Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 999 (1997)

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DOI: https://doi.org/10.5169/seals-986

Behaviour of Composite Box Girder Sections at Ultimate Limit State

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Summary

In this paper the method proposed by RPX-95[1] for the analysis of the behaviour of composite cross-sections subject to normal forces is briefly explained. This procedure allows the modelling of the behaviour in Ultimate Limit State, as well as in previous strain situations (moment-curvature diagram). An experimental program designed to test this approach, and presently under way, is also presented, as well as some of the results obtained so far.

1. Introduction

Eurocode 4 [2] as well as other standards [3,4] propose different approaches for the analysis of the bearing capacity of composite cross-sections subject to normal forces (Elastic, Corrected Elastic, Plastic, Elasto-Plastic). The Elasto-Plastic method, which models the behaviour in the most realistic manner, is formulated for slender compressed plates and stiffened compressed plates in terms of stresses. This fact does not permit the determination of the corresponding strain, and therefore does not allow to evaluate the ductility available.

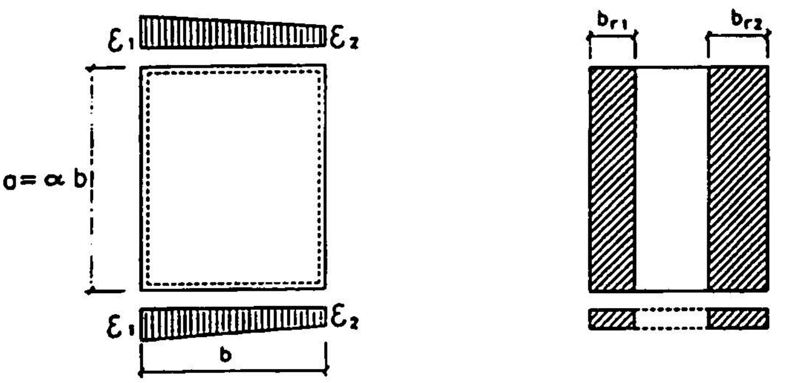
The recently published RPX-95 'Recommendations for the Design of Composite Highway Bridges' [1] includes a different elasto-plastic approach for the evaluation of the Ultimate Bearing Capacity (Ultimate Limit State) and for the evaluation of intermediate strain states (Moment-Curvature diagram). The main aspects of this procedure are discussed in what follows. This procedure allows to determine the deformational state of the cross section for every load level.

In order to test this procedure, an experimental program, which is briefly presented in this article, is being carried out. Some of the results obtained so far are also presented.

2. Sectional Behaviour

The study of composite cross-sections subject to normal forces requires the use of models which adequately represent the behaviour of slender compressed plates, stiffened compressed plates, slender plates stiffened by conection to a concrete slab (double composite action), etc. This subject has been extensively studied in the past few years [5] [6] [7]. The models developped, however, are formulated in terms of stresses, which makes their use difficult, since, when dealing with non-linear behaviour, the most adequate approach is the formulation in terms of strains.

The recently published RPX.95 'Recommendations for the Design of Composite Highway Bridges' [1] establishes a model which allows the representation of the behaviour of slender plates in terms of strain. This model has been developed on the basis of the classical method of efective widths [5], taking into account the tests and research carried out by several authors [8] [9][10] (fig. 1).



$$b_r = \rho b$$

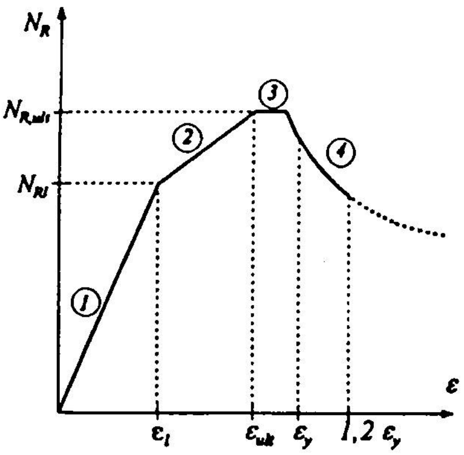
$$\rho = \left(\bar{\lambda}_p - 0{,}22\right)\frac{1}{\bar{\lambda}_p^2}$$

$$\bar{\lambda}_p = \sqrt{\frac{\varepsilon}{\varepsilon_{cr}}}$$

$$\varepsilon_{cr} = 0{,}9k\left[\frac{t}{b}\right]^2$$

Figure 1. Model for slender compressed plates.

For stiffened compressed plates, the model takes into account the instability of the both of the plate between stiffeners and the stiffener and the plate acting together (fig. 2).



1 Elastic behaviour
2 Plate buckling and/or stiffener buckling
3,4 Stiffener buckling and/or plate buckling

Figure 2. Model for stiffened compressed plate. RPX-95.

Finally, RPX-95 [1], following a similar method used in concrete structures for a long time, establishes a criterium in order to characterize the ultimate capacity of a cross section (fig 3). For this the ultimate strain of different fibres is assumed.

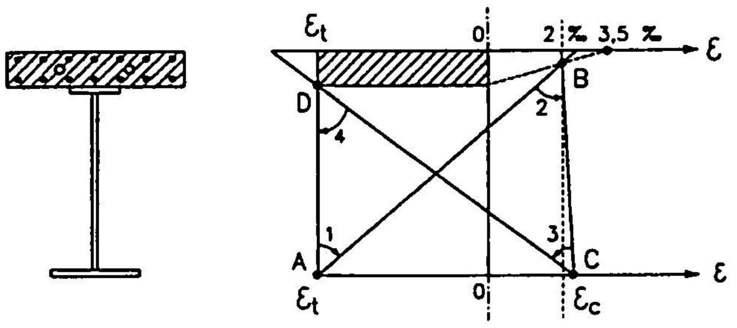


Figure 3. Ultimate strain conditions for Ultimate Limite State due to normal forces.

3. Experimental Program

3.1. Specimen description.

The experimental program includes four beams consisting, each one, in a span of 6600 mm and a cantilever of 2475 mm of length. In each test, the cantilever is initially loaded until failure of the support cross-section. Then, the main span is tested, also until failure of the most stressed cross-section.The beams are equipped with transverse diafragms over the supports and also with transverse stiffeners on the webs every 825 mm.

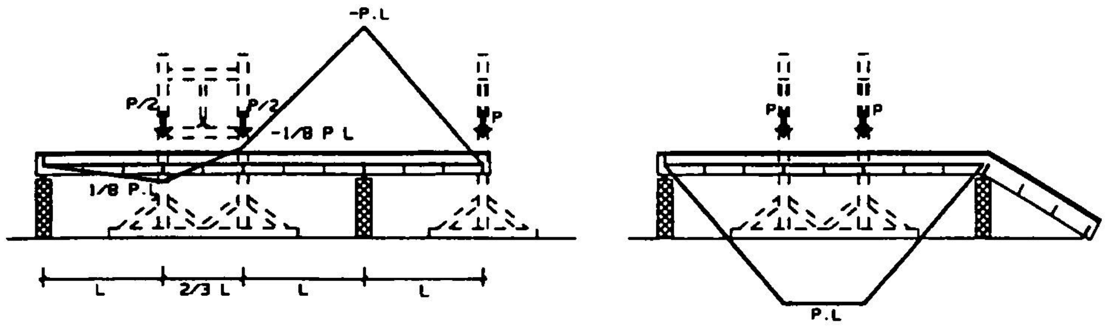


Figure 4. Test layout. Left: negative moments at support. Right: positive at center span.

The characteristics of the materials used for the beams are included in table 1.

Concrete		Steel		
Top slab	Bottom slab	Reinforcement	Plates	Stiffeners
C25	C25	Grade 500	S 355	S 275

Table 1. Nominal values of the materials used for the tests.

The geometry of the different critical cross-sections in the tested beams is shown in figure 5.

The sections are representative of the most widely used typologies for composite box girders in Spain (lower plate stiffened in the negative bending region with concrete, plates with different types of stiffening systems), and of the different structural behaviours.

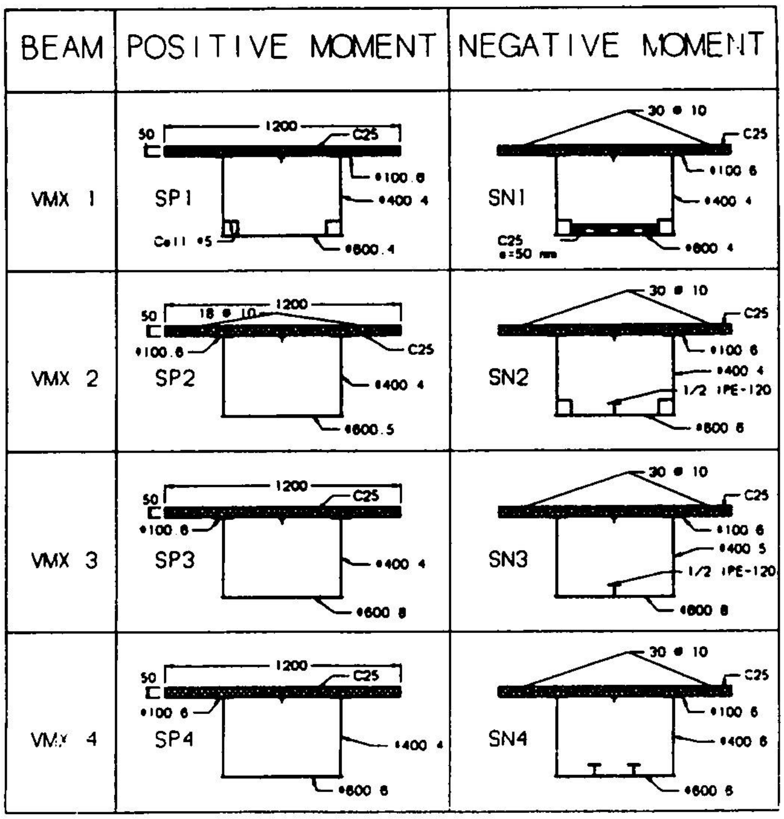


Figure 5. Geometry of the critical cross sections.

In order to take into account the construction procedures most frequently used, beams VMX2 and VMX3, on one hand, simulate unshored construction. Experimentaly, this situations is simulated by loading the structure before concreting the top slab (see photograph 1). Beams VMX1 and VMX4, which, on the other hand, simulate the case of shored construction, the top slab is concreted with the steel beam supported at intermediate points between the final supports.

In figure 6, the theoretical moment-curvature diagram, obtained according to the criteria presented in paragraph 2 for the cross sections at the center of the main span and at the support is shown.

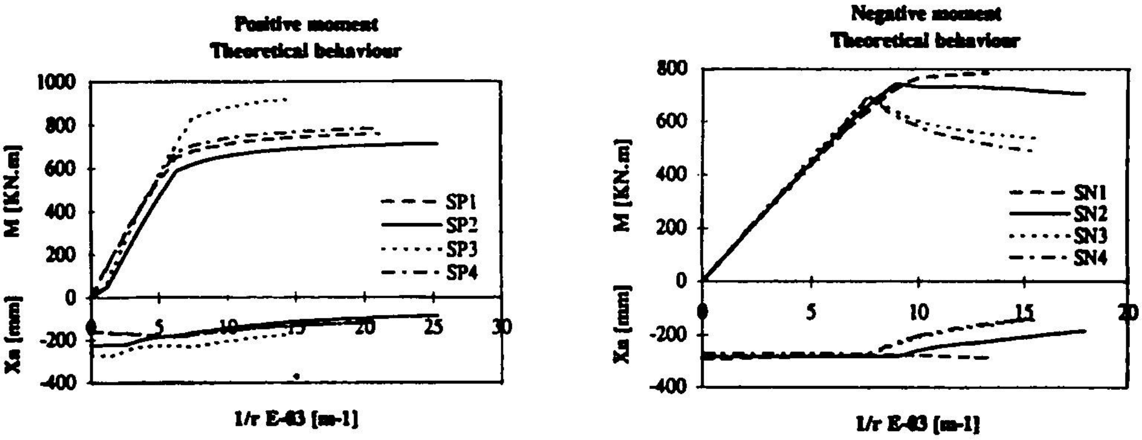


Figure 6. Theoretical moment-curvature diagrams for the critical cross sections.

3.2 Beam monitoring system

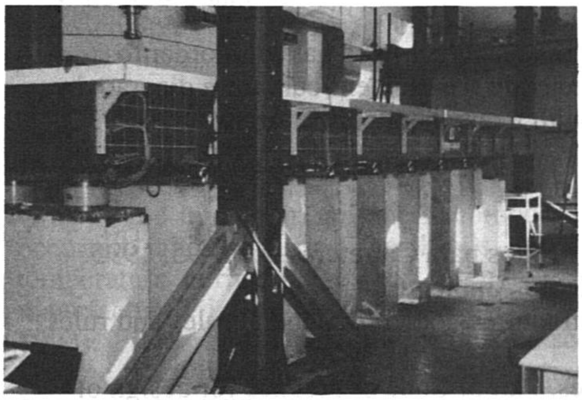
The monitoring system of the tested beams consists of:

- Load cells. In order to control both applied load and the reactions of the structure.
- Strain gauges in order to determine the state of strain at different cross-sections and plates.
- LVDT. The transducers are located on the concrete top slab and provide measurements of mean strains.
- Deflection gauges. They are used to measure global deflections of the cantilever and central span.

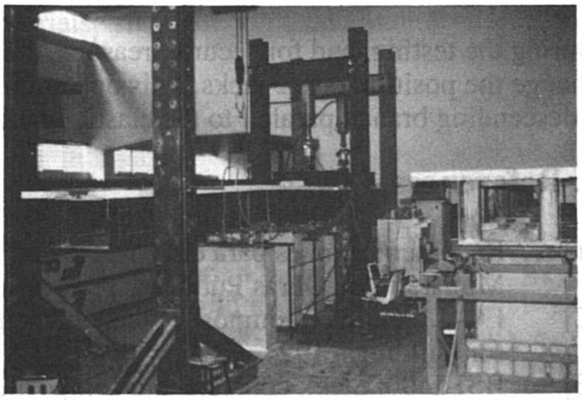
All the measurements were controlled and registered by a data adquisition system which allows the visualization in real time of the behaviour of different cross-sections and their comparison to the theoretical results.

4. Experimental results

In photograph 2, a moment of the loading of a center span is shown, after having completed the testing of the cantilever.



Photograph 1. Preloading of the steel girder VMX2 before concreting of top slab.

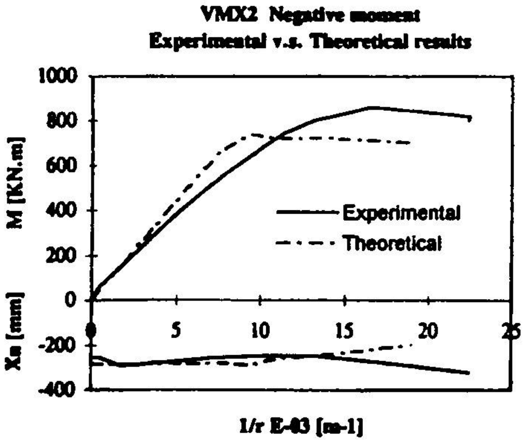


Photograph 2. Testing of center span. Beam VMX2.

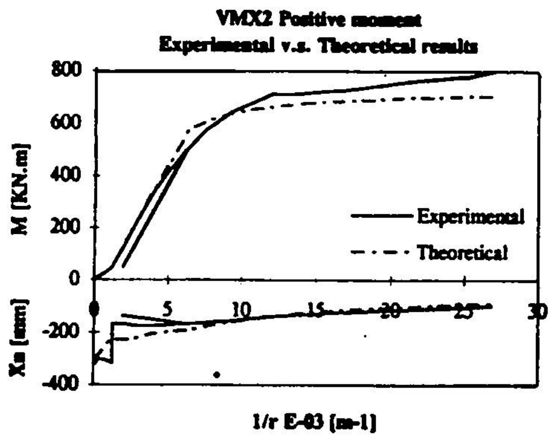
In figure 7.1, the theoretical moment-curvature diagram (obtained using the premises described in 2.) for the support cross section of beam VMX2 is compared to the experimental results. In the same figure the evolution of the fibre of zero strain is also shown. As can be seen the experimental results and the theoretical predictions show good agreement.

The first change in stiffness observed coincides with the cracking of the top slab. The second stiffness loss is due to the begining of the buckling of the lower plate. The failure of the cross section finally results from this instability.

In figure 7.2 the moment-curvature diagram and the evolution of the position of the zero strain fibre are shown, both the observed values and the predicted ones, for the center span cross section.The diagram shows the influence of pre-loading. After the concreting, the cross section behaves more or less linearly until the yielding of the structural steel takes place.



7.1 *Support cross section*



7.2 *Center span cross section*

Figure 7. Moment-curvature diagrams. Experimental v.s. theoretical results.

The measurements were halted when the measuring range of the monitoring devices was surpassed, however, the load process continued until failure of the beam was reached with a great deflection at center span.

As can be seen the position of the zero strain fibre is always high, so that almost all the steel cross-section is in tension. With the yielding of the steel, the position of this fibre becomes even higher.

During the testing, and for security reasons, the loading process had to be halted in order to change the position of the jacks. This operation is reflected in the moment-curvature diagram by a descending branch paralell to the elastic branch but with a remanent plastic strain.

5. References

[1] Recomendaciones para el Proyecto de Puentes Mixtos para Carreteras. RPX-95, 1995. Ministerio de Obras Públicas, Transportes y Medio Ambiente.

[2] EC-4.Design of composite steel and concrete structures. Part 1-1. General rules and rules for buildings. 1994

[3] BSI 5400. Steel, concrete and composite bridges. Part 5. Code of practice for design of composite bridges.1979.

[4] SIA 161. Constructions métalliques. 1990.

[5] P. Dubas; E. Gehri. Behaviour and design of steel plated structures. ECCS. CECM. EKS. 1986.

[6] European Recommendations for the design of longitudinal stiffened webs and of stiffened compresion flanges. Nª 60. ECCS. CECM. EKS. 1990.

[7] W. Hindi; J.E. Harding. Recommendations for the design of stiffened girder flanges under uniaxial compression. Bridge Assesment Management and design. Elsevier Science. 1994.

[8] K. Ghavami. Experimental study of stiffened plates in compression up to collapse. J. Const. Steel Research. Elsevier Science. 1993.

[9] Vayas, I.; Psycharis, I. Dehnungsorientierte Formulierung der Mehode der wirksamen Breite. Stahlbau, 61 (1992).

[10] Calvo, J.;Corres, H. Propuesta de ensayos de secciones mixtas en cajón en E.L.U. Informe anual. E.T.S.I. Caminos,Canales y Puertos de Madrid. 1994.