DOI: 10.1002/stco.200910025

The sliding isolation pendulum – an improved recentring bridge bearing

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Sliding isolation pendulum bearings, known as seismic isolators, with adaptations for the service condition, represent improved recentring bridge bearings. They are an attractive alternative to elastomeric bearings for the support of structures on recentring bearings, which lead to a better distribution of horizontal loads as well as to a reduction in constraints. In combination with a special sliding material and characterized by long life and high loadbearing capacity, sliding isolation pendulum bearings have small dimensions as well as the capability a exact presetting and for horizontal stiffness that is independent of load capacity, change of material characteristics due to temperature, ageing and manufacture. Further, the requirements in terms of serviceability of a bridge bearing are upheld.

1 General

Common bridge bearings are elastomeric bearings, pot bearings and spherical bearings according EN 1337 or European Technical Approval, e.g. [1]. Sliding isolation pendulum bearings, which are spherical bearings with curved main sliding surfaces, are used as seismic devices. Design rules are given in EN 1998-2 and EN 15129, the latter actually adopted. Due to special sliding elements and an appropriate design concept, these devices can be used as improved recentring bridge bearings as already shown in [2]. This paper gives a summary and outlines further developments.

Support systems for bridges usually consist of a combination of horizontally multidirectional and unidirectional moveable bearings as well as fixed bearings. The location of the fix point influences the movements of the bridge ends and the horizontal loads that the piers have to accommodate. The advantage of this support type is the statically defined transfer of loads. Here, the concentration of horizontal loads at a few supporting points only and the occurrence of constraint forces can be a disadvantage. An alternative support type is the so-called elastic support of bridges by means of reinforced elastomeric bearings. For this mode of support the horizontal loads are distributed to all bearings according to their horizontal stiffness. There is no defined but only a fictitious fix point, a so-called deformation resting point. An example of such a bearing scheme is shown in Fig. 1.

In 1999 the German Ministry of Transport issued a guideline for the application of reinforced elastomeric bearings for the elastic support of bridges, see ARS 21/99 [3] and Annex A of EN 1993-2:2006. Springs on the single support represent the rotational stiffness of the pier foundation, the bending stiffness of the pier and the shear stiffness of the bearing. The external action, e.g. braking forces, results in a horizontal displacement of the structure, which depends on the sum of the horizontal stiffness. Further, the horizontal load is allocated over the single supports, see Fig. 2. Here, K_i stands for the stiffness and l_i for the

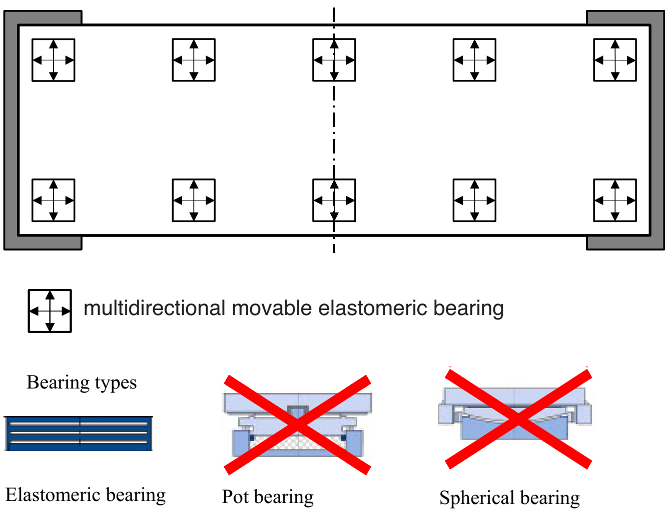

Fig. 1. Horizontally "elastic" support for continuous girders

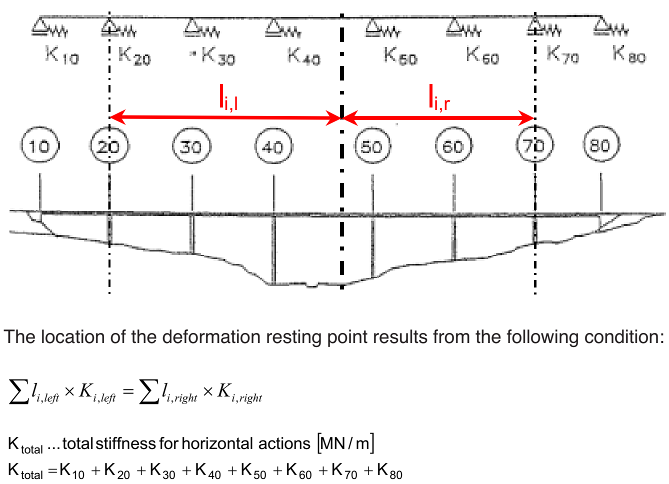

Fig. 2. Total horizontal stiffness and location of the deformation resting point [3]

Table 1. Major advantages and consequences, which can also be disadvantages for the elastic support of bridges

Advantages	Consequences
– Load distribution onto several piers and foundations	– Strain onto all support points
– Reduction in constraints because of the omission of guides	– Major transverse movements
– Balancing the movements to both bridge ends	– Larger total horizontal movement
– Seismic isolation of the structure	– Impact on the service life
– Energy dissipation in the case of seismic events	

distance of the support from the deformation resting point.

The application of elastic support by elastomeric bearings is limited to maximum vertical loads of 12 MN, and in the case of distances of more than 15 m to the deformation resting point or in the case of skew bridge ends of less than 80 gon, the use of guided bearings is required at the abutments at least.

2 Horizontal stiffness of elastomeric bearings

The horizontal stiffness of elastomeric bearings depends on the geometrical dimensions as well as on the shear modulus of the elastomeric compound selected. Since the dimensions of an elastomeric bearing are determined by the parameters vertical load, displacement and rotation, the horizontal stiffness depends on these input parameters and therefore cannot be freely selected in order to achieve an optimum distribution of the horizontal loads. The shear modulus deviates by a maximum of ± 20 %. To be added to this is a variation caused by ageing in the same magnitude, next a variation that depends on the effective temperature of the bearing of a max. 3-fold value at low and a max. 0.6-fold value at very high temperatures as well as a remarkable creep behaviour. This results in a considerable variation of the so-called deformation resting point and consequently large displacement at bridge bearings and expansion joints, see Fig. 3.

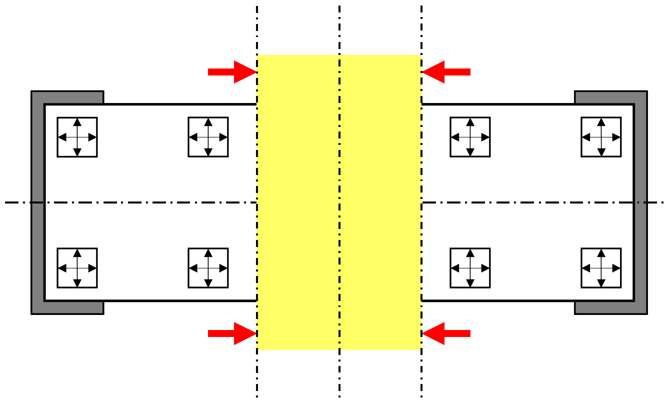

Fig. 3. Location area of the deformation resting point of horizontally "elastic" supports for continuous girders

3 The sliding isolation pendulum bearing

The so-called friction pendulum (FPS) of American origin [4] has been employed for about two decades for seismic isolation purposes, neglecting considerations of serviceability, which are of major importance in bridges. In EN 15129 the request was made that independent of the characteristics in case of a seismic attack, the characteristics of serviceability of a conventional bridge bearing shall be reached.

The sliding isolation pendulum bearing (SIP) is an enhancement of the friction pendulum and a variation of the spherical bearing (well established in bridge construction), where a normally plane sliding surface is replaced by a curved one (see Fig. 4). Analogous to elastomeric bearings it exhibits a recentring characteristic. Here, the advantage of a mathematical pendulum is employed, which, independent of the masses but depending on the displacement of the pendulum, creates a corresponding restoring force. Energy will be dissipated by friction in the sliding surface.

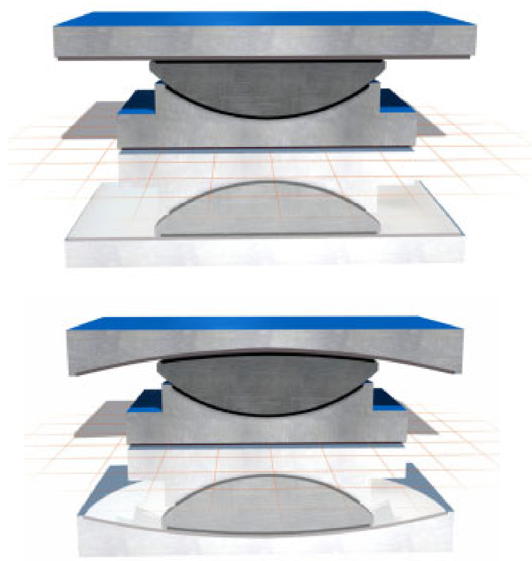

Fig. 4. Cross-section of a spherical bearing and a sliding isolation pendulum bearing

4 Recentring support of bridges

One of the crucial features of the recentring support is its capability to keep the structure in a horizontal "zero position", which means that due to a horizontal force and the consequent horizontal displacement a recentring effect can be created. Either conventional elastomeric bearings, or alternatively sliding isolation pendulum bearings can be employed in such a case. Fig. 5 shows such a support type.

Furthermore, in the case of sliding bearings the friction coefficient, the service life in the case of larger accumulated sliding displacements as well as the deformability

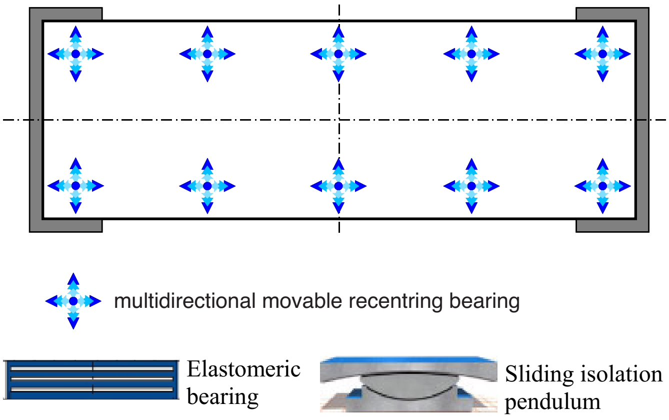

Fig. 5. Horizontally recentring support for continuous girders

of the sliding material in the case of settlements are important.

5 Sliding isolation pendulum bearings with special sliding material

The sliding material of sliding isolation pendulum bearings according to EN 15129 must comply either with EN 1337-2 or a corresponding European Technical Approval. For those requirements that are not covered in EN 1337-2, Maurer Söhne has developed a special sliding material called MSM® [5]. In comparison to PTFE, the following has to be highlighted:

– the special suitability of MSM® in the case of high displacement velocities
– the low friction coefficient, in particular at low temperatures
– a loadbearing capacity that is twice as high, in particular at high temperatures
– a significantly longer lifetime due to the high wear resistance at even larger accumulated sliding paths

Fig. 6 depicts the characteristic contact pressure of PTFE and MSM® as a function of the temperature. Even at effective bearing temperatures of 70 °C, MSM® reaches the permissible contact pressure of PTFE at room temperature. This characteristic is of particular importance when employing sliding materials in sliding isolation pendulum bearings because the sliding surface will incur temperature increases caused by the sliding velocity. On the other hand, Fig. 6 also demonstrates the settlement behaviour. The elasto-plastic deformability of the material is of major importance for the safeguarding of a uniform pressure distribution as well as for the adaptation of the sliding material to the settlement.

Fig. 7 depicts the execution and composition of a MAURER MSM® Sliding Isolation Pendulum Bearing (SIP).

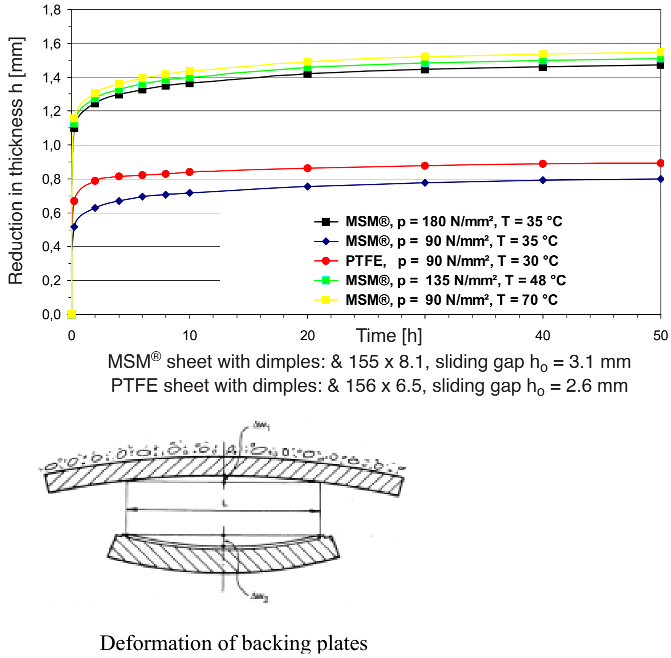

Fig. 6. Temperature-dependent compressive strength of PTFE and MSM®

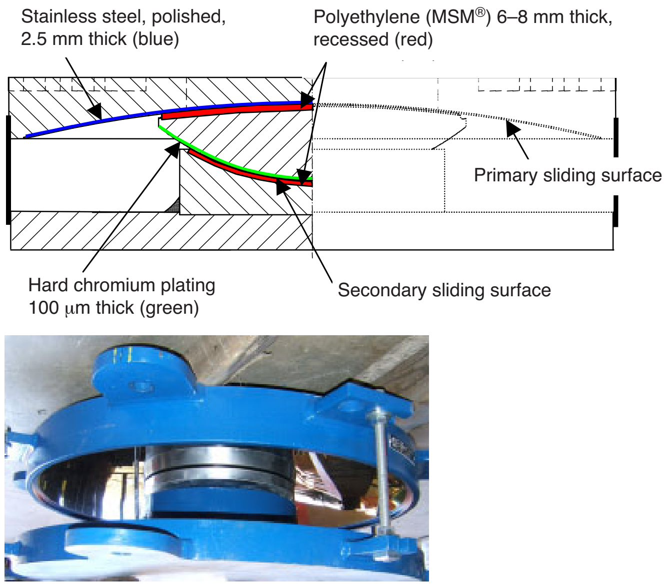

Fig. 7.MSM® Sliding Isolation Pendulum (SIP)

6 Mixed support systems

As a rule, sliding isolation pendulum bearings exhibit a central symmetric load deformation behaviour in the horizontal direction. In certain cases, e.g. in the case of large sliding displacements or an arbitrary allocation of hori-

Table 2. Main requirements for structural bearings and recentering bearings

Requirements for structural bearings	Additional requirements for recentering bearings
– safe transfer of loads	– a sufficient recentring capacity
– displacement capacity	– a sufficient or small restoring force
– rotational capacity	– a horizontal stiffness that has only a small dependency on the loads, displacements, temperature, manufacturing tolerances and installation
– long service life and serviceability	– a sufficient energy dissipation (if need be by way of additional devices)

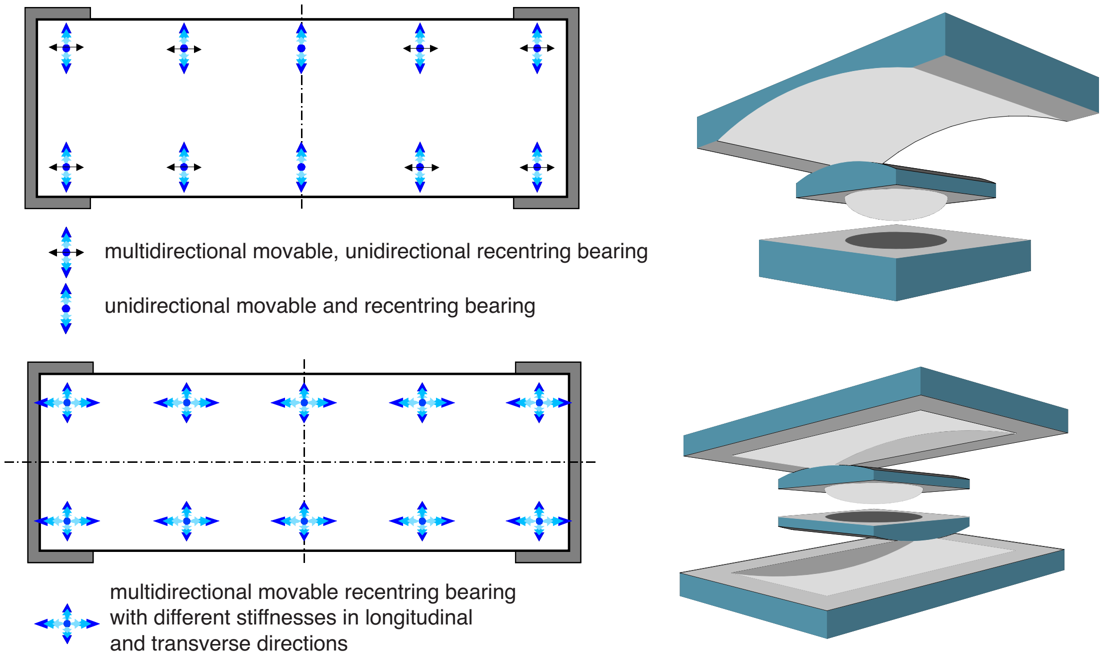

Fig. 8. Horizontally unidirectional and anisotropic recentering support for continuous girders

zontal loads, the use of unidirectionally recentring bearings can be advantageous. For such applications, the main sliding surface can be designed cylindrically instead of spherically. In the direction of the cylinder axis, the sliding isolation pendulum bearing performs like a conventional spherical sliding bearing. In the lateral direction, the pendulum characteristic is given, as described above. Combining orthogonally two unidirectional recentering and guided bearings, the horizontal stiffness of the bearing system becomes anisotropic if the friction in and/or the curvature of the two sliding surfaces is different. The friction coefficient can be varied by changing the contact surface and thus the contact pressure. This solution is of interest, for examples for piers with considerable differences in stiffness or load-carrying capacity in the longitudinal and transversal directions. Fig. 8 depicts the composition of such bearings and possible support systems.

7 Summary

Usually, the bearing system for a bridge must be executed in a way that minimizes constraint forces with restraint bearings and low-friction sliding bearings. For a better distribution of the horizontal loads to several supports or to realize a seismic isolation system the bearing system can also be realized without restraints, e.g. using elastomeric bearings. This “elastic bearing system” focuses on the recentring capacity of the same. Consequently, the components of such a system can be better described by the term “recentring bearing system”. Until now, sliding bearings without horizontal restraints could not be used for a recentring bearing system as they cannot provide any recentring capacity. State-of-the-art sliding pendula have a similar setup compared to spherical bearings, except the flat sliding surface is replaced by a curved one. While using the well-known function principle of friction pendula, the employment of newly developed materials and design approaches also satisfies serviceability demands such as wear resistance, long-term low friction as well as bedding deformability. In contrast to elastomeric bearings, the recentring effect is not provided by elastic energy, but by generation of potential energy. Restraint bearings are not required as the bridge deck is recentring due to gravitation. Isolation and load distribution can be designed exactly to meet structural requirements by combining recently developed sliding materials and lubricants, and independently of temperature, load and displacement. In that way, an optimum design of the structure can be realized. Applications for this new design approach are, for example, bridges for high-speed railways, structures facing poor subsoil conditions or heavy seismic activities, retrofitting of structures or very slender structures determined by architectural design.

References

[1] ETA-06/0131: Spherical bearing with special sliding material. Deutsches Institut für Bautechnik, 2006.
[2] *Braun, Ch., Fobo, W.*: Recentering bridge bearings – new devices to improve a known design concept. The 7th German-Japanese bridge symposium, Osaka, 2007.
[3] German Ministry of Transport: Richtlinie für den Einsatz bewehrter Elastomerlager zur elastischen Lagerung von Brückenüberbauten, Allgemeines Rundschreiben Straßenbau ARS 21/99.
[4] *Zayas, V. A., Low, S., Mahin, S.*: A simple pendulum technique for achieving seismic isolation. Earthquake spectra 6, 1990.
[5] *Braun, Ch., Fobo, W.*: Bridge sliding bearings with high long term performance. 5th Japanese-German joint symposium on steel and composite bridges, Osaka, 2003.
[6] *Braun, Ch., Medeot, R.*: The sliding isolation pendulum (SIP). 10th World Conference on Seismic Isolation, Energy Dissipation and Active Vibrations Control of Structures, Istanbul, 2007.

Keywords: bridge bearing; isolation; recentring devices; elastic support; sliding isolation pendulum

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