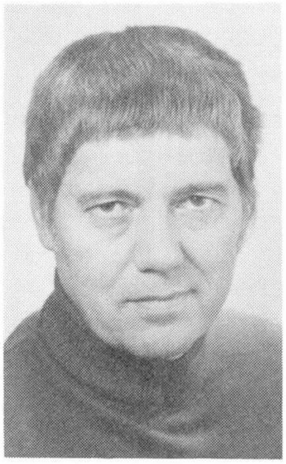
Design, Performance and Maintenance of Bearings and Joints

Conception, exécution et entretien d'appuis et de joints

Planung, Ausführung und Unterhaltung von Auflagern und Fugen

Waldemar KÖSTER
Civil Engineer
Consultant
Forsbach b/Köln, Fed. Rep. of Germany



Waldemar Köster, born in 1923, studied civil engineering at the Technological University of Darmstadt, Fed. Rep. of Germany. He worked twelve years in the bridge design offices of major construction firms at Cologne. Since 1966 Waldemar Koster is a consultant to the expansion joint and bearing industry and holds numerous world patents on their design.

SUMMARY
Bearings and joints are subject to movement processes, for which they are normally mechanically designed. In this way, modern bridges have become a mechanical feature. Problems of kinematic and dynamic nature will be discussed.

RESUME
Les appuis et joints de dilatation sont soumis à des mouvements en vue desquels ils ont été conçus du point de vue mécanique. C'est ainsi que les ponts modernes sont devenus des installations mécaniques. Les problèmes cinématiques et dynamiques sont analysés.

ZUSAMMENFASSUNG
Auflager und Fahrbahnübergänge sind Bewegungsvorgängen unterworfen, für die sie in der Regel maschinenbaumässig konstruiert wurden. Damit erhalten moderne Brücken maschinenbaumässige Eigenschaften. Probleme kinematischer und dynamischer Art werden untersucht.

DESIGN, PERFORMANCE AND MAINTENANCE OF BEARINGS AND JOINTS

In the autumn of 1981 the American Concrete Institute held a World Congress on the above topic. When the one week Congress opened there were 36 lectures prepared and printed on 734 pages [1-0].

The subject matter is therefore extensive and must necessarily be limited here to a brief outline of a few aspects.

1) INTRODUCTION

Bearings and expansion joints present more problems for the civil engineer than the remaining construction components of bridges [2]. This observation made in 1971 could be repeated unchanged in 1981 [1-1].

Bearings and expansion joints are both attributes of modern bridge construction, which only entered the picture at a later date. They became necessary when stone arch bridges were superseded by beam type steel structures, which altered considerably in length with changes in temperature. The art of bridge building, however, dates back to antiquity as still revealed today by arch bridges, which have formed part of the landscape apparently unchanging for hundreds of years. And it is this very tradition which makes it difficult for the civil engineer to come to terms naturally with the kinematic and dynamic problems of bearings and expansion joints. We must, however, accept that the actual construction problem of bridges today must also include the techniques of mechanical engineering and plastic design.

Bearings and expansion joints are both subject to movement processes. This, however, is in fact all these two construction elements have in common. In function and design they are basically different.

The bearing transmits loads, which normally change very little, and performs specific displacements and rotational motions with these loads. This function is a static and kinematic one and easily identified. In addition, there are accurate conceptions of materials and function tests. It is therefore understandable that regulations and standards primarily concern the more simply defined problems of bearings [3], [4].

The expansion joint in a carriageway as a transition structure must be considered in a basically different way. While the bearing is relatively motionless under the bridge, the transition is constantly moving under dynamic loads. The kinematic function of closing the verying carriageway joint is made more difficult by the necessity of withstanding dynamic traffic loading. The transition structure should also be watertight - to protect the bearing. Insulating materials and surfaces must be connected and should also be concealed so ingeniously in the carriageway that road users are unaware of their presence. The problem is therefore extremely complex and is impractical to control by introducing regulations and standards.

Functional tests on carriageway transitions are not simple to perform and usually only possible as part of the overall function. They are, however, urgently necessary in order to provide a firm basis for specifying the minimum performance required to ensure a positive influence on further developments. Regulations only appearing in the form of restrictions can only hinder future developments.

Interesting proposals for function tests on carriageway transitions can be found in [1-2]. Tests on anchoring systems in reinforced concrete are published in [1-4] and [5], while [6] and [7] provide measurements on carriageway transition with traffic loading.

Bearings and carriageway transitions are subject to movement processes, for which they are normally mechanically designed. And since motion is synonymous with wear, the maintenance of a bridge is associated with problems similar for example to those in the servicing of a vehicle. The bridge tests prescribed at regular intervals take account of this, but the special nature of the bearings and carriageway transitions should be emphasised more particularly in the instructions in the sense described, in order to identify them as mechanical structures [8].

The maintenance of a bridge is intended to prevent wear. The replacement or restoration of parts subjected to wear must be made according to test results and plan. It is in principle an extremely familiar task, when it is appreciated that the asphalt surface of a bridge is also subjected to wear and must be renewed.

Design faults on the other hand are congenital defects, which can usually only be remedied by surgery. These are the actual causes of damage, which are informatively described for example in [1-1].

Bearings and carriageway transitions, therefore, have their own problems. But structural problems disappear if the construction itself is avoided. This simple statement ought to appear at the beginning of every bridge design. There are a number of interesting possibilities: slender piers can bend, concrete hinges can tilt and even carriageway transitions can be dispensed with if for example a bridge is curved in the form of a quarter circle [1-3]. But it is only in exceptional cases when the skilful civil engineer can design a bridge without bearings and expansion joints.

2) BRIDGE BEARINGS

Without going into the history of bridge bearings, which is outlined in practically all introductions to the subject, only the structures relevant today will be considered here under kinematic aspects. A full description of bearings and bearing systems is given in [9] and [10] .

2.1 Degrees of freedom and constraints

These are the factors with which bridge bearings can be clearly differentiated kinematically. They should automatically possess rotational possibilities in all directions these days, since this is absolutely essential for universal application. Point rotation is thus the kinematic basis of all modern bridge bearings.

For a long time, line rocker bearings and roller bearings were standard components in bridge construction. When resistance to movement was drastically reduced by hardened rollers, however, fractures of these sensitive bearing elements revealed previously ignored constraints [11]. These are to be expected if the superstructure bends in the transverse direction or is displaced obliquely to the direction of rolling. Bending moments are then produced in the bearing line for which a roller bearing cannot be designed. Roller bearings can therefore only be employed under clearly defined conditions.

Bridge bearings are designed to accept general forces and not to transfer moments. Their basis structure is simply too small for this purpose. Instead, they should offer definite degrees of freedom for rotation about all three axes. Point rocker bearings rotate about both horizontal axes, normally also about the vertical axis, but exceptions also have to be noted in this case.

In addition to the vertical loading, horizontal forces from both axial directions are also borne if the point rocker bearing is fixed. A point rocker bearing movable in one direction with three degrees of freedom of rotation also possesses one degree of freedom of displacement, and a bearing movable in all directions has two such degrees of freedom. In this case, only the degree of freedom of vertical displacement is restricted, in order to accept the vertical loading.

Guide bearings, however, which are not intended to accept vertical loads, logically possess the degree of freedom of vertical displacement and instead restrict one or both horizontal directions of displacement. Guide bearings remain special cases, since normally the load accepting bridge bearings can already provide the displacement direction or fixed point. But they should also be defined as point rocker bearings, which likewise should possess the three degrees of rotational freedom.

It is extremely useful and instructive to consider the design of a bridge bearing not only from the aspect of load acceptance and direction of displacement, but also to study it the other way round of whether degrees of freedom are restricted which do not have to be. For damage to bridge bearings can very often be attributed to rotations or displacements, which it was not necessary to restrict for the bearing function - these are termed constraints [12].

2.2 Reinforced elastomeric bearings

The reinforced elastomeric bearings, above all, must be considered in this light, since these can largely avoid the constraints by elastic resilience. The six degrees of freedom of spatial displacement and rotation are already provided by elastomer as a material property, owing to its ductility. In order to be useful as a bearing, its vertical ductility must be restricted or stiffened. With the pot-type bearing this is accomplished by enclosing the incompressible elastomer and with the elastomeric bearing by reinforcement usually with laminated steel, which subdivides the bearing block horizontally and therefore provides sufficient vertical stiffening for its flexing under load to remain negligible from the constructional engineering aspect [Fig. 1].

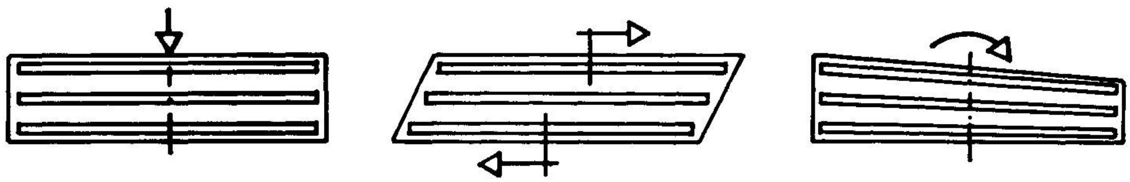


Fig. 1 Laminated Rubber bearing

The displacement capacity in all directions in relation to the elastomer depth is not restricted. This also applies to rotation about the vertical axis, while rotation about the two horizontal axes is indeed inhibited, but is useful owing to a corresponding elastomer depth. A general description in noteworthy detail of the reinforced elastomeric bearing is provided in [9]. Some new considerations and findings can be found in [1-0].

Reinforced elastomeric bearings are good-natured bearings, which if amply dimensioned absorb constraints without complaint.But they are also wilful bearings,which demand forces and moments and also the necessary possibility of movement for their deformations. Hence in a system of elastomeric bearings, the fixed point and also the direction of displacement are elastically variable and not capable of accurate determination. Bridge engineers should accept this as a desirable freedom for design and not make the error of trying to convert an elastomeric bearing to a fixed bearing, for example, by means of questionable auxiliary structures. If really necessary, it is simpler and cheaper with a steel rocker bearing, which also actually functions free from play in the required way [13].

Reinforced elastomeric bearings are simple and maintenancefree. They are important wherever their diverse degrees of freedom can be utilized, particularly in the low and medium range of loadings, displacements and rotations.

The displacement range of the reinforced elastomeric bearing can be extended with a sliding bearing mounted on top to obtain kinematically interesting shear -slide combinations. It should be noted in this case that a reinforced elastomeric bearing distributes the loadings over its area in the manner of a stress slope and manifests its rotational resistance in edge compressions of the PTFE-sliding disc. This makes the simple bearing somewhat more complicated [Fig. 2].

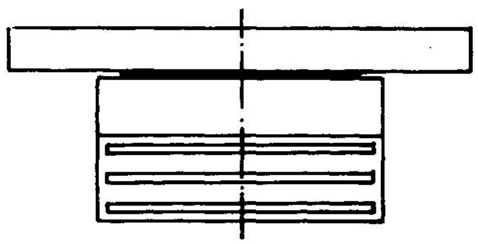


Fig. 2 Sliding Laminated Rubber Bearing

2.3 Point rocker bearings

Two building elements can mutually rotate or tilt by rolling together, sliding or deforming. Figs. 3 to 5 show these three typical forms of motion with examples of point rocker bearings, which can be combined in each case with sliding bearings. Various design principles with differing characteristics are involved, which are of importance in limiting conditions.

2.3.1 Steel rocker bearings

The steel rocker bearing shown in Fig. 3 rolls on a circular thrust member about both horizontal axes. The radii of curvature of the thrust member and possibly also of the bearing plate above are dependent on the loading and quality of the steel. They are normally so large that, on rotating the load moves noticeably from the centre. This is of special importance for the steel rocker sliding bearing, since the PTFE sliding disc is then loaded eccentrically. The permissiible mean PTFE compression cannot then be utilized, so that the sliding friction becomes higher than necessary [10]. The horizontal forces are absorbed without play, since the frictional tightness is normally adequate under the vertical compression and deformation. The stop of the bearing plate above also has an effect [13].

The rotations about the two horizontal axes are not thereby affected, but it should be realised that the frictional tightness inhibits rotation about the vertical axis. This is of little importance for the fixed steel rocker bearing and none at all for the steel rocker sliding bearing movable in all directions. It may however be necessary to correct the steel rocker sliding bearing movable in one direction by a rotation on the thrust member to compensate for an installation error in the direction of movement, without detriment to the sensitive sliding guide.

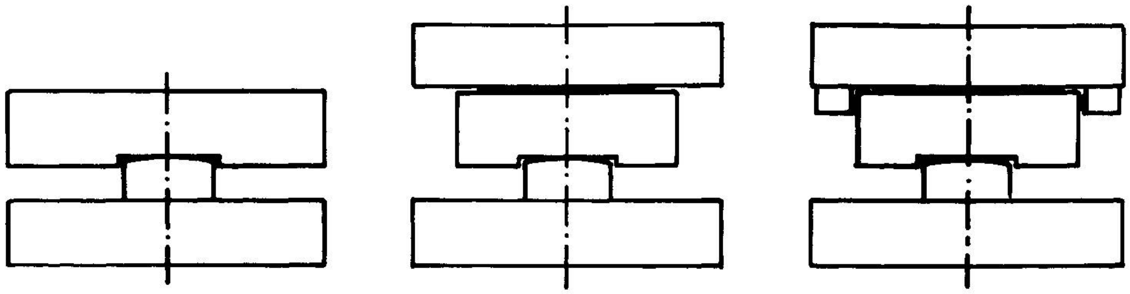


Fig. 3 Steel rocker bearing - fixed, multidirectional and unidirectional

From the contact point on the thrust member the load must be distributed over both bearing plate surfaces. This necessitates a large overall height, which is a hindrance to the transmission of large horizontal loads, since the edge compressions of the bearing plates and the PTFE sliding disc are correspondingly increased by the effect of moments [10]. The rotating part of the bearing is constructed in a remarkably simple and robust manner, but this desirable characteristic also influences the sensitive sliding piece.

2.3.2 Spherical bearings

The spherical bearing as shown in Fig. 4 rotates about both horizontal axes by means of the male portion, sliding cap in the concave lower bearing plate. The spherical radius of this rotating device is made as large as possible in order to obtain a roughly uniform PTFE compression in the curved sliding surface and to limit the thickness of the lower bearing plate [14].

The eccentricity of the applied load increases with the radius, however, since the rotational resistance effective in this case can be taken as the product of sliding friction and spherical radius [13]. In addition, the sliding friction must also be taken into account, which appears in the plain cap surface as a secondary load during rotation. An additional, geometrically caused eccentricity of the load, originating from the rotated position of the cap, is dependent on the overall height of the spherical bearing [10]. Various influences must therefore be considered in order to arrive at optimum rotating conditions.

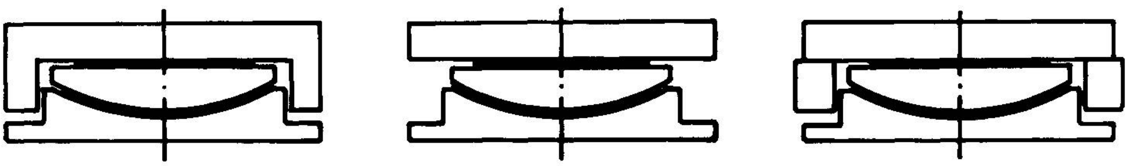


Fig. 4 Spherical Bearing - fixed, multidirectional and unidirectional

The curved sliding surface of the spherical bearing is not suitable for accepting horizontal loads. It would cause damage to the curved PTFE sliding-rotating disc placed within. For this reason, the upper bearing plate of a fixed spherical bearing is separated from the cap by a plain sliding surface. The horizontal forces are exerted directly on the lower bearing plate with a rotating stop. This system is not free from play and is subject to loading by the mutual friction of the stops during rotating motions.

It is clear from Fig. 4 that the basic form of the spherical bearing is of a bearing movable in all directions. The fixed spherical bearing is only produced from this by means of an auxiliary structure, comparable to the similar problem with the reinforced elastomeric bearings. This also applies to spherical sliding bearings movable in one direction, for which instead of a circular, surrounding stop, two guide rails couple the upper bearing plate with the lower certainly in sliding connection, but not without constraint, since the slide guides are loaded eccentrically when rotating about the axis in the sliding direction and these react more sensitively than the steel stop of the fixed bearing. Even more important, however, is the lack of freedom for vertical rotation. While on the steel rocker bearing it concerns restricting by friction in the same case, two rigid bearing plates are coupled together here. The function of the spherical bearing movable in one direction is dependent on the precise alignment between the slide guides of the bearing and the direction of displacement of the bridge deck [3]. Limiting conditions for movement of this kind are familiar with roller bearings.

The overall height of the spherical bearing is only one third of that for the steel rocker bearing, since the rotating device does not have to be concentrated at one point, but can be extended practically to the bearing whole surface. The spherical sliding bearing movable in all directions conforms best with the design principle, since no untoward horizontal forces have to be transmitted via the mechanism of the sliding rotating device.

2.3.3 Pot-type bearings

The pot-type bearing shown in Fig. 5 rotates about both horizontal axes by means of the pot top plate acting as upper bearing plate deforming the elastomeric pad in the pot. This behaves like a viscous, incompressible fluid. The elastomeric is conveniently produced from natural rubber, which exhibits a uniform deformability over a wide range of temperature [11]. The elastomeric pad is also lubricated, so that in this condition the deformation from rotating takes places largely free from constraint. The eccentricities from the rotational resistance are negligibly small if the elastomer is sufficiently thick [14]. Dimensioning is based, however, on the dry or non-lubricated elastomeric pad, which perhaps occurs after a long time. This may probably only be of interest for rotation due to traffic loading.

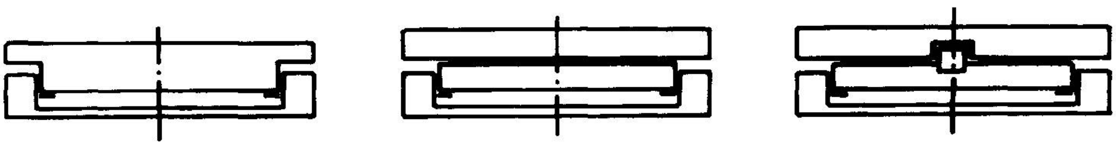


Fig. 5 Pot-type Bearing - fixed, multidirectional and unidirectional

The prerequisite function of the pot-type bearing is for a reliable sealing of the elastomeric pad against the movement gap between top plate and pot ring. The rotating part of the bearing must also be sealed externally, so that the elastomeric pad is protected and remains in the lubricated condition. The top plate located to the pot transmits the horizontal forces to the pot. As for the spherical bearing, the process is not free from play, but the surfaces in contact lie in the area of the grease deposit of the elastomeric pad, which extends in the movement gap up as far as the seal.

The functional connection between spherical and pot-type bearings is most clearly apparent with the bearings movable in all directions. Rotation and sliding are very similar in effect in both types. One basic difference can be seen, however, with the bearing movable in one direction. The pot-type bearing possesses a definite degree of freedom for rotation about the vertical axis, since rotating and sliding parts are clearly separated. It can rotate almost without resistance on the lubricated or even dry elastomeric pad, while this is only possible to a limited extent with steel rocker bearings and not at all with spherical bearings.

The overall height of the pot-type bearing is generally similar to that for the spherical bearing. It is important to know with respect to the sliding element that the elastomeric pad acting like a viscous fluid guarantees the required uniform compression of the PTFE sliding disc even with large tolerances in and under the pot. A disadvantage is the central guidance shown in Fig. 5 of the bearing movable in one direction, since the groove in the sliding plate represents a notch, similar to the guiding groove by roller bearings, which can lead to deformation of the sliding plate and to unacceptable compression of the PTFE sliding disc.

From the necessarily brief consideration of three different types of point rocker bearings, it is clear that there are significant differences even with respect to the degrees of freedom and constraints:

- With the steel rocker bearing the fixed bearing is of incomparable simplicity and robustness. It is an all-steel design, with the sole disadvantage of large overall height. The movable bearings are unsatisfactory.
- With the spherical bearing the type which is movable in all directions is a successful design, while the version movable in one direction has inadequate degrees of freedom.
- Pot-type bearings display no kinematic faults. Fixed bearings and bearings movable in one or all directions possess all degrees of freedom of rotation and displacement in all cases, provided they do not have to be restrained for a guiding purpose.

2.4 Design, performance and maintenance of a bridge bearing

All the relevant details have not been settled when the type of bearing has been decided for a structure, since the same design principle can be implemented in many different ways even within tight regulations. The construction, function and maintenance will be described with the example of a carefully designed pot-type bearing movable in one direction, to demonstrate their importance for the life of a structure [Fig. 6].

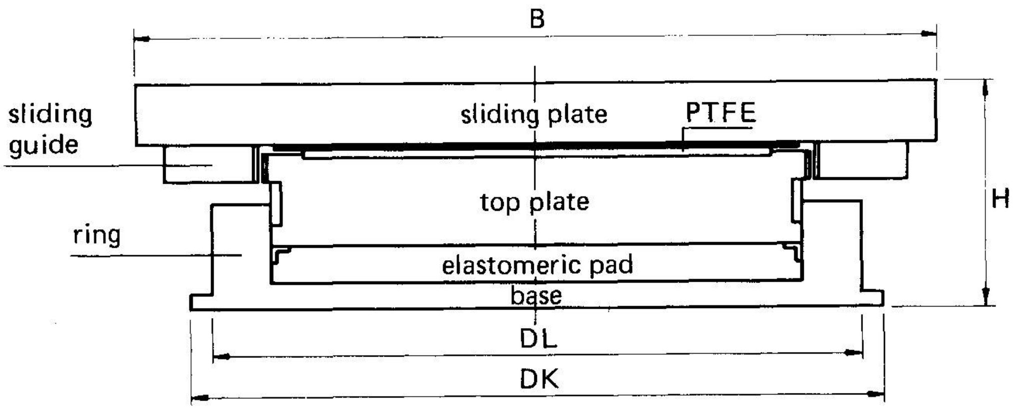


Fig. 6 Unidirectional Sliding Pot Bearing

The most important detail of a pot-type bearing is the sealing of the elastomeric pad against the movement gap between pot ring and top plate. Since the introduction of the pot-type bearing in 1959, three brass rings lying one above the other have successfully been used for this purpose. These rings are placed in a surrounding groove of the elastomeric pad so that their joints overlap [14]. In the search for materials capable of sliding better, a dimensionally stable sealing chain was developed, which consists of interlinked polyoxymethylene members (POM). It is vulcanized in at the time of manufacture of the elastomeric pad, so that it is immovably fixed in the pad when the bearing is assembled. Fig. 7 shows an elastomeric pad with this sealing chain, which slides without wear on the wall of the pot and adapts easily to all deformations of the pad owing to its chain-like structure.

The elastomeric pad must remain flexible in cold conditions. This requirement is not only limited to the rotational resistance, but also in particular to the security of the pad sealing, which would be subject to unacceptable loading from stiffening elastomer. An elastomeric pad of natural rubber avoids this disadvantage. It is not only unaffected by all ageing influences in the pot by the compressed gap seal, but also reliably protected by a further grease seal incorporated in the edge of the top plate [11].

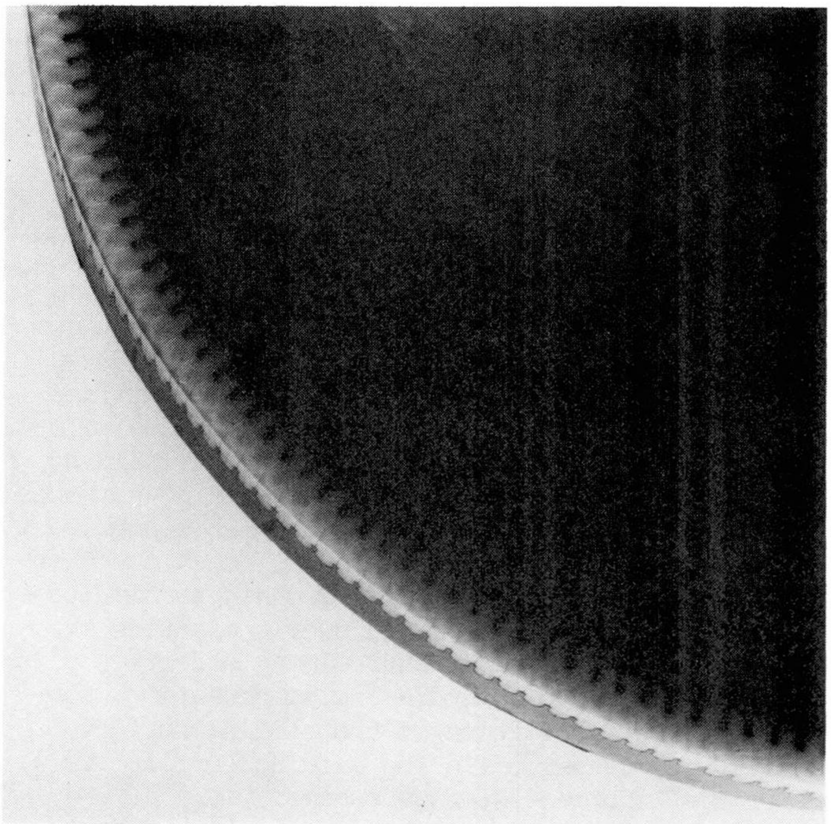


Fig. 7 Rubber pad with sealing chain

The elastomeric pad lies greased in its pot and during rotating motions slides on its grease bolster, which should always be present between pad and steel surfaces. Elastomeric pad, gap seal and sliding grease form a closed system of three elements, which must prove its reliability by joint endurance tests on a large scale before it can be responsibly employed [15], [16].

This also applies to the sliding bearing mounted on the top plate. Its three working elements are the PTFE sliding material, the high-grade steel sliding surface and the lubricant. The PTFE sliding material projects as a disc locked in a flat housing. The PTFE sliding disc should be sufficiently thick to provide a uniform supporting behaviour by plastic deformation. In conjunction with the requirement for limited edge compression from horizontal forces and rotational moments, this is a precondition for optimum sliding bearing design. This deformation capacity of the PTFE sliding disc is also utilized in order to achieve long-term lubrication of the system with lubricating pockets open to the sliding surface. In contrast with the elastomeric pad, the sliding disc of PTFE is exposed to destructive wear if the lubrication fails [17].

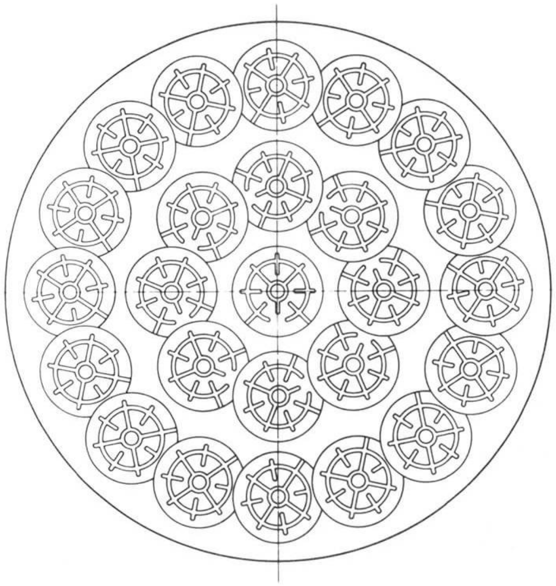


Fig. 8 Sliding Chain with Grease Storages

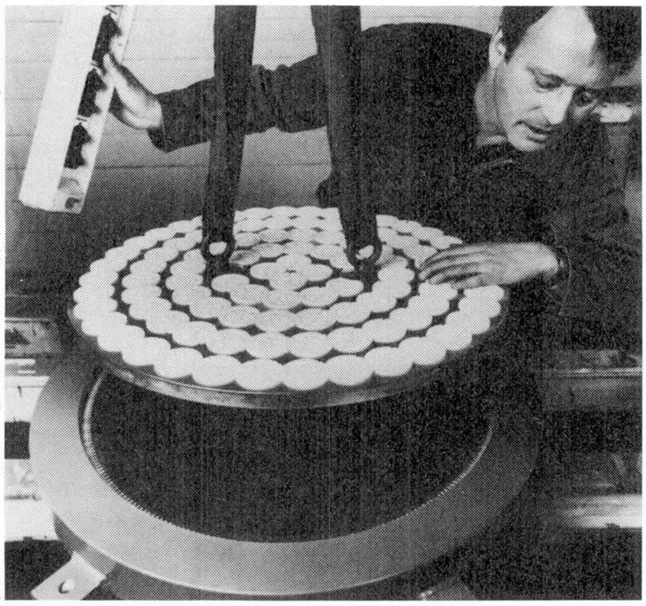


Fig. 9 Assembly of a Sliding Pot Bearing

This problem of long-term lubrication was solved in a new way with a modified sliding system. The enclosed PTFE sliding disc is divided into individual elements, each engaged in its own recess. They form intermeshing annular sliding chains, which like the annual rings of a tree can grow to form sliding surfaces of any size. Fig. 8 shows an arrangement of this kind, in which large lubricant storage spaces between the individual sliding chains ensure prolonged functioning of the sliding bearing free from wear. The outer sliding chain is simultaneously the sealing ring, so that by hydraulic compensation over the entire sliding surface the system acts as lubricating pad with particularly effective sliding characteristics [18]. This useful property of hydraulic compensation, however, is of the utmost importance for re-lubrication of the sliding surface, since fresh lubricant can very easily be inserted in the sliding surface via a hole leading from externally into the lubricant storage spaces.

In the sliding pot-type bearings shown in Fig. 6 the slide guides for movement in one direction are situated externally. This design is technically superior to the grooved central slide guide shown in Fig. 5. In addition to interference with load transmission, the notch in the sliding plate could possibly be a reason for questioning its flatness, particularly where substantial weights of fresh concrete may be expected during concreting of the bridge deck [1-5]. Damage to the sliding bearing by unacceptable PTFE-compression cannot then be excluded.

A carefully designed bridge bearing should also be clearly and unambiguously designated, since damage to bridge bearings is often due to installation errors pre-programmed by inadequate identification.

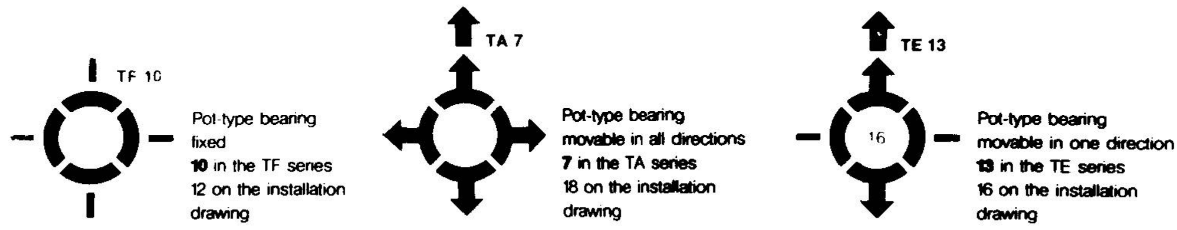


Fig. 10 Captions on Top Surface of Bearing

When placing a bearing attention is given to the upper surface. Everything should be marked there of importance for installation. Fig. 10 shows clear markings and their significance for fixed bearings and those movable in one or all directions. The double arrow points towards the fixed bearing.

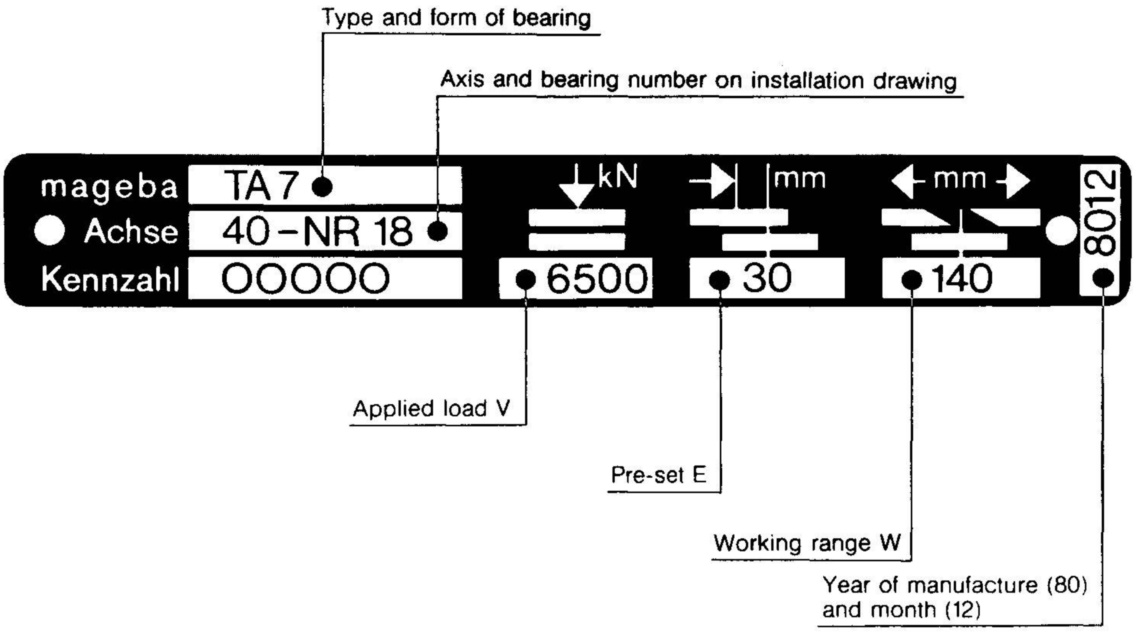


Fig. 11 Typeplate for Bridge Bearing

A typeplate should accompany every bridge bearing as a permanent and externally visible identification card. A typeplate of this kind is shown in Fig. 11 for a pot-type bearing movable in all directions with explanation of all data.

A working scale as shown in Fig. 12 should be attached for operation of the bearing, indicating the pre-set and working range in addition to the direction towards the fixed bearing. The scale and its limiting values marked by arrows and the pointer position should easily be recognizable with field glasses during inspection.

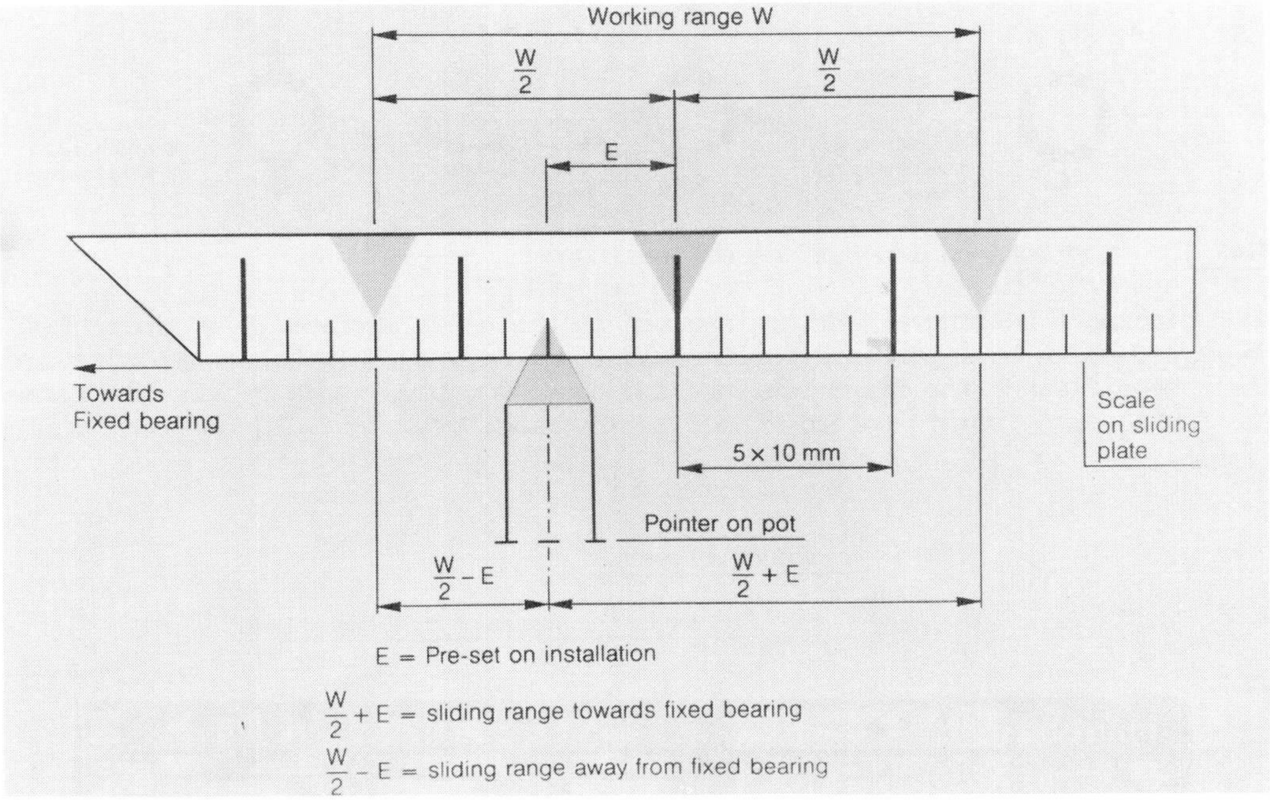


Fig. 12 Working Scale for movable Bearings

From the comments made above it is clear that bridge bearings are items which cannot be defined by the methods of building bridges alone. They are indeed designed in accordance with aspects of statics like the elements of a bridge, but their function is to accept loads in conjunction with the kinematic requirement for certain degrees of freedom. Apart from the smaller range of reinforced elastomeric bearings, this is only possible by mechanical engineering methods. For the maintenance of a bridge it follows from this that a bridge bearing also has parts subject to wear in addition to components requiring attention. It must be possible to replace these worn parts, since they risk losing their substance owing to their allotted function.

This would for example be the case for the PTFE sliding disc, if the lubrication failed. As the detailed description of the sliding pot-type bearing movable in one direction indicates, however, an endeavour is made further to develop the so-called wearing parts into components requiring care, which no longer lose their substance. But even highly encouraging results must still be proved by long experience. The principle formerly applied is that every bridge bearing must be replaceable at an acceptable cost.

3) EXPANSION JOINTS

Following the portrayal of bridge bearings, the mounting and suspension of expansion joints will be described as an important partial problem in the design of lamella joints. Comprehensive documentation on carriageway transitions and the associated problems can be found in [19].

3.1 Mounting and suspension

The kinematic function of bridge bearings can be clearly defined with the conceptions of degrees of freedom and constraints. For carriageway transitions with movable elements these terms are no longer sufficient to describe the scope of their movement functions. For it is not a question of accepting large loads mainly consisting of the dead weight with a bearing, but of mounting a structure movable in itself, which is more like a moving bridge than a bearing. An expansion joint has a number of bearings like a bridge, but it is exposed to the heaviest traffic loading nearly without dead weight. From this aspect, its basic function of closing the varying main gap in the carriageway becomes of secondary importance.

Since motions and simultaneous dynamic loadings are involved, mounting and suspension are the most suitable terms for describing this function. This can more readily be appreciated if one stands beneath an expansion joint and experiences the effect of the traffic roaring across. The effect is quite terrifying.

While the bearing in a bridge is already a different kind of design, the same is true in far greater measure for the expansion joint. The design principle should not only be mechanically oriented, but also pay far more attention to the mounting and suspension of a heavy vehicle, since in practice the expansion joint is the passive counterpart mounted in the bridge to the heavy vehicle rolling across.

The numerous old carriageway transition structures in our bridges were naturally constructed in earlier days with different concepts of design. They are scarcely equal to the demands made by modern heavy traffic and will largely have to be replaced in the long-term.

Mounting problems are encountered with all designs, which close the main gap with plate-like elements. These are the old cover plates on two bearing lines or the rocker plates on four bearing cams. They must be so stiff because of the wheel pressures from heavy vehicles that even powerful spring forces cannot adapt them to the statically indeterminate mounting. They shake and begin to knock under the traffic, making audible the incipient wear. Nor can this problem be avoided by complicated chain plates.

3.2 Resilient Mounting of Lamella Joints

The design of a lamella joint is made clear in the sectional model in Fig. 13. The lamella are grille bars, which unlike the familiar finger grilles do not intermesh, but divide the expansion path in traversable individual gaps in the direction of the traffic. This has the initial important advantage of simple sealing with elastomeric expansion sections, as is customary with only one joint gap with the small expansion joints.

Further advantages of the lamella design are revealed when the mounting is examined. Each lamella is secured against tilting, since it is firmly connected to its own cross-bearers, which provide it with a bearing base of joint width. This bearing base, however, not only signifies tilting security, but also a lever arm at the same time with which varying bearing conditions can easily be corrected by means of the torsional elasticity of the lamella. And this is possible without having to restrict the bending resistance of the lamella required for loadbearing.

Herein lies the basic difference in the mounting of lamella and stiff rocker plates.

This correction of the bearing conditions is enforced by the pre-tensioned sliding springs at each end of the cross-bearer. At the same time, they ensure a positive contact with the sliding bearing, which accepts the cushioning and damping of the wheel loadings with its resilience.

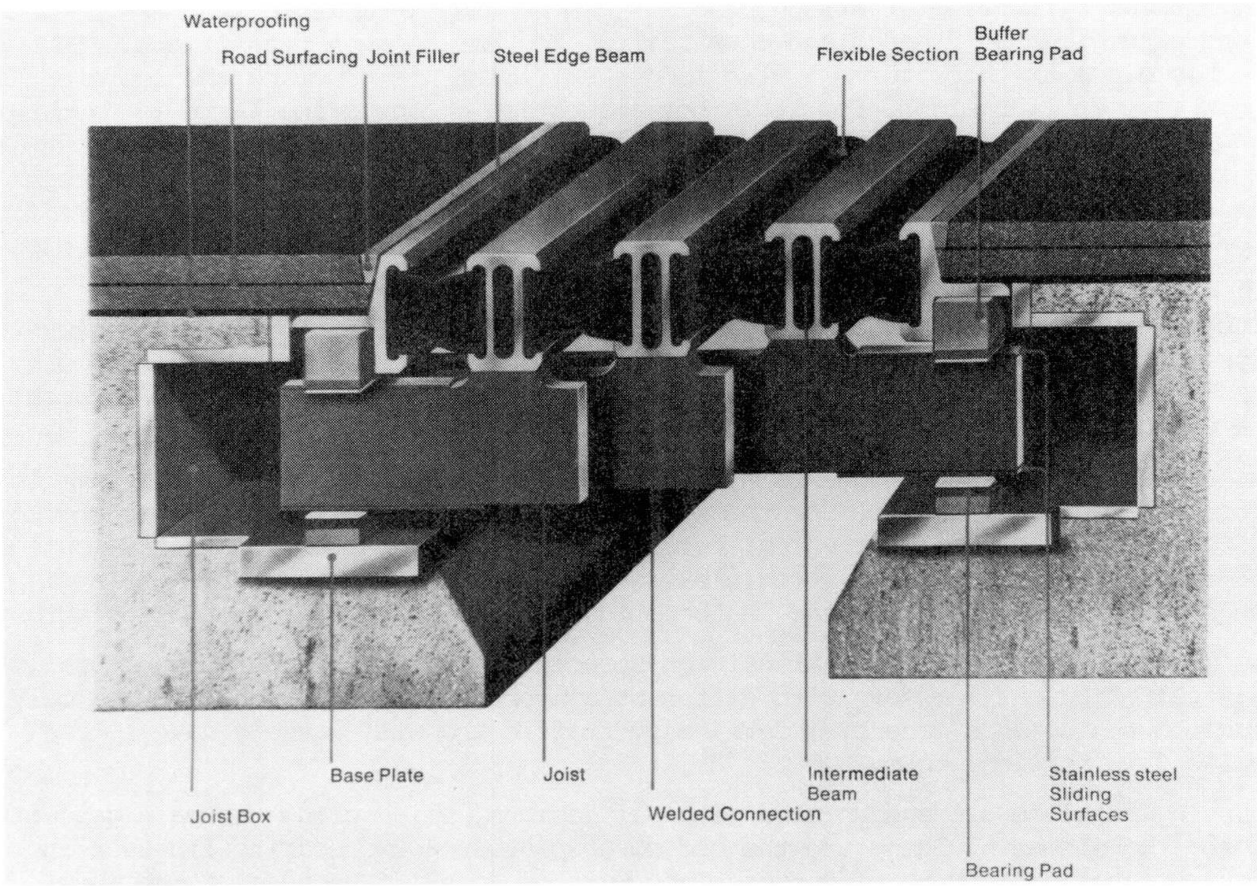


Fig. 13 Model Section of Lamella Joint

The diagram of Fig. 14 illustrates the qualitative correlations of the pre-stressed resilient mounting of a lamella joint in accordance with the sectional model of Fig. 13. The force P is plotted along the Y-axis against the flexing f along the X-axis. The steeper working line of the sliding bearing A_L starts at the origin, while the flat one of the sliding spring A_F begins where the overall system is sprung with f_S on assembly. The point of intersection S of the two working lines gives the pre-stressing value P_V and the division of the flexing f_S in the smaller sliding bearing section f_L and in the larger sliding spring section f_F. The cross-hatched triangle in the diagram marks the working area of the pre-stressed and resilient mounting. An external force P_A initially accepts the pre-stress value P_V of the sliding spring with the part P_1, until with the part P_2 it causes a further flexing f_A of the sliding bearing and a back-springing of the sliding spring.

Smaller wheel loads therefore traverse the expansion joint without flexing. Only with greater loadings from heavy traffic does the system provide cushioning and dampening in the desired manner, whereby the pre-stressing and spring stiffness are adapted to the upper limit of the load.

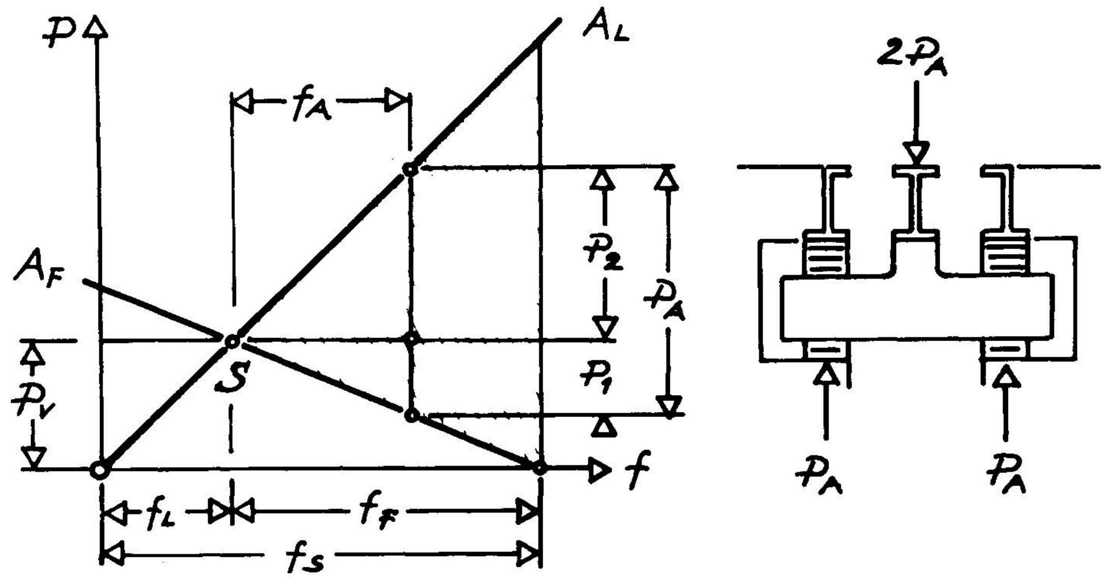


Fig. 14 Diagram of Resilient Mounting System

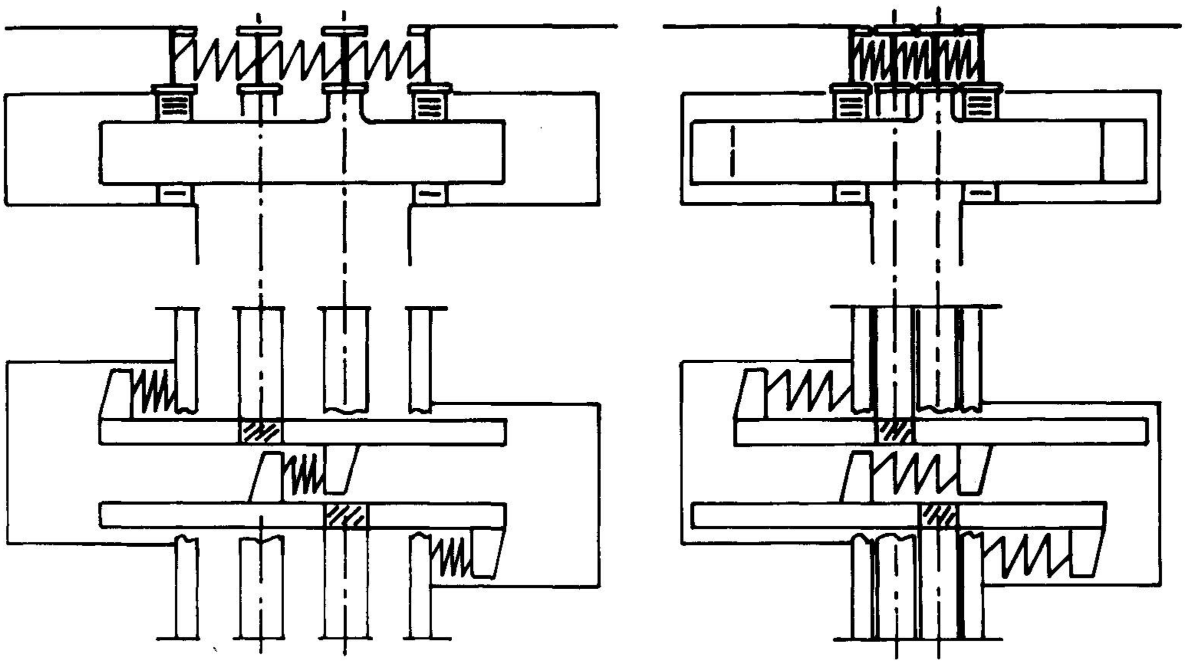


Fig. 15 Resilient Dual Control System

3.3 Resilient Control of Lamella Joints

Expansion joints are both vertically and horizontally loaded. Braking and accelerating forces are applied by the traffic and resistance of displacement is provided by the structure itself. These stresses necessitate control of the individually movable lamella to form a kinematically co-ordinated overall system.

This function can similarly be solved by means of resilient pre-stressing. And this is particularly effective when two pre-stressing systems work in opposition. Fig. 15 shows a cross-section and plan of a lamella joint in both the open and closed positions of the joint with a dual pre-stressing system of this kind. The cross-sections show the expansion sections represented by spring symbols as one system, while the plans depict control springs with same symbols as the other system. One operates between the lamellas, whilst the other works in the opposite way between the cams of the cross-bearers. It can be seen that the two systems work in opposition when the joint opens and closes, whereby both systems intermesh via the connection from lamella to cross-bearer shown hatched in the plan view.

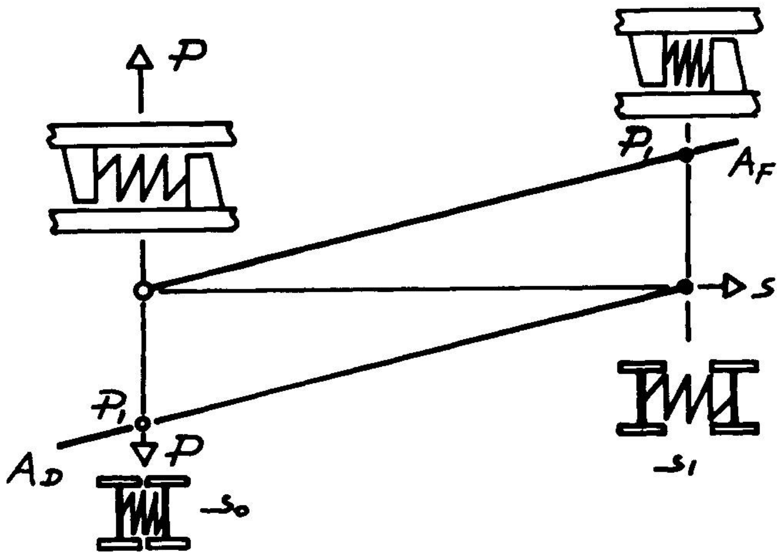


Fig. 16 Diagram of Forces for a Resilient Dual Control System

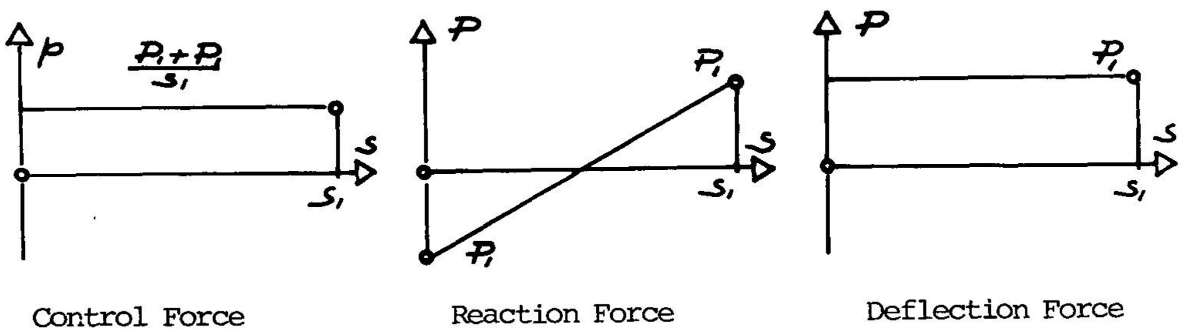


Fig. 17 Correlations of a Resilient Dual Control System

The diagrams of Figs. 16 and 17 show the qualitative correlations. It is assumed for the sake of simplicity that both pre-stressing systems have the same ultimate force P_1 and linear working characteristics. In all diagrams the force is plotted along the y-axis against the joint position along the x-axis. The closed joint is indicated by S_o and the open joint by S_1 at the origin of co-ordinates. Three effects of the resulting forces can be observed from the diagram of pre-stressing forces:

- The controlling force is the change in pre-stressing forces. It becomes effective when the lamellas have to follow on opening or closing of the joint.
- The reaction force is the difference of the pre-stressing forces. It is the resultant force applied from the system to the joint edges.
- The deflection force is the sum of the pre-stressing forces. It appears as a lamella resistance when this is deflected by external force such as braking or acceleration.

The noteworthy result is that both the controlling force and the deflecting force remain unchanged in all joint positions and that in addition the maximum value of the reaction force is only equal to that of one pre-stressing system. It becomes zero at the central position and applies no load to the bridge deck.

More attention must be paid to the avoidance of constraints with expansion joints than with bridge bearings, since the expansion joint in the carriageway is far more exposed to uncontrollable movements owing to its exposed position and spatial area than a defined bearing point below the bridge deck. The expansion joint must as it were always be a bearing movable in all directions with all degrees of freedom of rotation and displacement. Only for load compensation is the vertical displacement restricted, but under the dynamic conditions of cushioning and dampening. The lamella joint described with a grille bar system consisting of lamella and cross-bearers, together with resilient pre-stressed mounting and dual control, is equal to these demands.

There are also other solutions, however, for lamella joints, which instead of resilient elements employ kinematically more precise devices. These are, for example, lever or shear structures to control lamella and with which their loading can also sometimes be borne [20]. The attraction of such designs lies in the exact synchronization of the lamellas, which - if successful - certainly looks favourable, but must be obtained at the expense of a kinematically limiting mechanism. The comparison is raised here between the deformation possibilities of reinforced elastomeric bearings and those of steel bearing structures.

Mechanical control devices as primary system are important, however, when resiliently controlled lamella joints comprise more than ten or twelve lamellas. They are thereby divided into groups and thus permit expansion paths of any size in watertight lamella structures.

4) SUMMARY

Bearings and carriageway transition structures can be assessed by means of simple kinematic and dynamic considerations without mathematical calculations, in order to compare various designs. This fact should enable the civil engineer to understand the problems of bearings and carriageway transitions and to solve them in a technically satisfactory way. The success of a structure - and this is above all the duration of its usefulness - largely depends on this.

During the past two or three decades we have experienced an extremely rapid development. This has taken us so to speak from medieval time to contemporary times, if we consider the days without bearings and expansion joints as antiquity. Today it is a matter of consolidating current achievements, since spectacular new developments are hardly likely in the near future.

Consolidation of the field includes the functional tests already mentioned in the introduction, which are only in their infancy with respect to structures for expansion joints. For bearings they are already covered by regulations similar to standards, as for example is shown by the approvals for bridge bearings in Germany.

These findings from bearing tests are also in fact used for structures ten times larger than the test specimens. But it is perfectly normal in technology, however, that familiar designs also reveal previously concealed problems in a new order of magnitude. And unfortunately the technical order of magnitude is also associated with a financial order of magnitude.

It is certain that bearing designs cannot be extrapolated at will, even if contrary statements have a reassuring effect [1-5]. The reason for an opinion of this kind is simply because corresponding testing equipment has never existed. Reference may be made here, however, to a new testing device in Switzerland. [1-6] and Fig. 18. Loads up to 100'000 kN can be applied for testing bridge bearings. All the functions of a bridge bearing are carried out under this applied load and under additional horizontal forces for the various displacements and rotations.

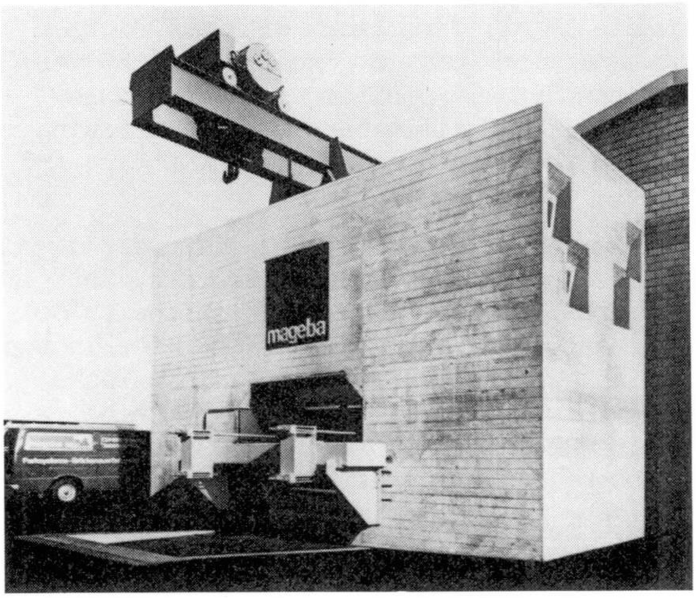


Fig. 18 Test Rig for Loads up to 100'000 kN

NOTATIONS

The figures have been provided by:

Mageba SA, Bülach, Schweiz: 6, 7, 8, 9, 10, 11, 12, 18

Maurer Söhne, München, Deutschland: 13

Author: 1, 2, 3, 4, 5, 14, 15, 16, 17

REFERENCES

1-0 ACI, Publication SP-70: Joint Sealing and Bearing Systems for Concrete Structures, Volume 1. American Concrete Institute 1981

1-1 ACI: LEE, D.J.: Recent Experience in the Specification, Design, Installation and Maintenance of Bridge Bearings

1-2 ACI: LINFANTE, A.: Performance Specification for Bridge Deck Joint Sealing Systems

1-3 ACI: MANNING D.G. and WITECKI, A.A.: Requirements for Deck Joints in Highway Structures

1-4 ACI: KOESTER, W.: Anchorage of Edge Sections for Expansion Joints

1-5 ACI: BAIGENT, M.G.: Practical Considerations in the Specification, Design, Manufacture and Quality Control of Mechanical Bridge Bearings

1-6 ACI: BUECHLER, W.R.: Proof Testing of Extremly High-Loaded Bridge Bearings

2 LEE, D.J.: Theory and Practice of Bearings and Expansion Joints. Cement and Concrete Association 1971, London

3 DIN 4141 - Entwurf Januar 1981: Lager im Bauwesen. Deutsches Institut für Normung 1981

4 BS 5400 - Part 9: Bridge Bearings. British Standards Institution 1981

5 KOESTER, W.: Die Verankerung im Stahlbeton bei Fahrbahnübergängen. Der Bauingenieur 49 (1974). S 69 - 73

6 TSCHEMMERNEGG, F.: Messung von Vertikal- und Horizontallasten beim Anfahren, Bremsen und Ueberrollen von Fahrzeugen auf einem Fahrbahnübergang. Der Bauingenieur 48 (1973). S 326 - 330

7 BLACK, W.P.N. and MOSS, P.S.: Horizontal Forces on Bridge Expansion Joints due to Vehicles. RRL Report LR 270, 1969

8 STANDFUSS, F.: Die Erhaltung von Strassenbrücken - Eine vordringliche Aufgabe der Strassenbauverwaltung. Beton- und Stahlbetonbau 11/1981. S 257 - 264

9 EGGERT, H., GROTE J. und KAUSCHKE, W.: Lager im Bauwesen. Verlag von Wilhelm Ernst & Sohn, Berlin-München-Düsseldorf. 1974

10 RAHLWES, K.: Lagerung und Lager von Bauwerken. Betonkalender 1977, Teil II. Verlag von Wilhelm Ernst & Sohn, Berlin-München-Düsseldorf. 1977

11 THUL, H.: Brückenlager. Der Stahlbau 12/1969. S 353 - 360

12 RESINGER, F.: Längszwängungen - eine Ursache von Brückenlagerschäden. Der Bauingenieur 46 (1971) S 334 - 338

13 EGGERT, H.: Lager für Brücken und Hochbauten. Der Bauingenieur 53 (1978). S 161 - 168

14 ANDRAE, W. und LEONHARDT, F.: Neue Entwicklungen für Lager von Bauwerken, Gummi- und Gummitopflager. Die Bautechnik 2/1962. S 37 - 50

15 ANDRAE, W., BEYER, E. und WINTERGERST, L.: Versuche und Erfahrungen mit neuen Kipp- und Gleitlagern. Der Bauingenieur 37 (1962). S 174 - 179

16 HEHN, K.H.: Prüfeinrichtung zur Untersuchung von Lagern. VDI-Zeitschrift 118 (1976). S 114 - 118

17 HAKENJOS, V. und RICHTER, K.: Dauergleitreibungsverhalten der Gleitpaarung PTFEweiss/Austenitischer Stahl für Auflager im Brückenbau. Strasse-Brücke-Tunnel 11/1975. S 294 - 297

18 UETZ, H., HAKENJOS, V. und BRECKEL, H.: Grundlagen zur Entwicklung und Prüfung von Brückenlagern aus Polytetrafluoräthylen. Materialprüfung 10 (1968) S. 23 - 24

19 KOESTER, W.: Expansion Joints in Bridges and Roads. 1969. Button E.P., American Elsvier Publisher, 201 Park Avenue S., New York N.Y. 10003

20 TSCHEMMERNEGG, F.: Verwendung von Kunststoff und wetterfestem Stahl sowie Rationalisierung der Fertigung im Stahlbau am Beispiel der Entwicklung dynamisch hochbeanspruchbarer, wartungsfreier, wasserdichter Fahrbahnübergänge
Der Bauingenieur 47 (1972). S 315 - 325