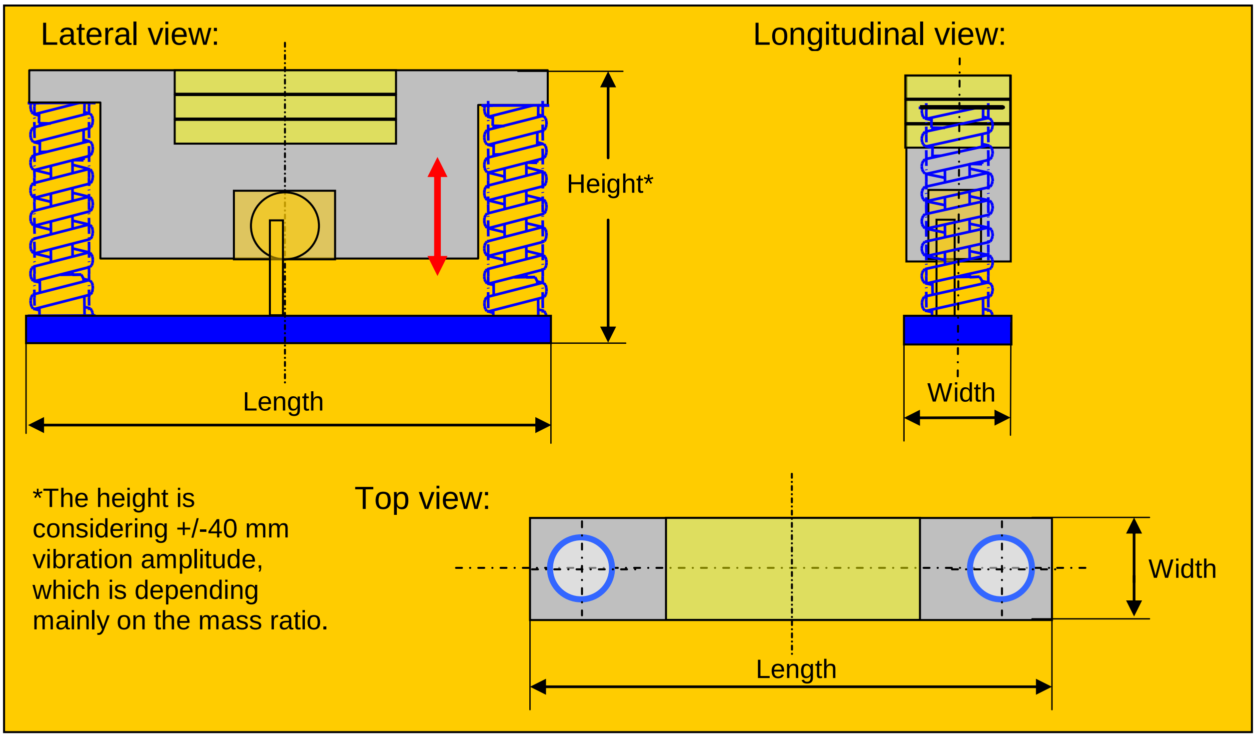
Tuned mass [kg]	Length [mm]	Width [mm]	Height* [mm]
250	600	560	275
500	800	556	325
750	1000	610	325
1000	1000	780	325
1500	1250	930	325
2000	1600	930	325
2500	2000	930	325
3000	2000	1080	325
4000	2000	1410	325
5000	2560	1410	325
6000	2780	1530	325

Fig. 13: Principle sketch of MTMD-V-flat and preliminary dimensions [*height may vary due to frequency and µ]

The damping element will be adjusted to the requested damping. The above preliminary dimensions are for a frequency range between 2 Hz and 3 Hz. Nevertheless the final dimensions depend on exact frequency values and fixation possibilities to the structure as all our TMD will be individually adapted to the final project requirements. For instance in case the length is requested to be shorter, the width and/or the height can be increased.

The MTMD-V mass can be increased as necessary (more than 30,000 kg), but handling and installation has to be considered, too.

Version 2: MTMD-V-tall (none scale)



Tuned mass [kg]	Length [mm]	Width [mm]	Height* [mm]
250	620	200	635
500	870	200	735
750	1020	200	905
1000	1220	200	935
1500	1420	240	1005
2000	1620	240	1085
2500	1750	250	1185
3000	1870	250	1285
4000	2120	280	1585
5000	2320	280	1705
6000	2520	280	1785

Fig. 14: Principle sketch of MTMD-V-tall and preliminary dimensions [*height may vary due to frequency and µ]

The damping element will be adjusted to the requested damping. The dimensions are valid for a frequency range between 2 Hz and 3 Hz. Nevertheless the final dimensions depend on exact frequency values and fixation possibilities to the structure as all our TMDs will be individually adapted to the final project requirements. For instance in case the length is requested to be shorter, the width and/or the height can be increased.
The MTMD-V mass can be increased as necessary (more than 30,000 kg), but handling and installation has to be considered, too.

5.1.2 Application of MTMD-V- MTMD-V- 5000: Singapur Skypark - Singapur

MTMD-V-flat:

a) Tuned Mass: 6000kg
b) Frequency: 0,8-1,2 Hz
c) Damping: max. 3978 Ns/m

Fig. 15: Marina Bay Sands Hotel

Fig.. 16: Cantilever of Skypark with event arena area (dancing etc.)

Fig. 17: Installed MTMD-V

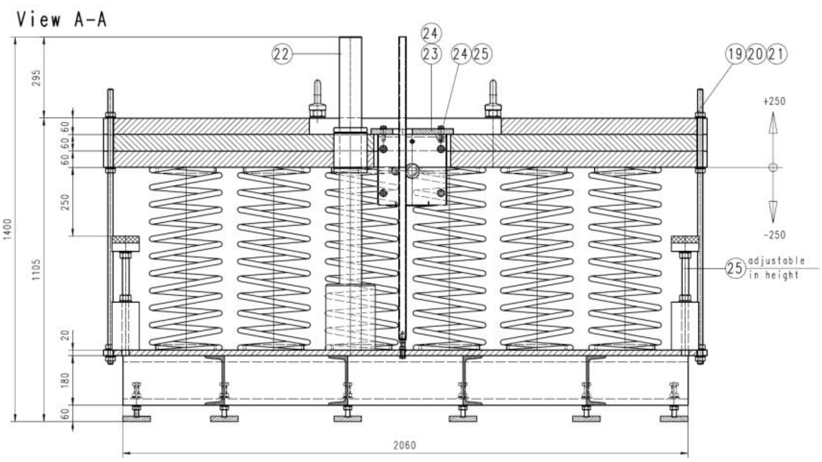


Fig. 18: Cross section of MTMD-V

5.2.2 Application of MTMD-V-550/725/1200: Abandoibarra Bridge in Bilbao - Spain

MTMD-V in tall version:

a) mass: 550 / 725 / 1200kg
b) frequency: 1,85 / 2,32 /2,78 Hz
c) damping: 681 / 815 / 1241 Ns/m

Fig. 19: Abandoibarra Bridge

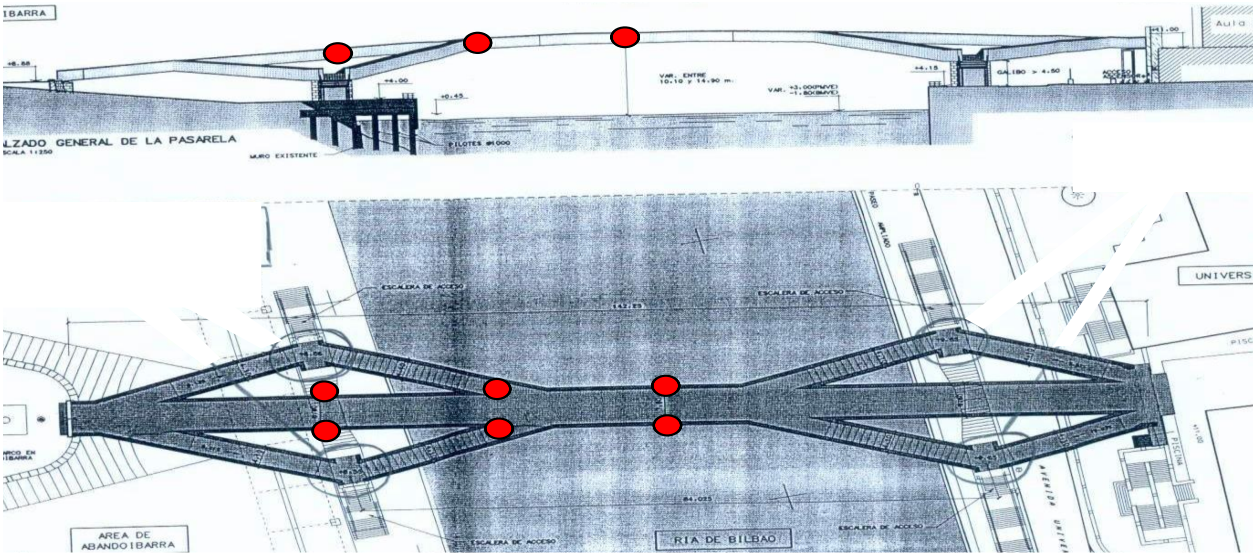


Fig. 20: Side and top view

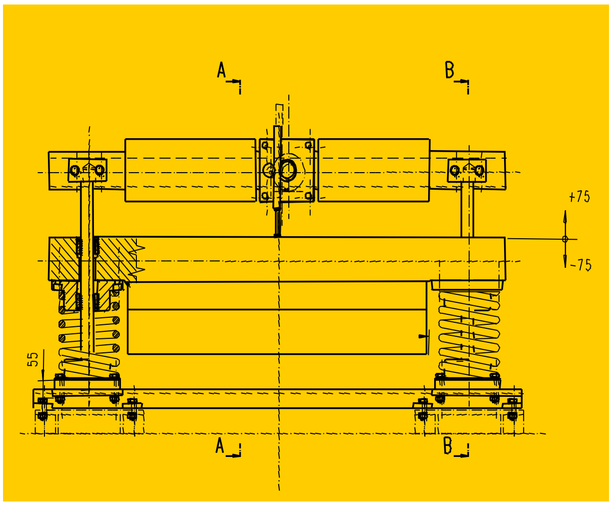


Fig. 21: Cross section through MTMD-V

Fig. 22: Installed MTMD-V in bridge rail

5.2. MTMD-H: Horizontally acting tuned mass damper

5.2.1. Technical description of MTMD-H

Principle of function:
The MTMD-H is placed at the structure´s location with the corresponding maximum of the vibration amplitude of the horizontal natural frequency.
The fixation to the structure is provided usually by bolt connections to girders or structural brackets.
The MTMD-H is consisting of a horizontally vibrating and guided mass, which is set between steel springs. In parallel to the springs a damping element is arranged.

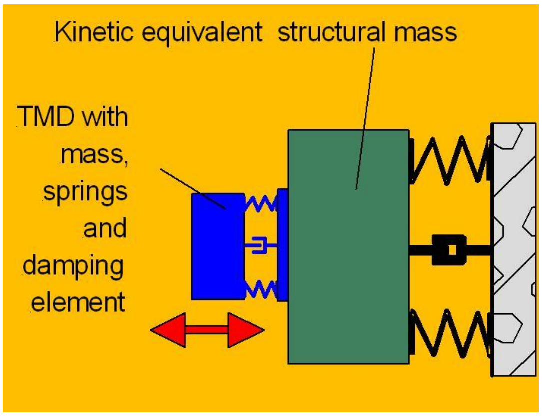


Fig. 23: Principle of function of MTMD-H

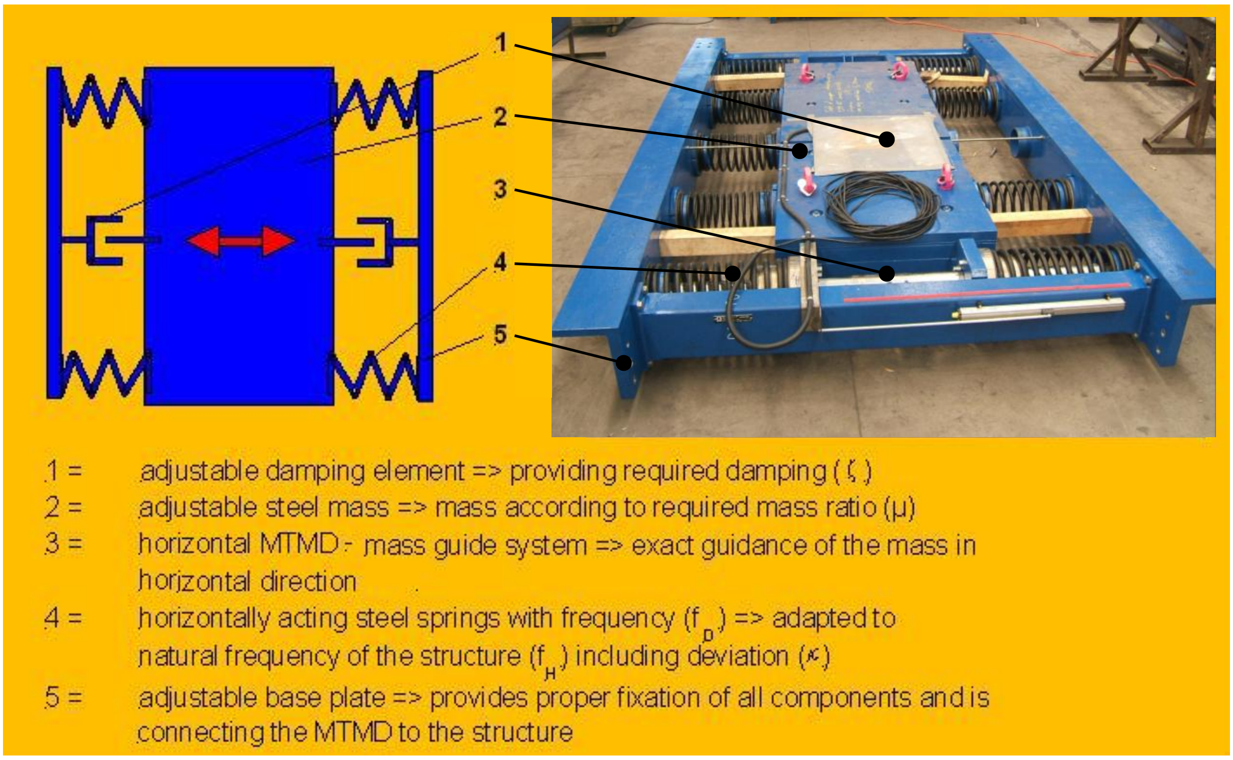
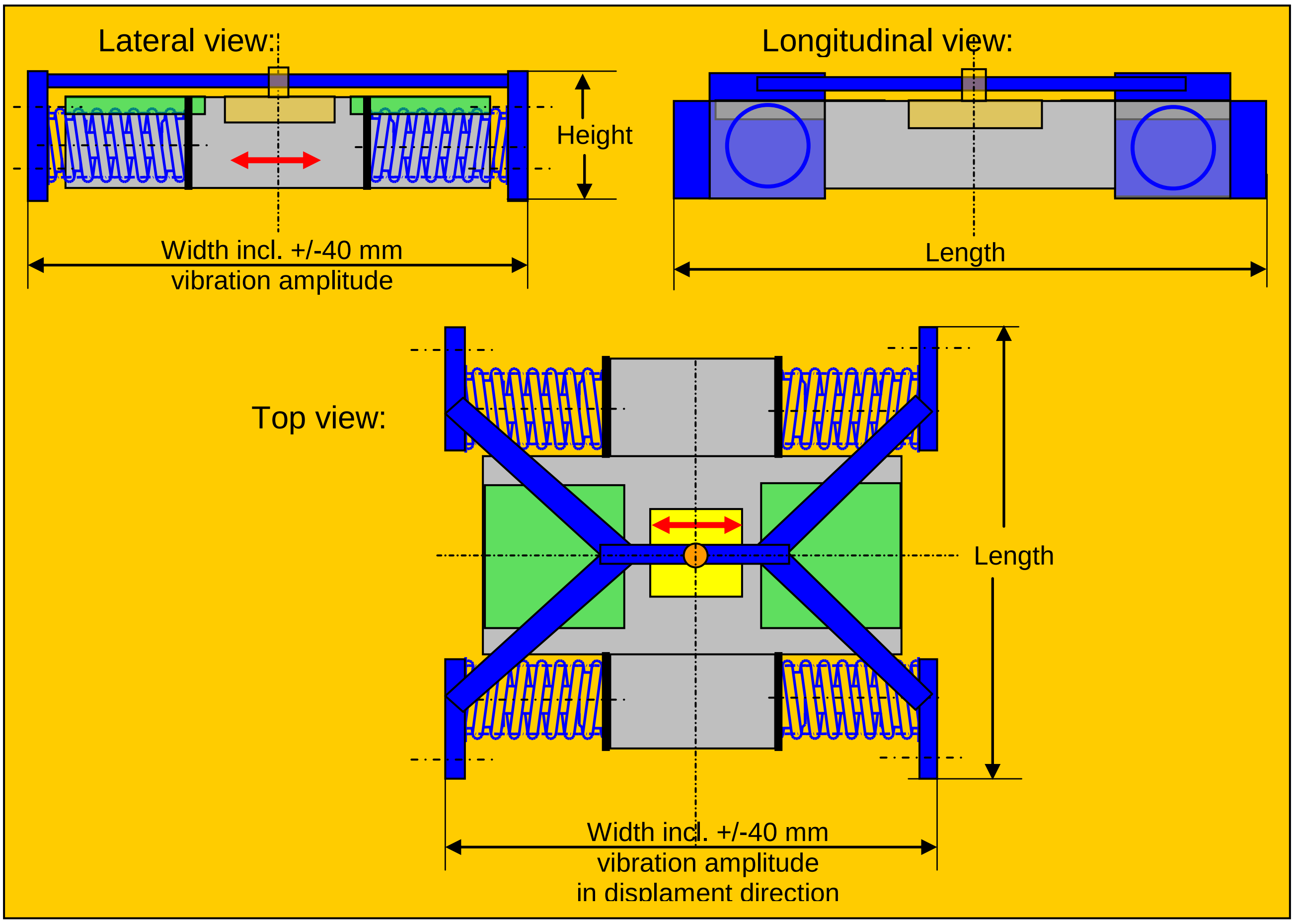


Fig. 24: Description of TMD-H

The MTMD-H is individually adapted to the structure in co-operation with the contractor and the designer. It is available in all sizes (30,000 kg or even more), shapes (flat, tall, etc.) and adjustment versions (frequency, damping, etc.).

Sizes of MTMD-H for first project phase (none scale)

Depending on the individual structure the MTMD-H dimensions are adapted by MAURER to the special request! **The below mentioned values are just for orientation to get a first idea of possible sizes.**



Tuned mass [kg]	Length [mm]	Width [mm]	Height [mm]
250	880	560	200
500	1080	670	200
750	1330	670	210
1000	1530	700	220
1500	1330	1020	260
2000	1330	1200	280
2500	1530	1200	280
3000	1800	1200	280
4000	1910	1320	310
5000	2140	1520	310
6000	2140	1780	310

Fig. 25: Principle sketch of MTMD-H and preliminary dimensions

The damping element will be adjusted to the requested damping. The dimensions are valid for a frequency range between 1 Hz and 2 Hz. Nevertheless the final dimensions depend on exact frequency values and fixation possibilities to the structure as all our TMDs will be individually adapted to the final project requirements. For instance in case the length is requested to be shorter, the width and/or the height can be increased.
The MTMD-V mass can be increased as necessary (more than 30,000 kg), but handling and installation has to be considered, too.

5.2.2 Application for MTMD-H-1900: Port Tawe footbridge in Swansea – United Kingdom

MTMD-H:

a) mass: 1900kg
b) frequency: 1,159 Hz
c) damping: 3876 Ns/m

Fig. 26: Port Tawe Footbridge

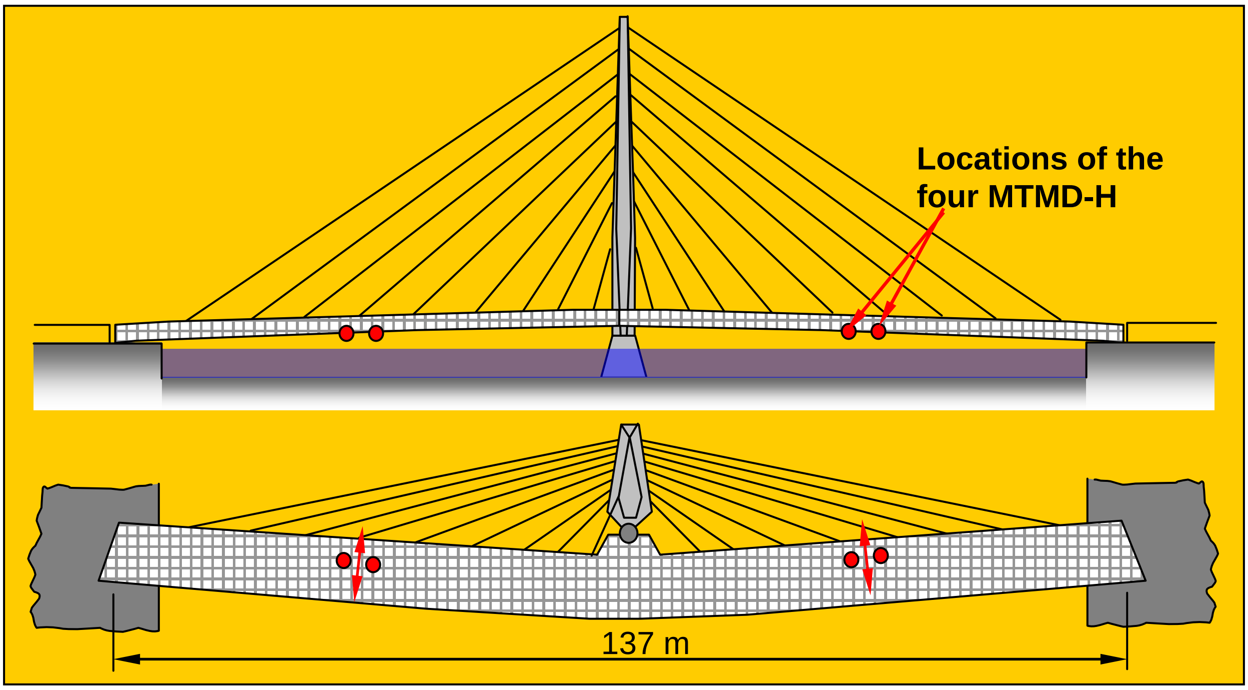


Fig. 27: Side and top view of bridge

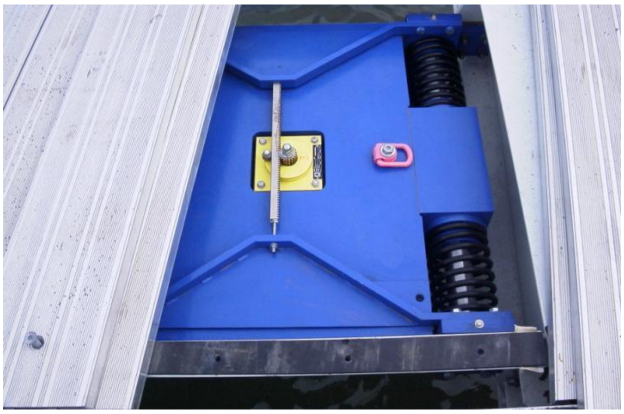


Fig. 28: Installed MTMD-H

Fig. 29: Port Tawe bridge deck

5.2.3 Application for MTMD-H-4000: Olympic Bridge in Turin - Italy

MTMD-H:

a)	Tuned Mass:	2 x 4000kg
b)	Frequency:	0,55-0,95 Hz
c)	Damping:	3876 Ns/m

Fig. 30: Olympic Bridge

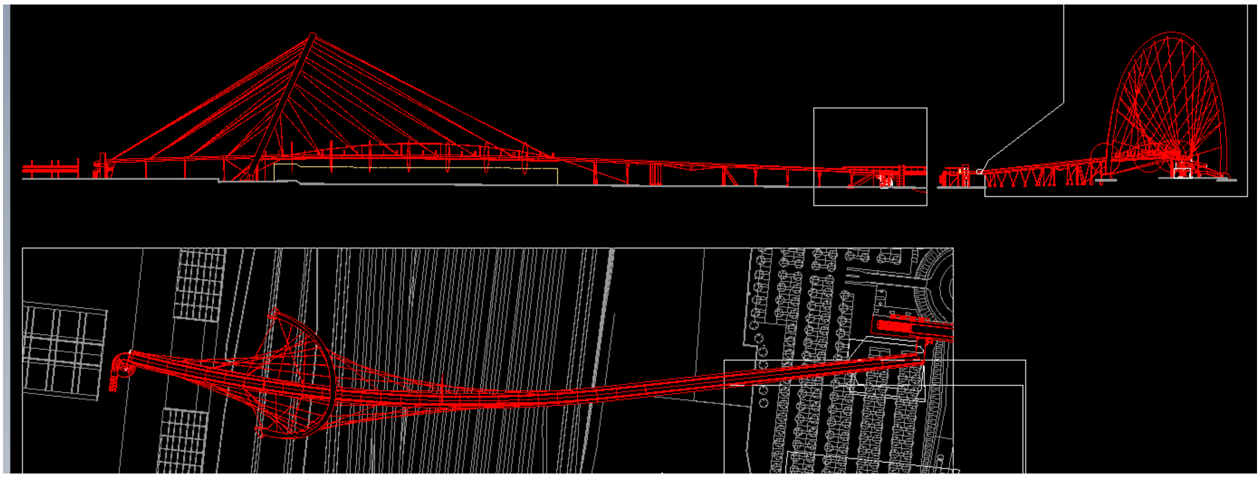


Fig. 31: Top view and side view on 368m long Olympic Bridge

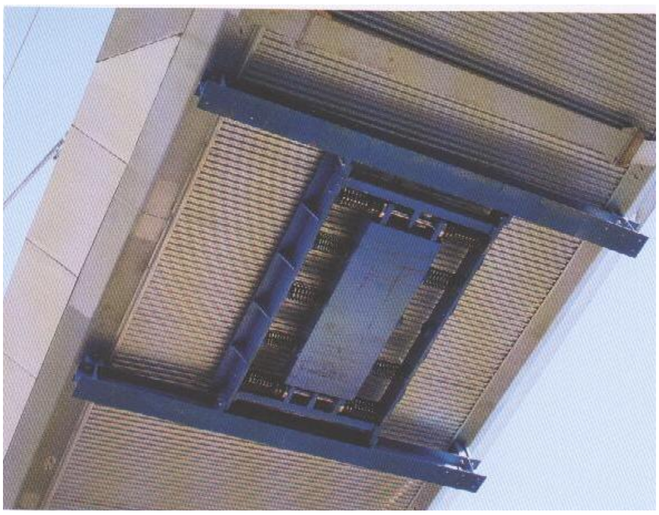


Fig. 32: Installed MTMD-H

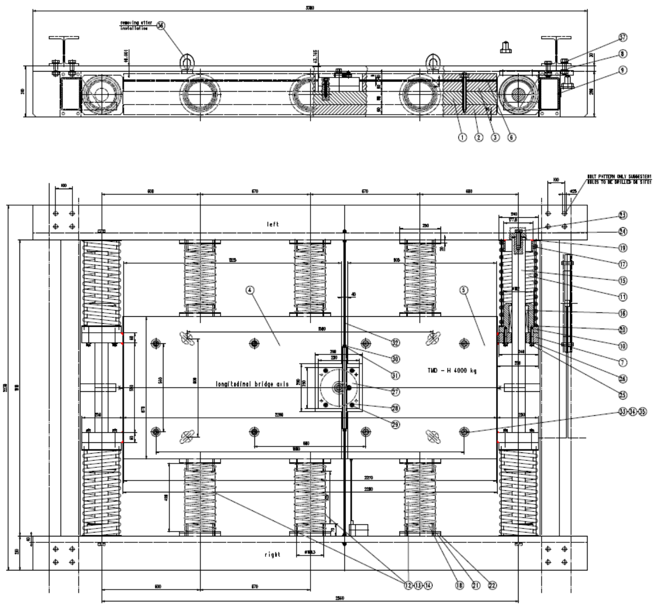


Fig. 33: Side & top view of MTMD-H

5.3 MTMD-P: Pendulum tuned mass dampers

5.3.1 Technical description of MTMD-P

Principle of function:
The MTMD-P is placed at the structure´s location with the corresponding maximum of the vibration amplitude of the horizontal or radial natural frequency.
The fixation to the structure is provided usually by bolt connections to girders or structural brackets.
The MTMD-P is consisting of a pending mass, which is fixed at the end of a pendulum rod. The re-centring is provided by gravity acting on the mass. The damping is achieved by friction plates or viscous damping devices.

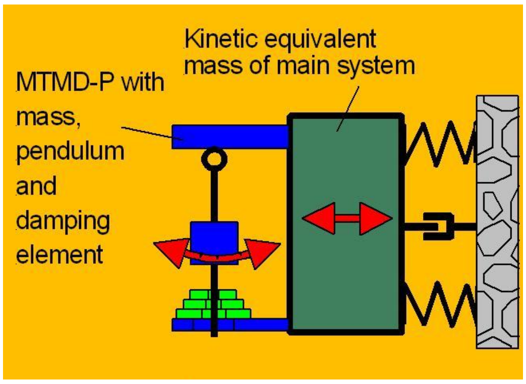
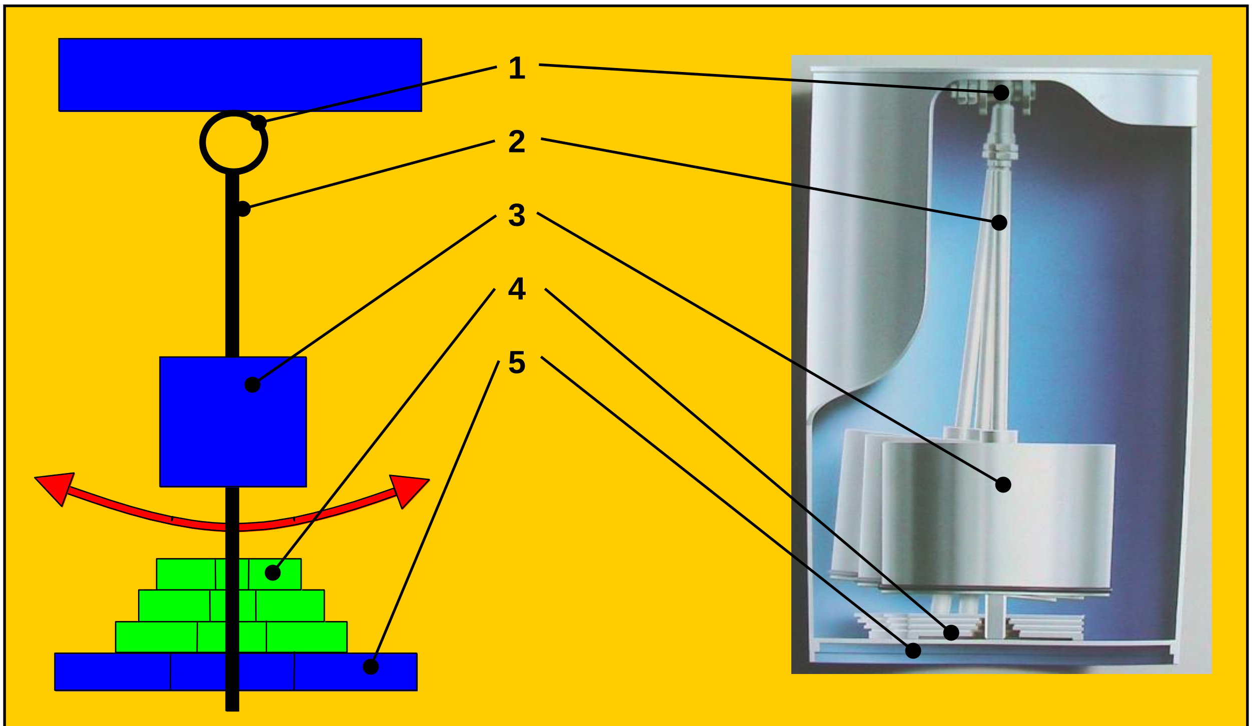


Fig. 34: Principle of function of MTMD-P



1 = spherical hinge enables radial pendulum movements in all directions
2 = pendulum rod
3 = tuned mass with adjustable mass plate numbers
4 = friction plates or viscous damping device provide necessary damping. The elements are not wearing.
5 = adaptable base plate connected to structure.

Fig. 35: Description of MTMD-P

The MTMD-P is individually adapted to the structure in co-operation with the contractor and the designer. Is available in all sizes (30,000 kg or even more), shapes (flat, tall, etc.) and adjustment versions (frequency, damping, automatic real time adaptive etc.). For pendulum length reduction by multi-pendulum-frame constructions can be also supplied. Sizes for that type are not mentioned here as very individual adaptation is necessary.

5.3.2 Application of MTMD-P-2100:

MTMD-P data:

a) mass: 2100kg
b) frequency: 0,45 Hz

Fig. 36: MH-Power Plant Ulm - Germany

Fig. 37: MVA Genf - Switzerland

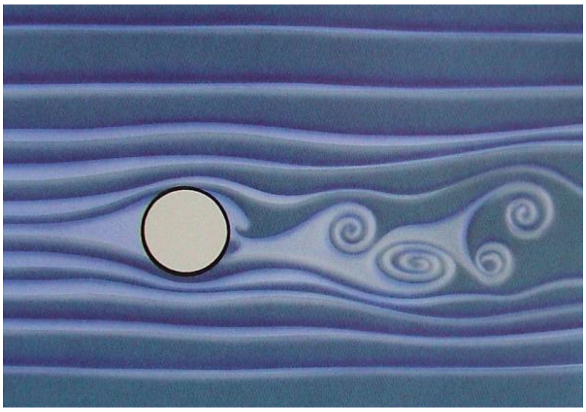


Fig. 38: Karman vortex street

Fig. 39: MVA Geiselbullach - Germany

5.3.3 Application for ATMD-P-62847: Alphabetic Tower in Batumi - Georgia

ATMD-P:

a) Tuned Mass: 62.847kg
b) Frequency: 0,32-0,49 Hz adaptive
c) Damping: 35.616 Ns/m adaptive

Fig. 40: Alphabetic Tower

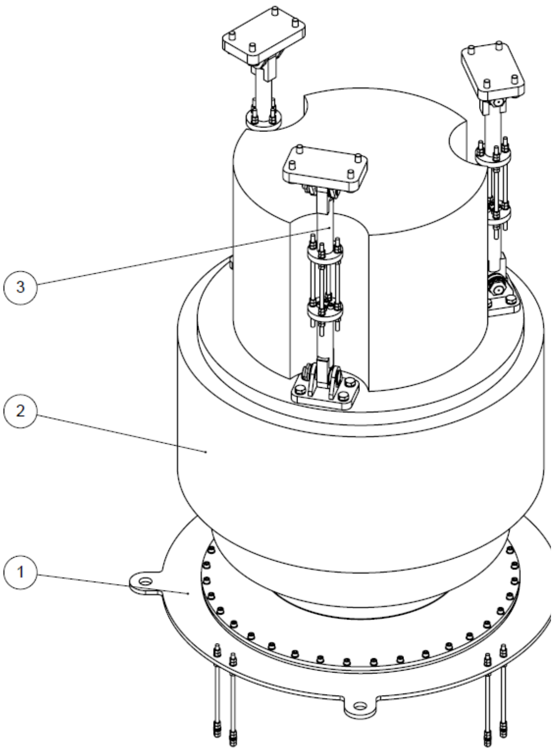


Fig. 41: Sketch of ATMD with pendulum elements

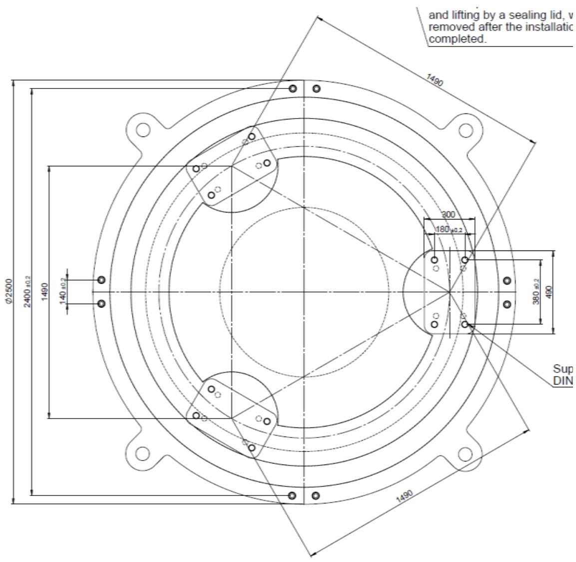


Fig. 42: Top view on ATMD-P

Fig. 43: Construction stage 09/2011

5.4. Adaptive ATMD Systems

5.4.1 Technical Description of ATMD

Function principle:
The ATMD is fitted with a adaptive damping element, which is automatically steplessly controlled in real time (~20-100ms). The structural frequency will be calculated from input data coming from displacement or/and acceleration sensors. With an industrial PC and a control algorithm these input signals are converted into an output signal for the adaptive damping element. **The damping is always optimally tuned to compensate totally environmental temperature variations and in addition the ATMD frequency can be tuned within up to +/-10% depending on application and design frequency!** With this adaptive control vertically, horizontally acting and pendulum TMDs can be fitted. Finally the structural movements will be reduced by 20-50% compared to regular passive TMD systems. On ATMD system allows even to damp several structural modes at the same time in case they are within +/-10% of the design frequency, which allows to optimize cost as only one TMD system provides the mass ratio for several frequencies.
This system was developed in close cooperation with EMPA Duebendorf/Switzerland.

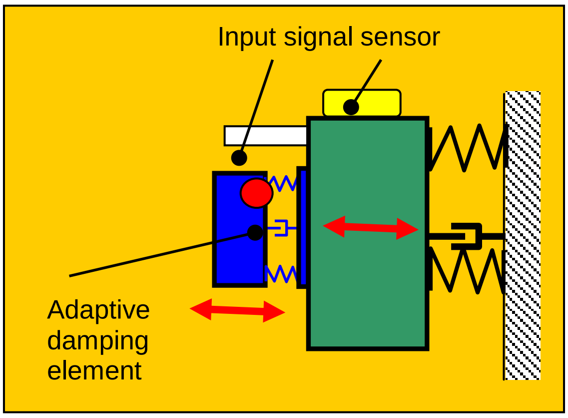
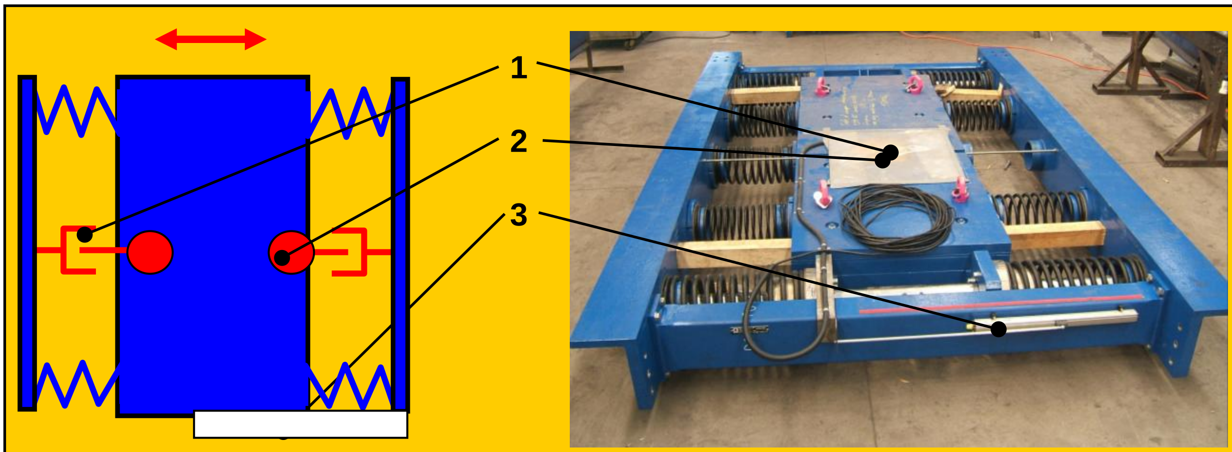


Fig. 44: Function principle of ATMD



1 = Adaptive damping element => for frequency tuning up to +/-20% and temperature compensation within 20-100ms
2 = Industrial PC for data processing and control of output signals to adaptive damping

Fig. 45: Description of ATMD

The adaptive control of the ATMD is individually adapted to the structural requirements in close cooperation with owner and designer.
With the ATMD the efficiency of the TMD system can be always held close to the 100% optimum, which is never the case for the passive TMD system, especially in case the structure is changing its frequency due to fatigue, temperature, traffic loading, etc.. In many cases one ATMD can cover even two or three frequencies lying close to each other, which is saving cost especially for big structures! The internal damping element can compensate temperature variations of the damping element within +/-10%.
The ATMD is fail safe as even without electricity supply the devic works like a regular passive TMD system.
In addition the ATMD system offers with small additional cost a full monitoring system for movements, frequencies occurring in the structure and the TMD itself, as the ATMD is anyway fitted with these sensors already.

5.4.2 Application for ATMD-V-5200: Bridge Volgograd - Russia

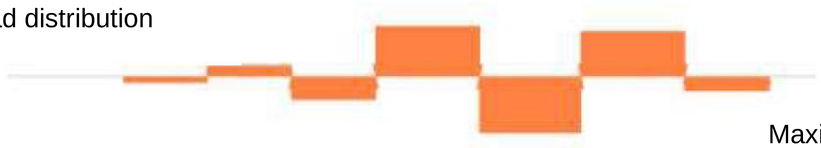
ATMD-V:

a) Tuned mass: 12 x 5200kg (=62,400kg)
b) Frequency: 0,45Hz, 0,57Hz, 0,64Hz adaptive
c) Damping: 1.620-2.260 Ns/m adaptive

Fig. 46: Volgograd Bridge

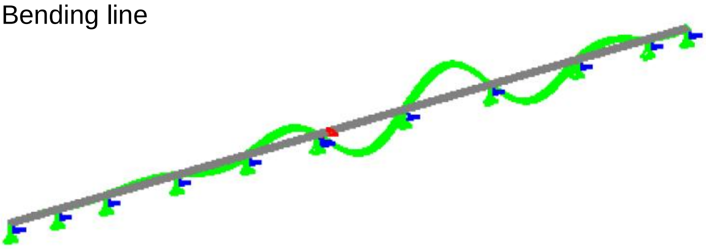
Fig. 47: ATMD with various basic frequency tuning and adaptive damping element

Load distribution



Maximun deformation values

Bending line



	Node	L/C	Horizontal X mm	Vertical Y mm	Horizontal Z mm
Max X	353701	1 ERSATZLA	**2.806**	0.821	-0.018
Min X	426201	1 ERSATZLA	**-0.285**	5.396	-0.140
Max Y	391059	1 ERSATZLA	1.223	**39.581**	-0.942
Min Y	316059	1 ERSATZLA	1.171	**-38.565**	0.756
Max Z	466218	1 ERSATZLA	1.218	-33.960	**0.917**
Min Z	391218	1 ERSATZLA	1.200	39.414	**-1.044**
Max rX	390054	1 ERSATZLA	1.173	39.531	-0.939
Min rX	456058	1 ERSATZLA	1.760	-30.950	0.744
Max rY	507164	1 ERSATZLA	1.843	-0.480	0.019
Min rY	424201	1 ERSATZLA	-0.278	8.478	-0.217
Max rZ	353057	1 ERSATZLA	-0.212	0.004	-0.001
Min rZ	425676	1 ERSATZLA	1.055	6.186	-0.158
Max Rst	391059	1 ERSATZLA	1.223	39.581	-0.942

Fig 48: System calculation for entire bridge for adjustment of electronic control of the ATMDs

6. Proposal for a tender text for tuned mass dampers

Tender-Position ???

TMD type MAURER SÖHNE (or equal) designed, fabricated and delivered according to below static and constructive requirements. The supplier shall have at least ten years of experience on the field of TMD design and fabrication, which shall be proven by references.

Design criteria:
- Active direction of the TMD or the sensitive vibration resp.: vertical, horizontal, torsion
- Frequency to be damped under specified load conditions: ??Hz
- Adaptive or passive: Frequency adaptation once on site or automatic in real time up to +/-10%; Temperature compensation by damping element within +/-10% limits
- Mass of TMD per device: ?? kg
- Mass ratio between TMD mass or modal mass: ??
- TMD mass shall be variable within +/-20%; the possibly necessary mass plates shall be included in the offer.
- Max. available space per TMD: length?? x width?? x height?? mm; hole arrangement for the fixation of the TMD: ???
- Fixation of the TMD shall be by bolt connections. The necessary brackets shall be provided by the steel construction company or the TMD supplier?
- The TMD must have a levelling device for proper levelling within +/-2mm.
- Corrosion protection coating: basic cover 80µm zinc spray, surface cover 80mm epoxy coating or a specified by the design engineer?.

For every TMD a function test shall be provided by the supplier. This test shall verify following values within the specified tolerances:
- Frequency (tolerance range +/-2% to required value),
- Damping (tolerance range +/-15% to required value for room temperature of passive TMD; tolerance range +/-10% to required value for -5°C to +40°C temperature of adaptive TMD),
- Internal friction within the guide system (tolerance field of max. 0,4% friction force part of the TMD mass for vertical and 1% for horizontal TMD guides.

On requirement by the design engineer, the test has to be supervised by an official independent expert with at least 10 years of experience on the field of TMD design. He shall certify the correctness of the test results..
The TMD shall be designed for a service life span of at least 30 years.
On the unobjectionable functioning of the TMDs at least 5 years of warranty are required
On any electronic components 2 years of warranty shall be provided..

?? nos.

Tender-Position ???

*** Optional
Vibration test on the bridge by an official independent expert with at least 10 years of experience on the field of vibration recording on bridges after the bridge is finished to determined the exact requirements for the TMDs. Based on these recorded results and the owner´s decisions the TMD shall be designed and fabricated.

1 nos.

Tender-Position ???

*** Optional
Installation of the TMD.

1 nos.

Tender-Position ???

*** Optional
Installation supervision of the TMD by a specialist of the supplier. The installation itself is carried out by local on site staff.

1 nos.

Tender-Position ???

*** Optional
Vibration test on the bridge by an official independent expert with at least 10 years of experience on the field of vibration recording on bridges after TMDs were installed into the bridge to verify the proper function of the TMDs.

1 nos.

7. MAURER piston viscous dampers (MHD) for vibration control

7.1 Technical description of MHD

Instead or in addition to the tuned mass dampers, viscous dampers with a piston can be applied for structural vibration control. The MAURER hydraulic dampers (MHD) are providing a substantial amount of damping and energy dissipation respectively at structural locations with relative deformations bigger than +/-10 mm.

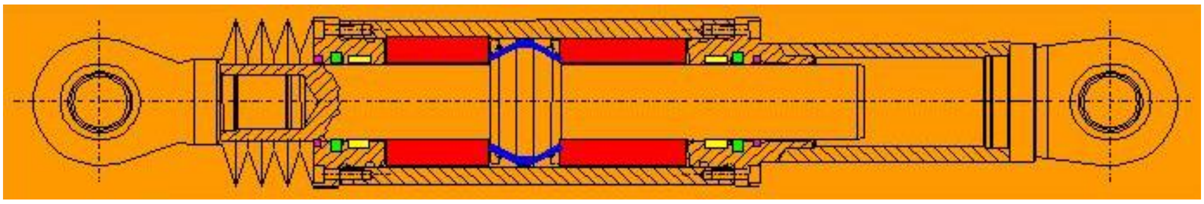


Fig. 49: Section through the MHD

MHDs are devices (Fig. 49), which enable displacements (thermal changes, creep, shrinkage, etc.) during service conditions without creating significant response forces, but dissipate huge amounts of energy during sudden appearance of vibrations, and the vibration energy is been converted into heat.

Fig. 50: MHD before installation

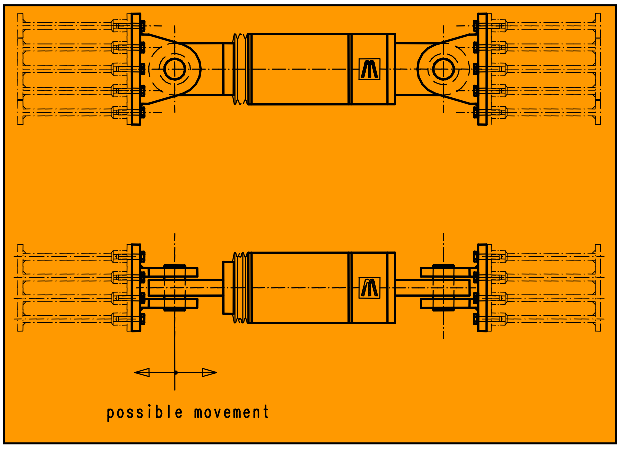


Fig. 51: MHD with concrete tension anchors

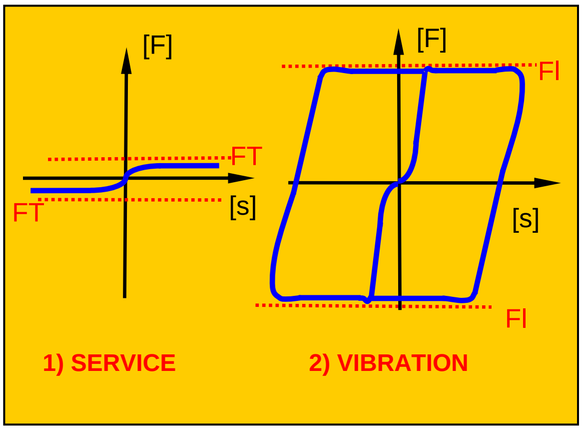


Fig. 52: Force [F] – Displacement [s] - Plot

Very slow displacements e.g. temperature changes, create insignificant response forces FT within the MHD (see **1** in Fig. 52 + 53). The fluid can flow from one piston side to the other.

When sudden vibrations with relative displacements occur between the linked structural sectors due to pedestrian traffic, wind or similar, inducing displacement velocities in the range of 0.1 mm/s to 0,7 mm/s, the MHD is responding with a force. The maximum response force is Fl (Fig. 52 + 53).

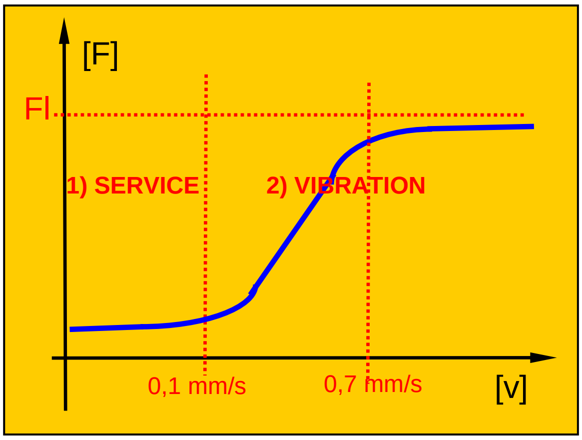


Fig. 53: Force [F] - Velocity [v] – Plot

During the load case VIBRATION, an integrated "intelligent" control mechanism enables relative displacements between the connected parts, but with still constant response force Fl. The very special feature is now, that Fl is independent from the vibration frequency, means independent from the displacement velocities (see **2** in Fig. 53). It is always on a constant level.

During these displacements the special control mechanism pilots the fluid flow very exactly from one piston side to the other in order to achieve this constant response force characteristic.

On one hand the bridge designer can be sure that a maximum of the induced energy into the structure is dissipated and on the other hand the maximum response force of the MHD acting onto the structure is well known independent from the occurring vibration frequency. Therefore the structure can be easily calculated for this constant response force, and high safety margins are realized in a very economical manner.

The damping constant and the maximum response force are individually adapted to the structural request.

Equivalent damping coefficients ξ:

MHD: ξ= up to 0,61

The damping coefficient ξ relates to the efficiency η according to following equation:

$$\xi = \frac{2}{\pi}\eta$$

This ends up in an maximum efficiency of up to η = 96% for the MHD!

$$F = C \times v^{\alpha}$$

F = MHD response force
C = Constant value adapted to request
v = vibration displacement velocity
α = damping exponent < 0.015 – 0,4

=> due to the possible low α value of 0,015 the MHD response force is independently acting from the displacement velocity/frequency as the term "v^{α}" runs against "1"

Fig. 54: Equivalent damping coefficient and efficiency

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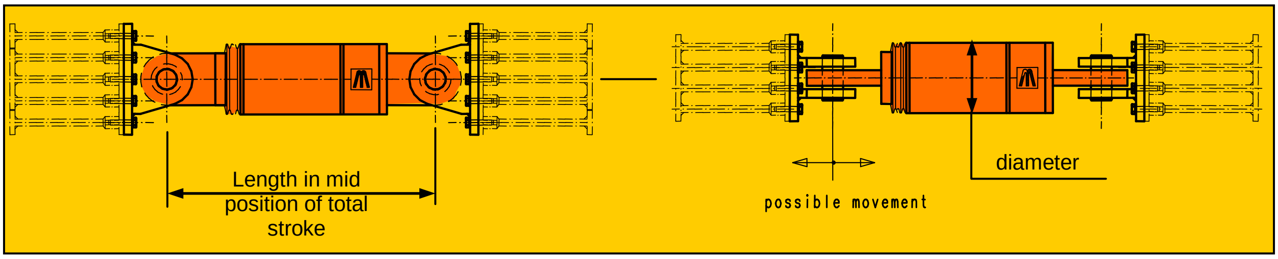
Overall characteristics of the MHD:

- During service conditions the device is not pre-tensioned and the fluid is under insignificant pressure.
- Maximum response force is well defined to a certain limit. No structural damages due to higher damping forces occur even in case the vibration frequency was higher than expected, and the design engineer can easily calculate with this constant maximum response force – independent from velocity or frequency – but still be sure to gain the maximum possible structural safety factor. This constant response force is resulting from the extra low damping exponent α < 0,015 to 0,4 (Fig. 54).
- Extreme great efficiency of up to η = 96% (Fig. 54) which corresponds with a maximum equivalent damping coefficient of 0,61. The highest possible energy dissipation is granted.
- The response force for displacement velocities less than 0,1 mm/s is less than 2-7% of the maximum response force. The exact value is depending on the final damper design.
- The possible displacement velocity range for damping is from 0,1 mm/s up to 1500 mm/s or even more.
- Maximum response force is given by the MHD within tenths of a second, so structural displacements and vibrations are most effectively minimized.
- Automatic volume compensation of the fluid caused by temperature changes without pressure increase inside the devices. Any compensation containers are located inside. On request they can also be placed outside.
- No maintenance works necessary. Visual inspection is recommended during the periodic bridge inspections. Depending on the accumulated displacements and displacement velocities the service life span is up to 40 years without maintenance.
- The devices are not prone to leaking, as a special high strength and wear resistant hydraulic seal-system is applied - like for Caterpillars, for automobile industry and similar machineries. On request prove tests are carried out. The MHD has got a 3-step seal-system consisting of a guide ring (guiding the piston and carrying the piston weight => yellow in Fig. 49), of the real seal (sealing the piston effectively against leaking => green in Fig. 49) and the dust brush (protecting the seal from fine dust => pink in Fig. 49).
- Very little elasticity of 3-5% depending on request. For instance at 50 mm displacement capability in the moving direction the maximum displacement of the damper piston till the damper force is fully acting is 1,5 mm at 3% elasticity of the special synthetic (non-toxic, not inflammable, not ageing) fluid.
- Range of operating temperature: -40°C to +80°C with tolerances of response force up to less than +/-5%.
- Small dimensions and simple installation.
- Depending on request spherical hinges are installed at both device ends to accommodate installation tolerances and displacement adaptation.
- On request the design can be fatigue resistant for more than 7 Mio cycles.
- Monitoring of temperature, pressure, displacement and other parameters possible.

Sizes of MHD for first project phase (none scale)

Depending on the individual structure the MHD dimensions can be adapted within a certain range by Maurer to the special request! **The below mentioned values are just for orientation to get a first idea of possible sizes.**

Lateral view: Top view:



axial force [kN]	total stroke [mm] & 0,3 [m/s] design velocity 100 D [mm]	100 L [mm]	250 D [mm]	250 L [mm]	500 D [mm]	500 L [mm]	750 D [mm]	750 L [mm]	1000 D [mm]	1000 L [mm]
250	171	815	171	1175	171	1800	171	2425	203	3100
500	203	960	203	1265	203	1890	203	2515	229	3190
700	229	1145	229	1400	229	2025	229	2650	267	3325
1000	267	1210	267	1450	267	2075	267	2700	318	3375
1500	318	1375	318	1600	318	2195	318	2820	368	3495
2000	368	1515	368	1740	368	2280	368	2905	394	3580
2500	394	1635	394	1860	394	2370	394	2995	445	3670
3000	445	1780	445	2005	445	2450	445	3075	508	3750
4000	508	2090	508	2315	508	2690	508	3305	559	3980
5000	559	2270	559	2495	559	2870	559	3420	610	4095
6000	610	2485	610	2710	610	3085	610	3570	680	4245

Fig. 55: Principle sketch and preliminary dimensions of MHD

The diameter dimension is also depending on the nominal operation pressure of the MHD, which is resulting from service life and friction requirements of the seal-system.

On demand any intermediate sizes, greater response forces than 6,000 kN or less than 250 kN and greater displacements than 1000 mm or less than 100 mm are possible on demand as well.
The design velocity will be adapted on demand as well.

The connection and anchoring of the MHD to the structure (concrete or steel) will be adapted to the structural request.

7.2 Application of MHD-250: Footbridge Traunsteg in Wels - Austria

MHD:

a) max. response force: 250 kN
b) damping constant : 2000 kNs/m
c) Frequencies above 0,3 Hz

Fig. 56: Traunsteg-Wels

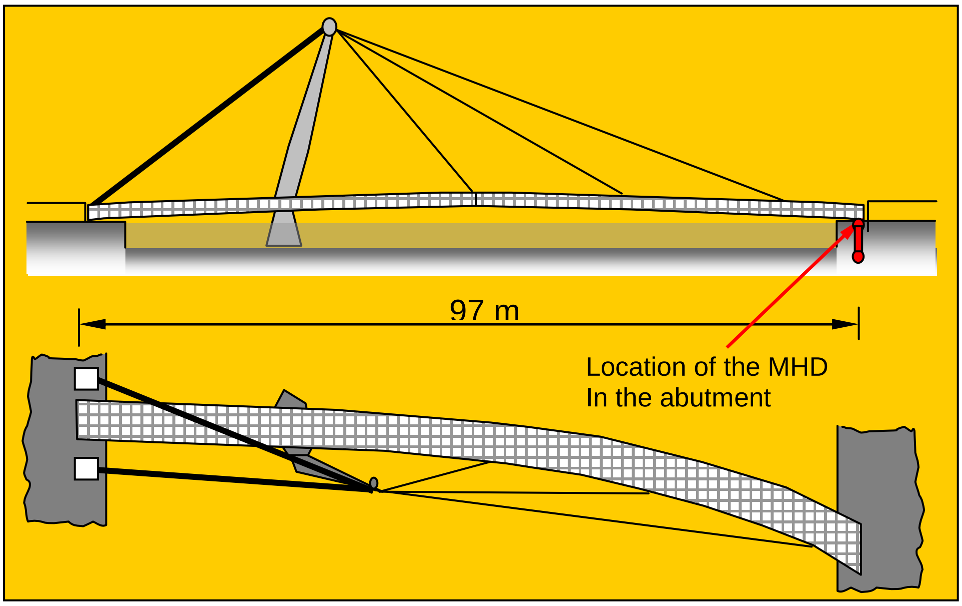
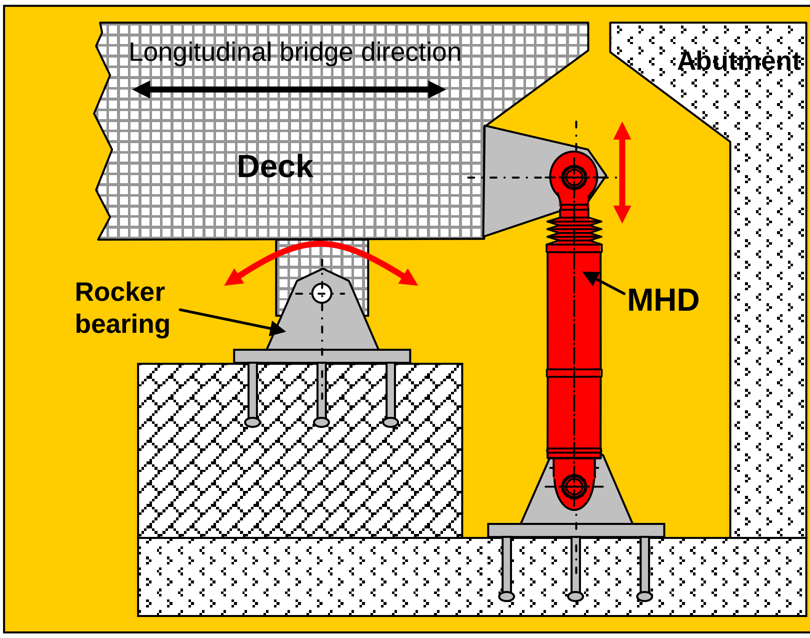


Fig. 57: Lateral and top view onto Traunsteg-Wels



MHD location & function:

- Due to vertical deck deflection in the river centre, the deck is rotating around the rocker bearing.
- The rocking rotation is inducing movement into the vertically arranged MHD, which is responding with maximum 250 kN force for displacement velocities above 0,1 mm/s between deck and abutment
- The MHD is dissipating the vertical vibration energy of the bridge.

Fig. 58: Vertical arrangement of MHD within the abutment

7.3 Application of MHD-3000: Russkiy Island Bridge at Vladivostok - Rissia

Data of MHD:

a) max. seismic response force: 3000 kN (design for max. 6000kN)
b) damping constant : 3148 kNs/m
c) Velocities up to 200 mm/s
d) Stroke 2200mm
e) Fatigue resistant for 7 Mio. wind impacts up to 2000kN
f) Displacement until full service force gets activated: 15-20mm in mid position
g) Operation force tolerance due to temperature (-40°C to +60°C) less than 6%.

Fig. 59: Russkiy Bridge with main span of 1104m

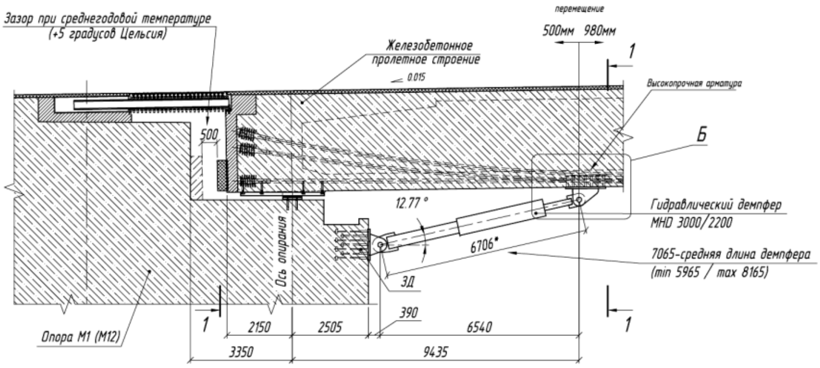


Fig. 60: Installation location at abutment of the approx. 7m long and 5,200kg heavy hydraulic dampers

Fig. 61: Testing at University of California San Diego

Fig. 62: Assembled MHD

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8. Proposal for a tender text for viscous dampers

Tender- Position ??? Viscous damper of Type MAURER-MHD (or equivalent) designed, calculated, fabricated and delivered according to specification.
The supplier must have a minimum experience of five years on the field of fabrication of viscous dampers.

Design criteria:
- Necessary response force for energy dissipation: ?? kN
- Maximum allowable response force almost independent from velocity to protect structure: ??kN
- Damping exponent α: less than 0,04 for independent response force from the impact frequency.
- Expected frequencies of the bridge for dead load of the bridge: ?? Hz.
- Vibration amplitudes at damper location with corresponding frequencies: ??, ??, ?? mm (+/-)
- Necessary maximum energy turnover of the damper per hour: ?? kW/h
- Duration of the maximum energy input: ?? sec
- Fluid volume accumulator.
- Total accumulated displacement path within the specified service life span: ?? meter
- Maximum allowable response force for displacement velocities less than 0,1 mm/s: less than 7% of the design response force.
- Stiffness of the damper under load: maximum 4% of the displacement capacity in the loaded direction.
- Damper has to be adjustable in length easily without significant efforts.
- Max. space required per damper with support brackets at both damper ends: ? x ? x ? mm
- Both damper ends shall be fitted with spherical hinges.
- Fixation and anchoring requirements: see structural drawings
- Piston rod shall be made of ductile structural steel with hard chromium and/or nickel plating.
- Corrosion protection: 80µm zinc spray + 2 x 80µm epoxy iron cover layers.

In case the check engineer is requiring testing following procedure shall be considered:
For one damper of each size a prototype test shall be carried out, which show results being within below listed tolerance limits:
- Response force for the occurring structural frequencies and deformations (tolerance of +/-10% of design force independent from the occurring frequency),
- Lowest response force level for displacement velocities less than 0,1 mm/s (maximum +20%),
- Energy turnover of damper (tolerance of +/- 15%),
- Stiffness of device in load direction under load (tolerance +/- 15%),
- Leakage test at 125% of the design pressure in the damper to be held constant for 120s without leaking effects.

The testing has to be carried out by an specialist institute (approved by the check engineer) with more than 5 years of experience on the field of damper testing.
The damper shall be designed for a service life span of ?? years.
On the unobjectionable functioning the supplier shall provide 5 years of guarantee.
?? nos.

Tender-Position ??? *** Optional
Vibration test on the bridge by an official independent expert with at least 10 years of experience on the field of vibration recording on bridges after the bridge is finished to determined if a damper is required. Based on these recorded results and the owners decisions the damper shall be designed and fabricated.
1 nos.

Tender-Position ??? *** Optional
Installation of the viscous damper.
1 nos.

Tender-Position ??? *** Optional
Installation supervision of the viscous damper by a specialist of the supplier. The installation itself is carried out by local on site staff.
1 nos.

Tender-Position ??? *** Optional
Vibration test on the bridge by an official independent expert with at least 10 years of experience on the field of vibration recording on bridges after the viscous dampers were installed into the bridge to verify the proper function of the devices.
1 nos.

9. Testing and recording of function characteristics

Each MAURER TMD is tested before leaving the workshop, means the proper function is checked and documented:

- The moving capability of the MTMD is checked, means the TMD mass has to move without significant internal friction within the guide system (Fig. 63).
- The specific spring frequency is recorded with a special sensor and electronic system (Fig. 64).
- The damping element is tested in a special testing rig.

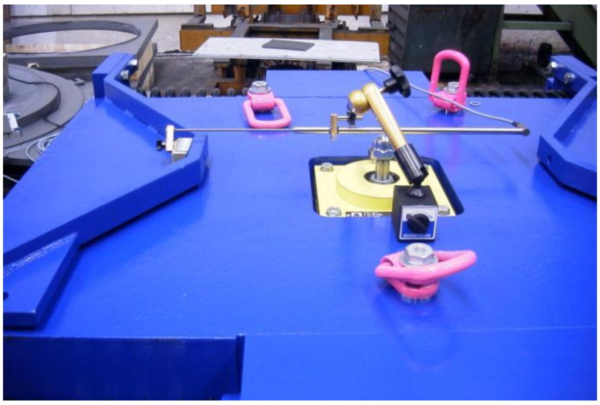

Fig. 63: Testing and possibly fine adjustment of the TMD function characteristics

Fig. 64: Recording of data with special sensors and documentation of results

- With special testing rigs the passive and adaptive damping element is tested (Fig. 65).

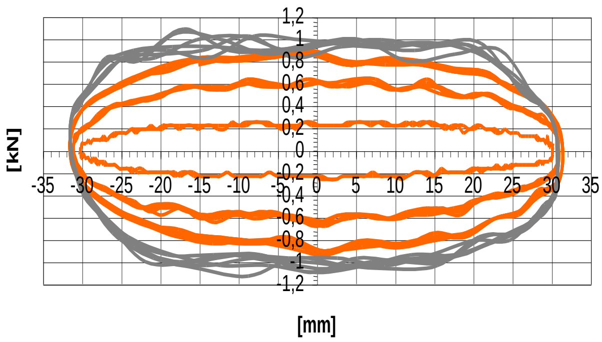

Fig. 65: Force-Displacement-Plot of damping element

Fig. 66: Testing rig for MHD

- For the viscous piston dampers (MHD) individual tests are carried out on request (Fig. 66) for instance at University Bochum, University Munich, University of California San Diego, EMPA Duebendorf or others.