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New developments in soil improvement under railway lines on soft soil

Nouveaux développements dans l'amélioration de sol sous les lignes ferroviaires sur le sol mou

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ABSTRACT
To analyse the dynamic soil-structure interaction of railway lines on soft soil experimental and numerical investigations have been carried out. The mean intention was to get information about the influence of different soil improvement layouts and further on to establish a design tool for railway lines on soft soil based on the additional results of a numerically supported parametric study. The principle part of the paper is the presentation of the experimental and numerical investigations.

RÉSUMÉ
Afin d’analyser l’interaction sol-structure d’une voie de chemin de fer sur un sol compressible des expériences et des simulations numériques ont été menées. Le but principal était dans un premier temps d’obtenir des informations sur l’influence de différents procédés d’amélioration du sol, pour ensuite établir outil de conception basé sur les résultats des simulations de cette étude paramétrique. Cet outil serait par conséquent adapté à ces lignes ferroviaires sur sols compressibles. Le présent rapport est principalement consacré à la présentation des résultats des mesures dynamiques obtenues lors des expériences.

1 INTRODUCTION

During the train passage the ground below the railway line is set into damped oscillations that will cause long time deformations of the track. The amount of these long time deformations is significantly influenced by the amount of the oscillations, that normally will be described in terms of particle accelerations or velocities. The amplitude of these oscillations depends mainly on the soil stiffness and the train speed. With decreasing soil stiffness the amplitude increases (Kramer, 1996).

To reduce the oscillations in the ground it is state of the art to increase the dynamic stiffness by soil replacement or soil improvement (Hildebrand, 2001). The get information about the influence of the soil improvement layout on the dynamic response of the total system experimental field tests are a proper and valuable method. Beyond this the results will be used to develop a numerical based design tool for different ground conditions like deeper soft soil layers and varying stiffness properties.

2 EXPERIMENTAL INVESTIGATIONS

To investigate the influence of the soil improvement layout under a railway line on soft soil experimental investigations were done in a 300 m long testing area in northern Germany.

2.1 *Layout of the test tracks TS0–TS4*

The column arrangement installed in the five different test tracks TS0-TS4 is given in Figure 1. The ground improvement was constructed by Lime-Cement Columns with a column diameter of 0.6 m. Based on the Design Guide for Soft Soil Stabilisation (BRE, 2002) a dry mixture of 90 % cement and 10 % lime was used, the amount of binder mixed in was about 110 kg/m³.

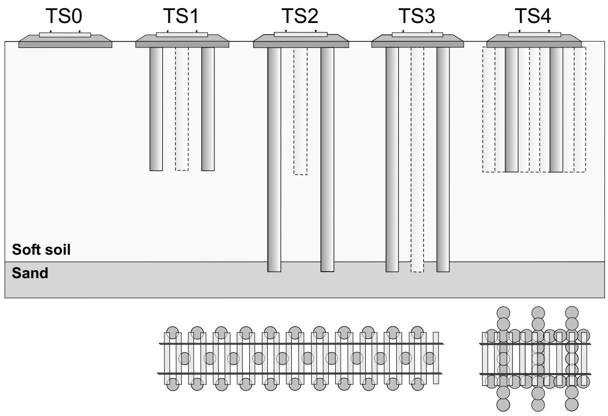

Figure 1. Column arrangement installed in the test field.

2.2 *Ground Conditions in the testing area.*

The ground below the track system in the testing area consists of a soft soil layer with a depth of about 10 m overlaying a good bearing middle dense to dense sand stratum. The average consistency index of the soft soil is $I_C = 0.4$, the water content varies with depth between w = 0.6–1 and the average organic content was about 10–15%. The groundwater table was 1 m below the surface. The mean mechanical parameters of the soft soil and the sand are given in Table 1.

Table 1: Mean mechanical parameters of the subsoil

Parameter	Symbol	Unit	Soft soil	Sand
Elastic module	E	MN/m^2	≤ 3	65
Friction angle	φ' / φ_u	°	25 / 0	30 / 0
Cohesion	c' / c_u	kN/m^2	5 / 40	0 / 0
Density	γ	kN/m^3	14–17	18–19

2.3 *Layout of the measurement program*

Each test track was equipped with multiple measurement devices pictured in Figure 2 to observe the dynamic response of the subsoil and the railway structure during operation. During the tests the area was passed for three month with different train speeds of V_1 = 30 km/h, V_2 = 50 km/h, V_3 = 70 km/h and V_4 = 90 km/h (V_4 only for the passenger trains). Altogether 1.200 train crossings were observed and recorded.

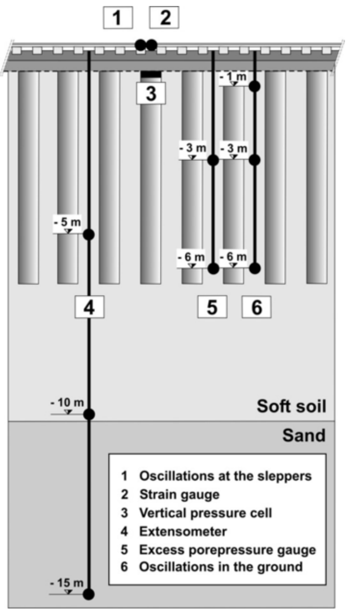

Figure 2. Layout of the measurement devices (example: TS1).

2.4 *Results of the experimental investigations*

In Figure 3 the measured vertical stress for a passenger train with V = 30 km/h and a freight train with V = 50 km/h is shown. The stress measurements were done in a depth of 0.4 m below the sleepers.

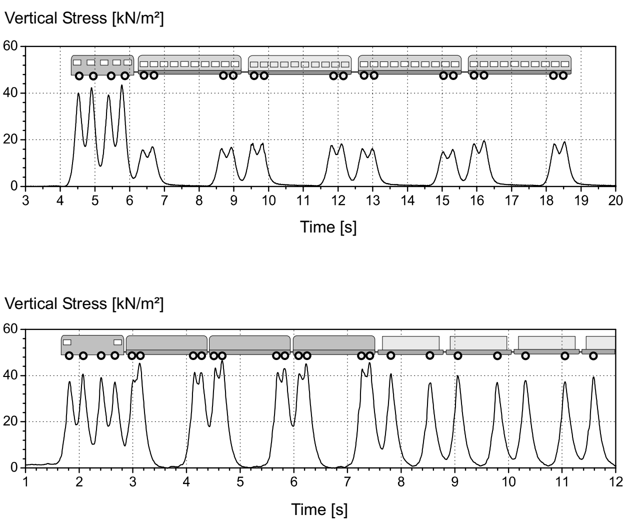

Figure 3. Vertical stress for passenger and freight train.

Each crossing of a train axis leads to a single stress amplitude. The frequency of the dynamic loading is strongly influenced by the distance of the wheel sets. Due to the lower weight the stress amplitudes of the passenger wagons are obviously smaller compared to the freight wagons. The axial loading for the passenger train was about 100 kN and for the freight train 225 kN witch is coincident with the maximum axial loading allowed in Germany.

In Figure 4 the excess porewater pressure in a depth of 3 m for a freight train with a speed of about 30 km/h is represented for test track TS0, TS1 and TS4. The measurements reveals that only a small amount of the dynamic loading is transferred in the porewater. For the test track configuration TS0 without any soil improvement the additional porewater pressure is p ≤ 3 kN/m².

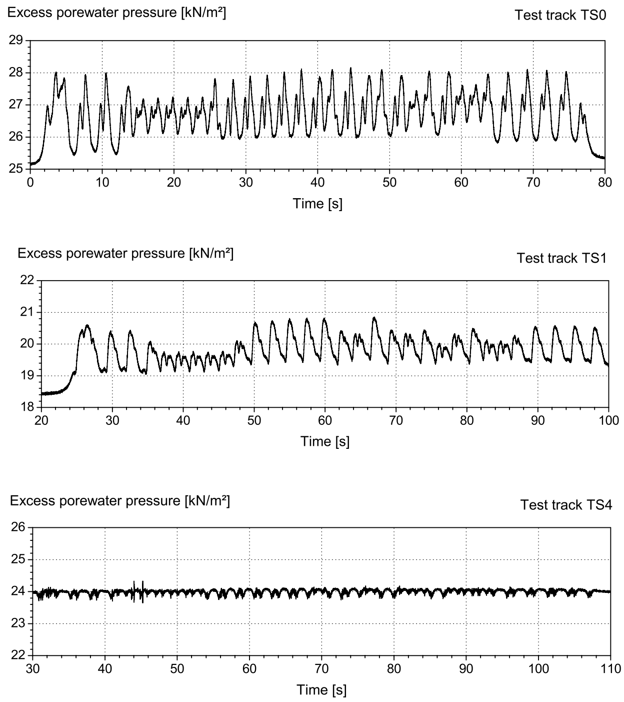

Figure 4. Excess porewater pressure measurements in TS0, TS1 and TS4.

Compared with test track TS0 in a depth of 3 m the measured porewater pressure in test track TS1 and TS4 are lower due to the higher hydraulic permeability of the young lime-cement matrix (Broms et al., 1977). Experiences made by Brandl in 1999 confirm that the hydraulic permeability of the young column matrix until the age of approximately 1 year is 400-1000 times higher than that of unstabilised soil. The highest hydraulic permeability thus is observed in test track TS4 were the columns are placed in grids.

To get information about the oscillations in the ground during the train passage triaxial acceleration measurements were performed in a depth of 1 m, 3 m and 6 m below the surface. The vertical accelerations are integrated into velocities and converted into the Root Mean square Values, abbreviated RMS. In Figure 5-7 the results for the freight trains for different train speeds in test track TS0, TS1 and TS4 are presented. To compare the results best fitting curves with an exponential function are added.

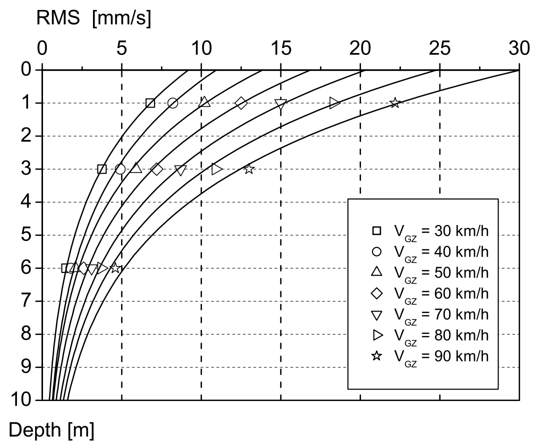

Figure 5. RMS vs. depth for test track TS0.

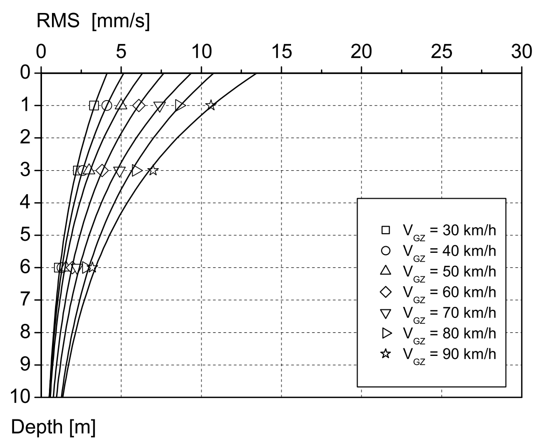

Figure 6. RMS vs. depth for test track TS1.

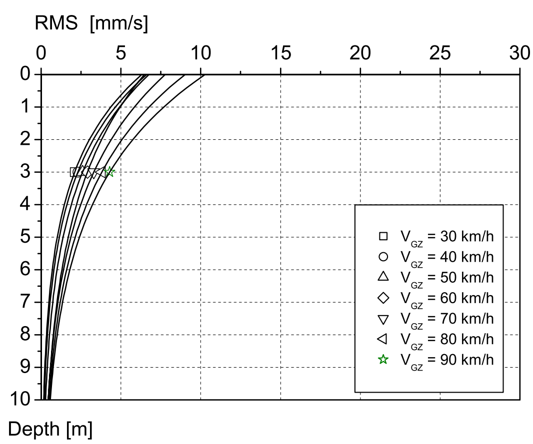

Figure 7. RMS vs. depth for test track TS4.

In Figure 5 the RMS decreases rapidly with increasing depth, the greatest values are measured in the near of the surface. Beyond this it can be recognized especially for the measurement point in a depth of 1 m that the RMS in test track TS0 increases more than linear with every train speed increment. Compared to test track TS1 and TS4 the RMS-Values close to the surface are obviously smaller due to the higher dynamic stiffness of the soil improvement under the railway track and thus connected with a smaller rate of long term deformation.

3 NUMERICAL INVESTIGATIONS

The first aim of the experimental field tests was to analyse the dynamic soil-structure interaction of a railway line on soft soil. The mean intention was to get information about the influence of different soil improvement layouts on the dynamic response of the soil for a specific project in northern Germany.

Beyond this the experience will be used to develop a numerical bases design tool for different ground conditions like deeper soil layers and varying stiffness parameters. The back analysis was done by 3D-calculations after the Finite Element Method (FEM).

3.1 *Finite Element Model*

The 3D-FE model used is pictured in Figure 8. The soil improvement was modelled using a area with mixed stiffness parameters below the railway track. In Figure 9 the cross section of the FE-model with and without soil improvement is shown. In the first step only test track TS0, TS1 and TS4 are computed.

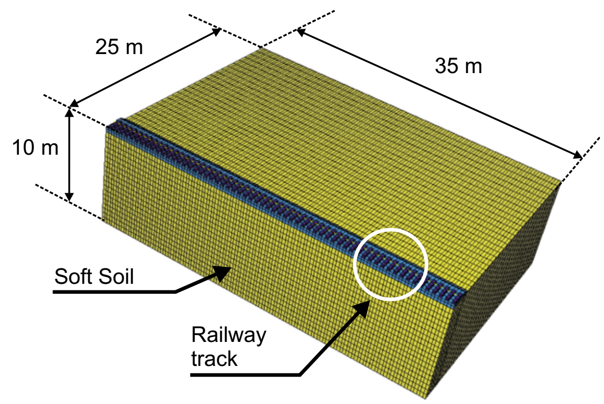

Figure 8. 3D-Finite Element Model.

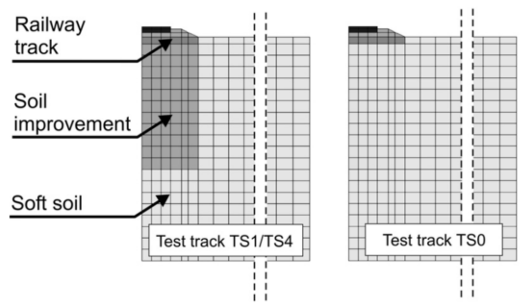

Figure 9. 3D-Finite Element Model (cross section).

To investigate the speed dependent dynamic response of the track system and the influence of the soil improvement layout a short freight train with three wagons pictured in Figure 10 was used with different train speeds of V = 30, 60 and 90 km/h parallel to the field tests. The axial load of each wheel set was 225 kN according to the maximum allowed axial loading in Germany. The thickness of the soft soil layer was 10 m. The deeper sand layer was not modelled. Due to the high stiffness of this layer fixed vertical boundary are implemented at the bottom of the FE model.

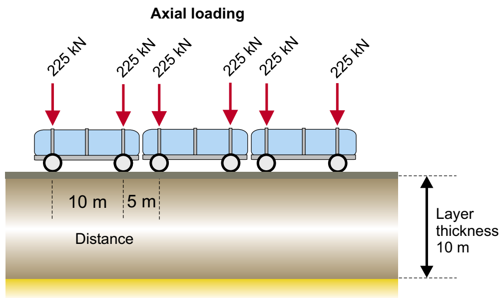

Figure 10. Numerical calculated freight wagons.

3.2 *Results of the numerical investigations*

In Figure 11 to 13 the measured values in the field and the numerical results for test track TS0, TS1 and TS4 for train speeds of 30, 60 and 90 km/h are represented.

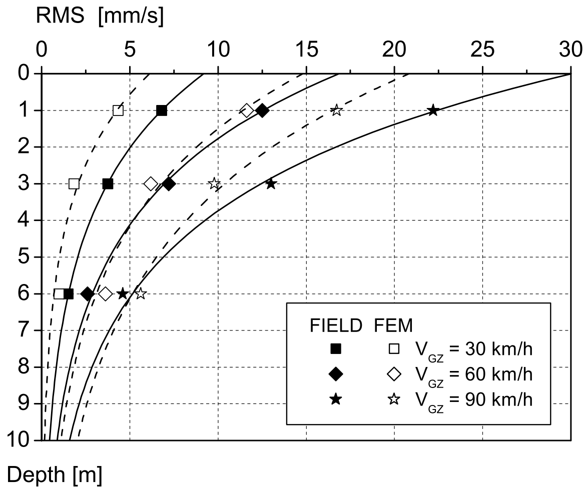

Figure 11. RMS, measurement vs. FEM, TS0.

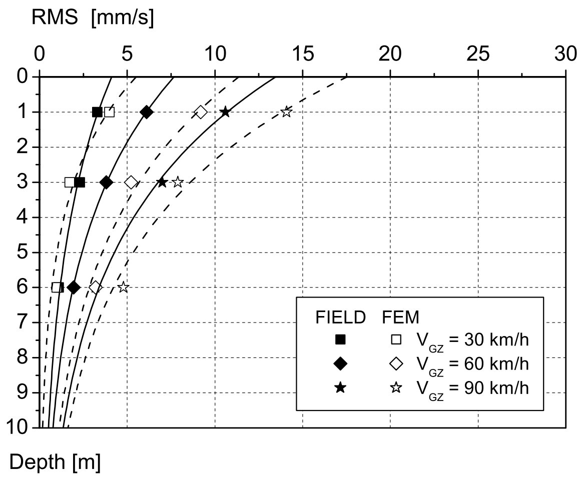

Figure 12. RMS, measurement vs. FEM, TS1.

The comparison gives a good agreement for the fundamental dynamic behaviour of the used FE model. With soil improvement a lower RMS for constant train speed is obtained.

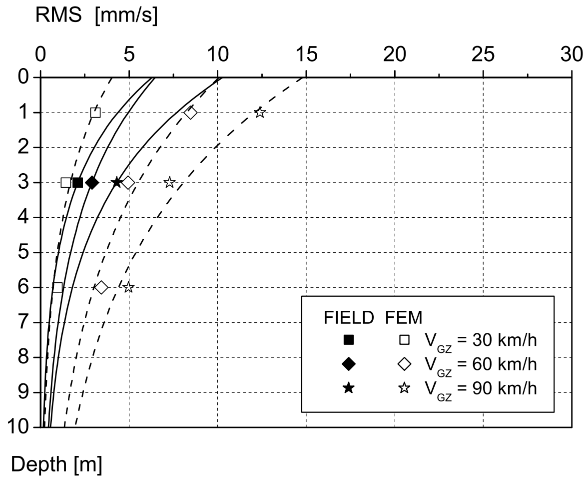

Figure 13. RMS, measurement vs. FEM, TS4.

The numerical computed amount of the vertical oscillations is the same range as the measurements but in the field the reduction due to the different soil improvement layouts in test track TS1 and TS4 is a little higher. The reason for this could be found for instance in the assumption of a constant shear modulus with depth in the numerical model. This first FE model will be corrected with regard to the dynamic behaviour of the soft soil and a progressive model will be used for future calculations.

4 CONCLUSIONS

To investigate the speed dependent dynamic response of the track system and the influence of the soil improvement layout experimental field tests combined and completed with additional numerical calculations are a proper and valuable method. The measurements and the results of the FE model demonstrate that the oscillations in the soft soil and thus the rate of long time deformation of the railway track can be reduced clear when soil improvement is done.

These experiences will be used to develop a design tool for soil improvement under railway lines on soft soil because a technical and economical solution depends on the local project conditions.

REFERENCES

Brandl, H. 1999. Long-term behaviour of soil stabilised with lime and with cement. *Proc. 12th Regional Conf. for Africa on Soil Mech. and Geotech. Engng. Geotechnics for Developing Africa*, Durban, South Africa. 219-232.

BRE. 2002. *EuroSoilStab - Design Guide Soft Soil Stabilisation*. British Research Establishment.

Broms, B.B., Boman, P. 1977. Lime Columns – A new type of vertical Drains. *Proc. IX Int. Conf. Soil Mech. Found. Engng. Tokyo*, Japan, Vol. 1, 427-432.

Hildebrand, R. 2001. *Countermeasures against railway ground and track vibrations*. Royal Institute of Technology, Dep. of Vibration Research, KTH, Stockholm, Sweden.

Kramer, S. L. (1996) *Geotechnical Earthquake Engineering*. Prentice-Hall International Series in Civil Engineering and Engineering Mechanics.