Load Testing and Monitoring of Swiss Bridges

by

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1. Introduction

Load testing of bridges offers an unique opportunity to investigate the behaviour of real structures. Over the past 20 years, the Institute of Reinforced and Prestressed Concrete (IBAP) of the Swiss Federal Institute of Technology (SFIT/EPFL) has performed more than 200 full-scale load tests of bridges.

Monitoring is a logical complement to load testing. While testing indicates how the bridge performs initially under short-term loading, monitoring investigates its behaviour over time. Ideally, bridge monitoring starts before the bridge is put into service, with an acceptance load test, after which the bridge is inspected at regular intervals throughout the rest of its life. Several post-tensioned concrete bridges have been instrumented in order to follow their deformations with time more closely and to detect possible abnormal behaviour.

2. Load Testing

The Swiss Codes recommend a load test for any new bridge with a span exceeding 20 m [15]. As a result, the majority of the load tests performed by IBAP are acceptance tests, carried out before the bridge is put into service. The objective of the load test is to determine and quantify the global behaviour of the bridge. The general acceptance criteria are:

- concordance between the measured and calculated deflections,
- presence of residual deformations,
- cracking,
- affinity between measured and calculated deflected shapes.

The loads used in a load test correspond roughly to 80% of the characteristic (unfactored) design loads, but have a rather large variation due to geometrical constraints. In general, this level of loading does not induce cracking in the structure. This is important for the Highway Authorities, particularly in the case of an acceptance load test, as they do not wish to have a new bridge unnecessarily damaged by unrealistic loading levels. This level of loading is relatively low compared to the factored design loads, and does not allow to extrapolate to the actual load-carrying capacity of the structure [9]. However, experience has shown a strong correlation between an unsatisfactory behaviour during a load test and an abnormal long-term behaviour of the bridge, characterised by a non-stabilisation of cracking and sagging. An abnormal behaviour of the bridge under its acceptance load test is an alarm signal, that generally leads to more frequent inspections, long-term monitoring and early maintenance work.

The principal results of the two hundred load tests have been collected in a computerised database. The large majority of the bridges contained in the database are post-tensioned concrete bridges. General information on the real behaviour of post-tensioned concrete bridges under short-term loading have been deduced.

2.1. Interpretation

The interpretation of a load test requires the design engineer to calculate the deflections at each of the measurement points. In his calculations, the engineer will need to assess the value of the various quantities describing the bridge: cross sectional properties, actual moduli of elasticity of steel and concrete, spans and loading conditions.

The modulus of elasticity of the structural concrete is a determinant parameter, as it is the principal component of the cross-sectional stiffness for uncracked cross sections (as is usually the case for post-tensioned bridges subjected to a load test). Unfortunately, the actual value of the modulus of elasticity is rarely measured on concrete specimens, and has a wide variation, making the estimation of the cross sectional stiffness difficult. Furthermore, the participation to the stiffness of "non-structural elements" such as reinforced concrete parapets or the asphalt layer is far from negligible.

2.2. Increased Understanding from the Database

A homogeneous data set concerning the load testing results on 82 continuous post-tensioned concrete bridges was extracted from the database. This data set was used to determine the contribution of the various "non-structural" components to the total cross sectional stiffness. Two distinct methods were used for the operation. The first method was statistical in nature: the bridges corresponding to each parameter (i.e. tested with or without R.C. parapets, etc.) were grouped, and their group characteristics and differences were filtered. By successively applying this method, the influence of each individual parameter was determined.

The second method, while still based on the database is more deterministic: for each bridge, the actual cross-sectional stiffness was computed, taking into account the parapets, the asphalt layer (with corrections for the actual temperature during the load test) and the reinforcement. The results were then averaged for the 82 bridges. The results of these investigations is shown in Table 1 [9].

Element	Contribution to cross sectional stiffness	
	statistical approach	deterministic approach
Asphalt layer	6%	5%
R.C. parapets	24%	28%
Reinforcement	6%	5%

Table 1: Participation to the cross-sectional stiffness of non-structural elements based on the statistical and deterministic approaches

Figure 1 shows the relative contributions to the cross sectional stiffness of the reinforced concrete parapets, of the asphalt layer and of the reinforcement for the data set of 82 bridges, obtained by the deterministic approach. It is clear that the contributions to the cross sectional stiffness of the "non-structural elements" cannot be neglected if the deflections of a bridge under a load test are to be accurately predicted.

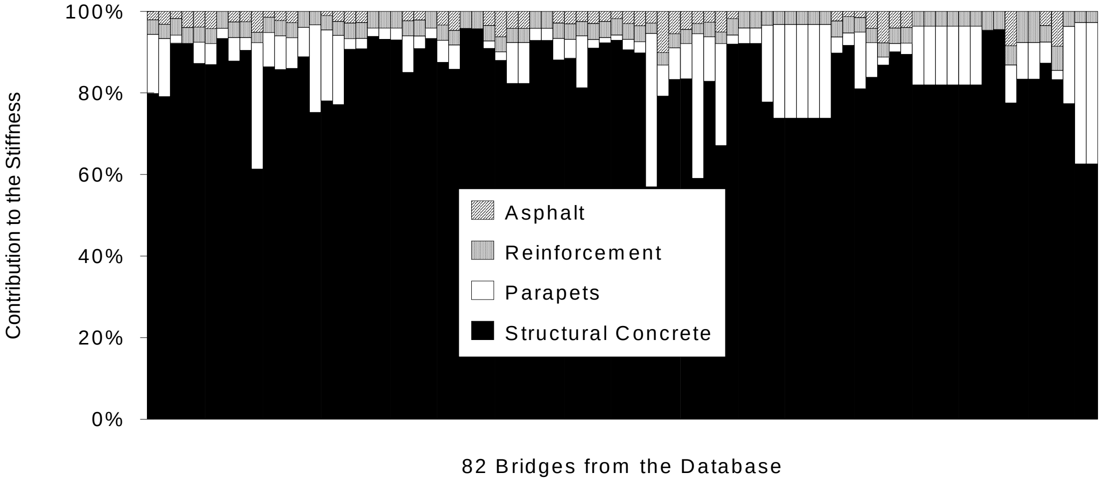

Figure 1: Contribution to the Cross Sectional Stiffness for 82 Post-Tensioned Bridges

The main contribution to the stiffness comes from the structural concrete. The actual modulus of elasticity of the concrete is often not known to the engineer, who must rely on code formulæ that are notoriously inaccurate. For bridges that have already been constructed, a good estimate of the modulus of elasticity can be obtained through the use of ultrasonic measurements [8]. For new structures, mechanical measurement on moulded specimens are more reliable and cost-effective.

3. Long-Term Monitoring of Deformations

Maintenance of the infrastructure is a of prime concern for public and private bodies in the end of this century. Thorough planning and careful investments are a necessity as resources are more scarce than they used to be. Long-term measurement of bridges is an effective method for the bridge owner, that allows him to be timely informed of deterioration and the need of maintenance for a bridge. For bridges that do not exhibit a satisfactory behaviour during the initial acceptance test, monitoring should be started immediately in order to detect structural deficiencies at an early stage.

It as well known that certain structures do not behave as expected. There is therefore a need on the academic and design side to better understand the actual behaviour of structures [12]. A better knowledge of the long-term behaviour of certain types of structures can also help to improve design and avoid past mistakes, for example by increasing the level of post-tensioning in new bridges built using a given construction method.

3.1. Deformations

Time-dependent effects such as creep and shrinkage of concrete and relaxation of prestressing steel are well known parameters that influence the behaviour of a structure under long-term loading. Of course, the actual initial value of deformation, i.e. the short-term deformation is also of great importance, as the long term deformation is usually expressed as a multiple of the short-term deformation. Creep alone can cause a three- to fivefold increase of the initial deformation. If, in addition to creep, cracking of the concrete occurs, the increase of the deformation can be significantly larger.

Creep and shrinkage normally occur during the first five years of the life of the structure. Therefore, the increase in deformation induced by these phenomena should be completed within about five years from the date of construction. However, it has been observed on several occasions that the deformations of post-tensioned concrete bridges have greatly exceeded the calculated values, and that the increase in deformation has continued more than ten years after construction. In such cases, long-term monitoring of deformations has been very useful in following the deformations and in determining if and when an intervention was needed.

3.2. Instrumentation

The instrumentation of bridges to monitor long-term deformations is a complex problem: the measurements must be repeatable and stable in the long-term. Additionally, it is desirable that the system be relatively inexpensive, so that monitoring can be performed on a large number of bridges. Hydrostatic levelling has been found to be a very accurate and efficient method to monitor long-term deformations of bridges [5]. Based on the laws of communicating vessels, a hydrostatic levelling system consists in a series of independent circuits of two or more graduated pots interconnected by transparent PVC tubing. The water level in all pots of a circuit is the same, allowing measurements to be taken in a fashion similar to optical levelling.

Figure 2: Longitudinal Section of the Lutrive Bridge with main dimensions

Figure 2 shows the structural system of the Lutrive Bridge, near Lausanne. The structure was built using the balanced cantilever method, and articulations (or concrete hinges) are located at mid-span of the two main spans. Figure 3 shows the schematic layout of the hydrostatic levelling system installed in this bridge. The white rectangles represent the hydrostatic pots, and the thick lines the tubing connecting the pots of a same circuit. Several important techniques are described in ref. [3], that allow a good accuracy and repeatability of long-term measurements using hydrostatic levelling.

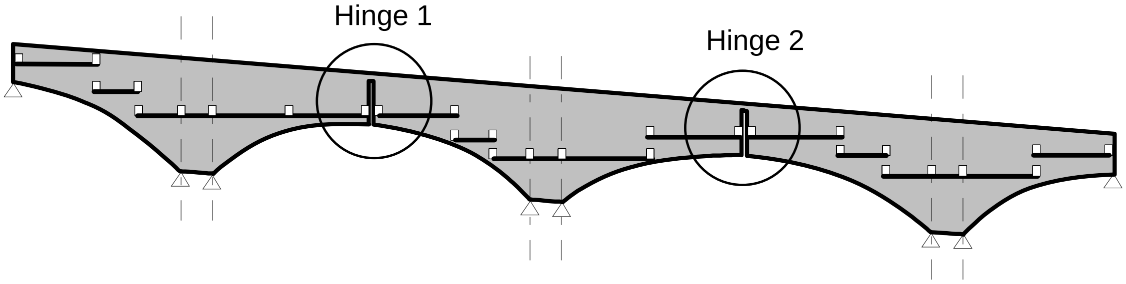

Figure 3: Hydrostatic levelling system in the Lutrive Bridge

3.3. Long-Term Measurements

In the past ten years, IBAP has instrumented ten post-tensioned concrete box girder bridges with hydrostatic levelling systems. Some of these bridges had been known to have problems, while others were considered sound. Because all the instrumented bridges are box-girders, the system is protected from outside influences and deterioration, and is easily accessible to the measuring crew. Three times every year, the bridges are inspected, and the evolution of the deformations is followed and documented. Long-term tendencies can thus be observed from the general trend in the measurements.

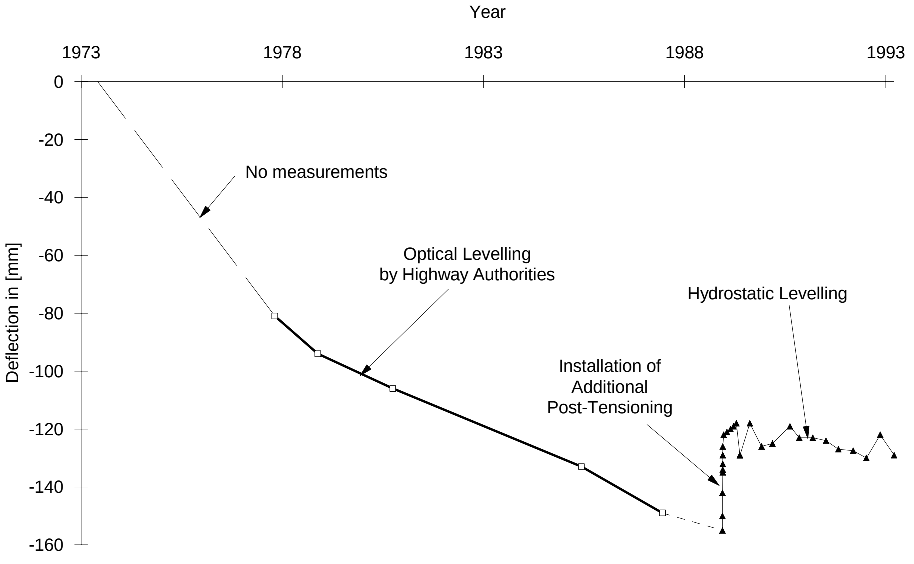

Figure 4: Evolution in time of the deflections at mid-span (hinge 1) of Lutrive North Bridge

Figure 4 shows the case of the Lutrive bridge. The bridge was initially followed by the surveyors of the Highway Authority. This is a fairly straightforward and standard procedure but because of the expense involved in taking the measurements, not to mention the interruption of the traffic, the bridge was levelled only every two to five years. Consequently, very few points were obtained in the early years. It was however detected that the deformations of the bridge were not stabilising, and that additional post-tensioning was required. About that time, a system of hydrostatic levelling was installed inside the bridge. In December of 1988, the new tendons were jacked causing the bridge to come up by about 35 mm. Since then, measurements are taken regularly to ensure that the bridges deflections have stabilised. Notice that the frequency of measurements by the hydrostatic levelling method is very high compared to the early monitoring by surveying. The cost of operation of the hydrostatic levelling system remains however very low.

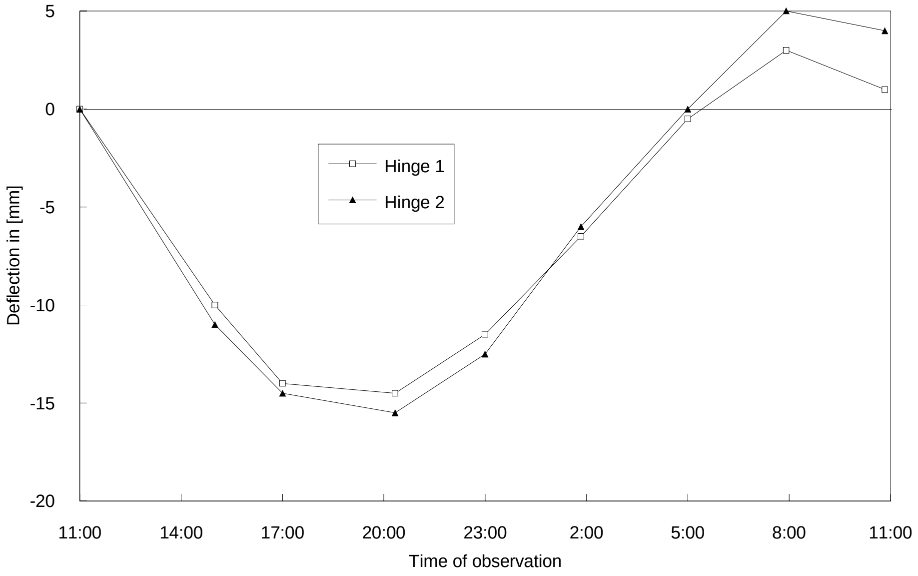

Figure 5: Evolution of the deflection at the hinges over a period of 24 hours

Daily variations in temperature often cause deflections of the same order of magnitude as the long-term deflections. This is illustrated in Figure 5, which shows the deflections of the Lutrive bridge over a period of 24 hours. Therefore, care must be taken when looking at the results presented in figure 4. However, by carefully measuring the actual temperature of the concrete while the measurements are being made and by performing the measurements at the same time every year, the results are generally reliable. Further developments, including an automatic monitoring of the bridge deflections over a period of one week around the time of the measurements, are being considered.

4. Conclusions

The interpretation of the results of load tests allows a better understanding of the actual behaviour of bridges under short term loading. The results presented here are still being treated and the calculation models are being refined. It is expected that a standard procedure to accurately compute the deformations under short term loads (load test) will be proposed shortly [7]. For a proper interpretation of the results of a load test, the actual modulus of elasticity of the bridge must be known. It is advisable that concrete specimens be taken to that effect during the construction of the bridge.

Long-term monitoring of deformations using hydrostatic levelling is very suitable and cost-effective for box girder bridges. However, because of the large deflections induced by daily temperature variations, some caution must be used when interpreting the results, especially in the initial phase of measurements. Additional developments are needed to enhance the precision of the measurements.

5. References

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