Latest developments and applications for bridge bearings

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Summary

The paper gives a brief introduction into the world of large bridge bearings with a focus on performance in service and durability as well as means of in – situ control of the behaviour of the entire bridge through intelligent bearings.

Attention is paid to quality assurance and testing procedures, admittance testing, detailing and production procedures which are all crucial to the overall durability of the bearings. Clever design thinks always ahead and bearings can be designed so that they are replaceable when their service life is over.

Based on the high quality of bearings and a stable quality focused customer base, technological advances such as lifting bearings or force measuring bearings are possible. This culminates in the development of electronically equipped bearings for remote monitoring.

In summary, the paper explains how a quality focused approach to bearing manufacture, attention to technical detail and a forward thinking approach to bearing design can provide a full range of long term solutions for all kinds of problems that normally arise on bridges.

1. Introduction

The main function of a bridge bearing is to transfer the loads, movements and rotations of the bridge superstructure into the abutments and piers. As all the loads from the superstructure are transferred through the bearing and the movement is also controlled, albeit being a small item in the overall bridge structure, bearings form an integral part of the bridge, without which the structure could not function properly and would fail. What is more, bearings can be used to measure the force flow through the entire structure and can therefore help to assess the stress to which the structure is subjected to and make predictions on the remaining service life.

2. Proper design of bearings

State of the art bearings are pot bearings, which consist of a steel pot and lid in which an elastomeric pad forms a damping reservoir in which the movements are accommodated, rotations are allowed and small shocks and vibrations of the bridge can be mitigated. The design of this pot has been optimised over the years through practical experience and sophisticated engineering tools such as FEM analysis.

The detailing has been refined by years of experience. For example, two different sealing materials (Polyoxymethylen and brass) can be used to prevent dirt and corrosive liquids from entering the elastomeric reservoir inside the pot. Each of these materials has its own advantage and is carefully selected for each situation. Where high stresses are expected special sliding materials with a much higher abrasion resistance than ordinary PTFE (Robo®SlideBlue) have been developed.

mageba has the capability to test the performance of its bearings using its unique testing rig which is capable of applying test loads of 100’000kN. This makes it one of the largest test rigs available in the world. Therefore, the theoretical behaviour of bearings can be compared to its performance under load. This is sometimes an important quality assurance tool especially for large bearings.

Long term tests have shown the capabilities of each of the materials used for the bearings such as silicon grease, PTFE, special polished stainless steel and other components used for bearing construction. In the hands of a capable designer and controlled production, these established and new materials are used to build extremely durable bearings.

In the long term good design and high quality materials are more economic in bridge bearing construction than on first glance cheaper bearings, which do not last as long. This is explained in detail in Chapter 4.

Over the decades different problems occurring in bridge construction has led to the invention of various different and innovative bearing forms. These are explained in the following Chapter.

3. Different types of pot bearings

Pot bearing exist in three basic forms: free, guided and fixed (Type TA, TE and TF). The movement capacity of each bearing is adapted to the requirements of the bridge. However, there are various variation from the standard pot bearing such as uplift bearings, with which negative loads can be transferred into the structure. It is a difference (design and price wise) if these uplift forces are permanent or temporary only.

For launching bridges, there are two options during the launching process the bridge is supported on a temporary bearing, which is removed after the construction is finished and replaced by ordinary bearings. However, it can be more economical to integrate the launching bearings into pot bearings and transform them into incremental launching bearings (ILM bearings). These stay in place after construction has finished and work as both launching bearing and pot bearing.

In earthquake zones, very often special rubber bearings with a high damping capability, so called HDR bearings, are used. However, as all rubber bearings these bearings are subject to ageing and the rubber material over time looses is flexibility and thus its damping capacity. Therefore, a clever combination of pot bearings with hydraulic dampers, which last a lot longer than rubber bearings, is the logical answer to this durability problem (Type HDB bearing).

Settlement of bridges sometimes occurs even when it was unforeseen. There are some possibilities to deal with such a problem and mageba has developed a system (Reston®Pot Inject) to lift existing pot bearings by a few millimetres, which is often sufficient to compensate the settlement and also one of the most cost effective ways of dealing with this issue. Where larger foreseen settlements occur, or for other special applications a pot bearing with integrated hydraulic piston (Reston®Pot Control Lift) can be used to compensate for these settlements. This system can also be integrated in a monitoring station to measure the actual loads on the structure (Robo®Control). This is explained in more detail in Chapter 5.

4. Life cycle analysis of bearings

A life cycle analysis was carried out for the bearings to be used on a very large bridge project where a highly corrosive (marine) environment, earthquake loads and due to the size of the bridge, also a high frequency and amplitude of rotations were expected. To accommodate this high stress level, two different quality levels of pot bearings were compared in this life cycle analysis and the budget needed for these two solutions over a period of 150 years was assessed.

4.1 Model Assumptions / Exclusions

Three different parameters were taken into consideration for the life cycle analysis. These were a corrosive environment, the high degree and frequency of rotations and earthquake loads. The corrosive environment will lead to a breakdown of the corrosion protection of the steel and commencement of corrosion after the breakdown of the coating. This will take place, depending on the applied corrosion protection system and its level of maintenance, after about 20 years. The remaining service live would be an additional 10 years when corrosion has started. The total service life of the bearings would be of the order of 30 years. However, this is largely dependent on M&R spending and could be increased much beyond that period of time, when M&R of the corrosion protection takes place at frequent intervals. For the sake of this analysis it was assumed that damages to the corrosion protection would not be repaired, leading thus to a 30 year life cycle. This effect is depicted in Figure 1.

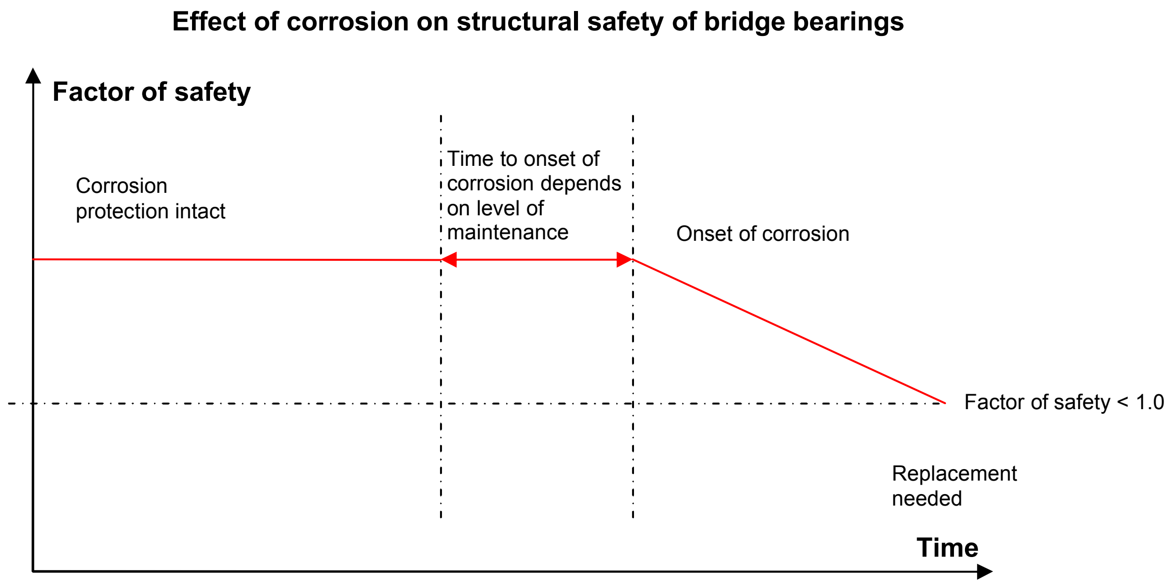

Figure 1 Effect of progressive corrosion on factor of safety of bridge bearings

While low cost pot bearings might be accepted for some bridges even though they have a lower durability, high quality bearings are in almost all instances the better choice, especially where a high degree and frequency of rotations is to be expected. This increased wear and tear load will result in the wear parts (such as PTFE disks) having to be replaced earlier compared to wear and tear parts of bearings located bridges with low expected stress levels.

For the purpose of the analysis it was assumed that two 50 year earthquake events and one 120 year event would occur. It can be assumed that a certain fraction bearings will be damaged beyond repair during the earthquake and will need replacement. Another fraction will be damaged and will need repair. This fraction is likely to be higher for low quality than for high quality pot bearings due to intrinsic design principles and redundancies with regard to sliding, rotation and behaviour under ULS loading.

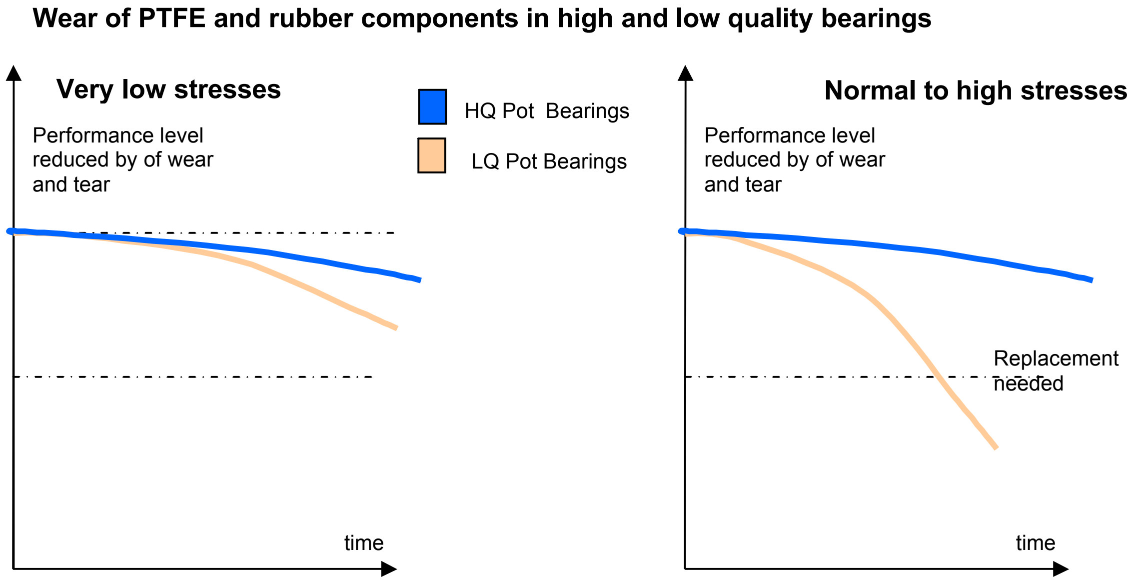

Figure 2 Performance of high and low quality bridge bearings of a normal bridge (normal rotations etc.) compared to a bridge with high degree of rotations.

4.2 Comparison of Initial Costs

In general, high quality pot bearings are about 2 – 2.5 times the price of low quality pot bearings, due to the intrinsic quality assurance processes involved in design, procurement and manufacture. However, when a bridge is subject to a high stress levels, the price even of low quality pot bearings will increase by about 1/3rd compared to ordinary pot bearings as design modifications have to be made in order to being able to take the high stresses. This is also schematically shown in Figure 3.

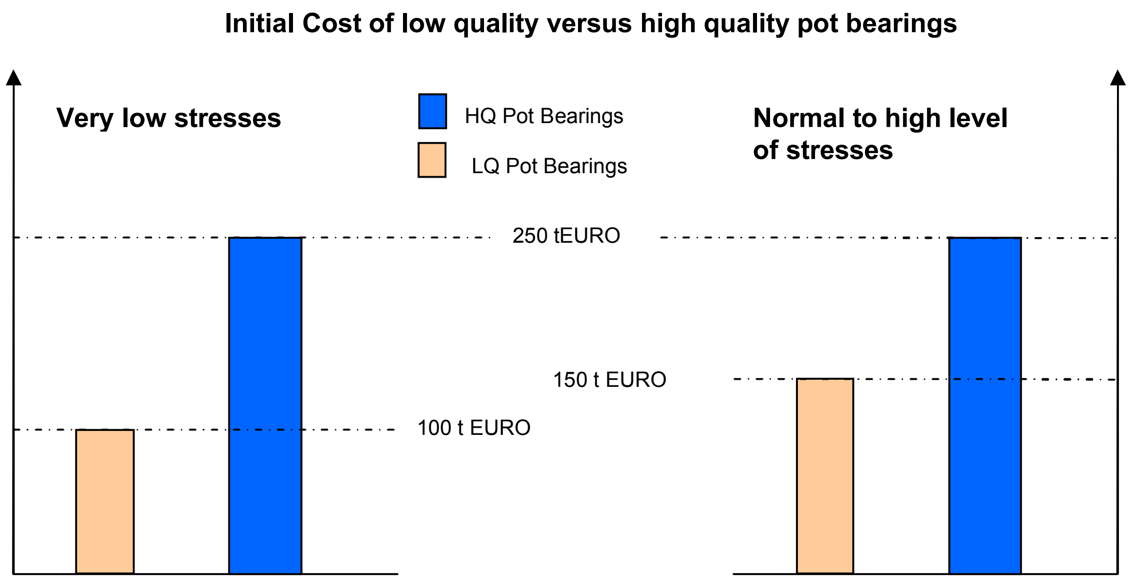

Figure 3 Initial cost of low quality pot bearing versus high quality pot bearings for a bridge subject to low stresses compared to a bridge subject to normal to high stresses.

For an ordinary large bridge the initial cost of low quality pot bearings is about 100’000 EURO, the price for high quality pot bearings about 250’000 EURO. In order to resists the high frequency and amplitude of rotations, certain design modifications would be necessary for the pot bearings raising the initial costs to about 150’000 EURO while the initial costs of the high quality pot bearings remain unchanged. The costs for the installation of low quality bearings is the same as for the high quality bearings and will therefore most certainly not change the overall result of this life cycle analysis.

4.3 Results of Life Cycles for low and high quality pot bearings

The results of the life cycle analysis of low quality versus high quality pot bearings are shown in Figure 4.

Despite lower initial and replacement costs, the expenses for low quality pot bearings will be 40% higher over the life time of the bridge with normal high degree of stresses than that for high quality bearings, under otherwise identical conditions.

This is caused by two factors:

1. First increased, maintenance and repair (M&R) spending due to premature wear and tear of rubber components of the bearings (see also Figure 2).
2. And second, in case of earthquakes a higher level of damage would be expected to occur in low quality pot bearings than in high quality bearings.

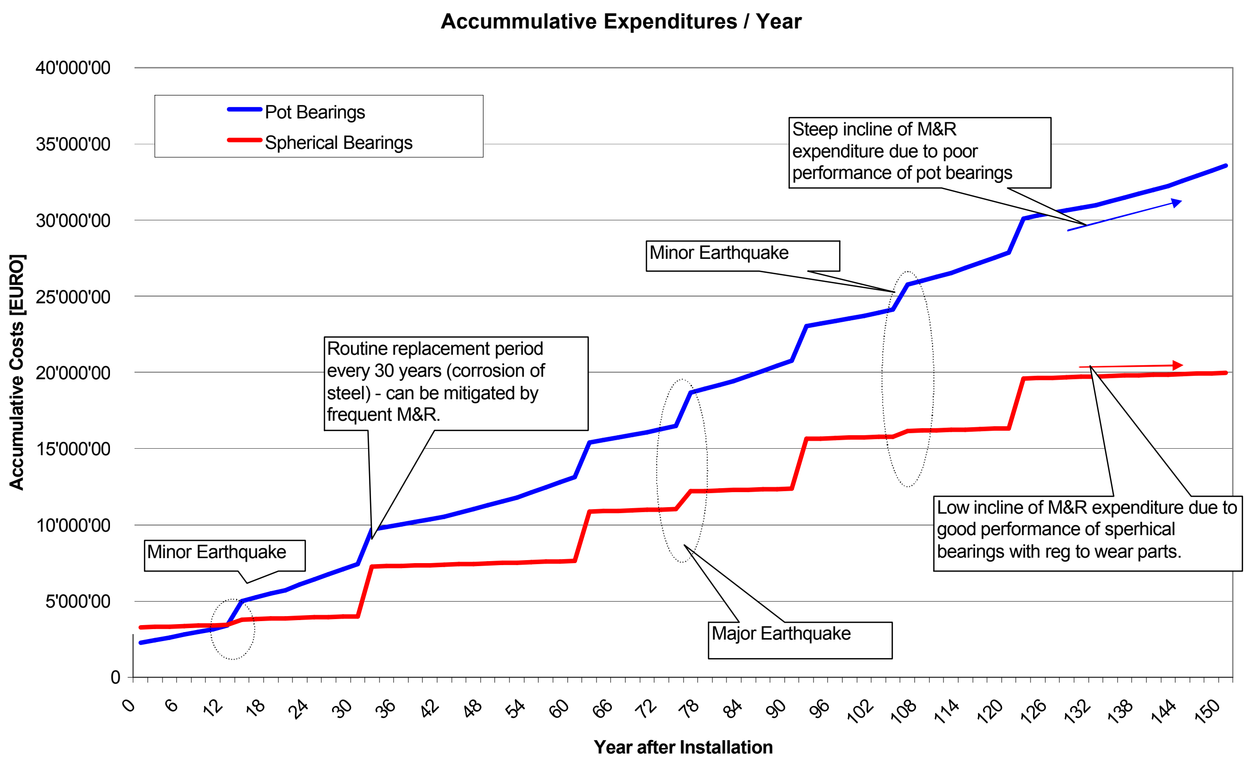

Figure 4 Results of life cycle analysis of low quality versus high quality pot bearings

With regard to the 40% higher accumulative cost of low quality pot bearings compared to high quality pot bearings for the bridge subject to high stresses, it is recommended to install high quality pot bearings, despite higher initial costs. The 30 year replacement cycle depends upon the integrity of the corrosion protection system. Should this be maintained at a high standard, the life cycle of high quality bearings is going too much longer than 30 years.

An optimised level of M&R spending could also be determined using the actual loads and stresses on the structure. These could be monitored using a Robo®Control, a remote monitoring system developed by mageba. This is also presented in the following Chapter.

5. Remote monitoring and control of bridges

To obtain a clearer understanding of the loads and other behaviour of a bridge mageba has developed a new remote monitoring system. The so called Robo®Control is a fully automatic and very robust bridge remote monitoring system, which can measure the following parameters:

- Force measurements are carried out on bridge bearings through preinstalled force measuring devices; however, they can also be retrofitted through mageba developed processes (to be resolved on site).
- Displacement measurements on expansion joints through additional installable displacement sensors, based on ultrasonic or magnetostrictive measurement technology.
- Vibration measurements can be performed either with conventional strain gauge or fibre optical sensors.
- These measurements can be used to secure evidence (see Figure 5) and the performance of the structure is recorded (see Figure 6).
- Temperature measurement through several temperature sensors.
- Other sensors, for example anemometers, cameras or inductive loops can be integrated on demand.

Figure 5 Monitoring system set up to act securing photographical evidence. Shown are the pictures taken from a web camera, which is triggered by strain measurements.

The Robo®Control system can be installed independent of from the conditions found at the bridge site, because its components can be powered by solar-energy. The system guarantees a power supply of 24 hours a day, 365 days a year; this means that even during night and winter, the data stream is guaranteed. In the event of using power and data intensive measuring methods, power is taken from the electric mains; however, a batteries bank is used to achieve a temporary redundancy, avoiding operation failure without prior warning.

Measured data analysis takes place on twofold: First, data is analysed and compressed on site. Afterwards, data is transmitted either as average value or at previously defined intervals. Different measuring methods make it possible to perform critical checks directly at the sensor and then to transmit an alarm message.

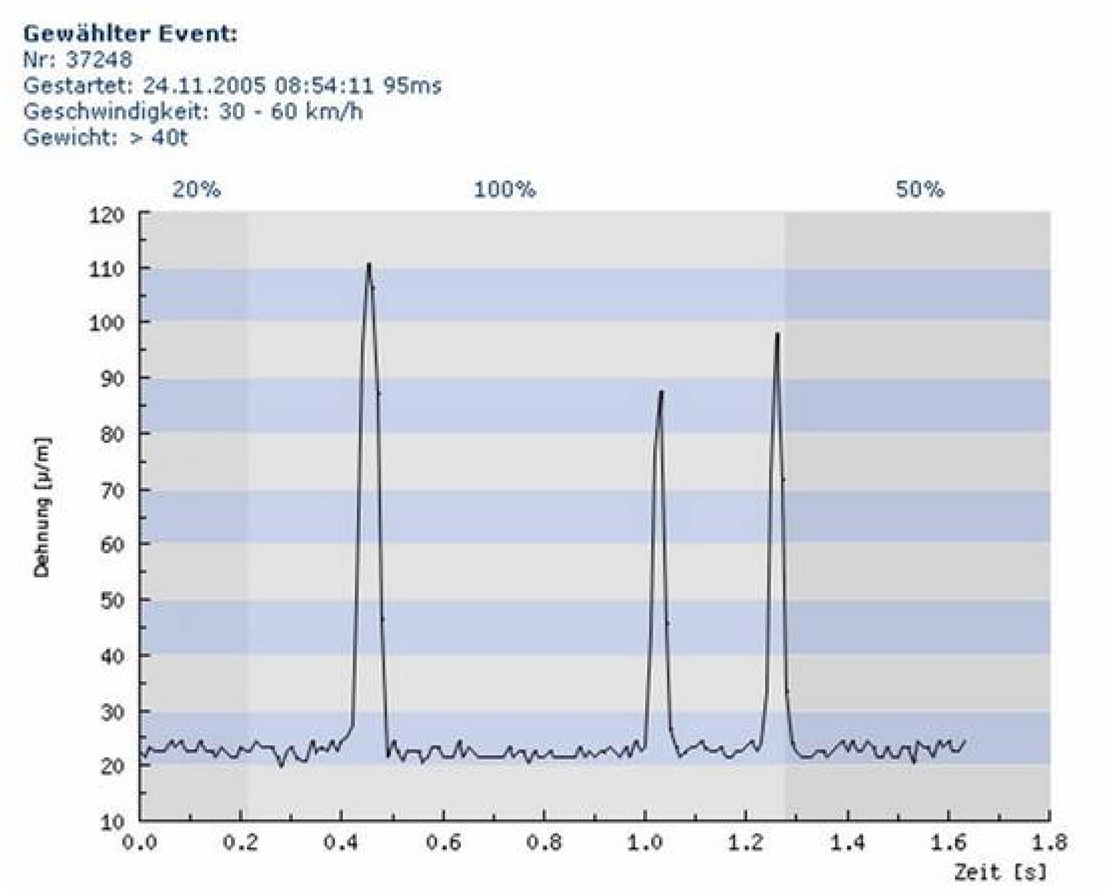

Figure 6 Recorded strain and vibration measurements measurements.

Finally, data is transmitted to mageba in a data packet and analysed once again. The data is transmitted either by means of a GSM/GPRS/UTMS module to a central computer system. There, the data is processed and the end user is able to access them through a secure web page. Now, plausibility checks such as transverse sum, long-term comparisons and other possible, necessary analysis take place.

Data presentation on Internet is by means of a secure web page, which can only be accessed through a username and password. In addition, sensible data as for example alarm parameters, can only be modified in agreement with mageba. Measured data are graphically displayed on Internet. Starting with an overview page containing structures images, technical drawings and descriptions, the client is redirected to the measured data page. There, all measured parameters, possible alarm parameters settings, as well as sensors detailed views are displayed. In addition, the client can download data as CSV files at any time for further analysis.

6. Conclusion and Outlook into the future

The service life and performance of bridge bearings is greatly influenced by the quality of its design, the detailing and components used and high quality bearings can greatly reduce the overall cost of a bridge structure over its life-time. Furthermore, there is a variety of improved sliding materials available from mageba, which could increase the service life of joints as well as bearings much beyond 30 years.

High quality bearings are more expensive to manufacture, but offer better durability due to a superior performance under normal to high level of stresses and also show a better redundancy under earthquake loads than low quality pot bearings. Under otherwise similar conditions, high quality pot bearings will therefore be about 40% cheaper than low quality pot bearings, even though the initial cost is about 40% higher.

What is more with high quality bearings, instead of relying on a theoretically determined intervention date, a remote monitoring system can be used, which measures actual loads and stress on the structure. This does allow an accurate budgeting and directed maintenance spending.