Use of multifunctional geocomposites as dampers for structure subjected to external vibrations

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ABSTRACT: Vibrations created by road or railway traffic are transmitted though soil to adjacent structures. In densely populated urban areas this can have an impact on the health and well-being of residents as well as affecting the value of their property. Geocomposite products with 3D looped filament polyamide cores have been used successfully over the world for decades in vertical and horizontal drainage applications. In situ monitoring coupled with complementary laboratory testing has led to a comprehensive understanding of the capabilities of these products, which due to the long-term elasticity of the polyamide core enables these materials to reduce the transmission of these vibrations. This paper discusses the efficiency of the geocomposite materials on the basis of newly executed field test results regarding the behaviour of geocomposite materials in dynamic pressure environment.

Keywords: vibrations, geocomposites, vibration damping

1 INTRODUCTION

The increasingly close proximity of adjacent structures necessitated by increasing urbanization coupled with the presence of sources of vibration including rail and road transport and mixed industrial-residential areas has introduced the need for innovative and cost effective vibration damping solutions. Multifunctional geocomposites are one potential solution. With special geocomposite products the transmission of horizontal vibrations to vertical parts of the building can be reduced. The geocomposite layer can be fixed directly to the building foundation or used as an absorbant layer between the vibration source and the building.

Enkadrain ST and Enkadrain CK geocomposites are multifunctional geocomposites for drainage, lost shuttering and vibration damping. The geocomposites have cavity-rich polyamide cores coupled with impervious PVC, coated filter or thermobonded fleece on to the sides to keep soil particles out of the core. In this research work the tested geocomposite was produced with polyamide core coupled with thermobonded geotextile layers on both sides.

2 GOAL OF THE RESEARCH

The aim of this research work is to determine the efficiency of the above-mentioned geosynthetic product as vibration dampers in areas where the rail or road traffic generated vibrations have to be reduced or minimized. On the basis of this research work and also the existing laboratory test results regarding the behaviour of the geocomposite materials in dynamic pressure environments (natural frequency, dynamic stiffness, and dynamic young’s modulus under different pressures) the final goal is to establish an empirical calculation method to evaluate the vibration attenuation under different dead loads, material thickness and oscillation rates.

3 TECHNICAL BACKGROUND - PROPAGATION OF GROUND VIBRATION

The science of predicting the transmission of vibration through the soil layer is complex. Propagation can be highly influenced by the soil properties and heterogeneous nature of the soil environment. Furthermore, one of the most important factor of the complexity is the difficulty of modelling precisely the sources of vibration and the resulting near- and far-field behaviour. In spite of these obstacles, with accurate information about the subsoil it is possible to make reasonable assessments of soil-transmitted vibration (T. G. Gutowski and C. K. Dym, 1976). For the analysis of vibrations, it is necessary to consider the combined effect of several factors such as the characteristics of vibration sources, the site characteristics, the propagation of surface and body waves in the soil, and response of structures (Dong-Soo Kim and Jin-Sun Lee, 1999). Vibration reduction can be attained either by increasing the damping capacity or by increasing stiffness of the structure and the construction materials. Rubbers and other viscoelastic products are commonly used as a vibration damping material (D.R. Manohar et al. 2014).

3.1 *Impulse method*

Vibration propagation in soils can be measured using the impulse method where basically the soil is excited by a force impulse and the vibration response is measured at points remote from the source. When introducing the force impulse into the soil a mechanical adapter can be used to prevent compaction of the soil, whilst a load cell measures the force impulse. Special software controls the measurements of the force and vibration signals, computes the spectra and the transfer functions, whilst enabling the detection and elimination of any background environmental vibrations within the measurement. This technique was adopted as the most appropriate for measuring the effects of the geocomposite material on soil borne vibrations.

3.2 *Types of Ground motion and soil hardness*

Ground vibrations consist of four separate wave types: Within the solid soil mass resistive forces act on both changes of volume and changes of form propagating both primary (P) waves and secondary (s) waves. At the ground surface the same vibrations propagate both Rayleigh (R) waves which move in the direction of the wave and Love (Q) waves which move perpendicular to the wave direction.

Vibration of any waveform can be expressed as overlapping sinusoidal waves, using the three elements of frequency f, propagation velocity v and wavelength **l** to establish the function v/f =**l**. Vibrations propagation velocity in soil differs according to the type of wave motion and ground properties.

Soil hardness can be expressed by the so-called N value. A 63.5 kg hammer is allowed to freefall a height of 75cm and impact a sampler for standard penetration tests as many times as necessary to create a 30 cm indent in the sampler. This is the measure for expressing soil hardness; the larger the N value, the harder the soil. A standard penetration test is conducted for the observation of excavated natural soil.

Table 1. N value, primary wave propagation velocity and secondary wave propagation velocity by type of soil

Type of soil	N value	Primary wave propagation velocity [m/s]	Secondary wave propagation velocity [m/s]
Soft silt	N < 4	300 – 1000	100 – 150
Neither soft nor viscous silt	4 < N < 8	300 – 1200	150 – 180
Viscous silt	8 < N < 15	300 – 1500	180 – 220
Hard silt	N > 15	400 – 2000	220 – 300
Loose sand and gravel	N < 10	300 – 1500	150 – 180
Compacted sand and gravel	10 < N < 50	300 – 1800	220 – 250
Very compacted sand and gravel	N > 50	450 – 2000	250 – 350
Bedrock	N >> 50	1000 – 2000	400 - 800

4 SITE AND MEASUREMENT DETAILS - TEST PROCEDURE

The site chosen for the measurement was in Békés, Hungary. According to the related geological map from the Geological and Geophysical Institute of Hungary the subsoil in this area is in the category of “hard silt”. The site area for the measurement was around 95x60m.

Three series of vibration propagation measurement were done:

- F1-V1: Measurement without applying any materials (reference);
- F2-V2: Applying 20m long, 2m deep section of excavated and filled back pit without any materials;
- F3-V3: Applying 20m long, 2m deep section of one layer geocomposite material;

4.1 *Mechanical adapters, load cell, force impulse*

At each measurement site a series of force impulses were measured, 10 valid impulses were generated. In practice this required more than 10 hits because some of the impulse hits were rendered invalid because of signal time out or environmental disturbing. In order to avoid soil compaction a special mechanical adapter was used to introduce the force impulse into the soil. Figure 1 shows this mechanical adapter with the load cell in its middle. The applied load cell can be loaded dynamically by maximum 70kN impulse force. A simple 5kg hammer generated the impulse force. At the vibration response points smaller mechanical adapter was used according to the standard MSZ 18163-2:1998 (Measurement of vibration). The measuring system was calibrated before and after the series of measurement.

Figure 1. Mechanical adapter and load cell for introducing impulse force into the soil

4.2 *Test procedure with/without applying materials for vibration reduction*

As a baseline reference vibration propagation was measured without applying any material for vibration reduction. Vibration damper products were then installed 3m away from the impulse point to a depth of 2m vertically into the soil. Figure 2 shows a sketch of the measurement with the applied distances of the vibration points from the place of the force impulse.

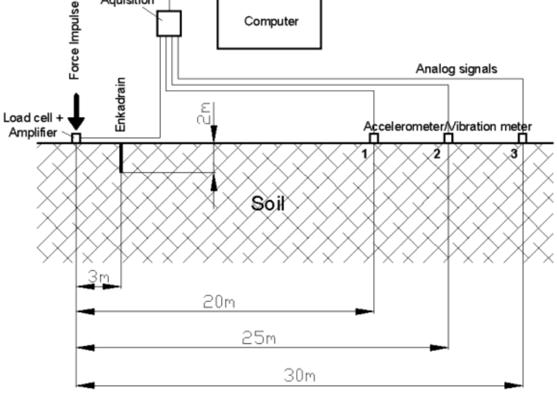


Figure 2. Measurement of vibration propagation using vibration damper geocomposite or excavated and filled pit

5 RESULTS AND DISCUSSIONS

The measuring software calculates the RMS average values of the frequency response functions (FRF) from the 10 valid impulse excitations. It also calculates the coherence for these 10 hits. When the coherence value is near to 1 the results are reliable. In this section the frequency response functions and the coherence values are shown for each measurement situation for the 20m, 25m and 30m distances from the excitation point:

Figure 3, Figure 4 and Figure 5 show the frequency response functions results in the different cases (F1-V1, F2-V2 and F3-V3)

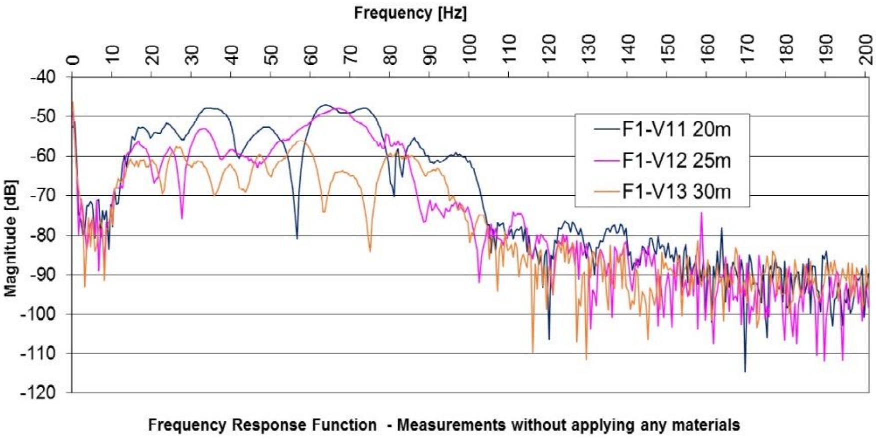


Figure 3. FRF results, frequency response functions without vibration damper product (F1-V1)

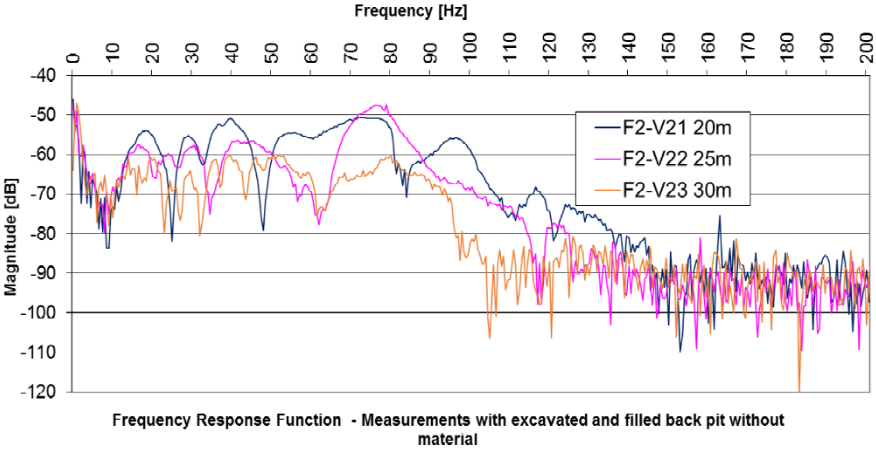


Figure 4. FRF results, frequency response functions with excavated and filled back pit (F2-V2)

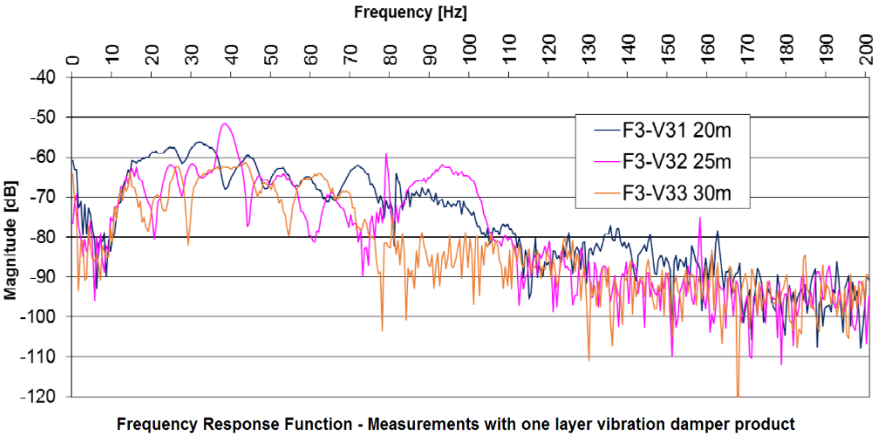


Figure 5. FRF results, frequency response functions with one layer geocomposite (F3-V3)

Figure 6, Figure 7 and Figure 8 show the coherence results in the different cases (F1-V1, F2-V2 and F3-V3)

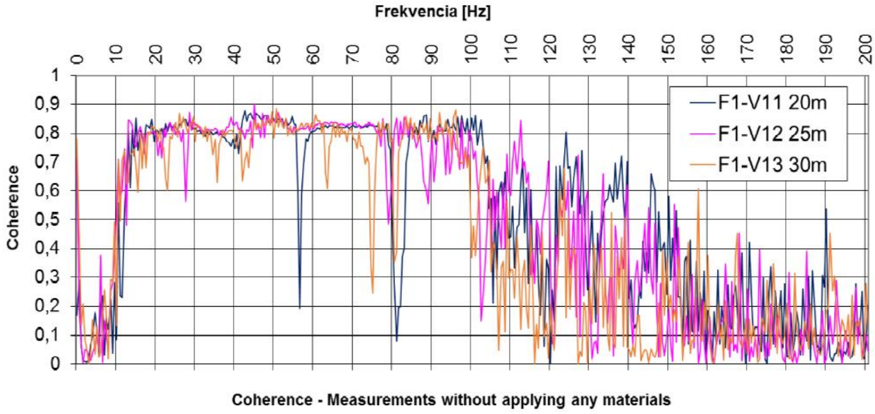


Figure 6. Coherence results without vibration damper product (F1-V1)

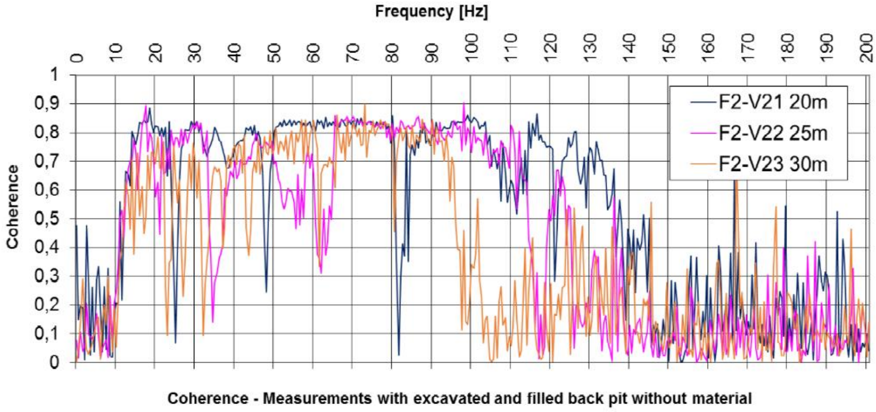


Figure 7. Coherence results with excavated and filled back pit (F2-V2)

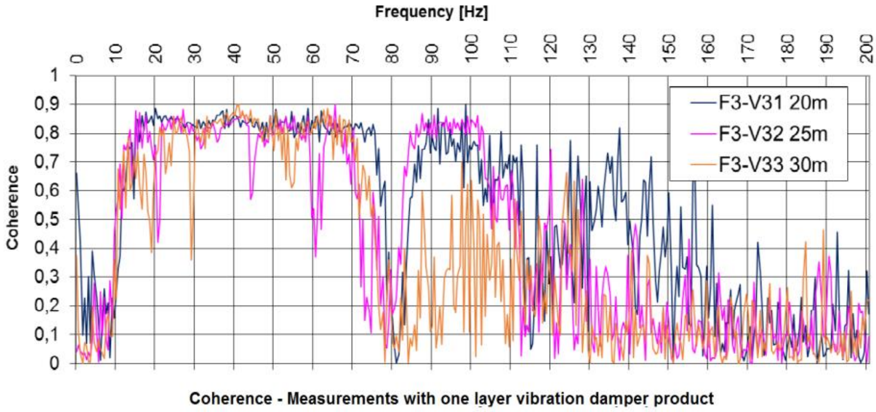
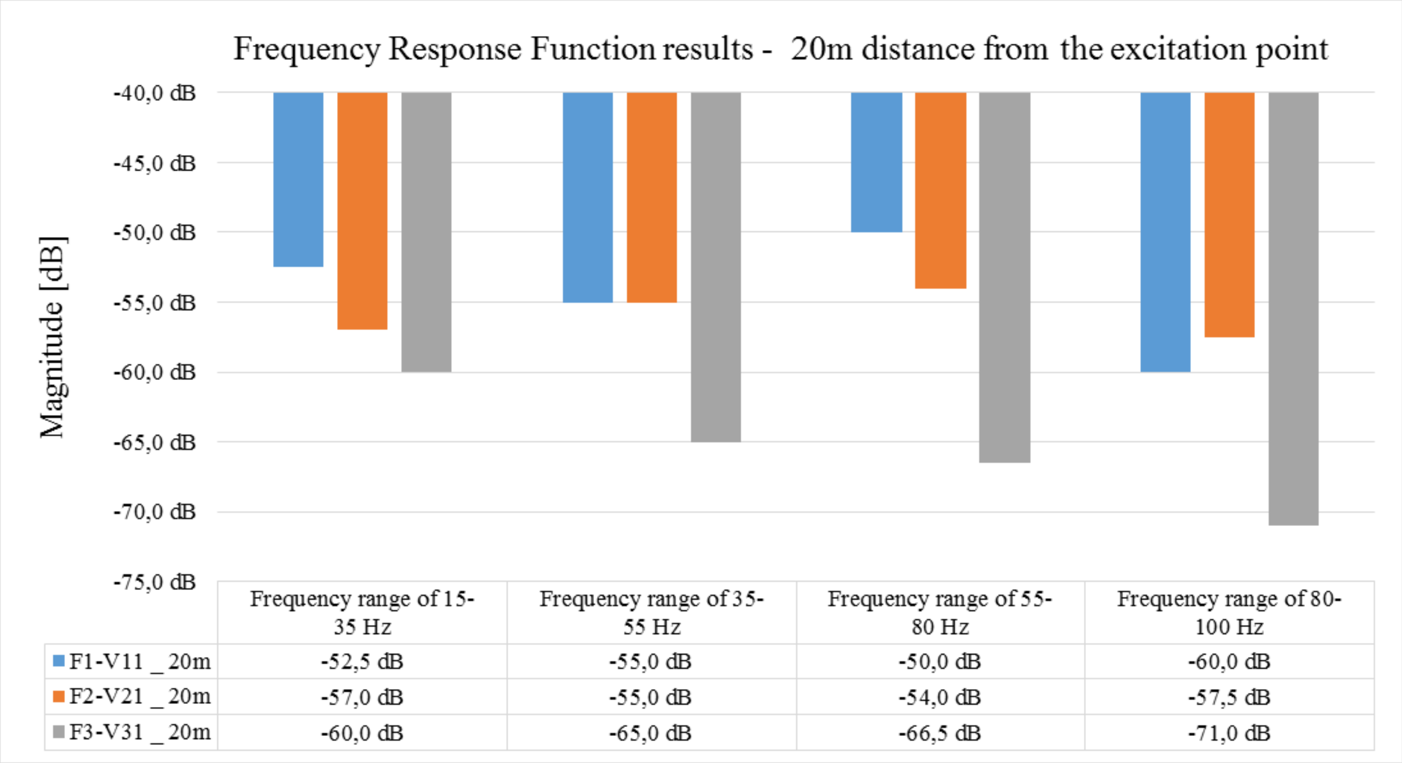


Figure 8. Coherence results with one layer geocomposite (F3-V3)

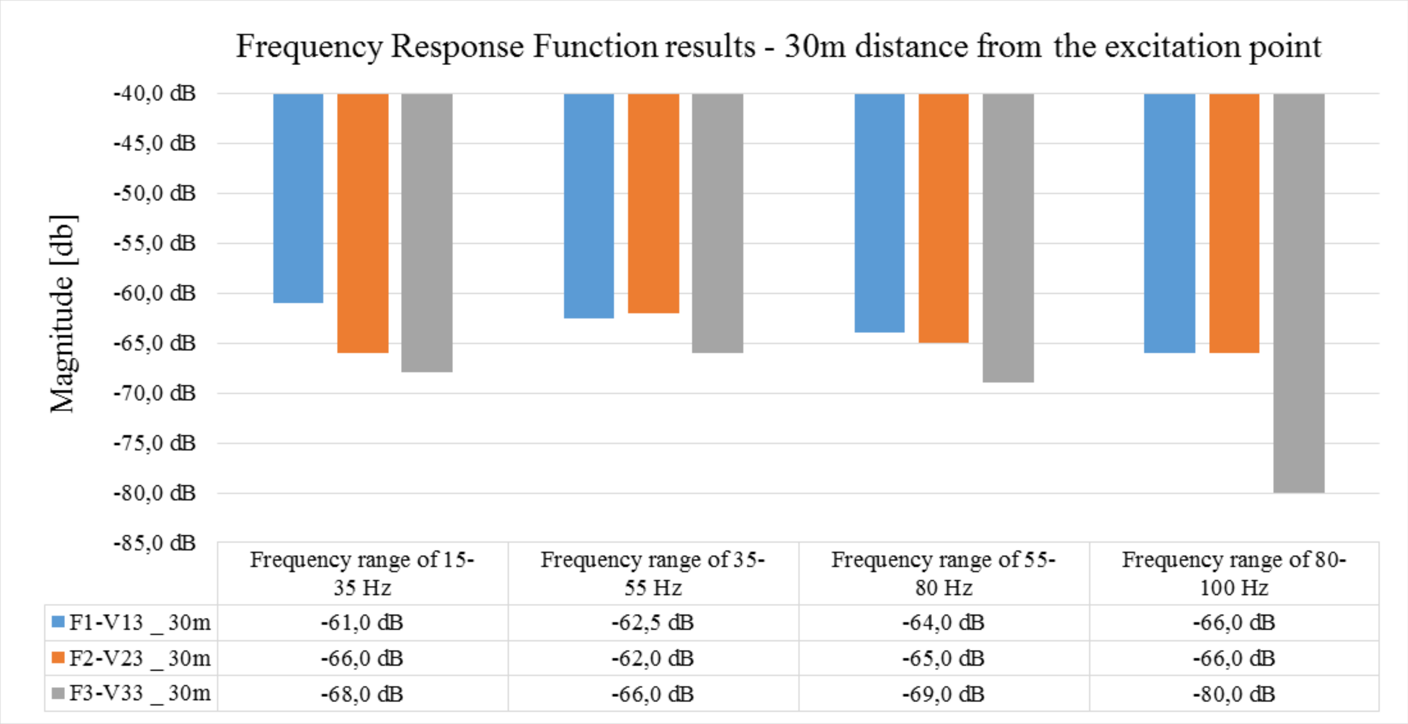
At the vibration response measuring points the vertical acceleration was measured. Based on the results of section 5.1 and 5.2 it can be stated that the measure transfer functions (with some exceptions) in the frequency range of 15-100 Hz are reliable. According to the expectations the attenuation is growing with the distance in the mentioned frequency range, however there are some exceptions. In Figure 9 and 10 the different attenuations can be seen comparing the different series in different frequency ranges: blue columns represent the situation without any interference in the soil, the oranges the excavated and filled back pit without any product, and the grey columns illustrate the attenuations of the geocomposite material. The average values are calculated from the FRF results (Figure 3-5) taken into account all the coherence values (Figure 6-8). Since the results are not reliable when the coherence values are far from 1.0 (less than 0.7-0.8) the average values are fine-tuned with taking away the unreliable results. Where the coherence value is lower, an outlier can be detected and it can be assumed that curve is uniform without any peak value. The different frequency ranges are the followings:

- 15 – 35 Hz;
- 35 – 55 Hz;
- 55 – 80 Hz;
- 80 – 100 Hz;



	Frequency range of 15-35 Hz	Frequency range of 35-55 Hz	Frequency range of 55-80 Hz	Frequency range of 80-100 Hz
🟦 F1-V11 _ 20m	-52,5 dB	-55,0 dB	-50,0 dB	-60,0 dB
🟧 F2-V21 _ 20m	-57,0 dB	-55,0 dB	-54,0 dB	-57,5 dB
⬜ F3-V31 _ 20m	-60,0 dB	-65,0 dB	-66,5 dB	-71,0 dB

Figure 9. FRF average values, for 20m distance from the excitation point



	Frequency range of 15-35 Hz	Frequency range of 35-55 Hz	Frequency range of 55-80 Hz	Frequency range of 80-100 Hz
🟦 F1-V13 _ 30m	-61,0 dB	-62,5 dB	-64,0 dB	-66,0 dB
🟧 F2-V23 _ 30m	-66,0 dB	-62,0 dB	-65,0 dB	-66,0 dB
⬜ F3-V33 _ 30m	-68,0 dB	-66,0 dB	-69,0 dB	-80,0 dB

Figure 10. FRF average values, for 30m distance from the excitation point

Comparing the different situations it is clear that the third situation performs significantly better than F1-V1 and F2-V2, however this difference in the attenuation decreased with the distance: in most cases at 25m and 30m distances the attenuation is less than at 20m. Comparing the results the following observations can be stated:

- Significant difference can be seen between F2-V2 and F3-V3 results, which proves the efficiency of the geocomposite in vibration damping applications;
- At lower distances the attenuation is higher;
- The results are reliable in the frequency range of 15-100Hz, and generally it can be stated that the highest effect of the excavated pit has in the range of 15-35Hz.

The attenuation range of the geocomposite material compare to the undisturbed (F1-V1) situation is between 2.5-16.5 dB, depending on the frequency range and the distance from the excitation point:

- In the range of 15-35Hz: 7.0 - 7.5 dB;
- In the range of 35-55Hz: 3.5 - 10.0 dB;
- In the range of 55-80Hz: 5.0 - 16.5 dB;
- In the range of 80-100Hz: 11.0 - 14.0 dB;

6 SUMMARY

The effect of the built in geocomposite samples (in 2m depth, acc. to Figure 2) on the vibration propagation in soil in the range of 20-30m distance is highly measurable. The geocomposite layer at 20m distance shows significant vibration reduction effect, with greater distances this effect is not so significant but still there and visible. It has to be mentioned that because of the given circumstances (i.e. undefined compaction level and background vibrations) the measured results are rather informative, and it cannot be integrated to a factual infrastructural project (i.e. decrease the vibrations next to roads and railways) without further calculations and/or local measurements. The available attenuation capacity for a factual project depends on the frequency range of the dynamic load, the soil conditions, the distance between the load and the protected area, the construction details and methods and also the depth of the built in geocomposite product. Based on this research work it can be stated that this vibration damping method can be applicable in most typical road and railway projects, and based on the results an empirical calculation method can be established to evaluate the vibration attenuation in different situations.

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