Structures entailing bridge bearings and expansion

The differential construction method in bridge construction

by Christian Braun

In analogy to mother nature, the evolution in bridge construction lead to a functional and thus to a differential construction method. This way, in avoiding constraints at critical (structural) locations, long-lived and robust structures emerged. This was and is being achieved with modern bridge bearings and expansion joints. Due to their relatively simple installation, long service life and low maintenance costs these structures are economical and with low exposure to disruption. Environmentally friendly and recyclable material as well as the effortless replacement of smaller units contribute to sustainability.

1 Introduction

In bridge construction, the construction method as well as the aesthetics are predominantly shaped by the structural elements. Due to the technical challenges of modern bridge construction on the one hand and the cost- and environmentally related general conditions on the other hand there exists a continuous selection and optimization of the products employed. Some of these products display disadvantages cuased by their function, for example a limited service life. However, such products can only be relinquished if the economical and ecological total balance does not become negative.

An „Optimisation of the Necessary‟ is therefore the better alternative. The knee joint or the intervertebral discs are problem zones of the human body – however as parts of a body rather a result and not the cause of natural evolution.

This paper is about normal bridges with bridge bearings and expansion joints as well as the possibilities of optimization. Thereby, the notion of a "Differential Construction Method", which is an established notion in mechanical engineering, is being introduced.

2 Definitions

2.1 Differential Construction Method

The differential construction method is defined as an optimum usage of materials and structural members in dependence on their respective function. "Differential" can thus also be termed "functional" or "normal". In distinction to the "integral construction method" this definition is reduced to the permission of planned and constraint free motions in joints.

2.2 Integral Construction Method

Integral bridges are defined as framework like structures without bridge bearings and expansion joints, and with an integration of the superstructure into the abutment or the pier.

3 Particularities and advantages of differential bridges

Caused by external and internal effects, materials and structural elements are subject to deformation. To a certain degree such deformation is being accommodated by the resilience of the structural members or by way of constraints. If limits are being surpassed, cracks may occur, or fatigue damages. Evolution now translates into the increase of positively acting characteristics, and the decrease of negatively acting characteristics. In the nature, evolution leads to the reduction of constraints. And the very same also holds for bridge construction: expansion joints and bridge bearings facilitate movements and ensure the functionality of the structure.

So we speak of differential bridges if both expansion joints and bridge bearings are being employed.

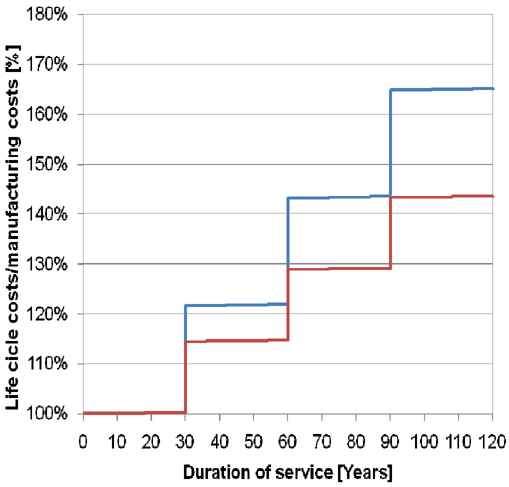
Differential bridges are characterised by clearly defined interfaces to their environment and within the structure. This leads to many advantages:

- can be used for all types of structures and construction methods,
- arbitrary combination of materials
- freedom of design
- modular and precast construction method possible,
- separation of geotechnics and structural design
- Independence from uncertainties in foundations and soil values
- minimisation of the risk of the subsoil and the system for the builder
- manageable engineering services independent from the category of traffic
- defined structural safety and statical sysmtes
- compensation of the dependence on time of the characteristics of the material and the structural members
- compensation of the mean variation of material characteristics
- adaptation to changed impacts (temperature, traffic loads) possible,
- seismic isolation possible
- simple conditions for transportation
- defined conditions for installation (temperature at installation, creep and shrinkage)
- superior fail-safe behaviour, thus less monitoring required
- simplified assessment procedures and consequently reduced work load for inspection
- avoidance of cracks in the structure leading to irreparable long term damages
- avoidance of damages in the asphalt
- simple maintenance methods that can be planned ahead
- partial repairs and disassemblies possible
- advantages in recycling

4 Economics of differential bridges

4.1 General

Publications concerning the integral construction methods cite the high maintenance costs of bridge bearings and expansion joints. For example "Composite bridges with integrated abutments (…) prove to be more economic in construction and maintenance, because beridge bearings and expansion joints which take a major share of the total maintenance costs of a structure are missing" [1]



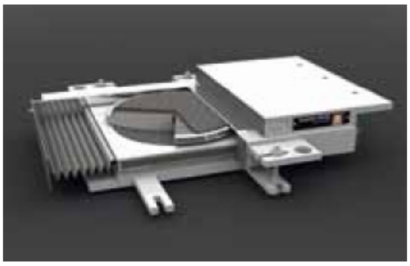
1 *Cost comparison: Frame bridge in composite construction and two-field-concrete-bridge © from [2] [3]*

An investigation at an exemplary structure which was conducted in the course of a research project for the enhancement of composite structures [2] points exactly to the opposite, as can also be illustrated by the following example:
Because of an additional pier in the river, a concrete bridge is about 50% more expensive than a composite bridge. The maintenance work which is conducted every 30 years for the corrosion protection and the cap take the major share of the maintenance costs. Although for the single seal expansion joint a life time of only 20 years was assumed which is too little anyway, and for the replacement of the strip seals a period of 10 years was assumed, the expansion joint and the 6 bridge bearings have no perceptible influence on the total costs (construction and maintenance) of the concrete bridge. Unfortunately, during the investigation the maintenance costs of the pavement were not considered, which are of dominant nature.
The total maintenance costs within the design life time of 100 years take about as much as the construction of the bridge. Of this, 10% are attributed to the expansion joints and bridge bearings, which take only 3% of the total procurement costs of the bridge [4]. The highest share with about 70% consider the maintenance costs for pavement and concrete, as well as for the corrosion protection.

Bridge bearings and expansion joints are exposed to demanding strains. Therefore, only such products have to be employed which either withstand in a functional way to all the exposures over the total life time of the bridge (e.g. bridge bearings), or they shall be replaced only in the course of a defined maintenance period at the structure (e.g., expansion joints). This way, maintenance costs for such structural members can be kept relatively low.

4.2 Bridge Bearings

In bridge construction, usually reinforced elastomeric bearings are being employed, or point rocker sliding bearings [5]. According DIN EN 1990:2002, Table 2.1, for bridge bearings a design life time of 10-25 years is being defined. At the hand of modern bridge bearings, such a constraint is neither necessary nor reaching the objective. This can also be confirmed by the evaluation of the general bridge inspections of the German Institute of Road Administration (BASt). The most complaints result from corrosion at the steel members or surface cracks at the elastomeric bearings. Spherical bearings display the least complaints. [6] The life time of reinforced elastomeric bearings is characterised by ageing due to environmental influences as well as fatigue effects of the material. For bridges of smaller and medium spans, for which the integral construction method is being recommended, fatigue of material does not play a role. The use of Chloroprene ensures a sufficient environmental compatibility. In case that the mating couples steel-steel are being employed instead of a sliding couple, the fixation elements and the guide bearings are prone to corrosion and wear.



2 ***MSM®-spherical bearing with calotte made of sliding alloy MSA®***
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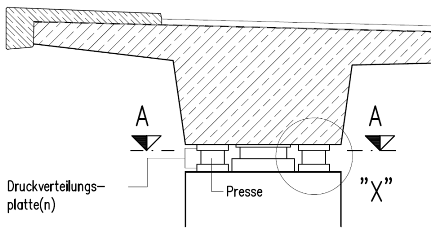
In case of point rocker sliding bearings the wear influences the life time of the tilting and of the sliding elements. Sliding elements made of PTFE acc. DIN EN 1337-2 or sealings of pot bearings acc DIN EN 1337-5 have their limitations in their accumulated slide paths. Spherical bearings with a special sliding element [7] however reach in case of bridges of smaller or medium main span the lifetime of the structure. Also for the tilting element (calotte) lately there exists a special sliding alloy as a corrosion resistant alternative, MSA®. Remains the corrosion protection at the outer surfaces, which can be taken care of in the course of general maintenance works. Apart from the corrosion protection, no other rehabilitation efforts are necessary.

Maintenance works are generally not necessary, und inspections can be carried out in the course of the general inspection cycle of the bridge. At the hand of procurement costs of 1-2% of the total structural costs and even lower costs for corrosion protection, modern bridge bearings give no cause for an avoidance of the differential construction method, in contrary: the motivation to go for an integral construction method just because bridge bearings shall be avoided is inefficient and cannot be properly evaluated in its expenditures.
For an eventual replacement of bridge bearings, at the substructure usually stationary toeholds for the press are being designed. These toeholds are usually not desired from a design point of view, and moreover create costs due to enlarged dimensions of the pier. Bridge bearings which shall be replaced only in exceptional cases, devising uplifiting points or adjacent structures for temporary uplifiting points (toeholds) for the press would be considerably more economic and aesthetic, as the two figures below illustrate.



3 ***Press arrangement at substructures; Directive drawing Lag 6, 2009***
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4 ***Viaduct Freimann at the BABA 9 temporary support for the installation of bridge bearings***
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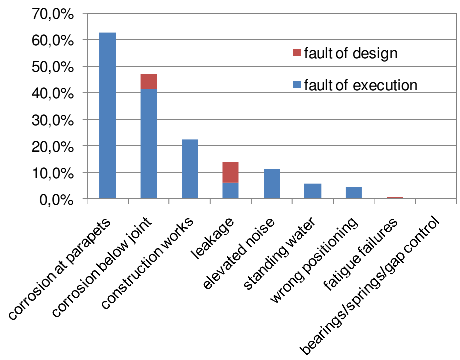
4.3 Expansion Joints

Expansion joints have to accommodate bridge movements and are being subject to strain just like the pavement. They count among the structural members which are subject to highest strain. They are subject to fatigue, to wear, and in comparison to the bridge structure, their lifetime is limited. Expansion joints in Germany have to cater for a service life of at least 40 years, and wearing parts that can be replaced without substantial inhibition of traffic, such elements have to endure 20 years (German specification, TL/TP FÜ).

For movements over 25 mm, as a general rule watertight expansion joints in lamella design are being devised, which can display the following essential shortcomings:

– fatigue damages at the steel structure
– malfunctioning of the bearing and control elements
– excessive noise development
– leakages
– corrosion



5 ***Damages at multi-seal Maurer-Expansion joints at Southern Bavarian Expressways © from [8]***

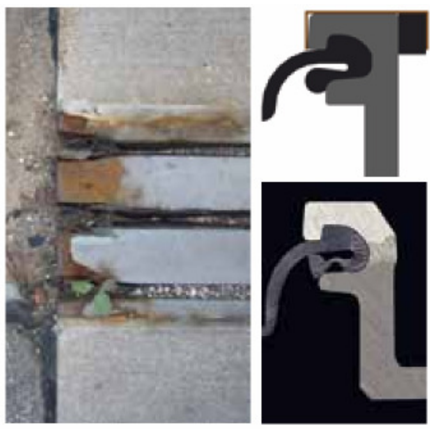
designed according to the German specification TL/TP FÜ, since 1994 almost no fatigue damages could be observed, also the supporting elements and control elements could be optimised into that direction. And for the reduction of noise emission, wave shaped covers have been employed for more than 10 years. Today's shortcomings concern leakages and corrosion. An investigation into multi-seal Maurer-Expansion joints which was jointly carried out with the Southern Bavarian Expressway Administration covered the results of all general inspections in the past 15 years. The result is illustrated above, displaying the distribution of the nature of the shortcomings, in relation to the numbers of expansion joints inspected.

6 7 ***Rounded design at the kerb unit and drainage of the strip seal © Maurer Söhne GmbH & Co. KG***

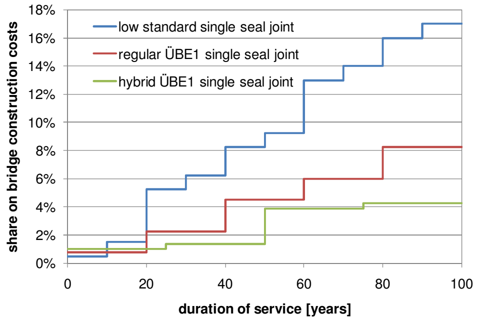
More than 60% of the expansion joints under investigation were not properly maintained. 50% of all leakages resulted from mechanical damage in service, and the other 50% from construction deficits in particular at the kerb units at the lowest points, and at the butt joint connections at site. The execution of butt joint connections therefore has to be improved in its implementation as well as in its quality assurance. Further, for the avoidance of damages at the kerb unit, a modified guiding of the profiles or a drainage is recommended. This would also reduce corrosion at the lower side of the expansion joints.

Corrosion at the upper surface of the footway area is mainly caused by clashes of cars to the kerb unit as well as by mechanically caused damages of the edge beams when cutting the joints at the concrete area. The latter is by far the most occurring cause for damage, and it could be prevented by temporary protection covers or by more careful work. Or by way of employing so called hybrid profiles with a stainless steel head. Expansion joints have procurement costs of around 10–15€/m^2 per surface area of bridge, which take about 0,50–1,00 % of the costs of the structure. When they should have to be replaced in the course of a general rehabilitation measure, it would cost three times as much, and should comprehensive traffic management be required which includes also the establishment of site equipment, it could cost as much as five or six fold. The replacement of the strip seal costs about half of the procurement costs, and when the corrosion protection should have to be renovated at the same time, double as much. It is therefore self-evident to extend the intervals of maintenance by way of constructive improvements, and so minimize the required maintenance works as well as the traffic management.

In Germany, bridges of small and medium main spans predominantly employ single seal expansion joints according to the directive drawing ÜBE 1 [9]. compares their costs for procurement and maintenance with other expansion joints which are available at the world market (life time maximum 20 years) and with novel stainless steel/hybrid profiles.



8 9 10 **corrosion damages on *footpaths, temporary cover profile and hybrid profile* *© Maurer Söhne GmbH & Co. KG***



11 **Acquisition and maintenance costs of expansion joints**
© from [9]

It is highlighted that the the procurement costs are of second importance to the total maintenance expenditures. Halving the procurement costs can quadruple the total costs. Not to be considered are here the damages at the structure as well as economic damages by way of inhibition of traffic. The integral construction method is also an alternative to avoid multi-seal expansion joints that require a special maintenance access from below. By way of novel type expansion joints in wave shaped design however the movement range can be increased to 95 mm without increase of maintenance works and simultaneously also taking advantage of the low noise emission of such joints.

5 Sustainability

Sustainability in bridge construction requires a construction method which is of high quality, economic and ecological. By way of increasing the lifetime of the products which leads to an avoidance respectively shortening of rehabilitation works, the aforementioned economic aspects also lead to national economical advantages caused by a decrease of traffic inhibitions. In the same time, the direct environmental impact is reduced
[9]. Due to the simpler construction method, differential bridges display a lesser environmental impact. Functionally separate structural members can be easily maintained, disassembled, and replaced
and disposed of in small units. Spherical bearings with special sliding material acc. 4.2 consist only of steel and UHMWPE. This sliding material is chemically resistant, environmentally compatible, and contrary to PTFE or elastomers free of harmful substances, so easy to be disposed of or to be recycled. Moreover, the reduced dimensions of such bridge bearings in comparison to other construction methods or concrete hinges result in a reduced environmental impact in construction, transportation, and disposal. By way of optimization of the individual structural members the probability of failure can be minimized. Consequently, differential structures can be considered as considerably more resource saving than integral structures.

12 ***Wave shaped single seal expansion joint***
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6 Summary

In combination with bridge bearings and expansion joints of long service life, differential bridges are economic and sustainable. Modern bridge bearings almost need no maintenance during the service life of a bridge. Expansion joints can be designed in a way that they need to be replaced only in the course of general maintenance procedures that are planned ahead. Procurement and maintenance costs for both products can reach 6% of the total costs of the bridge structure. For this, the slightly increased procurement costs for such long life products can easily be justified.

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