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Interaction of Railway Ties — Comparison with Seismic Wave Data

B. Prange

Institute of Soil and Rock Mechanics, University of Karlsruhe, West Germany

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B. Prange, Professor
Institute of Soil and Rock Mechanics
University of Karlsruhe, West-Germany

SYNOPSIS

The dynamic interaction problem of ties of a railway track is treated by a two-dimensional analytical solution. The resulting stiffness-functions are compared with the solution of the interaction problem of two foundations subjected to an incident Rayleigh wave. The compliances of a single tie and a system of interacting ties are given together with experimental data of a test track, excited by a new developed testing vehicle.

INTRODUCTION

At present, the maximum speed of German Railways regular trains is 200 km/h and 250 km/h of experimental trains. The design of particular test tracks and experimental vehicles is based on an ultimate speed of 350 km/h. This increase of train speed will only be possible if all parameters involved in the train-system can be analysed and computed numerically.

The investigation of the wheel-track-system in particular includes the determination of the dynamic properties of the track on the subgrade. These properties control the interaction between the vehicle and the track during the passage of a train and may be referred to as instantaneous dynamics. Similarly, they determine the propagation of vibrations into the environment.

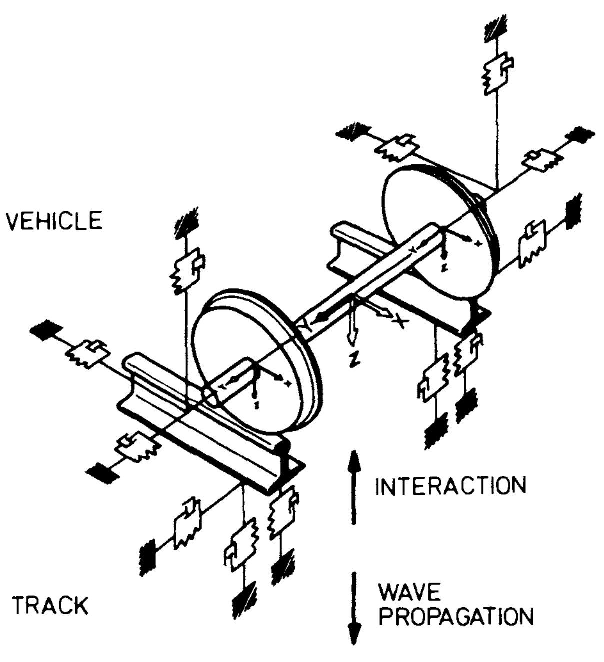

Fig.1 Simplified Wheel/Track System

Fig.1 illustrates the problems of soil dynamics on the simplified example of the passage of a single axle. The lumped-parameter springs and dashpots result from the dynamic boundary value problem track on subgrade, giving rise to interaction as well as wave propagation. They are derived from the geometry of the track and the dynamic parameters of the soil, Prange (1980), Prange, Huber, Triantafyllidis (1980).

STIFFNESS FUNCTION

For a single tie, the lumped-parameters can be calculated in the form of frequency-depending complex stiffness functions for the relevant degrees-of-freedom of the track. In a first approximation the subgrade is assumed to be an elastic, isotropic, homogeneous halfspace with linear stress-strain relations.

Fig. 2 shows the complex stiffness functions k_{ii} for the two translations x, y and the rotation ϕ_x. Equ.1 gives, as an example, the definition of the stiffness function k_{zz} for vertical translation z:

$$k_{zz}(a_o) = \frac{1}{2bG} P_z \;/\; u_z = Re(a_o) + Im(a_o) \qquad (1)$$

with
- k_{zz} stiffness function
- a_o normalized frequency = $\omega a/v_s$
- ω circular frequency
- v_s shear-wave velocity
- a , b o.5 tie width, length
- G dynamic shear modulus
- P_z vertical dynamic force (complex)
- u_z vertical translation of tie
- Re real part of stiffness function (elasticity)
- Im imaginary part of stiffness function (damping)

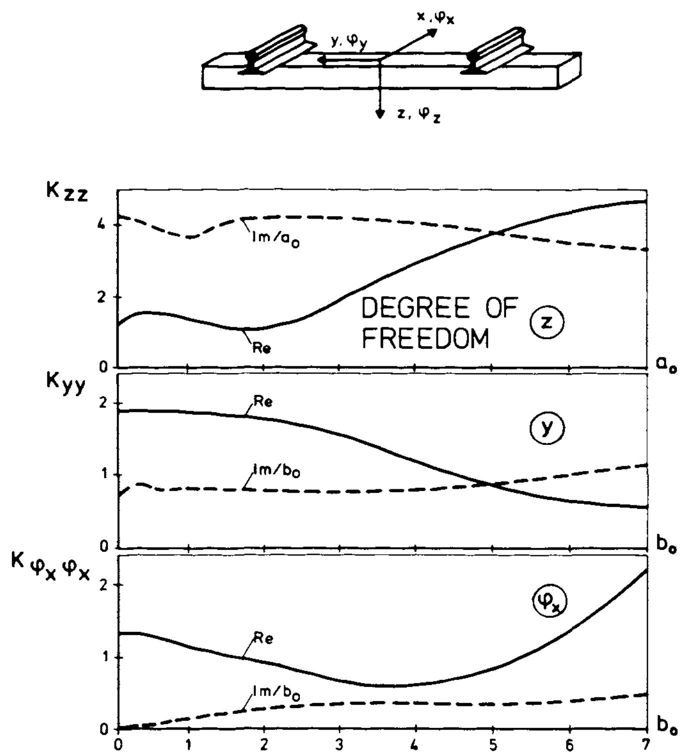

Fig.2 Stiffness Functions for Tie on Subgrade

In reality, the track consists of a great number of ties which interact with one another through the subgrade and the rails. Triantafyllidis (1981) gave an analytical solution to the two-dimensional interaction problem of ties on a halfspace. The three-dimensional problem will be treated by a later publication.
Fig.3 shows the comparison between the stiffness-functions of a single 3-dimensional tie (after Fig.2) and a system of 1 to 7 ties in two dimensions, interacting through the subgrade. Tie number 1 is excited dynamically.
It is seen that the consideration of 5 to 7 interacting ties is sufficient and that for large values of a_o the solutions converge to that of a single tie.

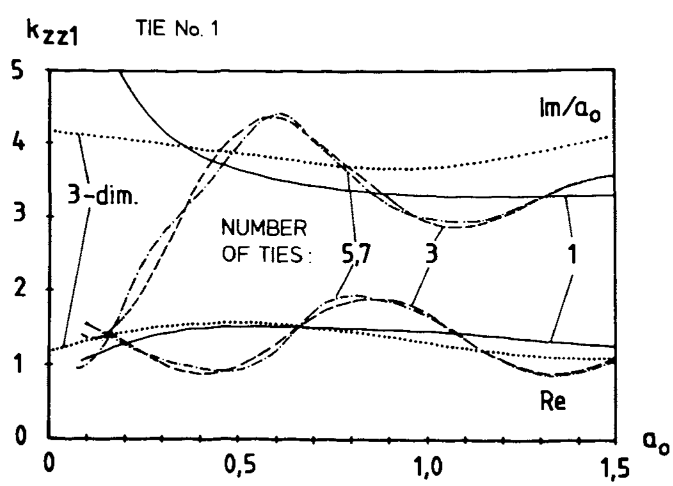

Fig.3 Stiffness Functions of 1 to 7 Interacting Ties (z-Translation)

Bielak and Coronato (1981) treat a similar problem of two adjacent foundations subjected to an incident Rayleigh wave. If we set aside that Bielak and Coronato give the 3-dimensional solution while Triantafyllidis deals with the 2-dimensional case, we find some interesting similarities in the theoretical results.
For convenience, Fig.3b of Bielak's paper is redrawn in the following Fig.4, with the distance/width-ratio almost equal to that of the German Railways track ($R/L = 4.62 \approx 4.67$).

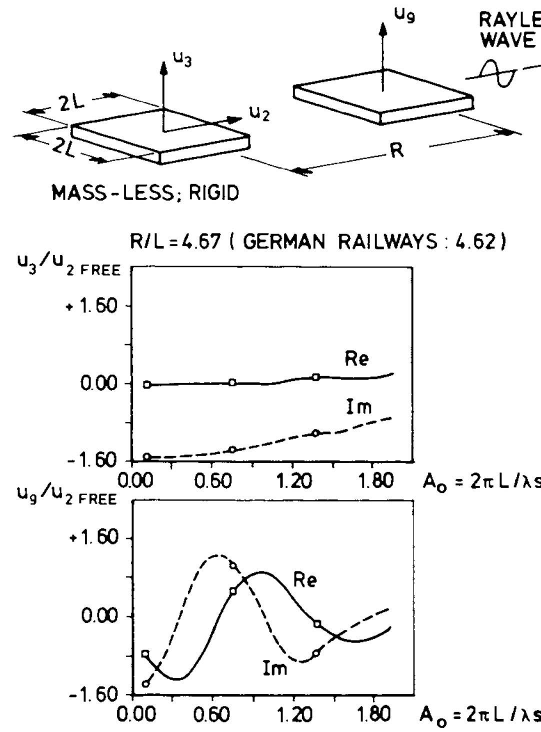

Fig.4 Displacements of Massless Foundations Subjected to Incident Rayleigh Waves (after Bielak and Coronato, 1980)

If we compare Fig.3 and 4 , we find the same pattern of frequency dependence of the real and imaginary parts of the respective functions. The "period" in the frequency-domain a_o is of the order of 1.0 - 1.2, the shift between real and imaginary parts beeing of the order of a quarter "period".

This indicates, that in certain frequency regions the real (or imaginary) parts of the vibrations of a tie are exaggerated due to the presence of neighbouring ties, while in other frequency regions they are diminished.

COMPLIANCE FUNCTION

If we introduce the inertia effects of the ties, we can calculate the complex compliance functions c_i derived from the stiffness functions.
Fig.5 shows these compliance functions for a single concrete tie (German Railways type B 70 W 60), assuming the tie to be rigid or elastic. To be consistent with experimental data, the compliance functions are plotted as magnitude and phase vs. frequency.

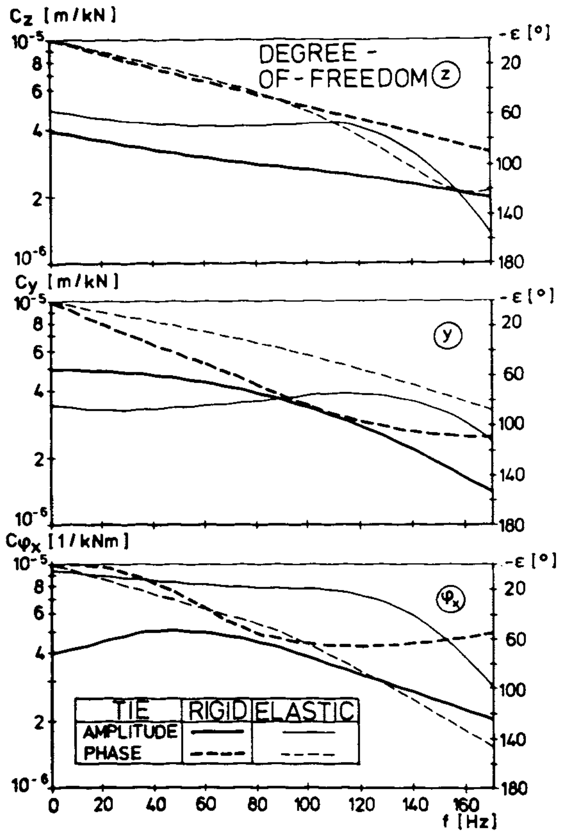

Fig.5 Compliance Functions for a Single Concrete Tie (Rigid and Elastic)

TEST RESULTS

To test the validity of the compliance functions of Fig.5, the dynamic response to dynamic loading of the ties of an experimental track was investigated. The test track consisted of concrete ties (B 70 W 60) on ballast with rails UIC 60. Provision were made to disconnect the rails from the ties in order to test the dynamic response of the individual ties without interaction through the rails. The test track was built for the purpose of track research at the Institute of Soil and Rock Mechanics by German Railways.

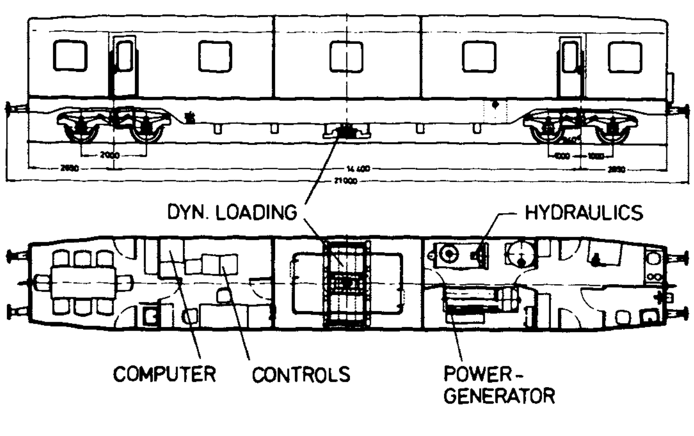

Fig.6 Dynamic Track Testing Vehicle Krupp Industrie und Stahlbau

A single tie was dynamically loaded by a testing vehicle developed by Krupp Industrie und Stahlbau, Essen, Germany, in cooperation with our Institute. Fig.6 shows details of the vehicle, which is arrested on the track with the static and dynamic loading devices on top of the resp. tie. With a tie distance of 0.6 m , 10 ties on either side of the excited tie lie within the distance of the inner axles of the trucks, giving sufficient space for tie interaction, as seen from Fig.3 .

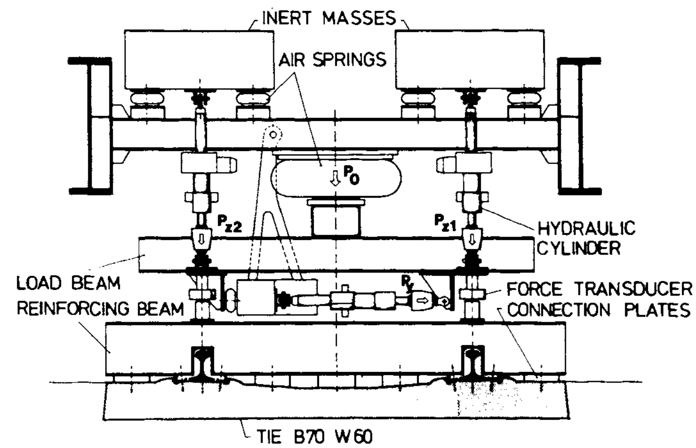

Fig.7 Static and Dynamic Loading Devices of Track Testing Vehicle

In Fig.7, the static and dynamic loading devices can be seen. A static load P_0 of max. 200 KN is generated by two large air springs and distributed to the rails or tie by a loading beam. P_0 simulates the static load af the axle. Three hydraulic cylinders provide the vertical (P_{z1} and P_{z2}) and the horizontal (P_y) dynamic forces. They are controlled by electro-hydraulic circuits and operate against low-tuned inert masses.

The condition of a "rigid" tie is achieved by a reinforcing beam connected to the tie by connection plates. In the case of the "elastic" tie, these plates are taken away. The clearances in the reinforcing beam allow for the rails to be disconnected from the tie.

Separate amplitude and phase controls of the electro-hydraulic circuits enable the excitation of uncoupled vibration modes in the three degrees of freedom (z, y, ϕ_x).

Reconnection of the rails to the tie facilitates the dynamic testing of the complete track. The experimental data thus gained will be published elsewhere.

Equ.(1) shows the influence of the dynamic shear modulus on the stiffness functions. Therefore, the variation of the compliance functions due to the dependency of the shear modulus upon the static stress level was calculated (influence of the static load P_0).

The dynamic properties of the subsoil under the test track were investigated in advance by field and laboratory methods (cross-hole testing and resonant-column tests).

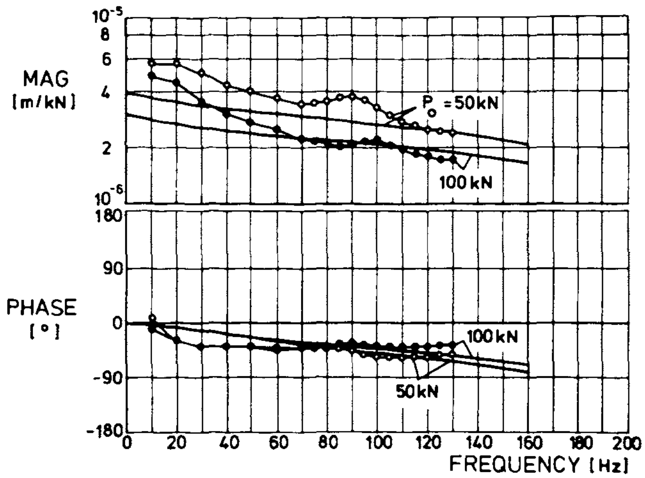

Fig.8 Compliance Functions Rigid Tie

Fig.8 shows the experimental data and the theoretical results for the "rigid" tie, Fig.9 the resp. data for the "elastic" tie.

Both compliance functions do not include the dynamic interaction of neighbouring ties.

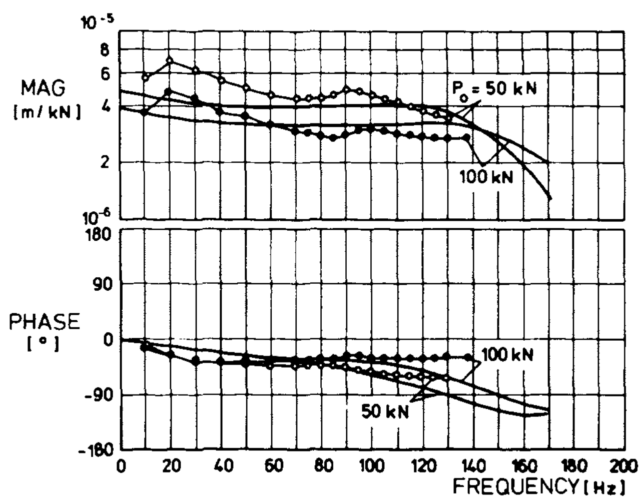

Fig.9 Compliance Functions Elastic Tie

This interaction is considered in the 2-dimensional analytic track model, the respective compliance functions being shown in Fig.10 for a system of 3 to 7 ties.

Here, the test results come closest to the theoretical values, the phase curves being almost identical. The theoretical value of the magnitude of the compliance functions is approx. 30% higher than the measured values. This may be due to the analytical track model having only two dimensions as well as neglecting the partial embedment of the ties.

A better coincidence of theoretical and experimental data is expected from the application of the three-dimensional analytical solution of the tie interaction problem.

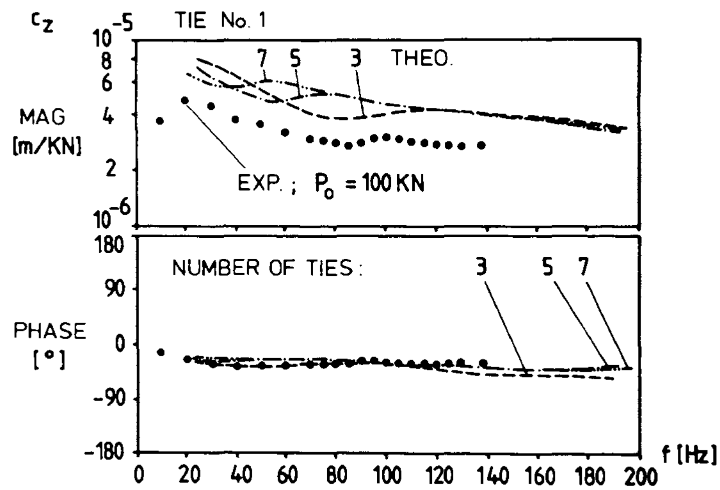

Fig.10 Compliance Functions for 3 to 7 Ties (2-dimensional analytical track model)

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REFERENCES

Bielak, J. and J.A.Coronato (1981) "Response of Multiple-Mass Systems to Nonvertically Incident Seismic Waves", Proc. Int. Conf. on Recent Advances in Geotechnical Eartquake Engineering and Soil Dynamics, St.Louis 1981 Vol.II

Prange, B. (1980) "Untersuchungsverfahren sowie Ergebnisse zum Untergrundverhalten und dynamischen Rückwirkunsmodell des Gleisoberbaus" Status-Seminar Spurgeführter Fernverkehr Rad/Schiene Technik, Bad Reichenhall, DEC 1980

Prange, B., G. Huber, Th. Triantafyllidis (1980) "Baugrunddynamische Probleme beim Rad/Schiene-System",Veröffentlichungen der Deutschen Baugrundtagung, Mainz 1980, DGEG

Triantafyllidis, Th. (1981) "Ein analytisches Verfahren zur Berechnung der Untergrundkopplung von mehreren, starren, auf der Halbraumoberfläche liegenden Streifenfundamenten bei harmonischer Erregung", Ingenieur-Archiv 1981