USE OF A COMPUTATIONAL MODEL FOR ASSESSING DYNAMICAL BEHAVIOUR OF RAILWAY STRUCTURE

J.M. Sadeghi[1], M. Fathali [2]

[1]Assistant Professor, Javad_Sadeghi@iust.ac.ir
[2]Research Assistant, M_Fathali@rail.iust.ac.ir
School of Railway Engineering, Iran University of Science and Technology, Tehran, Iran

***Abstract**: The railway structure is the mechanical system compounded of both vehicles and track and its foundation. The track itself is constituted not only of the rails and sleepers, but also of the various available supporting structures (slabs, bridges. The scope of the present study is more particularly dedicated to the dynamical behaviour of the track and its foundation. An original numerical method, including a proper modeling of track geometry irregularities, has been built to compute the movements of the structure under progressing loads. Applications presented here are restricted to some cases in the field of track component like comparison of sleeper types or influence of foundation constitution on ground vibration spreading. This theory and the associated program are still being developed. The final aim is to offer research or project engineer a specific tool to evaluate more easily influence of key design parameter (masses, inertias, stiffness, depth of foundation layers) for a satisfactory static and dynamic behaviour.*

***Keywords:** Dynamic behaviour, Track & its foundation, Track geometry, Numerical method*

1. INTRODUCTION

For historical and practical grounds, a railway structure is generally seen as constituted of two different components: on one side the rolling stock and on the other, the track with its foundation [1]. On a theoretical point of view, these two components have very often been studied separately, because of their specific mechanical behaviour. They are nevertheless interacting between each other at any instant, being linked together through the wheel - rail contact. The vertical and transverse irregularities of the track may thus influence the movement of the vehicles. Reciprocally, vibrational energy is transmitted to the track and spreaded into the soil [2].

In the present paper, the whole railway structure as a unique mechanical system is studied. The behaviour of the track foundation is described by a three dimensional dissipation medium [3], whereas the track and vehicles movement are described via a simple classical finite element method [4]. The forces generated between wheels and rails require particular attention, owing to their transient properties and to the nature of track defects. These theoretical preliminaries have been used to build a computational code which is written in MATLAB (a high-performance language for technical computing). Some results of parametric studies are given. Various tools have been devised under this scope in order to make data input and results display easier. Because it takes into account the transient effects of dynamic loads, this model might also be seen as an alternate approach to the problem of flexural wave in rail [5].

2. MODEL DESCRIPTION AND MECHANICAL FEATURES

The soil and the supported structure (track + vehicles) are described by two distinct methods.

2.1. Soil Description

It is a three-dimensional medium into which vibrational energy is spreaded and dissipated. This medium is made up of successive horizontal visco-elastic layers. Apart from its geometrical and massic properties (i.e. depth and specific weight), each layer is characterized by elastic and viscous constants [3].

The dynamical behaviour of the soil is given by the set of matrix equations as follow:

$$\hat{U}_j = I_{jk} * \hat{P}_k \qquad (1)$$

that relating the vector U_j of displacement components in the j_{th} layer and the vector P_k of forces components in the k_{th} layer. I_{jk} is a transfer matrix. These equations are made conveniently expressed in terms of FOURIER transforms which is noted by ^.

2.2. Track and vehicle description

The track and vehicle are a set of masses and beams linked by springs and dampers [6]. Choosing appropriate parameters, i.e. displacements and their time derivatives for the masses and displacements, slopes and their time derivatives for the beams, the global kinetic, viscous and potential energy are expressed as:

$$T = \frac{1}{2}\dot{U}^T M\dot{U} \qquad (2)$$

$$W = \frac{1}{2}\dot{U}^T C\dot{U} \qquad (3)$$

$$V = \frac{1}{2}U^T KU - F^T U - R^T U \qquad (4)$$

Where U is the vector containing displacements, slopes and their derivatives, M,C,K is respectively mass, viscosity and stiffness matrix, F is given applied forces (for example gravity), R is foundation reaction and T is transposition symbol. Application of virtual work principle and FOURIER time transform yield

$$-(2\pi f)^2 M\hat{\hat{U}} + (2j\pi f)C\hat{\hat{U}} + K\hat{U} = \hat{F} + \hat{R} \qquad (5)$$

where $\hat{R}$ may be written from (Eq.1) as a function of U whence it results the matrix equation $A.\hat{U} = \hat{F}$.

3. NUMERICAL EVALUATION OF WHEEL-RAIL FORCES

The vertical or transverse forces between wheel and rail depend on the wheel acceleration. This acceleration is the double derivative of trajectory which is not known beforehand [6]. The wheel vertical or transverse position w(x.t) at the abscissa x and time t is the sum of the structure displacement u(x,t) and the track defect n(x,t) as following:

$$w(x,t) = u(x,t) + n(x,t) \qquad (6)$$

Various kinds of reference defects n(x,t) have been tabulated and may be input to the program under analytical form. It is also possible to use directly the results of car recording under a loaded track as input defects.

With the notation of part 2, the time derivatives of U exhibit the following form:

$$\frac{du}{dt} = \frac{\partial u}{\partial t} + D1.U \quad (7)$$

$$\frac{d^2u}{dt^2} = \frac{\partial^2 u}{\partial t^2} + D1.\frac{\partial u}{\partial t} + D2.U \quad (8)$$

where ∂ is the symbol of partial derivative, and D1, D2 are square (n,n) matrices expressing the convective effects of load displacement

From (Eqs. 7 and 8), it results the following viscosity and stiffness matrix in the left side of (Eq. 5)

C+2.M.D1 (9)

K+C.D1+M.D2 (10)

whereas in the right side, the terms

$$-M\frac{d^2N}{dt^2} - C\frac{dN}{dt} - K.N \quad (11)$$

must be subtracted, with N vector containing the values of defects.

4. EXAMPLES OF APPLICATIONS

Three parameters studies made with this computational model have been chosen. These cases are explained as following:

4.1. Comparison of dynamical behaviour of a twin block sleeper and of a monoblock concrete sleeper laid on ballast

The mechanical properties of the sleepers are summarized below [7]:

- **Twin block**

Inertia:	(Rail section)	25000 cm^4
	(Center section)	73 cm^4
Mass:		258 kg

- **Monoblock**

Inertia:	(Rail section)	32700 cm^4
	(Center section)	8030 cm^4
Mass:		355 kg

The soil has been modeled by three layers [5]:

- Ballast: 300 mm
- Sub-ballast: 150 mm
- Subgrade

The two sleepers are loaded by a sinusoidal force having a variable frequency. The graphs of (Fig.1) display the ratio of the displacement U_{mb} of the monoblock and U_{tb} of the twin block. The reduction of bearing center surface simulates a tamping maintenance operation.

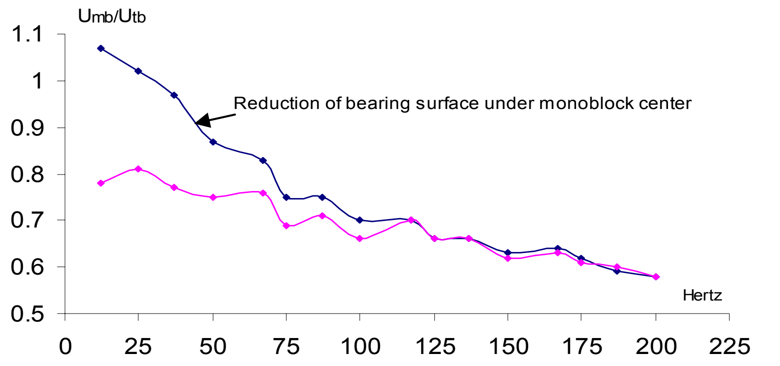

Fig1: Ratio U_{mb}/U_{tb} of displacements under monoblock and twin block

In both cases (with or without reduction), the monoblock sleeper has a better global behaviour. It is because of more suitable spearing of applied pressure via monolithic structure of monoblock sleeper.

4.2. Influence of ballast depth and of sleeper type on sublayer displacement under dynamical loads.

For economical and technical grounds, twin block U41 sleepers are used instead of wooden sleepers [7]. Their smaller surface imposes to increase ballast depth under concrete subsurface, in order to limit the static pressure. This statically approach has proven to be efficient in many practical cases.

Modeling of a track with three sleepers above ballast and sub-ballast shows the following under dynamical conditions (Fig. 2):

- An increase of 0.10 m in the total height (ballast e_b + sub-ballast e_s) given the same or even smaller displacements under U41 sleeper at subgrade level,
- The influence of ballast depth has no influence, except that of smoothing displacements at sleeper subsurface.

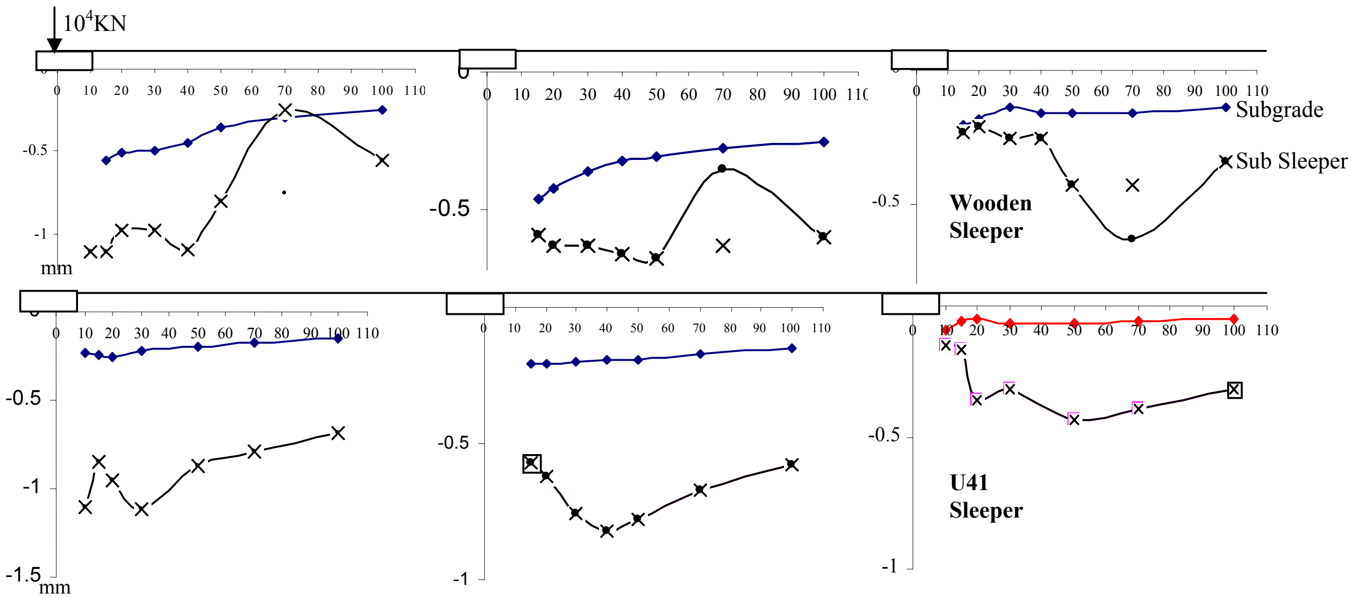

Fig2: Variation of displacement with frequency at sub-sleeper and subgrade level

4.3. Computation of propagated vibration under a track,

A test track site has been equipped with accelerometers at various depths and distances (Fig.3). This site was established in UW University with cooperation of the first author and its results are used here [8].

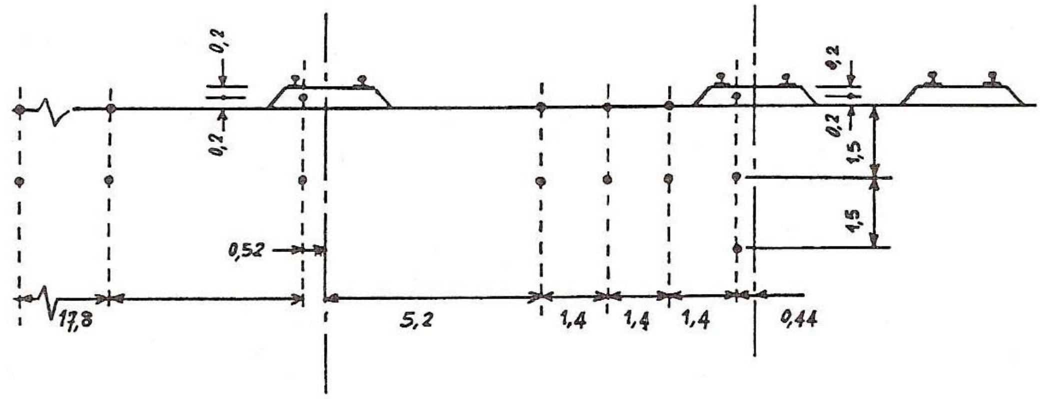

Fig3: Test track site

From the measured vertical accelerations at these different points, it has been possible to estimate a profile of vibration propagation and decay underneath the track (Fig.4). On the other hand computed values are plotted on (Fig.5) for two frequencies which appear to be preponderant from spectra of measured accelerations (Fig.6). The hypothesis chosen for the modeling –from investigations on the site and after some adjustments– are as follows [9]:

- Ballast layer

Depth:	45 cm
Specific weight:	1500 kg/m
Speed of pressure waves:	335 m/s
Quality factor (Inversely proportional to damping):	10

- Underlying clay

specific weight:	2000 kg/m
speed of pressure waves:	515 m/s
quality factor:	5

The results show apparently some discrepancies with measurements. In fact, it comes from the location of the reference source, which is not situated right under the rail for measurements. By selecting the same reference point in the computed values, the agreement becomes fairly good (Fig.7).

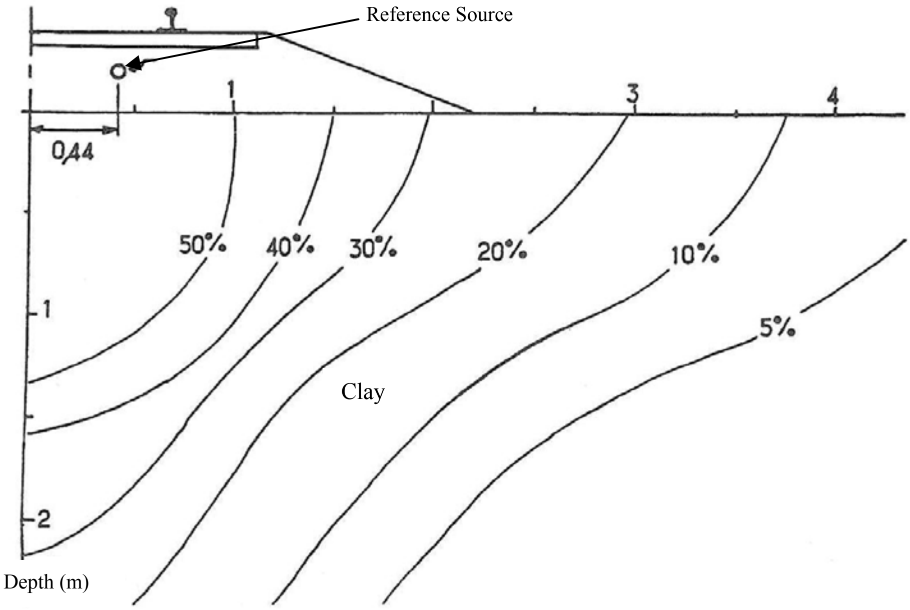

Fig4: Measured vibration profile

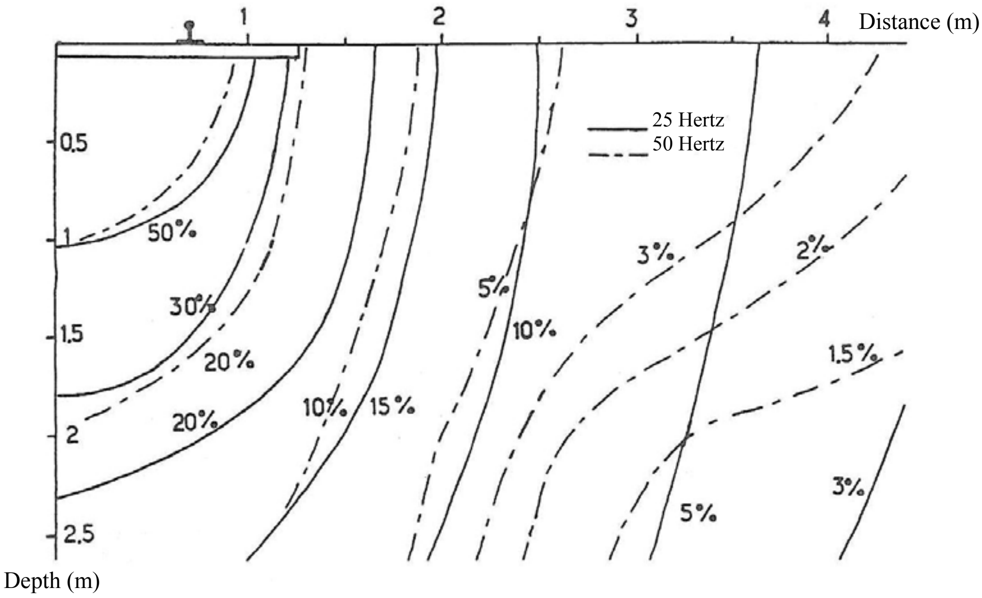

Fig5: computed vibration profile

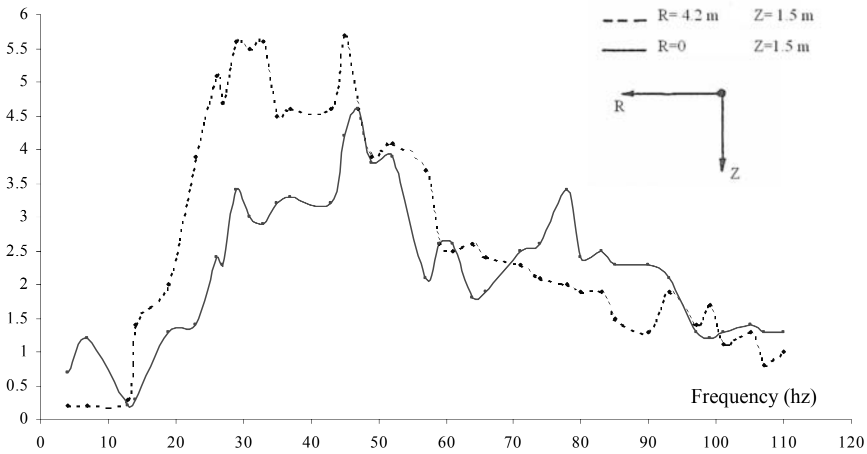

Fig6: Vibration spectra

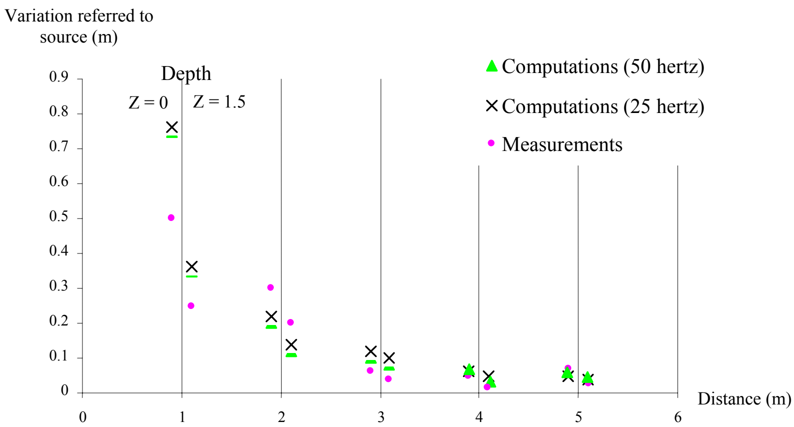

Fig7: Comparison of computed and measured vibration decay

5. CONCLUSIONS

This paper presents a model for assessing the dynamical behaviour of the track and its foundation and investigates the influence of key design parameters on track dynamic reaction. For the development of the model, a code written in MATLAB was used. Three parametric analyses were conducted using this computational model. First a comparison of dynamical behaviour of a twin block sleeper and a mono-block concrete sleeper, laid on ballast was made. It was shown that the mono-block sleeper has a better global behaviour. Then the influence of ballast depth and sleeper type on sub-layer displacement under dynamical loads was investigated. It was shown that an increase of 0.10 m in the total height of ballast or sub-ballast results in the same or even smaller displacements under the sleeper at the subgrade level. At last, propagated vibration under a track obtained form the model is compared with the experimental results obtained from a track field. The results indicate that by selecting the same reference point, the agreement becomes fairly good between measured and computed vibration profiles.

6. REFRENCES

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