Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 57/1/57/2 (1989)

Artikel: Assessment of a bow-string bridge 50 years old in Pavia
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DOI: https://doi.org/10.5169/seals-44293

Assessment of a Bow-String Bridge 50 Years Old in Pavia

Evaluation d'un pont de type bow-string de 50 ans à Pavie

Beurteilung einer 50-jährigen Stahlbeton-Stabbogenbrücke in Pavia

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SUMMARY

In situ and laboratory measurements on a reinforced concrete bridge severely deteriorated by concrete carbonation provided data for a cost/benefit analysis. Diagnostic studies provide useful data for the improvement of the degradation models and realistic criteria for design and construction of durable bridges.

RÉSUMÉ

Les essais in situ et en laboratoire sur un pont en béton armé sérieusement endommagé par la carbonatation du béton a fourni des données pour une analyse prix/bénéfices. Les études diagnostiques fournissent des données précieuses pour l'amélioration des modèles de dégradation et des critères réalistes pour le projet et la construction de ponts durables.

ZUSAMMENFASSUNG

Messungen an einer stark geschädigten Stahlbetonbrücke und im Labor ergaben die für eine Kosten-Nutzen-Analyse erforderlichen Daten. Diagnostische Studien führen zu verbesserten Modellen bezüglich Schädigungsvorgängen und zu realistischeren Bemessungs- und Konstruktionskriterien.

1. INTRODUCTION

The criteria for design and construction of durable bridges shall be derived from appropriate models of the deterioration processes (chemical and mechanical), but may take advantage of the observation of the damages to existing structures.

In the limited field of reinforced concrete and prestressed concrete, the main reasons of degradation have been identified in:

- concrete carbonation and consequent steel corrosion
- action of de-icing salts and steel corrosion
- fatigue effects of loading on concrete and steel.

Such phenomena are qualitatively known [4], but quantitative models are still vague or totally lacking, so that their application to the design of new structures is not yet reliable. On the other hand, the large number of badly damaged existing bridges [1] constitutes a large set of specimens for study, and the current numerous works of diagnosis and assessment are precious opportunities for the acquisition of new knowledge.

In several cases the pathological state of the bridge is so advanced that demolition and reconstruction have been already decided; the structure is then an ideal laboratory , where tests on the residual life may be performed.

The Structural Mechanics Department of the University of Pavia and the Structural Engineering Department of the University of Rome are performing along such lines a joint theoretical and experimental research on the viaduct Pecora Vecchia of the highway Bologna-Florence, which shall be replaced; the research is focused on the synergetic effects of mechanical and chemical agents [2].

The present report is dealing with a previous experience of diagnostic studies on a r.c. bridge in Pavia, which is now being replaced. Further laboratory tests on parts of the structure could bring additional informations on the studies of degradation processes.

2. THE BRIDGE

Built in 1932, the bridge (Fig.1) has two spans of 38 m, with a bow-string statical scheme, a popular structure in the 30ies.

A first reason of deficiency was the design load, considerably less than the present design load, and than the load of vehicles frequently present on the National roads. The design of the superstructure was based on an axle of 140 kN, when the present Code imposes a load of 360 kN on an area of 2.6 by 1.0 m, and a dynamic factor 1.34. Tandem axles of 260 kN are indeed very frequent today.

If the deficiencies were obvious in the grid of the superstructure, they were not evident for the main resisting elements of the bridge, because of the great preminence of permanent loads. However, a dramatic spalling of concrete and corrosion of reinforcement (Fig.2) led to the need of a deep diagnosis for the assessment of the residual carrying capacity and for decisions about its possible repair or necessity of replacement.

The conclusions of the tests and of the analyses led to establish the loads temporarily admissible on the bridge (100 kN vehicles) and provided the necessary data for a cost/benefit analysis. The data, combined with town planning considerations, led the Authorities to the decision of replacing the bridge with a new one.

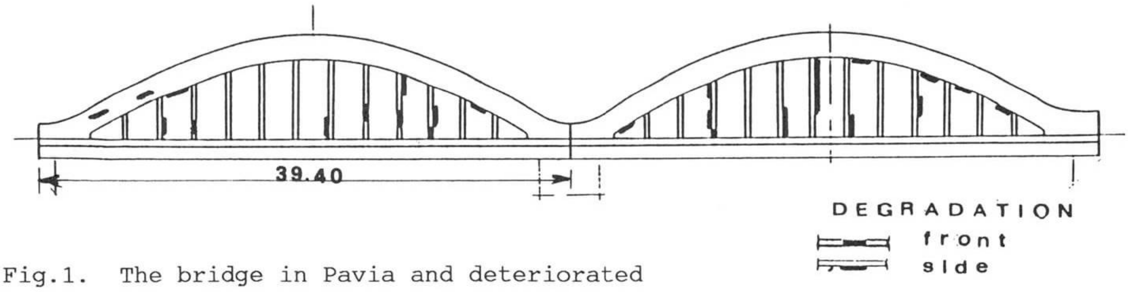

Fig.1. The bridge in Pavia and deteriorated parts in elevation

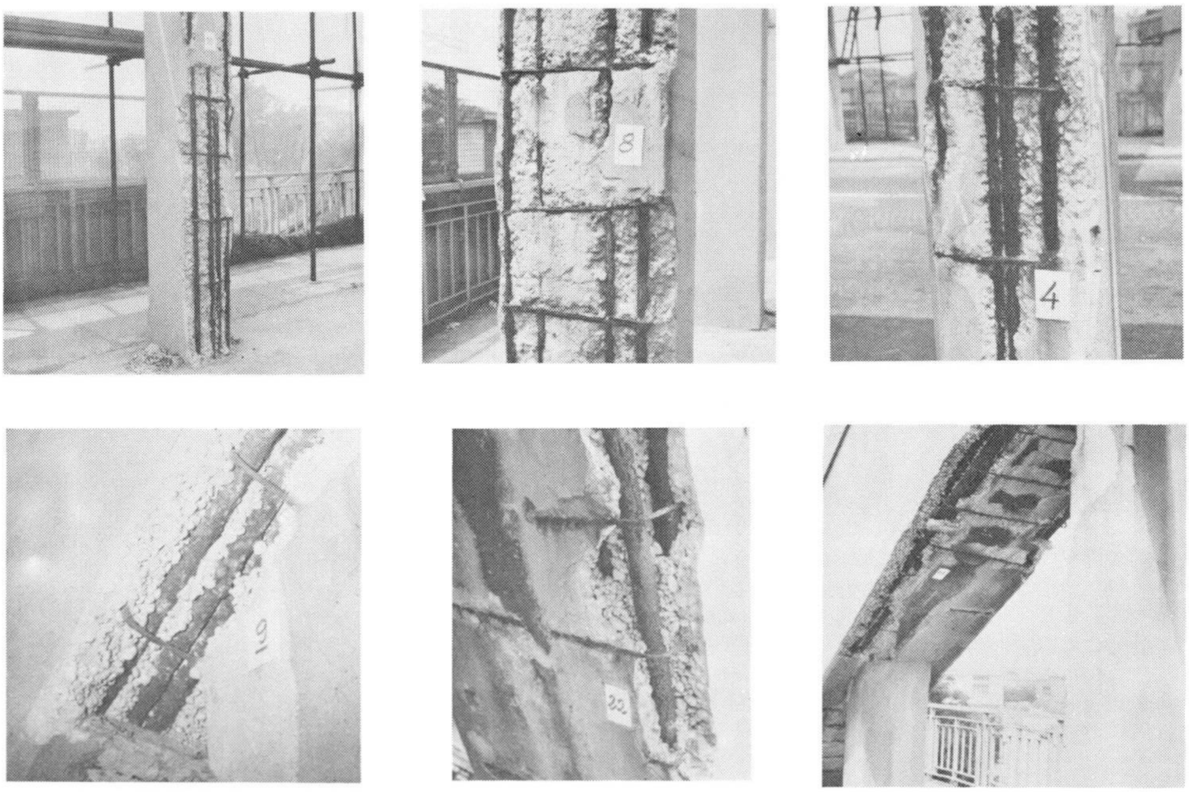

Fig.2. Corrosion of reinforcement and spalling of concrete on various elements of the bridge

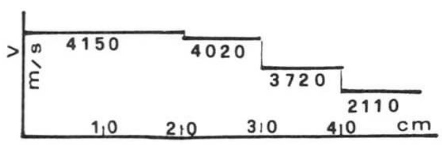

Fig.3. Decrease of ultrasonic pulse velocity for increasing path length (detecting intermediate cracks

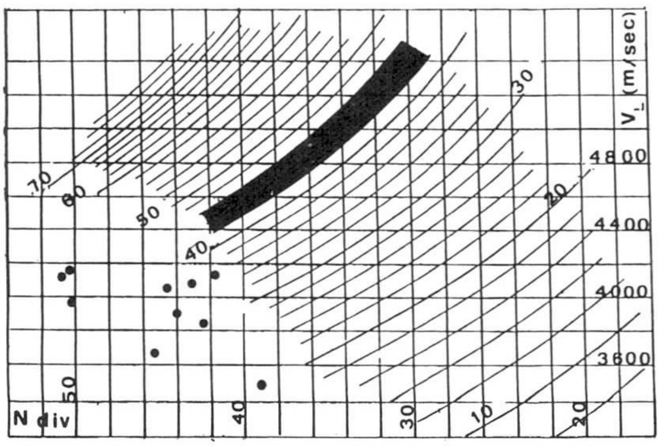

Fig.4. Concrete strength from hammer rebound index (sclerometer Schmidt)and ultrasonic pulse velocity (m/sec.). Shaded area is drilled core strength.

3. IN SITU AND LABORATORY MEASUREMENTS

3.1. Concrete

The strength and quality of concrete are needed not only for the assessment of the structure, but also for its correlation with the degradation phenomena, mainly carbonation and chloride penetration.
Non-destructive testing shall combine hammer rebound (Schmidt sclerometer) with ultrasonic pulse velocity (the RILEM SONREB method, Fig.4), because the first procedure is sensitive to superficial hardening due to carbonation, and the second one is sensitive to microcracking.
The detection of cracks and the elimination of their effects on measurements has been obtained by measuring the speed on different lengths on the same line (Fig.3); the highest values of speed have been retained as a property of the uncracked material.
The values of non-destructive tests are compared with the strength obtained on drilled cores, in the diagram SONREB (Fig.4).
The product of the correction factors may be roughly considered equal to 1.
The experimental points are plotted on the standard chart (the measurements in the damaged areas have been excluded); the band 42 to 46 MPa of the drilled core strength has been shaded.
It clearly appears that all the experimental points fall out of the area calibrated for new concretes. It means that the hammer rebound is measuring a skin hardness which is not correlated in the usual way with E modulus and strength, and this is due to the carbonation of concrete.
On the other hand, the ultrasonic velocity seems to underestimate the strength, perhaps due to a microstructural damaging of the old concrete. We cannot state anything of this kind at present; nevertheless, a warning is necessary: the use of non-destructive testing requires a special calibration for old structures.

3.2 Carbonation depth

The observed depth of carbonation was variable, but by far larger than expected according to the existing knowledge.
The measured values are plotted in Fig.5, and compared with the curve given in [10] for the development of carbonation with time.
Such unexpected level of the phenomenon cannot be associated with a bad quality of concrete; the strength was in fact exceptionally high for the time.
The question should be answered by further research on old structures and diffusivity in old concretes.

3.3 Corrosion of reinforcement

The dramatic spalling of concrete, mainly in vertical elements, as shown by Fig.2, is in complete agreement with the description of the phenomenon given in literature: the expansion of steel due to oxidation creates a pressure causing the spalling of the concrete cover; and oxidation is due to the destruction of the passivation layer caused by the carbonation of concrete.
At the time of the diagnosis the corrosion was already in progress on most reinforcing bars of the vertical tendons (all bars being disposed near to the external surface).
A reduction of 40% of the initial section of one bar has been observed locally; this value cannot obviously be generalized, but it caused a serious concern for the safety of the structure, because the progress of corrosion process in time cannot be estimated at present with reliable models.

3.4. Structural analysis

In the design of old structures the analysis has been often oversimplified;the modern methods of analysis can provide sometimes useful informations in the

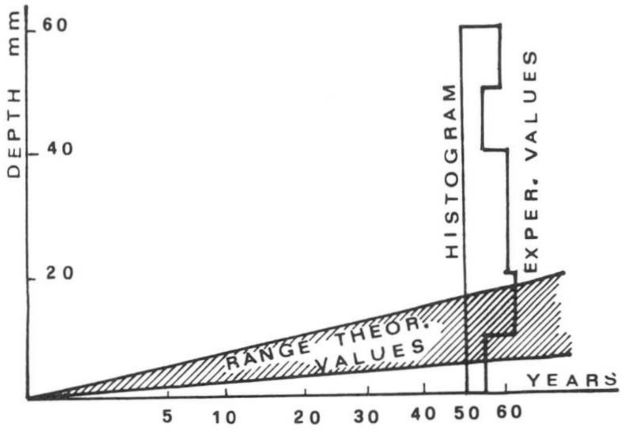

Fig.5. Carbonation depth vs time; plots indicate measured values.

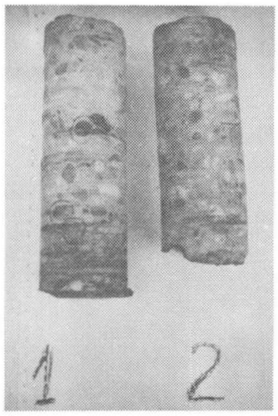

Fig.6. Drilled concrete cores.

diagnosis.
The 45 degree skewness of the bridge was not considered in the original analysis; therefore, the accurate analysis showed that conservative assumptions were done for the main resisting elements (as arches and ties), but bending and torsional moments were largely underestimated in the grid elements of the deck. Some elements needed urgent strengthening, but the entire superstructure was not in measure of carrying the present traffic loads, even in case of no degradation.
However, the analysis alone may be insufficient and ignore essential stresses which can appear under loading tests; it has been the case of the vertical tendons.

3.5. Loading tests.

In fact, the loading tests performed under the reduced load of vehicles of 100 kN (which was indicated as permissible load by the analysis) reserved a surprise: strain gauges applied on little degradated parts of the vertical tendons showed that the vehicles caused local stresses in the reinforcement of 170 MPa, several times the stresses anticipated by the analysis.
Such overstress can be explained if the redistribution of internal forces is considered between highly degradated tendons and the others: the formers lose the contribution of concrete and the corresponding stiffness, so that loads are transferred to the still rigid undamaged tendons. Such uneven stress distribution has been observed during the tests; the resulting stress range in steel was an unexpected danger of fatigue failure.

4. SUGGESTIONS FOR DURABLE BRIDGES.

The diagnosis of the old bridge has been the occasion for re-considering the criteria of design of r.c. and prestressed concrete bridges.

- Concrete.

The phenomena observed on the old concrete (both in the highly damaged elements and in the still well preserved parts) suggest to modify the criteria of design in the direction of an increase of durability and strength of concrete without increasing the stresses in service.

The equation: " strength = durability " has not been confirmed by our tests on the old concrete, which showed high carbonation depth in spite of the (apparently) high strength. However, extensive tests on modern high strength concretes show that they have much less porosity than ordinary strength concrete, and therefore less expected carbonation depth; moreover, less microcracking under short term and long term loading is a guarantee against progressive degradation and fatigue failure.
This concept implies to stop , at the same time, the constant increase of the stress level which has accompanied so far the improvement of the concrete quality.
- Cover.
The decrease of concrete porosity cannot be expected to reduce the carbonation to such an extent to justify the present values of cover; if carbonation depths higher than 40 mm (and locally 60 mm) have been observed in the 52 year old bridge, in spite of an overall good quality of construction, it would be wise to ensure a cover of at least 40 mm to a great percentage of the steel area of the main structural elements. We are perhaps forced to use different criteria for slabs, but envisage other kinds of protection!
- Diameter of bars.
The large diameter bars used in the 30ies provided a substancially safe life to the bridge in the essential elements (arch and tie). We should no more encourage the use of small diameters. Large diameter bars provide higher durability also in prestressed concrete bridges.
- Minimum thickness of resisting members.
Thin members have been used in the past, in the research of light and economic structures. Now thin girders and slabs are the most deteriorated parts of bridges both for the chemical attack and the fatigue action.
Minimum thickness has to be increased, and thick slabs should , when possible,substitute the conventional grids or box girders.

5. ACKNOWLEDGEMENTS

The support of the Municipality of Pavia and of the Italian Ministry of Education (MPI) are gratefully acknowledged.

6. REFERENCES

1. THUL H., Maintenance of Reinforced and Prestressed Concrete Bridges in the Federal Republic of Germany. IABSE Symp. Maintenance Repair and Rehabilitation of Bridges, Washington DC, 1982.
2. MACCHI G., RADOGNA E.F., MATERAZZI A.L. The synergetic effects of environment actions and fatigue. IABSE Symp. Lisbon 1989.
3. MACCHI G.,RADOGNA E.F., MAGENES G., MATERAZZI A.L. Probabilistic analysis of safety of bridges versus fatigue. CEB Bulletin n.185, 1988.
4. CEB Bulletin n.166. Draft CEB Guide to durable concrete structures.
5. KAVYRCHINE M. Inspection and Monitoring. IABSE Symp. Strengthening of Building Structures. Diagnosis and Therapy. Venice 1983.
6. TASSIOS T.P. Prolegomena to a generalised Design Space. CEB Bulletin n.152 1984.
7. SENTLER L. Service life predictions of concrete structures. Report TVBK 3018. Lund 1983.
8. GOTFREDSEN H.H., The decisions of non repair. CEB Bulletin n.152, 1984.
9. DE SITTER W.R., Costs for service life optimization. The "law of fives". CEB Bulletin n. 152. 1984.
10. SIEMES A.J.M., VROUWENVELDER A.C.W.M., VAN DER BEUKEL A., Durability of buildings: a reliability analysis. Heron, n. 3, 1985.
11. MARTIN H., RAUSEN A., SCHIESSL P., Carbonation of concrete made with different types of cement. Coll.Behaviour of Concrete Struct. Liege 1975