MAURER Seismic Isolation with Sliding Isolation Devices for Bridge Structures

Technical Information
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MAURER Seismic Isolation with Sliding Isolation Devices for Bridge Structures

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1. General Information about MAURER Sliding Isolation Devices

The family owned company MAURER SÖHNE, founded in 1876, has been gaining experiences on the design of spherical sliding bearings and isolators for more than 35 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 the type of the spherical isolation device is most suitable for many individual structures, with highest possible quality level, best function characteristics and service life spans up to 100 years and longer is granting for absolute earthquake protection.

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**Available Designs**

- **SI Type:** Spherical Sliding Isolators with horizontal free flexibility, **without re-centring.** See page 11
- **SIP Type:** Spherical Sliding Isolators with horizontal free flexibility, **with re-centring.** See page 12-15

- **SIP S Type** with a single sliding plate
- **SIP DR Type** with a double sliding plate

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**Available Sliding Partners**

- **Stainless steel with various roughness types:** polished, grinded, milled surface roughness (1µm to 50 µm)
- **Liner type:** Non-metallic elasto-plastic materials (polyethylene; compounds of several polyethylenes) and sintered metallic composite materials (polyethylene combined with graphite, bronze, etc.).

**Available standard average coefficient of friction µ = 0,5% up to µ = 7%**
(on request other values are available too)

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**Available steel types**

- **High grade structural steel S355J2G3**
- **High grade stainless steel types**
- **Low grade cast iron types**

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Fig. 1: Designs and materials for spherical isolation devices
The fabrication of all spherical sliding isolators, these are 4500-6500 nos. isolators per year of sizes between 300 mm to 4000 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 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 an unique German Type Approval and European Technical Approval for spherical sliding bearings issued by the highest German Authority for Civil Engineering the Institut für Bautechnik in Berlin and the European Organisation for Technical Approvals (EOTA).

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

![Diagram](image)

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

The devices are manufactured in Munich/Germany and are on demand conform to EN1337 and EN15129!
2. Principles of seismic Isolation with spherical Sliding isolators

Isolation and dissipation result in decreasing the energy induced into the system and the transformation from energy to heat. This is also designated as "energy approach", which especially takes into account the energy character of an earthquake. Applying this systems means prevention of cost-intensive structural stiffening and attainment of maximum level of protection for persons and structure.

Two rules are applied at the same time:

1. Seismic isolation:
The superstructure is separated from the subsoil by the spherical isolators. This method, also called seismic isolation, automatically limits the energy entering the structure and reduces the same considerably. As a result the natural structural period (periodical displacement) is increased, which grants for a considerable reduction of the structural acceleration during an earthquake (fig. 3). Depending on the installed type of isolators, they do not only guarantee for the vertical load transmission, but also for the re-centring capability during and after an earthquake. Re-centring means, that the superstructure, which has been displaced from neutral position during the earthquake, is automatically pushed back to its centre position. Thus accumulated structural displacements in a certain direction are prevented!

2. Energy dissipation:
By means of passive energy dissipation (transformation of movement energy into heat) the remaining energy, which effects the structure through to isolators, is effectively dissipated by additional damping, which can be achieved within the isolators themselves. The already dissipated energy does not effect the structure anymore (fig. 4 & 5). By this additional damping the maximum displacements of the deck structure are effectively reduced.

This method for energy mitigation, which combines seismic isolation with energy dissipation, is the best possible seismic protection.

Following summarized demands on seismic isolation have to be applied:
● Vertical load transmission,
● free movement in all horizontal directions,
● damping of structural vibrations, and
● re-centring to mid position.

Fig. 3: Characteristic response spectrum

Fig. 4: Possible arrangement of isolators and dampers in a bridge

Fig. 5: System of isolators dampers
3. MAURER Sliding Isolation Devices

3.1 Function principle and general types

For the design of pendulum isolators existing standards like European Norms (EN1337), International Standards and the European Technical Approval ETA-06/0131 for spherical bearings with MSM® are applied, i.e. the MAURER-Design is based on existing valid EN standards approved by the State Institute of Civil Engineering in Berlin/Germany and the European Organisation for Technical Approvals (EOTA). The bearing properties and the details shall meet with this existing standards, which can be checked by the client.

The sliding isolation devices 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. This measure may only be considered in areas for severe seismic impacts with peak ground accelerations greater than 0.6g. Usually the friction is kept low as possible for bridge applications (1-1,5%) and any additionally necessary damping could be provided by hydraulic dampers.

In general three types of sliding isolation devices are available.

1. **SI Type:** Sliding Isolator for vertical load transmission, horizontal flexibility, energy dissipation by friction, **no re-centring** capability, **single sliding plane**.

2. **SIP S Type:** Sliding Isolation Pendulum for vertical load transmission, horizontal flexibility, energy dissipation by friction, **with re-centring** capability and **single sliding plane**.

3. **SIP DR Type:** Sliding Isolation Pendulum for vertical load transmission horizontal flexibility, energy dissipation by friction, **with re-centring** capability and **double sliding plane with or without hinge**

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Fig. 6: Spherical isolator types
While the bearing is moving due to relative displacements between the ground and the bridge deck during an earthquake, the friction between the sliding partners creates energy dissipation. For bridges usually this friction is chosen to be as small as possible to be within the international standards of bearing friction, which is usually a maximum admissible value of 0.03 at –35°C. The structural control with damping can be either provided by a well defined coefficient of friction between the special sliding partners (liner and stainless steel => \( \mu = 0.005 \) to 0.07 for the individual bearing), which grants for the transformation of displacement energy into heat energy. In Fig. 7 the principle hysteretic loops of the SI and SIP-S/D type are shown.

**3.2 Applied materials with different coefficients of friction**

To fulfill individual requirements for each structure, MAURER is providing three different standard friction values for the MSM\(^{®} \) (MAURER Sliding Material) family. On request other friction values with other liner materials (compounds, composites with graphite, bronze or similar) are provided.

The standard dynamic sliding friction values are,

- **MSM\(^{®} \)- 1**: Average dynamic sliding friction at the design stress and room temperature is 1\%. The static sliding friction for velocities less than 0.1mm/s is 2\% at –35°C and for design load.

- **MSM\(^{®} \)- 4**: Average dynamic sliding friction at the design stress and room temperature is 4\%. The static sliding friction for velocities less than 0.1mm/s is 7\% at –35°C and for design load.

- **MSM\(^{®} \)- 6**: Average dynamic sliding friction at the design stress and room temperature is 6\%. The static sliding friction for velocities less than 0.1mm/s is 10\% at –35°C and for design load.

The yield stress of MSM\(^{®} \) type materials and permanent loading is greater than 180 N/mm\(^2\).

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

The applied MSM\(^{®} \) sliding material was tested already for 50,000m accumulated sliding path without showing any wear effects. The full scale dynamic testing of prototypes showed even after ten earthquakes no damages to the bearing. The MSM\(^{®} \) has got an ETA06/0131 with possibility for CE marking!

It has to be ensured that the breakaway friction is not higher than 11-12\% for design load cases, 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 and have very low friction values of 0.5-1%. High damping isolators have got approximately up to 25% equivalent viscous damping and high friction of 5-7%. The maximum friction coefficients of the applied sliding materials have to be checked to be always conform to existing standards and if the isolator is re-centring properly.

The friction values and the function can be confirmed and the fabrication can be under supervision on request 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. Check of data of the devices compared to the values in the European Technical Approval (ETA) for spherical MAURER bearings with special sliding material.

2) **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. Full scale production testing at University of Armed Forces in Munich/Germany or at the University Bochum may be performed in addition on request by the client.

3) **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 on request of the client. A detailed test report can be provided by the third party.

4) **Prototype testing** of a certain number of bearings specified by the client, by an independent specialized third party test institute, like the University of California San Diego/U.S.A. or the University of Armed Forces in Munich/Germany. 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.

The quality management and the design is not just an internal standard procedure of MAURER, it is based on standards (EN, etc.) and justified by official third party supervision body on request.

Fig. 8: Full scale testing at University of California in San Diego U.S.A. in the Caltrans Test Rig
3.3 Modelling

The MAURER spherical sliding isolators with re-centring capability (SIPS and SIP DR type) are modelled according to the below equations.

- Hysteretic loop

\[
\begin{align*}
\mu W &= \text{friction force value} \\
K_i &= \text{initial stiffness} \\
K_{SI} &= \text{stiffness of isolator} \\
K_{eff} &= \text{effective stiffness} \\
F_D &= \text{resisting force} \\
D &= \text{displacement}
\end{align*}
\]

Fig. 9: Characteristic hysteretic loop of a spherical sliding isolator

- Sketch of isolator with acting forces

Fig. 10: Principle sketch of a spherical sliding isolator of SIP S type
- Horizontal resisting force \( F_H = \frac{W}{R} \cdot D + \mu \cdot W \cdot (\text{sgn} \, v) \) \[1\]

where

\( W = \) vertical load, \( \mu = \) dynamic friction coefficient
\( D = \) horizontal displacement, \( v = \) horizontal displacement velocity,
\( R = \) radius of curvature.

- Horizontal stiffness due to rise of mass \( K_H = \frac{dF_H}{dD} = \frac{W}{R} \). \[2\]

- Period of the bearing \( T = 2 \cdot \pi \cdot \sqrt{\frac{M}{K_H}} \), where \( M = \frac{W}{g} \) and \( K_H \) is substituted by formula \[2\]. Means the period \( T = 2 \cdot \pi \cdot \sqrt{\frac{R}{g}} \). \[3\]

- Effective (peak-to-peak) stiffness \( K_{eff} = \frac{\Delta F}{\Delta D} = \frac{(F_{max})^+ - (F_{min})^-}{2 \cdot D} = \frac{W}{R} + \frac{\mu \cdot W}{D} \) \[4\]

- Effective period \( T_{eff} = 2 \cdot \pi \cdot \sqrt{\frac{R \cdot D}{g \cdot (D + \mu \cdot R)}} \). \[5\]

This equation shows that \( T_{eff} \) is independent from mass \( W \).

- Effects of damping produced by friction between the sliding couple (stainless steel against sliding liner material) can be taken into account by means of the damping ratio \( \xi_{eff} \), which is defined as: \( \xi_{eff} = \frac{2}{\pi} \cdot \frac{\text{area of hysteresis loop}}{\text{area of circumscribed rectangle}} = \text{Lehrsche Damping Ratio} \) \[6\]

where

\( \text{area of the hysteresis loop} = 4 \cdot \mu \cdot W \cdot D \), \[7\]
\( \text{area of the circumscribed rectangle} = 4 \cdot K_{eff} \cdot D^2 \) \[8\]

Introducing \[7\], \[8\] and \[4\] we obtain:

\( \xi_{eff} = \frac{2}{\pi} \cdot \frac{\mu}{D/R + \mu} = \frac{2}{\pi} \cdot \frac{\mu \cdot R}{(D + \mu \cdot R)} \) \[9\]

For \( D/R << \mu \) it is \( \xi_{eff} \approx 2/\pi \), while for \( D/R >> \mu \) it results \( \xi_{eff} \approx \frac{2 \cdot R \cdot \mu}{\pi \cdot D} \).

- Radius relation to period: \( R = \frac{g \cdot T^2}{(2 \cdot \pi)^2} = 0,25 \cdot T^2 \) \[10\]

- Upward displacement depending on displacement \( \delta_U = R - \sqrt{R^2 - D^2} \) \[11\]

- Static re-centring criterion: \( D/R > \mu \) must be fulfilled \[12\]

- Dynamic re-centring criterion: \( \mu \leq 4 \cdot \frac{1 - \cos \alpha_d}{\sin \alpha_d} \) \[13\]

where \( \alpha_d = \arcsin (D/R) \), which is the design angular displacement \[14\]

- Values for the radius \( R \): 1000 mm to 6200 mm or more.
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.

<table>
<thead>
<tr>
<th>Vertical load* (MN)</th>
<th>Horizontal displacements*** d [mm]</th>
<th>Dimension Q of SI based on 5% friction [mm]</th>
<th>Height of SI **</th>
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* 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 and will be individually adapted

Fig. 11: Sizes of spherical sliding 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 - 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. 12: Sketch of SIP S bearing

Section:

Elevation:

Plan View:

4-8 x M20 - M36 bolt

Temporary restraint plate

Height

Concave sliding plate

Stainless steel Sliding sheet

Spherical part with MSM®
<table>
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<th>Vertical load* (MN)</th>
<th>Horizontal displacements** [mm]</th>
<th>Dimension Q of SIP-S based on 5% friction [mm]</th>
<th>Height of SIP-S ** [mm]</th>
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* 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 and will be individually adapted on demand

Fig. 13: Sizes of sliding pendulum isolators (any other intermediate sizes are possible)

Fig. 14: Perfectly shaped stainless steel concave surface of a SIP S Type with eveness tolerances of up to +/-1mm
3.6 SIP DR Type with a double concave sliding plate

The Sliding Isolation Pendulum (SIP DR 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. +/-400 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.

On demand the rotation inside the bearing can be removed under certain conditions then the bearing is a SIP D.

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.

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**Fig. 15: Sketch of SIP DR bearing**

**Section:**
- **Q**

**Elevation:**
- Upper concave sliding plate

**Plan View:**
- Temporary restraint plate
- 4-8 x M20 - M36 bolt

**Elements:**
- Lower concave sliding plate
- Stainless steel Sliding sheet
- Spherical centre part with MSM®
<table>
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<th>Horizontal displacements*** d [mm]</th>
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* 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 and will be individually adapted on demand

Fig. 16: Sizes of sliding pendulum isolators (any other intermediate sizes are possible)

Fig. 17: 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.

- High quality management by internal supervision system and external third party testing and fabrication supervision on request.

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

4. Extract of References

4.1 New Acropolis Museum – Athens/Greece

4.2 Ponte 25 de Abril (Tagus Bridge) in Lisbon – Portugal