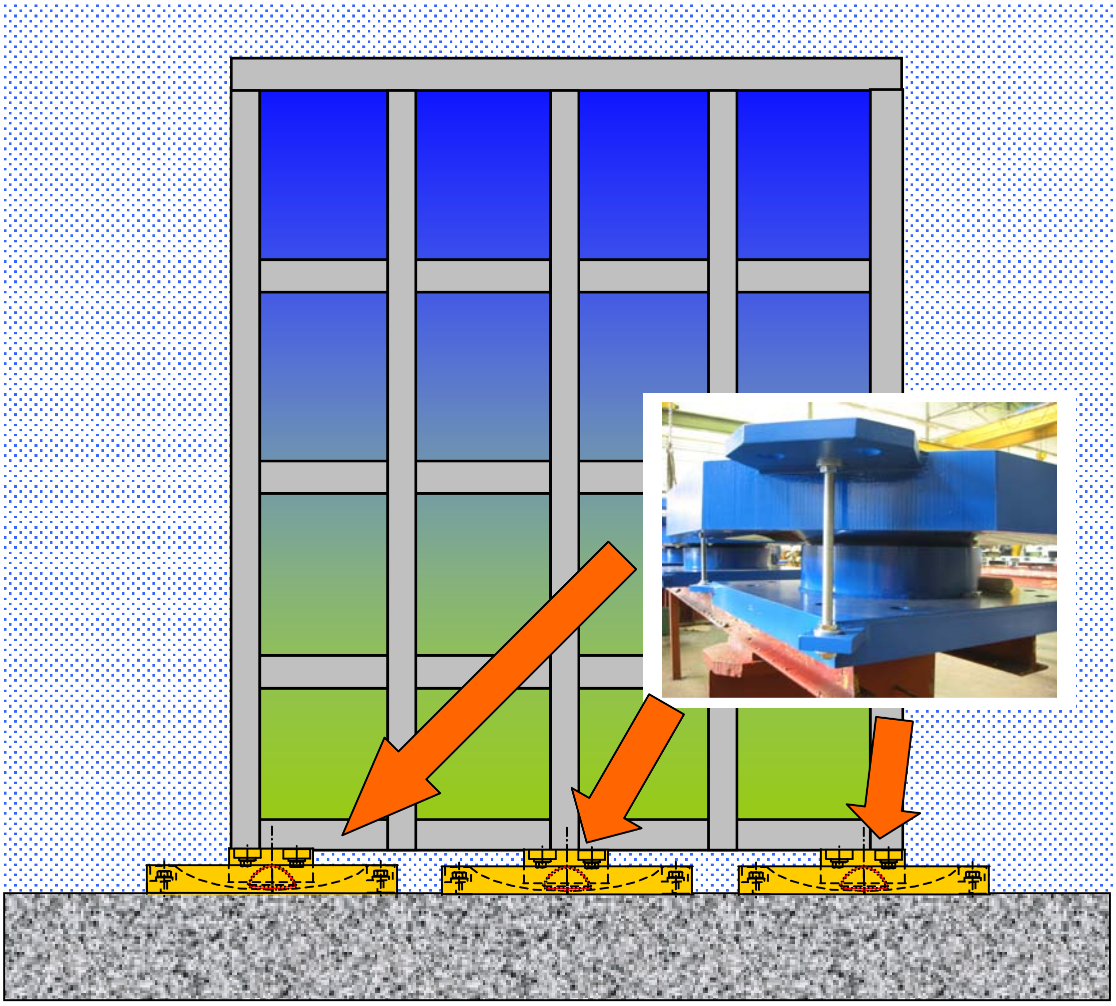
MAURER Premium Seismic Isolation with Spherical Sliding Isolators for Buildings and Tank Structures



Technical Information

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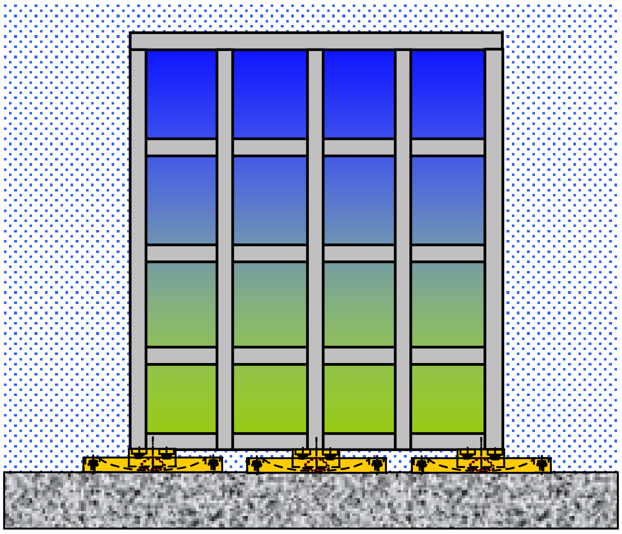

1. General Information about MAURER Spherical Sliding Isolators

The family owned company MAURER SÖHNE, founded in 1876, has been gaining experiences on the design of spherical bearings and isolators for more than 30 years. Within this time different designs, materials for sliding partners and steel types have been tested, developed and are available depending on the request for the individual project. Based on this KNOW-HOW a premium isolation device most suitable for each individual structure, with highest possible quality level, best function characteristics and service life spans up to 100 years is granting for earthquake protection.

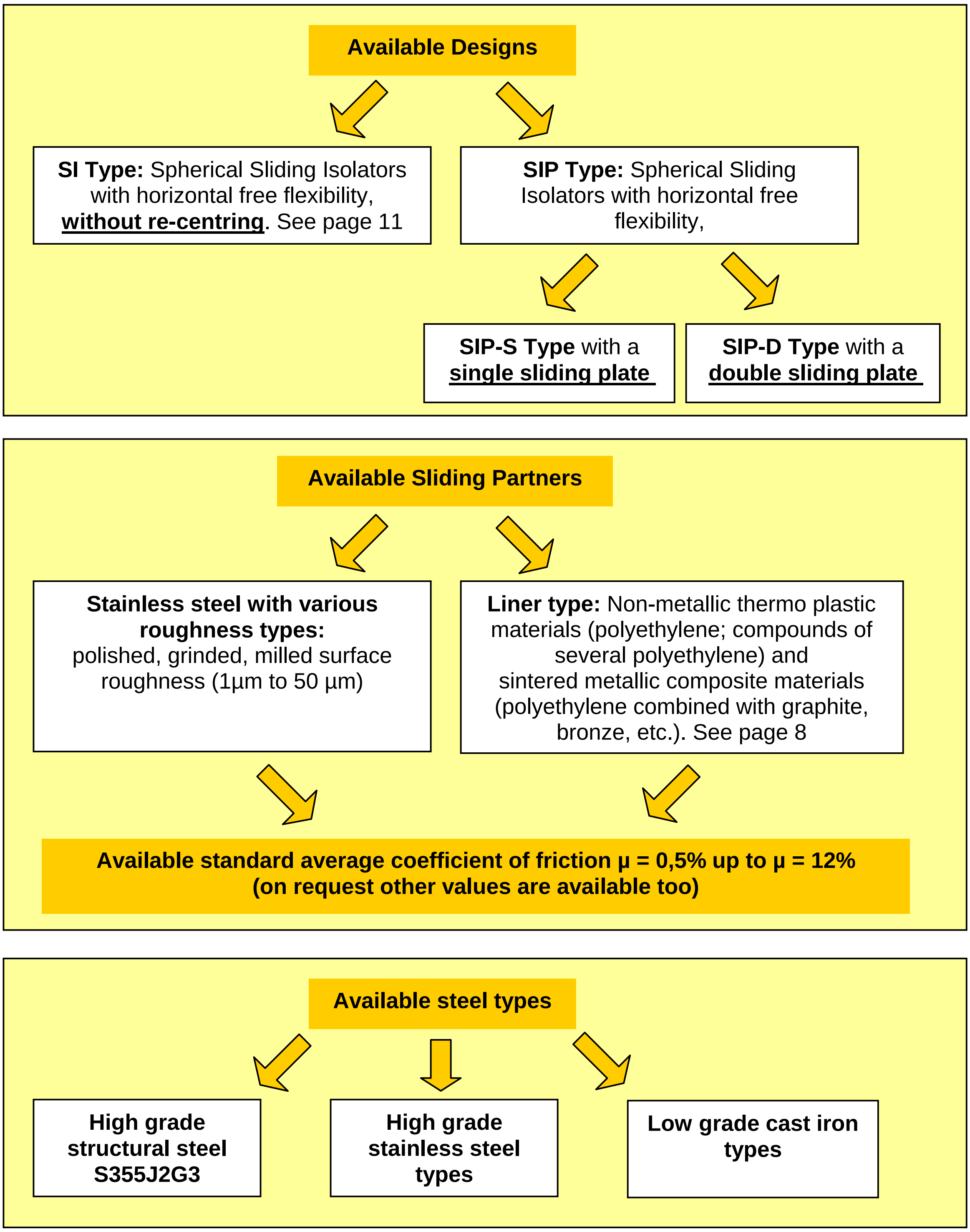

Fig. 1: Designs and materials for spherical isolation devices

The fabrication of all spherical isolators, these are 900 to 1500 isolators per year of sizes between 300 mm to 3000 mm of diameter or even more, is under strict internal quality management and external third party quality supervision (see page 8 for Quality Management).

MAURER spherical sliding isolators are equal in design principle to the so called "friction pendulum bearing".
However MAURER is supplying not just an isolator in a black box, but is providing services like extensive project consulting and detailed isolator design according to existing European Norms, International Standards and a unique German Type Approval for spherical sliding bearings issued by the highest German Authority for Civil Engineering the *Institut für Bautechnik in Berlin*.

A strict quality management consisting of ISO 9001, third party supervision of materials, fabrication and testing is granting for the device quality and long term function as well.

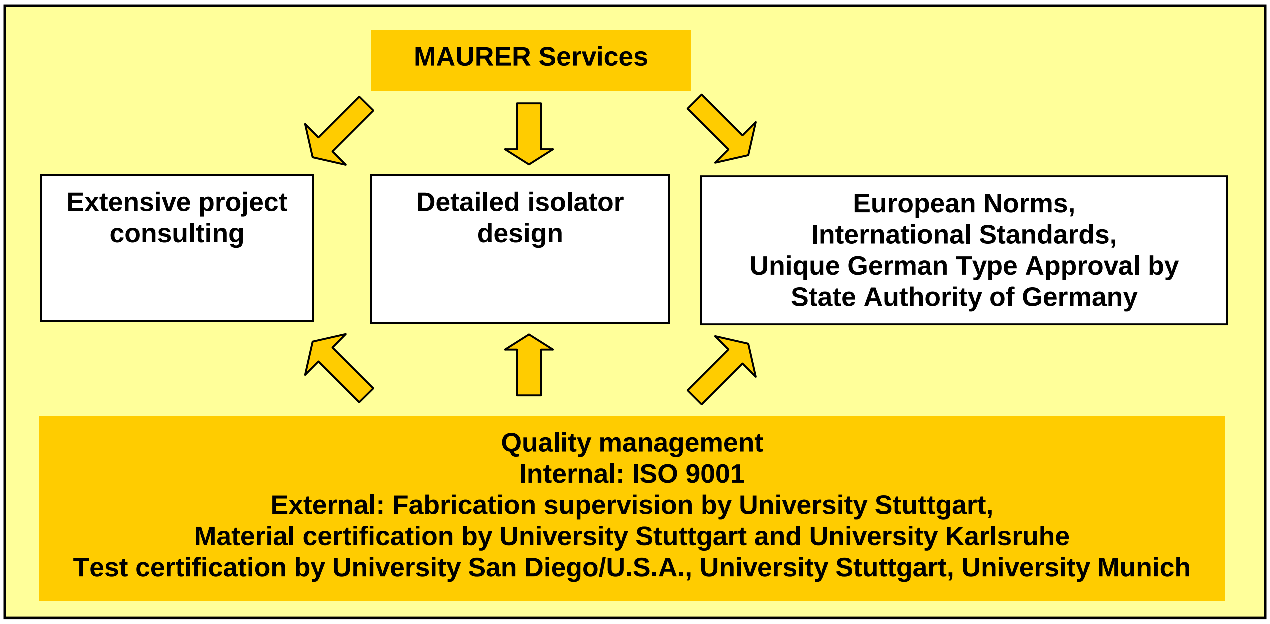

Fig. 2: MAURER Services and linked high grade quality management system

2. Principles of seismic isolation with spherical sliding isolators

In practice, the principle of Seismic Isolation is that of shifting the fundamental period of a building by the installation of spherical sliding isolators with a low horizontal stiffness between foundation and building (Fig. 3). The aim is to **mitigate** the seismic input not even to let the seismic energy enter the building or the tank structure.

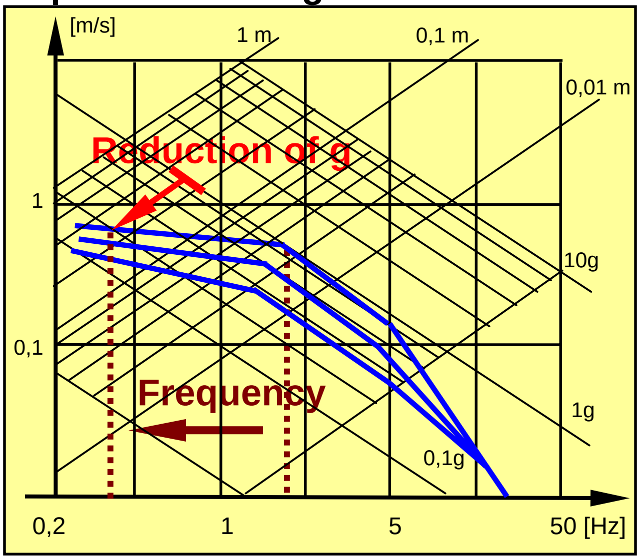

Fig. 3: Response spectrum for a building

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 or plastic deformations. 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.

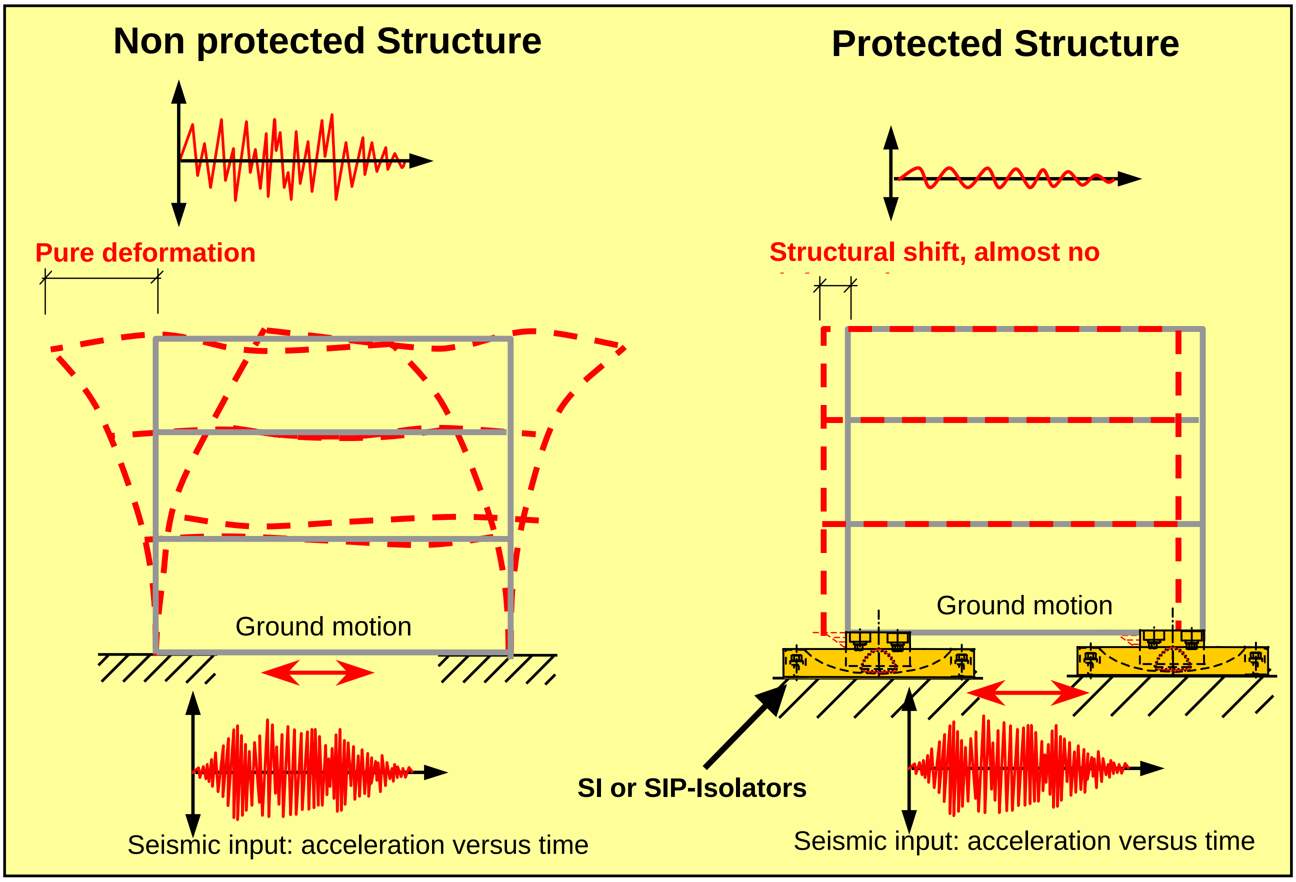

Fig. 4: Displacements and deformations of a non-protected and of an protected structure

The seismic isolation system with SI or SIP devices provides three or four fundamental functions respectively, as the isolators are placed between the building structure and the ground:

1. Transmission of vertical loads (Fig. 5) through the single columns onto the building base plate.
2. Allowance of displacements in the horizontal plane (Fig. 6) between the building and the base plate.
3. Dissipation of requested amounts of energy (Fig. 7) while the isolators are sliding within the sliding couple with a defined value of friction.
4. Assurance of self-centring (Fig. 6).

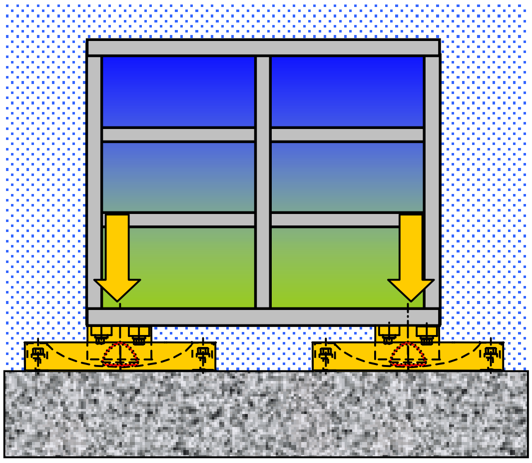
Fig. 5: Vertical load transmission by SIs and SIPs

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). As most of the building live span are without seismic attack, the seismic isolation system has to be carefully checked, that it is working during normal service properly (rotation, displacement, load transmission, life time, etc.) and that applied building codes and standards like EN (European Norm) or others are considered!

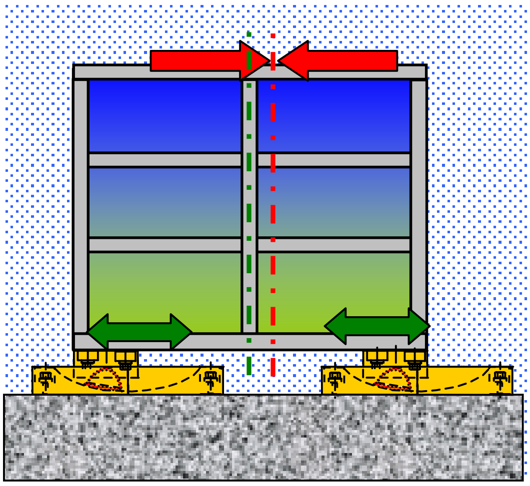
Fig. 6: Horizontal displacements by SI and SIP; self-centring by SIP only

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 massive ground shaking during an earthquake is not entering by 100% into the building as the momentum of inertia is ensuring that the building is de-coupled from the ground.

The third function of energy dissipation accommodates seismic energy within the device and controls the maximum seismic displacements.

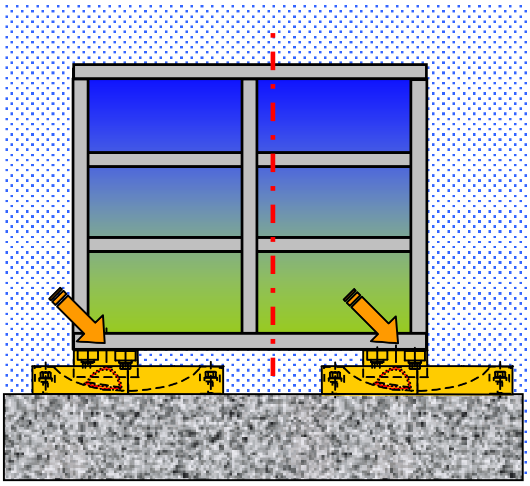
Fig. 7: Dissipation of requested energy amount within due to sliding friction of the sliding couple by SI and SIP

The fourth function is the assurance of self-centring (Fig. 6) due to the automatic storage of kinetic energy, which is released as potential energy again. Therefore the building systems will always return towards the centre position during and after an earthquake and any accumulated displacements are avoided at.
The re-centring is just provided by the SIP type, but not by the SI type, which needs additional re-centring devices like elastomeric bearings or self-centring dampers.

3. MAURER Spherical Sliding Isolators

3.1 Function principle and general types

Only existing standards like European Norms (EN1337), International Standards and the German Type Approval for spherical bearings with MSM® (Z-16.4-436) shall be applied, means the MAURER-Design is based mainly on the existing Type Approval, which is issued by the State Institute of Civil Engineering in Berlin/Germany. The bearing properties and the details shall meet with this existing standards, which can be checked by the client.

Spherical sliding isolators are consisting of three main steel parts with inner sliding surfaces. The shape of the internal part is always spherical and allowing rotations and horizontal sliding displacements as well. The device is transmitting the vertical loads and is providing free horizontal flexibility, while dissipating energy.

To provide more equivalent viscous damping than 25% within each device, while not effecting the isolation system or to increase the friction too much, we recommend to install additional viscous dampers.

In general <u>three types of spherical sliding isolators</u> are available.

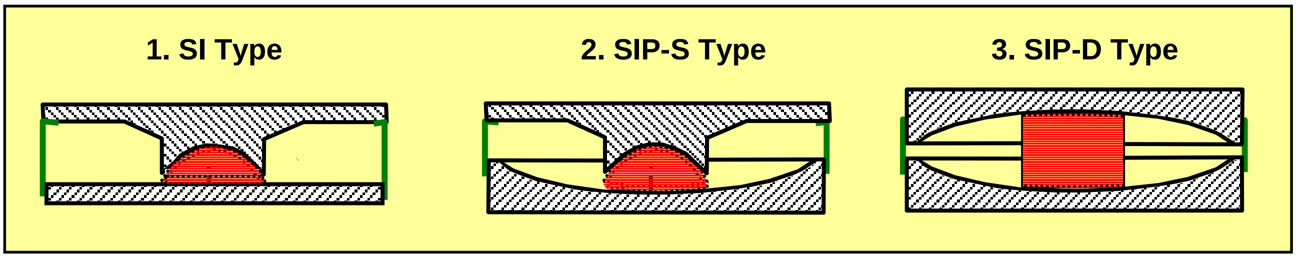

Fig. 8: Spherical isolator types

1. **SI Type:** Vertical load transmission, horizontal flexibility, energy dissipation by friction, **<u>no re-centring</u>** capability, **<u>single sliding plane</u>**.

2. **SIP-S Type:** Vertical load transmission, horizontal flexibility, energy dissipation by friction, **<u>with re-centring</u>** capability, **<u>single sliding plane</u>**.

3. **SIP-D Type:** Vertical load transmission horizontal flexibility, energy dissipation by friction, **<u>with re-centring</u>** capability, **<u>double sliding plane</u>**

While the bearing is moving due to relative displacements between the ground and the building during an earthquake, the friction between the sliding partners creates energy dissipation.
The structural control is provided by a well defined coefficient of friction between the special sliding partners (liner and stainless steel => μ = 0,005 to 0,13 for the individual bearing), which grants for the transformation of displacement energy into heat energy. In Fig. 9 the principle hysteretic loops of the SI and SIP-S/D type are shown.

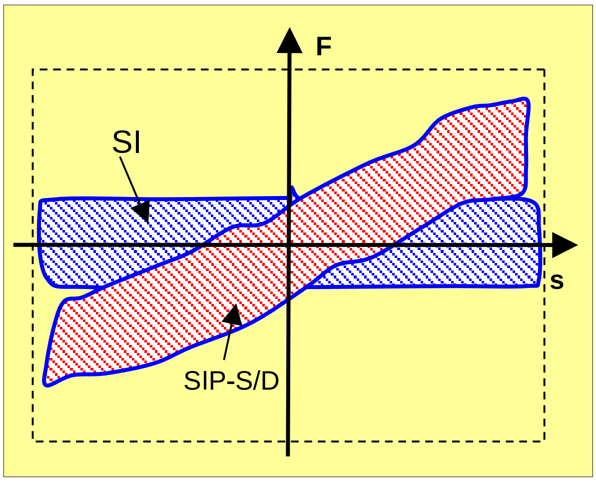

Fig. 9: Force [F] – Displacement [d] - Plot for a SI and a SIP-S/D isolator

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Innovations in steel
Since 1876

3.2 Applied materials with different coefficients of friction

To fulfil individual requirements for each structure, MAURER is providing three different standard sliding materials of the non-metallic MSM® (**M**AURER **S**liding **M**aterial) family with an average friction range of 0,5% to 9%.
On request other friction values with other liner materials (compounds, composites with graphite, bronze or similar) are provided.

The standard sliding materials are,

- **MSM®-0,5**: average friction at the design stress and room temperature is **0,5%**. Breakaway friction is maximum 4%.
- **MSM®-5**: Average friction at the design stress and room temperature is **5%**. Breakaway friction is maximum 9%.
- **MSM®-9**: Average friction at the design stress and room temperature is **9%**. Breakaway friction is maximum 11%.

Yield stress of MSM® type materials is 200 N/mm².

The mentioned friction values are based on the design stress onto the liner material, which is acting most of the time during an earthquake.

It has to be ensured that the breakaway friction is not higher than 11%, even after long standstill periods. MSM® is granting for these values.

The damping of the Isolators is adapted depending on request. Low damping devices provide less than 5% damping. High damping isolators have got approximately up to 35% equivalent viscous damping. The maximum friction coefficients of the applied sliding materials have to be checked to be always conform to existing standards.

The friction values to be confirmed and the fabrication has to be under supervision
by a **four step quality management** supported by independent third parties:

1) **Internal quality management** according to ISO9001 and according to the German Type Approval System, approved by State Institute for Civil Engineering in Berlin/Germany. For all bearings inspection cards and material test certificates have to be provided.
2) **Prototype testing** of 3% of all bearings or at least four full size bearings, by an independent specialized third party test institute, like the University of California San Diego/U.S.A. with the CALTRANS test rig. This test shows together with a detailed specified test procedure, the function characteristic under various load conditions. Therefore see also the provided detailed specification for the SIP devices. A detailed test report has to be provided by the third party.
3) **Production testing** of all bearing liners by an independent specialized third party test institute, like the University of Stuttgart officially authorized by State Institute for Civil Engineering in Berlin/Germany. A detailed test report has to be provided by the third party.
4) **Fabrication supervision** of all bearings by an independent specialized third party test institute, like the University of Stuttgart officially authorized by State Institute for Civil Engineering in Berlin/Germany. A detailed test report has to be provided by the third party.

The quality management and the design shall not be just an internal standard procedure of the supplier, it has to be based on standards (EN, etc.) and justified by official third party supervision.

3.3 Modelling

The MAURER spherical sliding isolators are modelled according to the below equations.

- Hysteretic loop

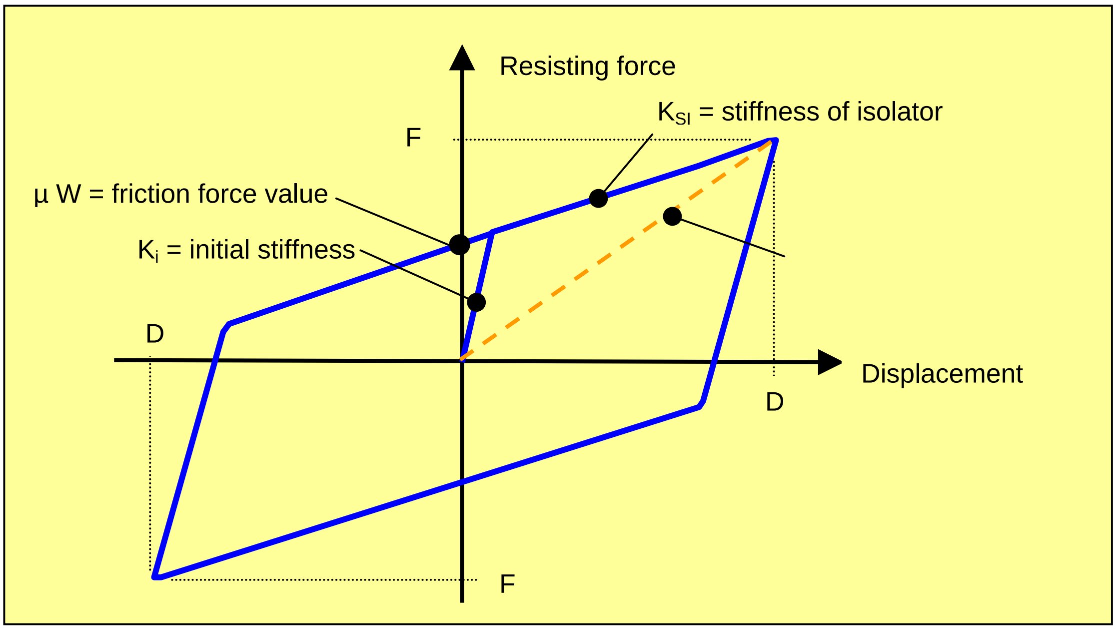


Fig. 10: Characteristic hysteretic loop of a spherical sliding isolator

- Sketch of isolator with acting forces

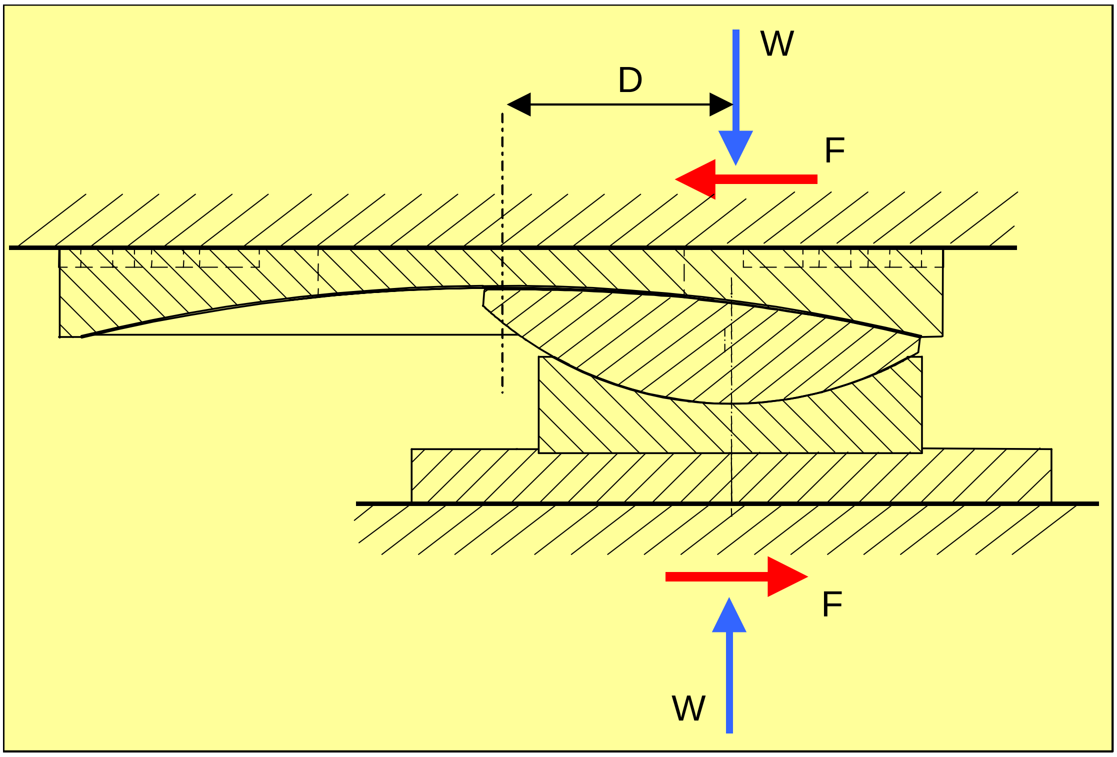


Fig. 11: Principle sketch of a spherical sliding isolator of SIP-S type

- Horizontal resisting force = $F = \frac{W}{R} \cdot D + \mu \cdot W \cdot (\operatorname{sgn} \dot{D})$

  with W = vertical load, μ = dynamic friction coefficient
  D = horizontal displacement, $\dot{D}$ = horizontal displacement velocity,
  R = radius of curvature

- Horizontal stiffness due to rise of mass = $K_H = \frac{W}{R}$

- Period of the bearing = $T = 2 \cdot \pi \cdot \sqrt{R/g}$, independent from the carried mass

- Equivalent (peak-to-peak) stiffness = $K_{eff} = \frac{W}{R} + \frac{\mu \cdot W}{D}$

- Effective period = $T_{eff} = 2 \cdot \pi \cdot \sqrt{\frac{W}{K_{eff} \cdot g}}$, independent from the carried mass

- Damping produced by friction between the sliding partners (stainless steel against MSM®) can be estimated by the code formula

$$\beta_{eff} = \frac{area\ of\ \ hysteresis\ loop}{4 \cdot \pi \cdot K_{eff} \cdot D^2}$$

  with the area of the hysteretic loop = $4\mu WD$, thus

$$\beta_{eff} = \frac{2}{\pi} \cdot \frac{\mu}{D/R + \mu}$$

  while this ranges from $2/\pi$ for small D to $2\mu/(\pi RD)$ as D increases.

- Radius relation to period => $R = \frac{gT^2}{(2\pi)} \approx 0.25T^2$

- Upward displacement δ_V depending on displacement = $\delta_V = R\left[1 - \cos\left(\arcsin \frac{D}{R}\right)\right]$

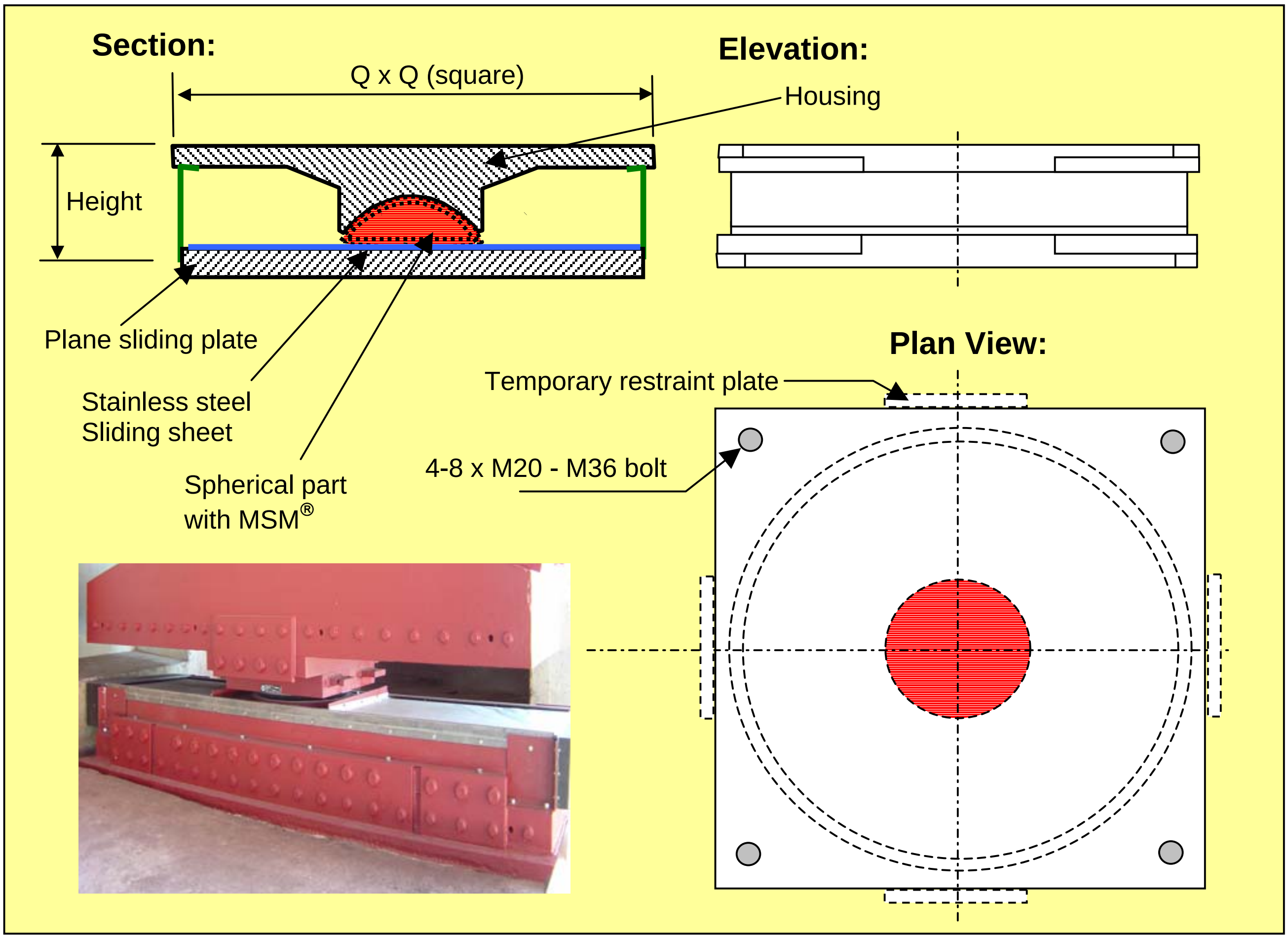
  Approximate value = $\delta_V = \frac{1}{2}\frac{D}{R^2}$

- Re-centring criteria: $D/R > \mu$ must be fulfilled

- Values for the radius R: 1000 mm, 1500 mm, 2200 mm, 3000 mm, 4000 mm, 6200 mm. Other intermediate radii are possible on request.

3.4 SI Type

The Sliding Isolator (SI Type) is consisting of a plane lower sliding plate with a stainless steel sheet on top. Against this the liner material MSM® is sliding. The MSM® is fixed by a special recess construction to the spherical part. On demand the upper side of the spherical part is hard chromium plated and is again sliding against MSM® material, which is fixed to the housing part. The bearing can also be installed up-side-down, this is depending on the load transmission capabilities of the super- and substructure. For dust protection an elastic rubber apron is fixed to the upper part and protecting the sliding surface from major dust.



Vertical load* (MN)	Horizontal displacements*** d [mm]	Dimension Q of SI based on 5% friction [mm]	Height of SI **
0,5	+/-350	944	90
1,0	+/-350	979	110
3,0	+/-350	1066	120
5,0	+/-350	1126	125
7,0	+/-350	1175	125
11,0	+/-350	1254	135
15,0	+/-350	1321	155
25,0	+/-350	1455	185
30,0	+/-350	1511	200
35,0	+/-350	1564	220
40,0	+/-350	1612	250

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

Fig. 12: Sizes of spherical steel isolators, any other intermediate sizes are possible

3.5 SIP-S Type with a single concave sliding plate

The Sliding Isolation Pendulum (SIP-S Type) is consisting of a **single** concave lower sliding plate with a stainless steel sheet on the surface. Against this the liner material MSM® is sliding. The MSM® is fixed by a special recess construction to the spherical part. On demand the upper side of the spherical part is hard chromium plated and is again sliding against MSM® material, which is fixed to the housing part.
Compared to the SI Type the SIP-S Type provides re-centring capability. The purpose of the self-centring capability requirement – return of the structure to former neutral mid position (Fig. 3) - 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 is very important to keep the structure in position during any possible load case to avoid uncontrolled shifting in one certain direction.

The bearing can also be installed up-side-down. This is depending on the load transmission capabilities of the super- and substructure. For dust protection an elastic rubber apron is fixed to the upper part and protecting the sliding surface from major dust.

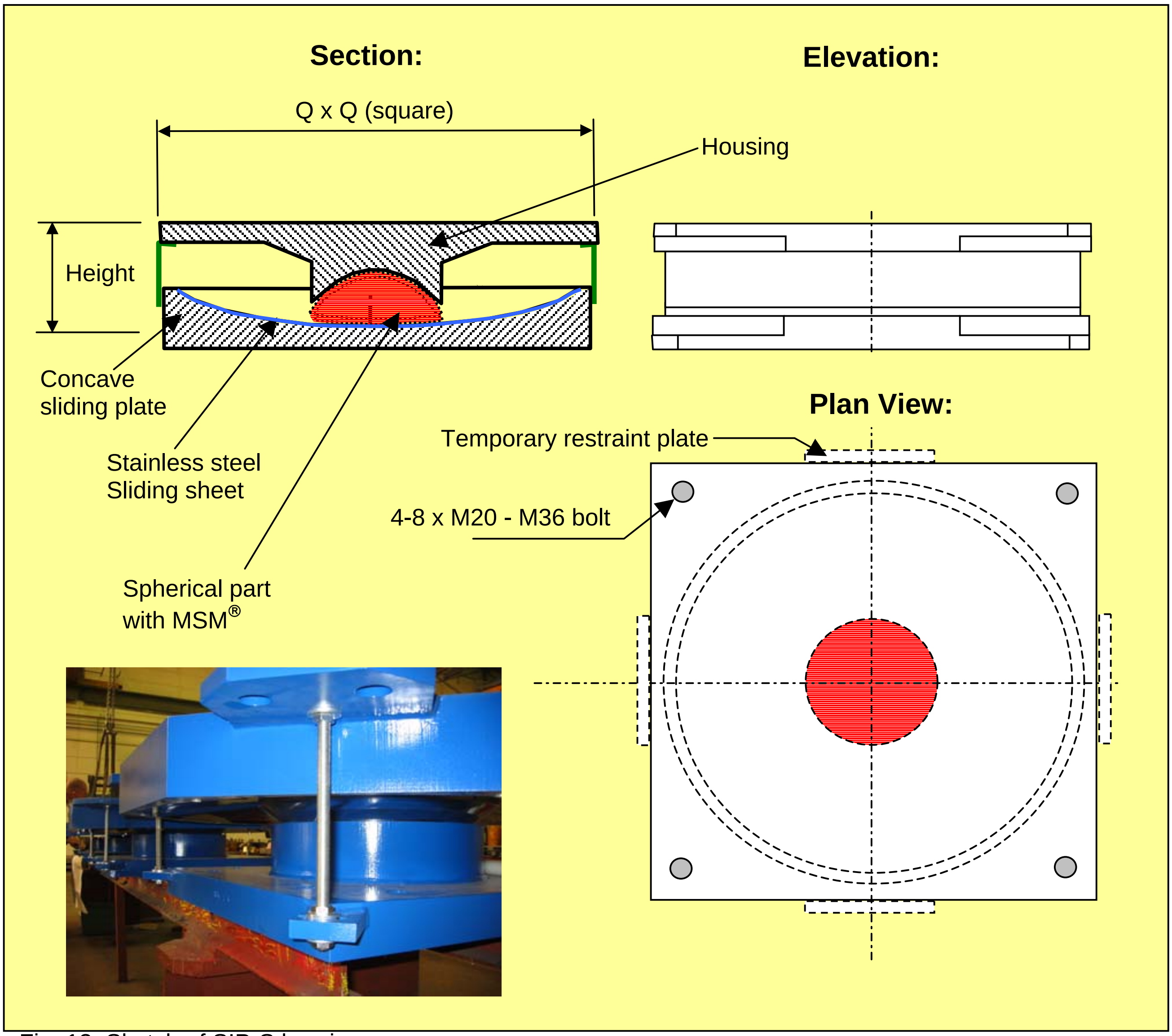


Fig. 13: Sketch of SIP-S bearing

Vertical load* (MN)	Horizontal displacements*** d [mm]	Dimension Q of SIP-S based on 5% friction [mm]	Height of SIP-S ** [mm]
0,5	+/-350	944	194
1,0	+/-350	979	216
3,0	+/-350	1066	273
5,0	+/-350	1126	312
7,0	+/-350	1175	364
11,0	+/-350	1254	455
15,0	+/-350	1321	498
25,0	+/-350	1455	586
30,0	+/-350	1511	622
35,0	+/-350	1564	656
40,0	+/-350	1612	688

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

Fig. 14: Sizes of spherical steel isolators, any other intermediate sizes are possible

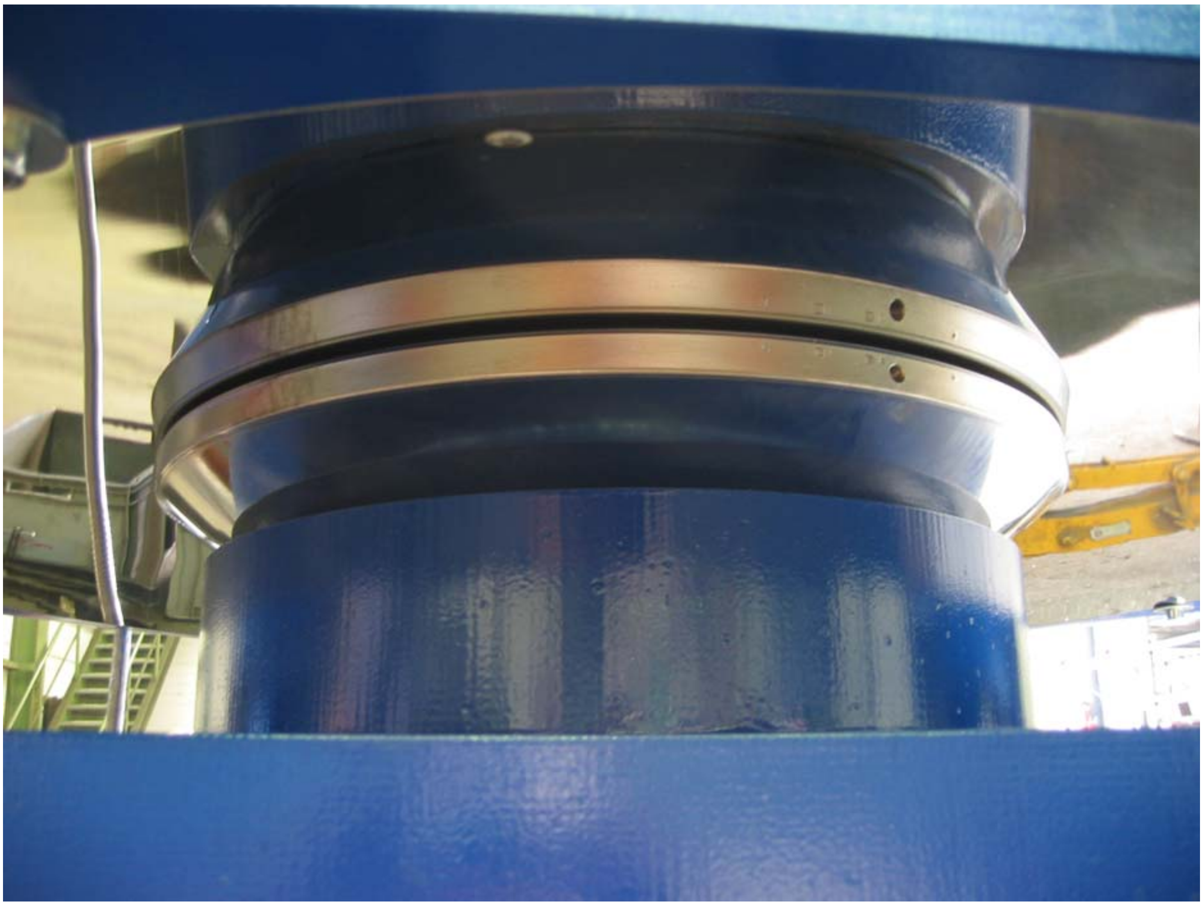


Fig. 15: Perfectly shaped stainless steel concave surface of a SIP-S Type with eveness tolerances of up to +/-1mm

3.6 SIP-D Type with a double concave sliding plate

The Sliding Isolation Pendulum (SIP-D Type) is consisting of a **double** concave lower and upper sliding plate with a stainless steel sheet on the surface. Against these two sliding plates the spherical centre part with the liner material MSM® is sliding. The MSM® is fixed by a special recess construction to the spherical centre part.
Compared to the SIP-S Type the SIP-D Type allows to slide on top and bottom, means to distribute simultaneously the displacement to the upper and lower sliding surface. Therefore the bearing size can be reduced and especially starting from approx. +/-600 mm displacement capacity this solution is more economical compared to the SIP-S type.
The function principle is the same compared to the SIP-S.

The bearing can also be installed up-side-down, this is depending on the load transmission capabilities of the super- and substructure. For dust protection an elastic rubber apron is fixed to the upper part and protecting the sliding surface from major dust.

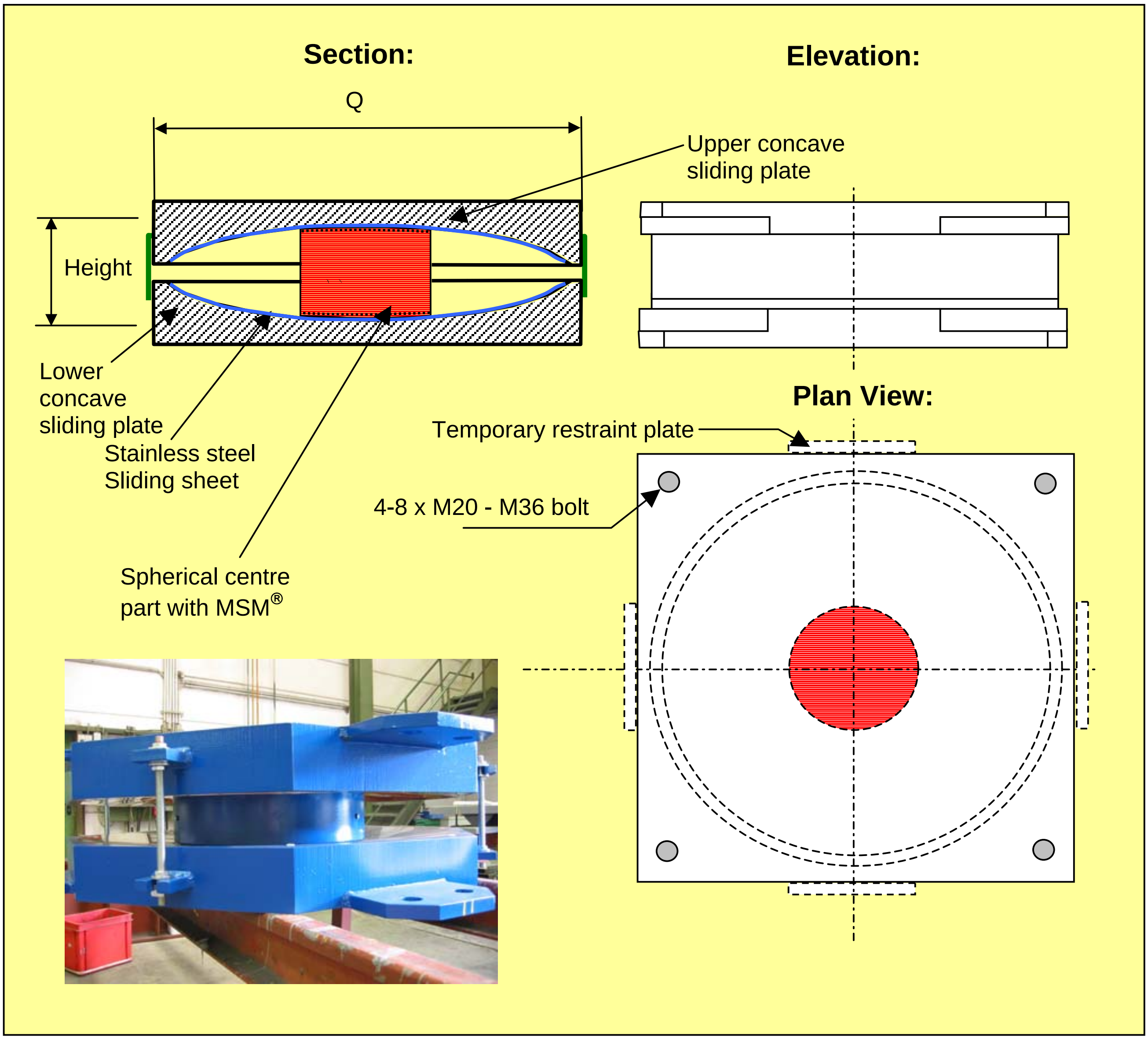


Fig. 16: Sketch of SIP-D bearing

Vertical load* (MN)	Horizontal displacements*** d [mm]	Dimension Q of SIP-D based on 5% friction [mm]	Height of SIP-D ** [mm]
0,5	+/-350	944	184
1,0	+/-350	979	206
3,0	+/-350	1066	263
5,0	+/-350	1126	302
7,0	+/-350	1175	344
11,0	+/-350	1254	435
15,0	+/-350	1321	478
25,0	+/-350	1455	566
30,0	+/-350	1511	602
35,0	+/-350	1564	626
40,0	+/-350	1612	658

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

Fig. 17: Sizes of spherical steel isolators, any other intermediate sizes are possible

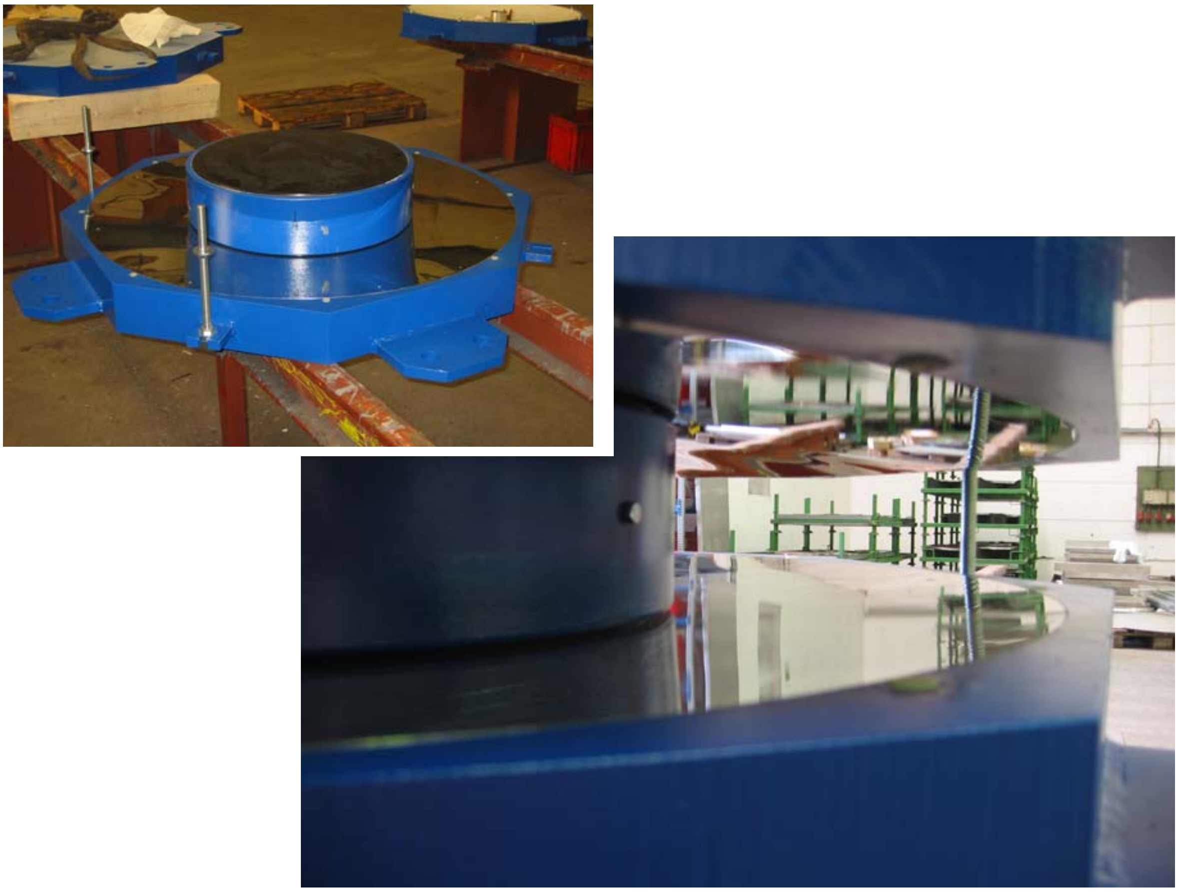


Fig. 18: Assembly of a SIP-D Type devices with perfect concave stainless steel sliding surfaces

4. Services provided by MAURER

- Qualified support based on more than 25 years of experience on the field of seismic engineering. Linear and non-linear analysis for design of structures.

- Premium quality management by internal supervision system and external third party testing and fabrication supervision.

- Permanent quick support during and after order phase by our local representatives and direct by the headquaters in Munich.

- Easy and quick delivery from Munich (=> all isolators are manufactured in Munich/Germany), means the delivery times are shortest possible. Depending on order situation, number and size of devices, the delivery period can start from 9 weeks after firm order.