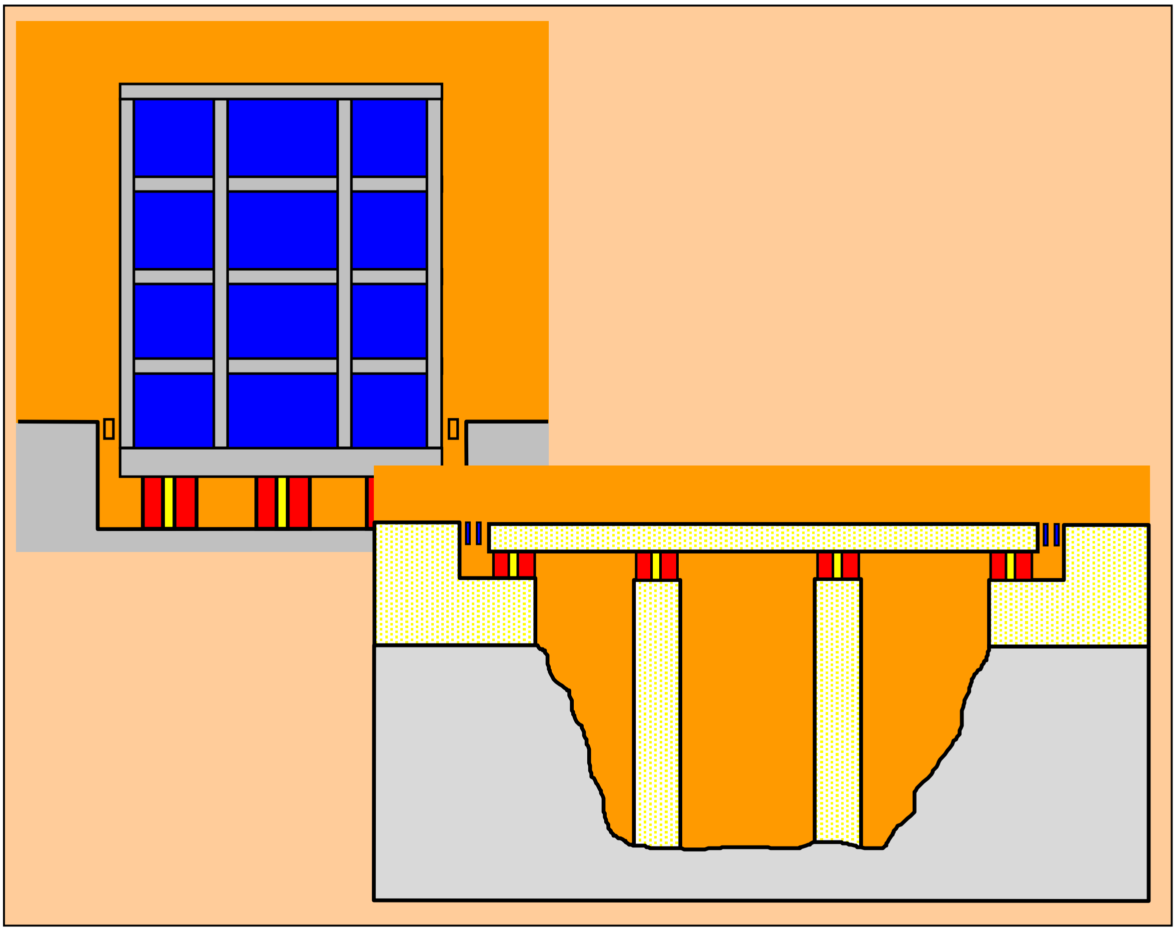
MAURER
Seismic Isolation Systems with Lead Rubber Bearings (LRB)



Product and Technical Information

Basic Principle of Seismic Isolation by Energy Mitigation realized with LRBs

ENERGY MITIGATION means applying the concept according to the energy approach 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 by LRBs:**
   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. 1). Depending on the type of the employed multidirectional seismic isolators – in this case LRBs - 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. 2+3). 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 LRBs:**
   By means of passive energy dissipation (= energy transformation) the seismic rest energy entering into the superstructure will be effectively dissipated by additional damping within the lead core of the LRB relieving the entire structure from additional strain (Fig. 2+3).

With the above suggested concept that combines seismic isolation with energy dissipation, a very good seismic protection for structures of all kind is achieved.

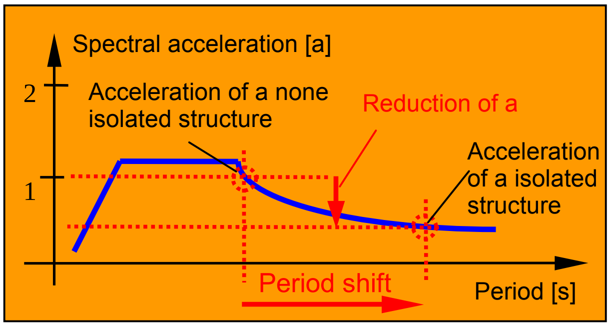


Fig. 1: Characteristical response spectrum of a bridge

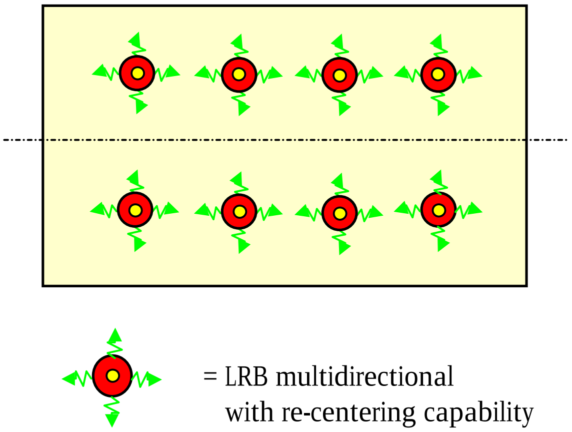


Fig. 2: Sample for a LRB arrangement

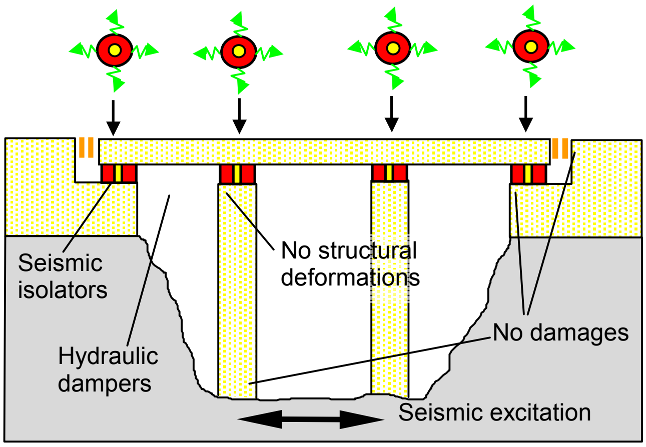


Fig 3: Bridge with LRBs with passive energy dissipation and arrangement of Fig. 2

The Concept of Energy Approach realized with LRBs

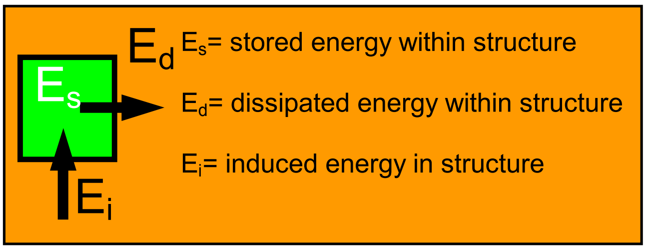


Fig. 4: Concept of energy approach considering the energy exchange between structure and environment

The concept of the energy approach (Fig. 4) 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.

$$E_i \le E_s + E_d$$

$$E_i \le \underbrace{E_e + E_k}_{E_s} + \underbrace{E_h + E_v}_{E_d} = \int -m\ddot{x}_G \, dx$$

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

Fig. 5: Energy balance equation for structures

The energy part E_h (Fig. 5) 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 directly associated with the LRB (see also technical characteristics).
Therefore this E_v increase is realized by the use of specially developed highly efficient LRBs.

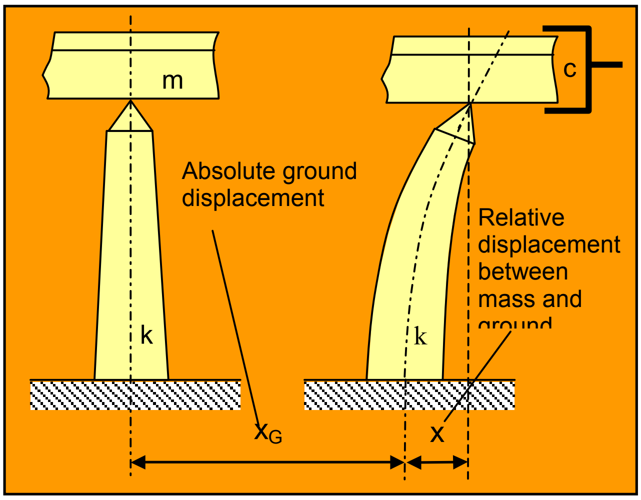


Fig. 6: Complex bridge structure explained with a simplified single ocillating mass

Exemplary and simplified, we´d like to show the earthquake effects on a single oscillating mass (Fig. 6).
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:

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

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

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

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

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

The Way to an optimal Seismic Protection System with LRBs

The especially adapted MAURER seismic protection system (Fig. 7) with LRBs 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.

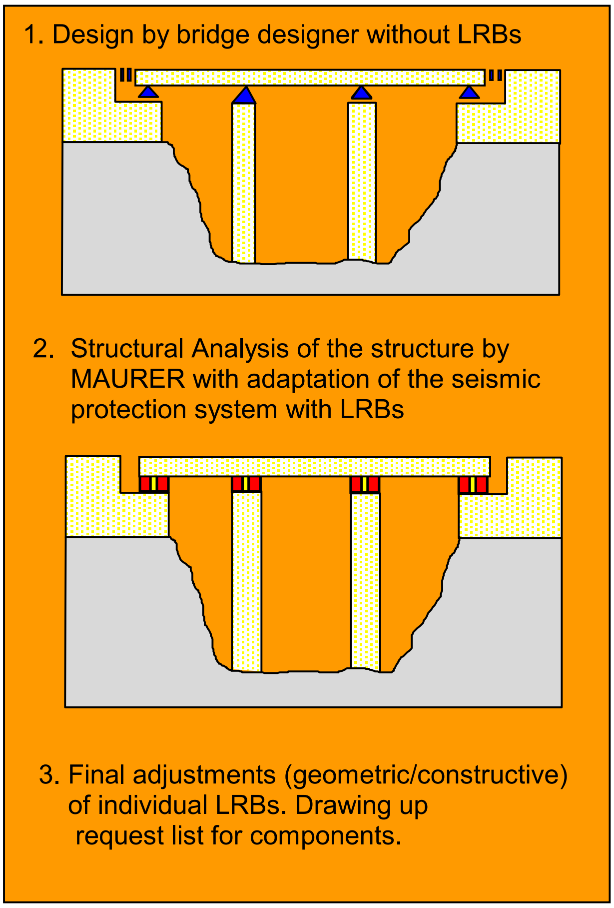
The employed mechanical MAURER components for the seismic protection have been proving successfully in service for many years. Depending on request for the single components the design can be done according to EURO NORM, AASHTO, BRITISH STANDARD, DIN or any other standard.

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 *dynamical structuralanalysis* of the entire structure with the input data of the bridge designer.

By application of the special seismic protection system of MAURER with LRBs, 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. 8) are obvious and satisfy protection and economic requirements.



1. Design by bridge designer without LRBs

2. Structural Analysis of the structure by MAURER with adaptation of the seismic protection system with LRBs

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

Fig. 7: Steps to built up a seismic protection system

Advantages by LRBs application:

- 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.

Fig. 8: Advantages of a MAURER Seismic Protection System with LRBs

The fundamental Functions of MAURER-LRBs

The four fundamental functions of MAURER LRBs are:

1. Transmission of vertical loads (Fig. 9).
2. Allowance of displacements on the horizontal plane (Fig. 10) providing the horizontal flexibility.
3. Dissipation of substantial quantities of energy (Fig. 11).
4. Assurance of self-centring (Fig. 12).

The first function means that the LRB acts as a conventional bearing, i.e. transfers vertical loads in the intended location from the superstructure to the substructure (Fig. 9).

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. 10). The flexibility is provided by the rubber of the LRB.

The dissipation of energy limits relative displacement of the isolated structural mass and provides better structural control with bigger safety for the structure (Fig. 11). The energy dissipation is realized by the rubber and by the inner lead core of the LRB.

The purpose of the self-centring capability requirement – return of the structure to former neutral mid position (Fig. 12) - 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). The recentring effect is based on the natural elasticity of the applied rubber.

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.

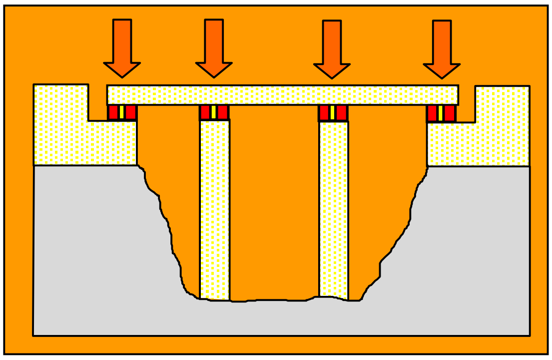


Fig. 9: LRBs for vertical load transmission

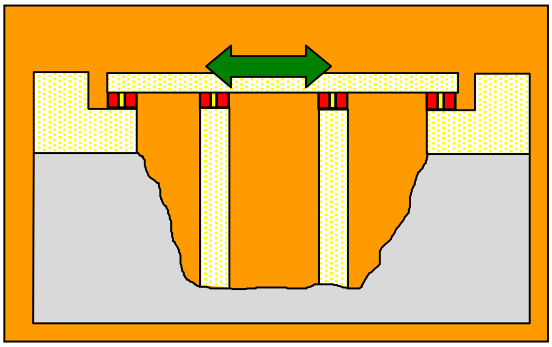


Fig. 10: LRBs for horizontal flexibility

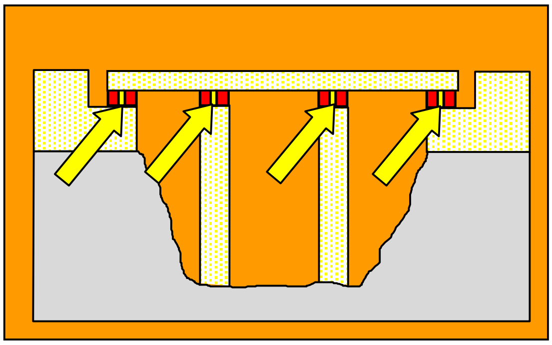


Fig. 11: LRBs for energy dissipation

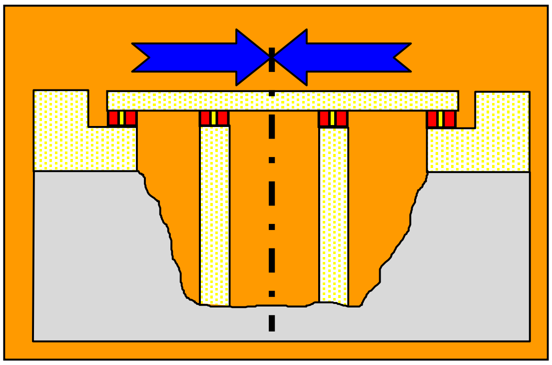


Fig. 12: LRBs for self-centring to the mid position

The Design and Characteristics of MAURER-LRBs

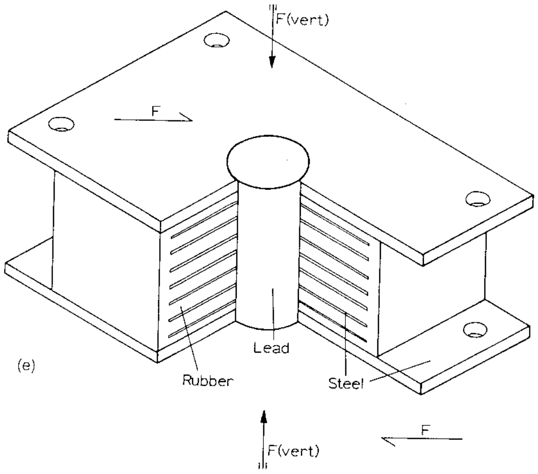


Fig. 12: Principle design of a rectangular LRB

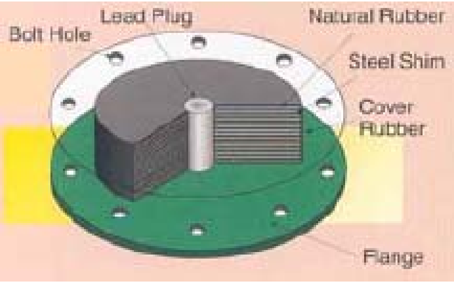


Fig. 13: Principle design of a round LRB

Technical characteristics:

- Dynamical rubber shear modulus: usually 1,1 tom1,2 N/mm², but can be adopted on request.
- Yield stress of applied lead: 18 MPA at 25°C, 10MPA at 75°C, 7MPA at 125°C and 4MPA at 225°C

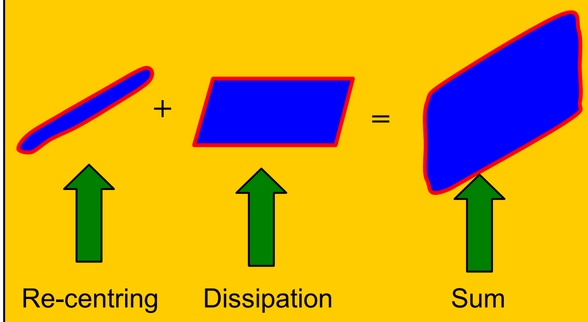


Fig. 14: Hysteretic loops of single function parts of a LRB

LRBs are consisting of a standard elastomeric laminated rubber bearing. The rubber compound can be of natural rubber or chloroprene rubber, while any standard (DIN, EN, SETRA, ASSHTO, BS, etc.) can be considered.

The shape can be either round or rectangular.

The LRBs are generally constructed with low-damping (unfilled) elastomers with shear moduli of 0,8-1,2 N/mm² and lead cores with diameters ranging 15% and 33% of the bonded bearing diameter for round bearings. The surface relation is kept the same for rectangular bearings.

The elastomer provides the isolation and re-centring, while the lead core offers the necessary energy dissipation or damping component.

The maximum shear strain value for LRBs is generally between 125% and 200%.

The inner steel shims do not only grant for good load capacity, but also for a proper confinement of the lead core.

As described in Fig. 14 the yield stress of lead is depending on the temperature. Therefore after one load cycle it can be assumed that the yield stress is 13MPA and after three it is 11MPA.

The MAURER LRBs are also able to transmit ULS-up-lift-forces on request!

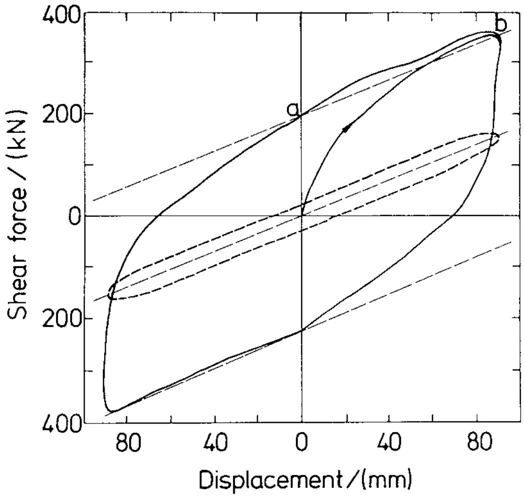


Fig. 15: Hysteretic loop of a LRB

The Design and Characteristics of MAURER-LRBs

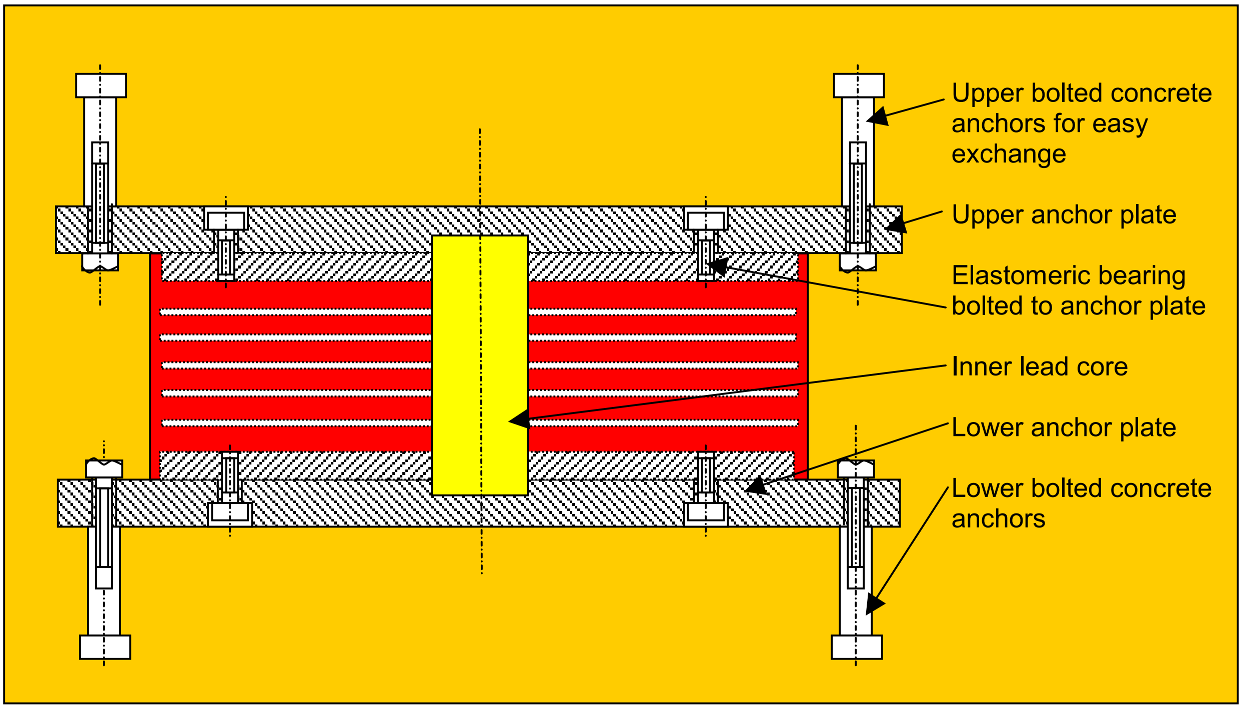


Fig. 16: Principle structure of MAURER LRB

The calculation of a LRB can be carried our like this:

- Bearing rubber surface is depending on vertical load. The maximal admissible stress on LRBs is considered to be 15N/mm².
- Stiffness (K) and characteristic strength (CS):

  => $CS = (P \text{ x } d^2 / 4) \text{ x } s_l$

  With P = 3,14, d = diameter of lead core, s_l = yield stess of lead = 11 Mpa after three cycles

  => $K = G \text{ x } Ar / t$

  With G = shear modulus = 1,1 Mpa, Ar = rubber area,
  t = total rubber thickness, to be selected

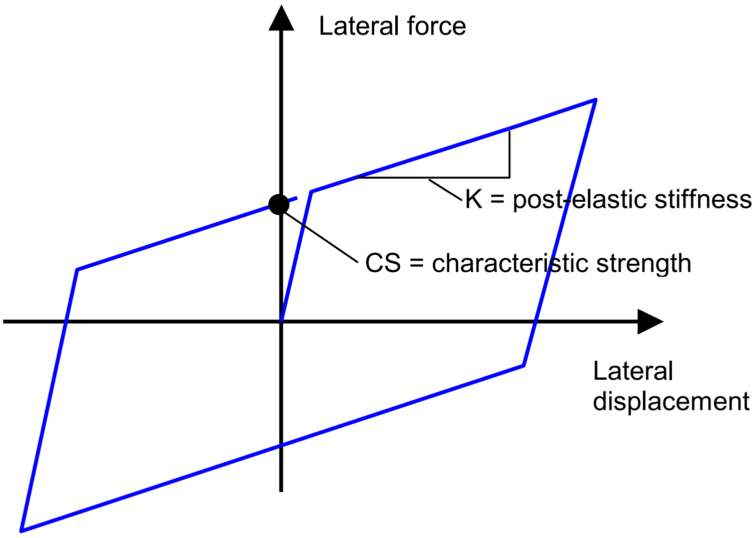


Fig. 17: characteristic value calculation for LRB

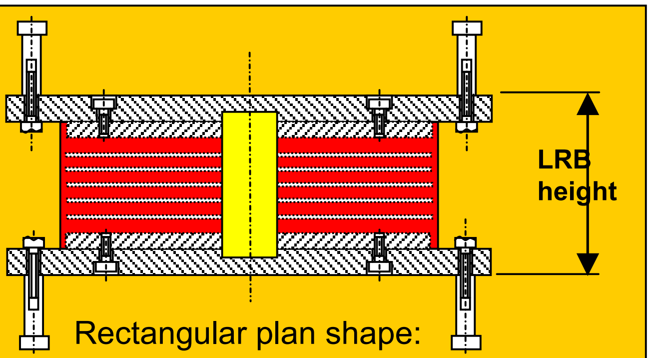
- The response force is resulting in: F = K x d + tPB x Ar
  With tPB = yield strength of lead (~11MPA), d = displacement

- The coefficient of damping can be considered between 15% and 30% depending on the lead core size. Therefore the damping is much higher than with High Damping Rubber Bearings (HDRB) but without having the disadvantages of HDRBs like scragging, load history, strain history, velocity, etc..

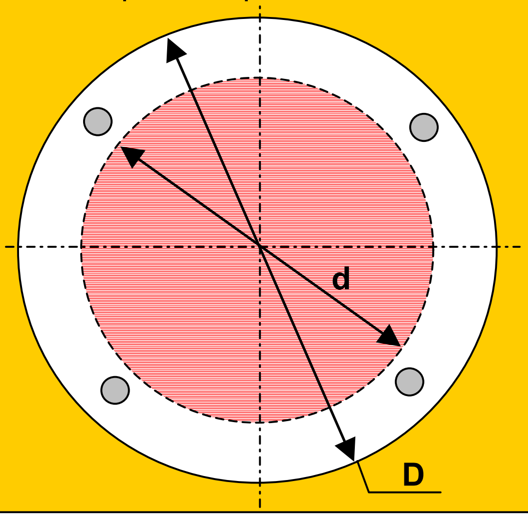
Dimensions of MAURER-LRBs

The Maurer LRBs are available in round and rectangular plan shapes. The size is individually adapted to the request and also the lead core is adopted individually. The below mentioned sizes are just possible sizes, which will be individually adapted on request!

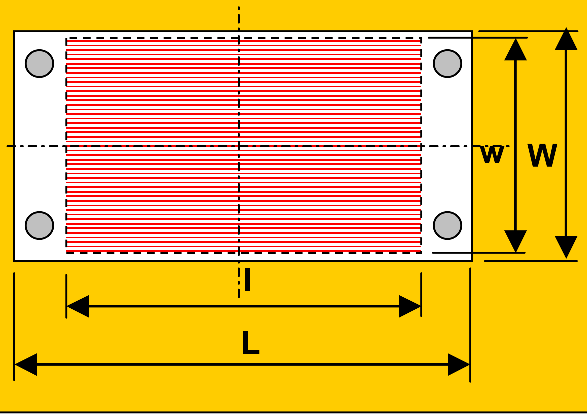
- **Shear modulus: 0,8 to 1,2 N/mm²**
- **Damping: 15% or 30%**
- **Sizes up to 1100 x 1100 x 400 mm, ∅1100 x 400 mm**



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
			min [mm]	max [mm]	min [mm]	max [mm]	min [mm]	max [mm]	layer [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 final maximum vertical load is depending on applied standard and lead core size

** the LRB height value is without anchor stud length, which is normally 180 mm or longer

Fig. 18: Sizes of LRBs