Structural Protection Systems

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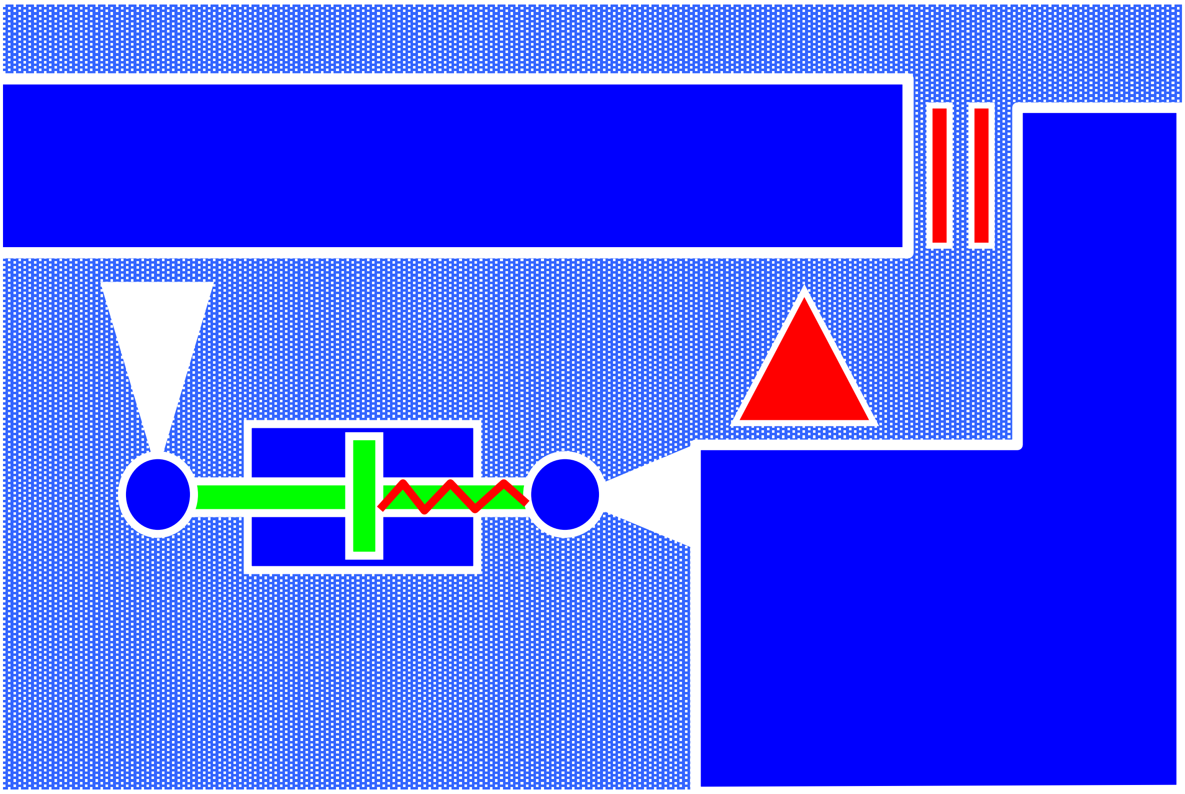
MAURER
Seismic Protection Systems



Technical Information and Dimensions

23.06.2004/SPS

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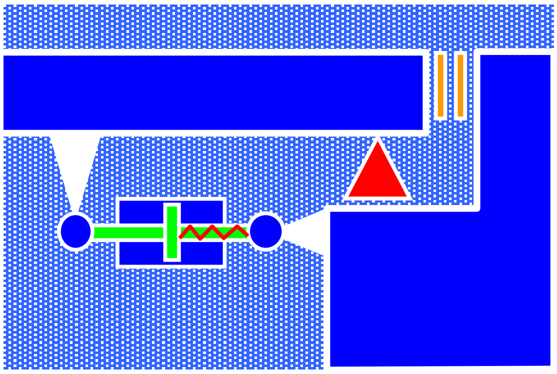

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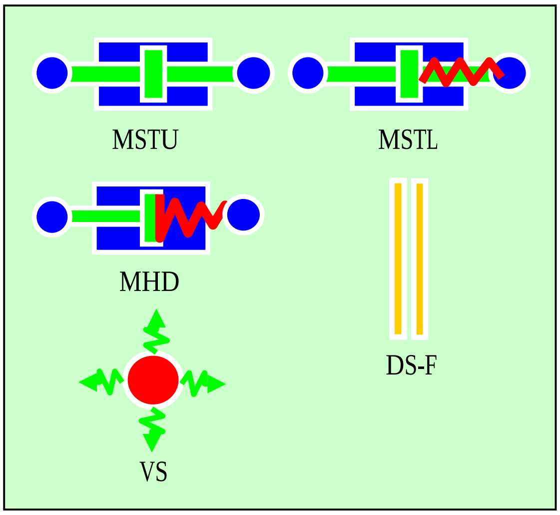

Fig. 1: Devices of a seismic protection system for a bridge

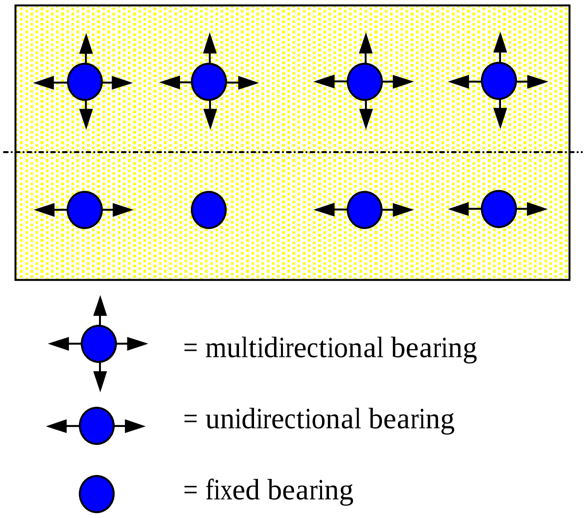

Fig. 2: Normal bearing arrangement like implemented in the below shown bridge

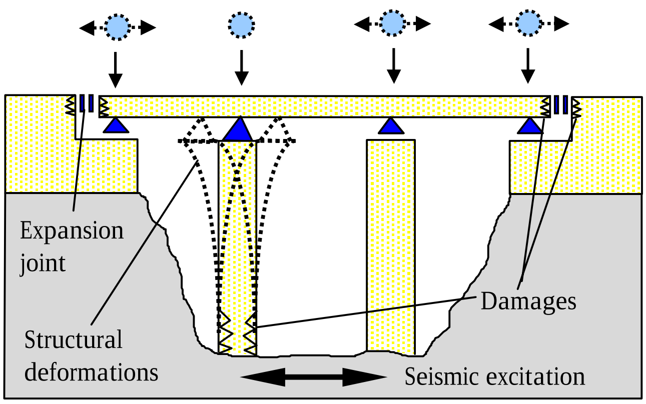

Fig. 3: Pier deformations and damages during seismic energy input into the bridge deck with the bearing arrangement of Fig. 2

1. Introduction

The technical state of the art allows structures of any kind to be adapted to different load cases, e.g. traffic, wind, seismic impacts, etc.. Therefrom, the appearing stresses are distributed in as far as possible a well-proportioned way over the entire structure or they are even essentially reduced from the very beginning in addition by special isolating and damping devices.

General concepts for appropriate protection of structures against earthquakes do not exist, as every structure is quite unique and requires individual considerations. Therefore MAURER SÖHNE is offering for every structure individual consulting and develops tailor made, mechanical devices for an effective adjustment of the structure to the occuring nominal seismic attack. A seismic protection system (Fig. 1) consists normally of seismic isolators (VS), or bearings, dampers (MHD) and / or shock transmitters (MSTU, MSTL) and seismic expansion joints (DS-F).

Earthquakes are often interpreted in terms of deformations and acting forces induced upon the structure. As a consequence, there is a tendency to think only about increasing the strength of the structure. Actually, forces and displacements are nothing but a mere manifestation of seismic attacks and do not in fact represent their very essence. An earthquake is actually a energy phenomenon and the forces causing stress in the structure are the final effect of that phenomenon.

Considering only the resulting response forces within the structure due to an earthquake leads to massive structural dimensions, stiff structures with enormous local energy accumulation and plastic hinges. This strengthening method combined with usual bearing arrangements (Fig. 2) permits plastic deformations by way of leading to yield stress and cracks. Aside of costly refurbishing interventions the structure is set temporarily out of service.

Consequently, severe structural damages occur if the structure is not sufficiently protected.

2. Concepts for seismic protection

2.1. ENERGY SHARING

ENERGY SHARING means, that the occuring seismic energy that enters from the soil is distributed to as many locations as possible, in order to facilitate constant stress all over the entire structure and to avoid significant energy accumulations at a few structural locations.
For this purpose special devices (Fig. 4), so called shock transmission units (see also page 8), permit relative displacements due to temperature differences, creep and shrinkage between deck and substructure during service conditions (Fig. 5). Only during the seismic load case or any suddenly induced traffic forces they behave like a rigid device (Fig. 6), distributing the horizontally acting seismic / traffic response forces to several spots. That way the capacity of the structure to store elastic as well as kinetic energy is increased. Accordingly, the corresponding structural displacements are smaller accordingly compared to not using shock transmission units. Thus the resulting horizontally acting forces are distributed more or less equally over the structure, and unequal energy distribution within the structure is avoided.

Unlike above assumption, the occurring forces and displacements during an earthquake are not the cause, but the effect of the short-lived dynamical occurance of enormous amounts of stored mechanical energy from the ground. To be more effective the applied seismic concept has to consider the character of the earthquake. The distribution of the energy input over several structural locations is mostly not sufficient to protect the structure. Yet, this principle works out very well for moderate traffic forces.

The huge seismic energy input still reaches without mitigation to the superstructure as during the seismic load case every support axis gets rigid (Fig. 6) and the energy reaches easily the superstructure. From there the entire superstructure gets accelerated.

For medium to severe seismic attacks our second proposal ENERGY MITIGATION for seismic protection is recommended to be applied.

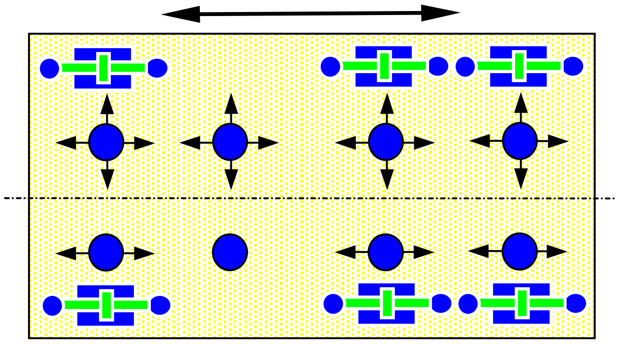

Fig. 4: Bearing arrangement with integrated MSTU´s

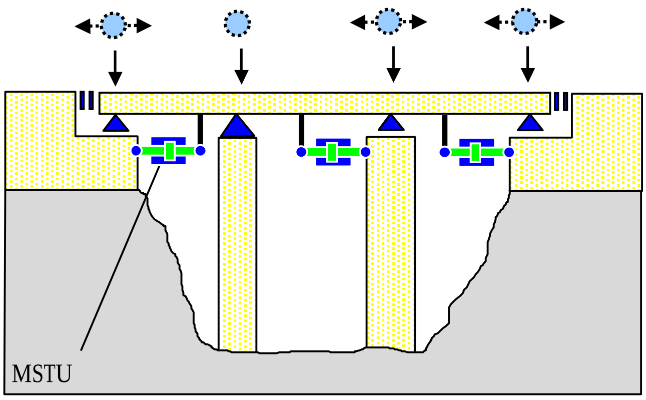

Fig. 5: Bridge during service load case with inactive MSTU`s

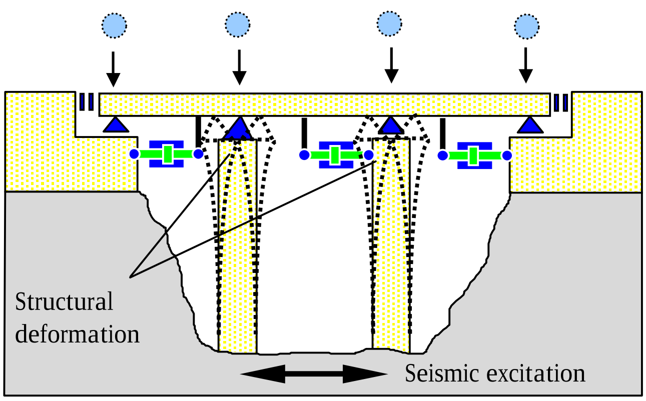

Fig. 6: Bridge with active MSTU´s during ultimate load case like traffic or earthquake

2.2. ENERGY MITIGATION

ENERGY MITIGATION means applying the concept according to the energy approach (see page 5 also) especially considering the „energy character“ of the earthquake. This method is based on ENERGY MITIGATION and costly strengthening measures are avoided.

Two methods are simultaneously applied:

1. Seismic isolation:
   The superstructure gets de-coupled from the ground. The so called seismic-isolation limits automatically the energy to a minimum to enter the superstructure during an earthquake. Due to this fact the natural period of the structure is increased, therefore reduces the spectral acceleration during a seismic attack (Fig. 7). Depending on the type of the employed multidirectional seismic isolators (see also page 15), they cater for not only the vertical load transmission but also for the active re-centering of the superstructure during and after an earthquake (Fig. 8+9). Re-centering means that the bridge deck displaced due to the seismic energy input is automatically shifted back by the seismic isolators into its original position.

2. Energy dissipation:
   By means of passive energy dissipation (= energy transformation) the seismic rest energy entering into the superstructure will be effectively dissipated by additional damping devices (see page 12) relieving the entire structure from additional strain (Fig. 8+9).

In case of need dampers can be additionally installed in lateral direction.

With the above suggested concept that combines seismic isolation with energy dissipation, the best possible seismic protection for structures is achieved.

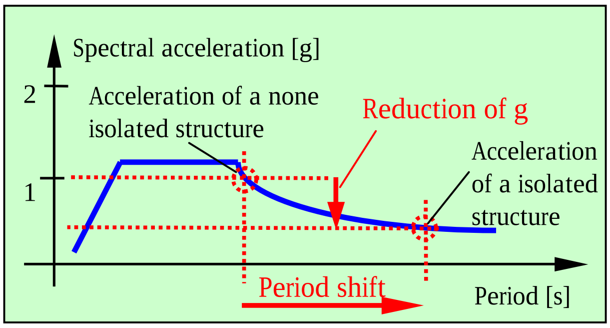

Fig. 7: Characteristical response spectrum of a bridge

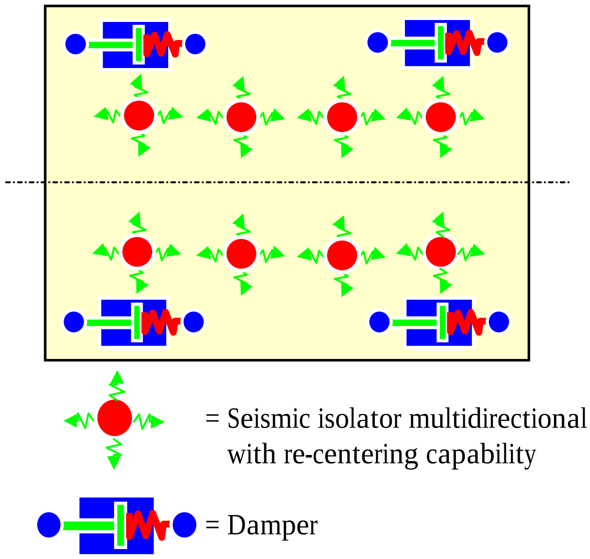

Fig. 8: Sample for a seismic bearing and damper arrangement

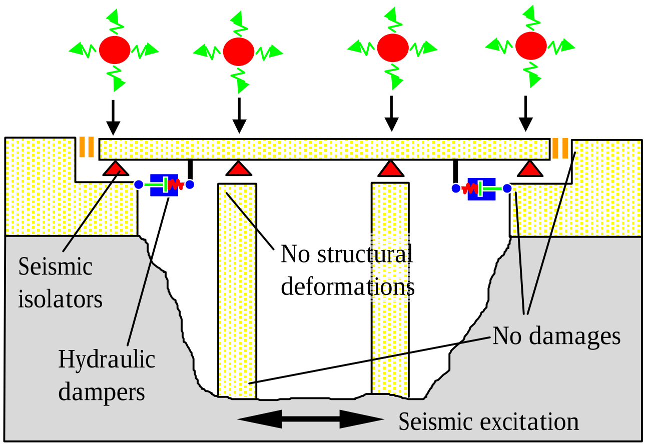

Fig 9: Bridge with seismic isolation and passive energy dissipation and arrangement of fig. 8

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In case flexible piers are located in the bridge center, the re-centering capability of the seismic system can also be achieved by placing fixed and laterally displacing spherical, pot or elastomeric bearings on these piers (Fig. 10). The fixed and laterally displacing bearings represent horizontally rigid devices in longitudinal bridge direction. During an earthquake the flexible piers will bend and will pull back the deck in the mid position. Simultaneously this system isolates the deck from the ground.

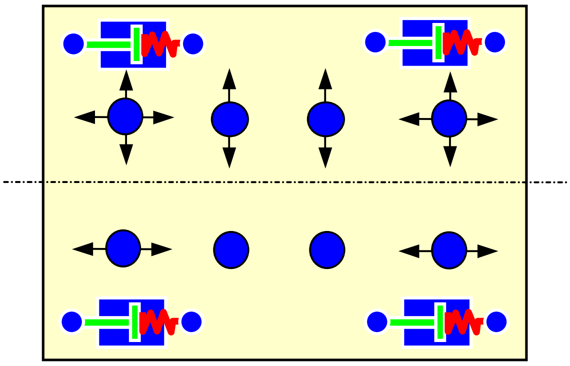

Fig. 10: Sample for a seismic bearing and damper arrangement

A major disadvantage of this system is the missing isolation in lateral bridge direction.
The resulting lateral horizontal seismic forces have to be fully transmitted by suitable bearings.
But in general such a system can be applied to retrofit projects, where normal sliding bridge bearings are already installed and a damping mainly in longitudinal bridge direction is required.

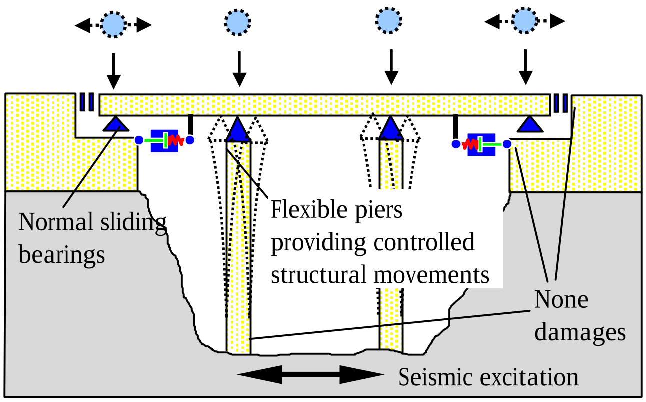

Fig 11: Bridge with protection system of fig. 10

The concept of *ENERGY MITIGATION* taking advantage of seismic isolation and energy dissipation is the most effective method to design structures very economically, and with great safety margins. This concept grants that the structure will survive an earthquake without damages, thus being immediately prepared to cope with a following seismic attack.

To accommodate the displacements of the deck at the abutments and fill the gap in the carriageway, special seismic expansions joints are installed (Fig. 12).
These joints have to enable quick alternating displacements in all directions (x, y and z), without getting damaged (see also page 18).

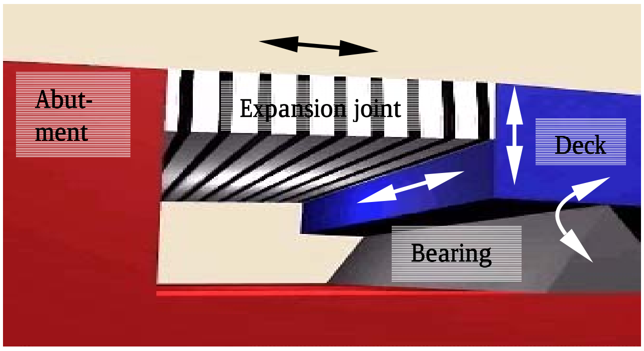

Fig. 12: Expansion joint displacement at the abutment during seismic conditions

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3. Energy approach concept for optimum seismic protection

As already mentioned in chapter 2.2. an earthquake is an energy phenomenon and therefore this energy character should be considered to achieve the best possible seismic protection for the structure.

Without any seismic protection system the seismic energy is entering the structure very concentrated at the fixed axis, thus hitting the structure mainly at one single axis (Fig. 13).

By means of shock transmission units the entering energy is distributed to several spots within the structure (Fig. 14). The energy input into the structure is still in same magnitude like without STU´s – no mitigation – but now the energy is spread over the entire structure in more or less equal portions.

By implementing additional seismic isolation and also energy dissipation capability, less energy is entering the structure (Fig. 15), and the remaining energy amount entering the structure is effectively mitigated.

The principles of physics that govern the effects of dissipation on the control of dynamic phenomena were studied more than two centuries ago (D´Alembert, Traité de dynamique, 1743). Nonetheless, their practical application has come about much later and within a much different time-frame in several sectors of engineering. The sector that was the first to adopt such damping technologies was the military (France, 1897) and let the country enjoy world supremacy in artillery for the better part of a decade. In not too short order the automobile industry followed in these steps by using dampers in their suspension systems to ensure the comfort and the stability of motor vehicles. In 1956 Housner already suggested an energy-based design for structures. Akiyama (1985), Uang (1988) and Bertero (1988) made a valuable contribution to the development of the aspects of an energy-based approach, which presently meets with great concensus.

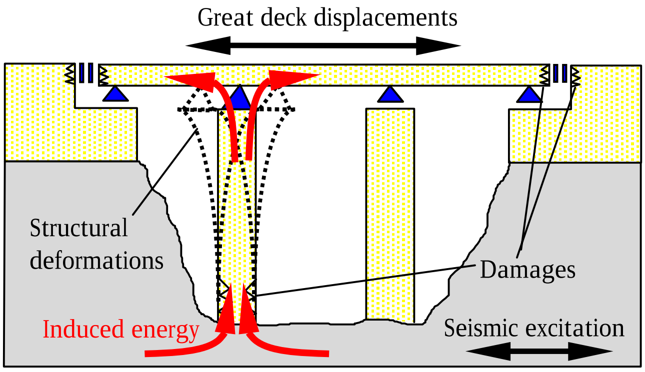


Fig. 13: Without seismic protection system seismic energy is penetrating into the structure

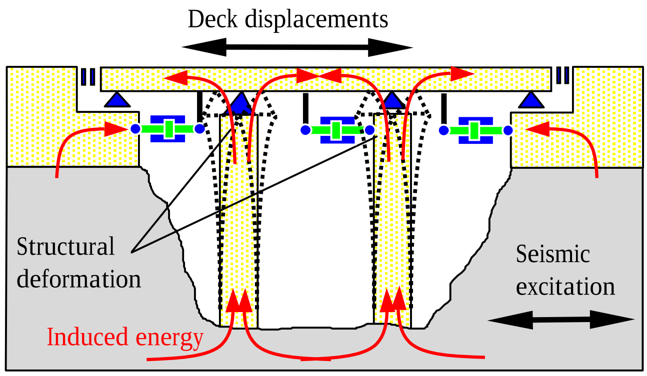


Fig. 14: Seismic energy is penetrating into the structure fitted with STU´s for energy sharing

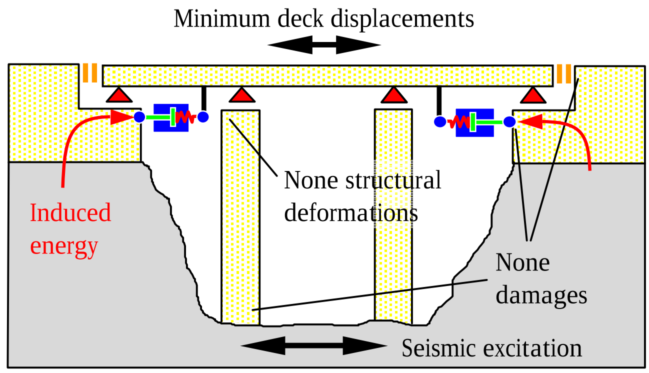


Fig. 15: Minimized seismic energy penetration by implementing seismic-isolation (isolators) and energy dissipation (dampers)

The concept of the energy approach (Fig. 16) reduces effectively the energy induced into the structure (E_i) by ground motion through its foundations.

The amount of the structurally stored energy (E_s) has to be as low as possible to avoid damages. Therefore the value of the dissipated energy (E_d) must be great.

The energy part E_h (Fig. 17) out of E_d due to plastic deformation of the structure has to be kept low, as this way of energy dissipation causes structural yielding and cracks.

The drastic increase of the value of the energy of viscous phenomena (E_v) is the final opportunity to control the energy balance of the structure. It should be pointed out that E_v is associated with the response forces (F) that depend only on the velocity (v) through a constitutive law of type:

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

where exponent a ranging from 0 to 1.8, depending on the type of device.
This E_v increase is realized by the use of specially developed highly efficient hydraulic viscous dampers named MHD (see page 12).

Exemplary and simplified, we´d like to show the earthquake effects on a single oscillating mass (Fig. 18).
For this case the equation of motion is valid:

$$m\ddot{x} + c\dot{x} + kx + h(x) = -m\ddot{x}_G \quad (1)$$

By integrating the single terms of equation (1) with respect to x, results in:

$$\int m\ddot{x}\,dx = \int m\frac{d\dot{x}}{dt}dx = \int m\dot{x}\,d\dot{x} = \frac{1}{2}m\dot{x}^2 = E_k$$

$$\int Fx\,dx = \int c\dot{x}\,dx = \int c\dot{x}^2\,dt = E_v$$

$$\int kx\,dx = \int \frac{1}{2}kx^2 = E_e$$

$$\int h(x)\,dx = E_h$$

$$\int -m\ddot{x}_G\,dx = E_i$$

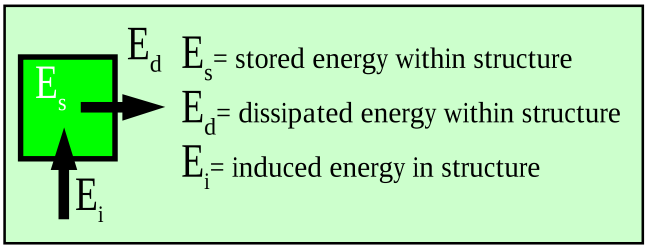


Fig. 16: Concept of energy approach considering the energy exchange between structure and environment

$$E_i \leq E_s + E_d$$

$$E_i \leq E_e + E_k + E_h + E_v = \int -m\ddot{x}_G\,dx$$

E_e = elastic strain energy
E_k = kinetic energy
E_h = energy dissipated by hysteretic or plastic deformation
E_v = energy dissipated by viscous damping
m = mass of isolated structure
x_G = absolute ground displacement

Fig. 17: Energy balance equation for structures

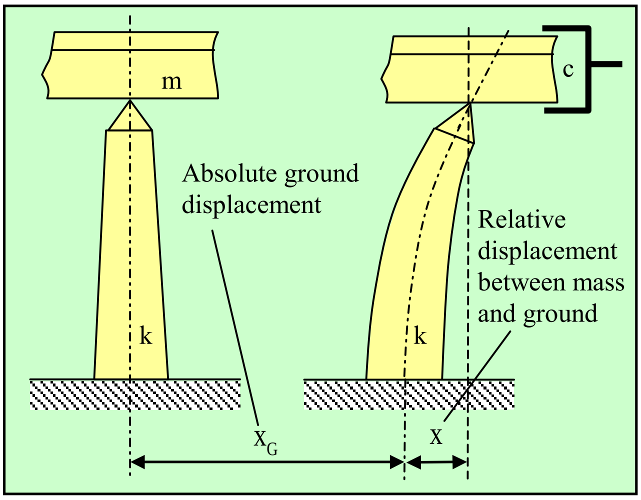


Fig. 18: Complex bridge structure explained with a simplified single ocillating mass

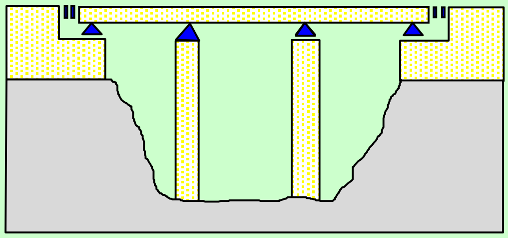
4. The way to the ideal seismic protection system

The especially adapted MAURER seismic protection system (Fig. 19) ensures full service abilities after the nominal earthquake and structural damages are totally avoided. Hence the structure is immediately ready for service again and for possibly following further earthquakes. In addition no refurbishing works of the devices or structure are necessary, which shows that this seismic protection system is also the most economic concept to choose.
The employed mechanical MAURER components for the seismic protection have been proving successfully in service for many years. Depending on request for the single components the design can be done according to EURO NORM, AASHTO, BRITISH STANDARD, DIN or any other standard.

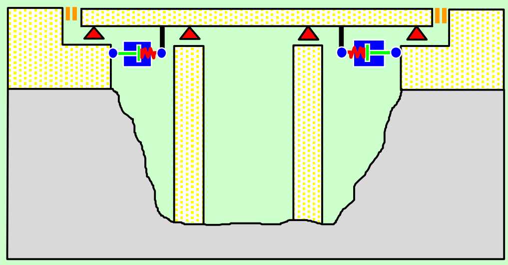
Despite the fact that some guidelines for seismic engineering have been implemented in the last few years, every structure is unique, has to be individually calculated, and requires tailor made components.

MAURER is offering extensive general and individual consulting for the seismic components, as well as for the principle design of structures. On request MAURER performs a *non-linear time history analysis* (see also page 20) of the entire structure with the input data of the bridge designer.
By application of the special seismic protection system of MAURER the bridge design needs not be changed. On account of the above mentioned reduced forces induced upon the structure by using this protection system the structural safety margins rise considerably. In order to save costs, it can also be considered to weaken the structure to the permissible stress limit by doing new structural calculations with the revised response forces. In that case, the actually requested safety margins stay on the same level as before without seismic protection system.
The advantages of a seismic protection system (Fig. 20) are obvious and satisfy protection and economic requirements.

1. Design by bridge designer



2. Non-linear Time History Analysis of the structure by MAURER with adaptation of the seismic protection system



3. Final adjustments (geometric / constructive) of individual seismic components. Drawing up request list for components.

Fig. 19: Steps to built up a seismic protection system

Advantages:

- Maximum seismic protection with great safety margins,
- Compared to other methods like *strengthening* much more economical,
- No structural damages due to the design earthquake => prepared for following earthquakes and passable for traffic,
- No design changes of the structure are necessary by implementing a seismic protection system,
- Components can be easily installed,
- Approved by tests and in service for many years.

Fig. 20: Advantages of a MAURER Seismic Protection System

5. Technical description of shock transmission units (MSTU / MSTL)

5.1.  MSTU - Standard shock transmission unit

Fig. 21: MSTU integrated into pot bearing installed into Viaduct Stura di Demonte in Italy

MSTU - MAURER shock transmission units are hydraulic devices (Fig. 21) to connect structural parts rigidly together in case of sudden occurrance of fast relative displacements due to earthquake, traffic, wind, etc.. During service these devices react with an insignificant response force due to thermal or creep / shrinkage displacements.

In literature often alternative names are used for such kind of devices, e.g. Lock-Up Device (LUD), Rigid Connection Device (RCD), Seismic Connectors, Buffers or similar.
But not all of these devices react in a similar way. Most of these devices don´t have the important force limiter function, which is described on following page for the MSTL.

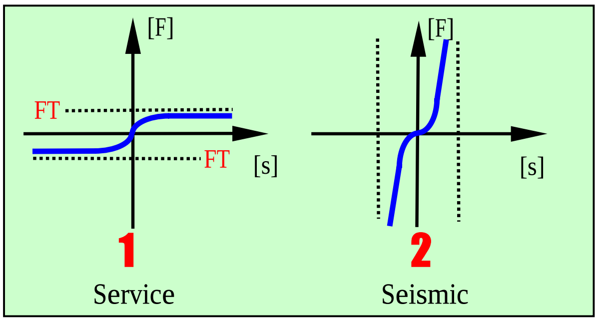


Fig. 22: Force [F] - displacement [s] – plot without force limiter

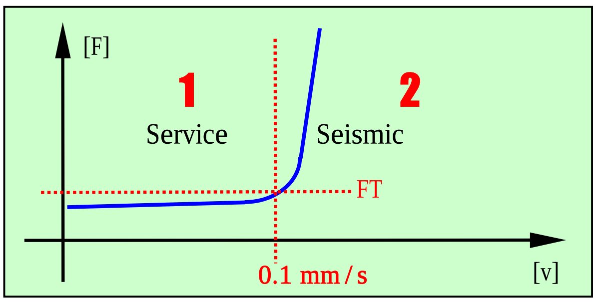


Fig. 23: Force [F] - velocity [v] – plot without force limiter

Depending on the displacement velocity, the MSTU reacts with a certain nominal response force (Fig. 22).
Very slow displacements due to temperature changes, and creep / shrinkage are causing minor response forces FT within the MSTU (see plot **1** in Fig. 22+23). The fluid inside the MSTU is flowing from one piston side to the other within the hydraulic cylinder.

During occuring sudden impact accelerations due to e.g. an earthquake or braking actions of vehicles, which result in greater relative displacement velocities between super- and substructure above approximately 0.1 mm / s, the MSTU reacts with a intense increase of its response force (see plot **2** in Fig. 22+23). The device is blocking any relative displacement between the connected structural parts now. The hydraulic synthetic fluid is not able to get from one piston side to the other at these great displacement velocities.

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5.2. MSTL - Shock transmission unit with force limiter

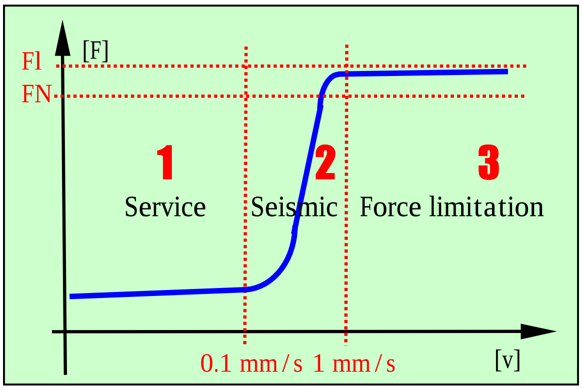

Fig. 24 : Force [F] - velocity [v] – plot with force limiter

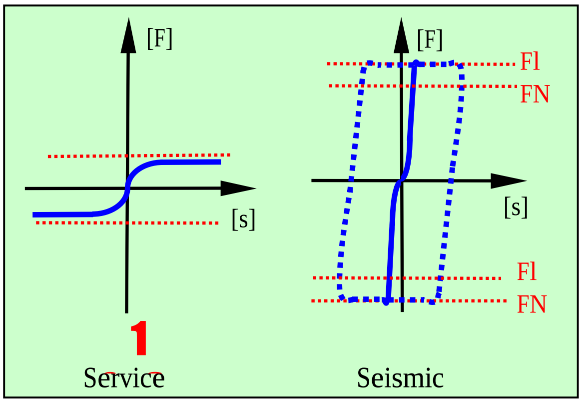

Fig. 25: Force [F] - displacement [s] – plot with force limiter

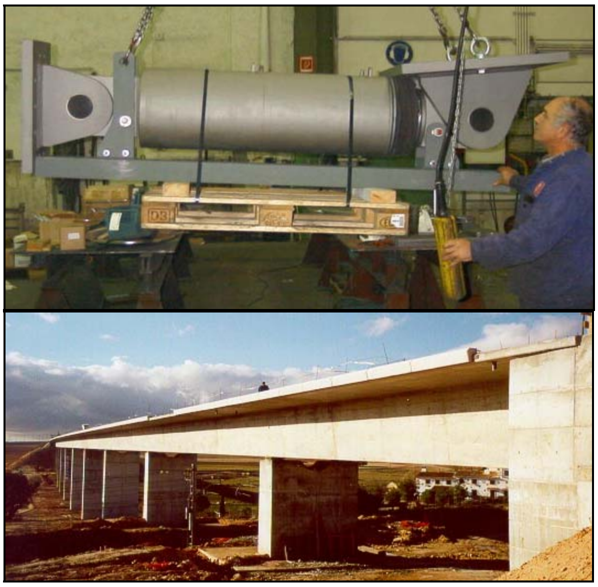

Fig. 26: 2.500 kN MSTL for railway viaduct De La Rambla in Spain

Usually MAURER Shock Transmitters are equipped with an additional force limiter on request.

Compared to the “normal” standard shock transmission units with a theoretical unlimited blocking force in case of unforeseen infinite energy input, the MSTL with force limiter reacts with a well defined maximum response limit force (see FL in Fig. 24+25).
This response force limit is normally defined slightly above the nominal blocking force (see FN in Fig. 24+25) or can also be chosen individually.

In case the maximum nominal response force of the MSTL will be exceeded by unforeseen dynamical seismic structural behaviour or too great seismic energy input, an “intelligent” control device enables displacements of the MSTL.
The response force is kept constant (see **2+3** in Fig. 25) by the “intelligent” control device, whereas the displacement velocity plays no important part, which means that the response force is independent from the displacement velocity during a seismic impact or a traffic impact.

The force limiter provides the designer the confidence and safety that the maximum response force of the shock transmission unit is well defined, independent from the amount of impact energy. This brings about the significant advantage that the structure can be calculated exactly for a defined response force. For normal standard shock transmission units without force limiter the structure has to be designed with greater safety margins – also more costly – and the shock transmission unit itself or the structure could be damaged in case the seismic impact is higher than expected.

The MSTL (Fig. 26) with force limiter in comparison to the standard MSTU safes structural overall costs and brings up a much greater structural safety margin without increasing structural costs.

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5.3. General characteristics of MSTU and MSTL

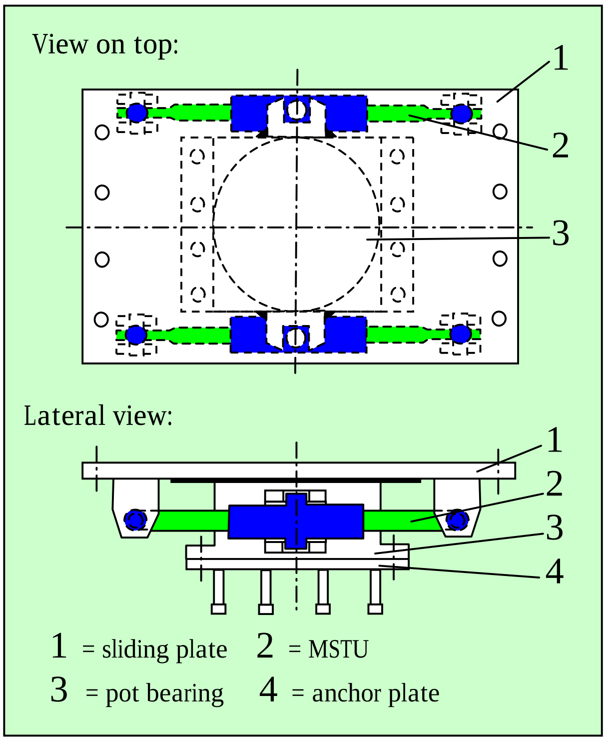

Fig. 27: MSTU integrated into a sliding pot bearing

MSTU / MSTL´s can also be integrated into sliding bearings like pot bearings (Fig. 27).
So the sliding bearings are moveable during service load case and behave like horizontally rigid devices in case of an earthquake or similar impacts.

Normally the devices are installed independently from the bearings like this is shown on the following page.

<u>Characteristics of a MSTU / MSTL with force limiter:</u>

- During service conditions the devices are not pre-tensioned and the fluid is under no significant pressure.
- Automatic volume compensation of the fluid caused by temperature changes is achieved without pressure increase inside the devices. Any compensation containers are located inside. On request they can also be located outside.
- No maintenance works necessary. Visual inspection is recommended during the periodic bridge inspections or after an earthquake respectively.
- The devices are not prone to leaking as special high strength hydraulic sealing rings are used like for Caterpillars, automobile industry and similar machineries. On request prove tests can be carried out.
- Very little elasticity of 2-5% depending on request.
- Range of 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.

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5.4. Dimensions and anchoring of MSTU and MSTL

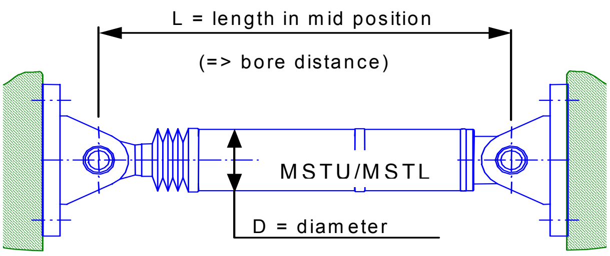

Fig. 28: Sample for installation position of MSTU / MSTL mainly used for abutments

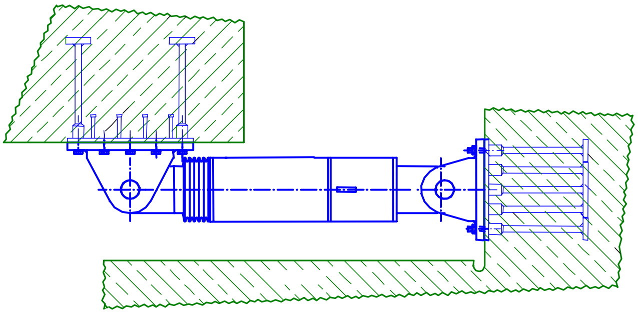

Fig. 29: Alternative installation position of MSTU / MSTL mainly used for piers

axial force [kN]	maximum stroke [+/-mm]													
	50		100		150		200		250		300		400	
	D [mm]	L [mm]	D [mm]	L [mm]	D [mm]	L [mm]	D [mm]	L [mm]	D [mm]	L [mm]	D [mm]	L [mm]	D [mm]	L [mm]
50	110	690	110	970	110	1250	110	1530	110	1810	110	2000	110	2550
100	120	720	120	1000	120	1280	120	1560	120	1840	120	2030	120	2580
200	180	760	160	1040	180	1320	180	1600	180	1880	180	2070	180	2620
500	195	790	195	1070	195	1350	195	1630	195	1910	195	2100	195	2650
750	215	805	215	1085	215	1365	215	1645	215	1925	215	2115	215	2665
1000	235	825	235	1105	235	1385	235	1665	235	1945	235	2135	235	2685
1250	280	890	280	1170	280	1450	280	1730	280	2010	280	2200	280	2750
1500	295	990	295	1270	295	1550	295	1830	295	2110	295	2300	295	2750
1750	325	1045	325	1325	325	1605	325	1885	325	2165	325	2295	325	2805
2000	365	1210	365	1490	365	1770	365	2030	365	2330	365	2400	365	2870
2500	405	1320	405	1600	405	1880	405	2140	405	2400	405	2540	405	2980
3000	455	1440	455	1680	455	2000	455	2260	455	2400	455	2660	455	3100
4000	505	1555	505	1795	505	2115	505	2375	505	2555	505	2775	505	3215
5000	540	1840	540	2080	540	2400	540	2660	540	2840	540	3060	540	3500
6000	590	2090	590	2330	590	2650	590	2910	590	3090	590	3310	590	3750

The above mentioned dimensions can change in final design depending on detailed request to the devices.
Also the anchor support sizes are not included yet.

The devices can also be delivered with the entire anchoring system like anchor supports and tension anchors as well. The design of the anchoring will then be individually adapted to the designers wishes.

6. Technical description of seismic dampers (MHD)

6.1. MHD - Seismic damper

Fig. 30: MHD´s ready for installation with assembly brackets

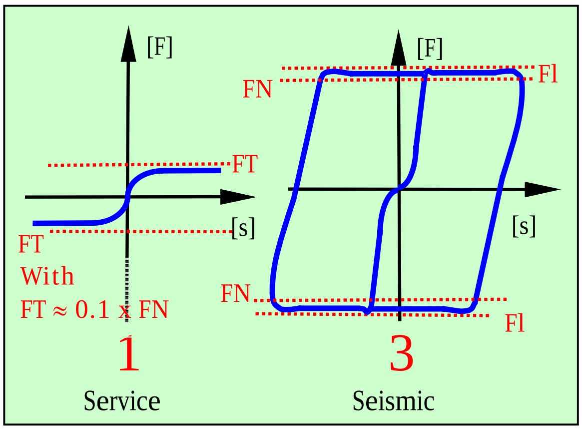

Fig. 31: Force [F] – displacement [s] - plot

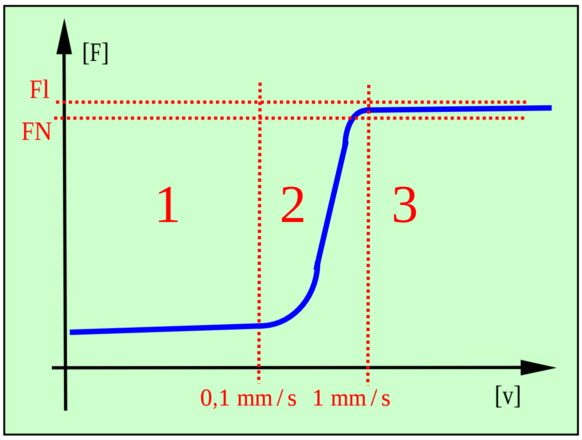

Fig. 32: Force [F] - velocity [v] – plot

MHD - MAURER hydraulic dampers are devices (Fig. 30), which enable displacements (thermal changes, creep, shrinkage, etc.) during service conditions without creating significant response forces, but dissipate huge amounts of energy during sudden occurance of dynamical seismic energy input, and the energy is been converted into heat.

Very slow displacements e.g. temperature changes, create insignificant response forces FT within the MHD (see 1 in Fig. 31+32). Identical to the MSTU and MSTL, fluid can flow from one piston side to the other.

When sudden impact accelerations occure between the linked structural sectors due to seismic energies, traffic or wind, inducing displacement velocities in the range of approximately 0.1 mm/s to 1 mm/s the MHD blocks and behaves rigidly. The characteristic for this velocity is nearly identical to the shock transmission units MSTU/MSTL (see 2 in Fig. 32) with a maximum blocking force of FN (Fig. 32).

After exceeding a defined energy input, the MHD is forced to overstep the maximum defined response force FN, e.g. during load case seismic, a integrated “intelligent” control mechanism enables relative displacements between the connected parts, but with still constant response force Fl, which insignificantly bigger than FN. The very special feature is now that FN is independent from the displacement velocities (see 3 in 31+32). 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.

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 how strong the seismic event may be. From there the structure can be easily calculated for this constant response force, and high safety margins are realized in a very economical manner.

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Fig. 33: Twin Viaduct Locica in Slovenia with MHDs

Equivalent damping coefficients ξ:

- Steel bridge ξ= 0.02
- Concrete bridge ξ= 0.05
- Elastomeric bearings ξ= 0.05 to 0.06
- High damping rubber bearings ξ= 0.16 to 0.19
- Lead rubber bearings and friction pendulum ξ= 0.30 to 0.40
- MAURER seismic damper 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 η= 96% for the MHD!

Fig. 34: Comparison of equivalent damping coefficients ξ of different structures and components

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

F = MHD response force
C = Constant value
v = displacement velocities up to 1.4 m/s
α = damping exponent < 0.02 (2%)

=> due to the low a value the MHD response force is independly acting from the displacement velocity as the term "v^{α}" runs against "1"

Fig. 35: MHD response force equation

Characteristics of a 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 occur even in case the earthquake was more severe than expected, and the design engineer can easily calculate with this constant maximum response force – independent from velocity – 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< 0.02 (Fig. 35).
- Extreme great efficiency of up to η = 96% which corresponds with a maximum equivalent damping coefficient of 0.61.
- Maximum response force is given by the MHD with tenths of a second, so structural displacements are minimized.
- For traffic loads due to braking and acceleration, the MHD acts like a shock transmission unit.
- 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 or after an earthquake respectively.
- The devices are not prone to leaking as special high strength hydraulic sealing rings are used like for caterpillars, for automobile industry and similar machineries. On request prove tests can be carried out.
- Very little elasticity of 2-5% depending on request.
- 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.

6.2. Dimensions and anchoring of the MHD

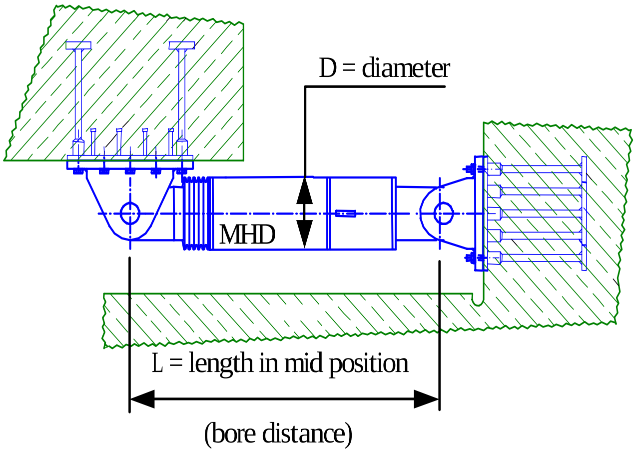

Fig. 36: Sample for anchoring of MHD at pier

Fig. 37: Sample for anchoring of MHD to abutment

axial force [kN]	maximum stroke [+/-mm]													
	50		100		150		200		250		300		400	
	D [mm]	L [mm]	D [mm]	L [mm]	D [mm]	L [mm]	D [mm]	L [mm]	D [mm]	L [mm]	D [mm]	L [mm]	D [mm]	L [mm]
50	110	740	110	1020	110	1300	110	1580	110	1860	110	2050	110	2600
100	120	770	120	1050	120	1330	120	1610	120	1890	120	2080	120	2630
200	180	810	160	1090	180	1370	180	1650	180	1930	180	2120	180	2670
500	195	850	195	1130	195	1410	195	1690	195	1970	195	2160	195	2710
750	215	865	215	1145	215	1425	215	1705	215	1985	215	2175	215	2725
1000	235	885	235	1165	235	1445	235	1725	235	2005	235	2195	235	2745
1250	280	960	280	1240	280	1520	280	1800	280	2080	280	2270	280	2820
1500	295	1060	295	1340	295	1620	295	1900	295	2180	295	2370	295	2820
1750	325	1125	325	1405	325	1685	325	1965	325	2245	325	2375	325	2885
2000	365	1290	365	1570	365	1850	365	2110	365	2410	365	2480	365	2950
2500	405	1410	405	1690	405	1970	405	2230	405	2490	405	2630	405	3070
3000	455	1530	455	1770	455	2090	455	2350	455	2490	455	2750	455	3190
4000	505	1645	505	1885	505	2205	505	2465	505	2645	505	2865	505	3305
5000	540	1940	540	2180	540	2500	540	2760	540	2940	540	3160	540	3600
6000	590	2190	590	2430	590	2750	590	3010	590	3190	590	3410	590	3850

The above mentioned dimensions can change in final design depending on detailed request to the devices.
Also the anchor support sizes are not included yet.
The devices can also be delivered with the entire anchoring system like anchor supports and tension anchors as well. The design of the anchoring will then be individually adapted to the designers wishes.

Seismic isolation combined with energy dissipation by dampers represent todays most effective tools in the hands of design engineers in seismic areas to limit both relative displacements as well as transmitted forces between adjacent structural elements to desired values. This means being able to control at will the structure´s seismic response and ensure the same the required degree of protection in a still economical way. Finally the stress upon the structure is decreased also, which brings structural cost reduction along in addition.

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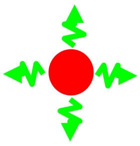
7. Technical description of seismic isolators (VS)

7.1  VS - seismic isolators (VS)

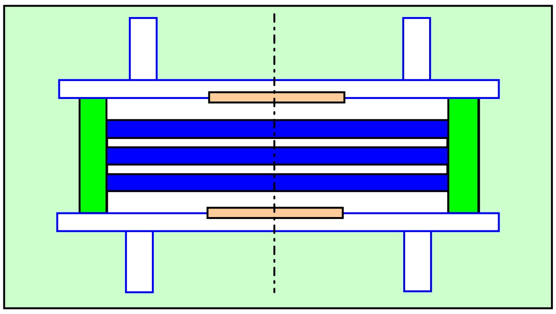


Fig. 38: Cross section of Seismic isolator type V2S

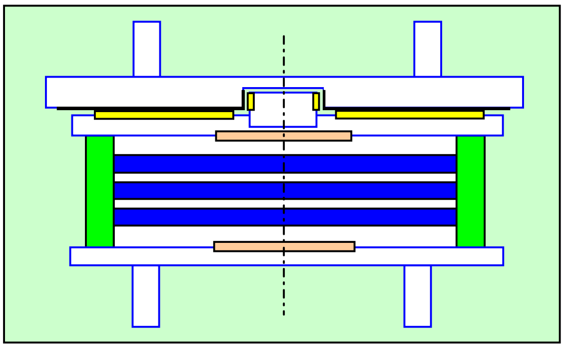


Fig. 39: Cross section of seismic isolator type VE2S

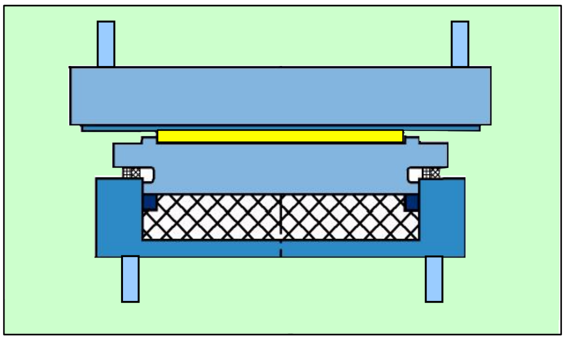


Fig. 40: Cross section of pot bearing free-sliding type TGA

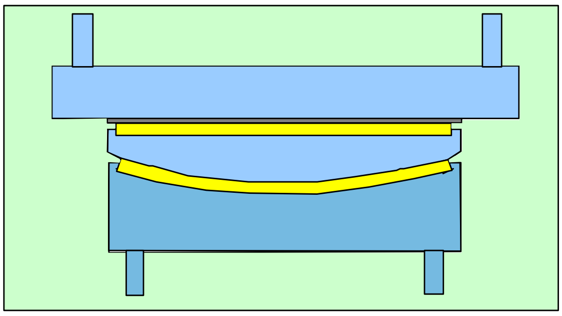


Fig. 41: Cross section of spherical bearing free-sliding type KGA

The VS - MAURER seismic isolator fulfils in general following characteristics:

- Seismic isolation from the excited ground,
- Vertical load transmission.
- Automatic adaptation to displacements and rotations of the superstructure relatively to the substructure.
- Providing re-centering capability to “pull back” the superstructure during and after an seismic attack in mid position in order to avoid dangerous displacement accumulations in one direction only.
- Inner rubber material consists of high quality natural rubber for best possible seismic behaviour. The outer cover surface is made of synthetic chloroprene rubber (marked green in Fig. 38+39) for very good ageing characteristics.

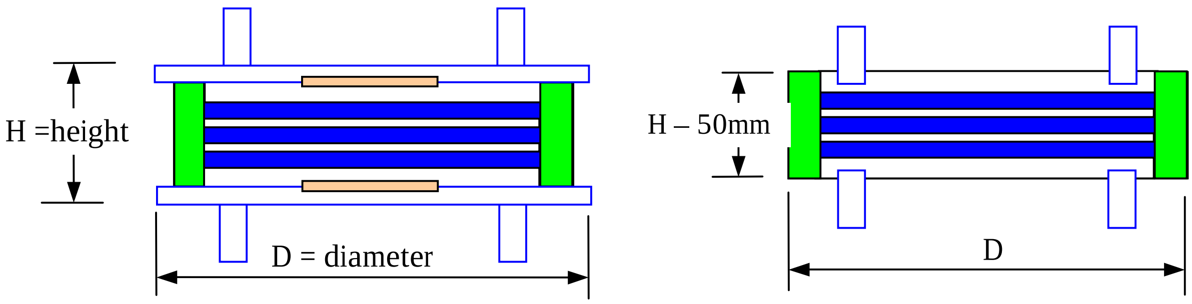
Mainly two types of VS seismic isolators are used:

- V2S: multidirectional deforming (Fig. 38),
- VE2S: laterally deforming – longitudinally sliding (Fig. 39)

Alternatively to the seismic rubber isolators also multidirectional sliding bearings of pot or spherical type (Fig. 40+41) can be used. These bearing types are preferably used for very huge loads (> 21,000 kN) or in countries with temperatures less than –30°C for a longer time span of the year. The sliding bearings do not provide re-centering capabilities. From there a bearing arrangement like shown in Fig. 10 has to be applied and the piers will act like re-centering springs then. For free-sliding bearings see also the MAURER brochures for pot and spherical bearings.
100% seismic isolation is not practicable and the finally induced energy upon the structure causes still displacements of the deck, which values are now easily controlled by the dampers. This structural flexibility ensures significant energy dissipation within the accepted displacements limits. As a result the forces onto the structure are effectively decreased compared to the strengthening concept.

7.2. Dimensions of V2S seismic isolators

Type V2S: Version I | Version II



max. service load [kN]	Max. displacement s laterally and longitudinally (service / seismic) [+/-mm]											
	D [mm]	s [mm]	H [mm]	D [mm]	s [mm]	H [mm]	D [mm]	s [mm]	H [mm]	D [mm]	s [mm]	H [mm]
600	350	35 / 68	145	350	41 / 98	165	350	45 / 108	180	350	46 / 120	190
900	400	35 / 68	145	400	41 / 98	165	400	45 / 108	180	400	46 / 120	190
1200	450	40 / 82	150	450	52 / 113	185	450	57 / 132	200	450	64 / 165	230
2400	550	40 / 82	150	550	52 / 113	185	550	57 / 132	200	550	64 / 165	230
3600	650	46 / 98	180	650	70 / 150	225	650	84 / 198	270	650	94 / 248	320
4200	700	53 / 113	185	700	74 / 158	230	700	91 / 202	270	700	112 / 285	360
5800	800	53 / 150	185	800	74 / 158	230	800	91 / 202	270	800	112 / 285	350
6600	850	53 / 150	185	850	74 / 158	230	850	91 / 202	270	850	112 / 285	350
7500	900	63 / 180	200	900	88 / 189	250	900	129 / 297	340	900	147 / 378	410
8500	950	63 / 180	200	950	88 / 189	250	950	129 / 297	340	950	147 / 378	410
9500	1000	63 / 180	200	1000	88 / 189	260	1000	129 / 297	350	1000	147 / 378	420
14000	1300	63 / 180	200	1300	88 / 189	260	1300	129 / 297	350	1300	147 / 378	420
17000	1400	63 / 180	200	1400	88 / 189	260	1400	129 / 297	350	1400	147 / 378	420

Length dimensions (L) are measured in longitudinal bridge direction and width dimensions (W) are measured in lateral bridge direction.
The seismic displacement is assumed to be 1.5 x rubber thickness. Depending on the standard this can deviate.

The above mentioned dimensions can change in final design depending on detailed request to the devices.
Also the sizes of the shear anchors are not included yet. Normally these anchor bolts are 25 mm in diameter and 100-150 mm long.

Further information concerning rubber pads can also be found in the brochure „MAURER Elastomeric Bearings“.

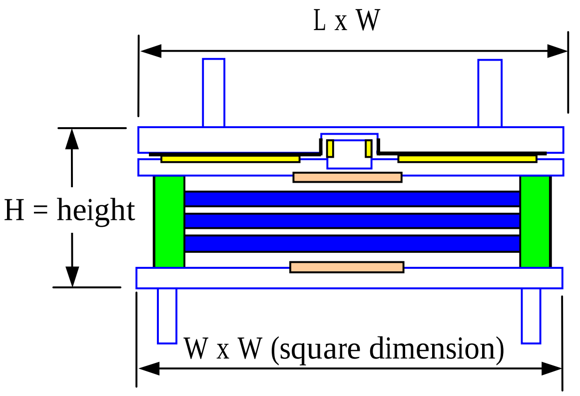
On request we are able to deliver any kind of isolator sizes to be individually adapted to the stiffness requirements.

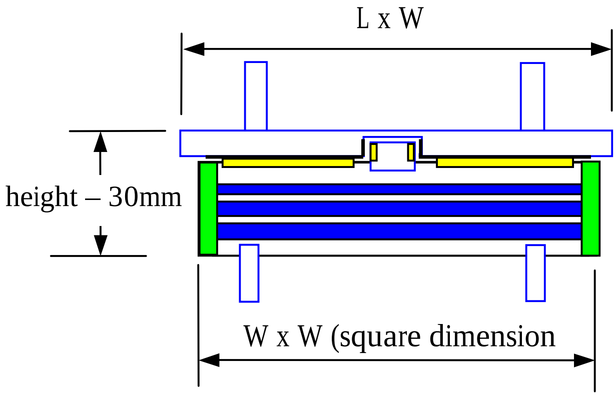
Depending on the rubber compound also special damping characteristics can be realized.
The maximum size for the rubber pad is 1200 x 1200 mm in plan view!

Also square and rectangular isolator sizes are available.

7.3. Dimensions of VE2S seismic isolators

Type V2ES: Version I Version II





max. service load [kN]	Max. displacement s laterally (service / seismic) [+/-mm]											
	W [mm]	s [mm]	H [mm]	W [mm]	s [mm]	H [mm]	W [mm]	s [mm]	H [mm]	W [mm]	s [mm]	H [mm]
600	350	35 / 68	175	350	41 / 98	200	350	45 / 108	215	350	46 / 120	225
900	400	35 / 68	175	400	41 / 98	200	400	45 / 108	215	400	46 / 120	225
1200	450	40 / 82	190	450	52 / 113	220	450	57 / 132	235	450	64 / 165	265
2400	550	40 / 82	190	550	52 / 113	220	550	57 / 132	235	550	64 / 165	265
3600	650	46 / 98	220	650	70 / 150	265	650	84 / 198	310	650	94 / 248	370
4200	700	53 / 113	230	700	74 / 158	270	700	91 / 202	310	700	112 / 285	410
5800	800	53 / 150	230	800	74 / 158	270	800	91 / 202	320	800	112 / 285	410
6600	850	53 / 150	230	850	74 / 158	270	850	91 / 202	320	850	112 / 285	410
7500	900	63 / 180	260	900	88 / 189	300	900	129 / 297	400	900	147 / 378	470
8500	950	63 / 180	270	950	88 / 189	310	950	129 / 297	400	950	147 / 378	480
9500	1000	63 / 180	270	1000	88 / 189	330	1000	129 / 297	415	1000	147 / 378	500
14000	1300	63 / 180	280	1300	88 / 189	330	1300	129 / 297	415	1300	147 / 378	500
17000	1400	63 / 180	280	1400	88 / 189	330	1400	129 / 297	415	1400	147 / 378	500

Length dimensions (L) are measured in longitudinal bridge direction and width dimensions (W) are measured in lateral bridge direction.
The seismic displacement is assumed to be 1.5 x rubber thickness. Depending on the standard this can deviate.
The length dimension L has to be calculated according following equation:
L + total displacement + 2 x 35 mm

The above mentioned dimensions can change in final design depending on detailed request to the devices.
Also the sizes of the shear anchors are not included yet. Normally these anchor bolts are 25 mm in diameter and 100-150 mm long.

Further information concerning rubber pads can also be found in the brochure „MAURER Elastomeric Bearings“.

On request we are able to deliver any kind of isolator sizes to be individually adapted to the stiffness requirements.

Depending on the rubber compound also special damping characteristics can be realized.

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8. Technical information for DS and DS-F seismic swivel-joist expansion joint

Fig. 42: Tejo Bridge in Lisbon
fitted with a DS seismic expansion joint

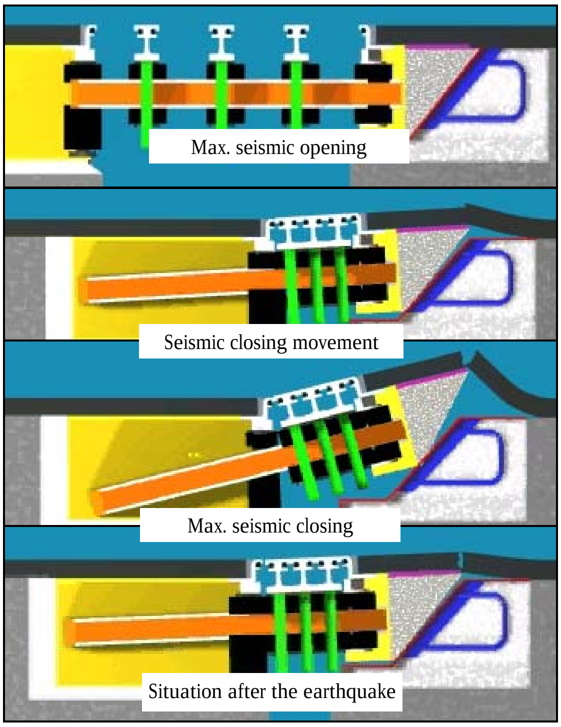

Fig. 43: Functional principle of the FUSE-BOX – System integrated in a swivel-joist expansion joint of type DS

Fig. 44: Swivel-joist expansion joint with FUSE-BOX ready for installation

There are two possibilities to design a MAURER expansion joint.

1. The joint is designed for the *service displacements* and in addition it can accommodate the entire *seismic displacements*. The swivel-joist joint of type DS suffers no damages due to the nominal seismic event and can be passed immediately after the earthquake.

2. The joint can accommodate the *service displacements* and the *seismic opening displacement*.
   The *seismic closing displacement* is not entirely accommodated. Therefore MAURER developed the special joint of type DS-F with the so called FUSE-BOX. When all gaps between the single profiles are already closed and the joint is still trying to close further more, some welding seams in the FUSE-BOX will fail in a controlled manner. One joint edge is pushed over a ramp out of the joint gap (Fig. 43). As the support bars are guided by elastomeric bearings the joint behaves flexible enough not to be damaged during this operation. After the earthquake the joint can be passed by emergency vehicles without problems. To get the joint ready for service again, only some minor works at the welding seams of the FUSE-BOX have to be done. The joint of type DS-F has a cost advantage compared to the DS type. In addition, the DS-F type requires also less space than the DS type.

The swivel-joist expansion joint represents in both versions – with or without FUSE-BOX – the best suitable joint for seismic conditions.

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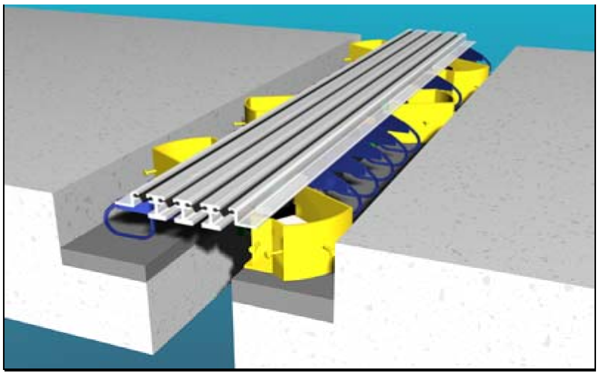

Fig. 45: DS type delivered on site, inserted into the gap, connected to the reinforcement steel and then grouted.

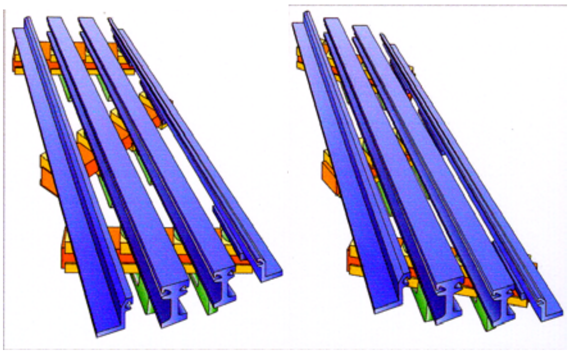

Fig. 46: Longitudinal and lateral displacement capability

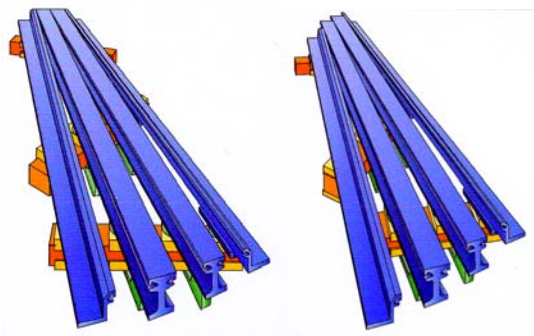

Fig. 47: Rotational capability around vertical bridge axis

Fig. 48: Few from underneath in the abutment on the control mechanism of a installed DS 2000 (Storebaelt Bridge, Denmark)

Earthquake can create displacements of considerably greater and faster magnitude than under normal service conditions, and with a complex three dimensional behaviour.
The optimum adaptation to these dynamical movements is ensured by the MAURER DS and DS-F type.

In general a seismic expansion joint has to fulfil the following requirements:

- Longitudinal and lateral displacement capability (Fig. 46).
- Rotational capability around the vertical bridge axis (Fig. 47).
- Vertical elasticity in the range of at least 0,5° necessary as due to dynamical deck vibrations small vertical misalignments resulting from rotations around the lateral bridge axis in the bearing points will appear.
- Design for very fast seismic displacement velocities of at least 500 mm/s or on request up to 1600 m/s.
- Granting for proper traffic ability after the earthquake, at least for emergency vehicles.
- It is often desired that any kind of refurbishment works on a potentially damaged joint after an earthquake is avoided, which means that during a seismic event the joint has to perform as usual without being damaged at all.
- Protection of the structure against impact damages due to too much seismic closing displacements.
- Avoidance of collapse of the joint construction into the gap while seismic opening displacements occure.
- Easy and quick installation (Fig. 45).

The above requirements are all fulfilled by the swivel-joist expansion joint DS and DS-F type.

A patented simple and effective control mechanism (Fig. 48) safeguards the unstrained absorption of movements, simultaneous transmission of traffic loads and prevents the joint from any damages.

For more detailed information about installation, dimensions and further more, please have a look in the *MAURER Swivel-Joist Expansion Joint* brochure.

9. General information for a non-linear time history analysis

On request, MAURER SÖHNE carries out a detailed non-linear time history analysis for any kind of structure and will select the seismic protection system that is best possible to satisfy individual requirements.

For a non-linear analysis, the following input data are necessary:

- Design drawings of the structure,
- Data of significant cross sections of deck, abutment and piers (surface; moment of inertia about the main axis of these sections, torsion constant of these sections, transverse shear stiffness).
- Materials (young modulus, shear modulus, density).
- Foundations (dimensions and soil winkler´s modulus, translation and rotation stiffness of equivalent springs).
- Seismic input: response sprectre and representative site accelerogrammes.
- Loads (dead loads, maximum live loads, live loads under seismic conditions).
- Admissible actions in most significant locations like pier bottoms, abutments etc. (admissible bending moments, shear+axial forces, and displacements).
- Special requirements of the design engineer.

Advantages of a non-linear time history analysis:

- Exact determination of structural displacements.
- Exact calculation of the seismic response forces acting onto the devices and structure.
- Optimized adaptation of the seismic protection system with respect to efficiency and economical benefits.
- Proof for best possible seismic protection.
- Exact evaluation of real structural safety factors.
- Design engineer is able to compare his own calculations with the analysis in order to get his results confirmed.
- Possible economical benefits due to savings in the design.

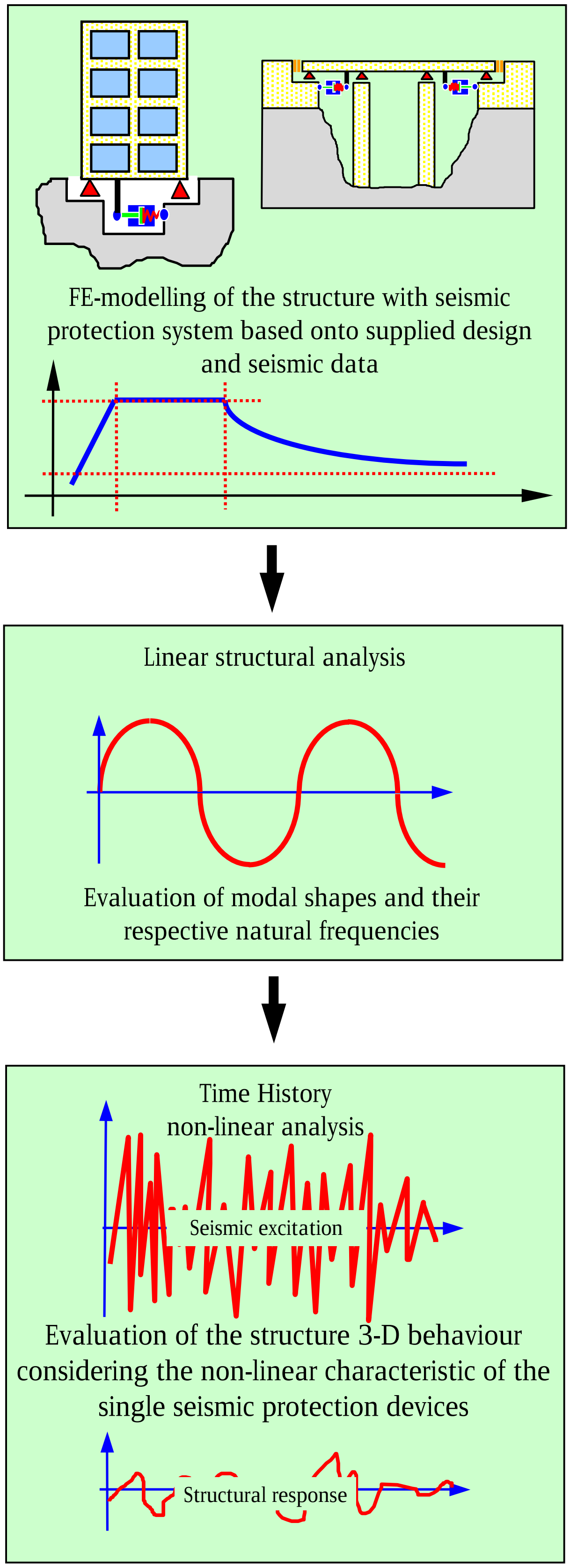

Fig. 49: Steps to be carried out for a non-linear analysis

10. Testing of seismic protection devices

In respect to their seismic suitability, components used for a MAURER seismic protection system have been extensively tested.

Fig. 50: Tests of damper (MHD) and shock transmitter (MSTU) at the Technical University Munich

Fig. 51: Tests of an elastomeric isolator

Fig. 52: Tests of a seismic swivel-joist expansion joint of Type DS at the Berkeley University - CA

In addition to the shown tests on this page, e.g. sliding tests for the sliding isolators are permanently carried out.

For all used materials corresponding material certificates can be supplied on request.