Expert Knowledge

Expert Knowledge:
Life-cycle cost analysis of structural bearings

Bearing Fruit

Introduction

That life-cycle costs should be considered when specifying and selecting bridge components such as bearings, as in any modern construction project, is today widely accepted. It is particularly true in the case of long and multi-span bridges due to the increased complexity of the demands and challenges they generally present, such as higher loading, greater multi-directional movements and more significant vibrations.

This paper presents an overview of the considerations affecting life-cycle costs for bridge bearings, with reference to factors right throughout the life-cycle of the bridge. It is important to consider the life-cycle of the bridge as opposed to that of its bearings, in order to include the costs of bearing replacements during the bridge's life. The costs of bearing replacements include not only supply costs but also installation costs (generally requiring lifting of the bridge deck), traffic management costs and the bridge user costs associated with delays, and are thus far higher than the initial bearing supply and installation costs at the time of the bridge's construction. It is therefore critical, in managing and minimising life-cycle costs, to ensure that the number of times the bearings need to be replaced during the bridge's life is kept as low as possible.

Challenges faced by bridge bearings

The bearings that support a bridge deck are not only (or always) required to:

- transmit vertical loads from the deck to substructures
- resist horizontal forces (longitudinal and/or transverse) while accommodating deck movements and multi-axial rotations as required by the bridge's design
- be replaced several times during the bridge's long service life as they are much less robust than the main bridge structure

As a result, it is important to carefully consider, during selection and design of the bridge's bearings, the complete life-cycle of the main structure and of the bearings themselves.

Life-cycle cost analysis

A great deal has been written to assist engineers and owners in the assessment of life-cycle issues, and the field of bridges is no exception – for example, with the 2003 report, "Bridge life-cycle cost analysis" (Hawk et al. 2003), published by the Transportation Research Board of the American National Research Council as Report 483 of the National Cooperative Highway Research Program (NCHRP).

This report notes, in relation to Life-Cycle Cost Analysis (LCCA): "LCCA is essentially a technique for considering the economic efficiency of expenditures". It goes on to define Life-Cycle Cost (LCC) for a bridge in terms of its constituent parts, as follows:

Equation 1

$$LCC = DC + CC + MC + RC + UC - SV$$

where

- **DC** = design cost
- **CC** = construction cost
- **MC** = maintenance cost
- **RC** = rehabilitation cost
- **UC** = user cost
- **SV** = salvage value

Life-cycle cost analysis thus represents a great improvement on the "traditional" approach often used in the construction of infrastructure, which considers only the initial direct costs of design and construction (i. e., the terms DC and CC in the equation above). This is explored in more detail in the next section, for the specific case of a bridge's bearings.

The importance of selection, design, installation and maintenance

It can be inferred from the foregoing statements that it is important that the complete life-cycle of a bridge's bearings be carefully considered when selecting, designing, fabricating, installing and maintaining them. This can be confirmed by closer analysis of the life-cycle costs, starting with a definition of what they include. **Equation 1**, formulated to define the life-cycle costs of a bridge as a whole, can reasonably be considered generally applicable also to the bearings within the bridge. Adapting **Equation 1** slightly for use in relation to bearings (with salvage value neglected):

Equation 2

$$LCC = ISC + IIC + IMC + DRC + UC$$

where

- **LCC** = life-cycle cost of bearings during life of bridge
- **ISC** = initial supply cost
- **IIC** = initial installation cost (at time of bridge construction)
- **IMC** = inspection and maintenance cost
- **DRC** = direct replacement cost
- **UC** = user cost

It is important that the life-cycle to which reference is made is that of the bridge structure, and not of particular bearings which are installed in the bridge at a particular point in time (e. g. at the time of the bridge's construction). This is an important distinction, because only consideration of the bridge's life-cycle will take account of the most significant costs associated with its bearings:

- the cost to the owner of periodic replacement works
- the user costs that accompany those works

The variety of costs

Sequential and proportional costs

The first 4 of the 5 costs on the right of **Equation 2** (ISC, IIC, IMC and DRC) are classified as Agency Costs, which are carried by the responsible agency or bridge owner, as opposed to the User Costs (UC) which are carried by the bridge's users (which include motorists and others who cross the bridge, and possibly the businesses and residents of nearby areas that rely on the bridge for access).

The significance of each of these cost groups is discussed below.

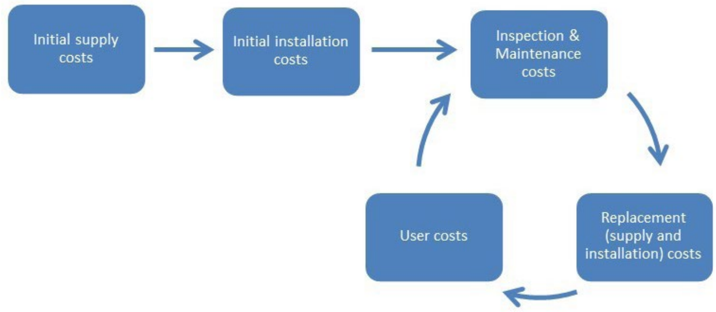
- **Initial supply and initial installation costs**
  The costs of supply and installation in a new bridge of its bearings depends on many project-specific factors, such as (perhaps most significantly) the forces the bearings must carry/resist and the deck movements they must facilitate. But the costs are also somewhat related to the construction costs of the bridge as a whole: the forces the bearings must carry/resist depend on the size/weight of the bridge, and the deck movements to be facilitated by the bearings increase with the bridge's length and width.

- **Inspection and maintenance costs**
  There are two general approaches to infrastructure management, proactive and reactive, and, in general, only the proactive approach can be recommended in the case of a bridge's bearings. Inspection and maintenance work is an essential part of the proper management of any bridge, and even more so in the case of its bearings, which as noted previously are less robust but subjected to greater demands than the bridge as a whole. Unfortunately, the reactive approach is applied far too often, with bearing issues only being addressed when a safety hazard has developed or the deck is being rehabilitated or replaced. A change of mind-set is therefore required of many of those who are responsible for inspection and maintenance activities; it should be recognised that the costs of a sensibly planned inspection and maintenance regime are well invested, and will likely result in much greater long-term savings by reducing the need for expensive reactive repairs and by delaying or avoiding the need for bearing replacement work.

- **Direct replacement costs**
  As noted above, a bearing of any type has a shorter life expectancy than the main structure on which it is installed. The direct cost to the owner of the replacement works that become necessary at the end of the service life of a particular bearing can be very significant. At any rate, due to the costs of site mobilisation, provision of access to the bearings, lifting of the deck, traffic management, etc., the costs are likely to be much higher than the initial supply and installation works that were carried out when the bridge was under construction (Fig. 2). Therefore, in order to minimise the life-cycle costs of a bridge's bearings, during the life of the bridge, it is clearly necessary to minimise the number of bearing replacements – by the use of bearings of suitable quality and durability, and proper attention to inspection and maintenance activities.

- **User costs**
  The user costs associated with a bridge's bearings result primarily from the disruption to traffic that is caused by bearing maintenance or replacement works. The assessment of these costs requires the estimation of such factors as the number of vehicles and occupants which will suffer delays, the average length of delays, the cost per hour per vehicle or occupant, and increased fuel consumption.

1



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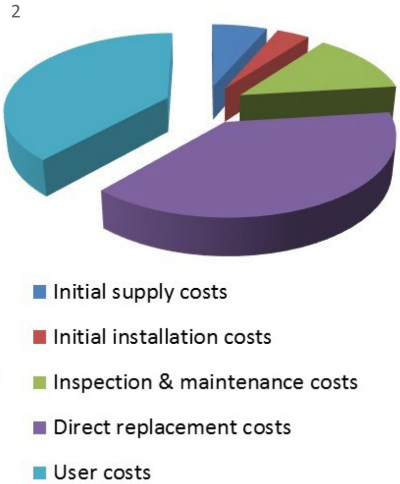

1 Representation (sequential) of the life-cycle costs of a bridge's bearings

2 Representation (proportional) of the life-cycle costs of a bridge's bearings (typical)

User costs will therefore vary greatly from one structure to another.

This emphasises once again the importance of minimising the frequency at which the bearings of a bridge will have to be replaced; by the use of bearings of high quality and high durability, and proper attention to inspection and maintenance, life-cycle costs can be minimised.

How to minimise?

The life-cycle costs of a bridge's bearings may be minimised in a number of ways, with reference to their constituent parts.

Careful bearing selection

First of all, the suitability, durability and quality of the bearings selected for use should always be maximised – for example:

- by clear specification of the demands to be satisfied by the bearings
- by selection of the optimal bearing type
- by verification of long-term bearing performance
- by evaluation of the needs of the preferred bearing type
- by designing bearings to maximise durability and extend service life
- by bridge design measures which can protect bearings and extend their lifespan
- by ensuring the quality of design and manufacture

Correct installation

Correct installation is also critical for long-term performance. This requires, for example, that the sliding surfaces of sliding bearings are parallel to each other and to the direction of deck movement, and that the bearings are installed with the correct presetting (considering the prevailing structure temperature at time of installation). It is also important that a bearing's transport fittings, which hold it together until fully installed, are cut at the correct time to avoid damaging constraint forces. The probability of a bearing's being installed properly can be enhanced by the provision of proper access, and by limiting the size of each bearing for improved constructability – e. g. by the use of spherical bearings with UHMWPE sliding surfaces, which are typically roughly twice as strong as other steel bearings containing PTFE or elastomer.

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Proper inspection and maintenance

A further contribution to good long-term performance can be made by ensuring the adequacy of inspection and maintenance activities – e. g. by providing adequate resources, ensuring proper access, and promoting technical understanding among staff. Proper inspection and maintenance can also be supported by the provision of type plates and movement scales, and the keeping and consultation of proper records of previous installation, inspection and maintenance work. Often, automated structural health monitoring systems can also assist greatly.

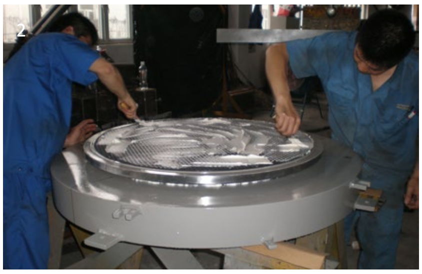
Special design measures

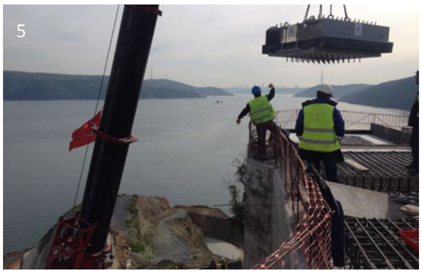
Finally, considering the significance of bearing replacement to life-cycle costs, bearing and bridge design should consider bearing replacement – e.g. by the provision of anchor plates.

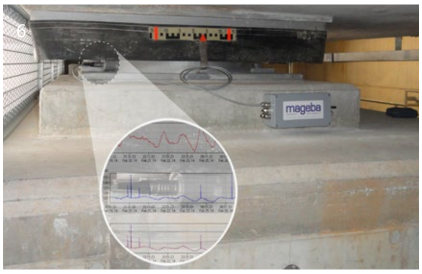
Conclusion

Consideration of the life-cycle costs of a bridge's bearings – including costs of maintenance and replacement throughout the bridge's life, and related user costs – thus demonstrates the **importance of devoting adequate attention and expenditure to the procurement, installation and maintenance of high-quality, well-detailed bearings.**
In particular, it also highlights the **importance of devising bridge construction contracts** in such a way that the party that selects the bearings has a real incentive to ensure their long-term performance.

Recognition of these key issues, and consideration of measures that can assist in implementing a long-term strategy, can thus help minimise the life-cycle costs of a bridge's bearings – **for the benefit of owners, users and society at large.**







1 Installation of elastomeric bearings on top of bridge piers
2 Pot bearing with sliding material
3 Spherical bearing to be installed in a building structure
4 Proper quality check of disk bearing
5 Correct installation of bearings in a superstructure
6 Strucutral health monitoring systems supporting proper inspection and maintenance