INTERACTION BETWEEN MOVING VEHICLES AND RAILWAY TRACK AT HIGH SPEED

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ABSTRACT

A numerical method was proposed for the analysis of vertical track behaviour as a result of moving railway vehicles. This approach has led to the development of an integrated model called DARTS (Dynamic Analysis of Railway Track Structures). The method was applied for evaluating car body accelerations, track deflections and wheel/rail forces resulting from the passage of a Thalys high-speed train, travelling on conventional ballasted track and on a non-conventional embedded rail structure. From the results presented conclusions could be drawn with respect to track structure performance under high-speed train operation.

INTRODUCTION

In recent studies, TU Delft was involved in the development of models for assessing the dynamic behaviour of railway track. The track system could be described by a transfer function, which expresses the relation between input force and response value as a function of frequency. A method was developed to estimate the track characteristics in terms of distributed mass, stiffness and damping by fitting the measured and calculated transfer function [1]. The ability of the track structure to reduce noise and vibration can be expressed by the so-called frequency-dependent distance damping.

In order to obtain realistic and reliable response data, the dynamic analysis cannot be restricted to just modelling the track and using a moving set of concentrated loads to simulate the vehicle. The entire train, with its individual vehicles, has to be modelled.

This article shows how the properties of both vehicle and track were integrated into one overall model called DARTS, whereby the full interaction between vehicle and track for the vertical direction was taken into account.

The investigated structures presented in this article were a Thalys travelling at different speeds, either on a conventional ballasted track, or on a non-conventional embedded rail structure (ERS). The ERS was supported by either a rigid concrete slab or a flexible concrete slab, the latter discretely supported by piles. The loads between vehicle and track were introduced by sinusoidal vertical rail/track irregularities. Different wavelengths were applied to investigate their impact on the response. Three track response components were investigated: car body acceleration, representing passenger comfort; track deflection; and the contact force between wheel and rail.

STRUCTURAL MODEL

The entire model consisted of two structures, namely the moving train and the railway track, each of which was modelled separately. During the dynamic analysis, consisting of a numerical integration procedure, the interaction between the two structures was taken into account.

Moving train

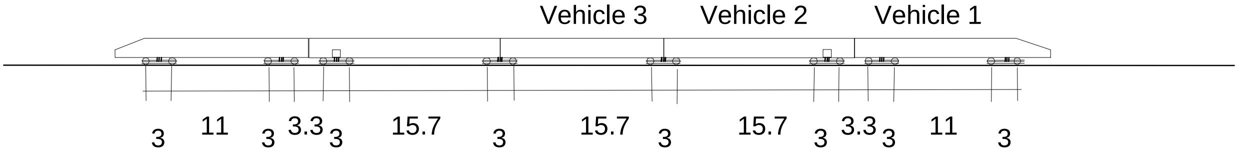

Fig. 1: Model of the Thalys (dimensions in m)

The train was modelled as a Thalys consisting of five vehicles (Fig. 1). In the Thalys concept, bogies between two coaches are shared. As indicated in Fig. 1, the total length between the first wheel and the last wheel amounted to 99.7 m. The coaches were schematised by rigid bodies, pivoted at the bogies by springs and dampers. Bogies and wheelsets were also modelled as rigid masses connected with springs and dampers. The vehicle model is schematically depicted in Fig. 2. Only vertical forces and displacements were considered.

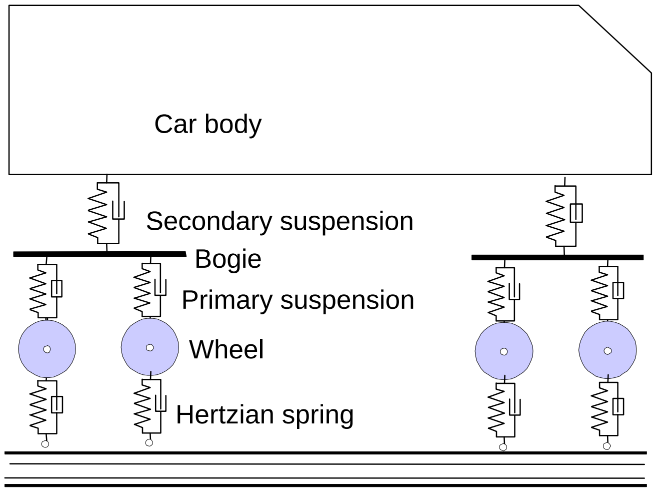

Fig. 2: Modelling of a moving vehicle

For the Thalys the following data applied:
- masses: traction unit 54,280 kg, coach 27,140 kg, additional lumped mass of 13,570 kg for the coach immediately following the traction unit, bogie 2,791 kg, wheels 1,013.5 kg;
- primary suspension springs (per wheel): K=1,150 kN/m, C=2.5 kNs/m;
- secondary suspension springs: K=600 kN/m, C=4 kNs/m;
- wheel radius: 0.42 m;

where K is stiffness and C is damping.

Railway track

In the analyses, two types of track structure were investigated (Fig. 3), i.e.:
- a conventional ballasted track, consisting of sleepers, rail pads and an elastic ballast bed; and
- an embedded rail structure (ERS), i.e. a structure whereby the rail is cast into the trough of a supporting concrete slab by means of Corkelast (polyurethane mixed with cork).

Three variants of ERS were investigated: firstly, a structure supported by a rigid, continuous concrete slab and, subsequently, a structure supported by a concrete slab on piles spaced at either 3 m or 6 m.

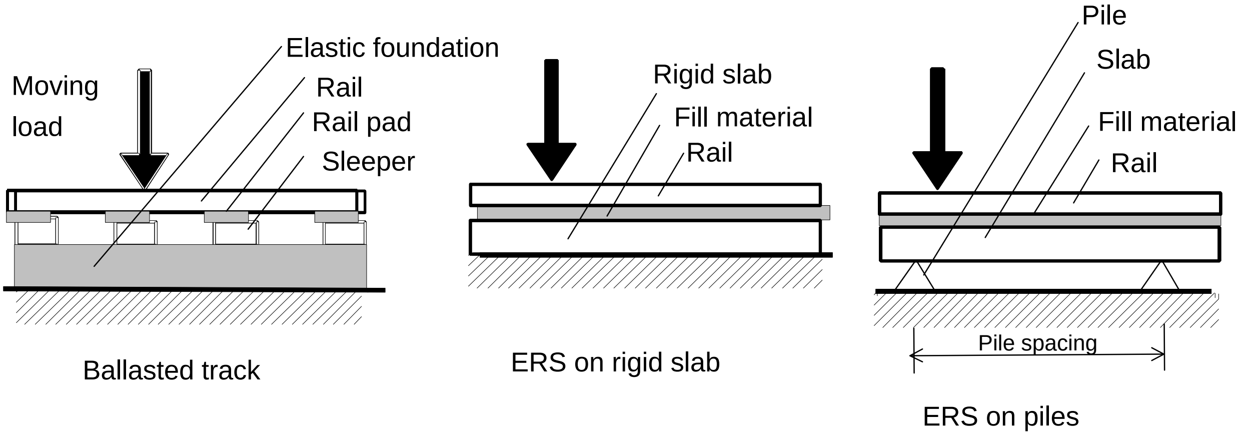

Fig. 3: Track structures used in the analyses

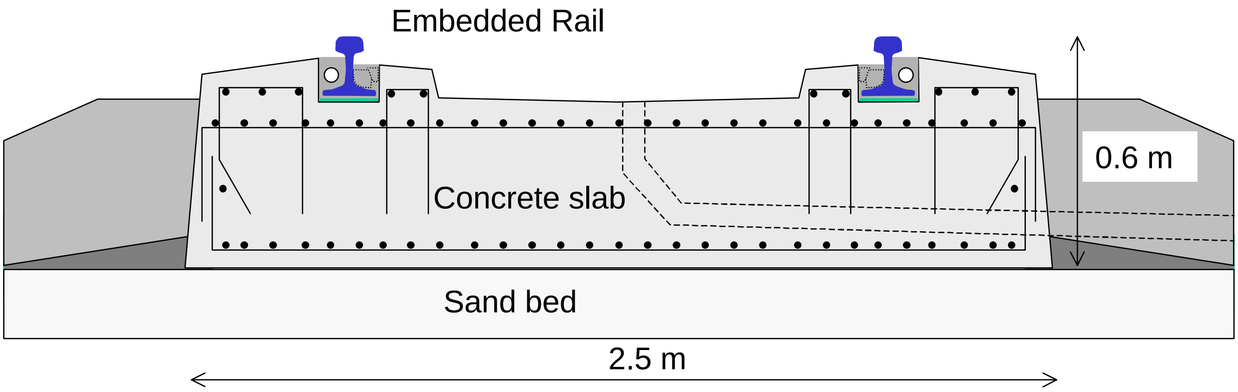

Fig. 4: Embedded Rail Structure as installed at 3 km test track near Best, The Netherlands

For the ballasted track, the following data applied:

- rail: UIC 60;
- rail pads: K=10^5 kN/m, C=15 kNs/m;
- sleeper: mass 300 kg, spacing 0.60 m, width 0.15 m;
- ballast bed: k=1.8 10^5 kN/m^2, c=82 kNs/m^2.

The data for ERS consisted of:

- rail: UIC 54;
- fill material: k=5.25 10^4 kN/ m^2, c=4.98 kNs/ m^2.

Where a piled foundation was used, the following slab parameters applied:

- slab: A=0.765 m^2, I=0.02746 m^4 , E=3.1 10^7 kN/ m^2, ν= 0.3, ρ=2,500 kg/m^3, where A is cross-sectional area, I is moment of inertia, E is Young's modulus, ν is Poisson's ration, and ρ is specific mass.

In the analysis half a track (i.e. 1 rail) was considered featuring a length of 150 m.

Load generation

Rail/track irregularities can be considered as one of the most important sources of loads, generated by a moving train. In the DARTS model, the loads were introduced via Hertzian springs traversing a sine-shaped rail/track surface, as shown in Fig. 5.

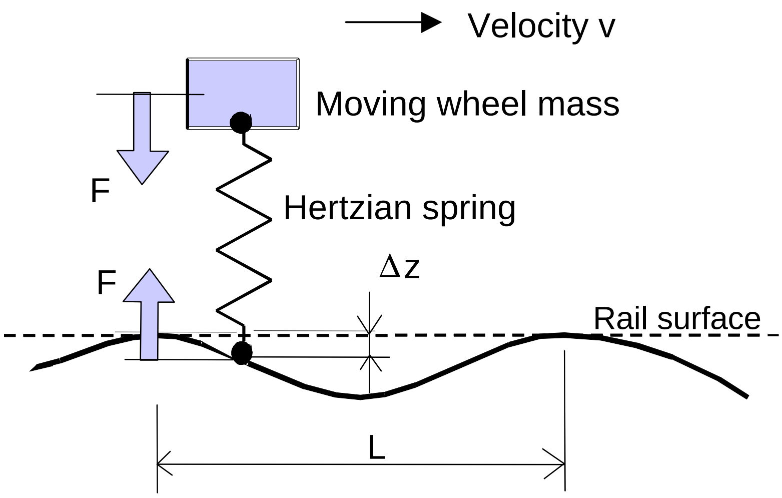

Fig. 5: Modelling of wheel/rail loads

Three irregularity shapes Δz, given by the algebraic formula

$$\Delta z = A(1 - \cos \frac{2px}{L})$$

were considered, in which the following data were substituted:

shape 1: L = 3 m, A = 1.5 mm
shape 2: L = 12.5 m, A = 3 mm
shape 3: L = 50 m, A = 6 mm

where L is wavelength and A is amplitude.

The moving train was analysed for the speeds 30 m/s, 60 m/s and 90 m/s.

Dynamic analysis

The equations of motion were formulated on the basis of the discussed structural models and were evaluated according to a direct integration procedure, based upon the concept of time space elements [2]. During a time step Δt, the train moves over a distance Δx, which is dependent on the train velocity v, and 'crosses' the time space elements as indicated in Fig. 6.

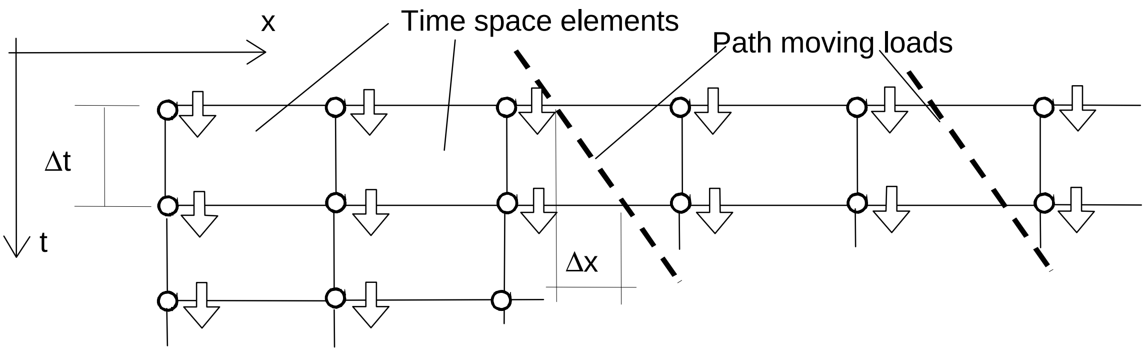

Fig. 6: Time space elements used in DARTS

To minimise the effect of boundary disturbances 'cyclic' boundary conditions were applied, resulting in tying the nodal displacements at the beginning and the end of the track model. To minimise the initial disturbances, the integration process was started with a static analysis of the track loaded only by the dead weight of the train.

It should be noted that the railway dynamics problem was formulated by the equations of motion and the initial conditions. This means that after a certain length of time, when the initial disturbances have damped out, a steady state solution is obtained.

The analysis was performed with 1,000 track elements of 0.15 m each and a time step Δt = 0.0015 seconds. Dependent on the wavelength of the rail/track irregularities, 1,600 time steps were applied (2.4 seconds) for L=3 m and L=12.5 m, and 4,000 time steps (6 seconds) for L=50 m.

RESULTS

The results of the analyses are addressed in the following sections.

Influence of running speed

To illustrate the influence of velocity on the dynamic response, some results for a Thalys travelling at three different speeds on an ERS track are presented in the Figs. 7, 8 and 9. The time interval for the presented results ranged from 1.8 to 2.4 seconds. The rail/track irregularity of the ERS track was given by a wavelength L=12.5 m and an amplitude A=3 mm. The maximum car body acceleration showed a sharp increase when raising the velocity from v = 60 m/s to v = 90 m/s (Fig. 7). Similar results were observed with respect to rail deflection (Fig. 8).

For v=90 m/s, the maximum contact force was 30% larger than the static value of 85 kN (Fig. 9).

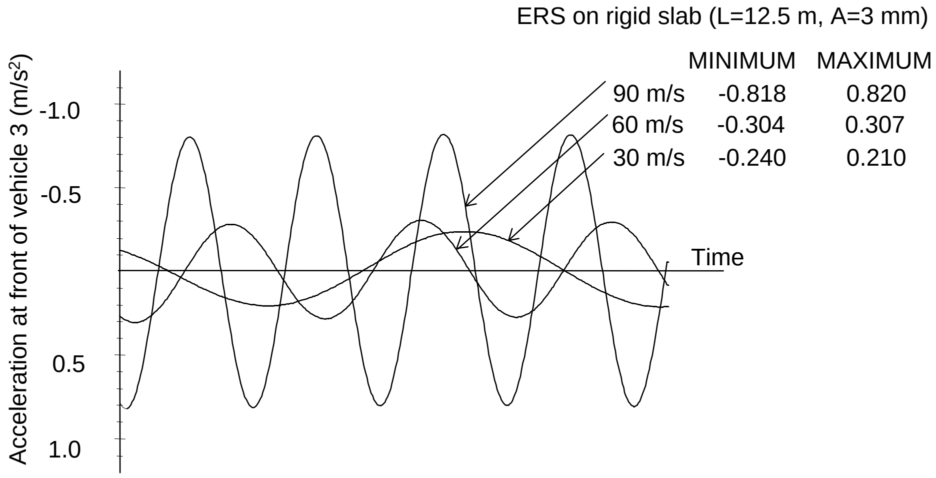

Fig. 7: Acceleration at front of vehicle 3

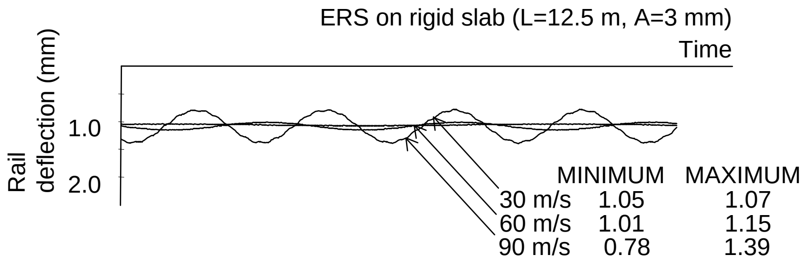

Fig. 8: Rail deflections at wheel 8

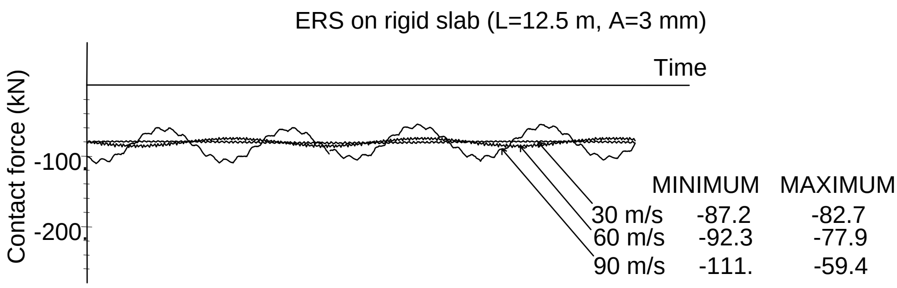

Fig. 9: Contact force at wheel 8

Influence of track structure

To study the specific effects of the different types of track structure under study, the maximum elastic rail deflection and contact force were investigated. In Figs. 10 and 11 the maximum values (between t=1.8 and t=2.4 seconds) are shown for the four types of tracks investigated. The extremes occurred for the combination short waves and high speeds. It is obvious that the ERS track supported by a rigid, continuous slab, or a slab with short pile distances (3 m), performed much better than the ballasted track, or an ERS track supported by a slab with large pile distances (6 m). Continuously supported ERS track showed a factor of 2 between static and maximum dynamic contact force, whereas the ballasted track and the ERS featuring a widely-spaced pile foundation (6 m) showed a factor of 3. For elastic rail deflection, the variations were even more distinct. In this respect, the ballasted track showed the poorest performance.

v=90 m/s, L=3 m, and A=1.5 mm

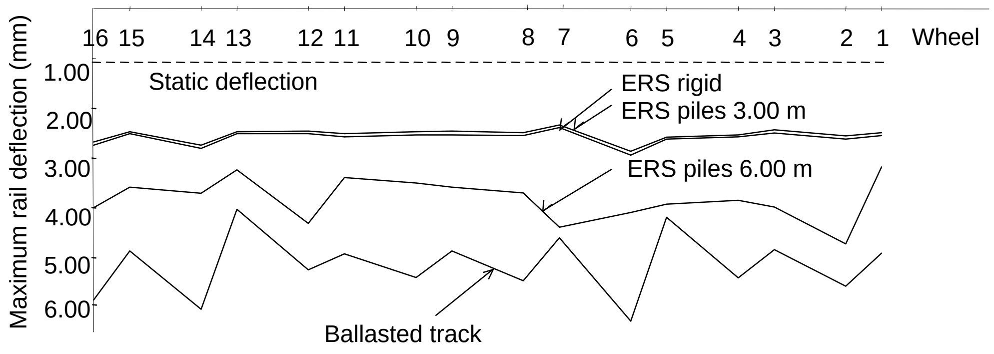

Fig. 10: Maximum rail deflection

v=90 m/s, L=3m, and A=1.5 mm

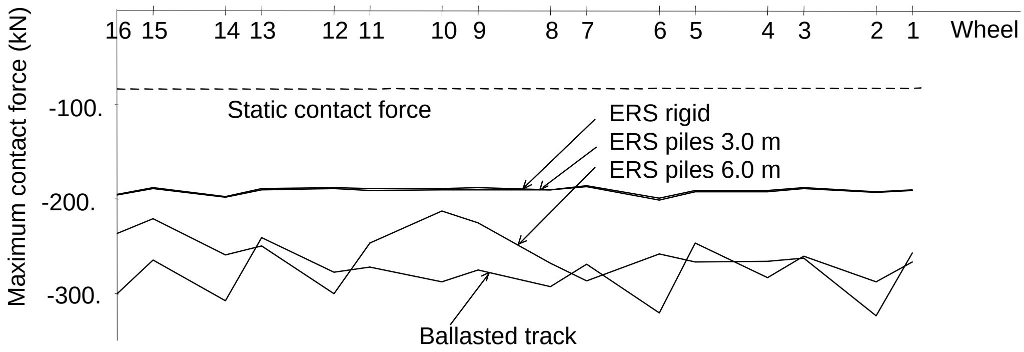

Fig. 11: Maximum contact force

Influence of track irregularities

To study the effects of track irregularities [3], the results for the Thalys travelling at 90 m/s on a rigidly supported ERS were used. In this respect, three different rail irregularity shapes were analysed. The maximum values obtained are shown in Figs. 12, 13 and 14.

ERS on rigid slab, and v=90 m/s

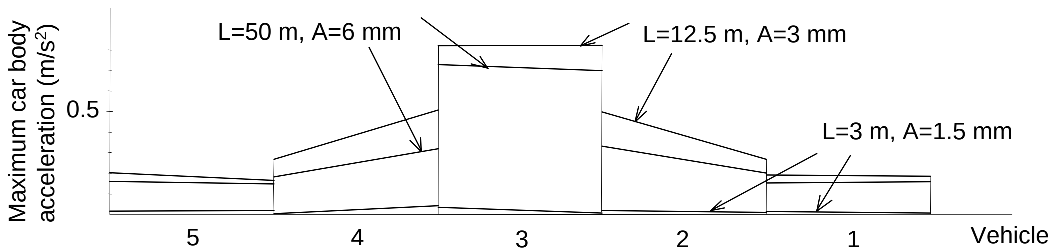

Fig. 12: Maximum car body acceleration

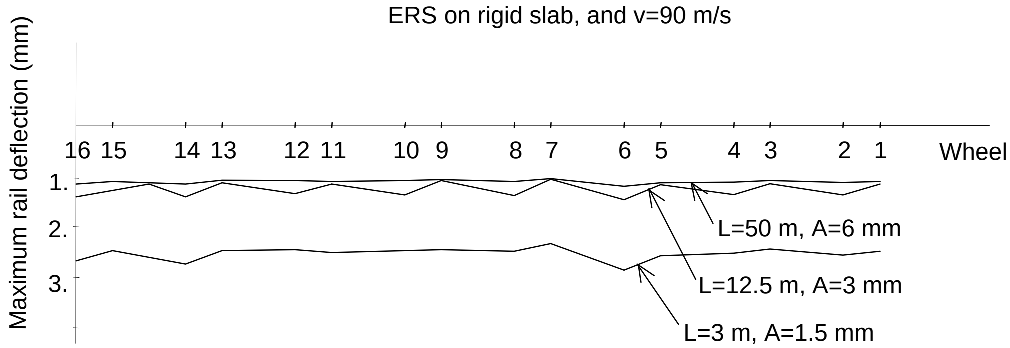

Fig. 13: Maximum rail deflection

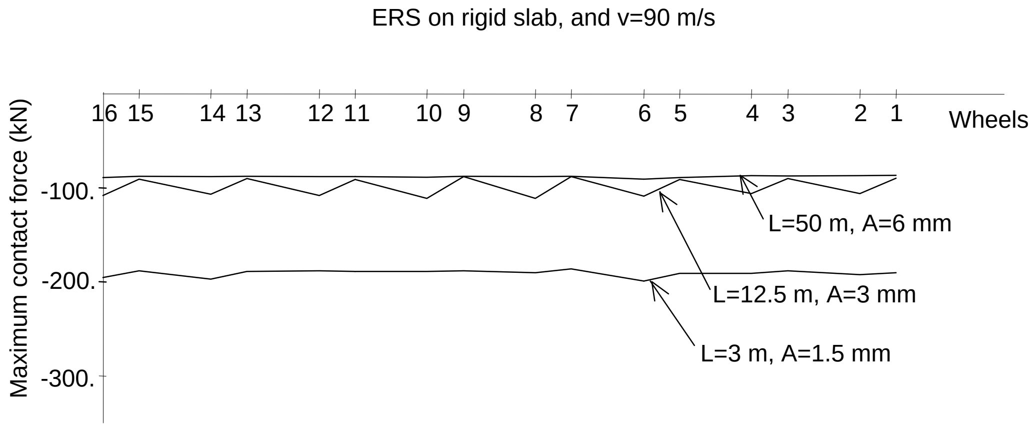

Fig. 14: Maximum contact force

In Fig. 12, maximum car body accelerations for a wavelength L=12.5 m and an amplitude A=3 mm are shown. As can be observed from Fig. 13, extreme rail/track deflections occurred for a wavelength L=3 m and an amplitude A=1.5 mm, showing an amplification factor of 3. However, it should be noted that in this respect, as was shown in Fig. 10, the ERS track performed much better than the ballasted track. Finally, as can be observed from Fig. 14, the short-wave irregularities produced a contact force which was approximately twice as high as that for the other two cases.

CONCLUSIONS

The analysis results discussed in this article confirmed many observations made by intuition or by simple manual calculations. The computations showed an increase in car body acceleration with increasing speed, and moreover indicated that long-wave irregularities have more impact on car body acceleration than short-wave irregularities. The results obtained revealed that the largest rail deflections and contact forces were induced by short wave irregularities.

In the analyses, a comparison was made between the performance of a conventional ballasted track and ERS, whereby the spacing of the piles supporting the ERS track structure was taken into account. Obviously, the ERS track performed better than the ballasted track with respect to contact force and rail deflection.

Although not all possible applications of the integrated track/vehicle model could be discussed in this article, it should be obvious that DARTS offers many new possibilities for investigating track performance resulting from load excitation by moving vehicles, operated at both conventional and high speed.

References

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[2] Kok, A.W.M.: *Lumped impulses, discrete displacements and a moving load analysis*, Heron, Vol. 42, No 1 (1997), ISSN 0046-7316, pp. 3-23

[3] Esveld, C.: *Modern Railway Track,* MRT-Productions, 1989, ISBN 90-800 324-1-7