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Reduced Models of Railway Track: Critical Velocity and Instability of Moving Inertial Objects

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Abstract

In this contribution, a new form of semianalytical results related to inertial objects that are traversing homogeneous infinite structures, introduced in previous author’s work, is used to analyse one-, two- and three-layer models of the railway track. The aim of these analyses is determination of the critical velocity of a moving force and of the onset of instability of moving masses or oscillators.

First of all, the possible range of dimensional parameters is identified. Within these ranges, there are significant differences between the models. While for the one- and two- layer models the critical velocities are well-defined and their number is 1 or 3, respectively, in the three-layer model their number depends on parameter values and can be 1, 3 or 5. Regarding the onset of instability, there are also significant differences, not only between the models but also between the cases with one or more moving masses or oscillators. For one-layer model, which is in fact the model of an infinite beam on the classical Winkler-Pasternak foundation, instability of one moving mass has regular behaviour and occurs always in the supercritical velocity range when damping is present and at the critical velocity in case of no damping. Two moving proximate masses already introduce severe alterations, because in damped case the dynamic interaction can shift the onset of instability deeply into the subcritical velocity range. The other models introduce other irregularities, even for one moving mass. This contribution will summarize all the differences and common features that exist between these models and within the full range of possible parameter combinations.

Keywords: moving proximate masses, dynamic interaction, contour integration, semianalytical solution, critical velocity, instability.

1 Introduction

In this contribution, a new form of semianalytical results related to inertial objects that are traversing homogeneous infinite structures, introduced in previous author's work [1], is used to analyse one-, two- and three-layer models of the railway track. The aim of these analyses is determination of the critical velocity of a moving force and of the onset of instability of moving masses or oscillators.

The new form of semianalytical results is related to infinite structures, but in addition to these derivations, equivalent finite models are presented and solved in order to provide easy validation of the results. For such structures, the eigenmode expansion method is used and therefore the natural frequencies and orthogonality conditions must be derived. Furthermore, due to the coupling of modal equations, a rearrangement of the terms involved is introduced to save computational time. All results, both from finite models and from infinite models, are presented as much as possible analytically using dimensionless parameters, and therefore can be used directly for several combinations of input data.

It is intended to present all results in dimensionless forms, so that they can be used for a large set of real parameter combinations. The results will be valid within the full intervals of all input parameters and thus, it will be possible to use them for any ballasted track configuration.

Knowing the critical velocity for moving force and velocity at the onset of instability is important for railway track design.

2 Methods

First of all, one-, two- and three-layer models of the railway track are defined, and their components are described. Then, governing equations for infinite and finite models are derived and modified to dimensionless forms. Infinite model is solved by integral transforms and contour integration. Finite models are solved by the eigenmode expansion method and therefore the natural frequencies and orthogonality conditions must be derived. Furthermore, due to the coupling of modal equations, a rearrangement of the terms involved is introduced to save computational time.

Finite models are presented and solved in order to provide easy validation of the results obtained on infinite models.

Further, an interval of possible values for each input parameter is specified and by their combinations the range of dimensionless parameters is obtained.

All results, both from finite models and from infinite models, are presented as much as possible analytically using dimensionless parameters, and therefore can be used directly for several combinations of input data.

This method will allow to summarize various results in one graph, which will be possible to use by the readers without redoing the calculations.

3 Results

First of all, results for the critical velocity of the moving force are presented. Within the possible range of dimensional parameters already identified, there are significant differences between the models. While for the one- and two- layer models the critical velocities are well-defined and their number is 1 or 3 [1-3], respectively, in the three-layer model their number depends on parameter values and can be 1, 3 or 5. By comparison with analysis of finite models, these values are confirmed. On finite models the critical velocity is obtained as the lowest resonant velocity. The resonant velocity is dependent on mode number. By admitting real numbers, instead of integer numbers, and by analysing local extremes, previously determined values on infinite models are confirmed. It happens that the even values of critical velocities in fact correspond to a local maximum and not to a local minimum, as it should be for the classical definition of the critical velocity. These values also cause resonance, but they are less pronounced when analysed by a parametric analysis. For a three-layer model, when the number of critical velocities is not equal to 5, there are pseudocritical velocities to complement the critical ones. Some of then are clearly marked but some of them not, which affects conclusion about the onset of instability.

Regarding the onset of instability, there are also significant differences, not only between the models but also between the cases with one or more moving masses or oscillators. For one-layer model, which is in fact the model of an infinite beam on the classical Winkler-Pasternak foundation, instability of one moving mass has regular behaviour and occurs always in the supercritical velocity range when damping is present and at the critical velocity in case of no damping. Two moving proximate masses already introduce severe alterations, because in damped case the dynamic interaction can shift the onset of instability deeply into the subcritical velocity range [2]. The other models introduce other irregularities, even for one moving mass [3]. On the three-layer model, the onset of instability can be limited by the pseudocritical velocity value or by the critical velocity value. The so-called onset lines that are tracking the mass ratio at the onset of instability as a function of velocity ratio are not regular and have several branches. For two moving masses, the onset of instability can again occur for very low velocities.

4 Conclusions and Contributions

This contribution summarizes all the differences and common features that exist between these reduced models of railway track within the full range of possible parameter combinations.

Conclusions of this study are important because these models are frequently used as efficient alternatives to detailed 3D finite element models.

Critical velocity is very important for the track design and real tracks must avoid it. Because the instability is generally accepted to occur only at the supercritical velocity range, less attention is placed on it. This study proves that this is not true for two proximate moving objects and on the three-layer model even for one single moving mass. Another important conclusion is that the increased damping can make the dynamic interaction between moving objects worse, instead of better, in the sense that the onset of instability can be shifted even more into the subcritical velocity range, which also contradicts the general opinion about damping.

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