Rehabilitation of an Arch Bridge

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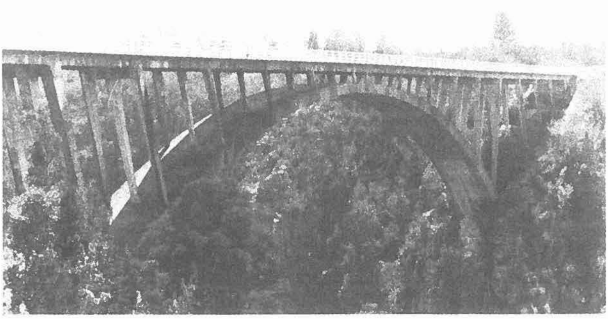
Abstract

The rehabilitation of a 100m span concrete arch bridge involving the widening and strengthening of the structure as well as the treatment of existing concrete affected by Alkali Aggregate Reaction (A.A.R.)

The widening of the superstructure involved the replacement of the existing cantilevers with larger ones of lightweight construction. To enable the bridge as a whole to carry the increased loads, it was necessary to strengthen the superstructure as well as the arch rib by the addition of externally bonded steel reinforcement.



In view of the age of the bridge and because it had been subjected to many cycles of wetting and drying, it was concluded that the concrete had established an equilibrium system. Ideally, the concrete should have been dried out, the cracks epoxy injected and the surfaces sealed, but since it is impractical to dry out the concrete structure, the moisture inside the concrete would cause the injected cracks to open up again, and then further cracking usually occurs rapidly. It was therefore decided that in this case the appropriate solution was the impregnation of the concrete with a hydrophobic substance which prevents external water penetrating the concrete while keeping the surface open enough for moisture to escape.

1. Introduction

The 100m span reinforced concrete open spandral arch bridge over the Storms River Gorge was constructed in the mid-1950's and in 1982, after many years of service, surface cracking of the concrete was noticed. Cores were obtained from the various members and laboratory testing confirmed that alkali aggregate reaction had taken place. It was realised that unless steps were taken to prevent further cracking, the bridge could deteriorate to an unacceptable level.

At this time, for financial and environmental reasons, a decision was taken not to construct a proposed new freeway together with a new bridge over the Storms River Gorge, but instead to reconstruct the existing road and, if possible, to rehabilitate and widen the existing concrete arch bridge.

2. Existing Structure

The encastre arch has a span of 100,58m and a rise of 20,12m. It has a box type cross section consisting of 3 cells, 2 relatively large outer cells and a very small narrow centre cell.

The deck has a carriageway width of 6,706m. The deck configuration is of the beam and slab type and consists of 3 main longitudinal beams, a top slab with short cantilevers and transverse diaphragms at the support points and the third points of the spans.

3. Widening of Superstructure

3.1 Width of Deck

The widened superstructure provides for a 9,2m wide carriageway consisting of two 3,7m lanes and two 0,9m shoulders as well as two 0,7m footwalks separated from the roadway by guardrail type of barriers; giving an overall width of 11,45m.

3.2 Principle of Widening

The overriding consideration in the selection of the method of widening the superstructure was to minimise the extra dead weight that has to be carried by the arch rib and columns. The method finally selected consisted of extending the top slab of the deck on each side in concrete up to the footwalk and to support the slab on welded plate girders located at each existing diaphragm. The resultant increase in dead weight of the superstructure is only 19%, which in turn introduces an increase of only 5% in the total dead load carried by the arch rib.

3.3 Construction Details

All rainwater incident on the top surface of the deck will be carried to the abutments through drainage junctions at each rib feeding into an open channel running the entire length of the deck under the footplates. Also accommodated beneath the footplate on each side are two 100mm dia service ducts.

4. Strengthening of Structure

4.1 Properties of Existing Concrete

In order to confirm the compressive strength and also to establish the Young's Modulus of the concrete, a number of 100mm diameter cores were drilled from various parts of the structure and tested. The testing showed consistently high compressive strengths of over 50 MPa for all the cores, while as expected for concrete made with Port Elizabeth Quartsite, the Young's Modulus was low for the recorded concrete strength being only 20 x 10^3 MPa for the arch rib.

4.2 Design Loadings

The effect of widening the superstructure was to increase its dead weight by 19% which in turn had to be carried by all parts of the structure. The bridge was analysed only for the effects of the type HA and type HB loadings. A detailed computer analysis of the bridge as a whole for the increased dead load and live load was carried out and it was found that both the deck and arch rib required strengthening.

4.3 Method of Strengthening the Bridge

In this instance the only practical way to increase the load carrying capacity of the existing bridge was by the addition of externally bonded steel reinforcement. The use of epoxy resin adhesives to bond steel plates to extend reinforcing to under-reinforced concrete members was first reported in the mid-60's and has since then been well documented and references (1 - 5) have been used as the basis for this project.

The role of the adhesive layer is to transfer all relevant stresses from the concrete into the steel plate so that the latter can perform its reinforcing function. The creep of the epoxy adhesive only becomes a problem when the added steel has to carry permanent loads which is not the case in this instance.

Although not universal practice, the provision of mechanical permanent clasping provides a constant compressive stress across the load line to prevent the peeling of the plates at the ends as well as the failure of the concrete epoxy interface under a tensile stress.

5. Treatment of Existing Concrete affected by Alkali Aggregate Reaction (A.A.R.)

5.1 Prediction of Present State of Structures

5.1.1 Natural Decrease in A.A.R. : In the U.S.A. where the movements of some dams have been monitored for many years, it has been found that after 20 years the expansion decreased and after 30 years it stopped, which means that the concrete's potential for expansion due to A.A.R. under the prevailing natural conditions has been exhausted. However, it is possible that cores taken from stable structures could, when tested under extreme laboratory conditions, still show a potential for further expansion which has no practical implications unless the natural conditions change.

If it is found that the potential for expansion is not exhausted then it is undesirable to rigidly tie a structure together that has cracked and relaxed. This is because one is dealing with a dynamic system. Once cracking has occured a quasi equilibrium is established which possibly slows down further damage. By filling the cracks this is destroyed and further cracking occurs rapidly. However, it may not be acceptable from a structural safety point of view to leave a structure as it is in which case the member affected has to be demolished and rebuilt.

5.1.2 Potential for Further Expansion due to A.A.R. : In view of the age of the structure and because it has been subjected to many cycles of wetting and drying, it can be assumed that the concrete has reached stable conditions, although under extreme laboratory conditions it has been found that there is still potential for further expansion due to A.A.R.

5.1.3 Prevention of Further Expansion due to A.A.R. : The best solution would be to completely dry out the concrete, inject any cracks, and then seal it against the ingress of any moisture. Since the drying out of the concrete is not practical in this instance, the structure cannot be sealed as the moisture inside would cause any cracks to open up again. Based on overseas findings (6 - 7), the appropriate solution in this case was the impregnation of the concrete with silane, a hydrophobic substance which prevents external water penetrating the concrete while keeping the surface open enough for moisture to escape.

5.2 Hydrophobic Treatment of Concrete

5.2.1 Chemical Background of Silanes : The ideal coating will stop penetration of water but allow water vapour to permeate through substrata.

The use of silanes produces this coating. By chemical reaction a water repellant hydrocarbon group is bonded to the substrata. It is not physical bonding power that affects the combination, but chemical bonding forces which are much stronger (8). In view of the chemical bonding the lifetime of the water repellant layer is thus as a first approximation equal to that of the substrata. For hydrolysis of silane, water is necessary. The normal moisture content of the substrata is therefore no problem. Damp substrata can be treated, and an acceptable effect can even be produced on partly saturated materials. Because of the good miscibility between the alcohol solution of silane and water, the silane can diffuse easily into the surface.

5.2.2 Prevention of Water Ingress Through Cracks : In the case of silanes, due to the larger molecules, the bridging of cracks is possible to a limited extent. For larger cracks the silanes should seal the sides of the crack. To test the depth of penetration an experiment has been carried out, ie. a cracked block of concrete, put together again to give a specific crack width was treated with silane (Dynasylan BSM 40) and then the depth of penetration checked and which was found to be surprisingly deep, around 100mm for 0,2mm wide crack.

5.3 Procedure for Rehabilitation

5.3.1 Selection of Impregnation Liquid : Of the products available, independent testing in Europe and the U.S.A. has proved the hydrophobic properties and durability of a silane produced by Dynamit Nobel Chemicals under the trade name "Dynasylan BSM 40". However for high strength concrete "Dynasylan BH" is specially effective as an impregnating water repellant. The high strength concrete possesses only a low porosity and the solventless "Dynasylan BH" ensures high penetration and that the pore volume that can be achieved on impregnation is filled with undiluted active component.

5.3.2 Method of Application : Concrete surfaces already exposed to the atmosphere and whose pores have been contaminated by dust, salts, oils etc. must be thoroughly cleaned using steam or water jet methods. "Dynasylan BH" can be applied to damp surfaces since it reacts with moisture present in the pores, but it should not be applied in direct sunshine, strong wind or rain. Ideally, "Dynasylan BH" should be applied by saturation flooding, but application by means of a low pressure airless type sprayer is acceptable.

5.3.3 End Product : "Dynasylan BH" reacts with the boundary layers in pores and capillaries and produces an invisible water-repellant interface compound without causing discolouration.

5.3.4 Monitoring Effectiveness of Impregnation : The best way to monitor the effectiveness of the impregnation is to intall strain gauges on the treated structure and to take systematic readings under the same conditions. Any abnormal expansion indicates that the A.A.R. has restarted due to failure of the treatment which must then be re-applied.

6. Conclusions

The process of rehabilitating the Storms River Bridge described in this paper not only represents a very cost effective way of upgrading an old section of the National Route system, but also may lead the way in the treatment of concrete structures suffering from the damaging effects of Alkali Aggregate Reaction.

In addition the Storms River Bridge represents to many bridge designers and contractors alike a symbol of bridge construction in South Africa and it is fitting that it should serve its role for many years to come.

7. Acknowledgements

This paper is published by kind permission of the Director-General, Transport.

8. References

.1 M Ladner and WH Weder - "Concrete Structures with Bonded External Reinforcement". Swiss Federal Laboratories for Materials, Testing and Research Report 206.

.2 P Marples - "South African Experiences with Externally Bonded Steel Reinforcing".

.3 MD MacDonald - "The Flexural Behaviour of Concrete Beams with Bonded External Reinforcement". Transport and Road Research Report 415.

.4 KD Raithby - "External Strengthening of Concrete Bridges with Bonded Steel Plates". Transport and Road Research Report 612.

.5 F Hugenschmidt - "New Experiences with Epoxies for Structural Applications". Ciba-Geigy Limited Report.

.6 H Olafssen, 1983 - "Repair of Vulnerable Concrete" - Proceedings : 6th International Conference on Alkalis in Concrete, ed. G.M. Idorn-Steen Rostam pp. 479-485, Copenhagen : Road Directorate.

.7 U Ludwig and W Bauer, 1976 - "Untersuchungen Zur Alkali Zuschlag - Reaktion". Zement-Kalk-Gips Jahrgang 29, Heft 9. Seite 401-411, Wiesbaden : Bau ver lag.

.8 Paper by Dynamit Nobel Chemicals - "Protection of Buildings and Concrete Constructions with Silanes".