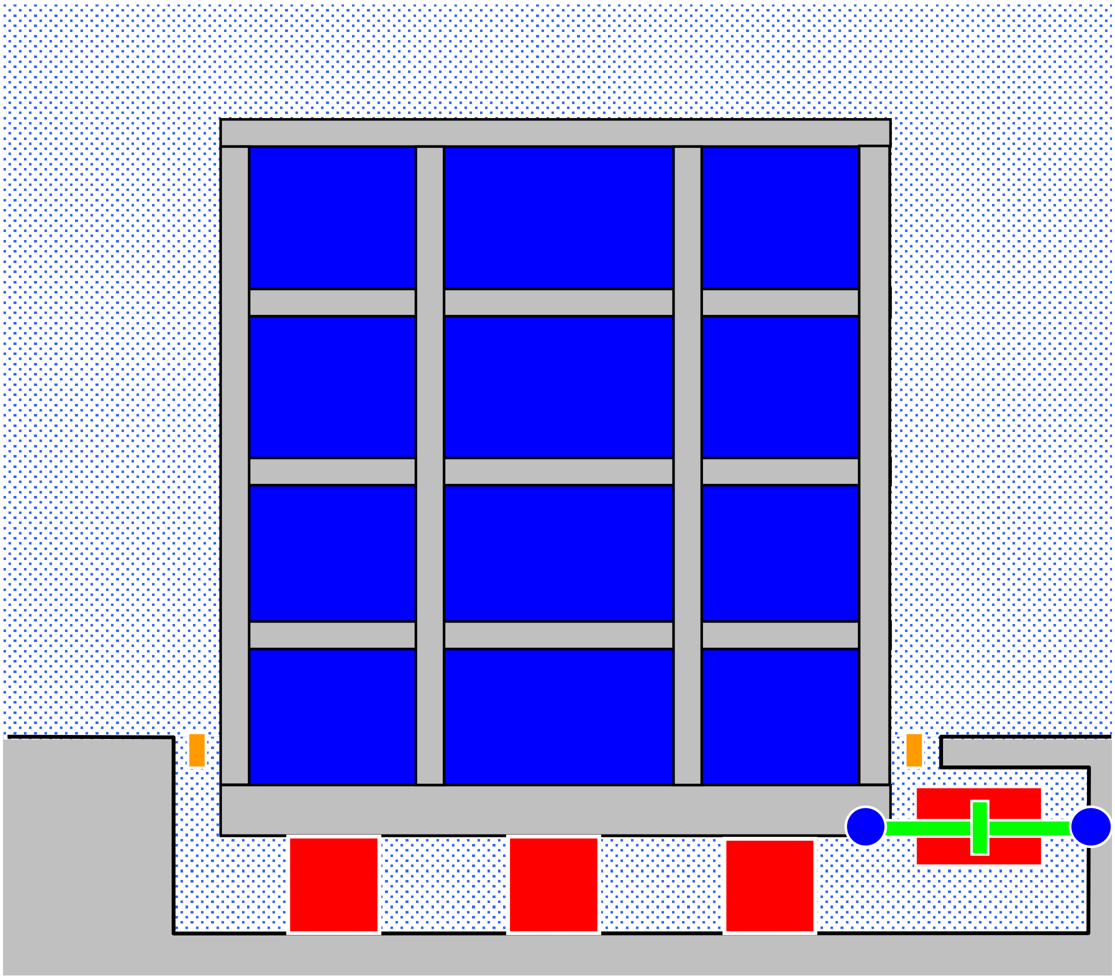
MAURER
Seismic Isolation Systems



Products and Technical Information

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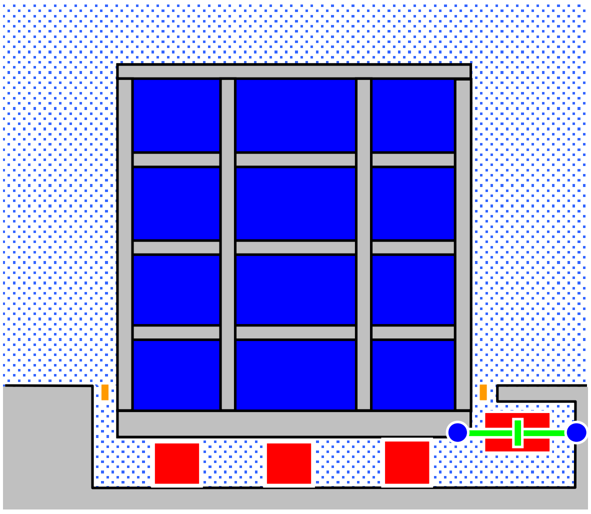
Seismic Isolation Systems



CONTENTS

1. Introduction 3

2. Products for Seismic Isolation 6
   2.1. Seismic Rubber Isolators 6
   2.2. Seismic Steel Sliding Isolators 8
   2.3. Seismic Dampers 10

3. Seismic Isolation Systems 13

4. Energy Approach Concept for optimal Seismic Protection 15

5. The way to the ideal Seismic Isolation System 17

6. Information for a non-linear Time History Analysis 18

1. Introduction

It is a statistical fact that every year 150 - 200 earthquakes with a magnitude of up to 7.0 occur worldwide. Fifteen of those seismic attacks exceed even this magnitude. The severe earthquakes of 1999 caused approximately 25,000 victims and financial damage was estimated at US-$ 20 billion (Izmit /Turkey), US-$ 14 billion (Athens/Greece) and US-$ 150 million (Taiwan) respectively. As there is no change in this trend in sight for a decrease in the frequency or severity of the attacks, the sensitivity of modern infrastructure calls for effective seismic protection systems.

Fig. 1: Taiwan earthquake 1999

One option to protect structures against earthquakes is Seismic Isolation, a structural design approach to mitigate earthquake damage potential.
The idea is that of reducing the seismic input into the structure instead of increasing its resistance to it.

This approach was already proposed in the early years of the last century. Precisely, the first patent application for seismic isolation was granted to Mr. J.A. Calantarients in 1909. His idea was to install a sliding layer between the building and its foundation to allow the building to slide during an earthquake. Thusly, the energy transmitted to the building itself is reduced.

Fig. 2: Izmit earthquake 1999

During the last 25 years, many types of devices have been developed to effect a resilient connection between foundation and building and achieve the goal of uncoupling the structural prevailing mass from the ground motion.

In practice, the principle of Seismic Isolation is that of shifting the fundamental period (= reciprocal value of the frequency) of a building (Fig. 3) by the installation of devices with a low horizontal stiffness between foundation and building (Fig. 4).

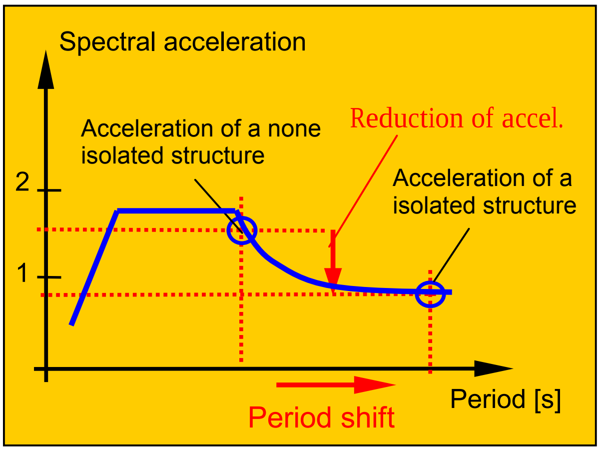


Fig. 3: Response spectrum

Figure 4 below shows the effects of a seismic attack on both a non-isolated and an isolated structure. Many non-isolated buildings have fundamental periods of 0,2-0,5 sec, i.e. the same fall within the typical range of high spectral acceleration (i.e. where the maximum energy content of the response spectrum is concentrated). Thus, the non-isolated buildings undergo resonance that results in dramatic amplification of ground accelerations within the structure as well as large inter-storey displacements. In the case of an isolated building, the fundamental period is shifted into an area with lower spectral accelerations. Resonance effects can be avoided and the building moves smoothly without showing appreciable structural deformations.

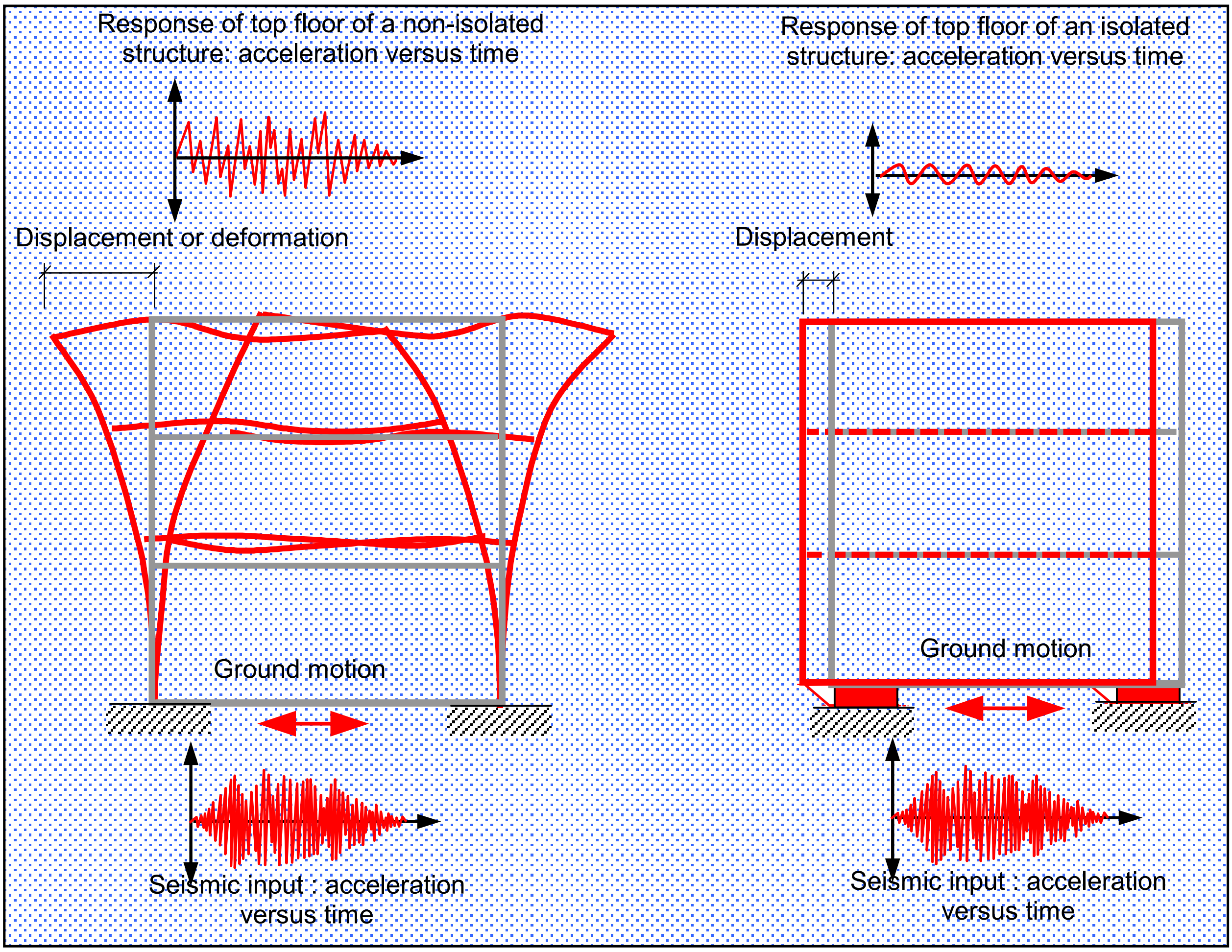


Fig. 4: Displacements and deformations of a non-isolated and of an isolated structure

The four fundamental functions of a seismic isolation system are:

1. Transmission of vertical loads (Fig. 5).
2. Allowance of displacements on the horizontal plane (Fig. 6).
3. Dissipation of substantial quantities of energy (Fig. 7).
4. Assurance of self-centring (Fig. 6).

These functions can be realised by so called ***isolators*** and ***dampers***.

The first function means that the isolation system acts as a conventional bearing system, i.e. transfers vertical loads in the intended location from the superstructure to the substructure (Fig. 5).

The second function produces uncoupling between foundation and superstructure and thus reduces transmitted forces or the amount of mechanical energy, which is essentially the same. The uncoupling allows horizontal flexibility of the structure (Fig. 6).

The dissipation of energy limits relative displacement of the isolated structural mass and provides better structural control with bigger safety for the structure (Fig. 7).

The purpose of the self-centring capability requirement – return of the structure to former neutral mid position (Fig. 6) - is not so much to limit residual displacements at the end of a seismic attack, but rather, prevent cumulative displacements during the seismic event.
Self-centring assumes particular importance in structures located in close proximity to a fault, where earthquakes characterized by highly asymmetric accelerograms are expected (Near Field or Fling effect).
It should be noted that energy dissipation and self-centring capability (sometimes referred to as restoring force) are two antithetic functions and their relative importance depends primarily on the case under examination.

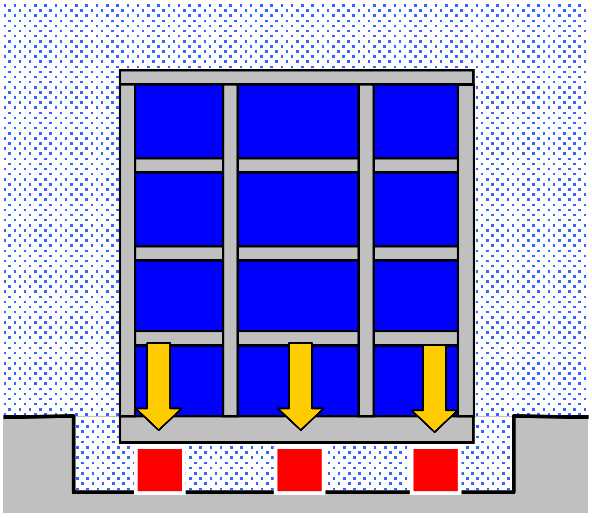


Fig. 5: Vertical load transmission by isolators

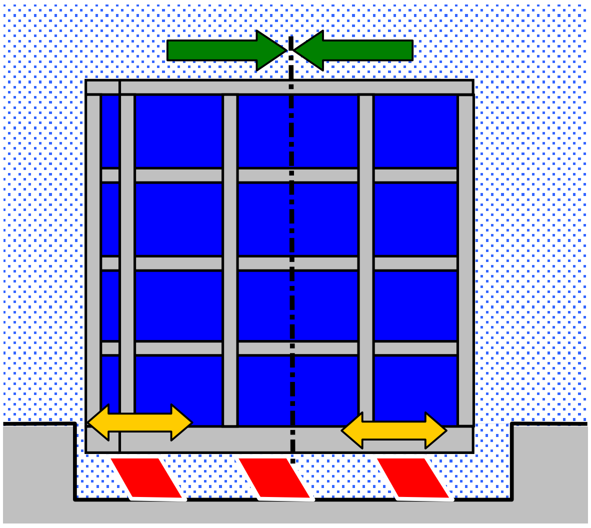


Fig. 6: Horizontal displacements and self-centring of structure to the mid position

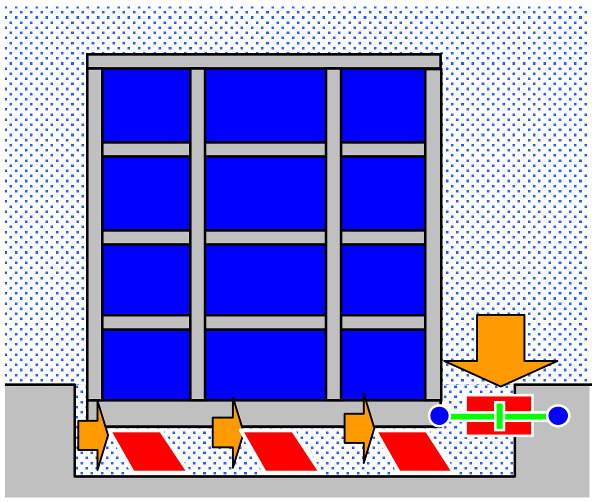


Fig. 7: Substantial energy dissipation within the isolation/damping devices during horizontal displacements

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2. Products for Seismic Isolation

In the field of Seismic Isolation MAURER SÖHNE offers the following hardware:

- **Seismic Rubber Isolators (VS)**
- **Seismic Steel Sliding Isolators (SI and SI-P)**
- **Seismic viscous dampers (MHD and MHD-R)** creating hybrid solutions that combine seismic isolation (=> isolators) with highest possible energy dissipating (=> dampers) to a optimum technical and economical benefit.

All below mentioned devices are maintenance free.

2.1. Seismic Rubber Isolators (VS)

Maurer rubber isolators (VS) are consisting of several rubber and steel plate layers, which are bonded together by a special curing procedure similar to car tires (Fig. 8).

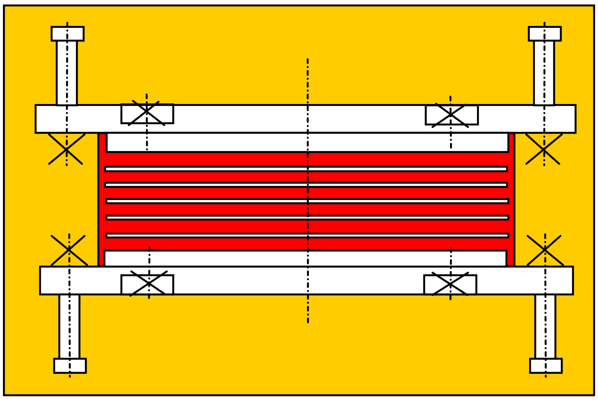


Fig. 8: Rubber isolator (VS) with anchor plates on top and bottom

The VS-Isolator is transmitting the vertical loads and is providing lateral flexibility together with automatic re-centring. The re-centring capacity is adapted to the structural request by the applied rubber height and the shear modulus of the rubber compound. For structural building isolators the shear modulus is available in the range of 0,6 to 1,0 N/mm². Higher values of shear modulus lead to stiff isolation behaviour and are therefore not desirable.

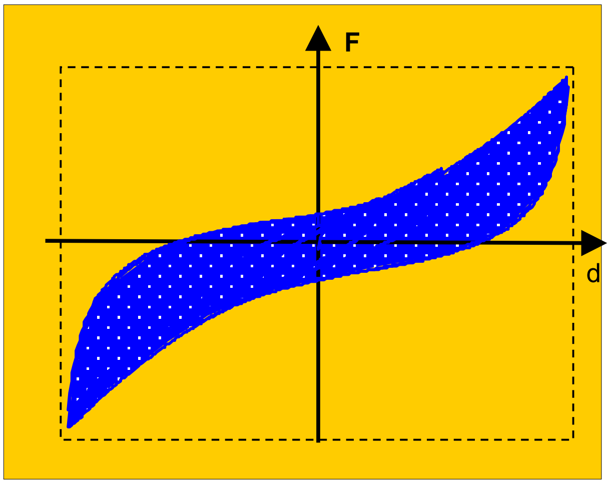


Fig. 9: Force [F] – Displacement [d] - Plot for different rubber isolators

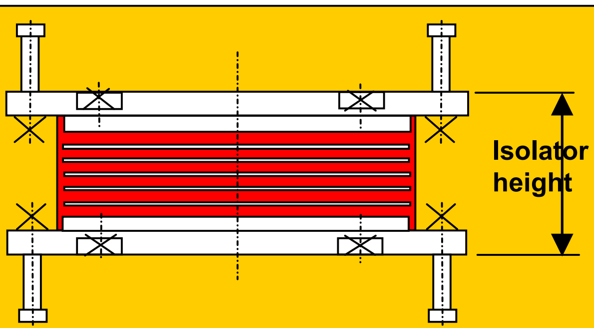
The damping of the VS is adapted depending on request. Low damping rubber isolators provide 6% damping. High damping rubber isolators have got 15% damping.

Rubber isolators with 15% damping are at least 90% more expensive than rubber isolators with 6% damping.
Often the damping capacity of rubber isolators in general – even of high damping rubber - is too poor to provide enough structural protection and energy dissipation (Fig. 9). To supply more damping it can be technically and economically reasonable to install additional viscous dampers, which is then still cheaper and even more effective than high damping rubber isolators.

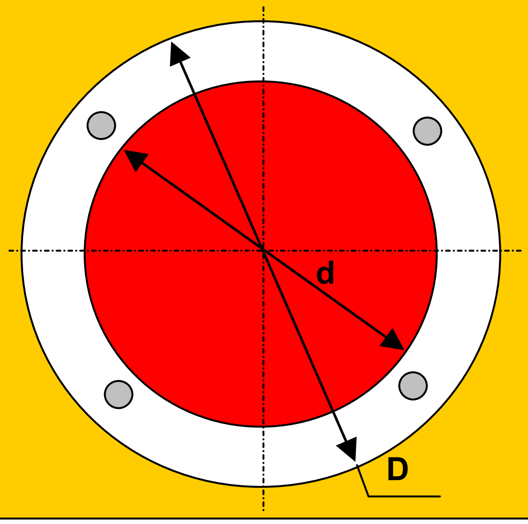
This is mainly depending on the individual structure and the most economical solution will be calculated and suggested by Maurer.

The Maurer rubber isolators (VS) are available in round and rectangular plan shapes. The size is individually adapted to the request. The below mentioned sizes are just possible sizes, which will be individually adapted on request!

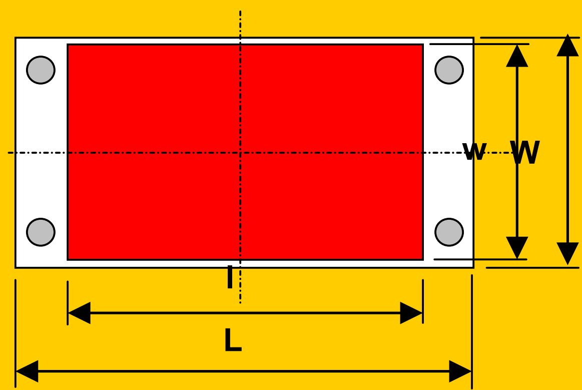
- **Shear modulus:** **0,6 or 1,0 N/mm²**
- **Damping:** **6% or 15%**
- **Sizes up to** **1100 x 1100 x 400 mm, ∅1100 x 400 mm**



Round plan shape:



Rectangular plan shape:



Vertical load* (MN)	Outline dimensions of isolator without anchor studs length (L) x width (W) or diameter (D) [mm]	Dimensions of rubber pad length (l) x width (w) or diameter (d) [mm]	Height values				Rubber layer thickness		
			Rubber height		Isolator height **		total		single layer
			min [mm]	max [mm]	min [mm]	max [mm]	min [mm]	max [mm]	[mm]
0,37 / 0,45	280 x 170 / 280 x 220	100 x 150 / 100 x 200	49	60	79	90	16	24	8
0,67 / 0,84 / 1,0 0,70 / 1,1	330 x 220 / 330 x 270 / 330 x 320 Ø 380 / Ø 430	150 x 200 / 150 x 250 / 150 x 300 Ø 200 / Ø 250	49	71	79	101	16	32	8
1,12 / 1,35 / 1,57 1,8 / 1,59	380 x 270 / 380 x 320 / 380 x 320 380 x 420 / Ø 480	200 x 250 / 200 x 300 / 200 x 350 200 x 400 / Ø 300	58	93	88	123	24	48	8
1,68 / 2,25 / 2,16	430 x 320 / 430 x 420 / Ø 530	250 x 300 / 250 x 400 / Ø 350	58	104	88	134	24	56	8
2,7 / 3,37 / 4,05 2,82 / 3,57	480 x 420 / 480 x 520 / 480 x 620 Ø 580 / Ø 630	300 x 400 / 300 x 500 / 300 x 600 Ø 400 / Ø 450	84	132	124	172	36	72	12
3,54 / 4,41	530 x 470 / Ø 680	350 x 450 / Ø 500	84	148	124	188	36	84	12
4,5 / 5,4 / 5,34	580 x 520 / 580 x 620 / Ø 730	400 x 500 / 400 x 600 / Ø 550	100	164	140	204	48	96	12
6,07 / 6,36	630 x 620 / Ø 780	450 x 600 / Ø 600	100	164	140	204	48	108	12
6,75 / 7,46	680 x 620 / Ø 830	500 x 600 / Ø 650	100	164	140	204	48	120	12
8,1 / 9,45 8,65 / 9,94	780 x 630 / 780 x 730 Ø 880 / Ø 930	600 x 600 / 600 x 700 Ø 700 / Ø 750	119	224	159	264	64	144	16
11,02 / 12,6 11,3 / 12,76	880 x 730 / 880 x 830 Ø 980 / Ø 1030	700 x 700 / 700 x 800 Ø 800 / Ø 850	119	224	159	264	64	160	16
14,4 / 14,3	980 x 830 / Ø 1080	800 x 800 / Ø 900	135	305	175	345	80	220	20
18,2	1080 x 930	900 x 900	135	305	175	345	80	220	20

* the maximum vertical load is depending on applied standard

** the isolator height value is without anchor stud length, which is normally 180 mm

Fig. 10: Sizes of rubber isolators

2.2. Seismic Steel Sliding Isolators (SI and SI-P)

Seismic steel isolators are consisting of three steel parts with inner sliding surfaces (marked in red). The shape of the internal part is always spherical and allowing rotation and horizontal sliding displacements (Fig. 11 and 12) as well.

The steel isolator is transmitting the vertical loads and is providing free horizontal flexibility.

The re-centring capacity for the SI-Type (Fig. 11) is provided either by rubber isolators which are set in between or the seismic viscous dampers (see page 10). With the SI-Isolator the horizontal stiffness of a isolator system with rubber isolators can be decreased to achieve a better isolation effect. The SI-isolators are available with different sliding materials for optimal sliding and energy dissipation control.

The seismic pendulum isolator (SI-P) is providing in addition to the SI-Type automatic re-centring capacity. While horizontally displacing the superstructure is vertically lifted (up to 100 mm and more) and therefore the accumulated energy enables the structure to slide back to the mid position again. Similar to the SI-Isolators the SI-P-Isolators can be equipped with different sliding materials for proper adaptation to the isolation, re-centring and energy dissipation aspects.

The damping of the steel isolators is adapted depending on request. Low damping steel isolators provide 5% damping. High damping SI-Isolators have got 35% damping. The maximum friction coefficients of the used sliding materials has to be checked to be always conform to existing standards.

To provide more damping while not effecting the isolation system or to increase the friction too much, we recommend to install additional viscous dampers.

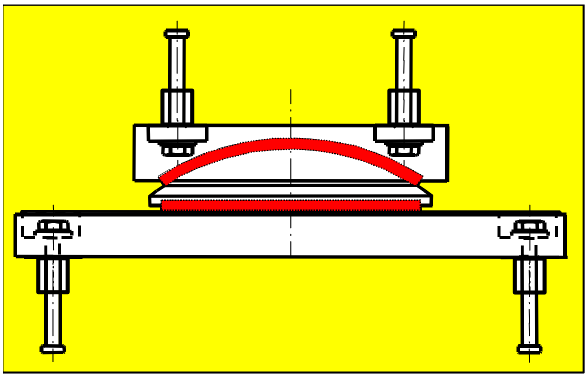


Fig. 11: Steel isolator (SI) with anchors on top and Bottom without re-centring capacity

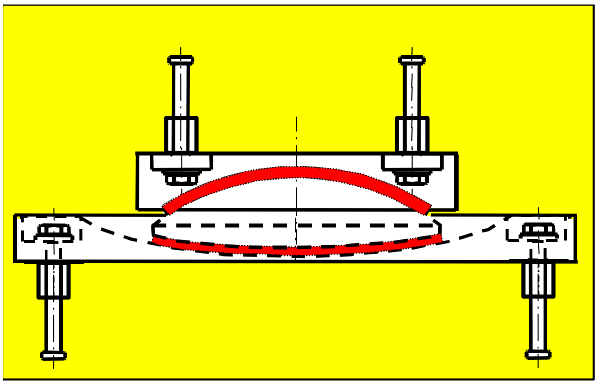


Fig. 12: Steel isolator Seismic Pendulum (SI-P) with anchors on top and bottom with re-centring capacity

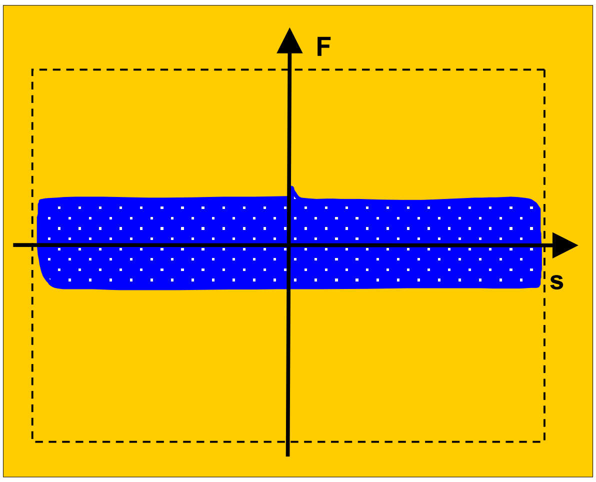


Fig. 13: Force [F] – Displacement [d] - Plot for different steel isolators

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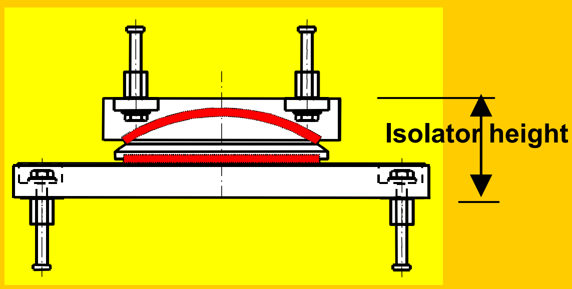
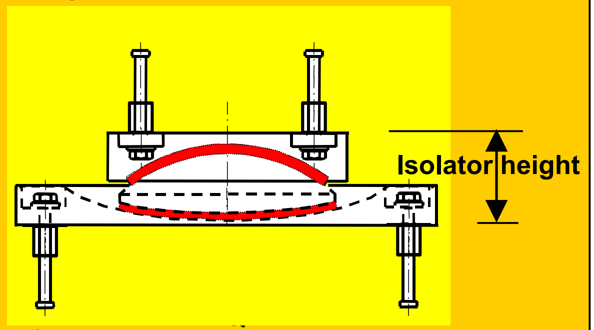
The Maurer steel isolators (SI and SI-P) are available in any size, which is individually adapted to the request. The below mentioned sizes are just possible sizes, which will be individually adapted on request!

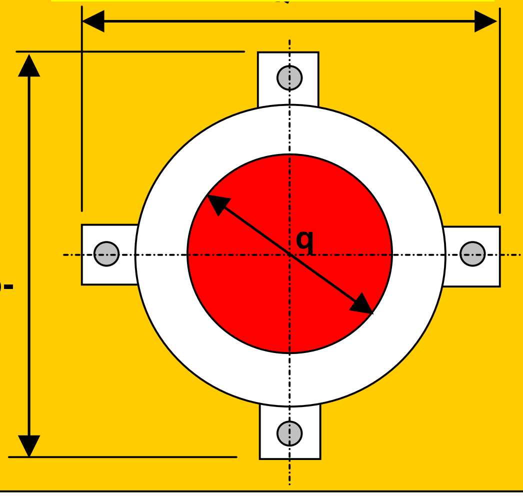
SI-Type:



SI-P-Type:



- coefficient of friction: 1,5% to 15%
- Damping: 5% or 35%
- Sizes up to 3000 x 3000 x 1000 mm,



The shown isolators can also be installed up-side-down!

Vertical load* (MN)	Horizontal displacements*** d [mm]	Dimension Q of SI Q = q + d + 100 [mm]	Height of SI **	Dimension Q of SI-P [mm]	Height of SI-P ** [mm]
0,5	+/-150	544	80	544	174
1,0	+-150	579	100	579	196
2,0	+/-150	628	110	628	228
3,0	+-150	666	110	666	253
4,0	+/-150	698	110	698	274
5,0	+-150	726	115	726	292
6,0	+/-150	751	115	751	328
7,0	+-150	775	115	775	344
8,0	+/-150	796	115	796	358
9,0	+-150	817	120	817	381
10,0	+/-150	836	120	836	393
11,0	+-150	854	125	854	435
12,0	+/-150	872	125	872	447
13,0	+-150	889	130	889	458
14,0	+/-150	905	135	905	468
15,0	+-150	921	135	921	478
20,0	+/-150	992	150	992	525
25,0	+-150	1055	165	1055	566
30,0	+/-150	1111	180	1111	602
35,0	+-150	1164	200	1164	636
40,0	+/-150	1212	230	1212	668

* the maximum vertical load is depending on applied standard
** the isolator height value is without anchor stud length, which is normally 180 mm
*** The displacement is assumed an will be individually adapted

Fig. 14: Sizes of steel isolators

2.3. Seismic Viscous Dampers (MHD and MHD-R)

MAURER viscous dampers are devices (Fig. 15), 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. These devices are usually acting in horizontal direction and are not transmitting vertical loads like isolators do.

Fig. 15: MHD with transport brackets

Very slow displacements e.g. temperature changes, create insignificant response forces FT within the MHD (see **1** in Fig. 16+17).

When sudden impact accelerations occure between the linked structural sectors due to seismic energy or wind, inducing displacement velocities in the range of approximately 0.1 mm/s to 1 mm/s the MHD blocks and behaves rigidly.
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 FI, which insignificantly bigger than FN. The very special feature is that FN is independent from the displacement velocities (see 3 in 16+17). 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 (Fig. 18).

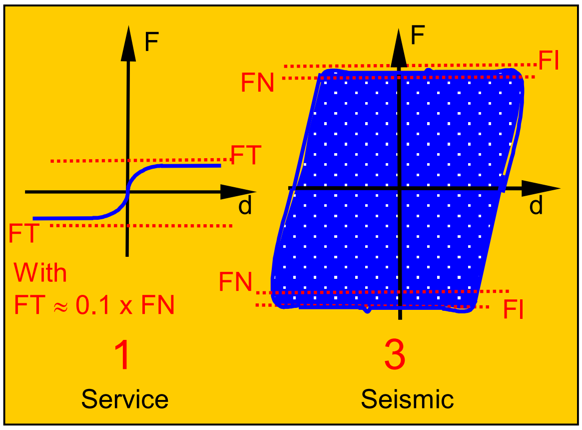


Fig. 16: Force [F] – displacement [d] - plot

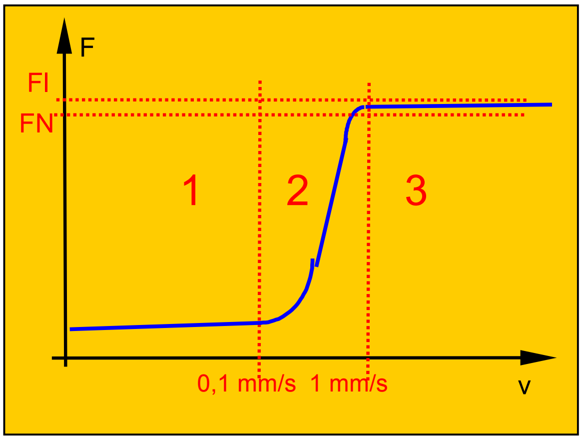


Fig. 17: Force [F] - velocity [v] – plot

On one hand the 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 independently how severe 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.

The MHD-R type has got an additional inner re-centring spring, means it develops while it is displaced from the neutral position a certain spring force, which is used to push back the structure during and after an earthquake into the mid position. The function equation is shown in Fig. 19 and 20. The re-centring function is decreasing the energy dissipation capability.

The integrated spring can substitute the re-centring capacity of the rubber or steel isolators - see also following chapter "Seismic Isolation Systems".

The efficiency (up to 96%! For a MHD), means the capability to dissipate energy is much higher for the MHD than for the before mentioned rubber or steel isolators. The viscous dampers offer a great opportunity for perfect damping adaptation to the structural requirement with biggest possible safety margins, while being still very economical.
The dampers are used in combination with the before mentioned isolators (see also page 14).

$$F = C \times v^a$$

F = MHD response force
C = Constant value characteristical for MHD
v = seismic displacement velocity
a = damping exponent < 0.02 (2%)

ð ⇨ due to the low a value the MHD response force is independently acting from the displacement velocity as the term "$\mathbf{v^a}$" runs against "**1**"

Fig. 18: MHD response force equation

$$F_R = A + k \times d + C \times v^a$$

F_R = MHD-R response force
A = constant for pre-compression force
k = spring constant of integrated spring function
d = displacement
C = Constant value characteristical for MHD-R
v = seismic displacement velocity
a = damping exponent < 0.02 (2%)

Fig. 19: MHD-R response force equation

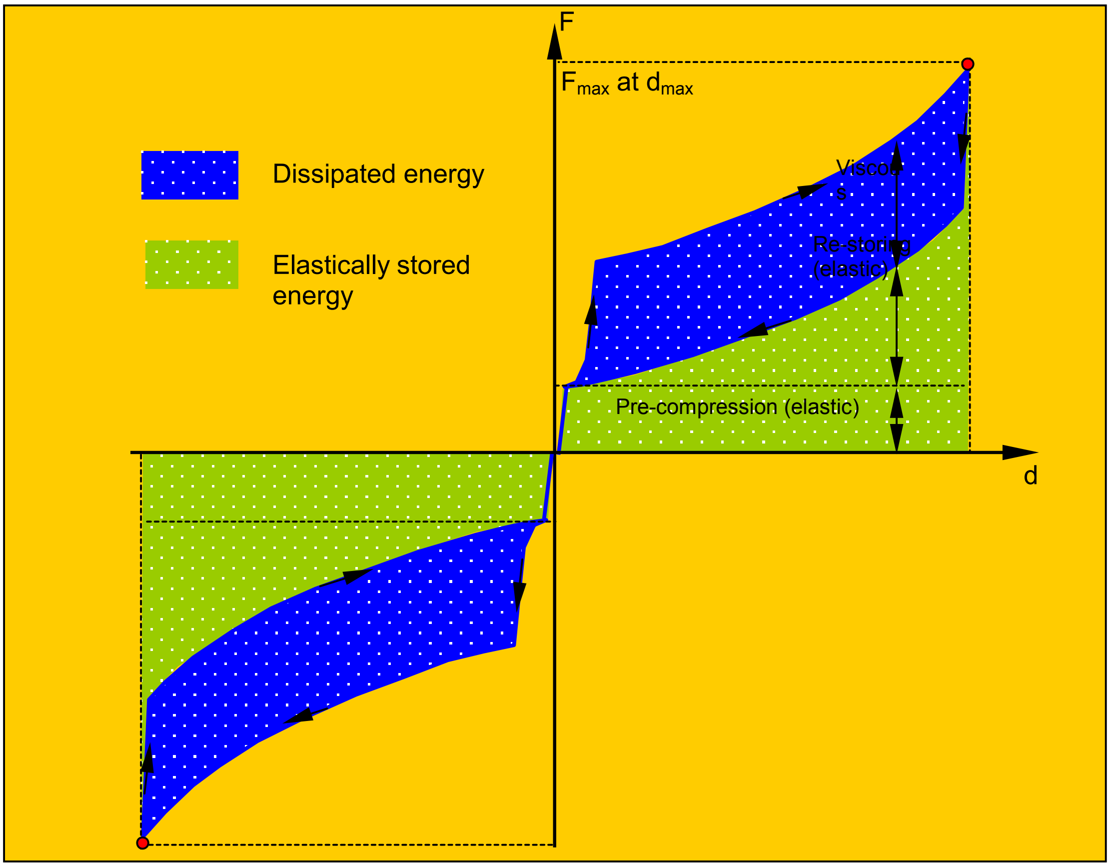


Fig. 20: Force [F] – displacement [d] – plot of a MHD-R

The Maurer viscous dampers (MHD and MHD-R) are available in any sizes. The size is individually adapted to the request. The below mentioned sizes are just for information and will be individually adapted!

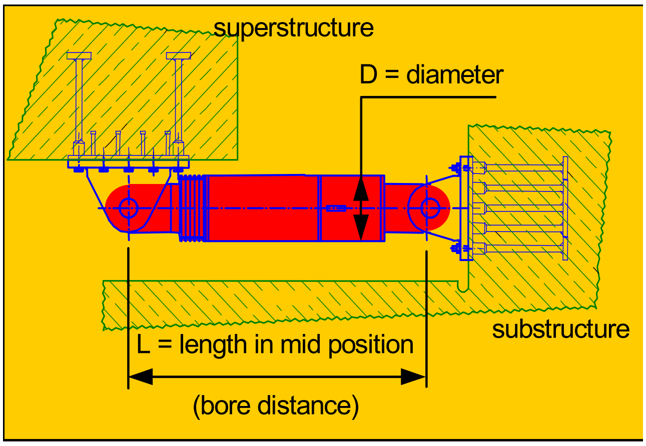


Fig. 21: Sample for anchoring of device to super- and substructure

Fig. 22: Sample for anchoring of device to concrete and steel structure

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	890	110	1170	110	1450	110	1730	110	2010	110	2200	110	2750
100	120	920	120	1200	120	1480	120	1760	120	2040	120	2230	120	2780
200	180	960	160	1240	180	1520	180	1800	180	2080	180	2270	180	2820
500	195	1010	195	1290	195	1570	195	1850	195	2130	195	2320	195	2870
750	215	1025	215	1305	215	1585	215	1865	215	2145	215	2335	215	2885
1000	235	1055	235	1335	235	1615	235	1895	235	2175	235	2365	235	2915
1250	280	1130	280	1410	280	1690	280	1970	280	2250	280	2440	280	2990
1500	295	1230	295	1510	295	1790	295	2070	295	2350	295	2540	295	2990
1750	325	1305	325	1585	325	1865	325	2145	325	2425	325	2555	325	3065
2000	365	1490	365	1770	365	2050	365	2310	365	2610	365	2680	365	3150
2500	405	1610	405	1890	405	2170	405	2430	405	2690	405	2830	405	3270
3000	455	1730	455	1970	455	2290	455	2550	455	2690	455	2950	455	3390
4000	505	1875	505	2115	505	2435	505	2695	505	2875	505	3095	505	3535
5000	540	2290	540	2530	540	2850	540	3110	540	3290	540	3510	540	3950
6000	590	2590	590	2830	590	3150	590	3410	590	3590	590	3810	590	4250

Fig. 23: Sizes for MHD and MHD-R devices

The above mentioned dimensions (Fig. 23) can change in final design depending on detailed request to the devices (displacement, re-centring, damping exponent). 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 (Fig. 21 and 22) as well. The design of the anchoring will then be individually adapted to the designers wishes.

Seismic isolation by conventional rubber isolators combined with energy dissipation by dampers **- up to 61% damping -** 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 ensures the required degree of protection in a still economical manner. Finally the stress upon the structure is decreased also, which brings structural cost reduction along in addition!

3. Seismic Isolation Systems

The isolation system will be adapted to the structural space conditions and to the seismic design impact.

The available hardware components always allow to achieve the technical best solution, while still being within a acceptable economical range.

The above listed components allow many different solutions for isolation systems. To give an overview, we showed up below two examples depending on the seismic input intensity.

The proposed systems are just to give an idea what is possible and for which field of application the single isolators are considered. Finally there is no general rule existing that a certain system is always the best for all structures and any seismic input intensity. Means depending on the structure and the seismic input the seismic isolation system has to be set together by the different shown components to maximize its efficiency to the highest possible level.

3.1. For low seismic input

For low seismic input and low ground peak accelerations in the range of 0,1 the superstructure is simply set onto rubber (page 6/7) or steel isolators (page 8/9). The isolators are adapted in a manner that the structural seismic displacements are always within a range of +/-150 mm. Considering the normally big mass of buildings, bigger design relative displacements than +/-150 mm should be avoided, otherwise the occurring energy amounts are quite difficult to control by will. For low seismic impacts and the proper isolation capabilities of the rubber and steel isolators this is possible.

The isolators provide vertical load transmission (①), horizontal isolation (②) and limited amount of internal energy dissipation (③), which is allowing to keep the structure within approximately +/-150 mm horizontal displacement range. The horizontal re-centring capacity (④) is provided by the rubber of rubber isolators (SR) or the inner concave shaped sliding plate of the steel isolator (SI-R).

The number and size of isolators is depending on the vertical load, the requested horizontal stiffness, the acceptable horizontal displacement and the amount of energy to be dissipated.

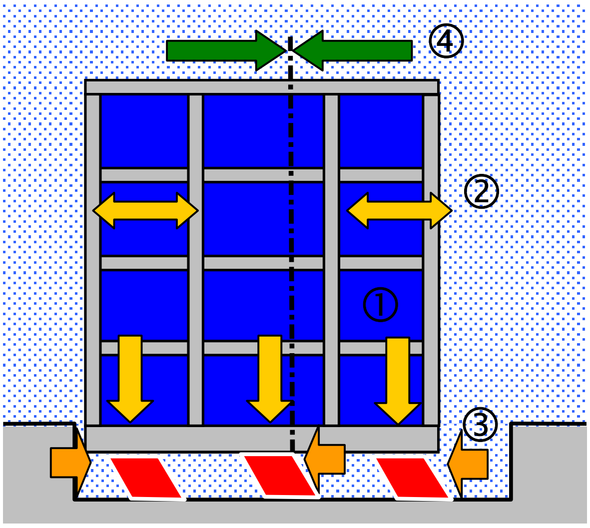


Fig. 24: Isolated structure by rubber or steel isolators

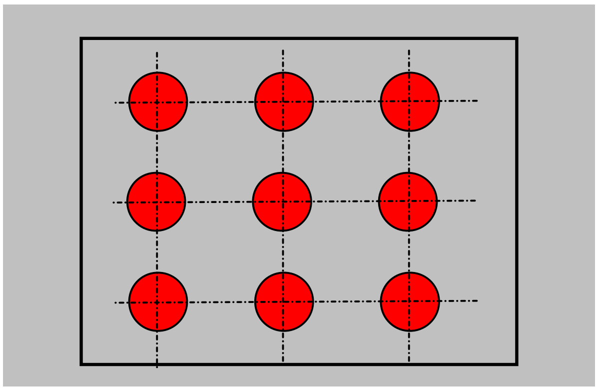


Fig. 25: Top view onto isolator arrangement

3.1. For severe seismic input

For severe seismic input and high ground peak accelerations in the range of 0,3 and greater the superstructure is set onto low damping rubber (page 6/7) isolators. In addition there are installed viscous dampers (page 10-12) of type MHD to dissipate the requested huge amounts of energy. With this concept it is possible to provide a proper isolation with low stiffness values, while the structural seismic displacements are in a maximum range of +/-100 to +/-150 mm.

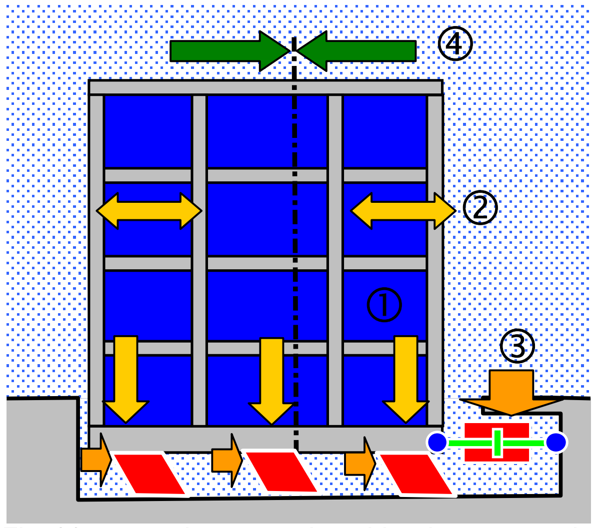


Fig. 26: Isolated structure by rubber isolators and damped by viscous dampers of type MHD

The isolators provide vertical load transmission (①), horizontal isolation (②) and limited amount of internal energy dissipation (③). The horizontal re-centring capacity (④) is provided by the rubber of rubber isolators (SR).

Almost the total energy dissipation is provide by the MHD dampers, as viscous devices are well known for the highest possible energy dissipation of all dissipation devices.

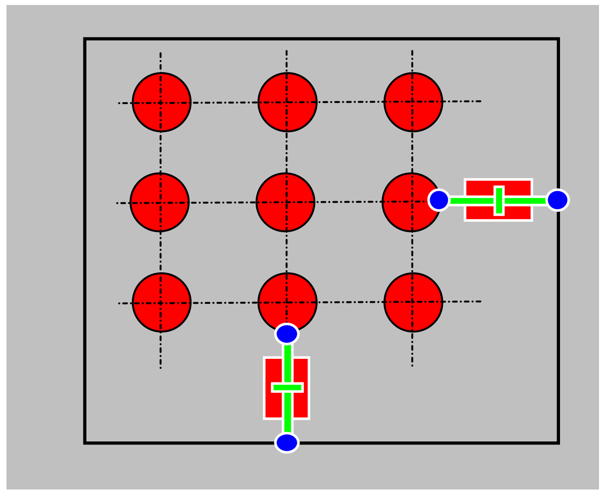


Fig. 27: Top view onto a principle isolator/damper arrangement

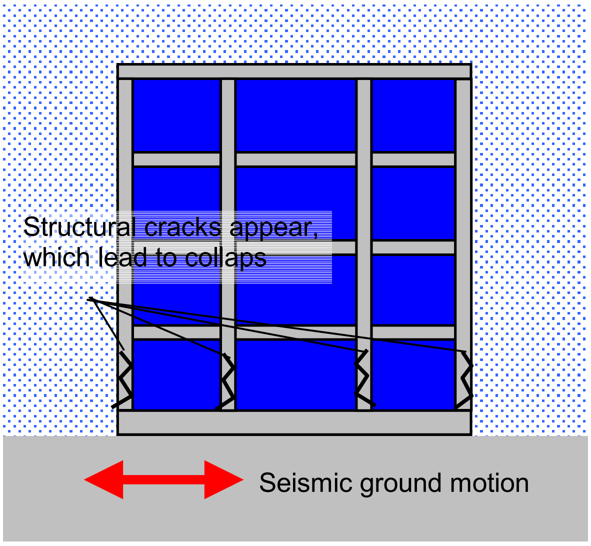
The number and size of isolators/dampers is depending on the vertical load, the requested horizontal stiffness, the acceptable horizontal displacement and the amount of energy to be dissipated.
For instance an average building with 50 isolators for 4000 kN load each is requiring approximately 4 to 6 (2 to 3 in each direction) viscous damping devices with a capacity of approximately 1000 kN each.

The above described system showed up to be the most economical, while technically fulfilling all requirements for severe seismic impacts.

4. Energy Approach Concept for optimal Seismic Protection

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 hardly at the contact surface of the structure to the ground (Fig. 28).



By implementing additional seismic isolation and also energy dissipation capability, less energy is entering the structure (Fig. 29), and the remaining energy amount entering the structure is effectively mitigated. From there seismic isolation does not only mean isolation itself, but it also including effective energy dissipation to limit the structural displacements during an earthquake to a reasonable limit.
Then the structure and its inner life is properly protected and damages are avoided.

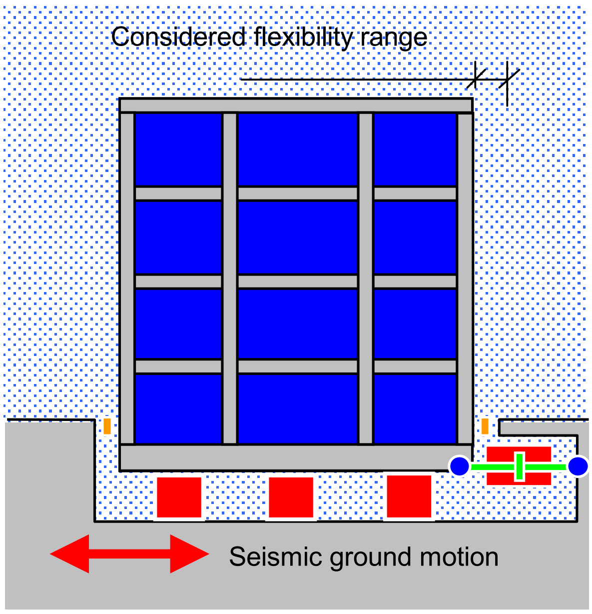


Fig. 29: Isolated structure allowing lateral displacement within certain limits and energy dissipation capability

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.

The concept of the energy approach (Fig. 30) 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. 31) 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:

$$F = C \times v^a$$

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 10).

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:

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

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

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

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

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

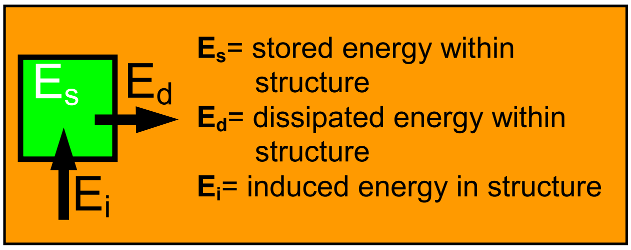


Fig. 30: Concept of energy approach considering the energy exchange between structure and environment

$$E_i \leq E_s + E_d$$

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

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. 31: Energy balance equation for structures

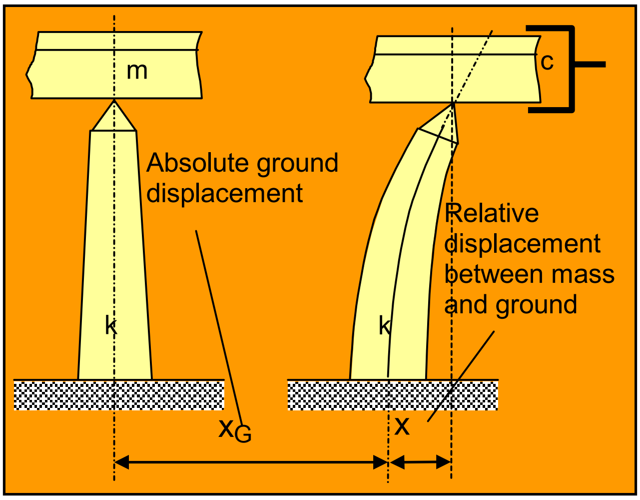


Fig. 32: Complex bridge structure explained with a simplified single ocillating mass

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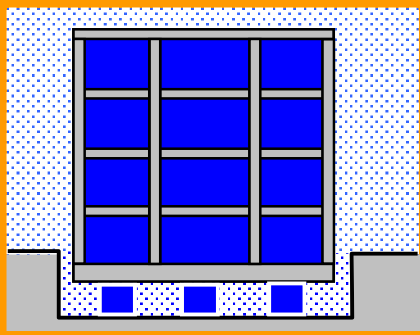
5. The way to the ideal Seismic Isolation System

The especially adapted MAURER seismic protection system (Fig. 33) 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.
Depending on request for the single components the design can be done according to EURO NORM, AASHTO, BRITISH STANDARD, DIN or any other standard.

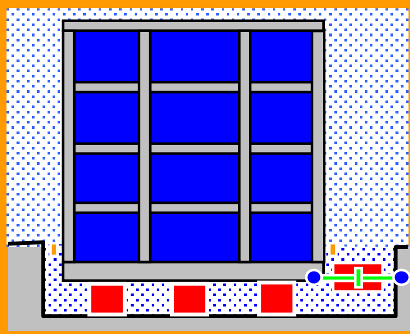
Despite the fact that some guidelines for seismic engineering have been implemented in the last few years, every structure is unique, has to be individually calculated, and requires tailor made components.

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 18) of the entire structure with the input data of the designer.
By application of the special seismic protection system of MAURER the structure´s design needs be changed with respect to ground isolation. As most of the structures which get protected have got a car garage in the cellar, only minor not really costly modifications have to be done.
On account of the above mentioned reduced forces induced upon the structure by using a seismic isolation 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 isolation system.
The advantages of a seismic isolation system (Fig. 34) are obvious and satisfy protection and economic requirements.

1. General design by designer



2. Non-linear Time History Analysis of the structure with adaptation of the seismic isolation system



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

Fig. 33: Steps to built up a seismic isolation system

Advantages:
- Maximum seismic protection with great safety margins,
- Compared to other methods like *strengthening* normally only minor changes,
- No structural damages due to the design earthquake => prepared for following earthquakes and ready for service,
- Normally only minor changes of the structure are necessary by implementing a seismic isolation system,
- Components can be easily installed,
- Approved by tests and in service for many years.

Fig. 34: Advantages of a MAURER Seismic Isolation System

6. Information for a non-linear Time History Analysis

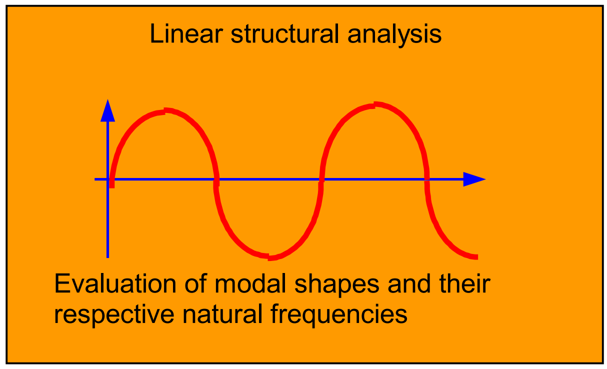
On request, MAURER SÖHNE carries out a detailed non-linear time history analysis for any kind of structure and will select the seismic isolation system that is best possible to satisfy individual requirements.

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 spectre and representative site accelerograms.
- 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.
- Optimised 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.



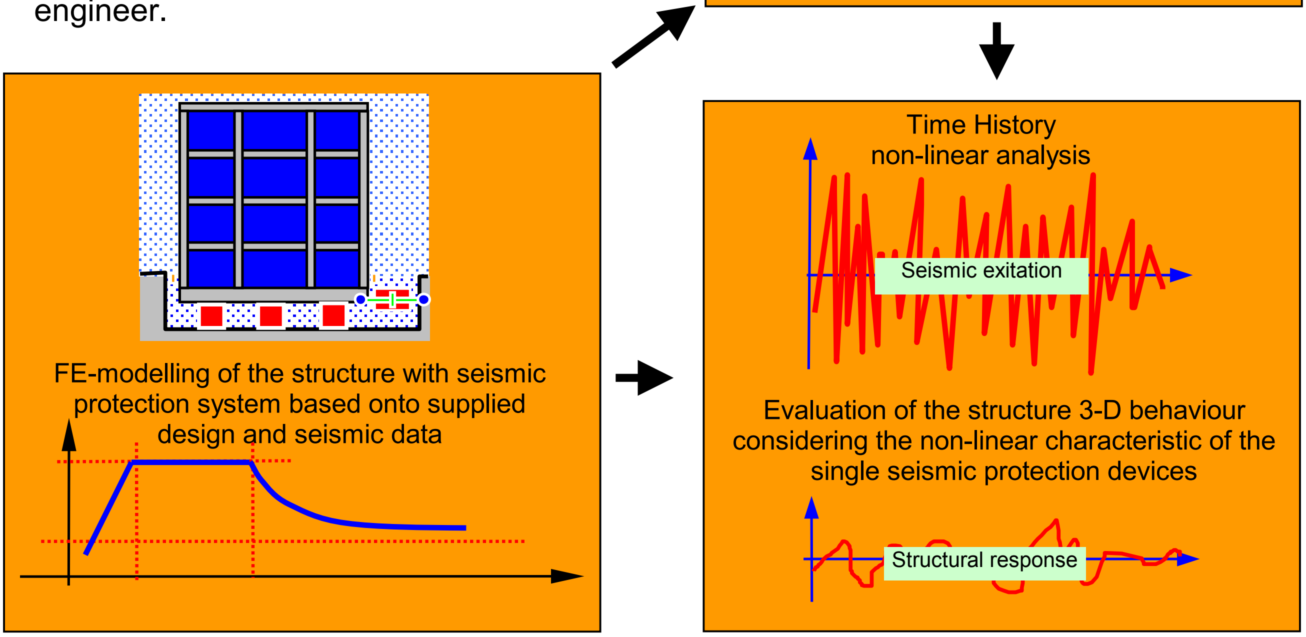


Fig. 35: Steps to be carried out for a non-linear analysis