Two- and Three-dimensional Methods for the Assessment of Ballast Mats, Ballast Plates and Other Isolators of Railway Vibration

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This contribution gives a simple two-dimensional method to calculate the dynamics of railway tracks which have been checked against the results of completely three-dimensional finite-element boundary-element calculations. The forces generated by the train are modified, amplified or reduced, by the vehicle-track interaction and the force transfer of the track, yielding the forces that are acting on the ground and exciting the ground-borne vibration. The overall force transfer function, which is the integral of all forces acting on the soil divided by the input force on the vehicle, is presented for a number of different track systems. Details are given for the track with ballast mats where the influence of wheel mass, track mass, subsoil condition, and the stiffness of the mat have been analysed. Experimental results of the Federal Institute of Materials Research and Testing and literature are used to check the theoretical results about ballast mats.

Nomenclature

A	– area
A_j	– constant
b	– width
c_S	– soil damping
c'	– damping per length
D	– material damping
E	– modulus of elasticity
EI	– bending stiffness
f	– frequency
f_{zz}	– compliance function
$\boldsymbol{f}$	– compliance matrix
F	– force
F_t, F_r, F_z	– transversal, radial, vertical force
F_S	– total force acting on the soil
F_T	– wheel-set force on the track
F_V	– exciting force on the vehicle
F'_S, F'_T	– force per length
G	– shear modulus
h	– height
H	– total force transfer function F_S/F_V
H_T	– track force transfer function F_S/F_T
H_{VT}	– vehicle-track force transfer function F_T/F_V
i	– imaginary unit
k_S	– soil stiffness
K_T	– track stiffness
K_V	– vehicle stiffness
$\boldsymbol{K}_S$	– soil stiffness matrix
$\boldsymbol{K}_F$	– track stiffness matrix
k'	– stiffness per length
k'_S	– soil stiffness per length
K'_S	– complex soil stiffness $k'_S + i\omega c'_S$
k'_D	– dynamic stiffness $k' + i\omega c' - m'\omega^2$
$\boldsymbol{K}'_D$	– dynamic stiffness $\boldsymbol{K}' - \boldsymbol{m}'\omega^2$
k''	– stiffness per area
m_W	– wheel-set mass
m'	– mass per length
$\boldsymbol{m}'$	– mass matrix of multi-beam track
$\boldsymbol{M}$	– finite element mass matrix
N_{zz}	– compliance in wavenumber domain
r	– radial distance
s	– irregularities of vehicle and track
t	– time
u	– displacement
u_t, u_r, u_z	– transversal, radial, vertical displacement
v_S, v_P	– shear and compression wave speed
$\boldsymbol{v}_j$	– eigenvector
x	– position along the track
$\boldsymbol{x}$	– position vector
ν	– Poisson ratio
ρ	– mass density
ξ	– wavenumber
ξ_S, ξ_P	– shear and compression wavenumber
ω	– circular frequency
u''''	– multiple differentiation with respect to x (position)
$\ddot{u}$	– multiple differentiation with respect to t (time)

1. INTRODUCTION

A variety of isolation measures exists to reduce the vibration in the neighbourhood of railway lines. They can be roughly classified as elastic or stiffening systems. The following elastic elements are used (Fig. 1): railpads or resilient fixation systems between rail and sleeper,[1] sleeper shoes under the sleepers,[2] and ballast mats under the ballast[1,3,4]. Stiffening systems (plates) are used as slab tracks,[5-7] floating slab tracks,[1,8,9] or mass-spring systems[10] and in a different way, as an under ballast plate[11-13]. The main interest of this contribution is ballast mats.

Ballast mats are an efficient measure to reduce the vibrations near railway lines. The vehicle-track system gets a low eigenfrequency due to the insertion of an elastic ballast mat under the ballast. For frequencies higher than this low vehicle-track eigenfrequency, the forces, that are generating the vibration of the soil, are considerably reduced.