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Rehabilitation of reinforced concrete gerber bridges

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ABSTRACT: Safety assessments and reliability forecasts for existing bridges are challenging assignments for engineers. These tasks are more demanding when the plans relating to earlier projects are missing and the critical structural components cannot be inspected. Cantilever bridges with expansion joints were favoured in the 1970s because of their ability to handle differential settlements and thermal expansions free of constraints in the structure. Meanwhile it was established that permeable expansion joints place a high risk on the structural safety of the bridge deck. The proposed strengthening methods reveal different approaches to restoring the load bearing capacity of damaged bridge decks with expansion joints.

1 INTRODUCTION

1.1 Maintenance strategy of the Swiss Federal Roads Office (FEDRO)

The complete renovation of sections of motorway in Switzerland has to be carried out in accordance with federal government motorway maintenance planning. With the aid of strategic planning it is possible to secure the long-term serviceability of engineering structures with optimised life cycle costs. In accordance with the applicable federal regulations, the maximum length of roadwork sites for maintenance projects is 5 kilometres. FEDRO always attempts to keep the duration of construction work as short as possible. The interval between maintenance works carried out on a given stretch of road may not be shorter than 15 years. This means that the residual service life of an engineering structure must be secured without the need for further intervention for the stated period. Depending on the condition of the structure, a broad variety of solutions, ranging from “no action” through to the replacement of the object concerned, has to be examined. The most appropriate measures have to be closely examined according to the increasing traffic loads and the extent of the deterioration to the structure.

1.2 Existing cantilever bridges

On 30 September 2006, a 20-metre wide 3-lane motorway bridge (Concorde viaduct) in the Canadian town of Laval, in the province of Quebec, collapsed, resulting in the loss of 5 lives. According to the inspection report, the bridge was in acceptable condition. The inspection report (Johnson et al, 2007) cited three main causes for the collapse: lack of quality controls, poor construction and poor quality of concrete. The collapse occurred following a shear failure in the southern cantilever carriageway deck.

The viaduct was constructed in 1970. It was periodically inspected, and during maintenance work in 1992, some damaged expansion joints were replaced. Both the reinforcement concept and the faulty assembly of the rebars also played a significant role. The penetration of salty water with chloride content into the cracked concrete during freeze-thaw cycles under heavy traffic loads gradually reduced the load bearing capacity of the cantilever bridge deck.

In the wake of the collapse of the Concorde viaduct, similar bridge constructions in Switzerland were inspected as a precautionary measure. A total of 58 bridges in the Swiss motorway network were identified and their bearing capacity verified. In an initial step, with the aid of the former construction plans the shear force load bearing capacity of the cantilevers was examined using basic truss models. It should be noted here that the standard requirements in terms of shear force strength have changed considerably over the past 50 years, and that it is usually possible to comply with the requirements in force today if at least the full cross section of the rebars is considered. Under the assumption of partial corrosion of the rebars, the structural security tilts generally towards the unsafe side.

Traces of sintering on the visible joint surfaces and the concrete spalling and/or corrosion of the reinforcement were detected and evaluated in the main inspection reports every 5 years. In most cases, due to the restricted access to the interior of the joints it was impossible to obtain unequivocal findings regarding the condition of the reinforcement. In these cases, an assessment was carried out regarding the risk of corrosion of the reinforcement within the joints.

Fig. 1: Permeable joint and traces of sintering
Fig. 2: Damaged hinge with spalling concrete and corroded rebars

After an inspection, if any doubts still remained concerning the load-bearing capacity of the bridge, emergency measures were prescribed. In addition to restricting the use of the carriage ways (through lane closures, traffic weight limits, etc.) it is possible in dangerous cases to temporarily support the bridge deck using steel yokes. The definitive strengthening or replacement of the bridge is generally carried out when the general maintenance of the motorway stretch takes place periodically every 20 years.

The selected examples illustrate two different rehabilitation concepts. The first one takes the form of local and external strengthening using steel profiles, while the second one takes the form of an internal intervention in the bridge deck and the removal of existing joints.

Fig. 3: Steel yokes beneath the suspended girder
Fig. 4: View of the underside of the bridge deck

2 ACHEREGG BRIDGE

2.1 Introduction

The Acheregg bridge, which was constructed between 1961 and 1964, is approximately 200 metres long and 16.4 metres wide. It provides a means of crossing a narrow section of the “Vierwaldstätter See” lake near Stansstad for road and rail traffic. The superstructure comprises a three-cell prestressed concrete box girder covering five spans with different width. The four pier pairs are erected on caissons installed in the soft lake bed. In order to avoid constraints due to uneven subsidence, a suspended girder was installed in the second and fourth spans of the bridge. The bridge therefore comprises four Gerber hinges (cf. Fig. 5).
The inspections revealed that the bridge has suffered damage and needs to be repaired. The Gerber hinges and their surroundings were found to be in very poor condition as a result of the penetration of salty water containing chloride into open deck expansion joints over a long period of time.

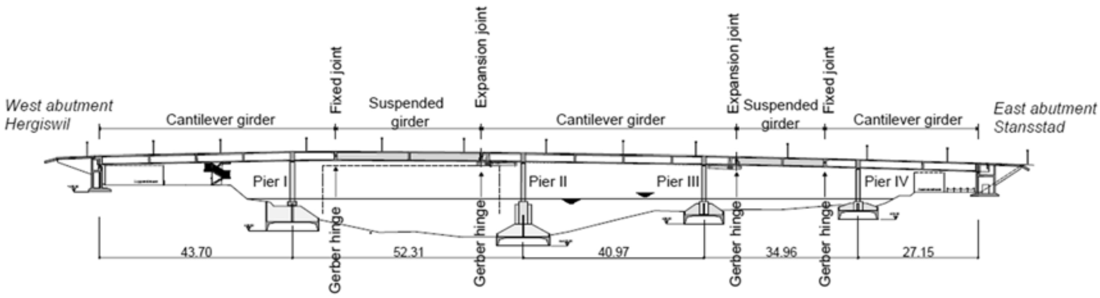

Fig. 5: Longitudinal profile of the Acheregg bridge

2.2 Evaluation of the condition of the bridge

Because direct access to the statically relevant sections – the bearing brackets of the longitudinal girders – was not possible, the inspections had to be limited to the immediately neighbouring cross girders. Very low readings were obtained from the potential field measurements carried out at the expansion joints, which indicated a significant degree of corrosion of the reinforcement. Drilling dust samples also indicated a high chloride content. These findings meant that a high level of corrosion had to be expected. Furthermore, soundings of the cross girders revealed signs of pitting.

Because of the lack of direct access to the relevant sections, it was not possible to inspect the effective condition of the prestressed tendons and the statically relevant rebars. It was also not possible to predict the further progress of the corrosion. Due to the observations that were made on the cross girders immediately next to the cantilever of the longitudinal girders, statically relevant cross-sectional losses had to be anticipated for the tendons and the rebars.

2.3 Strength estimation

A detailed static calculation was carried out as part of this examination. For this purpose, the bridge was modelled as a three-dimensional girder grid in order to precisely calculate the distribution of loads over the four longitudinal girders. Based on standard methods of verification, it was not possible to produce evidence of adequate structural load bearing capacity in the vicinity of the Gerber hinges. In view of this, more refined calculation methods were used that incorporated truss models and tension fields (cf. Fig. 6). With the aid of this method, for the original condition of the bridge, i.e. without taking corrosion-related cross-section losses into account, it was possible to demonstrate a barely sufficient load bearing capacity for most of the bearing brackets at the Gerber hinges.

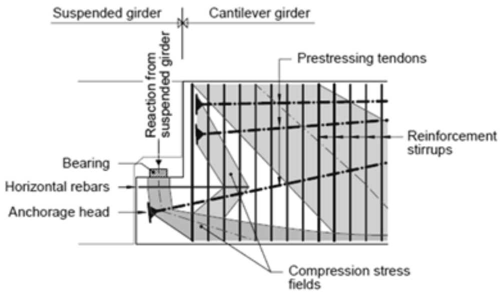

Fig. 6: Truss model for estimating the load carrying capacity of the brackets

As already noted, the corrosion of both the tendons and the statically relevant rebars could not be ruled out and it had to be assumed that the available load bearing capacity of the brackets is lower than nominally calculated.

2.4 Strengthening/rehabilitation concept

In view of the demonstrated barely sufficient compliance with the applicable security requirements and the assumed corrosion, it was decided to strengthen the Gerber hinges in the area of the expansion joints. A comprehensive analysis to identify potential solutions indicated that only an external strengthening with steel supports would yield the desired result. But since, even with this measure, it would not be possible to ignore the contribution of the tendons located in the hinge area of the girder, additional measures are necessary that would halt the further progress of corrosion of the tendons and the rebars. The decision was taken to protect the Gerber hinges at the expansion joints through a combination of a conventional repair of the concrete (in those areas that were directly accessible) and an active cathodic corrosion protection.

2.5 External strengthening of the movable hinges

The loads of the suspended girder from the central span will be carried by steel structures located under the 4 vertical webs of the cantilever box girder of the bridge. The tensile forces are suspended with prestressed drawbars into the bridge deck and transferred through the deck into the webs of the cantilever box girder (cf. Figs. 7 and 8). Since the drawbars run outside the vertical webs of the longitudinal box girder, the upper slab of the box girder has to be strengthened to enable the force transfer. For this purpose, additional reinforcement bars are slotted transversally into the bridge deck.

As already noted, the status of corrosion of the tendons was unclear, and for the design of the supporting steel structures it was assumed that 50 percent of the prestressed tendons were completely corroded at the anchor head.

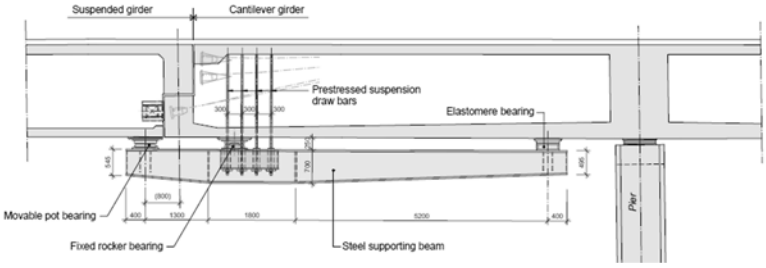

Fig. 7: Strengthening with steel cantilever beams beneath the bridge

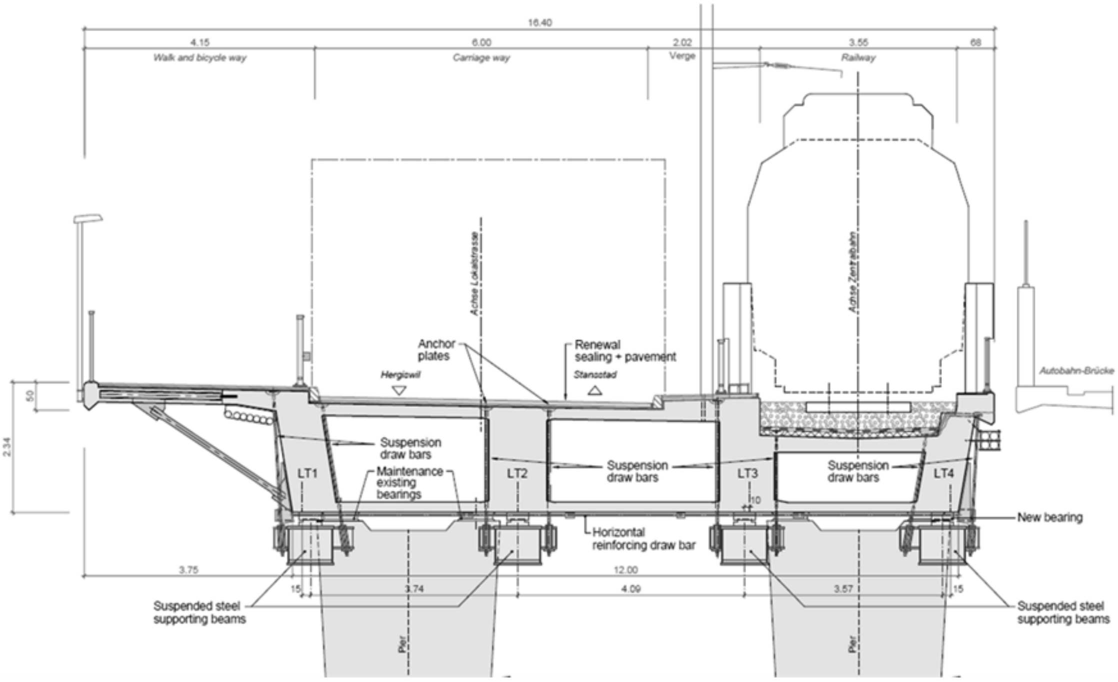

Fig. 8: Cross section of the bridge after rehabilitation

3 BRIDGE OVER SBB RAILWAY LINES AND RIVER SEEZ

3.1 Description of the structure

The bridge over the Swiss Federal Railways (SBB) and the river Seez in Flums serves as a connection between the Walenstadt/Flums motorway junction and the municipality of Flums. It passes over the SBB railway facilities and the river Seez. It was constructed in 1969. The structure comprises continuous girders with suspended beams. The spans are between 12 and 18 metres wide and the overall width of the bridge deck is between 10.9 and 12.3 metres. Suspended girders are installed in the field in front of the abutments (on the motorway and on the Flums side) and in the central part of the bridge (cf. Fig. 9). To reduce dead load, polystyrene foam infill cylinder blocks were incorporated into the concrete bridge deck. Longitudinal prestressed tendons were installed in the deck between the individual infill cylinder blocks.

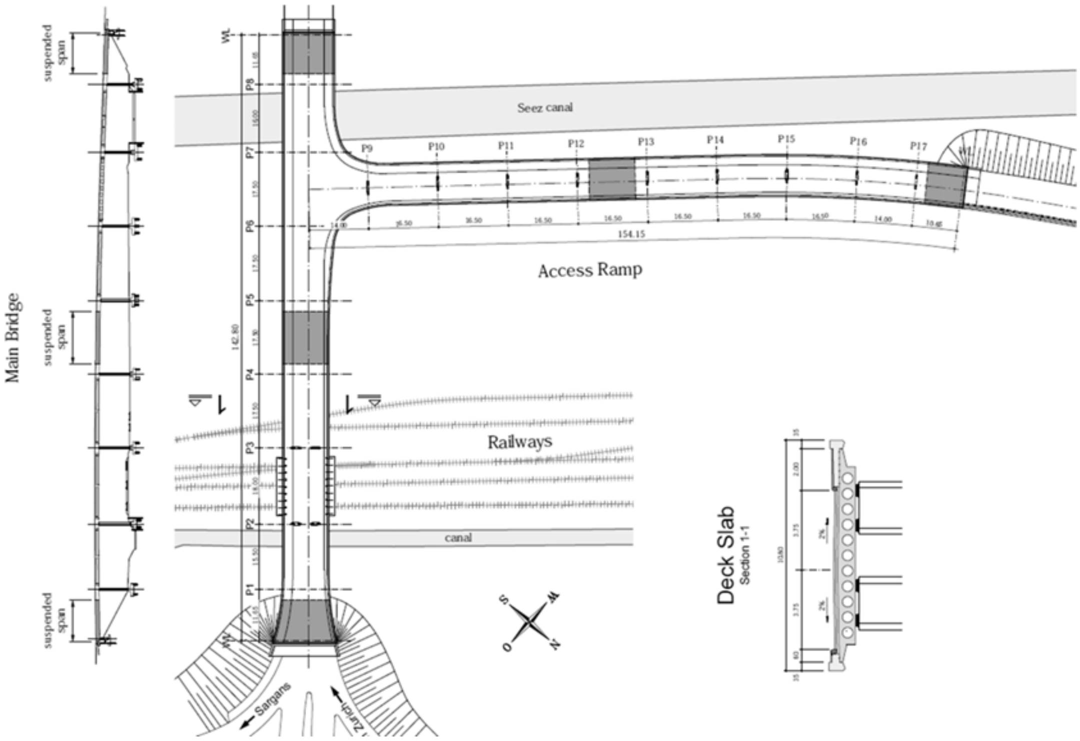

Fig. 9: Plan of the bridge over the SBB facilities and the river Seez, with the position of the old suspended girders shown in solid grey.

The suspended girders from the central spans were connected to the continuous girders using Gerber hinges, in some cases with steel shear keys incorporated into the concrete structure and standard reinforcements (cf. Figs. 10 and 13). The approximately 150-metre long ramp is also constructed as a continuous girder with 2 suspended beams, which are installed in the centre of the bridge and in front of the abutment.

3.2 Condition of suspended girders / Gerber hinges

The suspended girders showed signs of significant tilting in some places, which had negative impacts on the adjacent constructions. The tilting in the vicinity of the hinges caused the concrete to break away from the bearing brackets so that some of the reinforcement was entirely or partially exposed (cf. Fig. 4). The suspended girders displayed major damage in the hinges. Some of the bearing brackets were partial deteriorated (cf. Fig. 2). Water containing chloride was able to penetrate into the open joints and carriageway expansion joints, thus giving rise to pitting and corrosion of the rebars.
This situation had to be regarded as extremely critical, since a failure of the bearing brackets of the hinge would have caused the bridge (or at least some parts of it) to collapse.

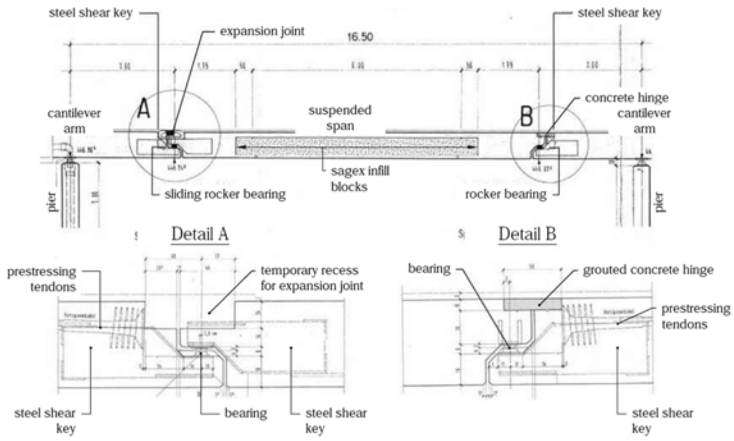

Fig. 10: Suspended girders and diagram of joint with steel shear keys

3.3 *Immediate measures*

In view of the alarming condition of the Gerber hinges, in 2008 steel yokes and/or support steel structures were installed under the hinges as an emergency measure (cf. Fig. 3). The steel yokes were installed directly beneath the Gerber hinges, as well as in the neighbouring midspan, since in the event of a failure of the hinges the bending moment at midspan would have exceeded the maximum permissible level.

3.4 *Rehabilitation project*

3.4.1 Replacement of existing suspended girders

Since in the existing circumstances it was not possible to carry out a durable rehabilitation of the hinges, the suspended girders were dismantled and the newly constructed bridge decks were joined monolithically to the remaining bridge structure (cf. Figs. 11 and 12). The new deck elements took the form of post-tensioned solid concrete slabs. Anchorages were placed both at the connection area to the existing bridge deck, and in the recesses at the location of the infill foam blocks behind the pier. For this purpose, the infill foam blocks were partially dismantled. Following the replacement of the suspension girders, the bridge was turned into a continuous monolithic construction (cf. Fig. 9) and the structural bearing concept was adapted accordingly.

3.5 *Findings obtained during the dismantling of the suspended girders*

During the dismantling procedure, the condition of the Gerber hinges was examined (cf. Fig. 13) and documented. Significant damage was detected (including corroded bearings, rebar corrosion with signs of pitting and cross-section losses, and incorrectly inserted reinforcement

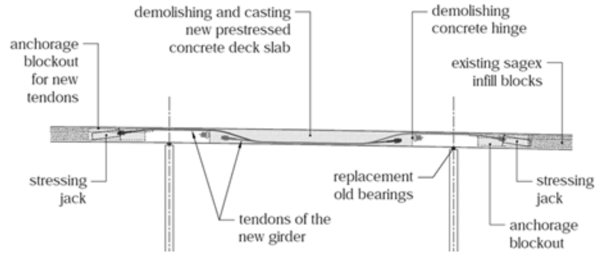

Fig. 11: Longitudinal profile of the post-tensioning tendons

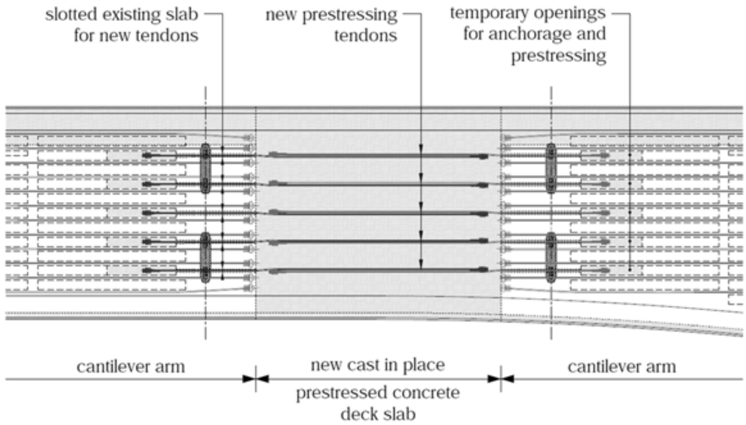

Fig. 12: Layout of tendons in the new bridge deck

Fig. 13: Gerber hinge with rebars and steel shear key after dismantling

4 CONCLUSIONS

With increasing traffic volumes and loads, the long-term serviceability of the expansion joints, and in particular their impermeability, has to be regarded with caution. The penetration into the joints of salty water with chloride favours corrosion of the rebars and tendons at locations that cannot be inspected. Rehabilitation of the damaged concrete cantilever bridges is both demanding and expensive. The option of replacement of the bridge offers considerable advantages compared with rehabilitation.

For the reasons outlined above, the FEDRO Guidelines (2005) promote the construction of robust and durable structures, and recommend conventional motorway overpasses, preferably in the form of monolithic integral structures without joints and bearings.

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