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Zarate - Brazo Largo Bridges: Stay Cable Damages and Rehabilitation

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Summary

The paper describes the reasons and basis for a structure related design basis for rehabilitation which is using the modern load resistance factor design. This design basis is formulated such that it depends on all available information regarding the loading conditions, results from material tests, observations of the degree of deterioration and an in-depth knowledge of the structure in question. The main results of a sensitivity analysis for the roadway load model are presented and the assessment of the stay cable capacity explained.

1 Introduction

The Zárate - Brazo Largo bridges are part of a roadway and railway infrastructure project in Argentina providing a crossing of the national road No 12 over the two main branches of the Paraná river - Paraná de Las Palmas and Paraná Guazú - northwest of the river delta close to the town of Zárate. The two bridges comprise cable stayed steel girder main bridges with spans of 110-330-110 m and a total of about 16 km concrete approach viaducts for railway and roadway traffic.

The bridges were constructed during the years 1972-1977, based on an alternative bid design submitted by the Joint Venture Techint - Albano, and opened to roadway traffic in 1977 and railway traffic in 1978 - the Guazú bridge is shown in fig 1.

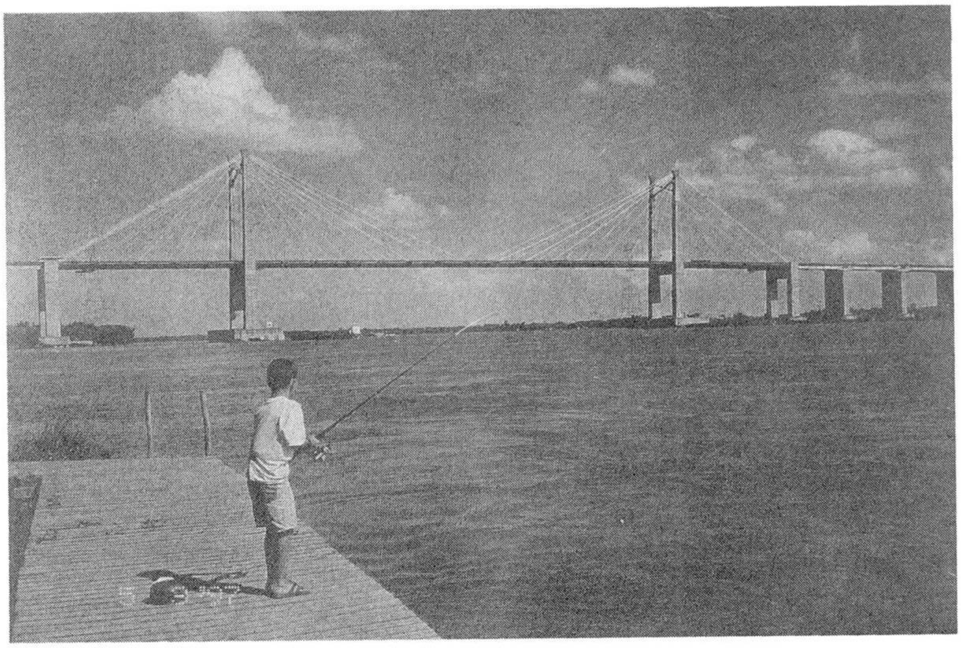

Fig. 1: Photograph of the Guazú bridge

Since the opening of the bridges the traffic volume and traffic pattern has changed. Due to the continuous development of the mercantile requirements for transportation as well as the use of new and heavier trucks. Since Argentina entered into the Common Market of South America, the MERCOSUR, late in 1991, the national road No 12 constitutes an important part of the infrastructure on an inter-American scale and its condition is a matter of highest importance.

Stay cable 7C of the bridge across Paraná Guazú ruptured on 20 November 1996. The stay cable failed close to the bottom socket at the deck level. The cable was removed from the top anchorage and put on the bridge deck. It showed that almost all of the 121 wires Ø 7 mm failed at about 200 mm outside of the bottom socket with severe signs of corrosion and fatigue-like ruptures in the wires.

As an emergency action, the bridges were closed to traffic on 25 November 1996, and the consortium Albano - DyCASA - Freyssinet (ADF) was entrusted by Dirección Nacional de Vialidad, DNV, the national highway authority of Argentina, with the immediate replacement of stay 7C, using the Freyssinet mono strand stay type.

2 Bridge Assessment and Rehabilitation Approach

The design and assessment of ordinary structures under normal conditions is appropriately accommodated by codes of practice and regulations. This is because the codes and regulations have been formulated and calibrated specifically to ensure that the most commonly built structures under normal conditions are both economic and sufficiently safe.

For the design and assessment of structures which are unique, e.g. by proportion, concept, material or condition, codes and regulations cannot be expected to yield structures which are appropriate in terms of economy and safety. It is therefore common practice for such structures to formulate and calibrate a design basis which is specific. Such a design basis can be understood as a specific code of practice for the design and assessment of that structure.

2.1 The rehabilitation design basis

The Zárate-Brazo Largo bridges are unique what concerns the condition of the deteriorated stays. The existing codes and regulations are thus not adequate for use as basis for a safety assessment and for rehabilitation design. Therefore, in order to ensure that the bridges are efficiently rehabilitated to a condition where they maybe accepted for safe continued use, and possibly even upgraded in terms of traffic loading, it is necessary to formulate and calibrate a rehabilitation basis specific for this bridge type, its observed state and the desired use of the bridges in the future.

To ensure the compatibility between this specific rehabilitation design basis and generally accepted design basis, such as the Eurocodes, the ISO codes and the AASTHO codes, the safety format for the rehabilitation design basis is the well-known load and resistance factor design (LRFD).

In general, the basis for the calibration of the safety factors and load combination factors is the application of modern reliability methods in accordance with the principles described in the background documents for the Eurocodes and the ISO codes, see [1].

2.2 Updating of the rehabilitation design basis

The rehabilitation design basis is formulated such that it can be modified for changes in the

- assumptions regarding past and future road and rail traffic
- results from material tests from dismantled stays
- measurements of stay forces
- inspections of damaged wires strengthening and replacement of stays.

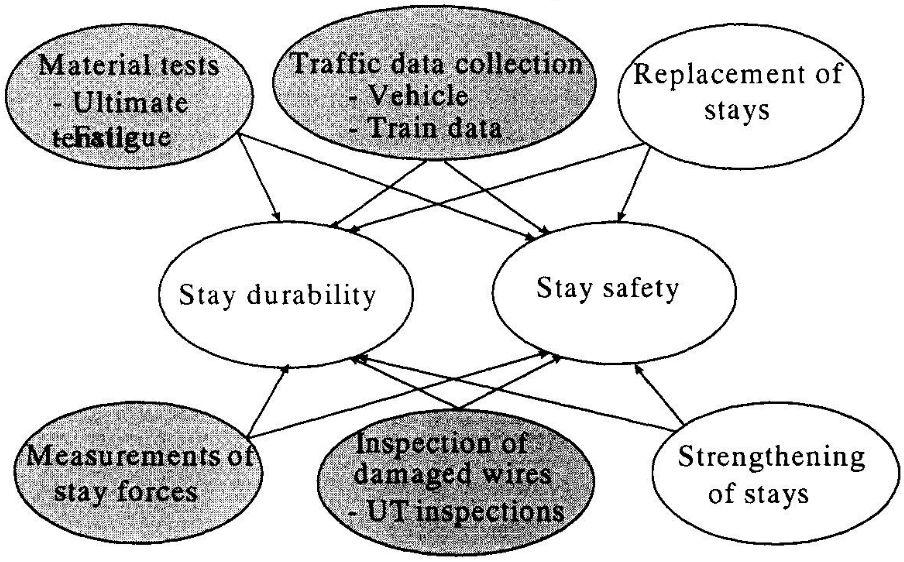

Fig. 2 *Illustration of the rehabilitation actions considered in establishing the rehabilitation design basis for the Zárate-Brazo Largo bridges.*

In fig 2 the rehabilitation actions considered for the rehabilitation of the Zárate-Brazo Largo bridges are illustrated. The grey toned "knowledge collecting" actions are those which continue changing during the course of the assessment and for which the rehabilitation design basis has been especially designed to accommodate.

The design basis for the rehabilitation of the Zárate-Brazo Largo Bridges presented in the following summarises the relevant information on loads and materials for the different stages of the rehabilitation of the bridges.

3 Roadway and Railway Loads

Probabilistic models have been formulated for the roadway and the railway loads acting on the bridges. With regard to the roadway load model basis has been taken in the theoretical framework formulated for the development of the design basis for the Great Belt East Bridge, see [2]. The railway load model has been formulated on basis of the model developed for the design of the Great Belt West bridge [3].

The roadway load model has been calibrated to the extend possible on the basis of traffic observations from the Zárate-Brazo Largo bridges. Some experience for European traffic has been used as a supplement when necessary.

The railway load model has been based on information regarding the actual traffic and traffic restrictions made available by DNV.

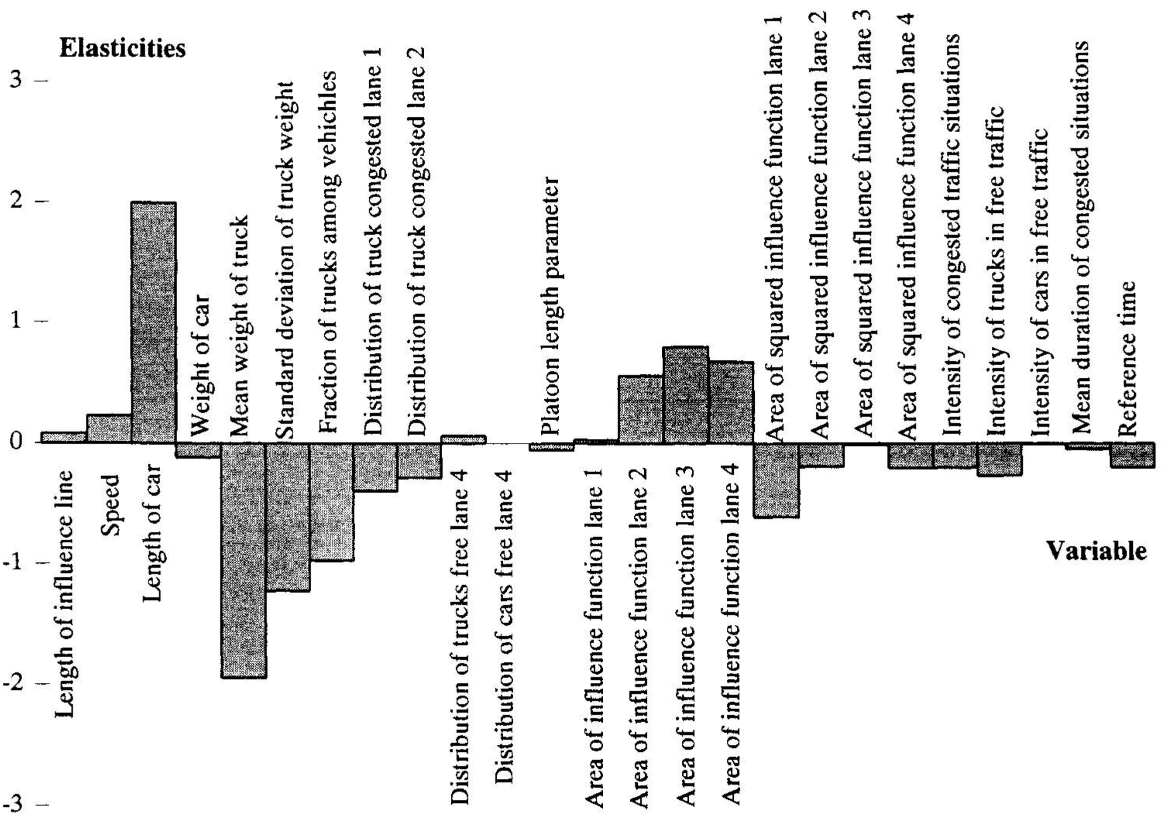

Fig. 3 *Sensitivity analysis of the roadway load model.*

Using the probabilistic load models together with influence lines for a number of selected load effects (including stay forces, road girder load effect and pylon load effect), the statistical distribution of the maximum load effect during one year has been determined. By defining the characteristic load as the 98 percentile of this distribution, an equivalent uniformly distributed load (EUDL) has been derived which yields the same load effect as the real load.

The results of a sensitivity analysis regarding the influence of the different input to the roadway load model is shown in fig 3.

Taking basis in the same requirements to safety as have been suggested in the back ground documents to both the Eurocodes and the ISO codes, the safety factors for the permanent and the variable loading together with the combination factors for vehicle and train loads have been derived on the basis of probabilistic principles.

4 Condition Assessment

To estimate the strength of a parallel wire cable it is necessary to determine the number of broken wires in the cable. The number of broken wires can be estimated by the use of UT-inspection. However, the UT-inspection will not be able to detect all broken wires with probability one. Furthermore, the inspection may indicate that intact wires are broken. To estimate the reliability of the inspection method it is necessary to determine the probability of detecting a wire which is broken and the probability of detecting that an intact wire is broken.

5 Assessment of Stay Cable Capacity

The resistance safety factors for the stay cables have been derived with basis in a probabilistic model of the time varying strength of parallel wire cables subject to fatigue deterioration. The model incorporates all available information regarding the material characteristics of the wires as obtained through testing under ultimate tensile as well as fatigue loading. The ultrasonic testing, together with the limited testing of cable 7C and two further cables, constitute the most essential data input to the current safety evaluation.

The model for the safety factor for the stay strength allows for a differentiation of safety factor in accordance with the intended service life of the considered stay. Furthermore the safety factors are given for the stays individually, taking specifically into account the damage condition and the loading on the individual stays.

Using the model, it is possible to derive safety factors corresponding to an interim period of the bridge (rehabilitation period) which is shorter compared to the situation where a normal service life is considered. Furthermore, the model also yields safety factors to be used in the design of stay cable replacements.

The computation of the residual life is based on a method proposed in [4]. The first step in the computation of the residual life is the estimation of the life distribution of a single wire. The number of cycles, t, to failure of a given wire subject to a stress range, Δs, is given by a Weibull distribution,

$$F_T(t,\Delta s) = 1 - \exp\left(- \left[\frac{\Delta s}{r_c}\right]^{\alpha} \left[\frac{t}{K}\right]^{\frac{\alpha}{m}} \right),$$ where α, m, K,

and c are unknown parameters, n is the number of sections of the test specimen with different properties and A_0 is the cross sectional area of the wire. The parameters m and K are also the parameters in the SN-curve which is given by $t = K\Delta s^{-m}$.

A large parallel wire cable with an infinite number of wires is considered. It can be shown that even though the number of wires is assumed to be infinite the results are in general valid for cables with a finite number of wires. The failure times of the intact wires given a certain level of mean stress and stress range are assumed to be identically and independently distributed. Also, the initial load on the cable is small enough to cause no static wire failure.

During service one wire breaks after the other due to accumulated fatigue damage. The wire with smallest failure time fails first in each state of the system. There is an immediate load redistribution after failure of a wire without dynamic effects during stress redistribution. The residual static strength of the individual wires is not influenced by the fatigue damage which might be accumulated. Finally, it is assumed that there is no dependency between the static strength of a given wire and the fatigue resistance of the wire.

The effect of corrosion is taken into account by determining a set of material parameters specifically for corroded wires. Further, corrosion implies that the length of wire where the material parameters can be assumed to be constant becomes small. Therefore, the parameter r_c which depends on n (the number of parts with different material parameters) depends on whether the wire is corroded.

References

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