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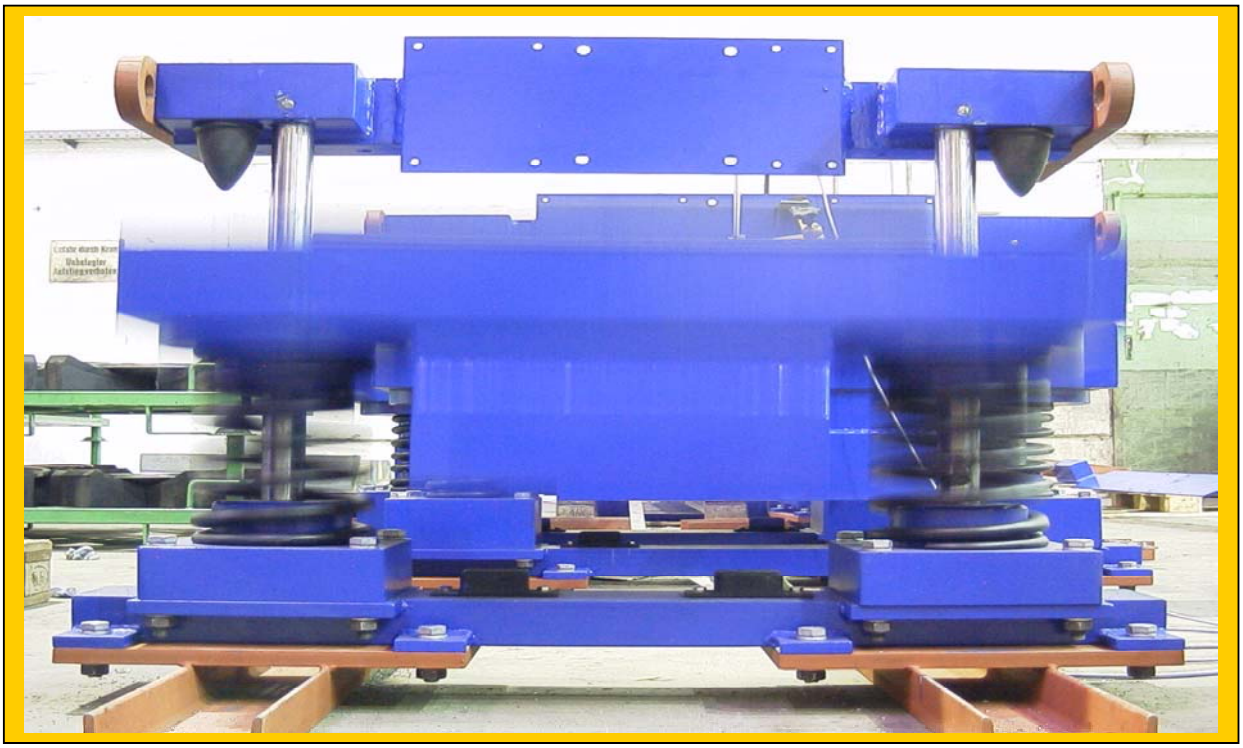
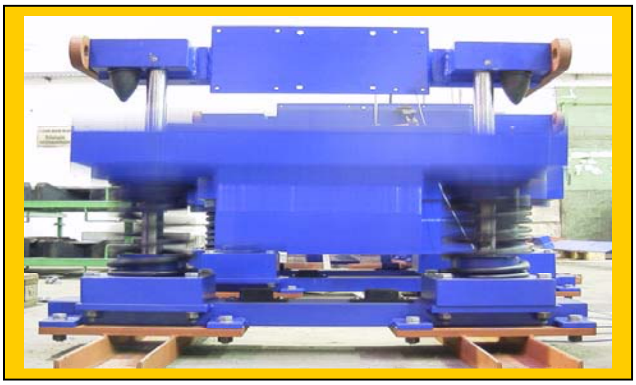
MAURER
Tuned Mass and Viscous Dampers



Technical Information and Products

MAURER SÖHNE
Innovations in steel
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 overhanging 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.

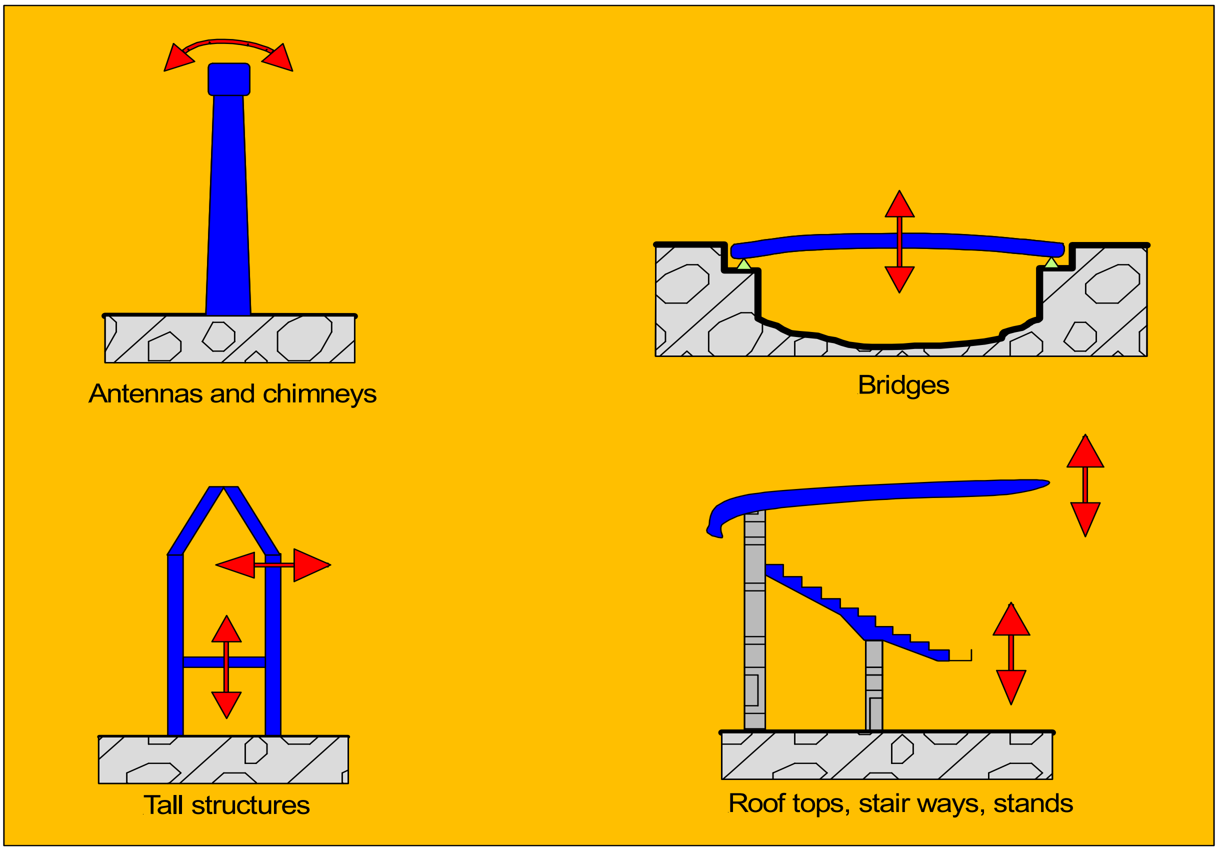


Fig. 1: Samples for vibration sensitive structures

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.**

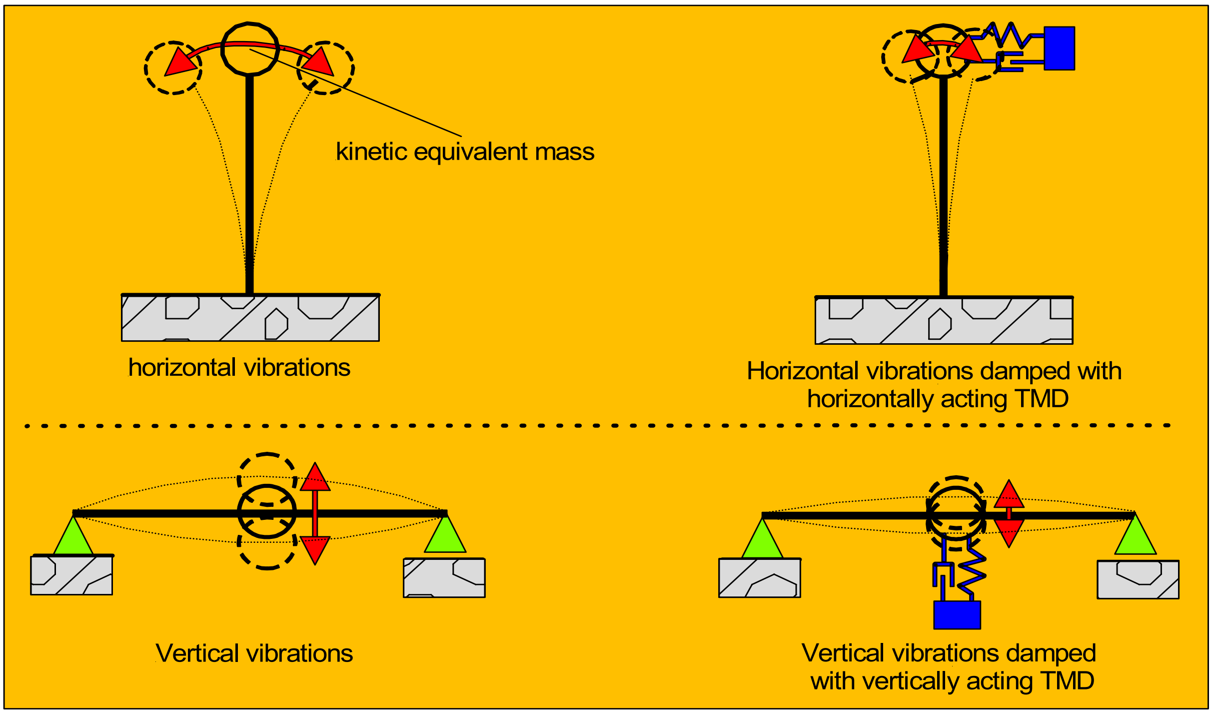


Fig. 2: Principle of system and location for TMDs

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.

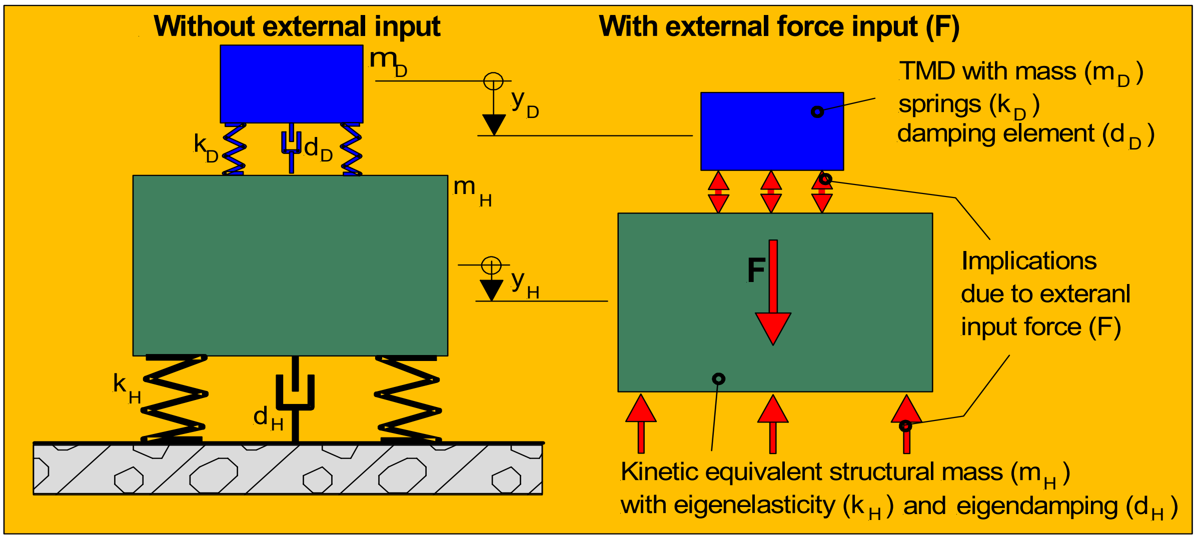


Fig. 3: Working principle of TMD

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 · sinWt is acting and the main system is vibrating stationary with the natural frequency W. 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.

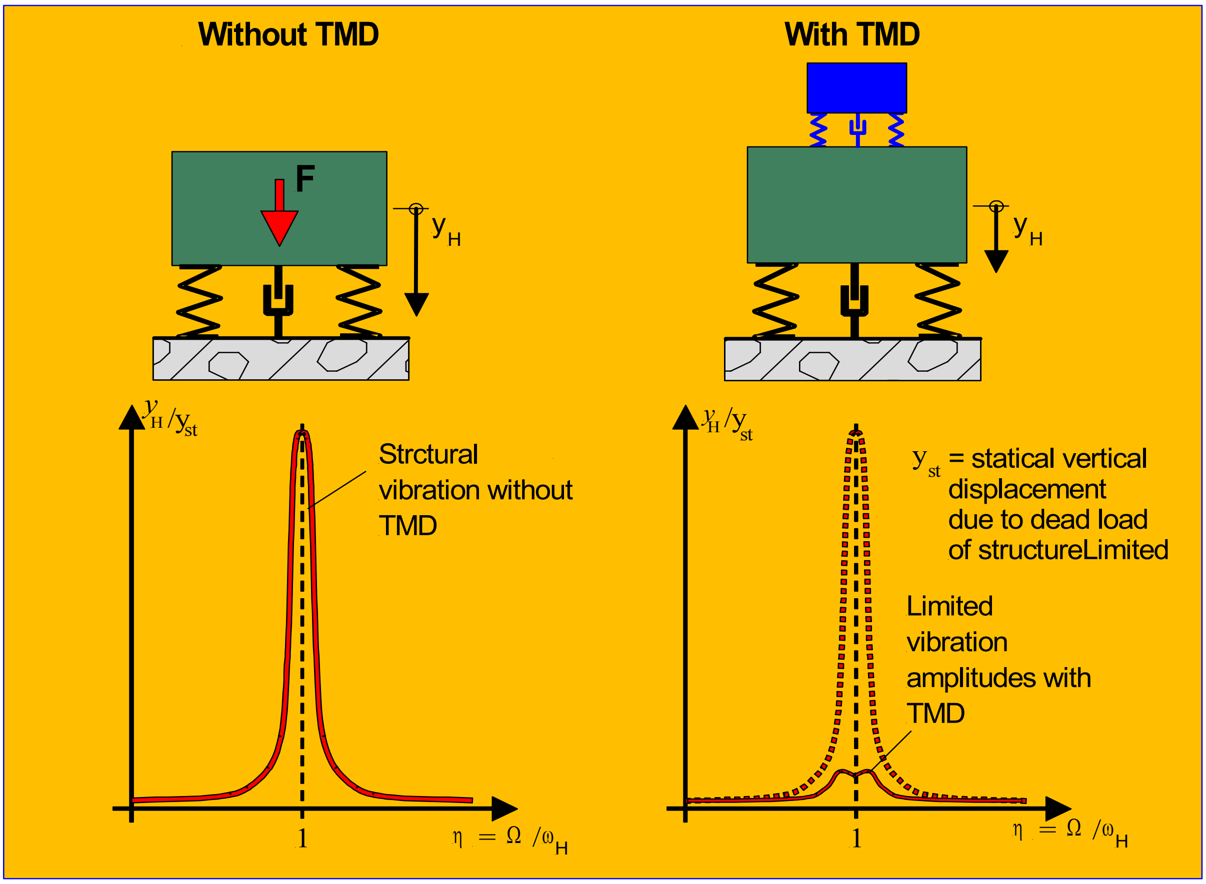


Fig.4: Dynamic response of the main system with and without TMD

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:

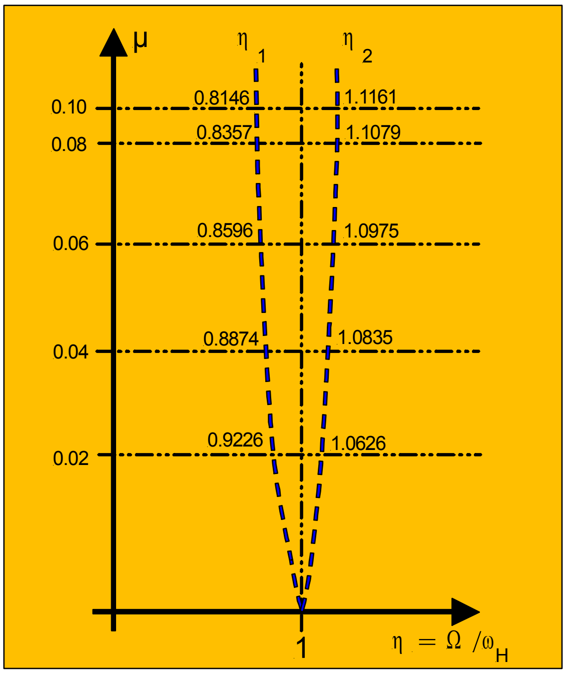


Fig. 5: Frequency range with respect to μ

- **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.

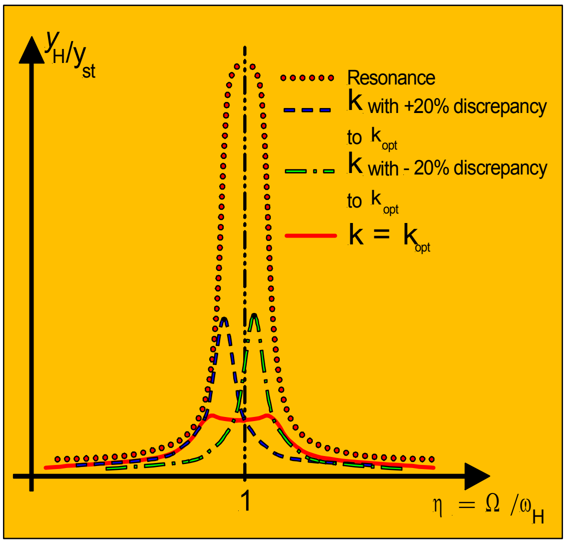


Fig. 6: Behaviour of main system if deviation varies

- **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:

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

- **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.

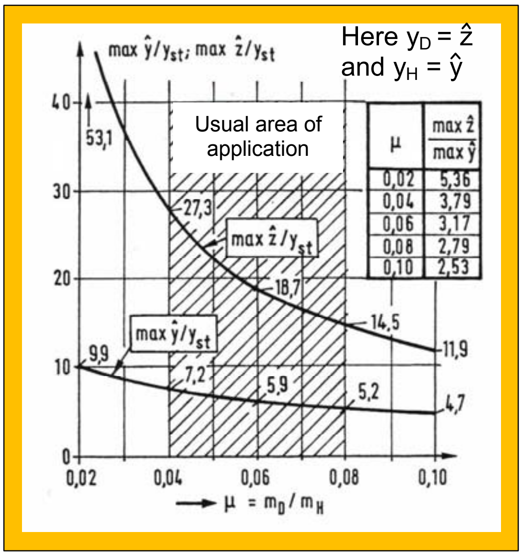


Fig. 7: Relative displacements of the TMD compared with the structure itself and usual area for mass ratios

- **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 k/k_{opt} (on horizontal axis).
  Example: In case of a value of 0.8 for the relation k/k_{opt} – the deviation k 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.

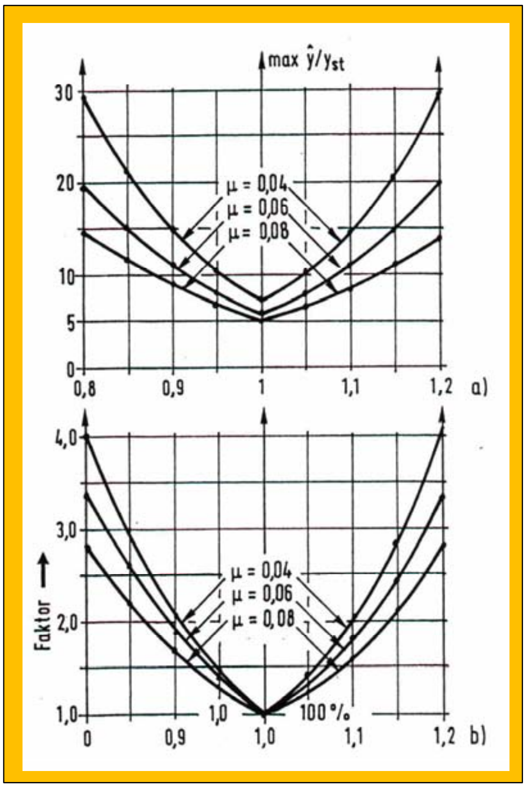


Fig. 8: Amplitude amplification factor in case the optimal deviation does not fit

- **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.

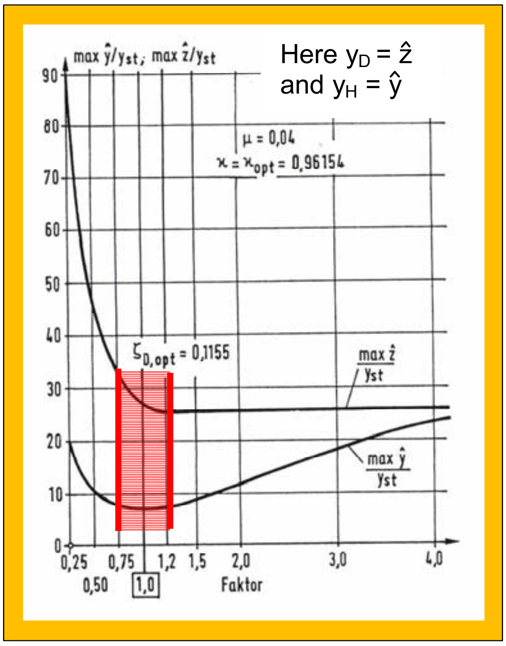


Fig. 9: Deviation of damping with resulting changes of structure and TMD amplitudes for μ = 0,04

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).

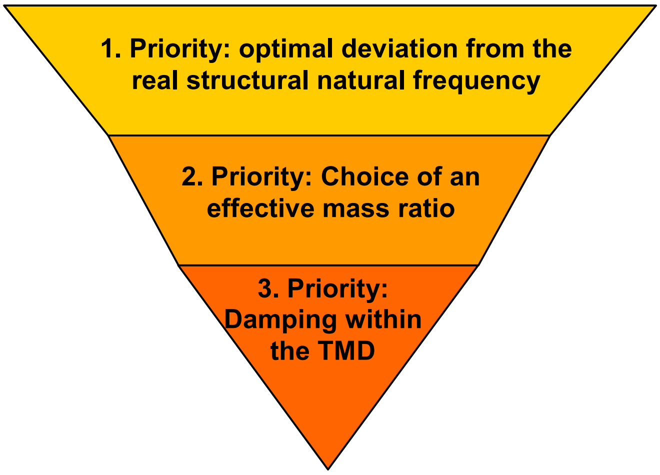


Fig. 10: Priorities of three main adaptation criteria

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

5.1. 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.

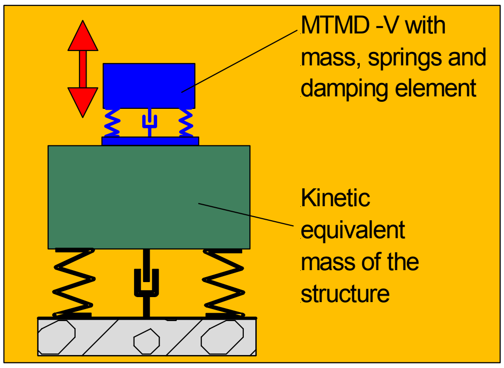
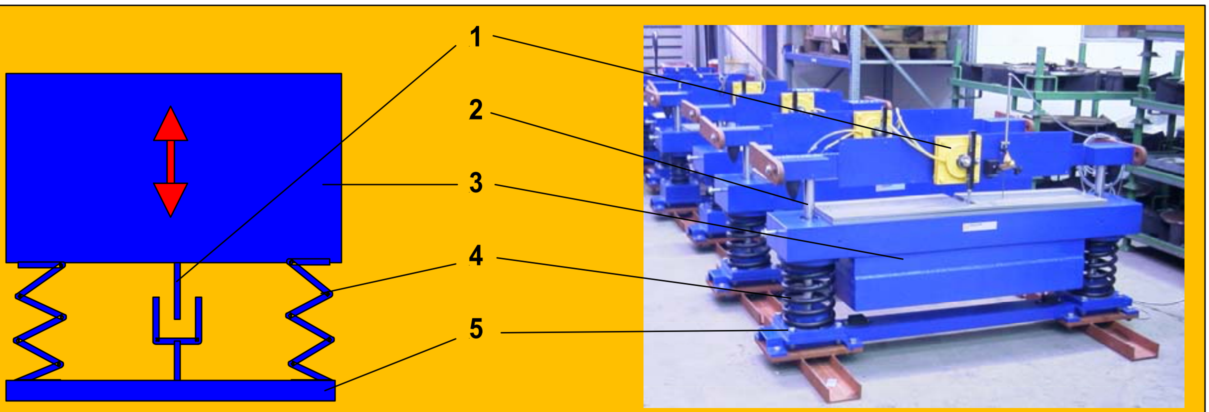


Fig. 11: Principle of function of MTMD-V



1 = adjustable damping element => providing required damping (ζ)
2 = vertical TMD-mass guide system => exact guidance of the mass in vertical direction
3 = adjustable steel mass => mass according to required mass ratio (μ)
4 = vertically acting steel springs with frequency (f_D) => adapted to natural frequency of the structure (f_H) including deviation (k)
5 = adjustable base plate => provides proper fixation of all components and is connecting the TMD to the structure itself

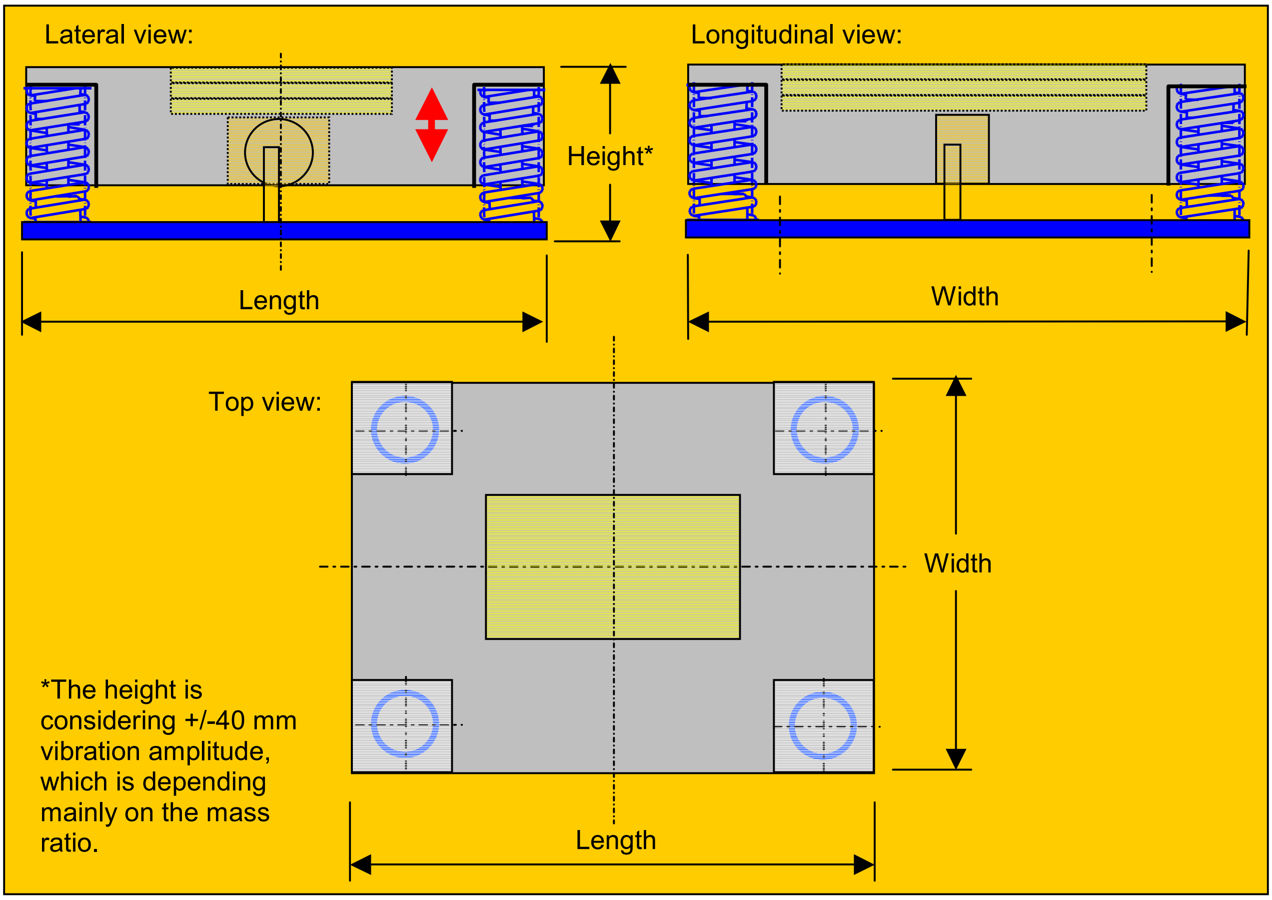
Fig. 12: Description of MTMD-V

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.).

Seizes 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)

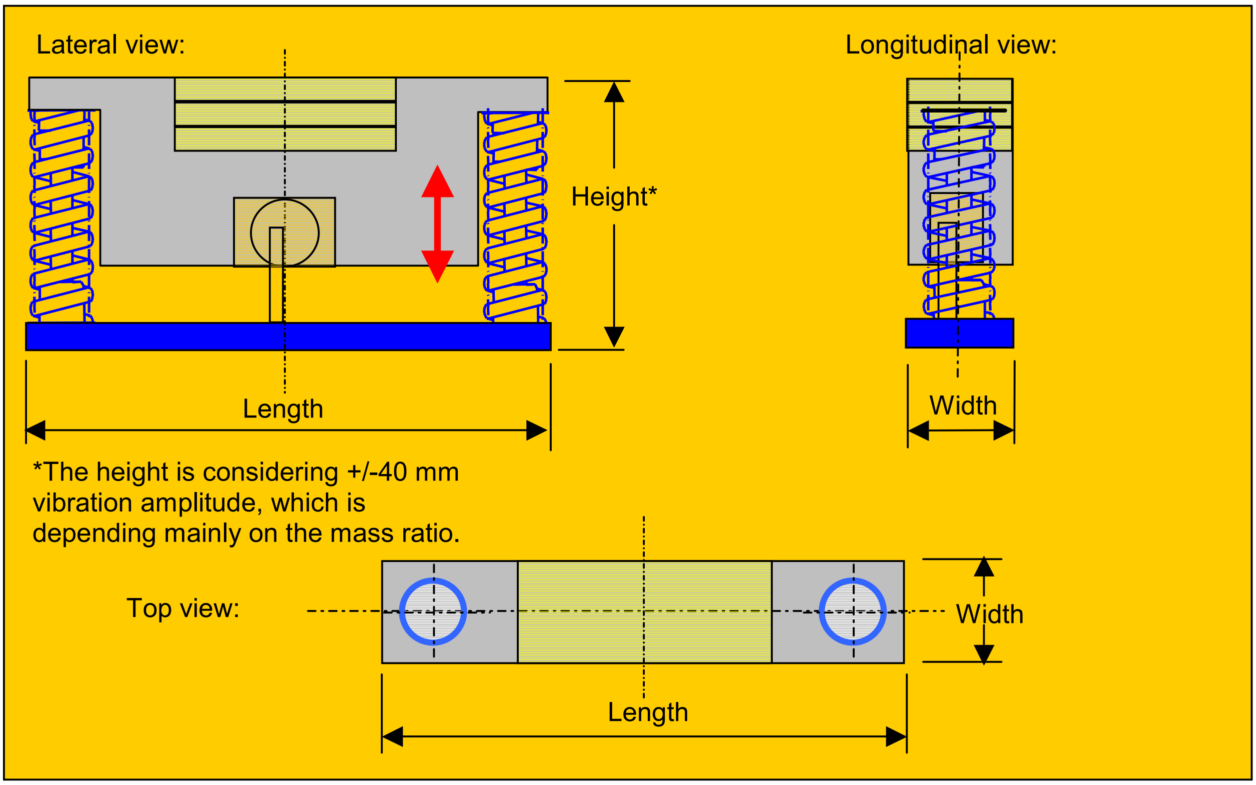


Tuned mass [kg]	Length [mm]	Width [mm]	Height [mm]
250	600	560	275
500	800	556	325
750	1000	610	325
1000	1000	780	325
1500	1250	930	325
2000	1600	930	325
2500	2000	930	325
3000	2000	1080	325
4000	2000	1410	325
5000	2560	1410	325
6000	2780	1530	325

Fig. 13: Principle sketch of MTMD-V-flat and preliminary dimensions

The damping element will be adjusted to the requested damping. The above preliminary dimensions are for a frequency range between 0,3 Hz and 5 Hz. Nevertheless the final dimensions depend on exact frequency values and fixation possibilities to the structure.
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

The damping element will be adjusted to the requested damping. The dimensions are valid for a frequency range between 0,3 Hz and 5 Hz. Nevertheless the final dimensions depend on exact frequency values and fixation possibilities to the structure.

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.

5.1.2 Application of MTMD-V-1000/1660: Footbridge in Forchheim - Germany

MTMD-V in flat version:

a)	mass:	1000 / 1660kg
b)	frequency:	1,255 / 2,7 Hz
c)	damping:	3280 /4585 Ns/m


Fig. 15: Bridge Forchheim

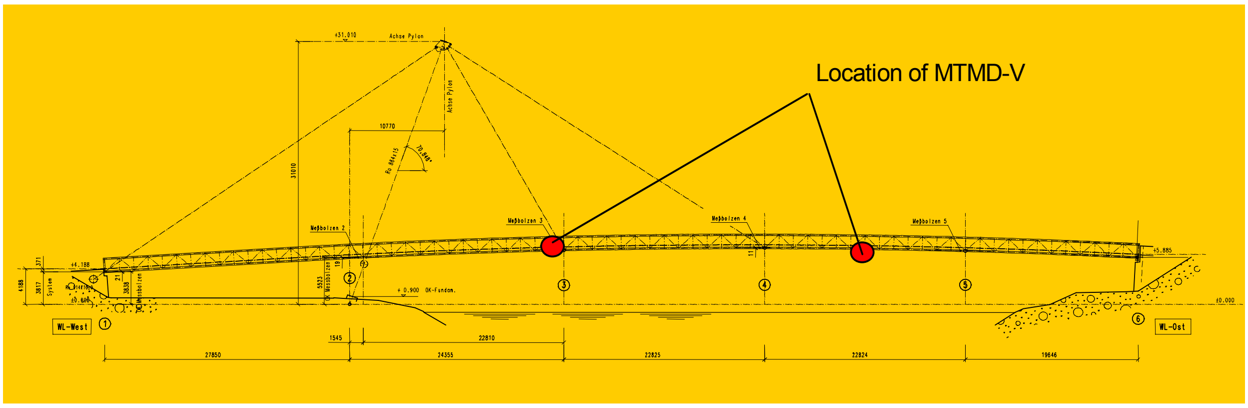

Location of MTMD-V

Fig. 16: Side view


Fig. 17: Installed MTMD-V

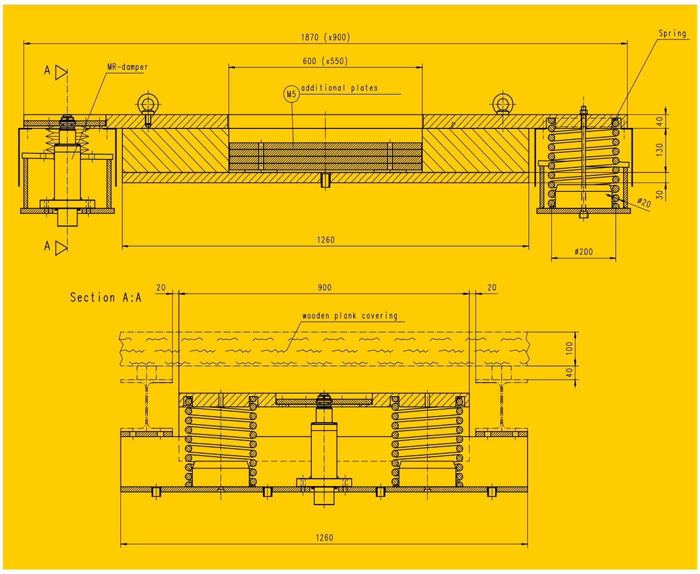


Fig. 18: Cross section through MTMD-V

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

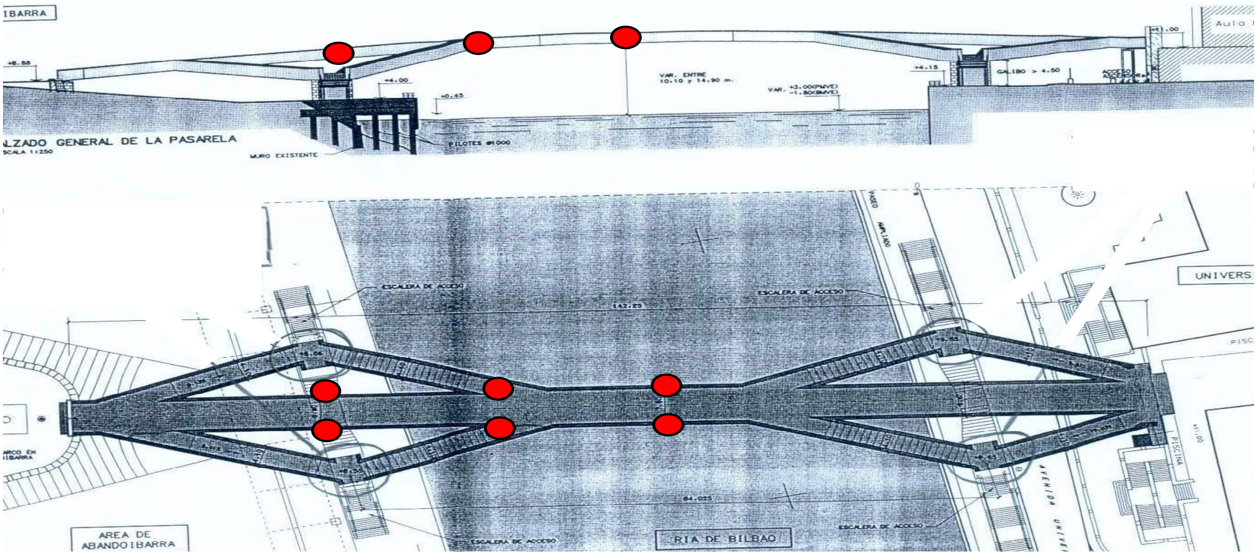


Fig. 20: Side and top view

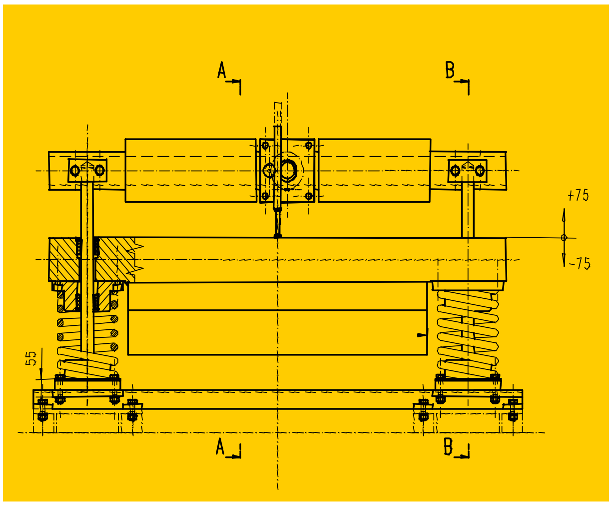


Fig. 21: Cross section through MTMD-V

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

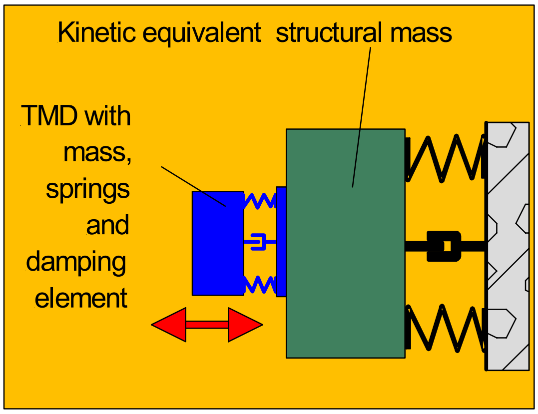
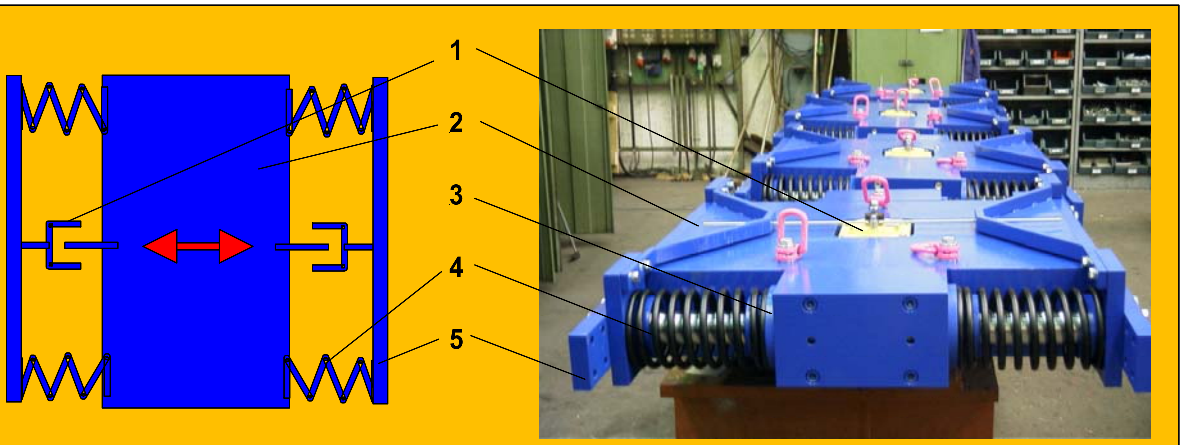


Fig. 23: Principle of function of MTMD-H

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.



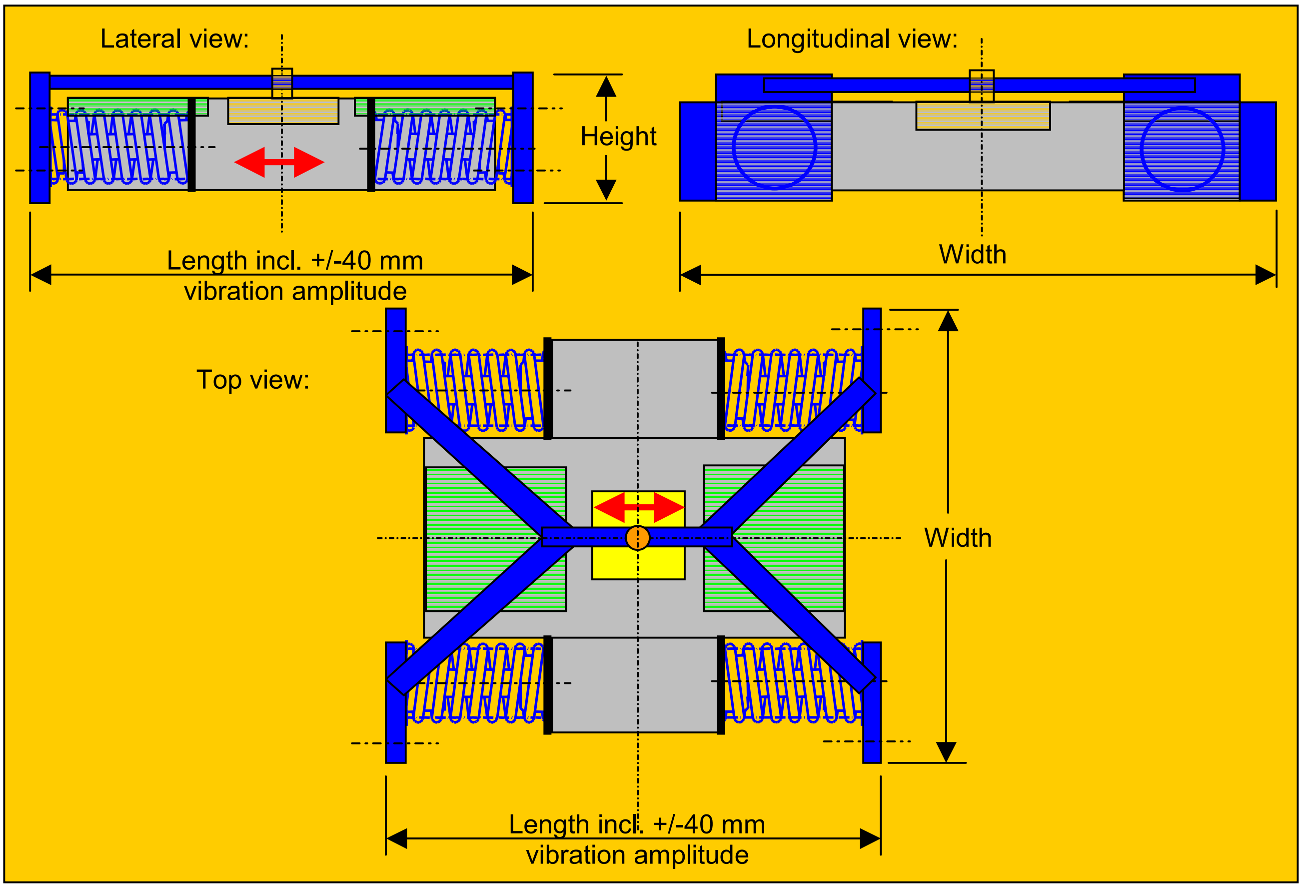
1 = adjustable damping element => providing required damping (ζ)
2 = adjustable steel mass => mass according to required mass ratio (μ)
3 = horizontal MTMD - mass guide system => exact guidance of the mass in horizontal direction
4 = horizontally acting steel springs with frequency (f_D) => adapted to natural frequency of the structure (f_H) including deviation (κ)
5 = adjustable base plate => provides proper fixation of all components and is connecting the MTMD to the structure

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.).

Seizes 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	Length	Width	Height
[kg]	[mm]	[mm]	[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 0,15 Hz and 2,5 Hz. Nevertheless the final dimensions depend on exact frequency values and fixation possibilities to the structure.
For instance in case the length is requested to be shorter, the width and/or the height can be increased.
The MTMD-H mass can be increased as necessary (more than 30,000 kg) but handling and installation has to be considered.

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

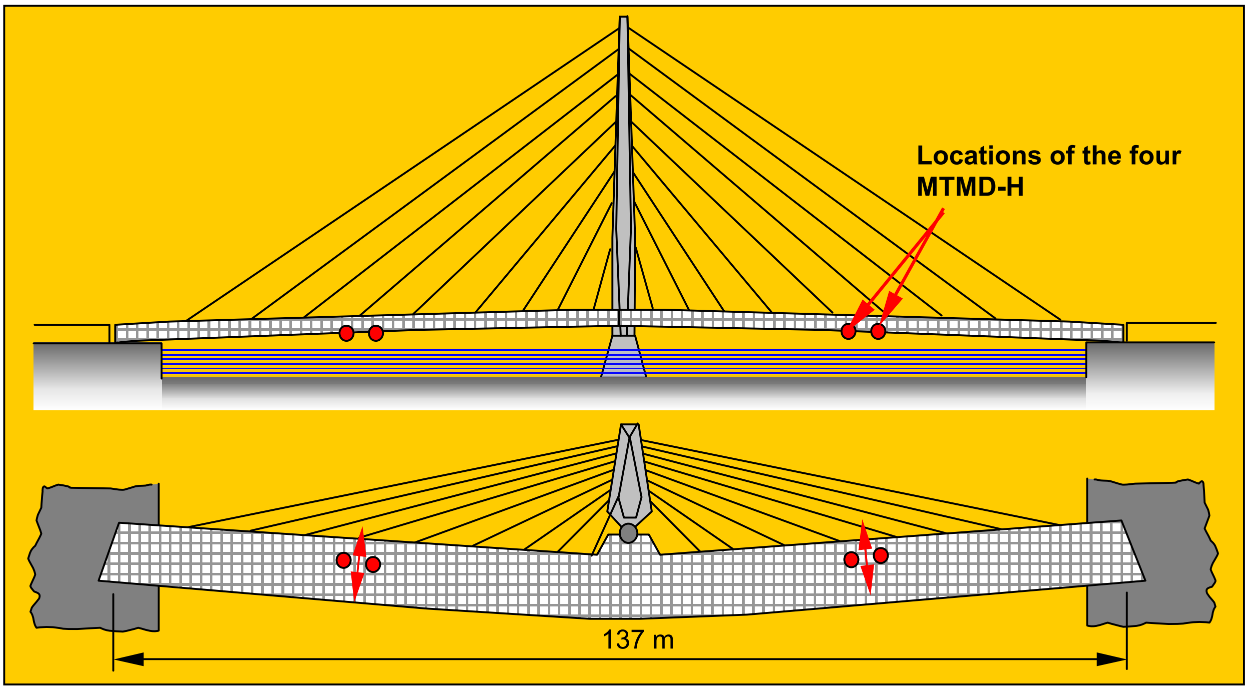


Fig. 27: Side and top view of bridge

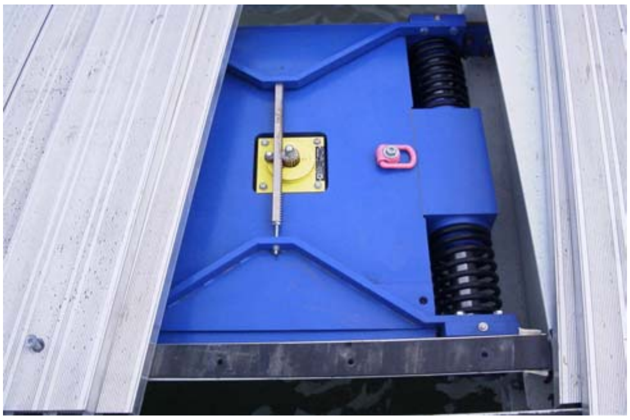


Fig. 28: Installed MTMD-H

Fig. 29: Port Tawe bridge deck

5.2.3 Application for MTMD-H-358: Transrapid in Shanghai - China

MTMD-H:

a) Mass: 358kg
b) Frequency: 14,51 Hz
c) Damping: 6327 Ns/m

Fig. 30: Transrapid on the elastic steel points girder

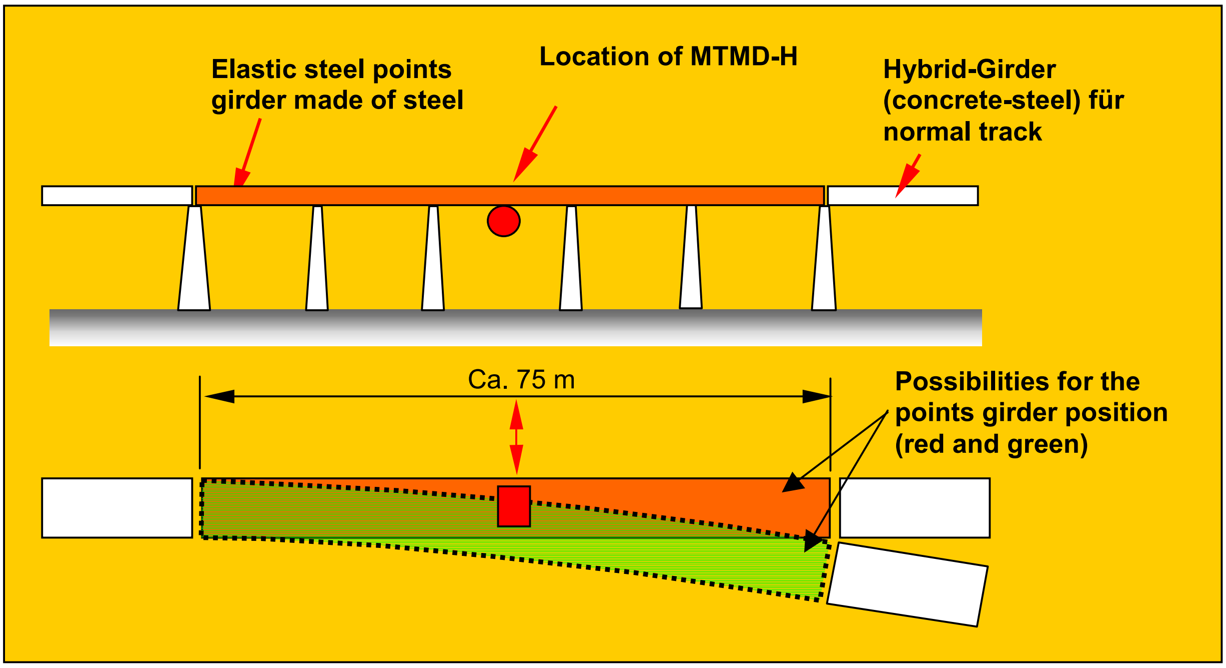


Fig. 31: Points girder of Transrapid

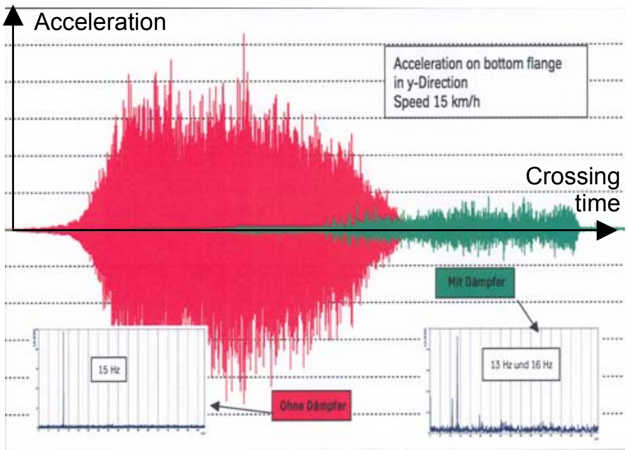


Fig. 32: Acceleration decrease by factor of „4“ with MTMD-H (green) instead of without (red)

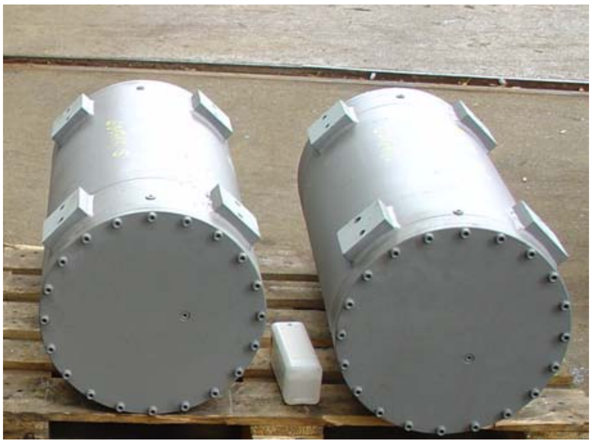


Fig. 33: Transrapid damper of type MTMD-H assembled, integrated in housing and protected against vandalism

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.

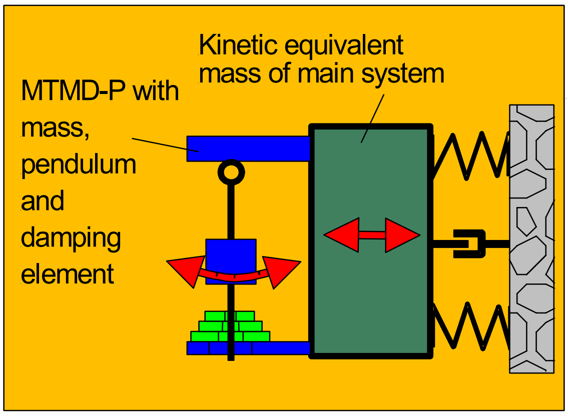
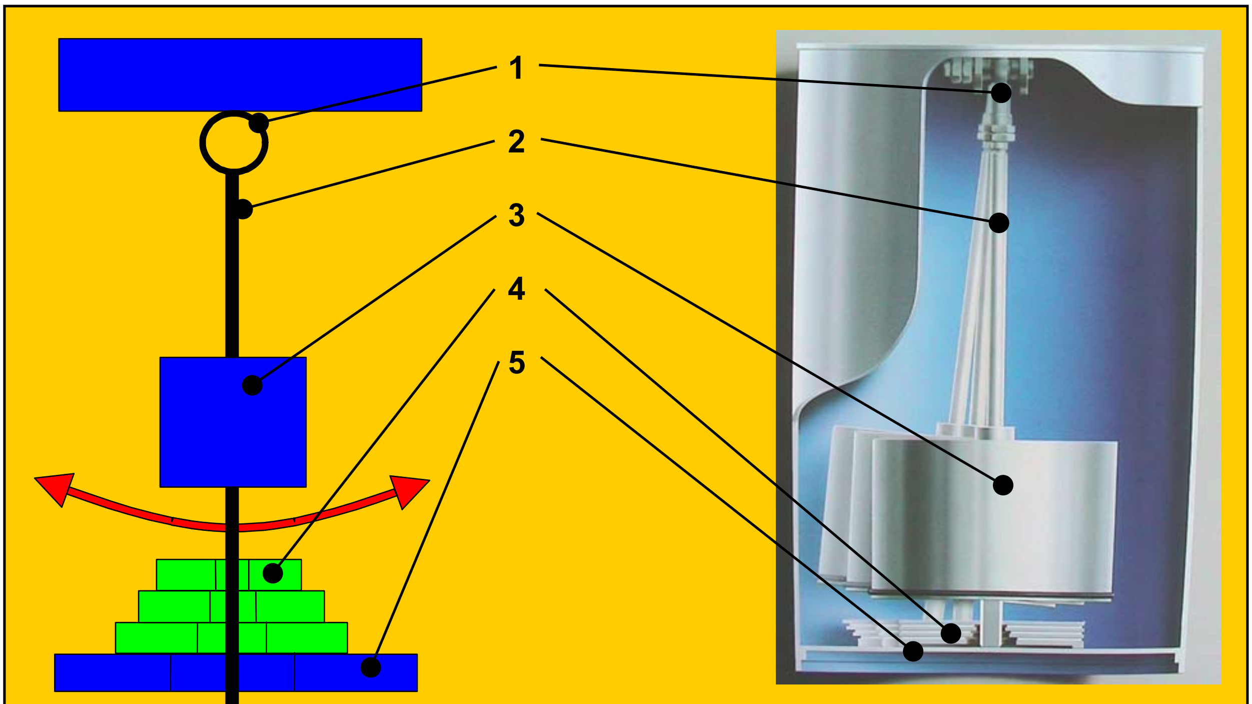


Fig. 34: Principle of function of MTMD-P



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, 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

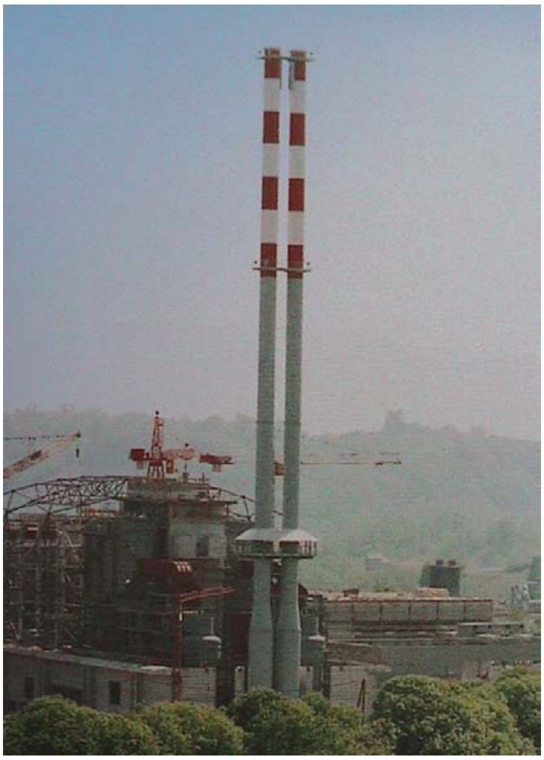


Fig. 37: MVA Genf - Switzerland

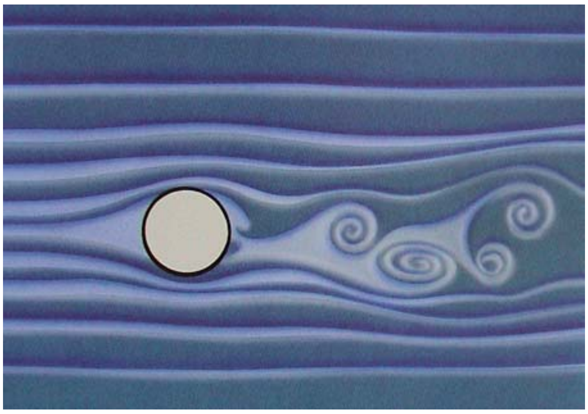


Fig. 38: Karman vortex street

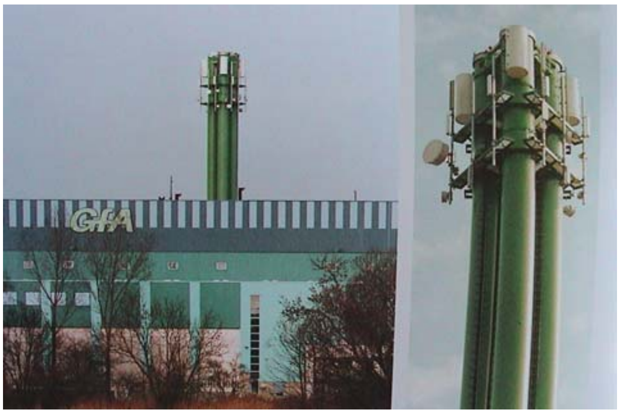


Fig. 39: MVA Geiselbullach - Germany

6. Proposal for a tender text for tuned mass dampers

LV-Position ???

Schwingungstilger System MAURER-PETERSEN (oder gleichwertig) nach statisch-konstruktiven Erfordernissen auslegen, zeichnen, herstellen und liefern.
Der Hersteller muss über mindestens fünf Jahre Erfahrung im Schwingungstilgerbau verfügen und dies mit Referenzen nachweisen.

Auslegungs- und Designkriterien:

- Wirkrichtung des Schwingungstilgers bzw. zu bedämpfende Schwingung: Vertikal oder horizontal oder Torsion
- Zu bedämpfende Eigenfrequenz der Brücke unter Eigengewicht: ?? Hz.
- Dämpfermasse pro Schwingungstilger: ?? kg
- Massenverhältnis zwischen Tilgermasse und kinetisch äquivalenter Brückenmasse: ??
- Tilgermasse muss innerhalb +/-20% variierbar sein; die möglicherweise zusätzlich notwendigen Masse-Platten sind einzurechnen.
- Max. vorhandener Raum pro Tilger: ?? x ?? x ?? mm; Lochbildvorgabe für die Verschraubung: ???
- Befestigung erfolgt mittels Schraubverbindungen zu bauseitigen Haltern, bzw. Trägern.
- Korrosionsschutz gemäß TL 918300 (Teil 2) wie für Brückenlager.

Für jeden Schwingungstilger ist vom Hersteller ein Funktionstest, welcher die nachfolgenden Werte innerhalb bestimmter Toleranzbereiche aufzeigt und entsprechend dokumentiert, durchzuführen:

- Frequenz (Toleranzbereich +/-3% von der Sollvorgabe),
- Dämpfung (Toleranzbereich +/-15% von der Sollvorgabe),
- innere Reibung in den Führungen (Toleranzbereich maximal 0,4% Reibkraftanteil von der Tilgermasse für vertikale Führungen und 1% von der Tilgermasse für horizontale Führungen)

Der Funktionstest ist von einem unabhängigen offiziellen Sachverständigen (von dem Auftraggeber anerkannt) mit entsprechender Erfahrung (mehr als 5 Jahre) auf dem Gebiet der Schwingungstechnik von Brücken zu überwachen und die Einhaltung der Toleranzgrenzen ist von diesem entsprechend zu bestätigen.
Die Schwingungstilger sind für eine Servicelebensdauer von 30 Jahren zu bemessen und auszubilden.
Auf die einwandfreie Funktion der Schwingungstilger ist 10 Jahre Gewährleistung gefordert.

?? St

LV-Position ???

*** Eventualposition
Schwingungsmessung durch einen unabhängigen Sachverständigen mit entsprechender Erfahrung (mehr als 5 Jahre) auf dem Gebiet der Schwingungstechnik von Brücken nach der Fertigstellung der Brücke (ohne Schwingungstilger) durchführen, auswerten und Abgabe von Empfehlungen für zu bedämpfende Eigenformen. Basierend auf diesen Messergebnissen und den Entscheidungen des Bauherrn hat der Schwingungstilgerhersteller die Tilger zu bemessen und herzustellen.

1 St

LV-Position ???

*** Eventualposition
Kompletteinbau der erforderlichen Schwingungstilger.

1 St

LV-Position ???

*** Eventualposition
Einbauüberwachung des Schwingungstilgereinbaus durch einen Monteur des Schwingungstilgerherstellers. Der Einbau selbst wird durch das vorhandene Baustellenpersonal durchgeführt.

1 St

LV-Position ???

*** Eventualposition
Schwingungsmessung durch einen unabhängigen Sachverständigen mit entsprechender Erfahrung (mehr als 5 Jahre) auf dem Gebiet der Schwingungstechnik von Brücken nach dem Einbau der Schwingungstilger durchführen, auswerten und Bewertung der Wirksamkeit der Schwingungstilger.

1 St

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.

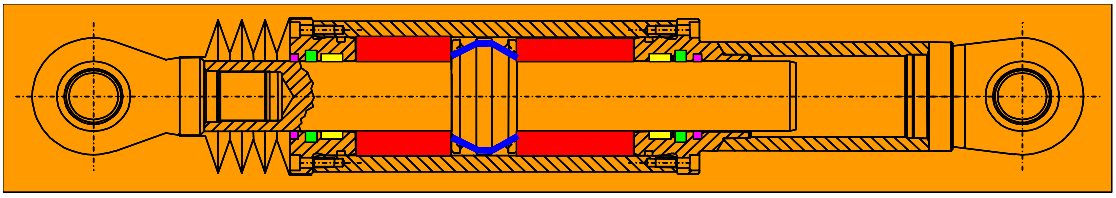


Fig. 40: Section through the MHD

MHDs are devices (Fig. 40), 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. 41: MHD before installation

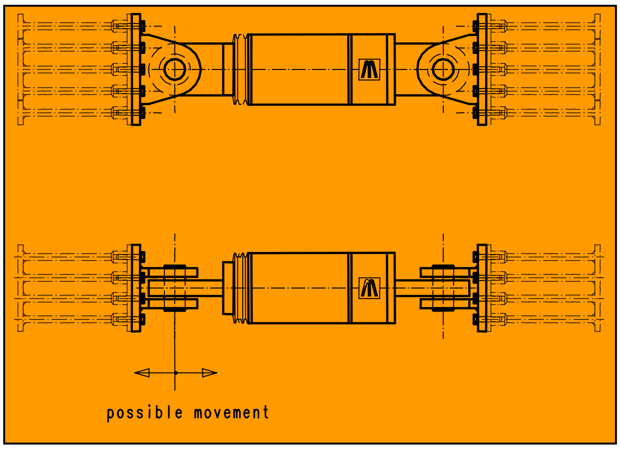


Fig. 42: MHD with concrete tension anchors

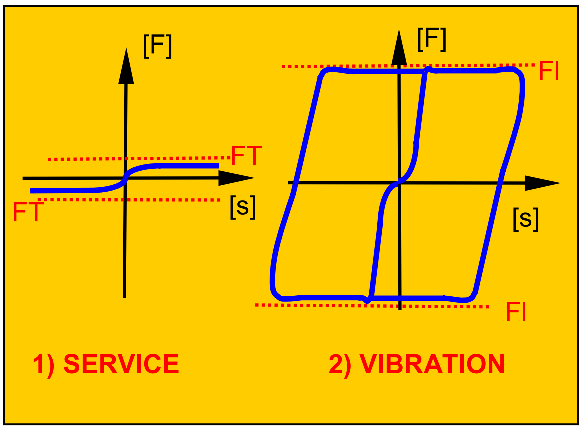


Fig. 43: Force [F] – displacement [s] - plot

Very slow displacements e.g. temperature changes, create insignificant response forces FT within the MHD (see **1** in Fig. 43 + 44). 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. 43 + 44).

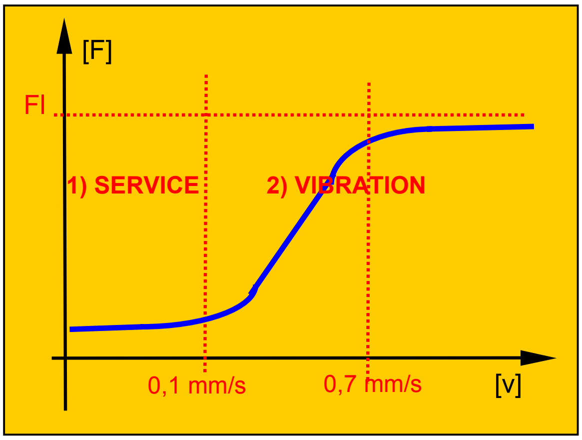


Fig. 44: Force [F] - velocity [v] – plot

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. 44). 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 **h** according to following equation:

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

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

Fig. 45: Equivalent damping coefficient and efficiency

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

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

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

Fig. 46: MHD response force equation

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 **a** < 0,015 to 0,4 (Fig. 46).

- Extreme great efficiency of up to **h** = 96% (Fig. 45) 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 10% 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. 40), of the real seal (sealing the piston effectively against leaking => green in Fig. 40) and the dust brush (protecting the seal from fine dust => pink in Fig. 40).

- 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 +70°C.

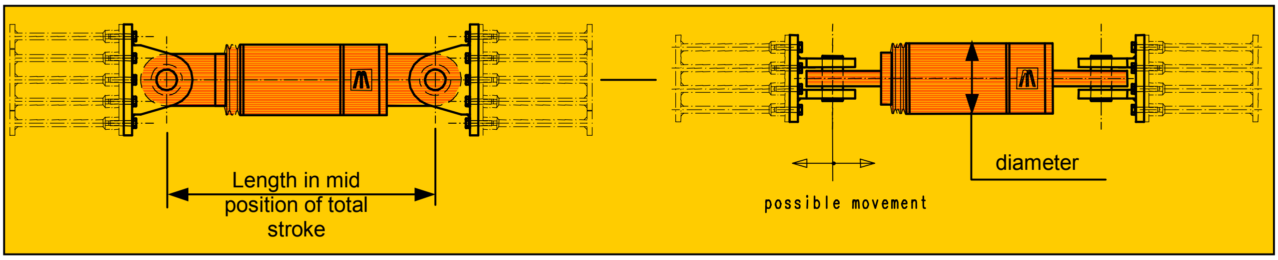
- Small dimensions and simple installation.

- Depending on request spherical hinges are installed at both device ends to accommodate installation tolerances and displacement adaptation.

Seizes 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]	maximum total stroke [mm]									
	100		250		500		750		1000	
	D [mm]	L [mm]	D [mm]	L [mm]	D [mm]	L [mm]	D [mm]	L [mm]	D [mm]	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. 47: 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, higher response forces than 6,000 kN or les than 250 kN and greater displacements than 800 mm or less than 100 mm are possible 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

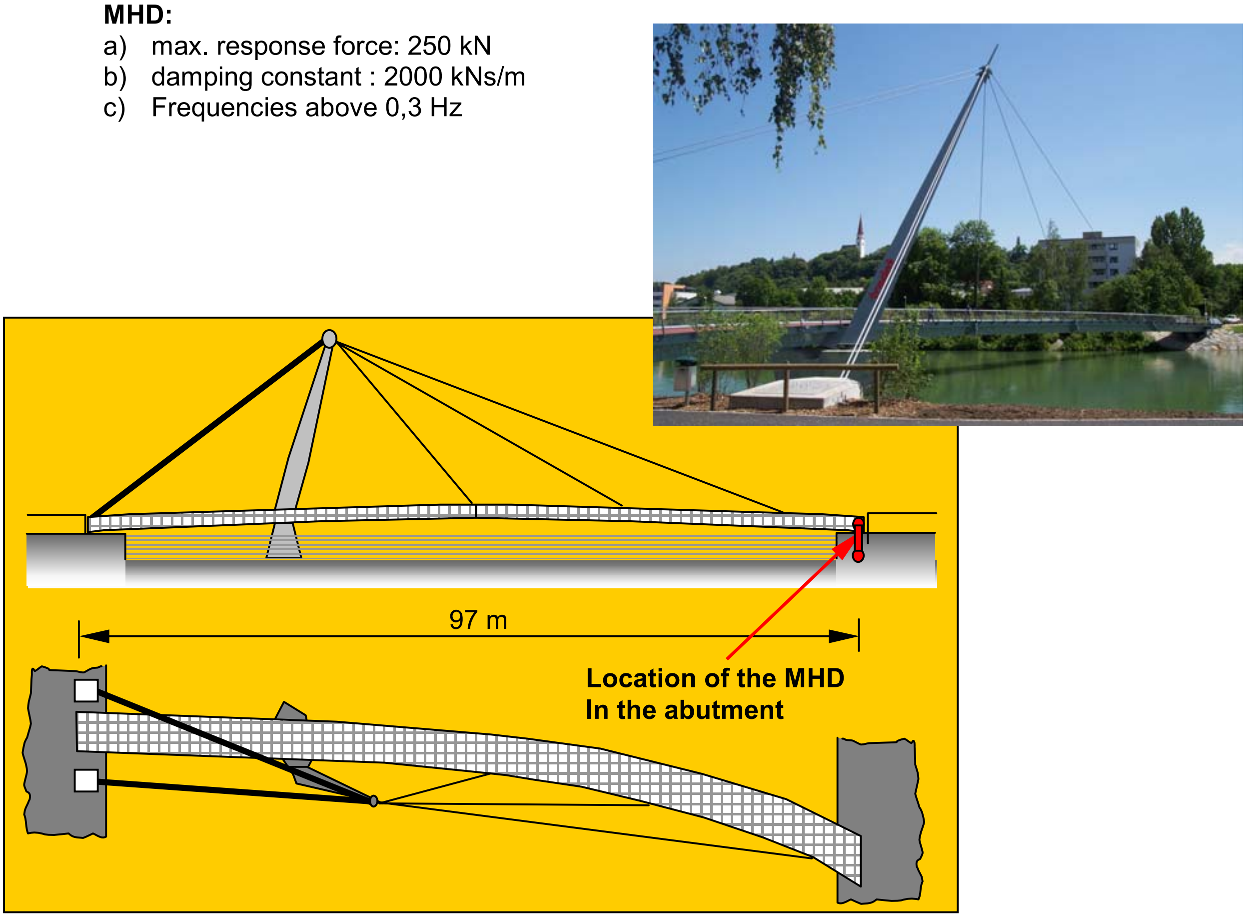
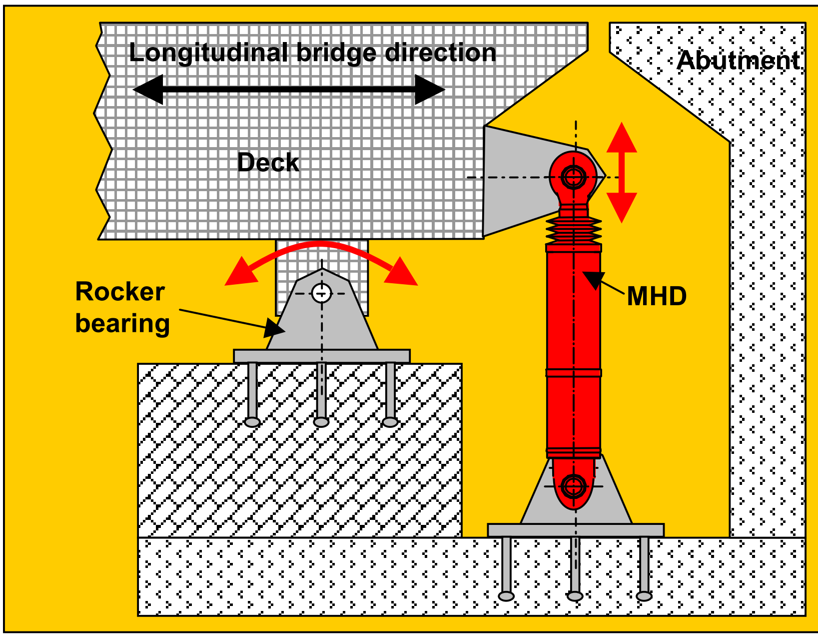


Fig. 48: Lateral and top view onto Traunsteg-Wels



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. 49: Vertical arrangement of MHD within the abutment

7.3 Application of MHD-700: City Metro Bridge in Adana - Turkey

Data of MHD:

a) max. response force: 700 kN
b) damping constant : 3000 kNs/m
c) frequencies above 0,7 Hz and velocities above 0,7 mm/s

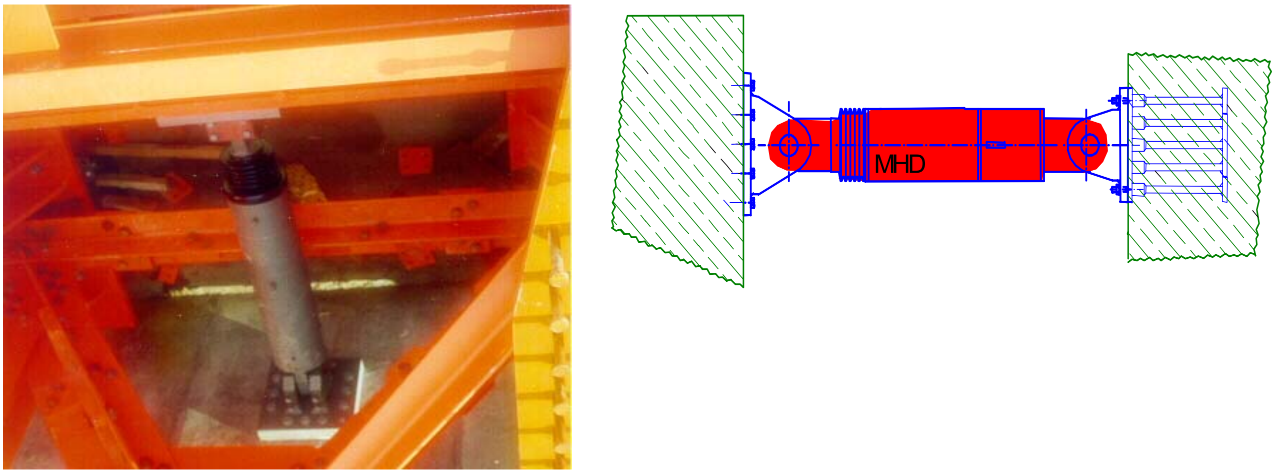


Fig. 50: Horizontal arrangement of MHD at abutment

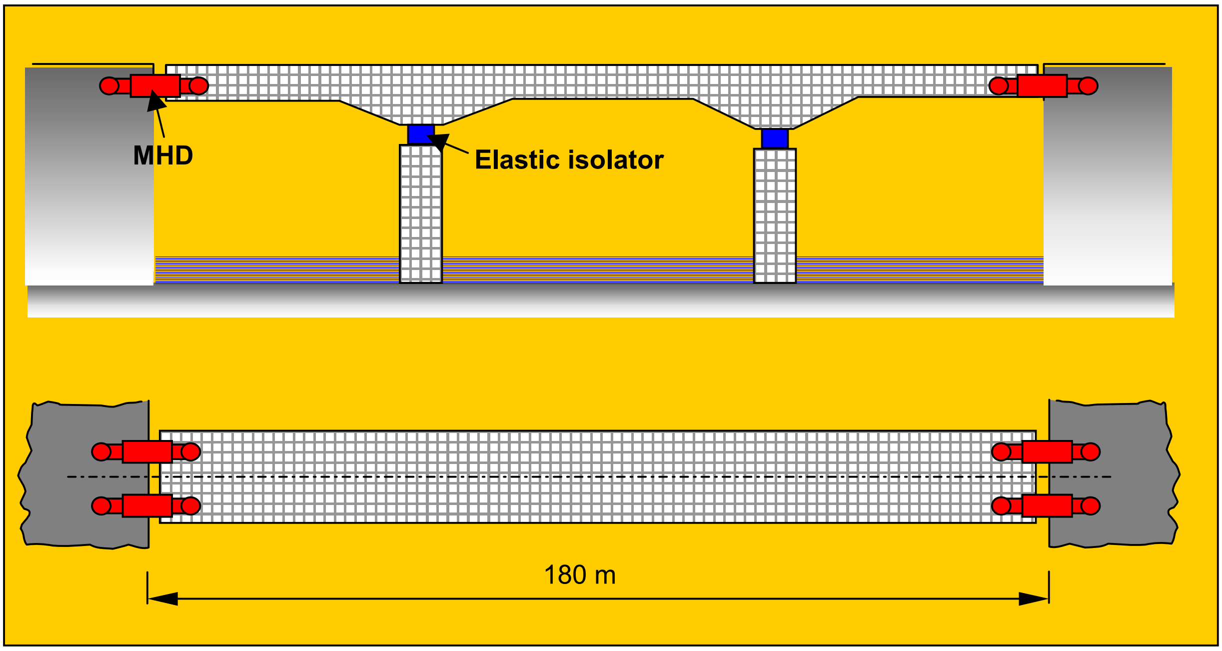


Fig. 51: Lateral and top view onto Metro Bridge Adana

8. Proposal for a tender text for viscous dampers

LV-Position ???Viskodämpfer Typ MAURER-MHD (oder gleichwertig) nach statisch-konstruktiven Erfordernissen auslegen, zeichnen, herstellen und liefern.
Der Hersteller muss über mindestens fünf Jahre Erfahrung im Viskodämpferbau verfügen und dies mit Referenzen nachweisen.

Auslegungs- und Designkriterien:

- Maximal zulässige und notwendige Antwortkraft: ?? kN
- Dämpfungsexponent a: unter 0,05, d.h. Antwortkräfte unabhängig von den auftretenden Frequenzen und Bewegungsamplituden
- Zu bedämpfende Eigenfrequenz der Brücke unter Eigengewicht: ?? Hz.
- Vibrationsamplituden des Bauwerks am Befestigungspunkt des Dämpfers für die ntsprechenden Eigenfrequenzen: ??, ??, ??, ?? mm (+/-)
- Notwendiger maximaler Energieumsatz des Viskodämpfers pro Stunde: ?? kW/h
- Dauer des maximalen Energieumsatzes: ?? Sekunden
- Fluidvolumenakkumulator muss in den Dämpfer integriert sein
- Aufkumulierter Dämpfweg über die angestrebte Lebensdauer: ?? meter
- Maximal zulässige minimale Antwortkraft des Dämpfers für Bewegungsgeschwindigkeiten unter 0,1 mm/s: unter 10% der Designantwortkraft
- Steifigkeit des Dämpferfluides unter Last: 4% des Hub
- Dämpfer muss ohne signifikanten Kraftaufwand längenjustier sein
- Max. Raum pro Dämpfer mit den Lagerböcken an beiden Dämpferenden: ? x ? x ? mm
- Beide Dämpferenden besitzen Kugelgelenkaugen mit Gleitpartnern
- Befestigungs- und Verankerungsvorgabe: siehe beiliegende Skizze ??
- Die Kolbenstange soll aus Baustahl (gute Duktilität und gutes Ermüdungsverhalten) mit Chrombeschichtung ausgeführt sein.
- Korrosionsschutz gemäß TL 918300 (Teil 2) wie für Brückenlager.

Für einen Viskodämpfer einer Bauart ist vom Hersteller ein Funktionstest, welcher die nachfolgenden Werte innerhalb bestimmter Toleranzbereiche aufzeigt und entsprechend dokumentiert, durchzuführen => diese Tests sind mit dem Auftraggeber und einem unabhängigen Prüflabor im Detail abzustimmen:

- Antwortkräfte bei den auftretenden unterschiedlichen Bauwerksfrequenzen (Toleranzbereich

+/-10% von der Sollvorgabe für die Designkraft unabhängig von der Frequenz bzw. Geschwindigkeit),

- kleinste Antwortkraft für Bewegungsgeschwindigkeiten unter 0,1 mm/s (maximal +20%),
- Energieumsatz des Dämpfers (Toleranzbereich +/- 15%),
- Steifigkeit des Dämpferfluides unter Last (Toleranzbereich +/- 15%),
- Dichtigkeitstest mit 125% des Nenndrucks für 120s ohne Undichtigkeiten

Der Funktionstest ist von einem unabhängigen offiziellen Sachverständigen (von dem Auftraggeber anerkannt) mit entsprechender Erfahrung (mehr als 5 Jahre) auf dem Gebiet der Hydraulik zu überwachen und die Einhaltung der Toleranzgrenzen ist von diesem entsprechend zu bestätigen.
Der Viskodämpfer ist für eine Servicelebensdauer von ?? Jahren zu bemessen und auszubilden.
Auf die einwandfreie Funktion der Viskodämpfer ist 10 Jahre Gewährleistung gefordert.

?? St

LV-Position ??? *** Eventualposition
Schwingungsmessung durch einen unabhängigen Sachverständigen mit entsprechender Erfahrung (mehr als 5 Jahre) auf dem Gebiet der Schwingungstechnik von Brücken nach der Fertigstellung der Brücke (ohne Schwingungsdämpfer) durchführen, auswerten und Abgabe von Empfehlungen für zu bedämpfende Eigenformen. Basierend auf diesen Messergebnissen und den Entscheidungen des Bauherrn bzw. des Designers hat der Hersteller die Viskodämpfer zu bemessen und herzustellen.

1 St

LV-Position ??? *** Eventualposition
Kompletteinbau der erforderlichen Viskodämpfer.

1 St

oder

LV-Position ??? *** Eventualposition
Einbauüberwachung des Dämpfereinbaus durch einen Monteur des Herstellers. Der Einbau selbst wird durch das vorhandene Baustellenpersonal durchgeführt.

1 St

LV-Position ??? *** Eventualposition
Schwingungsmessung durch einen unabhängigen Sachverständigen mit entsprechender Erfahrung (mehr als 5 Jahre) auf dem Gebiet der Schwingungstechnik von Brücken nach dem Einbau der Viskodämpfer durchführen, auswerten und Bewertung der Wirksamkeit der Viskodämpfer.

1 St

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. 52).
- The specific spring frequency is recorded with a special sensor and electronic system (Fig. 53).
- Das Dämpfungselement wird mit entsprechenden Prüfmaschinen getestet.

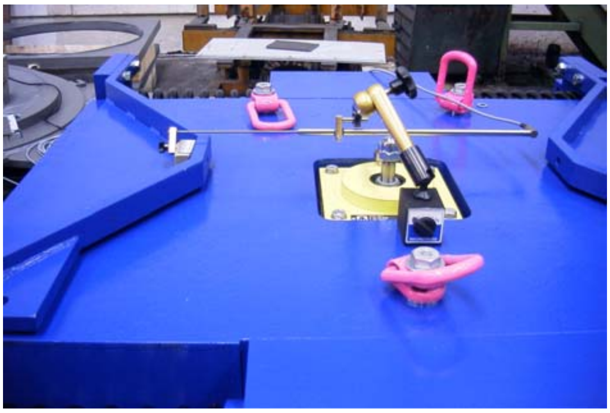


Fig. 52: Testing and possibly fine adjustment of the TMD function characteristics

Fig. 53: Recording of data with special sensors and documentation of results

- With special testing rigs the damping element is tested (Fig. 54).

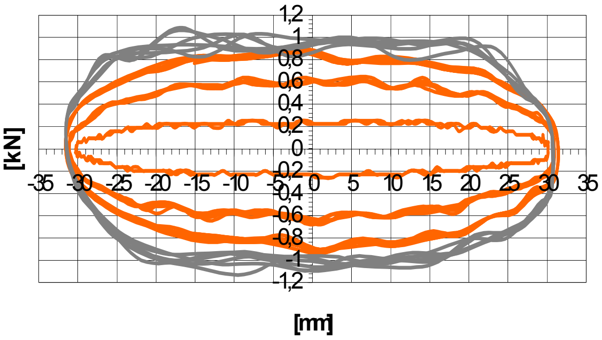


Fig. 54: Force-displacement-plot of damping element

- For the viscous piston dampers (MHD) individual tests are carried out on request, too (Fig. 55).

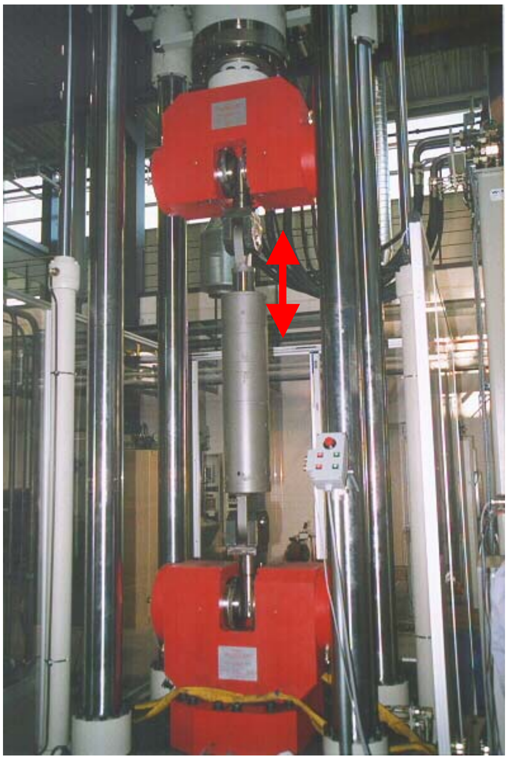


Fig. 55: Testing rig for MHD