High-Speed Railway Bridges

Conceptual Design Guide

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Foreword

At the request of the authors, I have been given the honour of writing the foreword to this book, which is devoted to railway bridges. It develops the aspects referring to their structural conception, taking into account the characteristics of railway traffic: actions, limit states, speeds, etc., and includes a detailed analysis of the superstructure of the track with its different components and singular elements (for example, expansion devices) that allow the correct behaviour of the track.

In the following chapters, the knowledge and experience of the authors is passed on. In this respect, I remember a technical conference that took place in the 1970s at the Eduardo Torroja Institute, dedicated to bridges; at that time, the undersigned engineer was assigned to the Renfe Bridge Division and attended it. Ramón del Cuvillo, professor of Concrete at the School of Civil Engineering in Madrid, presented a paper in which he focused on the defects and mistakes in design and execution in projects and works in which he had been involved. His presentation was the most applauded of the day's and, personally, the one from which I learned the most. I hope that reading this book will be useful to avoid the repetition of problems that can be avoided, without having to wait for experience after the execution of the works.

As the reader will appreciate, special emphasis is placed on the interactions between the structure and the track, subjected to railway and environmental actions, taking into account the requirements of their stability in different situations; solutions are also proposed and considered in relation to the transitions between the bridge and the adjacent infrastructure (and track).

Special attention is paid to the dynamic nature of railway actions, studying the dynamic response of the structure and its influence on the behaviour, also dynamic, of the track and its components, with the repercussions that this may have on safety, traffic flow quality, and maintenance needs.

To conclude, I would like to transmit here some ideas that the Emeritus Professor of Structural Engineering of the University of Berkeley, Edward L. Wilson, sets out in his book *Static and Dynamic Analysis of Structures*. In a section of Personal Remarks, he relates that his first-year physics professor warned his students 'not to use an equation they could not prove'; he also advises, with respect to modern structural engineering, 'not to use a structural analysis program unless you fully understand the theory and approximations contained in the program'. I fully agree with these considerations; I therefore share them with the reader, in the hope that they will be useful to them.

Madrid, June 2023

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About the Authors

José Romo is Chief Executive Officer and partner of FHECOR, and also a bridge engineer fully specialised in large-span bridges with more than 40 years of experience in bridge design, 35 of them working in FHECOR. He has vast technical knowledge based on his design background complemented with his activity as professor of concrete and steel structures at Madrid University, and his active participation in national and international associations of bridge designers and concrete and steel materials. He is a member of many scientific committees such as Eurocodes, IABSE, and ACHE where he became president in 2014 and was awarded with the honour's medal in 2008. He is a fellow of the Institution of Civil Engineers of UK. He has always worked as a bridge designer participating in innumerable bridge projects in Spain and worldwide, and also in the construction engineering for many of them. He has a great aesthetic vision that he applies to all the designs, while having great concern for sustainability and the use of new materials and construction techniques.

Alejandro Pérez-Caldentey is full Associate Professor at the Department of Mechanics of Continuous Media and Theory of Structures for the Civil Engineering School at the Polytechnic University of Madrid. He joined FHECOR in 1989 after graduating from UPM where he also obtained his PhD in Civil Engineering in 1996. During his more than 34 years of experience, Alejandro has developed structural bridge projects in countries such as Spain, Chile, Italy, and the USA. He is experienced in managing multidisciplinary structural teams, developing designs, and planning and defining the scope of works. He also has extensive experience in managing and developing Research and Development projects, in Standardisation (member of the Project Team for EN 1992-1-1:2023), and in Education (Professor at UPM). He holds Engineering licenses for Spain, Chile, Virginia, Texas, Florida, North Carolina, Québec, Ontario, and British Columbia. He is also a partner and member of the Board of FHECOR Consulting Engineers.

Manuel Cuadrado holds an MSc in Civil engineering from the Polytechnic University of Madrid. He is currently Associate Professor at the Carlos III University of Madrid and a member of the Technological Committee of the Spanish Railway Research Foundation (SRRF). Manuel Cuadrado has been working for 34 years, mainly in the railway industry, for Spanish and French Engineering companies, as an independent Consultant, and from 2005 to 2017 for the SRRF. He has participated both in key Spanish High-Speed projects and in International High-Speed Lines (Portugal, Turkey, California), and has been involved in many R & D projects mainly related to the mechanical behaviour of railway infrastructures. As a result of his R & D activity, he has produced many monographs, published several papers in national and international journals, and presented many papers in national and international congresses, including WCRR 1999-Tokyo, WCRR 2001-Köln, WCRR 2006-Montreal, WCRR 2008-Seoul, and WCRR 2016-Milan, and UIC High Speed Congresses 2010-Beijing and 2015-Tokio. He was also invited to participate as a specialist in the drafting of railway standards, as a member of Spanish, European, and international technical committees. Finally, from December 2017, he has been participating as Infrastructure Assessor and Lead Assessor in several Rail Safety & Interoperability assessments, as Infrastructure expert and as Slab-track expert.

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1
Introduction to High-Speed Railway Bridges

José Romo

1.1 Book's Content

One of the particularities of this book is that it includes not only the aspects related to the design and behaviour of these types of bridges, but also those questions linked to the railway technology of the track itself. It is clear that the knowledge of both fields and the interaction between these two technologies, structural and railway, is fundamental for the complete design of these bridges.

The first chapter of the book is dedicated to explain the particularities of high-speed railway bridges (HSRB), in comparison with structures for conventional railways. The typological particularities of this type of bridge are also explained, as well as the importance of these works as a legacy for future generations.

Chapter 2 is devoted entirely to explaining the technology of the track and the particularities of the high-speed infrastructure. This chapter explains the special constraints in terms of rail traffic safety and passenger comfort. It also deals with critical elements in the design of these structures, such as rail joints and other special track elements.

Chapter 3 reviews the main concepts which affect the design and includes the main typologies used in structures for high-speed railway lines. The dimensions and characteristic weights of the different solutions are also included. This chapter also describes the special structural elements of these structures, such as abutments and fixed points. Finally, the particulars of the design of HSRB located in seismic areas are included. This chapter also has a worked example corresponding to a railway viaduct, which starts with the general definition of the bridge in a specific valley and the geometric definition of the different structural elements that make up the structure.

Chapter 4 is dedicated to the Design Basis of bridges of the railways high-speed lines. In this section, the typical loads and design criteria are indicated, as well as its application to the worked example defined in Chapter 3.

Chapter 5 is devoted entirely to analysing the dynamic phenomena associated with HSR bridges. In this section the different methods of analysis, the trains that

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must be analysed to calculate the dynamic response, as well as the way to consider other aspects of the response, such as the irregularity of the track and the vehicle or the interaction between the vehicle and the structure, are presented. The chapter is completed with several practical examples and an appendix which includes the theoretical aspects of general dynamics and their application to the analysis of HSRB.

Chapter 6 is dedicated to the interaction between the track and the structure. This section analyses this phenomenon and how to take into account the thermal effects, traction and braking forces, vertical loads and rheological effects, in the case of concrete decks. In addition to the analysis models, the checks to be carried out to calculate stresses in rails and relative displacements are analysed. This chapter also deals with the criteria for the placement of track joints, as well as the practical application of the worked example.

Chapter 7 deals specifically with aspects linked to the conceptual design with maintenance of bridges for high-speed rail lines in mind.

In addition to Chapters 1–7, the book includes two appendices. One is devoted to a review of the general concepts of dynamics that the reader of Chapter 5 on the dynamic behaviour of these bridges should be familiar with. The second appendix includes a 'register' of high-speed railway bridges built in different parts of the world.

1.2 What is Special About a High-Speed Rail Bridge?

It is often asked what is so special about a railway bridge for a high-speed line and particularly, what makes a railway bridge for a high-speed line different from a conventional railway bridge. The corresponding Sections 1.2.1–1.2.4 that follow in this chapter describe the causes or aspects that make HSRB so special.

1.2.1 Dynamic Amplification and Resonance

On railway bridges, there are a number of factors that lead to a dynamic response of the structure under traffic loads.

On the one hand, the loads are fast so there is an impact effect. On the other hand, the trains are composed of a more or less long succession of vehicles which means that the loads are repeated, so the dynamic effect is amplified. Finally, the imperfections of both the track and the vehicles create disturbances in the value and the way of applying the loads, which leads to an increase in the response of the structure.

Therefore, the actual forces and deformations of a bridge due to rail traffic are of a dynamic nature and their values can be considerably higher than those due to static actions. In order to take this amplification into account in the calculations, an impact or dynamic magnification coefficient is applied to the static loads, a coefficient established in the design standards on the basis of statistical studies carried out on bridges in service.

But all these causes are increased when the speed of trains is increased, and as will be seen throughout the book, the critical range of speeds for the phenomenon of resonance on a bridge occurs when trains run over 220 km/h.

Resonance of a structure occurs when the frequencies of the dynamic excitatory actions coincide with the eigenfrequency of vibration of the structure f_0 (a whole fraction of it). In the case of railway bridges, resonance can be produced by the passage of trains with regularly spaced axle loads or groups of axles (d_k metres) running at a certain critical speed (v in m/s).

$$v/d_k = f_0/i \qquad \text{with } ; i = 1,2,3 \ldots \tag{1.1}$$

Thus for a 30 m span bridge with a typical eigenfrequency of 3.5 Hz, on which high-speed trains with 18 m coaches are running, the critical speed of passage is $3.5 \cdot 18 \cdot 3.6 = 227$ m/s.

The coefficients of dynamic load magnification do not cover the risk of the effects of the resonance of the structure.

The amplification of stresses and accelerations due to the proximity to the resonance frequency means that special problems typical of HSRB can occur. These problems can affect the functionality of the structure as they can lead on the one hand to safety problems for rail traffic and on the other hand to a loss of comfort for train users.

Therefore, it must be verified that the vibrations of the deck do not reduce the lateral support of the track or reduce the contact pressure between the wheel and the rail, which could cause the wheel to come off the track and the convoy to derail.

1.2.2 Rail Traffic Security

One of the effects that can jeopardise the safety of rail traffic as a result of the high speed of the train is the high vertical acceleration of the deck produced as a dynamic effect of the excitation of the structure if the frequency of the loads is close to the vertical frequency of the structure. In these cases, track instability can occur as a result of the loss of ballast support or the loss of geometric quality of the track.

Other effects, such as the danger of derailment by deck twist or by the deformation of the deck or rotations in supports, or by the transverse deformation of the deck, or by the relative displacement of the deck, increase considerably as the speed of passage of train increases.

All this obliges the establishment of much more rigorous limits for the highest speeds and even, as will be seen later, to create fixed longitudinal connection points between the deck and the infrastructure to avoid its relative movement.

1.2.3 Passenger's Comfort

Also, as a consequence of the vertical accelerations suffered by the structure, there may be a loss of comfort for train users. For this reason, the design of the structure must seek to distance the vibration frequencies of the structure from the frequency of passage of the bogies and therefore the loads, in order to reduce this problem so that the acceleration experienced by the passengers and therefore their loss of comfort is within manageable limits. To analyse that a dynamic analysis used different types of trains has to be carried out.