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Dynamic Modelling of High Speed Ballasted Railway Tracks: Analysis of the Behaviour

Inmaculada Gallego Giner

Associate Professor, Department of Civil and Building Engineering, (UCLM), Spain

Ana Rivas Alvarez

Associate Professor, Department of Civil and Building Engineering, (UCLM), Spain

Santos Sánchez-Cambronero García-Moreno*

Associate Professor, Department of Civil and Building Engineering, (UCLM), Spain

Julián Lajara Camacho

Master Student. Civil Engineer, (UCLM), Spain

Abstract

The aim of the paper is to present a numerical model for a ballasted railway track that includes the dynamic effect of a moving train load and predicts the values of the vertical stiffness of the infrastructure. This model is therefore deemed to be a tool for the evaluation of the state of the track during service situations as well as a predictive model of the behaviour of the system. Consequently, it will be very useful when sizing the cross section of a new railway line is required.

The main modelling tool is the finite element method. In regard to this, the application of damping elements to avoid the elastic wave reflection on the boundaries of the numerical domain will be studied. The proposed dynamic analysis consider the change in time of the value of the train load, but not the change in position along the tracks.

In the end, a set of suggestions for the numerical model with moving loads will be summarize aiming for the mitigation of the unusual behaviour of the contact surface between the ballast and the sleepers.

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* Corresponding author.
E-mail address: santos.sanchez@uclm.es

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1. Introduction

Practicing engineers require a wide range of skills in today's competitive world. Although they must be aware of the technical, environmental and economic context in which their task are held, sometimes the scale of the projects do not allow to control as many variables as it should be required. This presentation is an example of how a methodology can be implemented to help the engineers in the decision making process when facing design problems in high speed railways.

In today's economy, budgeting and project appraisal has become more and more important during the inception of a new infrastructure and during the tendering process. It is crucial to prove that the money is well expended. But when designers have not the appropriate tools, saving money become rather a hope than a fact. This example fits very well the case of the design of High Speed ballasted tracks. In Spain, the methodology for the design of this kind of railway lines have relied on the Card 719R by the UIC (Union International de Chemins de Fer, 1994). According to this, the thickness of the ballast and sub-ballast layers depend on the traffic of the line, and the quality of the materials of the subgrade. Different administrations have added their own recommendations, according to the national know-how. There have not been many discussions about whether this methodology is outdated or whether it can be improved.

The aim of the following document is to provide an idea of the research in this topic, on how numerical methods can be adopted in order to guarantee a cost effective infrastructure with tools that are currently available and have been proved right and useful by the industry. For this matter, a Finite Element Model has been built to be described in this paper.

When dealing with complex problems, with non-analytical solutions of equations, or with interactions between elements we need to rely on the outputs provided by numerical analysis. Otherwise, the amount of simplifications may lead to the study of a totally different scenario or even a wrong one. With this regards, the Finite Element Method can be a helpful tool for the railway designer or even to the administrators and managers. Just imagine the amount of money that would need to be put in experimental tests, or the nuisance of on-site testing, causing disruptions to the line and affecting eventually to the users. An initial investment for the calibration of a numerical model can be enough to characterise the whole infrastructure and have a better understanding of foreseeable problems.

The basic advantage that derives from the use of a model is that it allows the parametrisation of the basic geometry and properties. Therefore, these parameters can be changed and adapted to the different requirements of the track taking into account spatial variations, temporal effects, fatigue of the elements, etc.

The model proposed in this paper include a wide range of parameters, such as the number of sleepers of the model and the overall geometry of the substructure and superstructure.

2. State-of-the-art in numerical modelling of railways

The first numerical models aimed at the study of the behaviour of ballasted railway tracks were devised in the 70s and 80s. Those models were based on a multilayer infinite semi space composed by horizontal and homogeneous layers. The materials were supposed linear elastic and the contact between layers was assumed continuous.

However, this assumptions were lacking some consistency, as the geometry of the layers play an important role of the analysis, the materials does not behave linearly elastic and the contact between the layers is not perfect. Furthermore, a multilayer system approximates the behaviour of the system when the elastic modulus increase in depth and the elastic modulus are similar. Actually this is not very representative, as the elastic modulus of the steel of the rails is very different from the elastic modulus of the soil of the natural fill.

Apart from that, there is an important question to answer: is the ballast well represented by its elastic properties? The answer is no, and it is more accurate to use a discrete elements model (DEM) to represent it than assuming a continuous media like the soil. A finite element method (FEM) model can estimate the elastic behaviour of the ballast in the overall structure, but it cannot represent accurately stresses.

In railways, some of the proposed model were bidimensional, so a state of plane deformation was assumed (López (1977)). This did not work as expected, turning the researchers to analyse 3D models (Sauvage and Larible (1982); Profillidis (1983), (1987); Sahu et al (1999) and the Ministerio de Fomento (1999)). From this, the studies by