Vertical vibration mitigation along rail way lines

J. Keil, F. Walther

***Abstract*—** This article presents two innovative solutions for vertical vibration mitigation barriers including experimental and numerical investigations on the completed barriers.

There is a continuing growth of exposure to noise and vibration in people´s daily lives due to the quest for more mobility and flexibility. In previous times neglected, immissions caused by vibrations can lead, for example, to secondary noise or damage in the adjacent buildings.

Also people can feel very affected by vibrations. But unlike in new construction, in existing infrastructure and buildings action can be taken almost only on the transmission path of those vibrations.

In the following two solutions were shown how vibrations on the transmission path can be mitigated. These are the jet grouting method and a new installation method (patent pending) by means of a prefabricated hollow box which is filled with vibration reducing mats and driven down to depth, are presented. The essential results of the numerical and experimental investigations on the completed wave barriers are included as well.

This article is based on the results of a field test with the participation of Keller Holding, which was executed in the context of the European research project RIVAS (Railway Induced Vibration Abatement Solutions), and on a thesis done at the Technical University of Dresden with the involvement of BAUGRUND DRESDEN Ingenieurgesellschaft mbH and the Keller Holding GmbH.

***Keywords*—** jet grouting, rail way lines, vertical vibration mitigation, vibration reducing mats.

I. Introduction

THE quest for mobility and flexibility in their everyday lives mean that people are increasingly exposed to emissions of various types. Emissions resulting from vibration have to date been largely ignored in infrastructure development, and vibrations in buildings, for example, can lead to secondary noise or to damage to the structure. But people themselves can feel adversely affected by vibrations. In contrast to new buildings, the only measures possible with existing infrastructure and buildings involve taking action along the transmission path.

This paper describes two possible ways of reducing vibrations along the transmission path.

It introduces the “jet-grouting process” and the “installation procedure using a guide frame”, and the main findings from numerical and experimental investigations on the wave barriers thus constructed.

The paper is based on the one hand on the results of a field trial involving Keller Holding, carried out as part of the European research project RIVAS (Railway Induced Vibration Abatement Solutions), and on the other hand on the results of the thesis at the Technical University of Dresden [1], where both BAUGRUND DRESDEN Ingenieurgesellschaft mbH and Keller Holding GmbH were involved.

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II. Soilcrete® – Jet-grouting process

A. The Soilcrete® Construction Method

The Soilcrete® process can be seen as a method of jet grouting. With the aid of a high-energy cutting jet of water or cement suspension with outlet velocities ≥100 m/s, the in-situ soil in the area of the borehole is cut or eroded away (see Fig. 1). The eroded soil is redistributed and mixed with cement slurry. Depending on the soil type, and the method and the liquid used, the jet can erode soil up to a distance of 3.5 metres. After curing, Soilcrete® mortar has usable load-bearing properties. The procedure is regulated in European Standard EN 12716 [2].

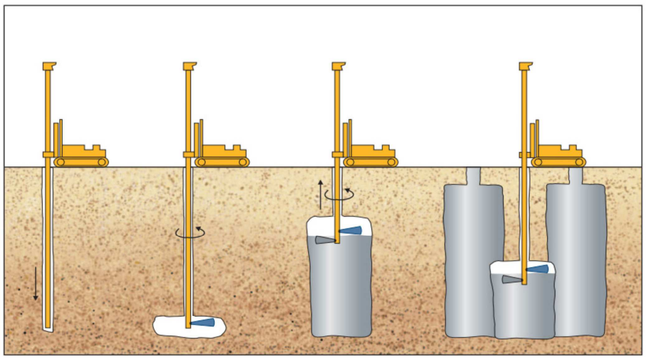

Fig. 1a Soilcrete® (drilling, cutting, soilcreting, extending)

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Fig. 1b Soilcrete® application

Conventional Soilcrete® applications are underpinning, deep foundations, tunnel outer shells, bottom seals, lamella walls, etc.

In contrast to conventional methods of soil stabilisation, Soilcrete® has been successfully applied in strengthening and sealing in a wide variety of soils (see Fig. 2). Soilcrete® can be produced by a variety of methods; these will not be described further here.

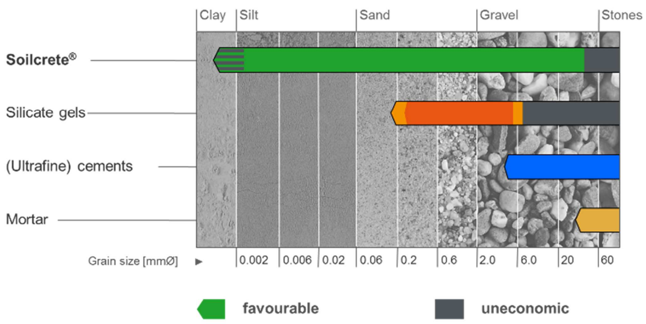

Fig. 2 Applications of Soilcrete®

B. Vertical Wave Barrier of Soilcrete® Columns

In the framework of the RIVAS European research project, KELLER constructed a vertical wave barrier using Soilcrete®-D in a 100 m-long trial section along an existing rail line and a parallel new high speed line (Madrid - Levante) in the south-east of Spain.

Based on a finite-element calculation, a wave barrier 55 m long, 7.5 m high, and 1.0 m wide was planned. The diameter of single columns was set at 1.5 m. The wave barrier is located in soft alluvial soils (silty clay). Its plan view and cross section are shown in Fig. 3.

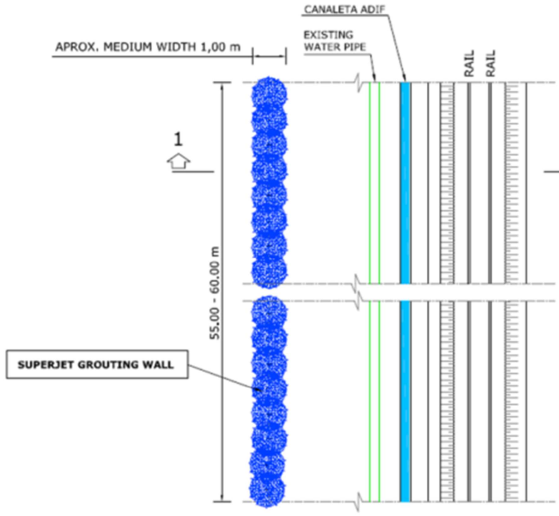

Fig. 3a Plan view – Soilcrete® as a vertical wave barrier

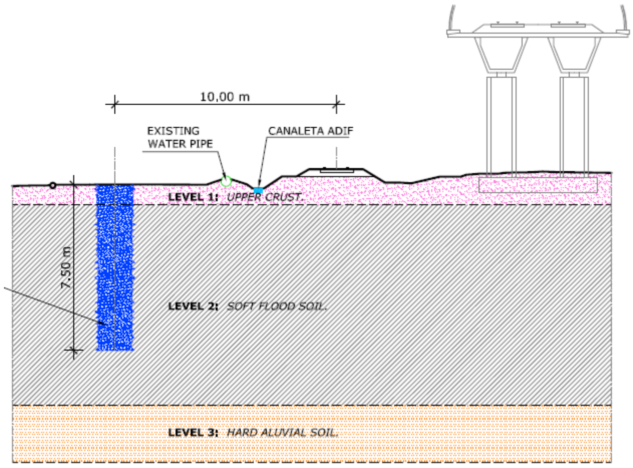

Fig. 3b Cross-section – Soilcrete® as a vertical wave barrier

The Soilcrete® jet-grouting process enabled very effective vibration mitigation in soft soils, and this was verified with vibration measurements. Starting at a low frequency, the test confirmed that the spread of vibrations in the soil was greatly reduced. Soilcrete® is thus a proven, forward-looking product with which an effective vibration mitigation in soft soils along existing rail lines and can be achieved in confined spaces. The ability to solve low frequency vibration problems has been recognized as a unique feature compared to most other vibration mitigation measures (such as sheet pile walls) studied with the RIVAS European research project. Further information is available in the relevant reports of RIVAS which are published on the website http://www.rivas-project.eu/ [3].

III. Installation Method with Guide Frame

A. Installation Method

In Fig. 4 the guide frame, the "heart” of the new installation procedure, is shown on the left, while the principle is schematically shown on the right.

Fig. 4a Guide frame (left) and principle of the installation method (right)

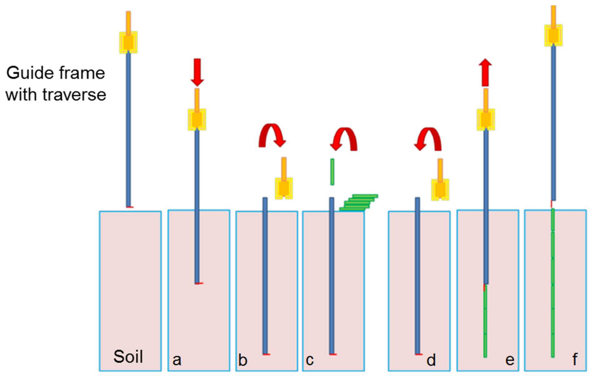

Fig. 4b Guide frame (left) and principle of the installation method (right)

The main steps consist of (a) driving of the guide frame using a vibro-hammer, (b) removal of the spreader bar, (c) construction of the barrier element, (d) re-attachment of the spreader bar, (e) withdrawal of guide frame with vibro-hammer, (f) completion.

The withdrawal process (e) causes the flap at the bottom of the guide frame to open, and the barrier material slips out of the box and remains in the ground.

B. Test Field and Investigation

A site with soil at its natural bulk density and relatively homogeneous soil conditions was identified at the SBU Sandwerke Dresden GmbH, Radeberger Straße. The size of the test section was initially based on the experience of BAUGRUND DRESDEN.

Using penetrometer tests (CPT) and test pits, the properties of layers down to greater depths were established and sample material for the laboratory tests was obtained (see plan of main investigation points in Fig. 5). The evaluation of the CPT was carried out with the numerical interpretation method according to Cudmani [4].

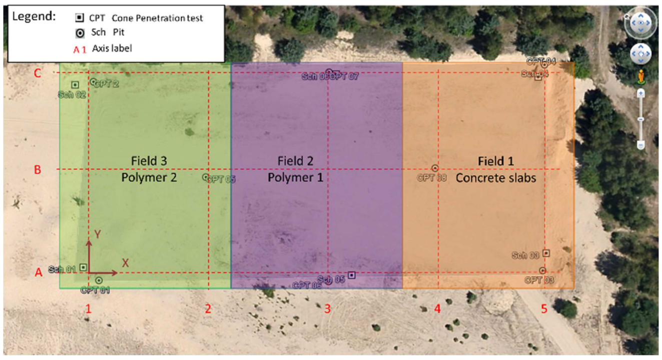

Fig. 5 Test area with sub-fields and main investigation points [5]

C. Field Trial

The field trial represented the first practical test of the new installation process developed by Keller Holding GmbH and it was used to validate the dynamic 3D-FE calculations previously carried out.

The test area (see Fig. 5) was divided into three sub-fields each 40 m x 60 m in size. In each sub-field, tests were performed to document the initial state *without a wave barrier (”zero test")* and the state *with a wave barrier (”test”)*.

The following materials were available for the field test, and each was assigned to a sub-field:

- Concrete slabs (high stiffness) [sub-field 1]
- Regupol vibration 450 from BSW GmbH [sub-field 2]
- Sylomer SR 18/25 from Getzner Materials (very low stiffness) [sub-field 3]

For the field test and its implementation, the following was among the equipment and items required on the test site:

- A vibro-hammer (here, a Müller Vibrator MS-16 HFV)
- A mobile crane, 80 t
- Guide frame
- Steel plate with adaptor
- Measurement technology to detect vibrations (BAUGRUND DRESDEN)

After the first penetration tests, minor modifications were necessary because the total weight of the Müller vibrator, the spreader bar and the guide frame was not sufficient to overcome the tip resistance of the guide frame in the soil. The soil was loosened in the immediate vicinity of the installation area. After this, the installation method with the device configuration was possible.

The individual barrier segments were produced with a slight offset of a few centimetres and an overlap of 10 to 15 cm to one another, this being dictated by the installation method. Because of the relatively large overlap the offset can be neglected.

The wave barrier in sub-fields 1 and 2 was 14 m in length and 3 m in depth, and had a thickness of 5 cm. In sub-field 3, the length was limited to 7.5 m.

The vibro-hammer was also used as the excitation source (static load 50.86 kN). A steel plate with adapter was fitted to the construction equipment, and it was thus possible to apply different frequencies to the subsoil (Fig. 6b).

Different distances between the excitation source and wave barrier were included in the study (2.5 m, 5.0 m, 7.5 m and 10.0 m). The frequencies, and a single impulse (the steel plate with the adapter was dropped from a height of 1 m), were applied at each point.

The vibration velocity was measured using geophones at points determined in advance. The location of the geophones is included in Fig. 6c.

Fig. 6a Driving of installation box

Fig. 6b Excitation source

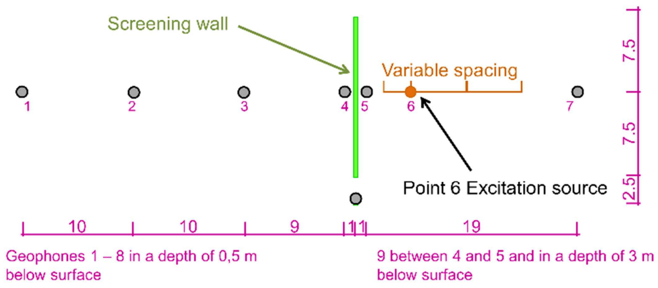

Fig. 6c Position of geophones

The DASYLab program allowed 543 measurement results to be recorded. To maintain clarity in the evaluation of the field test, the ratio values of the critical geophones were calculated and graphically represented. Geophone 5 was installed between the planned and constructed wave barrier and the excitation source. Geophone 4 was located behind the planned and constructed wave barrier. Along with other results, the previously conducted numerical examination (see following section) showed that a reduction in vibration only occurs in the area directly behind the wall. This was confirmed by the measurements carried out.

The evaluation is based on the assumption that a linear relationship exists between the decrease in vibration velocity and the different intensities of vibration.

Fig. 7a gives an exemplary picture of the ratio values of the concrete screening barrier and assigns these to the respective “zero test” or "test" and the respective frequency investigated. For a better understanding, the diagram was simplified by comparing only the ratios of all "zero tests" and "tests". These results are shown in Fig. 7b.

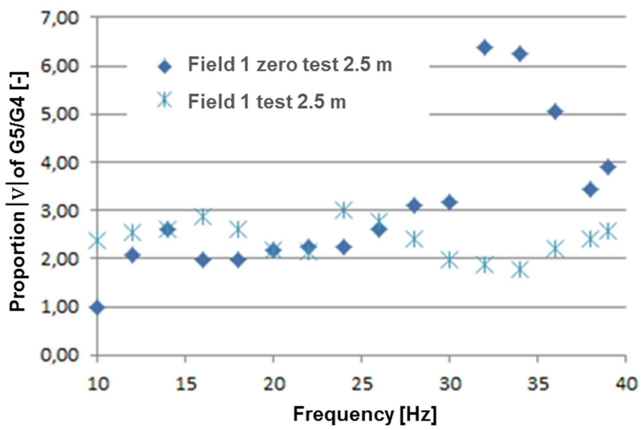

Fig. 7a Ratio G5/G4 Field 1

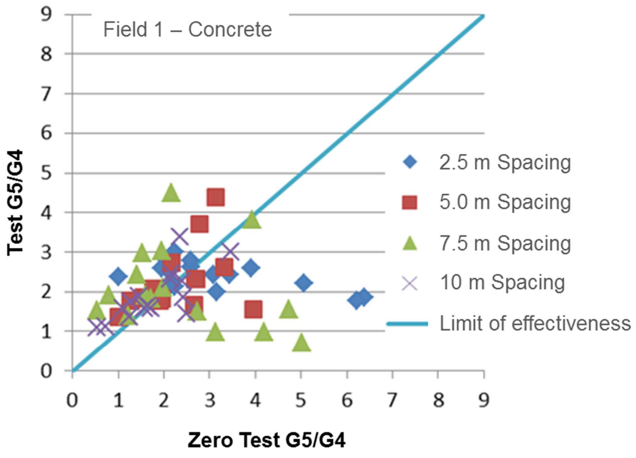

Fig. 7b Ratio G5/G4 Field 1 – concrete slabs

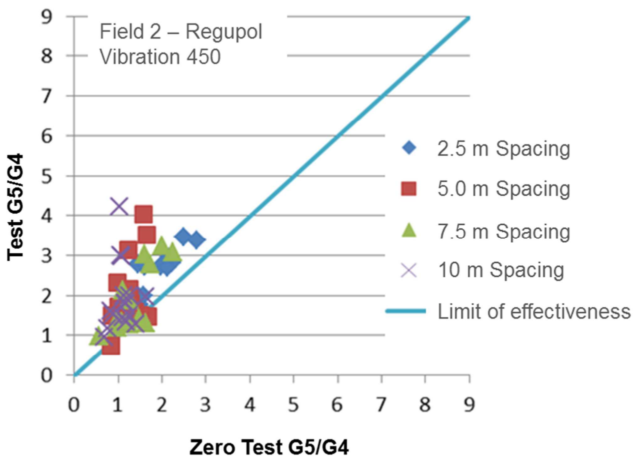

Fig. 8a Field 2 – Regupol Vibration 45

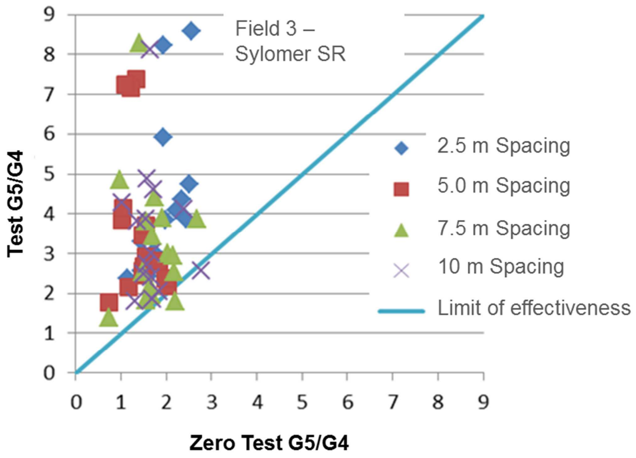

Fig. 8b Field 3 – Sylomer SR 18/25

Here, the blue line represents the effectiveness limit, and all ratio values (zero test G5/G4 / test G5/G4) above this limit show a screening effect. For the concrete wave barrier, a low shielding effect was observed (the majority of the points are above the limit). A very good mitigation effect was afforded by the Sylomer SR 18/25 material from Getzner (see Fig. 8a+b).

D. Numerical Investigations

Based on the numerical studies it was possible to estimate the effect of the barrier material. The finite-element software Plaxis 3D Version 2012.02 was used for the calculations.

These were based on the hypoplastic law with intergranular strain ([6], [7]). This constitutive law best represented the material behaviour of the sand, as even the smallest movements in the soil and the loading or deformation history are taken into account.

The results of the CPT evaluation (see Section "Test field and Investigation") were taken into account in the calculation model. The wave barriers were 7.5 m (Sylomer SR 18/25) or 15 m (concrete slabs and Regupol Vibration 450) wide. In the 3D finite element (FE) models the exciter source was reproduced as a cylindrical volume element and the dynamic load (max. 90 % of the static load) was initiated with the respective frequency. The wave barrier was also taken into account with finite-volume elements, and the different materials were simulated by Rayleigh linear-elastic attenuation. The minimum distance between the individual deformation grid points was determined with the formulae given in [8] and [9]. Points corresponding to the location of the geophones were defined in the respective 3D-FE models.

The maximum values of the resulting vibration velocity were considered in the evaluation. The critical results are shown in Fig. 9 a-c. The critical vibration velocities are limited to point 4 and are shown in Fig. 9a.

The various materials of the mitigation barriers exhibit different effects. The concrete wave barrier reflects, and the wave barriers Regupol Vibration 450 and Sylomer SR 18/25 absorb the shock waves (Fig. 10b). The greatest mitigation effect was observed with the material Sylomer SR 18/25 at a distance of 2.5 m from the emission source.

Due to the modifications in the test procedure and/or to the loosening process, an adaptation of the FE model (Fig.10a – red area) and a verification of the results was necessary. The results of the modified 3D-FE model are shown in Fig. 11 a-c.

For the “test” part of the test, it can be assumed that the loosened zone was compacted by the installation process and that there is no difference to the results of the numerical analyses.

The resulting maximum vibration velocities were used in the evaluation.

By taking the loosened zone into account in the recalculation of the *"zero tests"*, a partial approximation to the experimental results was possible.

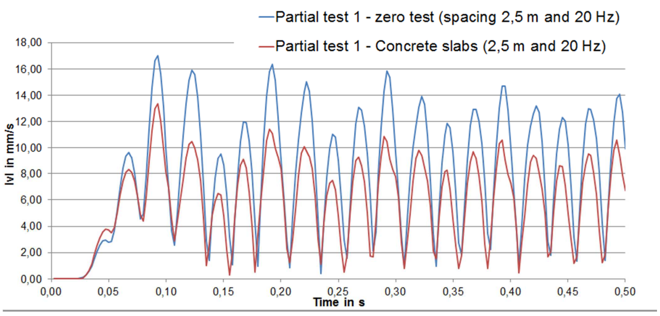

Fig. 9a Exemplary results – Partial test 1

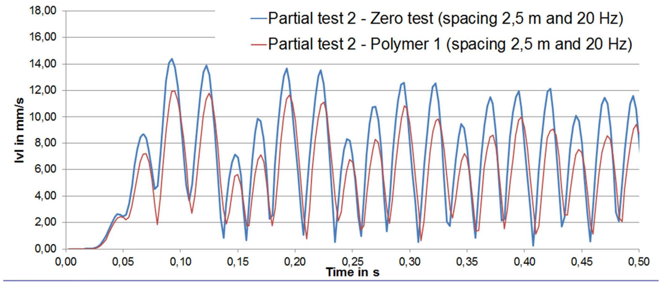

Fig. 9b Exemplary results – Partial test 2

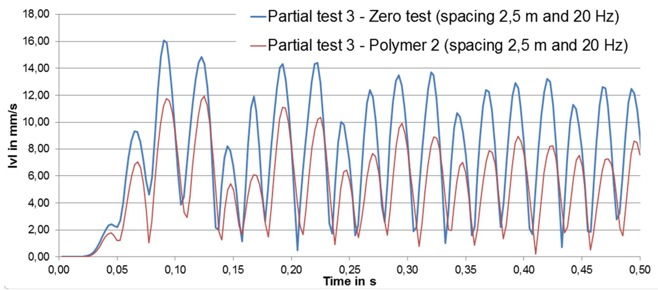

Fig. 9c Exemplary results – Partial test 3

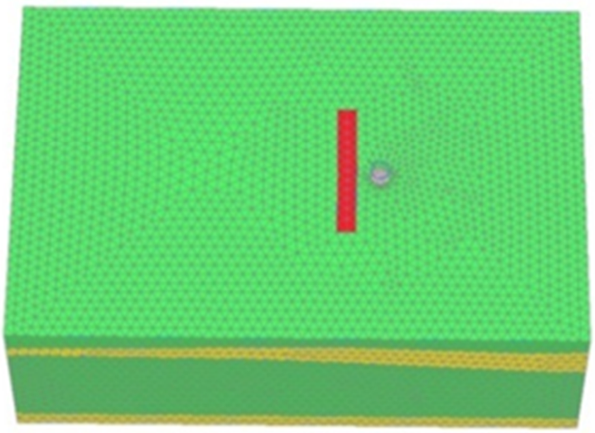

Fig. 10a A representation of the adjusted 3D-FE model (spacial view)

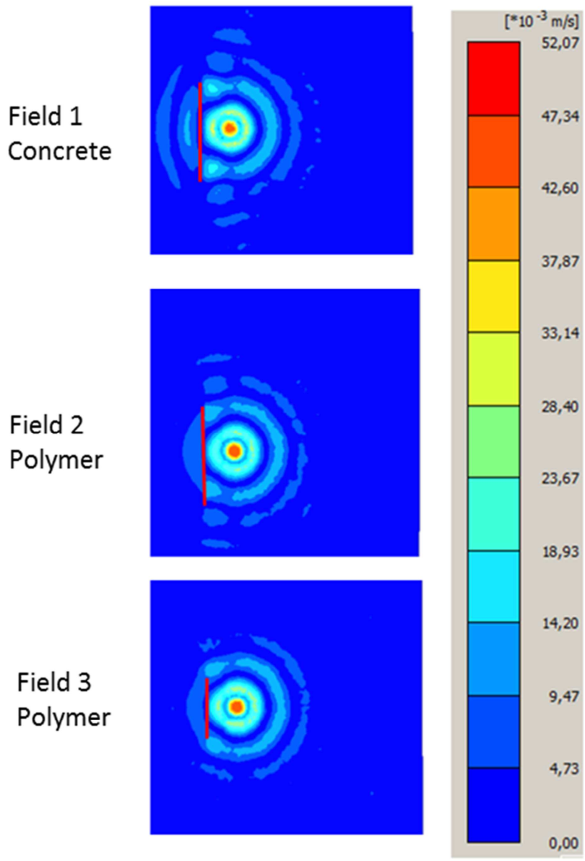

Fig. 10b A representation of the adjusted 3D-FE model (plan view)

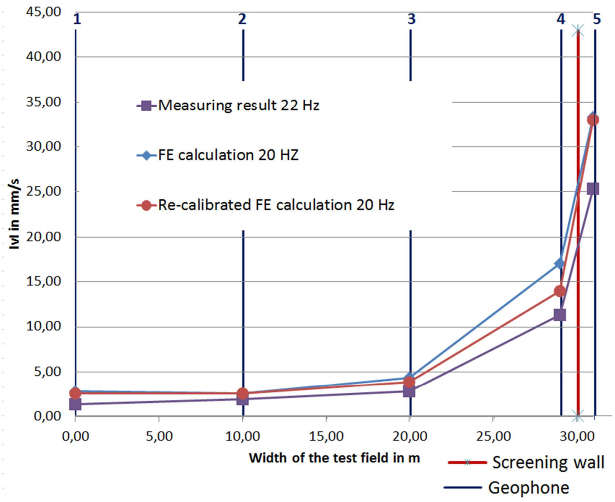

Fig. 11a Exemplary result of the recalculation – Field 1

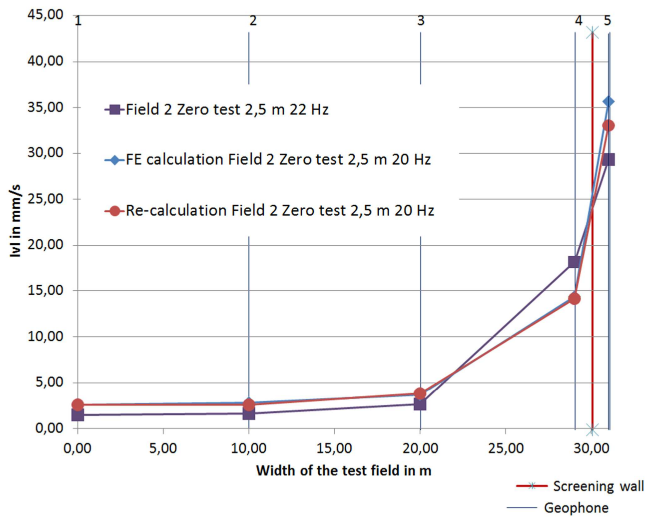

Fig. 11b Exemplary result of the recalculation – Field 2

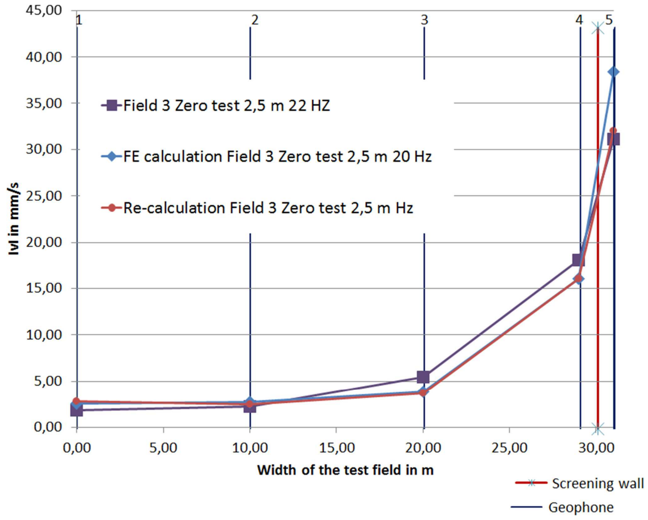

Fig. 11c Exemplary result of the recalculation – Field 3

IV. Summary

Two methods for the construction of wave barriers are presented here: "Jet-grouting" and "Construction using an guide frame". These represent economically interesting alternatives to previous methods (usually with substantial earthworks and associated personnel).

Both methods were successfully used. The ability of the "Jet-grouting" solution to solve low frequency vibration problems has been recognized as a unique feature compared to many other vibration mitigation measures. Optimizations (including device configuration – leader mast + guide frame) were developed for the "Construction using a guide frame".

The functionality of the wave barriers thus constructed was confirmed. A mitigation effect was observed both numerically and experimentally.

On the basis of the experience now gained and the results of the dynamic numerical studies, it is possible to develop reliable prediction methods and to use these to advantage, inter alia, in the planning and design of wave barriers.

References

[1] F. Walther, „Diplomarbeit" Abschirmungselemente gegen Bodenerschütterungen, Technische Universität Dresden, 2013 ("*Thesis*" Screening elements against soil vibration, *Dresden University of Technology*, 2013)

[2] *DIN EN 12716* execution of special geotechnical works – jet-grouting methods (high-pressure injection, high-pressure soil grouting, jetting), 2001

[3] RIVAS - Railway Induced Vibration Abatement Solutions; *http://www.rivas-project.eu/*, 09.07.2015 um 13:50

[4] R. Cudmani, V.A. Osinov, The cavity expansion problem for the interpretation of cone penetration and pressuremeter tests, *Canadian Geotechnical Journal* 38, 622-638, 2001

[5] Maps, *Google Earth* (version 7.1.2.2041)

[6] P.-A. von Wolffersdorff, A hypoplastic relation for granular materials with a predefined limit state surface, in *Mechanics of Cohesive-Frictional Materials*, Volume 1, Issue 3, pages 251–271, July 1996

[7] A. Niemunis, I. Herle, Hypoplastic model for cohesionless soils with elastic strain range, *Mechanics of Cohesive-Frictional Materials*, Volume 2., pages 279-299, 1997

[8] D. Wegener, I. Herle, On the determination of shear strains below dynamically loaded areas, *Geotechnik*, Issue 01/2010, pp. 12-18)

[9] W. Vogel, K. Lieberenz, T. Neidhart, D. Wegener, On the dynamic stability of railway lines with ballasted track on soft layers, *ETR, Eisenbahntechnische Rundschau*, Issue 09/2011, pp. 46-54)

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The second paragraph uses the pronoun of the person (he or she) and not the author's last name. It lists military and work experience, including summer and fellowship jobs. Job titles are capitalized. The current job must have a location; previous positions may be listed without one. Information concerning previous publications may be included. Try not to list more than three books or published articles. The format for listing publishers of a book within the biography is: title of book (city, state: publisher name, year) similar to a reference. Current and previous research interests ends the paragraph.

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