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The Spanish Recommendations for the Design of Composite Road Bridges

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Summary

The Spanish Ministry of Public Works has recently published the Recommendations for the Design of Composite Road Bridges, RPX-95. The paper presents the ideas that have guided the elaboration of the Recommendations, as well as some of the main aspects of their content.

1. Introduction

Starting in the early seventies, a large number of composite road bridges of different types have been built in Spain. Considerable attention has been dedicated to the quality of the design and normally box girder sections have been used, as well as the so-called "double composite action". In 1990, the General Directorate for Highways of the Ministry of Public Works, which is responsible for most bridges in Spain, decided to fund the drafting of the Recommendations. Succesive versions of the document produced have been intensely debated by a large number of specialized engineers. The final text of the RPX-95 [1] was completed in 1995 and edited by the Ministry of Development together with the Recommendations for the Design of Steel Road Bridges, RPM-95 [2] and with the Code for Actions on Road Bridges, IAP-96 [3].

2. Guidance for producing RPX-95

The main objectives pursued in drafting the Recommendations were the following:

a) To provide a set of guidelines to be considered, although not necessarily satisfied, when designing bridges for the General Directorate for Highways.

b) To promote the quality of design and construction of composite bridges.

c) To serve as an instrument in the process of standardization, dissemination and updating of the know-how of professionals working on composite bridges.

Among the main ideas which influenced the text of the Recommendations, the following ones can be underlined:

- The bases for calculations are similar to those established in the structural Eurocodes [4].
- The philosophy of the limit states is maintained explicitly throughout the text. The verification of the serviceability limit states and that of the ultimate limit states have different objectives and are, therefore, complementary.
- It is not possible to know precisely the distribution of stresses within a structure. Thus, the calculation of stresses must be considered an instrument and not an aim in itself.
- The assumption of ideally elastic behaviours implies that the behaviour of the steel is taken to be akin to that of glass and that steel structures are therefore brittle [5], [6], [7].

- Figure 1 shows that the ultimate moment of a section decreases softly with increasing slenderness of the web. However, the rotation capacity changes abruptly when the web slenderness increases from class 1 to class 2.

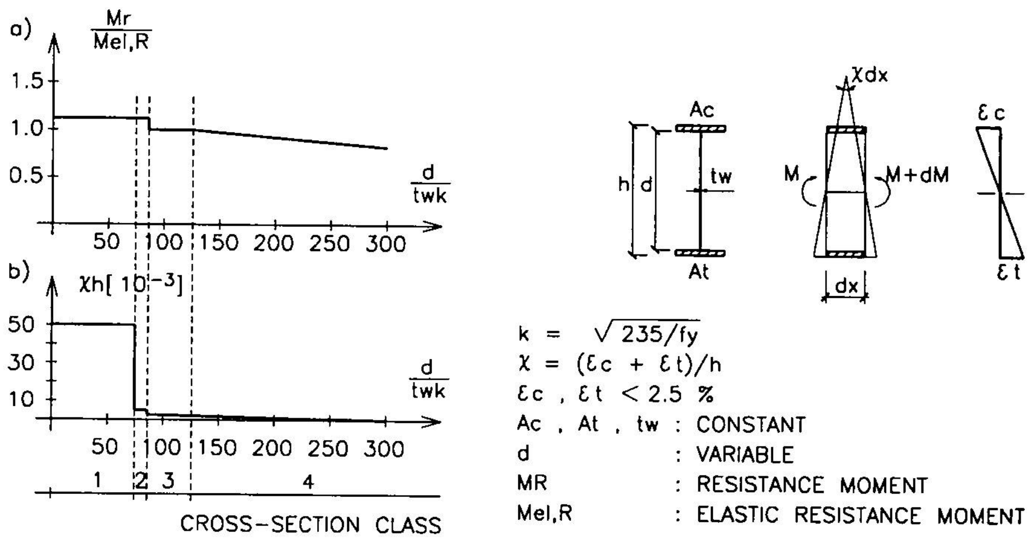


Fig. 1 Classification of cross-sections subject to bending

- It is essential, however, to guarantee a ductile behaviour. This justifies, among other things, dedicating less attention to the effects of shrinkage, creep, temperature, differential settlement of supports, seismic loads, etc. Ductility compensates some of our ignorance [8], [9].

- A good code is essential for a policy of quality which aims at progress in bridges.

- Besides the calculations, there are other aspects in the codes which are essential for achieving functionality, safety and durability: limit conditions imposed on the structural elements, durability specifications, maintenance and quality control of the design and construction processes.

- The users of the code should not use it as a substitute for thinking, neither they should consider it a collection of recipes.

- Codes also need maintenance. Every few years, the experience of their application should be assessed and, in view of the progress of knowledge, the code should be revised and updated.

3. Some characteristic aspects of the RPX-95

3.1 Structural analysis

The recommended methods of analysis are:

Method of analysis	Internal forces (ULS) Effects of actions (SLS)	Strength of sections (ULS)	Cross-section class
E/EC	Elastic (E)	Elastic with reduced section (EC)	Slender or semi-compact
E/P	Elastic (E)	Plastic (P)	All compact
E/EP	Elastic (E)	Elastic-plastic (EP)	Any cross section class
EP/EP	Elastic-plastic (EP)	Elastic-plastic (EP)	Any cross section class

The following criteria are established in order to define the mechanical characteristics of the different sections to be calculated:

Modified section denomination	Reason	To take into consideration SLS	ULS
Effective section	Shear lag	YES $b_r = \psi_{el} \cdot b$	YES $\psi_{el} < \psi_{ult} \leq 2\psi_{el}$
Reduced section	Local instabilities	generally NO	YES
Equivalent steel section	Different modulus of elasticity and creep of concrete	YES	YES
Cracked section	Cracking of the concrete under tension	Depends on the tensile stress level	YES

3.2 Serviceability Limit States

3.2.1 Limit state of deformations of the structure

1st Condition: Precamber shall be the addition of the deflection caused by the permanent actions, f_p for t = 0 and a part of the deflection caused by time dependent effects (creep and shrinkage) evaluated for $t=\infty$. This part shall be such that the difference between the grade line calculated for t=0, and the functional grade line defined in the project, and the difference between the grade line calculated for $t=\infty$ and the functional grade line, are smaller than the limits of the following table:

Type of bridge	Highways	High speed road	Local roads
One isostatic span	L/2000	L/1200	L/800
Several isostatic spans	L/4000	L/2300	L/1600
Continuous	L/1500	L/900	L/600

2nd Condition: Deflections due to the "rare combination of actions" shall not affect the appearance and the functionality of the bridge.

3rd Condition: Strength criteria. Deflection due to traffic loads in the frequent combination should not exeed the limit of L/1000.

3.2.2 Limit state of the web deformation

- Stress condition for the frequent combination of actions:

$$\frac{\sigma}{1{,}1\,\sigma_{cr}} + \left(\frac{\tau}{1{,}1\,\tau_{cr}}\right)^2 \leq 1$$

- Recommendations for the minimum slenderness of the web: $f_y = 355$ N/mm^2

Zone	Beams with transversal stiffeners	Beams with longitudinal and transversal stiffeners
Intermediate supports of continuous beams (M and V,max.)	160	250
End supports of continuous and isostatic beams (M, small)	200	300
Centre span of continuous and isostatic beams (V, small)	240	350

3.2.3 *Limit state of vibrations*

- Verification of road bridges, which can be idealized as a beam, with sidewalk for pedestrians:

$$y_L \leq \sqrt{f_0}\,\frac{L \cdot f_0 \cdot 18}{2000 \cdot f_0^2} \qquad (y_L \text{ and } L \text{ in meters})$$

where

f_0 frequency of the first vertical mode of vibration

y_L maximum deflection produced by a load of 10 kN/m^2 extended on the road width b and the length a = 0,9/b + 0,06 L.

3.2.4 *Limit state of local plastification*

The stresses must be checked, if it is not evident that the following limits are not exceeded:

Combination of actions	Structural steel	Structural concrete
Frequent	0,75 f_y	0,50 f_{ck}
Rare	0,90 f_y	0,625 f_{ck}

In particular it is necessary to check the stresses when ψ_{el} is below 0,6; in areas where in the ULS $\varepsilon_{max} > \varepsilon_y$ is accepted; and in singular areas with significant deformations in multiple directions.

3.3 Ultimate Limit States (ULS)

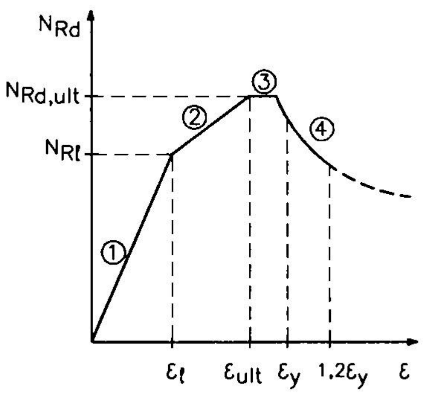
3.3.1 Ultimate bending moment, M_R, of beams

The values of M_R are established according to the σ-ε diagrams of the materials and to their deformation limits, which are summarized in the following table:

Method of analysis	Cross-section class	Deformations limits			Resisting section
		Steel		Concrete	
		Tension	Compression	Compression	
Plastic (P)	Compact	No limits	No limits	3,5 ‰	Complete
Elastic (E)	Slightly slender	4 ε_y	ε_y	$\varepsilon_c = f(\sigma_c)$	Complete
Elastic (E)	Slender	4 ε_y	ε_y	$\varepsilon_c = f(\sigma_c)$	Reduced
Elastic-plastic (EP)	Any section class	4 ε_y	1,2 ε_y	$\varepsilon_c = f(\sigma_c)$	Complete or reduced

3.3.2. Ultimate bending moment, M_R, of box girder sections

The value of M_R depends on the capacity of the compressed stiffened plate to transmit compresive forces, N_R, which is a function of the level of the deformations ε. In the Recommendations, criteria are given for determining the N_R-ε diagram of the stiffened plate [4].



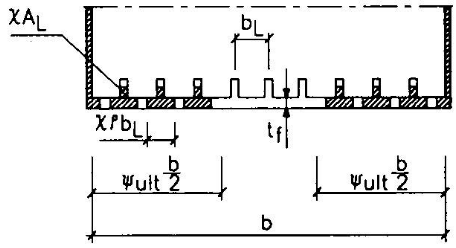


Fig. 2 Compressed stiffened plate *Fig. 3 Diagram* N_R-ε

The maximum value of $N_{Rd,ult}$ is determined by the expression:

$$N_{Rd,ult} = \left(b_r \cdot t_f + n \cdot A_{L,r}\right)\frac{f_y}{\gamma_a}$$

where: $b_r = \psi_{ult} \cdot \rho \cdot b_L(n \cdot \chi + 1)$ and ρ is a function of $\bar{\lambda}_p = \sqrt{\frac{\chi \cdot \varepsilon_y}{\varepsilon_{cr}}}$

The Recommendations also deal with stiffened plates connected to a concrete slab:

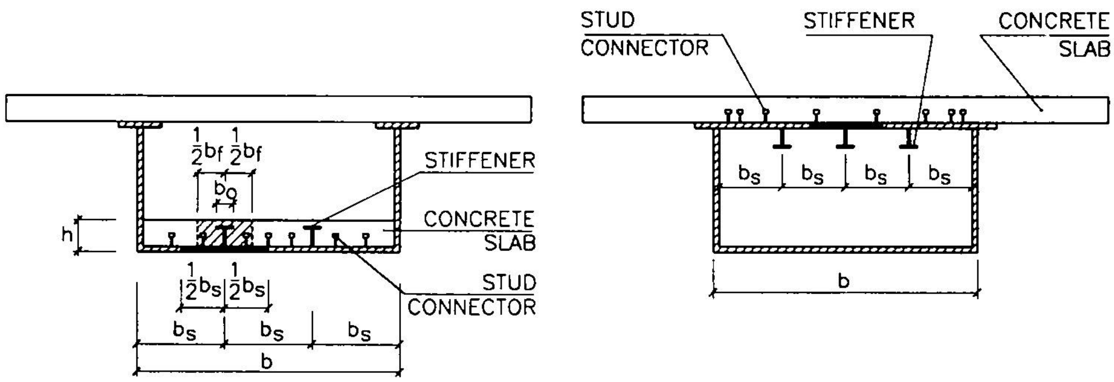


Fig. 4 Stiffened plate connected to a concrete slab

3.3.3 Interaction diagrams

The use of interaction diagrams in order to establish the safety control of sections under combined internal forces and moments has been generalized.

The influence of a simultaneous torsional moment is taken into account by reducing the ultimate bending moment and the ultimate shear force as a fuction of the external torsional moment, T_{Sd}, and the minimum value of the ultimate shear of the stiffened plate or the concrete slab, $R_{Rd,min}$:

$$M_{Rd}\sqrt{1-\left(\frac{T_{Sd}}{2\,A_{\phi}\,R_{Rd,min}}\right)^2}$$

$$V_{Rd}\left(1-\frac{T_{Sd}\cdot h}{A_{\phi}\cdot V_{Rd}}\right)$$

3.3.4 Longitudinal and transversal stiffeners

Some examples of recommended minimum conditions [6], [7]:

- T sections: $h_t/t_s \leq 30$ and $b_s/t_{bs} \leq 10$
- Longitudinal web stiffeners and transversal stiffeners of stiffened plates in box girder sections: $L_s/h_s \leq 25$
- Longitudinal stiffeners of stiffened plates: $L_s/h_s \leq 25$
- Distance, b_s, between longitudinal stiffeners of stiffened plates: $b_s/t_f \leq 120$ for tension plates, $b_s/t_f \leq 60$ for compression plates, where t_f is the plate thickness.

Besides, the necessary criteria for the evaluation of the strength capacity of the stiffeners and the required stiffness conditions are also established in the Recommendations.

3.3.5 Diaphragm in beam or box girder decks
Minimum distance between diaphragms:

- For box girders: $L_D \leq 4\,d$ (d, depth of the box girder)
- For beams: $L_D \leq 0{,}2 \frac{\pi}{\sqrt{3}} b \sqrt{\frac{E}{f_y}} \approx 8{,}7\,b$ (with $f_y = 355$ N/mm^2)

where b is the width of the compressed flange.

Further, minimum stiffness requirements and criteria for evaluating the strength capacity of the diaphragms are established in the Recommendations. This is done using a simplified model consisting of virtual bars under tension or compression [6], [7], which are supposed to provide the transmission of the forces acting on the isolated diaphragm. It is also necessary to ensure that the panels between stiffeners have the necessary dimensions to permit their plastification in order to fulfil the condition of compatibility of deformations.

4. Acknowledgements

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