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Experiences in Rehabilitation and Repair of Concrete Bridges

Expériences de rénovation et de réparation de ponts en béton

Erfahrungen in der Sanierung und Instandstellung von Betonbrücken

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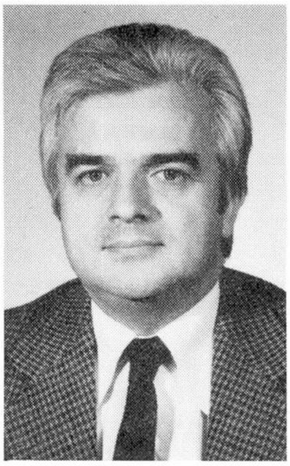

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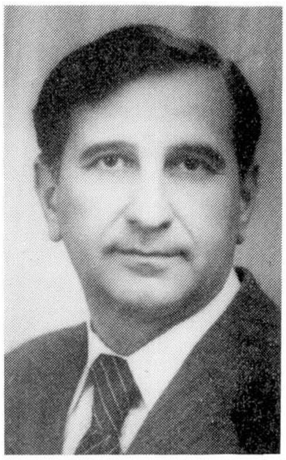

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SUMMARY
The serviceable value of a bridge, its durability, costs of maintenance and repairs are closely associated with the quality of the design and with the quality of the works executed. Proceeding from the basic principles of bridge designing, a prerequisite for a successful bridge, the possible causes of damage occurring on the bridge have been discussed. Besides the classification of damage, the gravity of its consequences have been commented. Some examples of rehabilitation of reinforced and prestressed concrete bridges illustrate the present considerations and viewpoints of this problem.

RESUME
L'utilisation et la durée d'un pont, les frais d'entretien et de réparation sont étroitement liés à la valeur du projet et à la qualité des travaux effectués. En partant des principes fondamentaux de l'élaboration d'un projet de pont, condition préalable de tout pont réussi, on a analysé des causes possibles de l'appariton des endommagements sur les ponts. On a également commenté leur classification ainsi que l'importance de leurs conséquences. Plusieurs exemples de rénovation de ponts en béton armé et précontraint sont présentés.

ZUSAMMENFASSUNG
Die Gebrauchsfähigkeit einer Brücke, ihre Dauerhaftigkeit, Unterhalts- und Instandstellungskosten stehen mit der Entwurfs- und der Ausführungsqualität in enger Verbindung. Nach den Grundprinzipien des Brückenentwurfs, Vorbedingungen einer erfolgreichen Brücke, werden die möglichen Gründe der erfolgten Schäden diskutiert. Neben der Schadenklassifikation ist die Schwierigkeit der Folgen analysiert. Einige ausgewählte Beispiele der Sanierung von Stahl- und Spannbetonbrücken werden vorgestellt.

Bridges are expensive and significant edifices that should serve for ages. When eliminated from use, consequences and damage are unpredictable. Their durability and costs of maintenance and repairs are connected with the quality of the project and the quality of work performance.

In the Belgrade school of concrete bridges, from the very beginning of its existence, emphasis has been put on the principles of the art of bridge designing - *objectivity, functionality, stability, rationality, originality and aesthetics.* The concept of stability implies not only stability in the narrower sense of the word, but the stability of everything that has an influence on change in the state of the structure as it was designed, associated with its purpose, functional requirements, traffic safety, durability and appearance, which is quite in agreement with the contemporary conception of the limit states. Successful can be considered only the bridge in which all the principles mentioned have simultaneously been achieved,

Defects (error is a heavy word) which may occur during the life of a bridge according to their cause are: *defects in designing, defects in construction, defects associated with maintenance,* and they may occur singly or in combination, or altogether.

Defects in designing are numerous: *inadequate choice of the static system, omissions and mistakes in static analysis and irregularly or badly solved structural details and fittings.*

Inadequately chosen static - structural conception in most cases is reflected on the rationality of the bridge, but it may also be the cause of serious functional defects - disturbance of functional, and even of general stability (girder or frame with cantilevers, shallow insufficiently rigid three-hinged arches, incorrectly solved cross-sections, etc.).

Omissions, overlooking and errors in static analysis may be very heterogeneous, from the most common ones, those of algebraic order, but with possible serious consequences, through glaring errors of static order, up to the badly estimated visco-elastic properties of concrete, which disturbs all the three aspects of stability. An experienced designer notices them during his work already, and corrects them in time, but they may be slipped by an inexperienced designer and be discovered only when the structure has been built, if the errors are of a somewhat more serious nature, or sometimes accidentally after longer use (when the bridge is tested for the passage of particular vehicles). Emphasis should also be put on the essential difference between the structures of reinforced concrete and those of prestressed concrete. In prestressed concrete structures one should know static influences much more precisely, especially in statically-indeterminate systems and bridges with a complex geometry in the plan (skewed and curved bridges). Computer technique has given a new dimension in designing and estimating structures. Besides the more precise and very fast computation, it offers the possibility of solving very complex, formerly inconceivable, problems. However, it requires programme testing, and in more complex structures also an adequate interpretation of the actual structure in a design model.

Incorrectly or badly solved structural details may occur as the consequence of not seeing the perspective development of traffic, of insufficient experience, or of excessive desire to present the structure as cheap as possible, as well as desire to overstimate the potential possibilities of the system. These incorrectnesses are reflected on the functionality and durability of the bridge, increased costs of maintenance and repairs, and even on the general stability (incorrectly solved cross sections, incorrect orientation of movable bearings of the bridge in a curvature, application of thin members, etc.).

Fittings are elements which do not involve the static-structural conception of the bridge, but essentially affect the regular serviceability and durability, What is the use of a beautiful, rational and grandiose bridge, if water drainage is not correct, so that various mishaps and accidents occur, or the solution of expansion joints is bad, which makes driving unpleasant and even risky, or water-proofing is left out or poorly solved, which shortens the life of the bridge, etc.

Defects in bridge construction may be numerous and heterogeneous, and they are generally: *nonachieved qualities of basic materials (mostly of concrete) and errors in construction.*

Under nonachieved qualities of concrete we imply not only lower strength, but all the irregularities in concrete placing (badly constructed break of concreting, local segregation, insufficient compaction, etc.). In prestressed concrete, this group also comprises irregularities in connection with the protection of cables from corrosion and their bonding with the basic section. The above mentioned defects need not be reflected directly on stability but on durability (resistance to frost or aggressive media, etc.) and vice versa (slender members and the like).

Errors in construction are all deviations from the design: *impreciseness of shuttering and falsework* which results in a change of structural geometry with all possible consequences (increase in steady load, displacement of the centre of mass, change in rigidity, undesirable eccentricity in high piers, inaccurate vertical alignement, etc.), *incorrect position of reinforcement and cables, insufficient protection layers, bad rectification of the bearing,* and the like, with far greater sensitivity of prestressed concrete structures. The gravity of consequences depends on the degree of deviation and may seriously disturb all the three aspects of stability.

Unfortunately, there are still opinions that concrete bridges are everlasting and that they do not require maintenance. It is not worthy of comments. However, *irregular and poor maintenance* may also be dangerous. Irregular maintenance, first of all, affects the serviceable value of the bridge, which must not be underestimated. It may be directly reflected both upon the state of structure (damage) and upon its stability - joint blocking, expansion action of ice in the joints, vehicle bumping into the structural members due to unrepaired bumper rails, scouring of piers due to change in the watercourse regime (sinking of vessels in the vicinity of the bridge, and the like), soil displacement caused by subsequent actions, etc. This group of defects is worthy of exceptional attention, because the problem of maintenance is often underestimated, and is connected with administrative difficulties - financing. The number of bridges requiring intervention is not small. Such a state is worthy of attention and requires a serious, expert and even scientific approach to the problem.

Dominant moments in *rehabilitation* of bridges and other structures are: *prompt discovery of deterioration,* which is not at first directly noticeable, and when observed - the consequences are more serious, and it may also be too late (rigid fractures, specificities of prestressed concrete structures, etc.), *determination of actual cause of damage* (possibly also of the history of the occurrence). These elements are an essential prerequisite for the successful rehabilitation of damage on bridges - an analogy to diagnosis/therapy in medicine.

The presented considerations will be illustrated by examples of rehabilitation of some bridges from the authors' practice. For understandable reasons the names of bridges, names of designers and contractors will not be mentioned, because our intention is not to judge, but to learn a lesson and to get new experiences.

Bridge A (Fig.1) is from an older generation of prestressed bridges in Yugoslavia, classified into a group for detailed control. The low building height induced the solution of the arch system above the prestressed two-way ribbed deck structure, being a tie at the same time. Suspenders are precast and prestressed. Such solutions are abandoned today. The arch is not indicated for small spans, and the conception with a suspended deck is a forced solution and belongs to the past.

During the detailed surveying vertical cracks almost on all suspenders were observed. In view of the vital significance of these members, possible causes of deterioration, the actual state and the necessity of interventions were analysed in detail. The results of the examination of concrete showed that the required

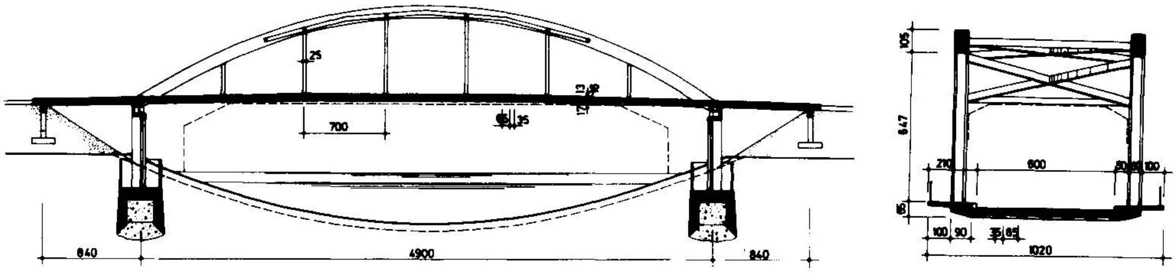


Fig.1 Bridge "A", general arrangement

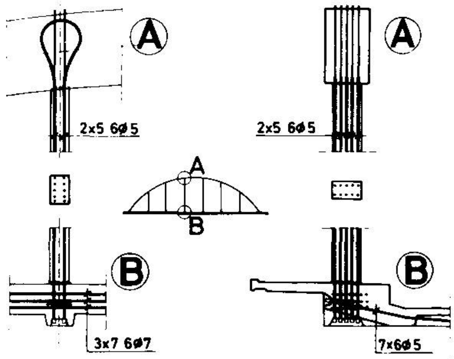


Fig.2 Suspender cables

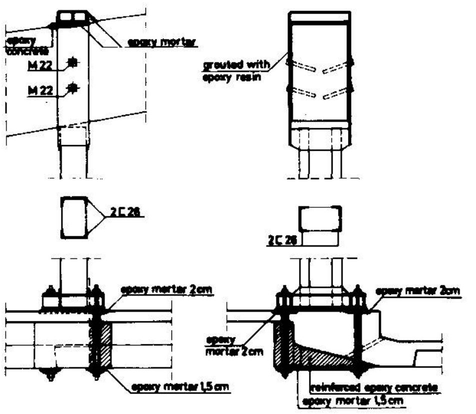


Fig.3 Suspender rehabilitation

strength was achieved. The examination of cable corrosion showed that the protection of cables (grouting) was not satisfactory. Cables were seized by severe corrosion, with a considerable reduction of cross section. A considerable contribution to this state was made by a detail to which not sufficient attention was paid during the construction (Fig.2). After the grouting, control pipes on the arch extrados were cut off without particular treatment of these places. The insufficient compaction of the grouting mass enabled with time the penetration of weathering waters into the lower parts of suspenders, and the corrosion cables.

When cables were opened, expansive action due to corrosion of frost was not detected. The cause of the appearance of longitudinal cracks was the low percentage of reinforcement, particularly of stirrups, at high stresses of pressure in the concrete.

The dense arrangement of cables in the deck structure, as well as the impossibility of simultaneous release of the existing suspender cables did not allow the incorporation of new cables. Therefore, the suspenders were strengthened by rolled steel U-bars (Fig.3), which were partially activated by prestressing of high-strength bolts on the connection with the deck structure and with time they will completely overtake the role of corroded cables.

In Bridge "B" (Fig.4) all the basic forms of the above mentioned defects occurred (inadequate static system under today's conditions of traffic, defects in construction and defects connected with maintenance).

In a detailed examination of the bridge, it was established that the cracks of the main girderabove the medium supports, registered and injected already during the inspection of quality of work (20 years ago), were 0.1 - 0.3 mm wide and were still effective. Also, cracks were discovered in the central part of the middle span in the lower zone of the upstream box, as well as vertical cracks on the walls of piers through which cables were embedded. By detailed examination and analysis it was found that vertical cracks of piers were the result of the low percentage of reinforcement, particularly of transverse one. Cracks of the main

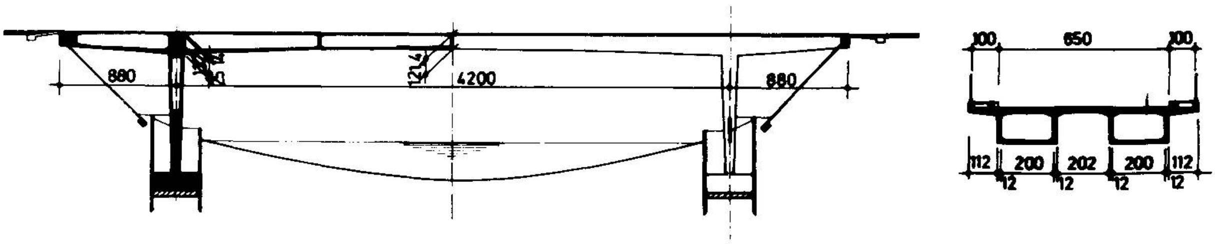


Fig.4 Bridge "B", general arrangement

girder in the central part of the span indicated a far more serious situation, also after heavy vehicles crossings the bridge, it vibrated for a long time. As during the bridge construction openings for box inspections were not left, they were now immediately made. On entering the upstream box, the surprise was not small. One of the four groups of all bridge cables running directly close to the pier, was almost completely broken due to corrosion (Fig.5). Although cable protection, practically along the whole length, was well and efficiently carried out, above the pier, where cables entered the carriageway slab (Fig.6), there was a small zone in which the cable protection could not be efficiently performed. However, the absence of waterproofing and the appearance of cracks in the carriageway slab were enough to produce serious damage which was discovered late, but still on time.

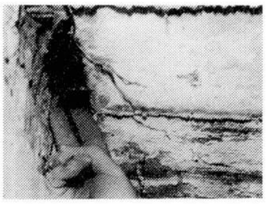


Fig.5 Cable damage

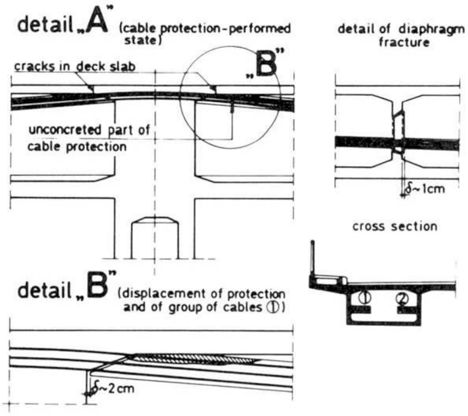


Fig.6 Cable damage arrangement

This is an example of two defects in structural details which could have been fateful: cable protection in the zone of piers is always very difficult to carry out and openings for the boxes were not constructed, which made periodical inspections and earlier discovery of damage impossible. The applied arrangement of cables, formerly used very often, has been abandoned throughout the wourld as well as in Yugoslavia.

The bridge, because of seriously jeopardized stability, was excluded from traffic and rehabilitated according to a particular design. Cables of the girder were completely replaced, and supports were formed at either end of the bridge, so that the system for live load was transferred into a continuous frame with three spans. Cable replacement was made without a special falsework by temporary underpinning of the main girder by external cables.

Bridge C (Fig.7), across the channel, is a reinforced concrete skew frame with cantilevers. It was reconstructed during World War II on the modified foundations of a destroyed, similar bridge from 1939. The bridge conception, with comparatively large cantilevers and considerable deflections at the ends, with a small width of the carriageway, with steep bridge approaches in sharp horizontal curvatures and without transition slabs, does not correspond to the contemporary principles of bridge construction and to the conditions of today's traffic.

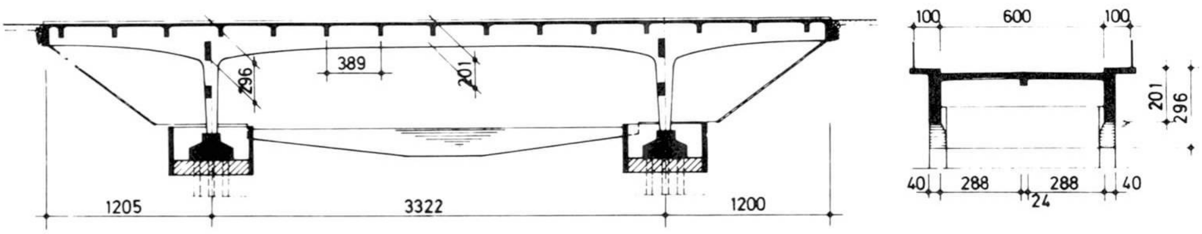


Fig.7 Bridge "C", general arrangement

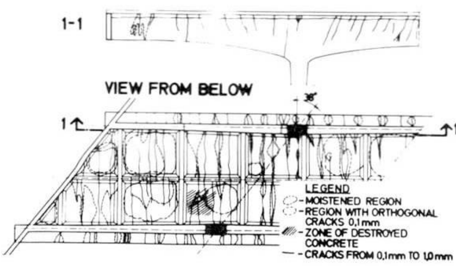


Fig.8 Detail of cracks

The bad state of the bridge, established by a former examination, required an urgent detailed examination and analysis. The state of cracks in the structure was observed, concrete quality examined and the general state of all the bridge members was established. A great number of cracks, mostly of nonpermissible width, were registered. A particularly bad state was found in the carriageway slab (Fig.8), made without waterproofing, where almost all cracks were moistened, and individual parts of the slab were so cut by cracks that only the reinforcement prevented the separated pieces of concrete to fall out.

This fact required an urgent intervention. Opposite to the author's opinion that the best solution was to construct a new bridge, nevertheless, for certain reasons (of administrative nature) it was concluded to rehabilitate the existing bridge. The old carriageway slab was removed and a new one made (Fig.9). The connection between the new slab and the existing main and transverse girders was achieved through the existing reinforcement, undamaged owing to very careful work, as well as through new anchors, placed in drilled holes and sealed with epoxy resin. The new slab was concreted step by step, taking into account symmetrical development of work. Cracks of the existing girders were injected with epoxy resin, according to a special procedure, and the structure was transversely and longitudinally prestressed by introducing moderate stresses of pressure. Longitudinal prestressing required a reconstruction of transverse girders at either end of the bridge in order to obtain anchor blocks. Finally, transition slabs were made, and before constructing a new pavement, waterproofing was carried out.

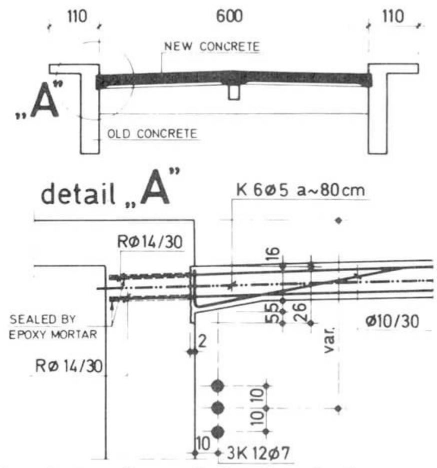


Fig.9 Replaced deck slab

Bridges D, at the approach to a city bridge across a large river, are prestressed continuous frames with slender columns. The cross-section consists of two boxes connected with a carriageway slab. These bridges belong to the first prestressed bridges in Yugoslavia and are loaded with all "childhood diseases", which is not the case only in our country. Here certain defects appeared in designing (thin elements at the cross-section, a small amount of reinforcement, cables inside the boxes, even without protection pipes, in construction (unattained design force of prestressing, insufficient cable protection), and in irregular maintenance.

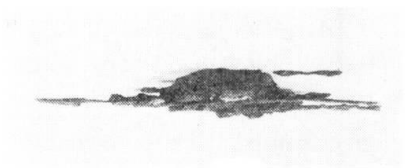
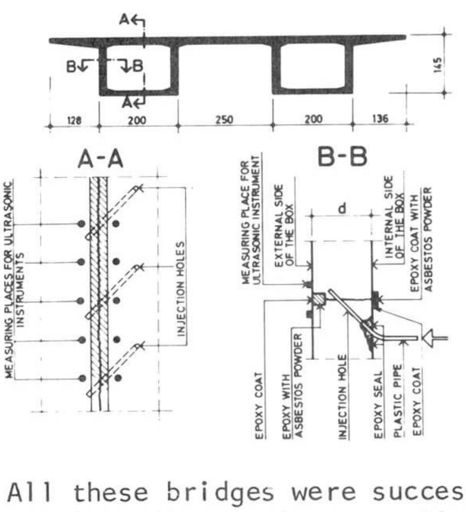


Fig.10 Cable destroyed by corrosion

Even before the bridges were put into operation, four structures, due to the appearance of cracks, were improved by additional prestressing with cables inside the box. Subsequent detailed observation revealed a comparatively large number of cracks, as well as an unattained prestressing force and badly protected cables, attacked by corrosion, and even completely broken (Fig.10).

The state established required urgent rehabilitation. Cracks were injected with epoxy resin, according to a special procedure (Fig.11). Bridge rehabilitation required additional prestressing with cables inside the boxes anchored in specially constructed blocks. Also, because of irregular maintenance, other repairs had to be carried out.



All these bridges were successfully rehabilitated and, after test loading, were put into the regular operation.

Our approach to this problem is from the aspect of designers, as well as from our experiences acquired in rehabilitation of bridges, with the intention to contribute to a more successful solution of this problem.